The Unintentional Introduction into the USA of *Chaetorellia succinea* – a 'Lucky Break' for Biological Control of Yellow Starthistle?

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In 1996, during surveys to recover *Chaetorellia australis*, a tephritid seed head fly approved for release to control yellow starthistle (YST) in the USA, we detected another similar fly. This was subsequently identified as *Chaetorellia succinea*. Through review of voucher specimens and release records, we determined that this fly was unintentionally introduced in 1994, when a shipment from Greece containing not only the approved *Chaetorellia australis*, but also *Chaetorellia succinea*, was released in southern Oregon. This site was subsequently used for redistribution to many other sites in several states. We present a map of this fly's current distribution in California, and discuss the recoveries of this fly in adjoining states. Although there were only a few releases in California, it has spread quickly and is now the most widespread natural enemy attacking YST in this state. At many sites it is very abundant, destroying a large portion of the YST seeds. However, European scientists had earlier rejected this fly from further consideration as a biocontrol agent for YST, because they felt that *Chaetorellia succinea* might pose a threat to safflower growers. We report on the preliminary results of our 'trap plant' studies, and two years of monitoring commercial safflower fields in California. We feel that this unintentionally released fly poses only an insignificant risk to commercial safflower growers.

Plant Phenology as an Indicator of Developmental Events in Weed-Feeding Insects

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Leafy spurge, *Euphorbia esula* (Euphorbiaceae), is an exotic weed infesting grassland habitats in the United States and Canada. Phenology models describing the seasonal abundance of insects utilized as leafy spurge biocontrol agents have been developed for the US, based on accumulated degree-days. These agents are employed across a large area of the western and midwestern US, an area characterized by considerable latitudinal and elevational variability. In addition, recording weather stations are often widely scattered,

Proceedings of the X International Symposium on Biological Control of Weeds
4-14 July 1999, Montana State University, Bozeman, Montana, USA
Neal R. Spencer [ed.]. (2000)

especially over large areas of the western states. Thus, local land managers rarely have access to real-time degree-day data. Air or soil temperatures appear to have a controlling influence on plant as well as insect phenology in the Northern Hemisphere. If plant and biocontrol agent phenologies respond similarly to a common degree-day regime, plants could serve as "proxy weather instruments" that could be used to predict biocontrol agent phenology. Thus, the objective of this study was to determine if phenological patterns exhibited by various plant species can be used to forecast seasonal abundance patterns among collectable life stages of leafy spurge biological control agents.

The relationships among flowering, fruiting, and vegetative phenology for 12 perennial plant species and accumulated degree-days (LDT = 0°C) were examined at two Montana sites. These relationships were well described by linear regression models ($r^2 > 0.70$). Plant phenology was compared to spurge biocontrol agent phenology on a common degree-day basis. Phenological events in several plant species may serve as reasonably accurate indicators of peak agent abundance in the field. For the peak abundance of leafy spurge flea beetle (*Aphthona* spp., Coleoptera: Chrysomelidae) adults, such relationships include: (1) *A. czwalinae*/*A. lacertosa* (mixed populations) and *A. nigriscutis* – peak flowering of the native plants *Lupinus argenteus*, *Rosa woodsii*, or *Achillea millefolium*; and (2) *A. cyparissiae* and *A. flava* – peak flowering of the exotic weed *Hypericum perforatum* and peak ripeness of fruits of the native shrub *Amelanchier alnifolia*. The completion of flowering by the introduced shrub *Syringa vulgaris* can be an indicator of peak first-generation pupal abundance for the leafy spurge bud gall midge *Spurgia esulae* (Diptera: Cecidomyiidae).

Biological Control of *Schinus terebinthifolius*: Past, Present, and Future

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Many criticisms of biological control can be attributed to lack of baseline data for target plants, control agent life history and distribution, and little, if any, monitoring after release of biological control agents. However, for many non-indigenous plant species in Hawaii, biological control offers the only feasible possibility to manage invaders. Therefore, better planning and monitoring of biological control projects in Hawaii is imperative. The purpose of this project is to implement such planning and monitoring in the biological control of one of the most aggressive, noxious weeds in Hawaii: Christmasberry (*Schinus terebinthifolius*). Phase I of this project evaluated the little known status of biological control agents established previously in Hawaii. Two purposely introduced insects from Brazil are established, a seed-feeding beetle, *Lithraeus atronotatus*, in 1960, and a leaf-rolling moth, *Episimus utilis*, in 1954-1956. An accidentally introduced South African seed-feeding wasp, *Megastigmus transvaalensis*, continues to

increase its population and level of infestation of Christmasberry seed. Detailed information was collected on the target weed and its natural enemies in Hawaii along an elevational gradient. Base line data on presence and spread of Christmasberry have been gathered. Outcomes pertaining to Phase I will be presented such as distribution, relative abundance, phenology, and impact of the natural enemies. Phase II research focuses on host specificity testing, release of a potential biological control agent, and post-release monitoring. The Brazilian sawfly, *Heteroperryia hubrichi*, is currently under study in quarantine as a potential biological control agent of Christmasberry in Hawaii. An update will be presented of the sawflies' status and potential as a biological control agent. This project will further the implementation and monitoring of new biological control agents against Christmasberry. Also, protocols developed in this study will be applicable in controlling other invasive plants in Hawaii.

Measuring the Impact of Biocontrol—Theory and Practice

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Nearly a thousand exotic releases have been made worldwide for the biological control of weeds. However, the number of published quantitative studies of their impact is small. It is a truism that, like most ecological field experiments, a successful measurement of impact is a multi-stage process with a certain probability of success at each stage, which may be portrayed as follows: Probability of quantitative measurement of impact appearing in literature = Probability of establishment x probability of impact x probability of permanency of site x probability of implementing statistically valid design x probability of detection of impact x probability that study is written up. Clearly the product of these probabilities is likely to be extremely low. Simple maths, though, shows that if we can raise the average probability for each stage just slightly, we would expect a substantial increase in the rate of publication of successful results, something that would help us in gaining support for our work and in advancing the discipline. Suppose the average probability at each of the six stages is 0.3 - multiply this by itself six times and we would expect only 0.0007 or 0.07% of releases to result in a published successful impact measurement. However, increase the average performance only to 0.5 and we would see a 2% success rate, a roughly 20-fold increase in overall performance. Here I focus on improving the design and detection probabilities of biocontrol field experiments. I propose as a robust solution the adaptation of asymmetrical designs used in environmental impact assessment that have been developed to avoid pseudo-replication problems. These designs may play an important role in impact measurement where multiple release sites and pesticide treatments are not possible.

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Aphthona spp. Movement and Leafy Spurge Control along Railroad Right-of-Ways

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Leafy spurge (*Euphorbia esula* L.) is often found in long narrow corridors such as railroad right-of-ways and is difficult to treat. Two experiments were conducted to determine the establishment, population increase, and movement of *Aphthona* species flea beetles in confined area of leafy spurge. *A. nigriscutis* was released in a dense stand of leafy spurge along a railroad corridor on June 28, 1993. There were five treatments consisting of 100, 200, 300, 400, and 500 adult insects released per treatment, plots were 80 m apart, and replicated three times along a 4 km stretch of railroad right-of-way. *A. nigriscutis* flea beetles were found in all treatments each year after release and leafy spurge stem density began to decline the second year after release. The greatest stem density decrease was 72% when 500 beetles/plot were released. *A. nigriscutis* rate of spread from the release point was similar regardless of the initial release number. A similar experiment was established on July 10, 1995 with a mixed population of *A. czwalinae/lacertosa* on a separate corridor. The number of insects released was increased to 500, 1000, 1500, and 2000 adults per treatment. *A. czwalinae/lacertosa* were found at all release points one year after release. The average stem density declined 71, 48, 60, and 23% within three m of the release point for the 2000, 1500, 1000, and 500 insect treatments, respectively. *A. czwalinae/lacertosa* were found at least 21 m from the release point within 2 years of the release. *Aphthona* spp established along the railroad right-of-ways and the rate of spread was similar regardless of the initial release number. However, the larger the release number the more rapid the leafy spurge stem density declined.

Assessing Target and Non-Target Effects of *Lema cyanella* Released for Control of Canada Thistle

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The European leaf-feeding beetle *Lema cyanella* (F.) (Coleoptera: Chrysomelidae) was released and established at one site in Alberta, Canada, as a biological control agent for Canada thistle, *Cirsium arvense* (L.) Scop. Its impact on the target weed was investigated in a controlled field experiment, using caged 1 m^2 plots on an existing natural stand of Canada thistle in a randomized complete block design. There were no significant dif-

ferences in biomass, height or percent cover of thistle plants in cages treated with *L. cyanella*, but there was a trend towards reduced flower head and seed production. The lack of impact is thought to be related to predation on immature stages of the beetle. Possible impacts on non-target native *Cirsium* species were investigated in an open-field multiple choice experiment, supplemented by studies in large field cages. Results indicate that some native thistles should be completely safe from attack, but that others may be quite heavily damaged. Contrary to some optimistic predictions made on the basis of pre-release studies, susceptible non-target species do not gain any protection by being present at very low densities in comparison with the target species. The expected balance of target and non-target effects does not favour further attempts to use *L. cyanella* against Canada thistle.

Climate Compatibility of the Weevil *Stenopelmus rufinasus*, a Biocontrol Agent, on the Water Fern *Azolla filiculoides* in South Africa

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Azolla filiculoides Lamarck (Pteridophyta: Azollaceae) is a highly invasive aquatic fern accidentally introduced to South Africa. The frond-feeding weevil *Stenopelmus rufinasus* Gyllenhal (Coleoptera: Curculionidae) was released as a biological control agent for the weed in 1997. The field population is a mixture of weevils collected from Florida (USA) and Argentina. This study was initiated to investigate the thermal tolerances of the weevil in order to predict where it might establish in South Africa, since the weed is largely restricted to the cooler high-lying areas of the country. Testing included measuring critical thermal minima (CT_{MIN}) and maxima (CT_{MAX}), upper and lower lethal limits (LT_{50}), as well as thermal measurements of *Azolla* mats in the field. Adult weevils were found to have a CT_{MIN} of 2.1 \$plom 0.17 \$oC (mean \$plom SE, n = 20, range = 0 - 7) and a CT_{MAX} of 47.4 \$plom 0.76 \$oC (mean \$plom SE, n = 20, range = 41 - 48). The lower LT_{50} for adult weevils is -12.5 \$oC (n = 120, range = 0 to -16), while the upper LT_{50} is 36.5 \$oC (n = 260, range = 30 to 42). Thermal measurements of *Azolla* field sites indicate that mats of the weed will not drop below zero degrees Celsius, even if the ambient temperature does. These findings indicate that the establishment of the weevil in South Africa is unlikely to be limited by temperature.

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Long-term Monitoring of the Impact of *Aphthona nigriscutis* on Leafy Spurge: the Beverly Bridge Sites

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Aphthona nigriscutis Foudras (Coleoptera: Chrysomelidae) was introduced into Alberta, Canada, from Hungary in 1983 as a biological control agent for leafy spurge (*Euphorbia esula* L.). The adult beetles feed on leafy spurge leaves and the larvae feed on the roots. It has been most effective against leafy spurge on lighter soils, in spurge stands with flowering heights of less than 70 cm, and on well drained sites such as upper slopes or hill tops. In 1988 and 1989, a total of 1,350 *A. nigriscutis* were released at six sites in a heavy leafy spurge infestation in Edmonton, Alberta. These were located along a south-facing railway embankment above the North Saskatchewan River, just west of the Beverly Bridge. Initial leafy spurge densities ranged up to 272 shoots m^{-2} and percent cover was 15 - 40%. Each year in August since these releases, vegetation parameters have been measured on fixed transects located at each of the original release points. Leafy spurge density, percent cover and biomass are measured, as well as percent cover and biomass of grasses, forbs and woody plants. All sites are also photographed from standard viewpoints each year in early July. *Aphthona nigriscutis* established at all the release points and increased to very high population densities 3 - 4 y after the releases, coinciding with a dramatic drop in leafy spurge populations. By 1993 leafy spurge densities had dropped to 1 - 14 shoots m^{-2} and cover was below 1%, with a corresponding increase in the biomass of grasses and other vegetation. The reduced leafy spurge growth and increased grass production have been maintained since then. Over 100,000 beetles have been collected and redistributed from this site.

Evaluating the Use of Pheromones for Monitoring Establishment of *Agapeta zoegana* (Lepidoptera: Cochylidae), a Biological Control Agent of Spotted Knapweed

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Although there are many examples of pheromone applications to monitor or regulate populations of insects considered pests, little work has been done on using phermones to

monitor population numbers or trends of beneficial insects such as *Agapeta zoegana* Haw., a biological control agent of spotted knapweed, *Centaurea maculosa* Lam. *A. zoegana* is a root boring insect that has been propogated and released for spotted knapweed control across Montana over the past 15 years. This study evaluated the attractiveness of *A. zoegana* to four pheromone formulations in 1998, and in 1999, evaluated the most attractive pheromone formulation and compared effectiveness of pheromone trapping to larval and adult visual sampling. There were significant differences (p=0.05) between both Z11-14Ac formulations and the control. Traps baited with Z11-14Ac plus Z11:14OH caught significantly fewer moths than traps baited with Z11:14Ac alone, suggesting the Z11:14OH may have an inhibitory effect on male attraction. In 1999, the higher strength (2.5ug)/trap attracted significantly more (p=0.05) male moths than the lower concentration (0.5ug)/trap and the control. There was a strong relationship between 1999 trap catches and relative abundance of adult moths (r=0.75) and with significance (p=0.01) and an even higher correlation between larvae found in 1998 and 1999 (r=0.90). This study identified an attractive pheromone formulation for trapping *A. zoegana*, and appears to be an effective monitoring tool for assessing populations without capturing large numbers of males as to adversly impact the population.

Pre-Release Studies and the Selection of Biological Control Agents

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Pre-release studies were conducted on meadow hawkweed to determine how it compensates for stolon and scape damage. This information may be useful in the selection of biological control agents in the near future. Meadow hawkweed produced the same number of scapes and stolons regardless of treatments, which included artifically removing none, one half, or all of the scapes and stolons in a randomized block factorial experimental design. The ability of meadow hawkweed to compensate for damage suggest multiple agents imposing cumulative stress will likely be needed for biocontrol of this clonal weed. This study is one of three that were initiated in 1997 to evaluate how plant damage affects individual plant performance, the subsequent development of the clone, and how damage, in combination with fertility and interspecific competition, mediates the population dynamics of an established meadow hawkweed infestation.

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Neal R. Spencer [ed.]. (2000)

Effectiveness of *Trichosirocalus horridus* against *Carduus nutans* in Australia

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Rhinocyllus conicus and *Urophora solstitialis* were the first two agents introduced into Australia to control nodding thistle, *Carduus nutans*. Impact assessment data indicated that these two agents were unlikely to sufficiently reduce seeding under Australian conditions to result in population declines in nodding thistle. Consequently the rosette weevil *Trichosirocalus horridus* was released. The impact of this weevil was studied on a field population of nodding thistle in southern New South Wales, using forty 0.25 m^2 quadrats. Insect attack was prevented by regular application of the systemic insecticide Rogor to 20 of the quadrats. Rosette growth was measured at six weekly intervals throughout the autumn, winter and spring on all quadrats. Three destructive samples of 10 quadrats (5 attacked and 5 sprayed) were taken during the winter and spring, whilst the number and sizes of capitula on plants on the remaining quadrats were followed fortnightly throughout the flowering period from late spring until the plants died in summer. *T. horridus* had a great impact on both the vegetative and reproductive success of the plants. It killed about 50% of attacked rosettes, and greatly reduced the vegetative vigour of the surviving thistles. This weevil indirectly impacted on reproductive potential of the weed, with the attacked plants producing 30% of the seed observed in the control plants. Implications for the long-term control of nodding thistle are discussed.