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**COVER: *Efferia coulei* Wilcox (Diptera: Asilidae)**

This robber fly is common in May and June in BC grasslands from the Okanagan Valley north to the Chilcotin Plateau. It ranges south to eastern Washington. Most of the 110 North American *Efferia* species live in the West, where they are major invertebrate predators in aridlands; there are seven species in BC. They are easily seen and heard, buzzing about in the open, frequently perching on the ground and attacking a variety of insects from beetles to damselflies. This species is about 15 mm long. The oval object on the fly's thorax is the larva of a parasitic mite (Parasitengona).

Photograph details:
Male *Efferia coulei*, captured at Penticton, BC in June 1982 and photographed live in a glass terrarium. Nikon F2 with 55 mm macro lens, #1 extension tube and two small strobe flashes; Kodachrome 64 film. Robert A. Cannings and M. Brent Cooke, Royal BC Museum.

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# First record of the Western Grape Leafhopper, *Erythroneura elegantula* Osborn (Homoptera: Cicadellidae), in Canada

D. THOMAS LOWERY[1] and GARY J.R. JUDD[1]

## ABSTRACT

Surveys conducted in the South Okanagan Valley, British Columbia, revealed that a new leafhopper pest of grapes, the western grape leafhopper (WGL), *Erythroneura elegantula* Osborn, was widespread and often abundant in vineyards on the east side of the valley from just north of Penticton south to the United States border. Infestations occurred on drier upland sites where most commercial grape production occurs. The largest populations of up to 40 nymphs per leaf were recorded from commercial vineyards that had applied reduced rates of the insecticide carbaryl for control of the Virginia creeper leafhopper, *E. ziczac* Walsh.

**Key Words:** Western Grape Leafhopper, *Erythroneura elegantula*, distribution

## INTRODUCTION

The western grape leafhopper (WGL), *Erythroneura elegantula* Osborn, is often considered the most important insect pest of grapes in the western United States as far north as southern Washington State (Wolfe 1955, Jensen and Flaherty 1981). Believed to be native to coastal California where it feeds on a species of wild grape, *Vitis californica* Bentham (Doutt and Nakata 1965), WGL is now found in most commercial vineyards throughout the western U.S. (Wells and Cone 1989). Previous research and surveys of arthropod pests of grape did not record WGL in vineyards in the south Okanagan and Similkameen Valleys of British Columbia (Madsen and Morgan 1972, McKenzie and Beirne 1972), and it had not been found elsewhere in Canada (Beirne 1956). As recently as 2000, the BC Management Guide for Grapes did not include WGL in its list of grape pests (BCMAFF 2000).

While conducting research on parasitism of Virginia creeper leafhopper (VCL), *E. ziczac* Walsh, eggs by *Anagrus daanei* Triapitsyn (Hymenoptera: Mymaridae) in South Okanagan vineyards in 1998 (Lowery *et al.* 2007) an unusual leafhopper was discovered and later confirmed to be WGL. This paper reports on the results of a survey conducted in south central BC to establish the distribution and abundance of this new leafhopper pest of grapes.

## MATERIALS AND METHODS

Following verification that WGL had invaded the south Okanagan, during 1998 to 2003, leaves from commercial, wild and backyard grapes located in the main production areas from Kelowna south to the United States border and in the Similkameen Valley near Cawston and Keremeous were collected and brought to the laboratory for examination. A smaller number of samples was also collected from Virginia creeper, *Parthenocissus quinquefolia* (L.) Planchon, and Boston ivy, *P. tricuspidata* (Siebold and Zuccarini), vines. Leaves were initially inspected in the field and only

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brought to the lab if leafhoppers were present. For commercial vineyards, a minimum of five leaves infested with leafhoppers was collected from five locations per vineyard, while five to 10 infested leaves were sampled from individual grape or ornamental vines.

Numbers of WGL and VCL were also monitored approximately weekly throughout spring and summer in vineyards located between Penticton and north Osoyoos where WGL was first discovered. Six yellow sticky traps (7.5 x 13 cm, PheroTech Inc., Delta, BC) per vineyard were used to monitor adult leafhoppers. Nymphs of WGL and VCL were also counted on leaves sampled randomly from the infested zone (BCMAL 2006) and inspected in the laboratory under a magnifying lens.

## RESULTS AND DISCUSSION

WGL nymphs were first collected in early July, 1998, in a commercial vineyard south of Penticton on the east side of Skaha Lake, Okanagan Valley, BC (49° 23' 23" N, 119° 33' 24" W). By mid-July nymphs showed pale yellow spots on the dorsum of the thorax and eyes appeared pale rather than dark red as for VCL. When adults appeared at the end of July specimens were sent to Dr. K.G.A. Hamilton, Agriculture and Agri-Food Canada, Eastern Cereals and Oilseeds Research Centre, Ottawa, for species verification. Voucher specimens are retained in the Canadian National Collection of Insects, Ottawa.

Characters for distinguishing nymphs of WGL from VCL are included in Wells and Cone (1989). Briefly, WGL have a whiter body colour, paired diffuse yellow spots on the dorsum of each thoracic segment in the last instar, pronounced pairs of setae on the dorsum of each abdominal segment, and pale rather than red eye colouration. The paired markings on the thorax of last instar VCL nymphs are larger and brown or reddish brown in colour. Adult WGL retain the paler body colour and pale eyes, and markings on the body and wings are red or reddish brown rather than brown.

From 1998 to 2003, nearly 80 commercial vineyards and 20 locations having wild grapes, table grapes or ornamental *Vitaceae* were sampled at least once in the Okanagan and Similkameen Valleys for WGL. This new pest was found to be widely distributed throughout the east side of the Okanagan Valley from just north of the city of Penticton (49° 31' 24" N, 119° 34' 13" W) south to the US border (Fig. 1). Infestations occurred on the drier areas away from the valley bottom. The main production areas for commercial grapes also occur in the drier upland areas.

WGL infests grapes throughout south-central WA (Wells and Cone 1989), but we are not aware if this species occurs in the northern part of the state. McKenzie (1973) reported that VCL was the only leafhopper pest of grapes found in the Okanagan Valley, BC. Two of the sites in this 1972 study were located south of Oliver within the current WGL distribution zone (Fig. 1). He did not survey any vineyards located between Penticton and Okanagan Falls, however, where the largest populations of this leafhopper were located in 1998.

Reports of leafhopper damage likely attributable to WGL dating back to the mid 1990s and the relatively widespread current distribution of this leafhopper suggests that it arrived in the Okanagan Valley many years before 1998. It is possible that small numbers of WGL have existed in BC for a much longer period of time and that only recently has the population expanded in response to warmer weather and an industry shift from hybrid varieties to more favourable *vinifera* varieties. Prior to 1990, most Okanagan and Similkameen vineyards were of French hybrid and *Vitis labrusca* varieties, which were found to be more hardy, productive, and resistant to pests and diseases (Bowen *et al.* 2005). Oviposition by VCL is lower on American varieties of *V. labrusca* than on *V. vinifera*, and younger nymphs often become entangled in the hairs

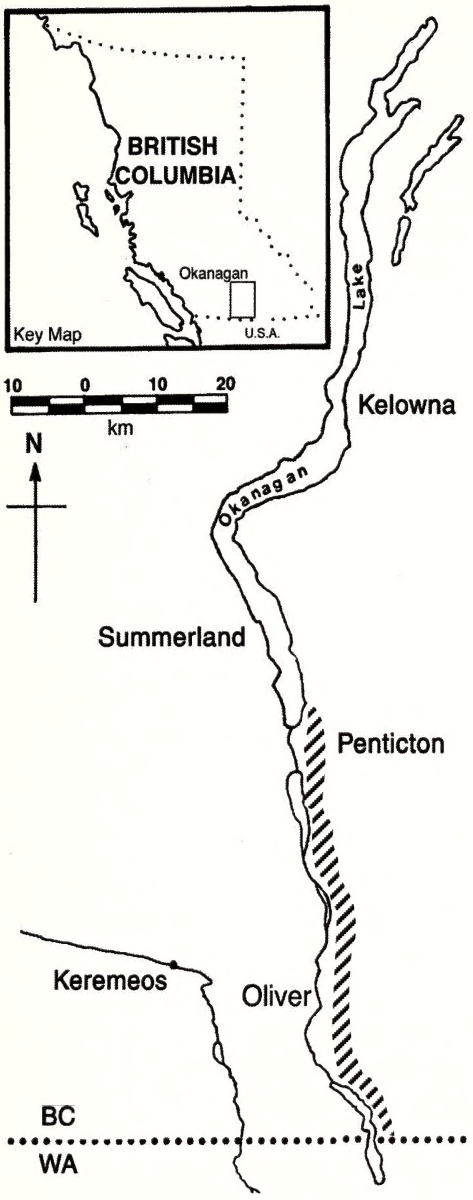


**Figure 1.** Current distribution of the western grape leafhopper, *Erythroneura elegantula*, on the east side of the Okanagan Val-

of American grapes (McKenzie and Beirne 1972).

VCL have shorter developmental times than WGL and, therefore, occur more commonly at higher latitudes than WGL (Wells and Cone 1989). WGL is currently found in the upland portions on the east side of Okanagan and Similkameen viticultural regions 5, 3 and the southern portion of region 2, as designated by Bowen *et al.* (2005). The relatively higher temperatures in parts of these regions might partially explain the current distribution of this leafhopper, but it does not explain the absence of WGL from other areas, such as region 4 (Golden Mile), that are as warm as, or warmer than, infested areas farther north.

WGL was detected at only one of nine sites of non-commercial grapes or Virginia creeper vines located within the infested zone (data not shown). At this one site, only three nymphs were found on a sample of 10 leaves collected from one vine in north O.K. Falls. In certified organic vineyards and in unsprayed grapes and ornamental vines, populations were generally low, rarely exceeding one nymph per leaf (Table 1) or one adult per trap per day (Table 2). Numbers of WGL in the two organic vineyards might have been influenced by their close proximity to conventional vineyards that had large numbers of this pest. The highest densities of WGL were recorded in conventional vineyards. In certain areas of one vineyard located adjacent to the initial discovery site (north O.K. Falls 2), numbers of first generation WGL exceeded 40 nymphs per leaf in July. Very little green leaf material was evident on the leaves of these vines by the end of the season. Peak numbers in the monitored area of this vineyard were 24.1 nymphs per leaf (Table 1) and 15.9 adults per trap per day (Table 2). Discussions with this grower indicated that a serious leafhopper problem had occurred for several years previously. This and a second vineyard (south Penticton 1) with high numbers of WGL had both been sprayed repeatedly with reduced rates of carbaryl that had been used effectively to control VCL.

Monitoring of conventional vineyards suggested that recommended rates of carbaryl provided some control of WGL. Other than the two organic vineyards and the two conventional vineyards treated with reduced rates of carbaryl (south Penticton 1, north O.K. Falls 2), the vineyards were treated with carbaryl at full rates to at least

**Table 1.**

Numbers of western grape leafhopper (WGL), *Erythroneura elegantula,* and Virginia creeper leafhopper (VCL), *E. ziczac*, nymphs / leaf in commercial vineyards located on the east side of the Okanagan Valley ranging from Penticton in the north to Osoyoos in the south based on monitoring conducted during 1998 to 2003.

| Location | Date[1] (y/m/d) | Production practice | Avg. no. nymphs/leaf WGL | VCL |
|---|---|---|---|---|
| south Penticton 1 | 99/07/14 | conventional | 6.2 | 33.3 |
| south Penticton 2 | 01/07/19 | conventional | 2.0 | 3.8 |
| north O.K. Falls 1 | 98/07/06 | organic | 0.9 | 8.1 |
| north O.K. Falls 2 | 99/07/15 | conventional | 24.1 | 18.3 |
| north O.K. Falls 3 | 98/09/09 | conventional | 1.4 | 0.2 |
| south O.K. Falls 1 | 01/08/30 | conventional | 1.5 | <0.1 |
| south O.K. Falls 2 | 01/08/30 | conventional | 1.7 | 0.6 |
| south O.K. Falls 3 | 99/07/14 | organic | 0.7 | 22.3 |
| north Osoyoos 1 | 02/06/24 | conventional | 0.1 | 1.1 |

[1]Except for north O.K. Falls 3, which was sampled only once, dates relate to peak numbers of WGL nymphs recorded during the year of monitoring when the leafhopper was first recorded at that location.

**Table 2.**

Numbers of adult western grape leafhopper (WGL), *Erythroneura elegantula,* and Virginia creeper leafhopper (VCL), *E. ziczac*, Adults / sticky trap / day in commercial vineyards located on the east side of the Okanagan Valley ranging from Penticton in the north to Osoyoos in the south based on monitoring conducted during 1998 to 2003.

| Location | Date[1] (y/m/d) | Production practice | Avg. no. nymphs/leaf WGL | VCL |
|---|---|---|---|---|
| north Penticton | 02/05/23 | conventional | 0.1 | 0.5 |
| south Penticton 1 | 99/06/16 | conventional | 10.1 | 51.7 |
| south Penticton 2 | 01/05/16 | conventional | 0.1 | 30.4 |
| south Penticton 3 | 01/05/16 | conventional | 0.1 | 4.1 |
| south Penticton 4 | 01/05/16 | conventional | <0.1 | 0.2 |
| north O.K. Falls 1 | 98/07/31 | organic | 0.8 | 43.1 |
| north O.K. Falls 2 | 99/06/16 | conventional | 15.9 | 14.3 |
| north O.K. Falls 3 | 98/08/13 | conventional | 0.3 | 0.1 |
| south O.K. Falls 1 | 01/08/07 | conventional | 1.4 | 8.5 |
| south O.K. Falls 2 | 01/05/29 | conventional | 0.1 | 1.5 |
| south O.K. Falls 3 | 99/08/18 | organic | 0.5 | 18.8 |
| north Osoyoos 2 | 01/05/08 | conventional | <0.1 | 0.6 |
| north Osoyoos 3 | 01/07/23 | conventional | <0.1 | 0.8 |

[1] All locations were monitored more than once. Dates shown relate to peak numbers of adult trapped during the year of monitoring when the leafhopper was first recorded at that location.

those portions where leafhopper numbers were damaging (Table 1, 2). Leafhopper populations in these vineyards were relatively low, but numbers of WGL often exceeded those of VCL, suggesting that the former species may be less affected by carbaryl. Resistance of WGL to various insecticides has been reported previously (AliNiazee *et al.* 1971). The first report concerned the failure of DDT to control this pest on grapes in California in 1952 (Stafford and Jensen 1953).

Parasitism of WGL by the egg parasitoid *Anagrus erythroneurae*, which overwinters in eggs of leafhoppers on plants in the families Rosaceae and Betulaceae (Lowery *et al.* 2007), might limit the range of WGL in the Okanagan Valley. Most vineyards on the east side of the valley that are infested with WGL are located adjacent to uncultivated areas dominated by sagebrush; there are few host plants that support overwintering *A. erythroneurae*. Reduced rates of carbaryl used to control VCL (BCMAFF 2000) likely caused the observed outbreaks of WGL in south Penticton 1 and north O.K. Falls 2. Reduced-rate sprays were ineffective for the control of WGL, but they would have reduced numbers of *A. erythroneurae*. Numbers of WGL quickly dropped below 1 nymph per leaf (data not shown) after the insecticide program was altered to a single well-timed spray to less than 10% of the vineyard where the heaviest infestation occurred. The effectiveness of insecticides for the control of WGL needs to be re-evaluated, and growers will have to consider altering their spray practices where WGL occurs.

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# Leafhopper host plant associations for *Anagrus* parasitoids (Hymenoptera: Mymaridae) in the Okanagan Valley, British Columbia

D. THOMAS LOWERY[1], SERGUEI V. TRIAPITSYN[2] and GARY J.R. JUDD[1]

## ABSTRACT

*Anagrus* spp. are important natural regulators of leafhoppers infesting grapes, tree fruits, and other crops in south central British Columbia (BC). Predominantly four species of these egg parasitoids, *A. atomus* (L.), *A. avalae* Soyka, *A. daanei* Triapitsyn, and *A. erythroneurae* Triapitzyn and Chiappini, were reared from dormant host plants and from summer host plants in the Okanagan Valley. The largest numbers of *Anagrus* specimens were collected from roses, *Rosa* spp; blackberry, *Rubus* spp; apple, *Malus domestica*; and other members of the rose (Rosaceae) family. Species of mint, family Lamiaceae, were important host plants for several species, with lavender, *Lavendula angustifolia,* and garden sage, *Salvia officinalis*, being both a summer and winter host plant for some species. The most likely leafhopper host on these plants is the mint leafhopper, *Eupteryx melissae* Curtis. This study contributes to our knowledge of the biology of *Anagrus* species in south central BC and could contribute to future efforts to preserve or enhance populations of these beneficial insects.

**Key Words:** Mymaridae, *Anagrus*, parasitoids, leafhoppers, plant hosts

## INTRODUCTION

Egg parasitoids of the family Mymaridae (Hymenoptera) include the smallest known insects (Chiappini and Huber 2004). Despite being important in natural control of leafhoppers (Cicadellidae) and planthoppers (Delphacidae), they have been underutilized in biological control programs as a result of their minute size, difficulties in their identification and handling (Huber 1986), and their poorly known biology. Species of *Anagrus* Haliday have been used successfully, however, to control leafhoppers on apple, *Malus domestica*; rice, *Oryza sativa*; grapes, *Vitis* sp.; and greenhouse crops (Vidano *et al.* 1987, Chiappini *et al.* 1996, Triapitsyn and Teulon 2002, Agboka *et al.* 2004). For example, *Edwardsiana froggatti* (Baker), native to Europe, was a serious pest of apple in Tasmania, Australia, until it was brought under control with the importation of *Anagrus avalae* Soyka from New Zealand [Vidano and Arzone 1982 - misidentified as *Anagrus armatus nigriventris* Girault (Triapitsyn 2001)]. Their potential as highly effective natural control agents merits further study of their biology, ecology and leafhopper host associations (Agboka *et al.* 2004).

Taxonomic revisions of *Anagrus* (Chiappini 1989, Chiappini *et al.* 1996, Triapitsyn 1998), have greatly improved the reliability of taxonomic and biological information on these important regulators of leafhopper populations. Until recently it was thought that eggs of all the grape-feeding Typhlocibinae in North America (NA) were attacked by the same species, *Anagrus epos* Girault. Differential parasitism rates where two species of leafhoppers co-occurred on grape led to the suspicion

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that *A. epos* consisted of several biotypes, and Pickett *et al.* (1987) assumed that some of these were true species. *Anagrus epos* is now known to consist of several species (Trjapitzin and Chiappini 1994, Triapitsyn 1995, Chiappini *et al.*1996, Triapitsyn 1998), with *A. erythroneurae* Trjapitzin and Chiappini being the most common egg parasitoid of the western grape leafhopper (WGL), *Erythroneura elegantula* Osborn, and the variegated leafhopper, *E. variabilis* Beamer, in California (Trjapitzin and Chiappini 1994). Specimens of *A. erythroneurae* were identified from as far north as Wenatchee, WA, but there are few records of this species from Canada (Trjapitzin & Chiappini 1994, Triapitsyn 1998).

In 1998 we began to research parasitism of Virginia creeper leafhopper (VCL), *Erythroneura ziczac* Walsh, and WGL in vineyards in the Okanagan and Similkameen Valleys, British Columbia (BC), (DTL, unpublished data) with the goal of preserving and possibly increasing populations of *Anagrus* parasitoids. These parasitoids overwinter as immature stages within the eggs of alternate leafhopper hosts (Williams 1983), while the leafhopper pests of grapes spend the winter as adults. Thus, the availability of suitable overwintering and early spring leafhopper hosts plays an important role in the biology of *Anagrus* parasitoids and their ability to control leafhoppers on grape. This paper reports on the rearing of *Anagrus* adults from a wide range of plants that served as hosts for other species of leafhoppers utilized by these parasitoids.

## MATERIALS AND METHODS

Between February and June of 1999 to 2003, dormant plant hosts potentially containing overwintering *Anagrus* in their host eggs were gathered throughout the Okanagan Valley and placed in sealed, waxed corrugated cardboard boxes in the laboratory at room temperature. *Anagrus* spp. emerging from these woody prunings were collected in two glass vials (32 ml) screwed into holes cut with cork borers into the upper side of each box. Specimens were preserved in 70% ethanol and shipped to the University of California, Riverside, for identification by one of us (S.V.T). Properly point- and slide-mounted voucher specimens were then deposited in the Entomology Research Museum, University of California, Riverside. Adult *Anagrus* were also collected from leafhopper-infested leaves of grape and other summer hosts. Leaves or stems were placed in distilled water in small flasks (50 ml) with the tops of the flasks sealed as much as possible with parafilm. The cuttings were then placed inside two large waxed paper cups (900 ml, Dixie Cup™, Norwalk, CT) fastened securely together and with a single collection vial (8 ml) fastened into a hole cut into the upper end of one cup. In total, 211 collections were made, including 76 plant species.

## RESULTS AND DISCUSSION

More than 2,000 *Anagrus* emerged and were identified from dormant and summer host plants, with nearly half the specimens emerging from dormant roses, *Rosa* spp. (Table 1). Roses were sampled most intensively, 20 of 211 total collections of plant material, but they also harboured large numbers of parasitoids. For cultivated roses heavily infested with leafhoppers, we collected about 31 *Anagrus* per 100 cm of dormant wood, compared with 4.4 per 100 cm for blackberry, *Rubus* spp., and less than 1 per 100 cm for plum, *Prunus domestica.* We successfully reared *Anagrus* from 22 of 76 plant species sampled over the course of this study. The predominant species from all hosts were *A. atomus* (L.), *A. avalae*, *A. daanei* Triapitsyn, and *A. erythroneurae*

**Table 1.**

Plant species in the Okanagan Valley, British Columbia, that served as winter (W) or summer (S) leafhopper hosts from which *Anagrus* egg parasitoids (numbers in parentheses) emerged. Numbers in parentheses following the sampling season (W or S) refer to the number of sites and number of times each host plant was sampled.

| Plant family | Common name | Season | *Anagrus* species |
|---|---|---|---|
| Rose (Rosaceae) | Cultivated rose, *Rosa* sp. | W (3, 10) | *atomus* (~445), *avalae* (3), *erythroneurae* (~76) |
| | Wild rose, *Rosa* sp. | W (7, 10) | *atomus* (~287), *avalae* (2), *erythroneurae* (~155) |
| | Blackberry and Tayberry, *Rubus* spp. | W (5, 11) | *atomus* (~190), *erythroneurae* (~15) |
| | Sweet cherry, *Prunus avium* | W (3, 6) | *erythroneurae* (1) |
| | Choke cherry, *P. virginiana* | W (7, 11) | *atomus* (~10), *avalae* (~101), *daanei* (2) |
| | Cultivated plum, *P. domestica* | W (5, 9) | *erythroneurae* (9) |
| | Apple, *Malus domestica* | W (3, 7) | *atomus* (6), *avalae (1), erythroneurae* (24) |
| | Strawberry, *Fragaria* x *ananassa* | S (1, 1) | *atomus* or *erythroneurae* (10) |
| Dogwood | Red osier dogwood, *Cornus stolonifera* | W (3, 3) | *erythroneurae* (1) |
| | Red osier dogwood, *Cornus stolonifera* | S (4, 7) | *daanei (1?), erythroneurae* (3) |
| Willow (Salicaceae) | Willow sp., *Salix* sp. | W (3, 10) | near *nigriventrus* (1), *Anagrus* sp. (9) |
| Birch (Betulaceae) | European white birch, *Betula pendula* | W (2, 2) | *atomus* (1) |
| | Water birch, *B. occidentalis* | W (3, 5) | *atomus* (4), *avalae* (14), *erythroneurae* (3) |
| | Alder, *Alnus* sp. | W (3, 3) | *erythroneurae* (1) |
| Maple (Aceraceae) | Douglas maple, *Acer glabrum* | W (4, 6) | *atomus* (1) |
| Elm (Ulmaceae) | Siberian elm, *Ulmus pumila* | W (4, 6) | *atomus* (4) |
| Grape (Vitaceae) | Grape, *Vitis vinifera* | S (5, 6) | *daanei* (348) |
| | Virginia creeper, *Parthenocissus quinquefolia* | S (2, 3) | *daanei* (15) |
| Mint (Lamiaceae) (=Labiatae) | Catnip, *Nepeta cataria* | S (6, 11) | *atomus* (217), *erythroneurae* (7) |
| | Persian catmint, *Nepeta* x *mussinii* | S (1, 2) | *atomus* (~26), *erythroneurae* (~15) |
| | Garden mint, *Mentha* sp. | S (1, 1) | *atomus* (6), *erythroneurae* (2) |
| | Mint sp., *Mentha* sp. | S (1, 1) | *atomus* (5), *erythroneurae* (1) |
| | Lavender, *Lavendula angustifolia* | W (1, 1) | *atomus* (4) |
| | Garden sage, *Salvia officinalis* | W (1, 1) | *atomus* (~33), *erythroneurae* (~27) |

(Table 1). The only other *Anagrus* collected were a single probable specimen of *A. nigriventris* Girault, and an unknown species from willow (*Salix* sp.).

The common and widespread European species, *A. atomus*, which also occurs in South America and Asia (Triapitsyn 2001), was the most commonly collected species (Table 1). It was identified from 16 host plants from six families. Most of our host associations for *A. atomus* confirm earlier reports (Chiappini 1989, Triapitsyn 1998). Although it parasitizes the eggs of leafhoppers on grapes in Europe and Asia, all Nearctic records are from plants other than those in the Vitaceae. We also failed to obtain *A. atomus* from grapes; most of our records were from roses; blackberry, *Rubus* sp.; choke cherry, *Prunus virginiana*; and apple. Material examined by Triapitsyn (1998) included specimens collected from apple and rose in the Okanagan Valley by McKenzie (1973). Reported leafhopper hosts for *A. atomus* associated with these host plants include the white apple leafhopper, *Typhlocyba pomaria* McAtee, and green apple leafhopper, *Empoasca maligna* Walsh, on apple; the rose leafhopper, *Edwardsiana rosae* (L.), on rose and blackberry; and the plum leafhopper, *E. prunicola* (Edwards), on plum (Triapitsyn 1998).

Given their size and abundance, trees in the birch (Betulaceae), maple (Aceraceae) and elm (Ulmaceae) families should be considered important overwintering plant hosts for this species. Yet only a small number of *A. atomus* were collected from dormant twigs from plants in these families (Table 1). Maple, alder and birch support a number of leafhopper species (Hamilton 1985). The likely host for *A. atomus* on Siberian elm, *Ulmus pumila*, is *Empoasca bipunctata* (Oshanin), as it was the only species reported by Hamilton (1985) to feed on Siberian elm in BC. Large numbers of *A. atomus* were collected in summer from several species of plants in the mint (Lamiaceae) family, and it was also collected from sage, *Salvia officinalis*, and lavender, *Lavendula angustifolia*, in March. The mint leafhopper, *Eupteryx melissae* Curtis, occurs on these plants in southern BC (Beirne 1956), and this is the likely host for *A. atomus* during the summer on these plants. It may be the first overwintering record for a species of *Anagrus* on plants in this family.

*Anagrus erythroneurae* is clearly the most important egg parasitoid of WGL and the variegated leafhopper on grapes in California and Baja California Norte, Mexico (Triapitsyn 1998). In the Napa and Sonoma Valleys of CA, more than 95% of the egg parasitoids emerging from eggs of WGL were *A. erythroneurae*. Triapitsyn (1998) also reported it from apple infested with the white apple leafhopper and from plum infested with the plum leafhopper. *A. erythroneurae* was recognized only recently as a new species (Trjapitzin and Chiappini 1994) and its host associations and biology are not well known. Many previous reports referring to the effective control of WGL by *A. epos* can likely be attributed to *A. erythroneurae* (Chiappini *et al.*1996). *Anagrus erythroneurae* is known to parasitize the eggs of a number of leafhopper species, most of which belong to the genera *Erythroneura* Fitch, *Dikrella* Oman, and *Typhlocyba* Germar. Not all species within these genera are suitable hosts, however. We did not rear *A. erythroneurae* from leaves of grapes or Virginia creeper vines, *Parthenocissus quinquefolia,* infested only with VCL (Table 1). In BC, the rose leafhopper overwinters as eggs in the stems of rose and blackberry, and this is the likely host on these plants. The early spring and summer host on plants of the mint family is likely the mint leafhopper. Other potential summer host plants are strawberry, *Fragaria x ananassa*, and red osier dogwood, *Cornus stolonifera* (Table 1).

Our sampling of potential winter and spring hosts resulted in rearings of *A. erythroneurae* from 14 plant species (Table 1). Overwintering *A. erythroneurae* were collected primarily from roses, blackberry, and plum. Members of the birch family have not been recorded previously as overwintering host plants, and we do not know which leafhopper species are being parasi-

tized by *A. erythroneurae* on these trees. *Anagrus erythronuerae* is likely parasitizing eggs of the mint leafhopper on catmint, *Nepeta x mussinii*; catnip, *Nepeta cataria*; garden sage; and garden mint, *Mentha* spp. Additional research is required to identify the leafhoppers on these trees and other host plants used by *A. erythroneurae* as winter or summer hosts in BC.

Parasitism by *Anagrus erythroneurae* might limit the range of the WGL in the Okanagan Valley. Many of the vineyards on the east side of the Okanagan Valley south of Penticton are located some distance from apple and *Prunus* orchards and few nearby areas support wild roses or blackberry. In California vineyards, some control of WGL usually occurs near riparian areas supporting blackberry or rose (Doutt and Nakata 1965, Williams 1983) or French prune trees (Kido *et al.* 1984) that maintain overwintering *Anagrus*. Reductions in numbers of WGL in Okanagan vineyards might be achieved by preserving natural refugia and planting suitable overwintering (i.e. plum and rose) and early spring (i.e. catmint) hosts, provided that such areas are approximately comparable in size to the nearby vineyards and are able to sustain viable and sizeable populations of alternate host leafhopper species.

*Anagrus avalae* is another common European species recorded in NA parasitizing eggs of the rose leafhopper on rose and white apple leafhopper on apple (Chiappini and Triapitsyn 1997; Triapitsyn 1998). McKenzie (1973) collected it from roses in the Okanagan Valley. We collected it from dormant twigs of rose, choke cherry, apple and birch (Table 1). Mulla (1956) was able to collect this species, incorrectly referred to as *A. armatus nigriceps* Girault, from the summer eggs of plum leafhopper, but not from overwintering eggs. Interestingly, although it winters in the eggs of leafhoppers on other members of the rose family, we also did not collect *A. avalae* from dormant twigs of plum. This species has not been recorded parasitizing leafhopper eggs on grapes in NA, and we did not rear it from this plant host in BC.

*Anagrus daanei* was recognized as a new species only recently (Triapitsyn 1998) and there is little unequivocal information available relating to its winter hosts. It has been collected from eggs of leafhoppers infesting grapes in NA (Triapitsyn 1998) and was the only species we recovered from eggs of VCL (Table 1). Triapitsyn (1998) identified *A. daanei* from California associated with dormant blackberry, and from eggs of the rose leafhopper in dormant rose in New York. We were unable to rear any specimens from dormant blackberry and rose in BC, perhaps reflecting differences in leafhopper species on these plants in the two regions. A small number of *A. daanei* were collected from dormant twigs of choke cherry near Armstrong at a location far from commercial vineyards, but not from dormant choke cherry at a number of sites in the south Okanagan Valley close to vineyards. Large numbers of parasitoids moving from vineyards in fall might eliminate nearby alternate leafhopper hosts, or there might be differences in leafhopper species or abundance between the warmer, drier south Okanagan and the cooler, wetter north. Several species of leafhopper occur on choke cherry, including four native species of *Typhlocyba* that occur across the continent (Hamilton 1985).

McKenzie (1973) reared what was at that time believed to be *A. epos* from parasitized eggs of VCL on Okanagan grapes. He described the females as light brown in colour, which is characteristic for *A. daanei* (Triapitsyn 1998). *Anagrus* were also reared from dormant branches of wild rose infested with the rose leafhopper and from apple infested with the white apple leafhopper, but no mention was made as to the colour of females from these collections. McKenzie (1973) noted that *Anagrus* parasitoids emerging from rose shoots in spring did so during two distinct periods and speculated that this bimodal emergence pattern might result from differences in the time when eggs were parasitized in fall. In addition to *A. erythroneurae*, we also reared *A. atomus* and *A. avalae* from dormant rose shoots. The bimodal emergence noted by

McKenzie (1973) most likely represented different emergence times for different species.

VCL is one of the most important pests of grapes in south central BC, and sprays are frequently required to prevent economic damage. The small number of wintering *A. daanei* collected during our study reflect the low rates of parasitism of VCL in most commercial vineyards. Parasitoids are rare or absent from many vineyards until late in the season (DTL unpublished) and *A. daanei* rarely controls VCL populations adequately. In New York vineyards, in contrast, *A. daanei, A. erythroneurae* and *A. tretiakovae* contribute to the biological control of several species of *Erythroneura* leafhoppers infesting grape (Triapitsyn 1998, Williams and Martinson 2000). Known leafhopper hosts for *A. daanei* on grapes in New York include the Eastern grape leafhopper, *Erythroneura comes* (Say), VCL, and *E. bistrata* McAtee (Triapitsyn 1998). Records from dormant plant hosts in eastern NA include apple; sugar maple, *Acer saccharum* Marsh.; prickly ash, *Zanthoxylum americana* Mill.; black locust, *Robinia pseudoacacia* L.; and rambler rose, *Rosa multiflora* Thumb. (Triapitsyn 1998). We did not record *A. daanei* from these or closely related winter hosts in BC. The relative scarcity of VCL in eastern NA vineyards might be due to greater overwintering success of *A. daanei* in that region.

*Anagrus tretiakovae*, native to eastern NA, was apparently introduced to California in 1987 as a biotype of *Anagrus epos* Girault to control leafhoppers on grape. We did not collect *A. tretiakovae* from dormant host plants or from grape. This species is likely to invade BC eventually, but it could be considered for intentional importation for the biological control of leafhoppers on grape. Detailed rearings of *Anagrus* spp. from leafhopper hosts on their overwintering host plants are needed to confirm host associations and determine which plant species might be used as overwintering refugia around vineyards in BC.

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# *Anagrus* spp. (Hymenoptera: Mymaridae) reared from plants collected during winter in south central Washington and north central Oregon

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## ABSTRACT

*Anagrus daanei* S. Triapitsyn, *A. erythroneurae* S. Trjapitzin and Chiappini, and *A. tretiakovae* S. Triapitsyn parasitize western grape leafhopper, *Erythroneura elegantula* Osborn, and Virginia creeper leafhopper, *E. ziczac* Walsh, eggs during the summer. These leafhoppers overwinter as adults and *Anagrus* overwinter in leafhopper eggs. Thus, *Anagrus* must find other leafhopper eggs in which to overwinter. To identify plants on which these parasitoids and their host eggs overwinter, we collected 31 species of plants from 52 sites in the grape growing region of south central Washington and north central Oregon during the winter from 2000 to 2007. A total of 733 female and 1066 male *Anagrus* was reared from the plants. Twelve plant species harboured *Anagrus* spp. during the winter. *Anagrus erythroneurae* was reared from blackberry, *Rubus armeniacus* Focke; willow, *Salix* spp.; Wood's rose, *Rosa woodsii* Lindley; sweetbrier rose, *R. eglanteria* L.; rugose rose, *R. rugosa* Thunberg; and ornamental roses, *Rosa* spp. L. *Anagrus tretiakovae* was found on choke cherry, *Prunus virginiana* L.; rugose rose; *Rosa* spp.; and blackberry. Only one specimen, from ornamental rose, was tentatively identified as *A. daanei*. Other specimens were identified as *A. atomus* L., *A. avalae* Soyka, *A. nr. sp. avalae*, *A. nr. sp. columbi* Perkins, *A. nigriventris* Girault, and *A. nr. sp. nigriventris*.

**Key Words:** *Anagrus*, *Erythroneura elegantula*, *Erythroneura ziczac*, Mymaridae, *Vitis vinifera*, grape, leafhopper, overwintering

## INTRODUCTION

Mymarid wasps in the genus *Anagrus* Haliday (Hymenoptera: Myrmaridae) are egg parasitoids, principally of Homoptera and Heteroptera (Chiappini *et al.* 1996). An *Anagrus* species identified as *A. epos* Girault was determined to be an important biological control agent of the western grape leafhopper, *Erythroneura elegantula* Osborn, in California (Doutt and Nakata 1965) and Washington State (Wells and Cone 1989), and of the Virginia creeper leafhopper, *E. ziczac* Walsh, in British Columbia, Canada (McKenzie and Beirne 1972). However, Trjapitzin (1995) found that the California leafhoppers were not *A. epos* and later identified them as *A. erythroneurae* S. Trjapitzin and Chiappini and *A. daanei* S. Triapitsyn (Triapitsyn 1998). Regardless of the species involved, the main obstacle to successful biological control is that grape leafhoppers overwinter as adults but *Anagrus* wasps need leafhopper eggs in which to overwinter (Doutt and Nakata 1965). Therefore, *Anagrus* spp. must overwinter in the eggs of other leafhopper species on other plants and subsequently recolonize vineyards the following year. In California, *A. epos* [most likely *A. erythroneurae* (Triapitsin 1998)] overwinters on blackberries, *Rubus* L. spp., in the eggs of the leafhopper *Dikrella cruentata* (Gillette) (Doutt and Nakata 1965) and on French prunes in prune leafhopper, *Edwardsiana prunicola* (Edwards), eggs (Kido

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*et al.* 1984, Wilson *et al.* 1989). McKenzie and Beirne (1972) found *Anagrus* spp. overwintering on wild rose and apple, *Malus domestica* Borkhausen, in British Columbia. In New York, *Anagrus* spp. were reared from 13 plant species collected from December to April (Williams and Martinson 2000). The closer vineyards were to overwintering sites, the better the recolonization by *Anagrus* spp. in the spring (McKenzie and Beirne 1972, Doutt and Nakata 1973, Kido *et al.* 1984, Wilson *et al.* 1989, Corbett and Rosenheim 1996, Murphy *et al.* 1996).

*Erythroneura elegantula* and *E. ziczac* are leafhopper pests of Washington wine grapes, *Vitis vinifera* L., (Wells and Cone 1989). *Erythroneura elegantula* eggs were parasitized primarily by *A. tretiakovae* S. Triapitsyn but also by *A. erythroneurae*, and *A. daanei*. Most *E. ziczac* eggs were attacked by *A. daanei* but *A. tretiakovae* was also recorded (Prischmann *et al.* 2007). These three species are also the principal *Anagrus* spp. that parasitized grape leafhoppers in New York (Williams and Martinson 2000). The non-grape host plants of two of these *Anagrus* spp. in New York were: black willow, *Salix nigra* L. (*A. erythroneurae)*; sugar maple, *Acer saccharum* Marsh.; black locust, *Robinia pseudoacacia* L.; multiflora rose, *Rosa multiflora* Thunberg; and common prickly ash, *Zanthoxylum americanum* Miller (*A. daanei*). Williams and Martinson (2000) did not report any non-grape hosts for *A. tretiakovae*.

The ultimate objective of the *Anagrus* spp. work is to achieve effective biological control of grape leafhoppers in Washington state vineyards. This will likely involve manipulating the agroecosystem by planting cover crops in or near vineyards (English-Loeb *et al.* 2003) or *Anagrus* spp. overwintering plants near vineyards (Kido *et al.* 1984, Wilson *et al.* 1989, Corbett and Rosenheim 1996, Murphy *et al.* 1996, 1998). One of the first steps toward this objective is to identify the overwintering hosts of *Anagrus* spp. (Prischmann *et al.* 2007). Therefore, the goal of this study was to identify plants that harbour overwintering *Anagrus* spp. that parasitize grape leafhoppers in central Washington.

## MATERIALS AND METHODS

Plants were collected from 48 sites in the Yakima Valley of Washington (the principal grape growing area) from near Benton City (46°16'N, 119°29'W), Benton County, in the east to near Harrah (46°24'N, 120°33'W), Yakima County, in the west. The distance between these two sites is about 82 km. Most of these plants were collected near Prosser (46°12'N, 119°46'W). Other Washington sites included two from near Bickleton (46°0'N, 120°18'W), Klickitat County, and one from Little Rattlesnake Cr. valley near Nile (46°49'N, 120°56'W), about 35 km NW of Yakima, Yakima County. One collection from Oregon was from a site near the Umatilla River about one km south of the city of Umatilla (45°55'N, 119°20'W), Umatilla County. The number of samples collected each year from 2000 to 2007 in order were: 11, 35, 20, 18, 19, 11, 9, and 9. Some sites were sampled more than once in different years. Between early January and mid April, branch terminals from the selected plants were cut, placed in plastic bags, and taken to the laboratory. Plants less than about two m in height were sampled by selecting branches from different heights and, if possible, from sun and shaded areas. Branches from taller plants were collected from about two m high or less. Plants were identified using keys and descriptions (Hayes and Garrison 1960, Gilkey and Dennis 1973, Hitchcock and Cronquist 1973, USDA 2007, UWBM 2007). Most of the plants were growing in uncultivated areas. Ornamental roses were sampled near residences. *Rosa rugosa* Thunberg plants were purchased and planted in a vineyard on Washington State University property, about eight km north of Prosser. Plants not identifiable during the winter were revisited

when flowers or leaves were present. Branches from each plant sample were trimmed to about 45 cm in length, the cut ends were inserted into a plastic bucket with water, and placed in an emergence cage (33 w x 46 l x 36 d cm) (Southwood 1978), which was made of plywood or cardboard with a 15 ml glass vial or 237 ml glass jar attached for collecting the emerging *Anagrus* adults. The parasitoids were attracted to the light coming through the collection vials and trapped there. The plant samples were placed in the cages within one day of collection and left in the cages for at least four weeks. The cages were placed in a greenhouse with natural and supplemental lighting (16:8 h L:D). The temperature ranged from about 22 to 28 °C. *Anagrus* spp. specimens were stored in 70% ethanol until they were mounted on microscope slides in Hoyer's mounting medium (Borror and DeLong 1971). Female specimens (keys are available only for females) were examined under a compound microscope and identified using the keys of Chiappini *et al.* (1996) and Triapitsyn (1998).

We collected leafhopper nymphs and adults near Prosser from ornamental roses on 11 April and 10 May 2002 and from blackberry on 12 and 15 April 2002 to identify the species feeding on those plants. Specimens were identified using the descriptions in Elsner and Beers (1988).

## RESULTS

We collected 132 plant samples comprised of 31 plant species from 52 different sites. A total of 733 female and 1068 male *Anagrus* was reared from 12 of the plant species (Table 1). *Anagrus erythroneura* was the most numerous grape leafhopper parasitoid collected (Table 1). It was reared from Himalayan blackberry, *Rubus armeniacus* Focke; Wood's rose, *Rosa woodsii* Lindley; sweetbrier rose, *R. eglanteria* L.; rugose rose, *R. rugosa*; willow, *Salix* spp. L.; and ornamental roses, *Rosa* spp. L. *Anagrus tretiakovae* was recovered from choke cherry, *Prunus virginiana* L.; ornamental roses, *Rosa* spp.; *R.. rugosa*; and Himalayan blackberry. One specimen, which was identified as *A. daanei* or a closely related species, was recovered from an ornamental rose (Table 1). *Anagrus atomus* L. was reared from Himalayan blackberry; evergreen blackberry, *R. laciniatus* Willdenow; *Rosa woodsii*, *R. eglanteria*; *R. rugosa*; willow, *Salix* spp.; ornamental roses, *Rosa* spp. and possibly from Antelope bitterbrush, *Purshia tridentata* (Pursh) de Candolle (Table 1). Some *Anagrus* specimens could not be identified due to their poor condition; usually they were missing antennae. Tentative identifications were given to *Anagrus columbi* Perkins, *A. daanei,* and some *A. nigriventris* Girault because the specimens did not exactly fit the descriptions in the keys. Voucher specimens are deposited at the Washington State University Irrigated Agriculture Research and Extension Center, Prosser, Washington.

The plants harbored from zero to six *Anagrus* spp. each (Table 1). *Rubus armeniacus* had the most *Anagrus spp.* with six. *Rosa* spp. had five species; *Salix* spp. and *R. rugosa* had three; *P. virginia, R. eglanteria* and *R. woodsii* had two each; and *Chrysothamnus nauseosus* (Pallas) Britton, *Prunus avium* L., *Purshia tridentata*, *Rubus lacinatus,* and *Salix babylonica* L. had one each (Table 1). *Chrysothamnus nauseosus* produced only one female with missing antennae and only one male emerged from *P. avium*.

All adult and nymph leafhoppers collected from roses or blackberries were rose leafhoppers, *Edwardsiana rosae* (L.).

**Table 1.**

*Anagrus* spp. reared from plants collected in south central Washington and north central Oregon during the winters of 2000 to 2007.

| Plant scientific name | Plant common name | No. of years collected | No. of sites[1] | No. of samples | No. of branches | No. of *Anagrus* females | No. of *Anagrus* males | *Anagrus atomus* | *A. erythroneurae* | *A. tretiakovae* | Other *Anagrus* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Acer saccharum L.* | Silver (sugar) maple | 2 | 2 | 3 | 70 | 0 | 0 | | | | |
| *Alnus rhombifolia Nuttall* | White alder | 1 | 1 | 1 | 20 | 0 | 0 | | | | |
| *Artemesia tridentata Nuttall* | Big sagebrush | 3 | 3 | 3 | 41 | 0 | 0 | | | | |
| *Celtis reticulata Torrey* | Hackberry | 1 | 1 | 1 | 12 | 0 | 0 | | | | |
| *Chrysothamnus nauseosus (Pallas) Britton* | Common rabbit brush | 2 | 2 | 2 | 35 | 1 | 0 | | | | |
| *Cornus sericea L., ssp. sericea* | Red-osier dog-wood | 3 | 3 | 4 | 86 | 0 | 0 | | | | |
| *Cornus sp. L* | Ornamental dog-wood | 1 | 1 | 1 | 8 | 0 | 0 | | | | |
| *Crataegus douglasii Lindley* | Black hawthorn | 2 | 2 | 2 | 42 | 0 | 0 | | | | |
| *Lonicera involucrata (Richard) Banks* | Bearberry honey-suckle | 1 | 1 | 1 | 24 | 0 | 0 | | | | |
| *Populus trichocarpa Michaux* | Black cotton-wood | 1 | 2 | 2 | 43 | 0 | 0 | | | | |
| *Prunus avium L.* | Sweet cherry | 2 | 5 | 5 | 100 | 0 | 1 | | | | |
| *Prunus cerasifera Ehrhart* | Flowering plum | 2 | 4 | 4 | 48 | 0 | 0 | | | | |
| *Prunus domestica L* | Prunes, Italian | 1 | 1 | 1 | 12 | 0 | 0 | | | | |
| *Prunus emarginata (Douglas ex. Hook.) Eaton* | Bittercherry | 1 | 1 | 3 | 68 | 0 | 0 | | | | |
| *Prunus sp. L.* | Flowering cherry | 1 | 1 | 1 | 20 | 0 | 0 | | | | |
| *Prunus virginiana L.* | Choke cherry | 5 | 10 | 13 | 296 | 4 | 3 | | | 3 | 1 *A. avalae* |
| *Purshia tridentata (Pursh) de Candolle* | Antelope bitter-brush | 3 | 4 | 5 | 101 | 2 | 1 | 2? | | | |

**Table 1 (continued)**

| Plant scientific name | Plant common name | No. of years collected | No. of sites | No. of samples | No. of branches | No. of *Anagrus* females | No. of *Anagrus* males | *Anagrus atomus* | *A. erythroneurae* | *A. tretiakovae* | Other *Anagrus* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Ribes aureum Pursh* | Golden currant | 1 | 1 | 1 | 20 | 0 | 0 | | | | |
| *Robinia pseudoacacia L.* | Black locust | 1 | 1 | 2 | 40 | 0 | 0 | | | | |
| *Rosa eglanteria L.* | Sweetbrier | 4 | 5 | 5 | 106 | 28 | 12 | 5 | 20 | | |
| *Rosa gymnocarpa Nuttall* | Dwarf rose | 1 | 1 | 1 | 22 | 0 | 0 | | | | |
| *Rosa nutkana K. Presl* | Nookta rose | 1 | 1 | 1 | 20 | 0 | 0 | | | | |
| *Rosa rugosa Thunberg* | Rugose rose | 2 | 3 | 3 | 50 | 5 | 7 | 1 | 3 | 1 | |
| *Rosa spp. L.* | Ornamental rose | 3 | 9 | 21 | 415 | 419 | 802 | 126 | 242 | 9 | 1 *A.* nr. sp. *daanei, 1 A. avalae* |
| *Rosa woodsii Lindley* | Wood's rose | 8 | 10 | 10 | 215 | 26 | 31 | 5 | 20 | | |
| *Rubus armeniacus Focke (R. discolor, R. procerus)* | Himalayan blackberry | 5 | 17 | 17 | 234 | 242 | 208 | 80 | 155 | 1 | 2 *A.* nr. sp. *columbi, 2 A. avalae, 1 A. nigriventris* |
| *Rubus laciniatus Willdenow* | Evergreen blackberry | 1 | 1 | 1 | 11 | 1 | 0 | 1 | | | |
| *Rubus parviflorus Nuttall* | Thimbleberry | 1 | 1 | 1 | 10 | 0 | 0 | | | | |
| *Salix babylonica L.* | Weeping willow | 1 | 1 | 1 | 35 | 1 | 0 | | | | 1 *A.* nr. sp. *avalae* |
| *Salix spp. L.* | Willow | 5 | 9 | 12 | 329 | 4 | 3 | 1 | 1 | | 2 *A.* nr. sp. *nigriventris* |
| *Vitis vinifera L.* | Grape (leaf litter) | 1 | 2 | 2 | 7 liters | 0 | 0 | | | | |
| *Vitis vinifera* | Grape (canes) | 1 | 2 | 2 | 56 | 0 | 0 | | | | |
| Total | 31 species | - | 108[1] | 132 | 2589 | 733 | 1068 | 219, 2? | 441 | 14 | |

[1] A total of 52 different sites were sampled. Some sites were sampled more than once.

## DISCUSSION

Except for *Salix* spp. (Salicaceae) and *C. nauseosus* (Compositae) all *Anagrus* spp. were reared from members of the Rosaceae. Of the *Anagrus* overwintering plants that we found, *R. woodsii, Chrysothamnus nauseosus*, *Prunus virginiana*, *Purshia tridentata*, and *Salix* spp. are native plants; the others were introduced (Hitchcock and Cronquist 1973).

*Anagrus erythroneurae* was the most abundant (based on identified females) (Table 1). It was reared from several species of roses and from blackberry. The *Rosa* spp. appear to be new plant host records (Triapitsyn 1998, Williams and Martinson 2000). Although *A. erythroneurae* is the most common egg parasitoid of *E. elegantula* in northern California (Triapitsyn 1998), *A. tretiakovae* was about 10 times more abundant on *E. elegantula* in Washington (Prischmann *et al.* 2007). Biotypes of *A. erythroneurae* vary in their host preferences and rates of parasitism (Triapitsyn 1998). Thus, the introduction of more effective biotypes may be possible.

Although *A. tretiakovae* was the most abundant *E. elegantula* egg parasitoid collected from grape in Washington (Prischmann *et al.* 2007), it was found in relatively low numbers on non-grape plants (Table 1). The hosts were choke cherry, at least two species of rose, and blackberry (Table 1), all of which appear to be new host records (Triapitsyn 1998, Williams and Martinson 2000). The recovery of *A. tretiakovae* from *P. virginiana* suggests that other *Prunus* spp. such as French prunes (Kido *et al.* 1984) also may also be potential overwintering refuges.

*Anagrus daanei* has been found in other states on Virginia creeper, *Parthenocissus quinquefolia* (L.) Planchon; almond, *Prunus dulcis* (Miller) D. A. Webb; blackberry; apple (unconfirmed); *Acer saccharum* Marshall; *Robinia pseudoacacia* L.; *Rosa multiflora* Thunberg; and *Zanthoxylum americanum* Miller (Triapitsyn 1998, Williams and Martinson 2000). Because *A. daanei* has been recovered from blackberry and a species of rose, it may overwinter on these plants in Washington, although presumably in low numbers.

*Anagrus atomus* was found in relatively high numbers on several species of plants. *Salix* and *Purshia* are genera not previously reported as host plants (Triapitsyn 1998, Williams and Martinson 2000). Although *A. atomus* is not known from grapes in North America, it has been reported as a parasitoid of grape leafhoppers in Europe and Iran (Böll and Herrmann 2004, Hesami *et al.* 2004). Triapitsyn (1998) believes that European, grape-inhabiting *A. atomus* is a candidate for importation into the United States to control *Erythroneura* spp.

The main grape growing area of Washington is in the arid Columbia Plateau ecoprovince that historically was composed of shrub-steppe habitat, but much of the land has been converted to agriculture (NWHI 2007). Average annual precipitation at the Washington State University Irrigated Agriculture Research and Extension Center near Prosser was 19.2 cm from 1924 to 1976 (Kleingartner 1977) and 19.1 cm from 1986 to 2007 (PAWS 2007) with only about 5% of the precipitation falling in July and August combined. Therefore, almost all crops grown in this region need to be irrigated. Blackberry bushes grow in places where they can access water – often where the water table is high due to irrigation. Wild roses grow almost exclusively in riparian habitats, principally near the Yakima River. Attempts to increase leafhopper parasitism in California by planting blackberries near vineyards were not very successful, probably because the habitats were not favorable for the blackberries or their leafhoppers (Wilson *et al.* 1989). In south central Washington, refuge plants probably would need to be irrigated. Even drought resistant plants such as *Rosa rugosa* may need irrigation to be suitable hosts for leafhoppers. Because pesticides can cause mortality to leafhoppers and *Anagrus* spp. (de Courcy Williams and Gill 1996, Martinson *et al.* 2001), refuge plants should not be planted within vineyards or where they would be exposed to spray drift.

Blackberry and roses were good overwintering plants for the grape leafhopper parasitoids *A. erythroneurae* and *A. tretiakovae*. Other host plants, perhaps better ones, almost certainly exist. Because *A. daanei* was the most common parasitoid reared from *E. ziczac* eggs (Prischmann *et al.* 2007), finding an acceptable overwintering plant is critical for successful biological control of this leafhopper in south central Washington.

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# Spatial patterns of western flower thrips (Thysanoptera: Thripidae) in apple orchards and associated fruit damage

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## ABSTRACT

Western flower thrips, *Frankliniella occidentalis* (Pergande), is an economic pest of apples in orchards of North America. Western flower thrips causes damage ("pansy spot") to apples by its egglaying activities during the bloom and immediate post-bloom periods. Difficulties in monitoring this pest and incomplete understanding of its biology during the bloom period have complicated control efforts in apple orchards. Densities of western flower thrips were monitored in seven (2003) or eight (2004) apple orchards at each of four bloom stages; in each orchard, thrips counts in blossom clusters were estimated at four to six distances into the orchard from an orchard edge that abutted native sagebrush-steppe habitat. We hypothesized that numbers of thrips in blossoms would decline with increasing distance along transects into orchards if the native habitat acted as a source of thrips. Thrips numbers in blossom clusters peaked at full bloom and petal fall. Densities showed a linear drop with increasing distance into the orchard, which we interpreted as evidence that the native habitat adjacent to each orchard did indeed act as a source of thrips moving into the orchards. Pansy spot incidence declined with increasing distance into the orchard. The major drop in damage occurred between the border row trees and samples taken at the adjacent distance (nine m away), suggesting that border rows adjacent to native habitats should be monitored with particular care. Regression analyses showed that damage and thrips density were positively correlated, albeit with substantial levels of unexplained variation in levels of damage.

**Key Words:** *Frankliniella occidentalis*, apple orchards, pansy spot, sampling, damage

## INTRODUCTION

Western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), is a pest of stone and pome fruits throughout North America (Terry 1991, Beers *et al.* 1993, Pearsall and Myers 2000). In stone fruits, damage is caused by the feeding activities of the adult or immature thrips, whereas in apple orchards damage occurs as females deposit eggs into the developing fruit. The egglaying causes a whitish discoloration of the skin surrounding the oviposition scar, a condition known as pansy spot (Venables 1925, Childs 1927, Madsen and Jack 1966). Apple varieties in which damage is most noticeable are the lighter-skinned cultivars such as Granny Smith, McIntosh, or Rome Beauty (Madsen and Jack 1966, Terry 1991). It is not completely clear at what stage of blossom or fruit development that damage occurs, although several studies have suggested that most of the egglaying in tissues where damage is of concern (i.e., on the developing fruitlet) occurs at late full bloom through petal fall or just following petal fall (Venables 1925, Childs 1927, Madsen and Jack 1966, Terry 1991). Densities of adult thrips in blossoms appear to peak at full

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bloom and petal fall (Terry 1991; see also below).

The use of insecticides to control western flower thrips in apple orchards requires care to avoid harming pollinators and to minimize disruption of integrated mite control (Bush 2000, Smith *et al.* 2006). Thus, it would be beneficial to growers if chemical applications were made only if densities of thrips were high enough to warrant spraying, and if applications were made only in areas of the orchard actually requiring treatment. These needs have led to efforts to develop monitoring tools for western flower thrips in orchards (Terry and DeGrandi-Hoffman 1988, Bradley and Mayer 1994), as well as to studies that have defined the relationship between bloom phenology and timing of damage (Terry 1991). Objectives of the current study were to determine whether counts of western flower thrips in apple blossoms and damage to developing fruit were affected by distance into the orchard, particularly for orchards that abut native sagebrush-steppe rangeland. Studies done in nectarine orchards suggested that edges of orchards adjacent to native habitat experienced higher densities of western flower thrips than areas abutting other orchards (Pearsall and Myers 2000, 2001). The native habitat apparently was a source of thrips moving into the nectarine orchards. We tested whether thrips numbers and incidence of pansy spot within apple orchards declined with increasing distance into the orchards, and assessed whether bloom stage affected this relationship. We also analyzed the relationship between thrips densities and incidence of pansy spot in apple fruit, as the quantitative relationship between thrips counts and damage to apples has yet to be clearly established (Beers *et al.* 1993).

## MATERIALS AND METHODS

**Study sites and sampling methods.** Studies were done in April-May, 2003 and 2004 at orchards located in northcentral and southcentral Washington State. Three (2003) or four (2004) orchards were monitored near Brewster (Douglas County) in northcentral Washington, and an additional four orchards (both years) were monitored in western Yakima (Yakima County) located in southcentral Washington State. In 2003, cultivars were Granny Smith (four orchards) and Red Delicious (three orchards); in 2004, cultivars were Granny Smith (two orchards), Fuji (one orchard), Cameo (two orchards), and Red Delicious (three orchards). All orchards had at least one edge adjacent to native sagebrush-steppe habitat. Insecticides were not applied during the studies.

Thrips densities and fruit damage were monitored along transects at four (2003) or six (2004) distances into each orchard, from an edge in each orchard that abutted native habitat. In 2003, the four distances were 0 (border row of trees), 30, 60, and 90 m into the orchard. The 2003 data suggested that the major drop in thrips numbers occurred between 0 and 30 m, so two additional distances (9 and 18 m) were added in the 2004 study. In all but two orchards, tree rows were parallel with the orchard border being monitored, thus transects in most orchards ran perpendicular to the tree rows.

Western flower thrips were sampled at each of four bloom stages: pink, open king bloom, full bloom (80% of flowers open), and petal fall (80% of flowers without petals). At each bloom stage and at each orchard, 25 flower clusters (each with five to six flowers) were clipped from 15-25 trees per distance; trees and flower clusters were chosen haphazardly. Height of samples was 1.5 to 2 m. The 25 clusters for each sample were placed in a self-sealing plastic bag, stored in an ice chest, and taken to the laboratory for examination. At the laboratory, thrips were extracted by immersing and agitating the blossoms in solutions of water and dishwashing soap. The tips of unopened flowers in pink and king bloom samples were cut away before immersion to allow the solution to freely circulate

through the flower. Extracted thrips were stored in 70% ethanol until they were identified and counted beneath a dissecting microscope. For each sample of 25 clusters, we recorded numbers of adult female *F. occidentalis*.

Thrips damage was assessed in each orchard at all distances to determine if a correlation existed between damage and distance into the orchard. We limited fruit examination to the 2004 study. Developing apples varied from 1.9 to 3.2 cm in diameter at the time samples were taken, and pansy spot was readily visible on all cultivars (pansy spot disappears in red varieties as the fruit color intensifies later in the growing season). At each of the six distances in each orchard, 250 fruitlets were haphazardly selected from 15-25 trees (10-15 apples per tree) and examined for pansy spot. Height of samples was again 1.5 to 2 m. Two people did all of the fruit examination (each person sampling four orchards) to minimize variation among observers in assessing for the presence of pansy spot.

**Data Analysis.** Mean number of thrips per 25 blossom clusters was compared among distances and among bloom stages using a doubly repeated measures analysis of variance (due to repeated sampling in space [=distance] and time [=bloom stage] within each orchard). The data were transformed by ln(x+1) (Zar 1974) and analyzed using PROC GLM (SAS Institute 2002). Greenhouse-Geisser adjusted *P*-statistics are presented throughout. To assess the relationship between thrips density and distance into the orchard, we examined linear and quadratic effects using the Polynomial command in the Repeated statement of PROC GLM (SAS Institute 2002). The effect of distance on proportion of fruit showing pansy spot was assessed using repeated measures ANOVA including only distance as the repeated factor. Proportions were arcsine transformed before analysis (Zar 1974). Linear regression was used to test whether the percentage of fruit showing damage depended upon thrips densities in the bloom samples. Separate regressions were fitted for the four bloom stages, and for thrips counts summed over the four bloom stages.

## RESULTS

We observed substantial variation among orchards in counts of thrips both years (Figs. 1-2). Thrips densities were significantly affected by bloom stage both years (Table 1). Densities were higher during the full bloom period (mean = 13.6 and 14.4 thrips per 25 clusters in 2003 and 2004, respectively; sample distances pooled) and petal fall period (14.4 and 16.3) than in the pink (1.3 and 2.4) and king bloom (4.6 and 7.0) stages. The interaction between distance and bloom stage was not significant either year (Table 1), so it is appropriate to examine the main effects of distance to determine whether thrips density changed with location in the orchard (Figs. 1E-2E). Distance effects were highly significant both years (Table 1). Thrips density declined as a linear function of distance from the native habitat both years (Table 1).

Mean percentage of fruit showing pansy spot declined with distance ($F = 3.8$; df = 5, 35; $P = 0.027$; Fig. 3). Linear and quadratic effects were examined, and suggested that damage declined as a quadratic function of distance into the orchard (linear: $F = 5.7$; df = 1, 7; $P = 0.048$; quadratic: $F = 6.0$; df = 1, 7; $P = 0.04$). A second analysis was done in which 5 profile contrasts were extracted to compare damage at consecutive distances (i.e., 0 vs 9 m, 9 vs 18 m, 18 vs 30 m, 30 vs 60 m, 60 vs 90 m). The analysis suggested that the primary decline in damage occurred between 0 and 9 m ($F = 14.8$; df = 1, 7; $P = 0.006$; the other 4 contrasts were non-significant).

Percentage damage increased with increasing thrips density, but with substantial scatter in the data (Fig. 4). Data for one of the eight orchards (labeled "Orchard 3" in Fig. 4) fell consistently out of the scatter shown in the other data. Regression models

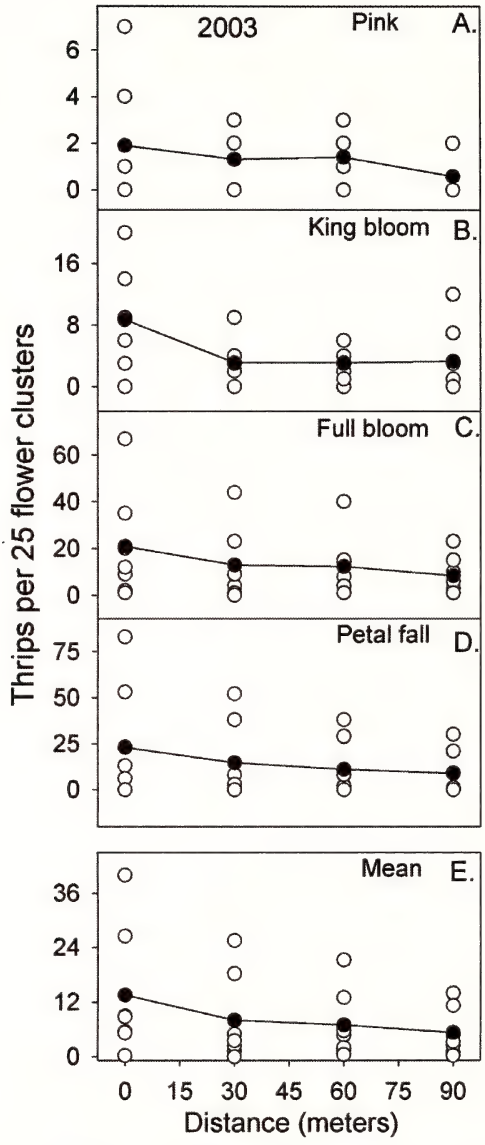


**Figure 1.** Number of adult female western flower thrips per 25 flower clusters in four bloom stages as a function of distance into the orchard (panels A-D); 2003 data. Panel E shows thrips counts averaged over bloom stage. Open circles show results for each orchard (N = 7 orchards; some data points overlap), while filled symbols depict numbers averaged over orchard. See Table 1 for ANOVA results.

were fitted both with and without the Orchard 3 data (Table 2). In all models, the intercept term differed significantly from zero, indicating that the models predicted some level of damage at a measured density of zero thrips (see also the scatter plots in Fig. 4). Slope coefficients were significantly different from zero in all models for which the Orchard 3 data had been excluded (Table 2); $r^2$ values were low in all models ($\leq$0.26), reflecting the large scatter in the data. Regression models fitted to counts summed over bloom stage were significant (Fig. 5), albeit again with substantial scatter around the fitted lines.

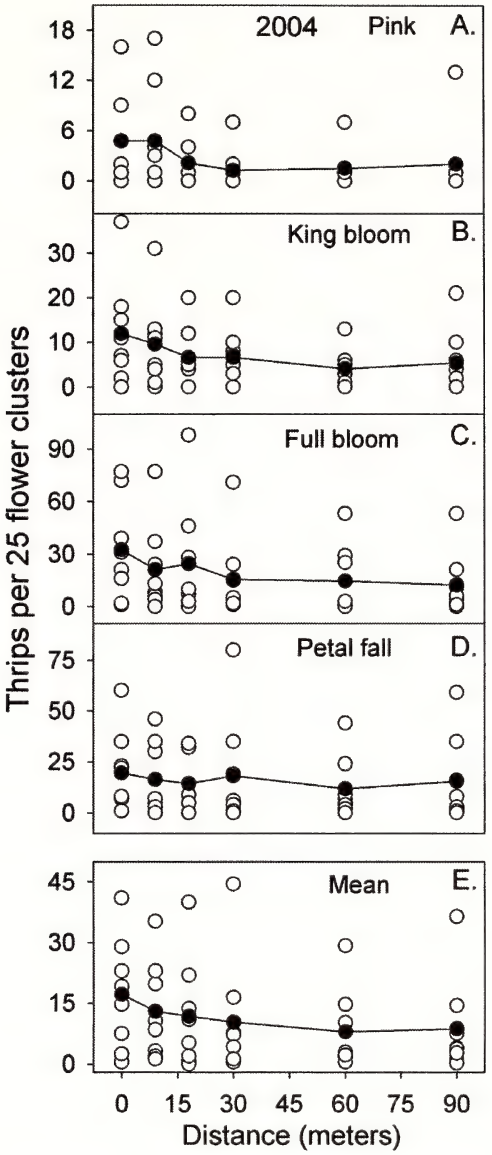


**Figure 2.** Number of adult female western flower thrips per 25 flower clusters in four bloom stages as a function of distance into the orchard (panels A-D); 2004 data. Panel E shows thrips counts averaged over bloom stage. Open circles show results for each orchard (N = 8 orchards; some data points overlap), while filled symbols depict numbers averaged over orchard. See Table 1 for ANOVA results.

## DISCUSSION

Densities of western flower thrips in apple blossoms peaked between the full bloom and petal fall stages (Figs. 1-2), as shown also in other sampling studies done in apple orchards of western North America (Madsen and Jack 1966, Terry 1991). We observed a linear decline in thrips densities with increasing distance into orchards, from transects beginning at the edge of orchard that abutted native habitat. Other studies done in crop or commercial forest systems have shown that non-agricultural habitats adjacent to crops may be a source of pest thrips colonizing the crop, leading often to

**Table 1.**

Results from repeated measures ANOVA assessing effects of bloom stage and distance into the orchard on thrips densities in bloom clusters (Figs. 1-2). Greenhouse-Geisser adjusted *P*-statistics shown for main effects and interaction terms. Linear and quadratic contrasts are extracted for the distance effects.

| | 2003 | | | 2004 | | |
|---|---|---|---|---|---|---|
| | df | *F* | *P* | df | *F* | *P* |
| Bloom stage | 3,18 | 5.3 | 0.042 | 3,21 | 9.3 | 0.003 |
| Distance | 3,18 | 8.2 | 0.009 | 5,35 | 5.7 | 0.007 |
| Linear | 1,6 | 15.4 | 0.008 | 1,7 | 10.0 | 0.02 |
| Quadratic | 1,6 | 0.7 | 0.45 | 1,7 | 3.9 | 0.09 |
| Stage x distance | 9,54 | 1.1 | 0.36 | 15,105 | 1.0 | 0.42 |

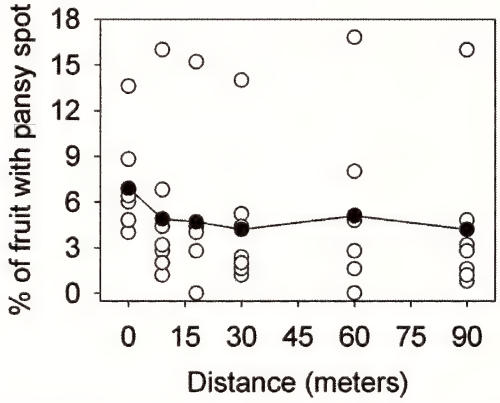


**Figure 3.** Percentage of fruit showing pansy spot as a function of distance into orchard. Open symbols show results for each orchard (N = 8 orchards; some data points overlap), while filled symbols show damage averaged over orchard. 250 fruit examined at each distance for each orchard.

high densities of thrips at field edges (Lewis 1973). Native habitat adjacent to nectarine orchards was a source of western flower thrips colonizing orchards in western Canada (Pearsall and Myers 2000, 2001). Orchards surrounded by other orchards tended to have lower densities of thrips than orchards adjacent to native habitat (Pearsall and Myers 2000). These studies failed to describe quantitatively how thrips densities or damage to fruit declined with increasing distance into orchards. In our study, patterns in damage paralleled patterns in densities of thrips. Incidence of pansy spot declined with increasing distance into orchards, with the major drop in damage levels occurring between 0 and 9 m into the orchard. The density and damage results suggest that apple growers may in some circumstances be able to limit spray applications to border rows.

A major impediment to developing control protocols for western flower thrips in apple orchards has been our lack of information regarding the quantitative relationship between adult thrips density and egg density in blossoms, or between density and actual damage (Terry 1991, Beers *et al.* 1993). We showed that percentage damage was positively correlated with thrips counts in blossoms (Figs. 4-5). However, there was substantial unexplained variation in the data, at all bloom stages (Figs. 4-5). Moreover, fruit damage often occurred even in the absence of thrips in samples (see scatter plots in Fig. 4 and regression models in

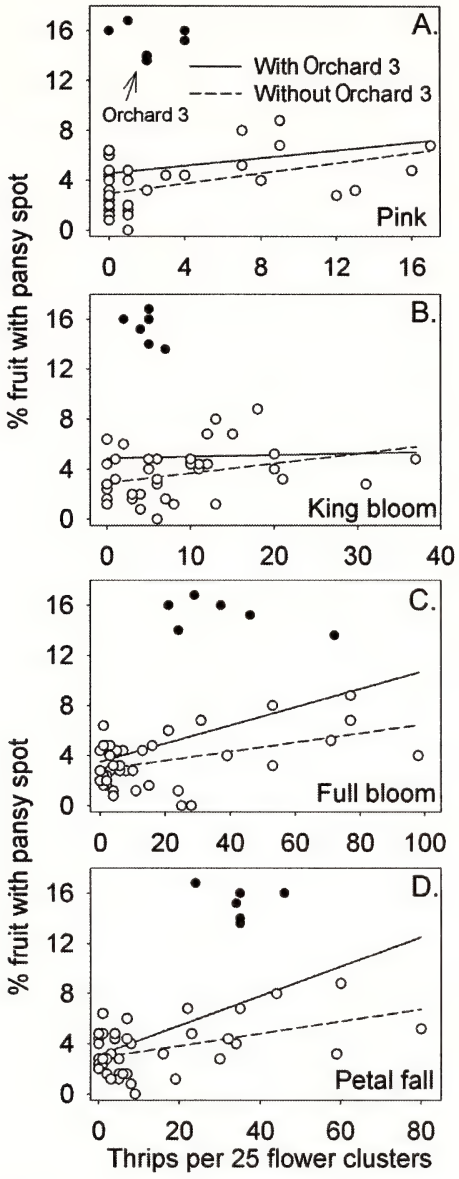


**Figure 4.** Scatter plot and linear regressions showing relationship between numbers of adult female western flower thrips in blossom clusters and percentage of 250 fruit showing pansy spot. Data from Orchard 3 are solid dots, other data are circles. Regressions fitted with (solid lines) and without (dashed lines) data for Orchard 3 (a Red Delicious orchard located in western Yakima). See Table 2 for regression statistics.

Table 2). We observed a damage level of 4.4% at one distance in an orchard for which no thrips were collected in any of the four sampling periods (Fig. 5). These results suggest one or more of the following: (a) our sample sizes were too small or taken too infrequently to adequately estimate thrips densities in the orchard; (b) limiting our samples to the four bloom stages between pink and petal fall means that we failed to sample during other stages of apple development in which the fruit is susceptible to thrips; (c) our method for extracting thrips from blossoms missed a significant number of thrips.

One Red Delicious orchard ("Orchard

**Table 2.**
Results from linear regressions relating percentage of fruit having pansy spot to thrips density. Separate models fitted with and without results for Orchard 3. Scatter plots and regression lines shown in Figures 4 and 5.

| Bloom stage | Include Orchard 3 | Intercept[1] | Slope | *P* | $r^2$ |
|---|---|---|---|---|---|
| Pink (Fig. 4A) | Yes | 4.56 | 0.154 | 0.30 | 0.02 |
| | No | 2.94 | 0.203 | 0.002 | 0.21 |
| King bloom (Fig. 4B) | Yes | 4.89 | 0.013 | 0.88 | 0.01 |
| | No | 2.91 | 0.078 | 0.03 | 0.11 |
| Full bloom (Fig. 4C) | Yes | 3.53 | 0.073 | 0.004 | 0.17 |
| | No | 2.89 | 0.036 | 0.003 | 0.20 |
| Petal fall (Fig. 4D) | Yes | 3.11 | 0.118 | 0.0002 | 0.26 |
| | No | 2.87 | 0.049 | 0.003 | 0.20 |
| Cumulative (Fig. 5) | Yes | 3.28 | 0.037 | 0.003 | 0.18 |
| | No | 2.72 | 0.019 | 0.001 | 0.23 |

[1] All intercept terms significantly ($P < 0.05$) different from zero.

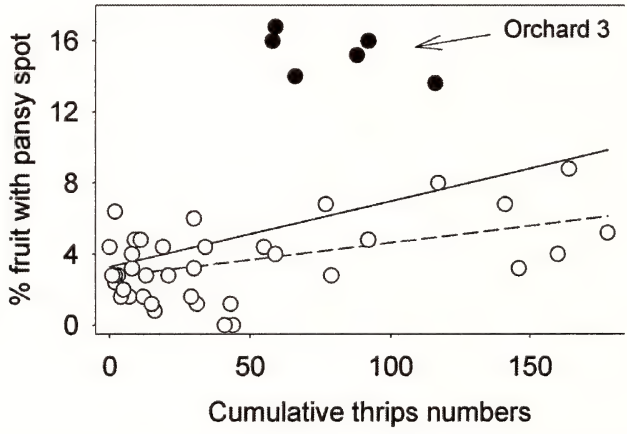


**Figure 5.** Scatter plot and linear regressions showing relationship between numbers of adult female western flower thrips in blossom clusters (summed over the four bloom stages) and percentage of 250 fruit showing pansy spot. Data from Orchard 3 are solid dots, other data are circles. Regressions fitted with (solid lines) and without (dashed lines) data for Orchard 3 (a Red Delicious orchard located in western Yakima). See Table 2 for regression statistics.

3" in Fig. 4) had damage estimates well above levels seen in the remaining seven orchards, for unknown reasons. This orchard had stands of feral alfalfa in the understory, and it is possible that the alfalfa acted as a source of western flower thrips moving into the trees whenever the understory was mowed. Venables (1925) stated that alfalfa cover crops in apples may affect incidence of pansy spot. Pearsall and Myers (2000) showed that alfalfa and other flowering plants in the understory of nectarine orchards supported potentially large numbers of western flower thrips. Bush (2000) cautioned against destroying flowering dandelions in orchard understory during the bloom period in apples, as thrips occupying dandelion flowers may then move into the trees and cause damage to developing fruit. It is possible that the alfalfa in Orchard 3 acted as an important source of western flower thrips moving onto developing fruit. In any case, data for Orchard 3 added substantially to the scatter of points surround-

ing the regression lines (Figs. 4-5, Table 2). These results again reinforce observations made elsewhere that the relationship between damage and thrips densities in apple blossoms can be difficult to predict (Terry 1991).

## ACKNOWLEDGEMENTS

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# Phenology of western flower thrips *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) on plant species in and near apple orchards in Washington State

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## ABSTRACT

Both orchard and adjacent native vegetation harboured adult western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), from early spring until fall. *Frankliniella occidentalis* made up the great majority of adults collected in flowers of most plant species sampled, including apple. Other species found on apple flowers included *Anaphothrips obscurus* Müller, which lives on grasses, and *Thrips brevipilosus* Moulton. A mixture of thrips species, including *F. occidentalis*, *Scirtothrips citri* (Moulton), *Thrips tabaci* Lindeman, and *Thrips treherni* Preisner, occurred on apple shoots. Thrips were found in orchards as early as green tip (early April), with the highest concentrations of *F. occidentalis* in shoots occurring in June and July. Thrips declined in late summer as shoots formed dormant buds; however, some *F. occidentalis* adults were still found in early September. Five common woody plants and forbs selected for sampling in the sagebrush-steppe habitat had *F. occidentalis* adults present, especially during bloom. Western flower thrips can exploit open flowers or young shoots from spring through fall in native vegetation because of the diversity of plants and their different growth habits.

## INTRODUCTION

Western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), is native to western North America, where it has long been a crop pest (Bailey 1940). In the latter half of the 1900s, it spread to various crops, greenhouse cultures, and native plants in other areas of North America, where it became one of the most common thrips species (Felland *et al.* 1993, Chellemi *et al.* 1994). During the same period it also spread to native and cultivated habitats throughout the world (Kirk and Terry 2003). *Frankliniella occidentalis* is attracted to showy, fragrant flowers of numerous species (Terry 1997), but also feeds on wheat (Toapanta *et al.* 1996).

*Frankliniella occidentalis* is a pest of apple, where it oviposits on developing fruitlets around the flowering period (Terry 1991, Beers *et al.* 1993). Oviposition sites on fruit develop scar tissue surrounded by a larger, pinkish-white surface discoloration called a pansy spot. This damage is most apparent on green or light-coloured apple cultivars (Venables 1925); not all cultivars show the damage at harvest. After flowers are no longer available, additional generations develop in the apical portions of growing apple shoots (Venables 1925).

The cause of pansy spot was unknown for many years after it was first noted in the early 1900s, until Newcomer (1921) made detailed observations and found thrips to be the cause. However, in the original work, the species was not identified. Venables (1925) was the first to identify the species associated with apple. Although *F. occidentalis* is cited as the most likely cause of injury to apple, Venables also found *Aeo-*

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*lothrips fasciatus* (L.), *A. conjunctus* Pergande, and *Taeniothrips* sp. He notes, however, that the latter species are likely predacious on *F. occidentalis*. Childs (1927) positively implicated both *F. occidentalis* and *A. fasciatus* as causing injury, even though he later notes that *A. fasciatus* was supposed to be predacious and was not common. Madsen and Jack (1966) list *F. occidentalis*, *Rhopaloandrothrips corni* Moulton, *Thrips hukkineni* Priesner (=*T. trehernei* Priesner), *Thrips tabaci* Lindeman, *Haplothrips niger* Osborne, and *Leptothrips mali* (Fitch) as occurring on apple, with the latter two species as probable predators. The leaf-feeding species *T. tabaci* was considered a visitor from grass hosts. Pearsall and Myers (2001) note that 12 species of thrips were found in nectarine orchards in central British Columbia, Canada, again with *F. occidentalis* as the most common species. An investigation of the species inhabiting apple has not been done in the fruit-growing regions of central Washington.

The possible influence of plant species in or near the orchard on potential damage by thrips was first suggested by Venables (1925). He noted that alfalfa was a host, and that its common use as a cover crop might contribute to thrips damage. This idea was expanded by Madsen and Jack (1966), who sampled thrips on a variety of native plants commonly found near apple orchards in the dry interior valleys of British Columbia. They concluded that *F. occidentalis* moves from host to host as the plants flower. In addition, they note the overlapping species complex between apple and native hosts. However, they present only a list of thrips species collected from various plant hosts, without temporal or quantitative information. Further studies were conducted in the mid-1990s (Pearsall and Myers 2000a, 2000b, Pearsall and Myers 2001) that examined thrips ecology and dispersal in orchards near native habitat in central British Columbia. These authors concluded that thrips abundance in nectarine orchards was related to dandelion density, and to proximity of native habitat. The role of weeds on the orchard floor and native plants in extra-orchard habitats has not been investigated in central Washington. This information is foundational to the development of effective pest management strategies.

The work herein has two objectives. The first objective is to determine the species of thrips adults in apple flowers and shoots in central Washington state. The second is to determine if and when selected weed and native plant species are inhabited by the adults.

## MATERIALS AND METHODS

Four 'Granny Smith' apple orchards near the towns of Vantage (Kittitas County), Orondo (Douglas County), Brewster (Okanogan County), and Bridgeport (Douglas County) in central Washington were selected as study sites and sampled in 2002. All sites were typical of apple orchards in the Columbia River valley in that they were irrigated regularly to maintain fruit trees in a climate that receives an average of 30-50 cm of precipitation per year, the majority as snowfall. Orchards were bordered by native vegetation on one or two sides. None of the sites was near riparian habitat.

The three northern sites, Orondo, Brewster, and Bridgeport, were adjacent to sagebrush-bunchgrass steppe. These areas had a mixture of grass species, including bluebunch wheatgrass, *Agropyron spicatum* (Pursh) Scribn. and J. G. Smith, and needlegrass, *Stipa* spp. Forbs and woody plants included arrowleaf balsamroot, *Balsamorhiza sagittata* (Pursh) Nutt., lupin, *Lupinus* spp., big sagebrush, *Artemisia tridentata* Nutt., and snow buckwheat, *Eriogonum niveum* Douglas ex Berth. Patches of plants characteristic of higher elevations were also present, such as western yellow pine, *Pinus ponderosa* P and C Lawson, and antelope bitterbrush, *Purshia tridentata* (Pursh) DC. The orchards were

irrigated by sprinklers and had a stand of Italian ryegrass, *Lolium multiflorum* Lam. (Orondo site), orchardgrass, *Dactylis glomerata* (L.) (Bridgeport site), or weedy species such as downy brome, *Bromus tectorum* L. (Brewster site). All three sites had a mixture of broadleaf weed species on the orchard floor, including dandelion, *Taraxacum officinale* G. H. Weber ex Wiggers.

The Vantage site, the farthest south, was bordered by rocky soil and talus. Grasses included bluebunch wheatgrass and sandberg bluegrass, *Poa secunda* J. Presl. Forbs and woody species included phlox, *Phlox* spp., daisy, *Erigeron* spp., big sagebrush, and gray rabbitbrush, *Chrysothamnus nauseosus* (Pallas) Britt. The orchard was drip-irrigated and the soil surface was dry for most of the summer. The ground cover included dry-adapted species such as downy brome and flixweed, *Descurania sophia* (L.) Webb. ex Prantl.

The Orondo site was under organic management. No insecticides were used other than horticultural oil. All the other orchards were under conventional pest management. The Brewster site received no pesticides for thrips, and only azinphosmethyl during May through August. The Bridgeport site was treated with formetanate hydrochloride for thrips at full bloom, then pyriproxyfen and methoxyfenozide for lepidopteran pests. The Vantage site was treated with horticultural mineral oil and chlorpyrifos at green tip, and spinosad for thrips at full bloom.

The objective of sampling was to count adult thrips, presumed to be primarily *F. occidentalis,* concentrated on the preferred tissue (flowers and very young leaves) of the various plant species. Beginning in early March, after the snow had melted, samples were taken from apple trees, selected plants in the orchard ground cover, and plants located 10-50 m into surrounding uncultivated native vegetation. All samples were collected, placed in 15 × 15 cm self-sealing plastic bags, and immediately stored in a cooler. Additional details of sampling procedures are described by habitat.

**Apple trees.** As soon as the apple buds started to grow (green tip), 100 buds were taken weekly, or during bloom, twice per week, from each site. Flower bud samples and vegetative bud samples were taken separately. From king bloom to petal fall, 100 individual flowers, or, after petal fall, king fruit, were sampled. Vegetative bud samples were taken from actively growing shoots throughout the summer. These became scarce as the shoots completed growth later in the year. Sampling ended when growing tips could no longer be found, by late summer. A sample of 20 dormant shoots was taken at each site in October.

**Ground cover.** The two most common plant species on the orchard floor, one grass species and one broadleaf weed, were selected for sampling. The most common species varied by site. Grasses included Italian ryegrass, orchardgrass, and downy brome. Broadleaf weeds included dandelion and flixweed. Four replicate samples per site were collected weekly. Samples consisted of individual plants cut off at ground level, or when the plants were too large for the sample bags, the flower stalks or crowns containing the youngest leaf tissue were selected. Sampling was discontinued when the above-ground plant parts had dried due to dormancy, or in the case of annuals, had gone to seed and dried. Sampling began again when winter annuals began to sprout in the fall.

**Sagebrush steppe.** Three to four of the most common species of plants in the surrounding native vegetation were selected in the beginning for sampling. Four replicate samples were taken weekly. One of the species was a grass and the others were forbs or woody plants. Grasses included bluebunch wheatgrass, sandberg bluegrass, and needlegrass. Other plants included gray rabbitbrush, big sagebrush, antelope bitterbrush, arrowleaf balsamroot, and snow buckwheat. The sampling methods for grasses were the same as for those on the orchard floor. For large forbs and woody species, several shoot cuttings, about 15 cm long, were collected in sufficient quantity to

fill a sample bag. If available, cuttings with actively growing leaves or flowers were selected preferentially over dormant or non-flowering shoots.

**Extraction of thrips.** Thrips were separated from the plant material by filling the sample bag with water, adding a few drops of liquid detergent, and agitating for several seconds. Thrips and plant material were separated from the soapy water by pouring through two sieves (Hubbard Scientific Co., Northbrook, IL). The larger sieve (#10, 0.25 mm mesh) trapped most of the plant material, and the finer sieve (#230, 0.0014 mm mesh) trapped the thrips (Lewis *et al.* 1997a) Thrips were then rinsed into a vial of 50% ethanol.

Adult and larval thrips were counted separately. Adult specimens from apple flowers were all slide-mounted in PVA Mounting Medium (BioQuip Products, Inc., Rancho Dominiguez, CA) and identified. The small number of species was sent to Cheryl O'Donnell, Department of Entomology, University of California, Davis, CA, as vouchers for identification. Adult *Frankliniella* specimens from apple shoots and other plant species were slide-mounted and identified to species. A representative sample of the other species on apple shoots was also slide-mounted and sent to Cheryl O'Donnell for identification.

Most of the samples contained fewer than 50 specimens. However, a few samples, especially those from dandelion, contained an unusually high number of thrips, often exceeding 150. If the number of adult thrips exceeded 50, the total was recorded, and half of the specimens were randomly selected for a subsample. The original numbers of *F. occidentalis*, other species, and other unidentified thrips were estimated by dividing the numbers in the subsample by the proportion of adults selected.

## RESULTS

Apple trees were still fully dormant when sampling began in early March. When the apple buds reached green tip, about the second week in April, adult thrips began to appear in the shoots (Fig. 1). Adult thrips were present in the opening apple flowers as petals began to unfurl (pink) (Brewster, Bridgeport, and Vantage sites) or by the time the first flowers in the clusters had fully opened (king bloom) (Orondo site). Larvae were also found at king bloom. By full bloom, both adults and larvae were abundant. Insecticide applications (formetanate hydrochloride and spinosad) reduced the numbers of adults and larvae, but only temporarily. Although thrips at the Vantage site may have been affected by the chlorpyrifos application at green tip, adults were found in blossom clusters by pink. Adults and larvae declined after full bloom, but a few were still present at the end of the blossom period. Some thrips were recovered from young fruit at petal fall.

*Frankliniella occidentalis* made up the great majority (90.3%) of the adults collected in apple flowers (Table 1). *Anaphothrips obscurus* Müller, a species found on grasses (Lewis *et al.* 1997b), made up 8.9%. *Thrips brevipilosus* Moulton, a species originally collected from native forbs, potential orchard weeds such as alfalfa and wild mustard, and a species of *Artemisia* (Moulton 1927), made up the remaining 0.8%. *Frankliniella occidentalis* comprised a little more than one-third of the adults collected from apple shoots (Table 1). *Thrips treherni* made up 12.7% of specimens, while *Scirtothrips citri* (Moulton) and *T. tabaci* together made up most of the remaining 49.5%.

Thrips numbers in apple shoots were low during bloom, then greatly increased at petal fall (mid-May) (Fig. 1). No apparent break occurred between one generation and the next. The highest concentrations of *F. occidentalis* in shoots occurred in June and July. Larvae outnumbered adults in May, June, and part of July. Adult and larval populations declined in late summer as shoots formed dormant buds; however, some *F. occidentalis* were still found in early September (Fig. 1). Samples of the

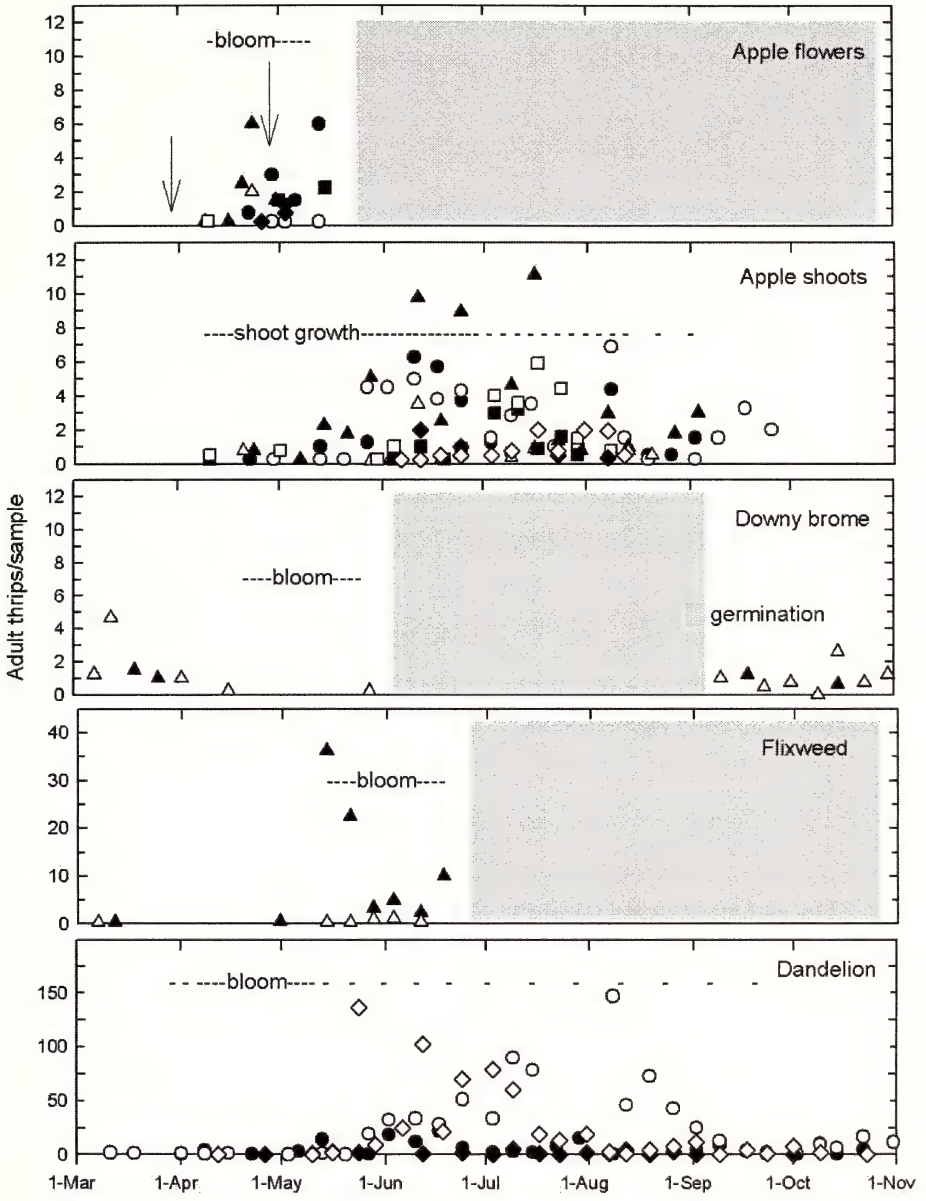


**Figure 1.** Adult *Frankliniella occidentalis* (solid symbols) and other thrips species combined (open symbols) found in plant samples in orchards near Brewster (●), Vantage (▲), Bridgeport (■), and Orondo (♦) in 2002. Periods of plant growth are indicated with dashed lines. A gray background shows a period when samples were not taken. Samples with zeros are not represented. Arrows indicate the date of application of chlorpyrifos at the Vantage site (pre-bloom) and formetanate hydrochloride or spinosad at the Bridgeport and Vantage sites (full bloom).

dormant buds in October yielded a few specimens of other species at one site.

Few thrips specimens were found in orchardgrass or Italian ryegrass, and no *F. occidentalis* adults were found on these species. A few unidentified larvae were found on both species in the fall. *Frankliniella occidentalis* adults were found on downy brome both in very early spring and when new plants germinated in September (Fig. 1, Table 1). Moderate numbers of larvae were also found in very young downy

**Table 1.**

Percentage of adult *Frankliniella occidentalis* in collections from plants at different stages of growth.

| Plant | Type of sample | Number of samples | Total adult thrips | *F. occidentalis* (%) |
|---|---|---|---|---|
| apple | flowers | 116 | 124 | 90.3 |
| | shoots | 368 | 932 | 37.8 |
| dandelion | flowering plants | 263 | 8058 | 9.1 |
| downy brome | spring plants | 126 | 47 | 19.5 |
| | fall plants | 52 | 40 | 20.0 |
| flixweed | prebloom | 46 | 4 | 75.0 |
| | bloom | 20 | 329 | 96.4 |
| arrowleaf balsamroot | prebloom | 12 | 2 | 0.0 |
| | bloom | 24 | 521 | 47.0 |
| antelope bitterbrush | bloom | 32 | 22 | 64.3 |
| | shoot growth | 176 | 73 | 12.3 |
| Gray rabbitbrush | prebloom | 84 | 26 | 7.7 |
| | bloom | 52 | 967 | 83.3 |
| snow buckwheat | prebloom | 167 | 12 | 41.7 |
| | bloom | 92 | 568 | 86.3 |
| big sagebrush | prebloom | 283 | 113 | 14.2 |
| | bloom | 112 | 628 | 89.2 |

brome.

Flixweed, a yellow-flowered winter annual, was common at the Vantage site. This plant flowered for about six weeks after apple bloom. *Frankliniella occidentalis* was found on the flowers until it was mowed in late May (Fig. 1). Afterward, thrips were less abundant on flixweed and declined until the plant went to seed and dried, around late June.

Dandelion bloom began in April and lasted until frost, but peak bloom occurred in April and early May, declining just before peak apple bloom. Some dandelion plants had over 10 flowers opened at peak flowering. Most dandelions did not produce flowers after May, but about 1% could be found on any one sample date with a single flower until frost. *Frankliniella occidentalis* were present on dandelion before apple trees broke dormancy (Fig. 1). Dandelions sampled from March through the end of apple bloom (mid-May) had a low concentration of thrips, although the flowers were abundant. Some *F. occidentalis* were found in dandelion flowers throughout the growing season, however, other species were more abundant (Table 1), especially *T. treherni*. From mid-May until late September, *T. treherni* were highly concentrated in the few open flowers, with dozens of adults occurring on a single plant. By late summer and fall, very few larvae were found, and thrips populations decreased in October.

Arrowleaf balsamroot began to bloom at this site in early May, and thrips, including *F. occidentalis*, were abundant in the flowers (Fig. 2). Many larvae and a few adult *F. occidentalis* were found on bitterbrush in early May, when the plant was in bloom (Fig. 2). Few thrips were found on the plant as its fruit matured in mid-May to mid-

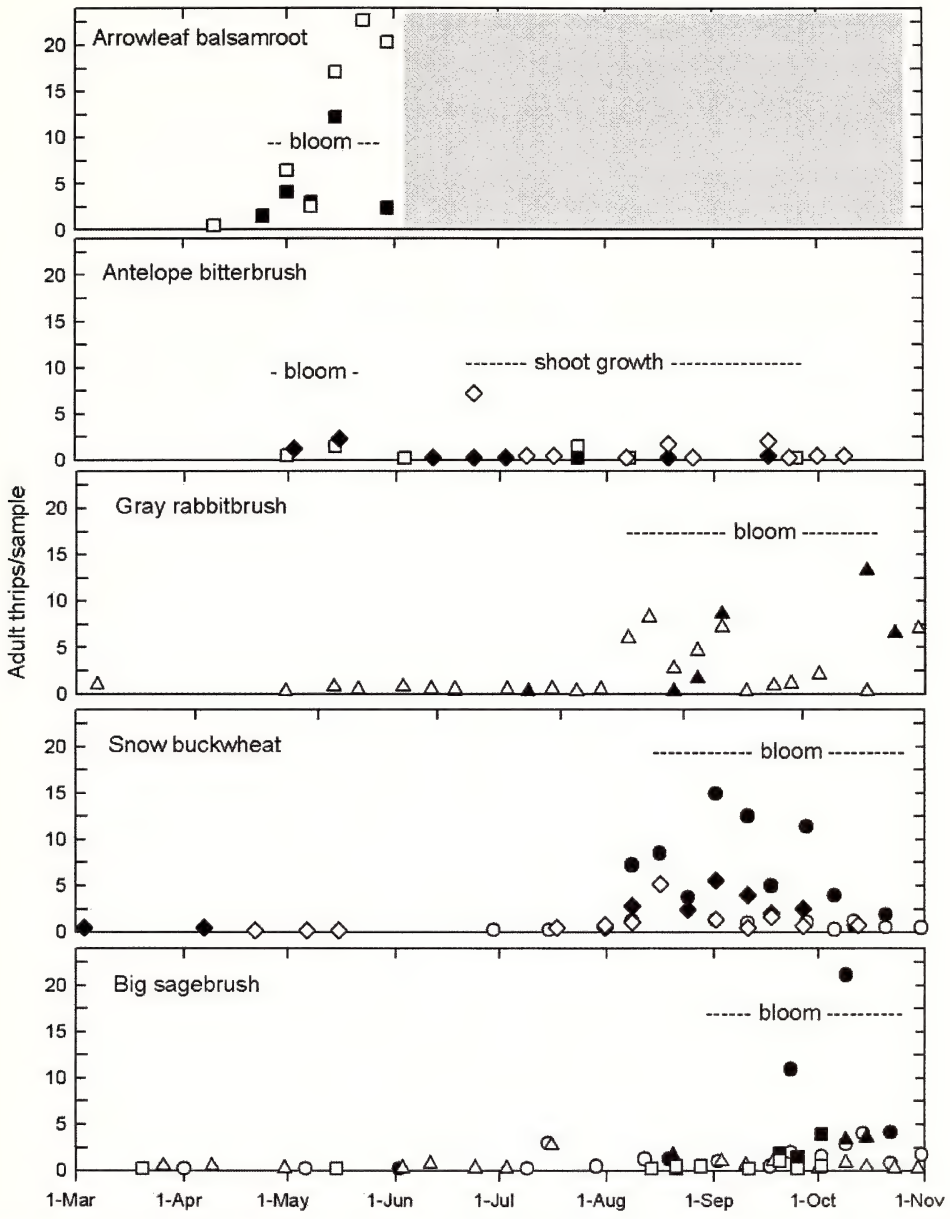


**Figure 2.** Adult *Frankliniella occidentalis* (solid symbols) and other thrips species combined (open symbols) found in plant samples of native vegetation adjacent to orchards near Brewster (●), Vantage (▲), Bridgeport (■), and Orondo (♦) in 2002. Periods of plant growth are indicated with dashed lines. A gray background shows a period when samples were not taken. Samples with zeros are not represented.

June. When bitterbrush began to grow new vegetative shoots in late June to fall, both adults and larvae were found. These were mostly other thrips species, but a few *F. occidentalis* were collected (Table 1).

Very few thrips occurred on snow buckwheat, big sagebrush, and gray rabbitbrush when shoots were growing in the summer, and those collected were species other than *F. occidentalis* (Fig. 2). Flower heads began to form on big sagebrush in July, and by September and October, thrips were abundant on the open flowers. Adults were found first, followed by larvae 1-2 weeks

later. Gray rabbitbrush and snow buckwheat also attracted thrips to their flowers, including *F. occidentalis* (Fig. 2, Table 1). Native grasses such as bluebunch wheatgrass, sandberg bluegrass, and needlegrass had very few thrips and no *F. occidentalis* were collected.

## DISCUSSION

In Washington, *F. occidentalis* was the most numerous adult thrips and was most likely the predominant species ovipositing in apple flowers. They produced most of the fruit injury, and the abundant larvae found at king bloom and later. Thus, orchard management aimed at reducing numbers of this species is key to minimizing pansy spot. *A. obscurus*, also recovered from apple flowers, is a specialist on grasses (Lewis *et al.* 1997b) and highly unlikely to oviposit in apple blossom clusters. *Thrips brevipilosus*, rare in our samples, has not been collected on apple previously and may have been reproducing on weeds (Moulton 1927).

*Frankliniella occidentalis* is considered to be highly nomadic (Terry 1997) and movement from plant to plant likely explains much of the fluctuations in population density. The sequence of movement in apple orchards can be inferred from the phenology on individual hosts. *Frankliniella occidentalis* overwinters as mated adult females in leaf litter and on the bark of trees (Pearsall and Myers 2000a). Adults begin emerging in early March and continue emerging for six weeks (Pearsall and Myers 2000a). In Washington orchards, the earliest plants attractive to adults include downy brome and dandelion. As soon as apple trees begin to grow, they attracted a few adults to flowering as well as vegetative buds. Adults concentrated in apple flowers after the petals began to open, the corolla colour changed from pink to pink and white, and flowers released fragrance. Adults of this anthophilous species were most likely drawn to apple and other host flowers based on a combination of colour and fragrance (Terry 1997). In addition, the magnitude and timing of migration to apple flowers may have been in response to temperature (Pearsall and Myers 2000a).

After petal fall, *F. occidentalis* adults joined a mixture of species in apple shoots from early spring until late summer. This season-long presence on apple trees, although alluded to by Venables (1925), has gone largely ignored and unstudied since that time. Adults can also move to flixweed when it flowers briefly after apple bloom from mid-May to mid-June, or return to dandelion, which maintains limited flowering throughout the summer and fall. *Thrips trehernei* was the most common species on dandelion in Washington, echoing the findings in British Columbia (Madsen and Jack 1966, Pearsall and Myers 2001). In early fall, *F. occidentalis* adults can move to young downy brome. Thus, *F. occidentalis* can continuously inhabit apple orchards.

All plant species selected for sampling in the sagebrush-steppe habitat, except the grasses, had *F. occidentalis* adults present, especially during bloom. *Frankliniella occidentalis* has been collected on almost every flower sampled from western orchards and surrounding vegetation (Madsen and Jack 1966, Pearsall and Myers 2000a). Thrips can probably find open flowers or growing shoots throughout the year in native vegetation because of the diversity of plant species and their different growth habits. There are a few gaps in the phenology of plants sampled in this study when concentrations of *F. occidentalis* adults could not be located, namely March to early April, and June through July. Some common species not sampled were observed blooming in March, such as bluebell, *Mertensia longiflora* Greene, and sagebrush buttercup, *Ranunculus glaberrimus* Hook. Plant species other than those sampled in our study could be found blooming in June and July, such as lupin, *Lupinus* spp., and desert buckwheat, *Eriogonum* spp., and could be important in the population dynamics of *F.*

*occidentalis*. Pearsall and Myers (2001) caught most *F. occidentalis* on sticky cards placed in sagebrush steppe during March, late April to early May, and again in September. Two of these periods correspond to the blooming of arrowleaf balsamroot and big sagebrush, which may be the cause of increased flight or abundance. Thus, much of the population dynamics can be inferred by plant to plant movement within this habitat.

The possibility remains that *F. occidentalis* migrates between native, dry habitats and orchards during periods of sparse shoot growth or bloom. For example, fruit trees appear to attract thrips into orchards in spring (Pearsall and Myers 2001). Alternatively, the woody species big sagebrush, gray rabbitbrush, and snow buckwheat, which had a high concentration of *F. occidentalis* adults in their flowers, may attract *F. occidentalis* out of orchards when in bloom in the fall. Migration in and out of orchards has not been studied and remains critical to understanding the phenology and population dynamics of this species.

Reduction of weedy hosts has been suggested as an integral part of management of *F. occidentalis* in orchards (Venables 1925). However, our samples indicated relatively low numbers of thrips in two abundant weeds, downy brome and dandelion, before apple bloom. The apple trees themselves harboured adults throughout the growing season, as did numerous other plant species in and adjacent to orchards. Thus, indirect management of this pest through reduction of any one plant species may prove challenging.

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# Timing of oviposition by western flower thrips (Thysanoptera: Thripidae) in apple fruit

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## ABSTRACT

Adult western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), were most abundant on flower clusters of apple, *Malus* × *domestica* Borkhausen, from king bloom to full bloom. Low numbers of thrips remained on the clusters after petal fall as fruit enlarged. Thrips larvae peaked in numbers after densities of adults had peaked, usually by petal fall. Two staining procedures were developed for detecting thrips eggs in the surface of fruit ovary tissues (the edible portion of fruit), and in other blossom tissues (stamen, style, calyx, stem and leaves). Eggs were abundant in the latter tissues throughout the bloom and post-bloom periods; the calyx appeared to be highly preferred. Few eggs were detected in fruit ovary tissues during bloom. Egg numbers in ovary tissues began to increase about 8-13 d after full bloom, when fruit had grown beyond 5 mm diameter. The most effective timing of pesticides corroborated the oviposition data. Formetanate hydrochloride or spinosad caused the greatest reduction in oviposition injury (pansy spot) when applied from full bloom to about 5 mm fruit diameter.

**Key Words:** *Frankliniella occidentalis*, western flower thrips, pansy spot, oviposition, apples, sampling

## INTRODUCTION

Western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), damages the fruit of a number of crops (Childers 1997). Feeding by larvae or oviposition by adult females produces distinct symptoms which can occur at different times during fruit development. Feeding on peach fruit after bloom causes a superficial skin blemish referred to as 'silvering'. Nectarines develop a more serious skin deformity from feeding called 'russetting' (Childers 1997). Damage on a number of other crops is caused by oviposition. The disorder known as pansy spot of apple, *Malus* × *domestica* Borkhausen, a pale halo surrounding a corky, raised scar, is caused by oviposition of female thrips (Newcomer 1921). Pansy spot marks are most visible on light-coloured fruit and result in downgraded fruit quality (Madsen and Proctor 1982). Damage on grapes is identical to pansy spot of apples (Jensen 1973), and a similar pale halo surrounds oviposition scars on tomato (Salguero Navas *et al.* 1991).

The timing of thrips oviposition on apple fruit is still a matter of dispute. Newcomer (1921) was first to discover thrips eggs in the center of pansy spots. He deduced that oviposition must occur "some time during bloom", and advocated an insecticide application at pink (opening flower buds) to control the adults responsible. Venables (1925) believed that oviposition in fruit occurred "some time between bloom and closing of the calyx", which occurs shortly after petal fall (80% of the flowers with no petals). Childs (1927) observed oviposition in fruit occurring much later, shortly after bloom and continuing

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until fruit were about 25-38 mm diameter. Madsen and coauthors (Madsen and Jack 1966, Madsen and Arrand 1971, Madsen and Proctor 1982) believed that overwintering adult female *F. occidentalis* first lay eggs on sepals and flower parts, and not on the edible portions of young fruit, beginning in early bloom. The larvae develop in the corolla and pupate away from the flower clusters. New adults begin emerging after petal fall and it is these individuals that lay eggs in the developing fruit. However, because western flower thrips pupates in soil litter, these newly emerged adults would have to recolonize the apple clusters to be responsible for the damage, and it is not yet clear that this recolonization occurs to any extent. The detailed work by some recent authors (Terry and DeGrandi Hoffman 1988, Terry 1991) concluded that oviposition on young fruit occurs during pink to full bloom (80% of the flowers fully in bloom), although the majority of eggs deposited during those stages are laid in flower parts, and therefore do not cause injury.

The current control recommendation is to apply insecticides either at pink (Smith *et al.* 2005) or during bloom, when adult western flower thrips are most abundant (Terry and DeGrandi Hoffman 1988). Insecticides (formetanate hydrochloride, spinosad, and acetamiprid) used for control of thrips on apple, are moderately toxic to bees; materials that are highly toxic to bees are restricted during bloom. Mitigation of toxicity is accomplished by spraying either at night or in the early morning before bees are actively foraging. Targeting sprays after bloom would expand the choice of chemical control tactics, and eliminate hazards to pollinators, providing a benefit to apple pest management.

The purpose of this investigation is to assess the timing of thrips oviposition on apple fruit in central Washington, and evaluate insecticide timing based on this information. We have built on the work of previous authors by expanding the time period and tissues in which the eggs are observed, as well as testing our data with insecticide timing experiments.

## MATERIALS AND METHODS

**Timing of Oviposition in Fruit.** Densities of eggs, larvae, and adult thrips on apple were assessed in 2004-2006 at three locations. In 2004, a block (about 2 ha) of 'Delicious' trees at the Washington State University Tree Fruit Research and Extension Center (WSU-TFREC) in Wenatchee, WA, was used. No chemical thinning sprays were used in the block. Blossom clusters (n=100) or, starting at petal fall, king fruit (n=100) were collected at intervals corresponding to the developmental stages of the apple bloom. One sample was taken per tree. Sample timings were early tight cluster (flower buds unopened and touching) (2 and 6 April), pink (9 April), king bloom (bloom of the first, central flower in the blossom clusters) (13 April), full bloom (14 April), the start of petal fall (19 April), and four stages of fruit growth (23 April, 27 April, 4 May, and 11 May). Plant tissue samples were placed in self-sealing plastic bags, stored at 5 °C and processed within a week. Thrips were separated from plant tissues by filling the bag with water, adding a few drops of liquid detergent, and agitating for several seconds. Thrips and plant material were separated from the soapy water by pouring through two nested sieves (Hubbard Scientific Co., Northbrook, IL). The larger sieve (#10, 0.25 mm mesh) trapped most of the plant material, and the finer sieve (#230, 0.0014 mm mesh) trapped the thrips (Lewis 1997). Thrips were then rinsed into a vial of 50% ethanol. Adults and larvae were recorded separately.

After the plant tissue samples were washed, blossom clusters were trimmed so that only the king bloom fruitlet ovary tissues remained, and these were examined for thrips eggs. Only eggs in this structure, which becomes the edible portion of the fruit, cause economic damage. Direct obser-

vation of apple fruit, a method used by Terry (1991), was found unsatisfactory. A staining technique (Backus *et al.* 1988, Teulon and Cameron 1995) was used instead. Trimmed fruitlets were placed in McBride's stain (0.2% acid fuchsin in 95% ethanol and glacial acetic acid (1:1 vol/vol)) for 24 h, then transferred to clearing solution consisting of one part each of distilled water, 99% glycerin, and 85% lactic acid (1:1:1 vol/vol/vol). This method allowed samples to be stored for up to three months without deterioration. Samples in the clearing solution were heated in a double boiler under a fume hood for 1 h to soften the tissue. After clearing, the skin and underlying flesh of the fruit was sliced off to a thickness of 0.5 mm, and the remaining fruit tissue discarded. The skin was placed between two glass microscope slides and pressed flat. The thin tissue was observed under a dissecting microscope using transillumination to reveal the darker eggs.

The timing of egg deposition was further studied in 2005 in a commercial orchard block (2 ha) of 'Braeburn' apples near the town of Omak, WA, and in 2006 in a commercial orchard block (4 ha) of 'Cameo' apples in Bridgeport, WA. Flower clusters and king fruit were sampled as described previously, including sample sizes. In 2005, samples were taken at tight cluster (16 April), pink (20 April), king bloom (24 April), full bloom (28 April), petal fall (1 May), and five stages of fruit growth (4, 8, 11 16 and 23 May). In 2006 samples were taken at pink (24 April), king bloom (28 May), full bloom (4 May), the end of petal fall (12 May), and four stages of fruit growth (16 and 24 May, 2 and 9 June). The larger range of fruit sizes collected in 2006 necessitated slightly modified handling. Smaller fruit (<15 mm diameter) were stained and examined as described previously. Larger fruit (≥15 mm) were stained only, without clearing or dissection. Because the skin of the larger fruit was almost free of trichomes, the punctures and pink-stained eggs were clearly visible using light microscopy. In a few rare cases, oviposition sites were excised for closer examination.

**Apple Tissue Oviposition Studies.** In addition to studies of oviposition in apple fruit ovary tissues, more detailed studies were carried out to determine relative oviposition preference in both vegetative and reproductive tissues of apple. Blossom clusters were collected from three orchards located in Yakima County, WA in both 2005 and 2006. Apple varieties included were 'Delicious', 'Fuji', and 'Granny Smith'. At each orchard, a sample consisted of 10 blossom clusters, randomly selected from several trees along the orchard edge, shown in another study (Miliczky *et al.* 2007) to support the highest densities of ovipositing thrips. In 2005, clusters were collected at five developmental stages: pink, king bloom, full bloom, petal fall, and 15 - 25 mm fruit size. In 2006, the pink through petal fall stages were again sampled, but two post-petal fall samples were taken: 10 mm fruit size and 25 mm fruit size. Clusters were placed in self-sealing plastic bags, and transported to the laboratory on ice.

A modified egg staining procedure was used for these studies. Blossom samples were immersed in a warm (60 °C) solution of white vinegar (Heinz Distilled White Vinegar, H.J. Heinz, Pittsburgh, PA) and blue food colouring (McCormick Blue Food Coloring, Hunt Valley, MD), using six drops of food colouring in 40 ml of vinegar. Samples were left in the solution for 20 min, after which the tissues were removed from the solution and blotted dry. The vinegar caused tissue layers to separate, exposing the eggs, while the blue food colouring stained the oviposition scar and egg. Samples were examined under a dissecting microscope to assess egg numbers.

Egg numbers on each of the five structures were determined: flower reproductive organs (stamen, style), flower calyx, stem below flower or fruitlet, leaves, or fruitlet ovary tissues. For each blossom cluster, we counted total number of leaves and flowers in the cluster, and then randomly selected a subsample of three flowers and three leaves of each cluster for examination. Once egg numbers had been determined for each of the five structures within this subsample,

we used these estimates of density in combination with our counts of leaves and flowers in the cluster to obtain by extrapolation an estimate of egg numbers for each of the five structures in the entire blossom cluster. Percentage distribution of eggs among the five structures was then determined using these extrapolated estimates of egg densities. Samples from the three orchards were pooled.

**2004 Insecticide Timing Trial.** This trial was conducted at the same site used for the 2004 oviposition study. Insecticides were used to kill adult thrips in blossom clusters at different stages of blossom or fruit development. One hundred 'Delicious' apple trees were selected randomly, and one branch with 7-10 flower clusters was selected on each tree. Adult thrips were allowed to migrate back to the branches, thus treatments created periods of reduced adult presence. The experiment was a completely randomized design with 10 treatments (spray timings) and 10 replicates (branches). Thrips were killed by spraying the branches to drip with a solution of formetanate hydrochloride (Carzol® 92SP, Gowan Co., Yuma, AZ) at 27.6 g AI/100 litres. Material was mixed in a ½-litre spray bottle. Applications were made at one of nine stages from tight cluster through about 16 mm fruit diameter (Table 1). One group of 10 branches was sprayed on all nine dates to eliminate thrips during the entire bloom and early fruit growth period. Fruit were harvested from each treatment on 24-25 May. The proportion ($p$) of fruit injured by thrips was transformed by arcsine [square root ($p$)], then analyzed using analysis of variance for a completely randomized design (Statistical Analysis Institute 1988). Treatment means were separated with a Least Significant Difference test, $\alpha$=0.05.

**2006 Insecticide Timing Trial**. This experiment was conducted in the same commercial orchard block used for the 2006 oviposition study. The orchard (4 ha) was bordered on three sides by native vegetation. The 8-year-old 'Cameo' trees were pruned to a trellis about 3 m high. Tree spacing was 0.9 × 3.7 m. The experiment was a randomized complete block design with blocks determined by proximity to the native vegetation. Four replicated plots (15 trees in a single row) were sprayed with either formetanate hydrochloride or spinosad (Success® 2SC, Dow AgroSciences, Indianapolis, IN) using an airblast orchard sprayer (Rears Pak-Blast, Rears Mfg, Eugene, OR) calibrated to deliver 1,871 litres/ha. Plots were separated by five untreated rows. Application timings ranged from king bloom through 27 mm fruit size (Table 2), plus an untreated check. The first three sprays were applied at night to avoid contact with pollinators. All other sprays were applied during the day.

Between 110 and 150 fruit per plot were examined for pansy spot under a microscope on 6 June. The proportion ($p$) of fruit with pansy spot was transformed with arcsine [square root ($p$)]. Data were analyzed with two-way ANOVA for two insecticide treatments and six application timings. Main effects means for insecticide or spray timing were separated with a Least Significant Difference test.

## RESULTS AND DISCUSSION

**Timing of Oviposition in Fruit.** The abundance of adult thrips on apple blossom clusters increased as apple blossoms opened (Fig. 1). Abundance in blossoms was highest at king bloom. From petal fall onwards, king fruit were sampled rather than blossom clusters. Adults were most abundant on king fruit at the beginning of petal fall, then decreased rapidly. Low numbers remained in the samples during the post petal-fall period in 2004 and 2006. Adults were still recovered on the 17.3 mm diameter fruit sample date in 2006, 24 d after full bloom. Larvae, which could not be identified to species, peaked after adults, usually on king fruit after petal fall (Fig. 1). Contrary to expectation, the peak abundance of eggs in fruit was later than the peak in larvae, with

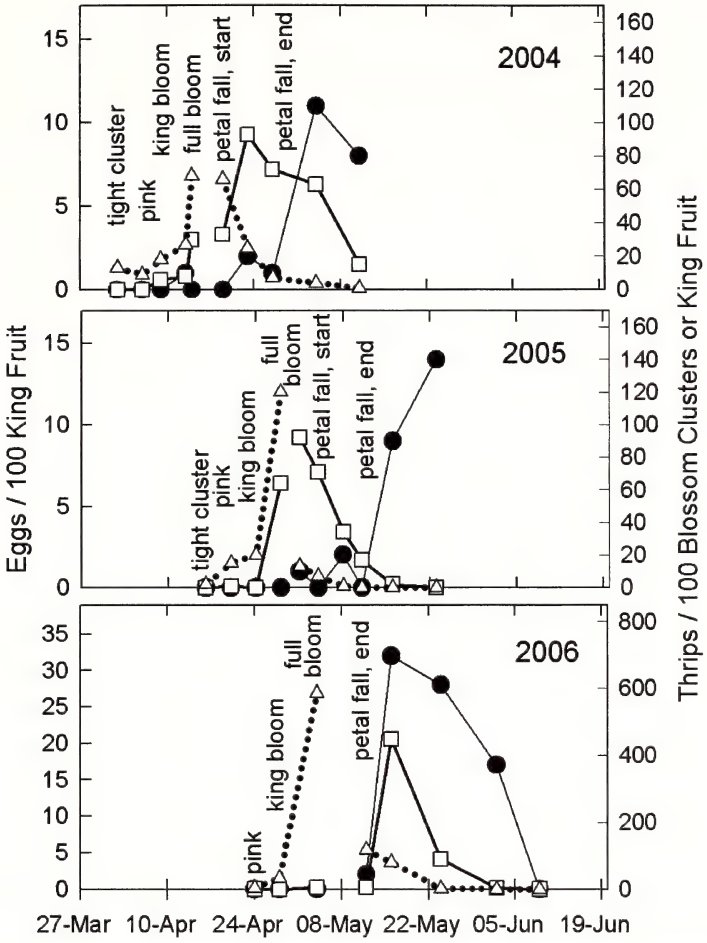


**Figure 1.** Densities of thrips eggs in king fruit ovary tissues, and adult and larval stages on blossom clusters (tight cluster to full bloom) and king fruit (petal fall and later). Adult thrips (Δ); larvae (□); eggs (•).

a relatively long lag period between peak abundance of adults in flower clusters and eggs in the fruit ovary tissues. This result suggests that females deposited eggs extensively in other, unsampled plant structures within the blossom clusters (see Apple Tissue Oviposition Studies).

Relatively few thrips eggs were found in fruit during the period most often targeted for sprays (Fig. 2), viz., pink through petal fall, although this is the period when adults were most abundant (Fig. 1). The greatest increase in egg numbers deposited in fruit occurred after the start of petal fall, between 5.6 - 9.0, 6.0 - 11.6, and 5.7 - 12.5 mm diameter in the three years of the study. This corresponded with 13 - 20, 13 - 18, and 8 - 16 d after full bloom, respectively. This is substantially later than is reported by some authors (Newcomer 1921, Venables 1925, Terry 1991), but in general agreement with others (Childs 1927, Madsen and Jack 1966). Stained eggs were detected in oviposition scars after 25 mm in 2006 but were no longer found in scars in fruit that were 31.7 mm diameter in early June, which agrees with the observations of Childs (1927).

**Apple Tissue Oviposition Studies.** The calyx and stem received between 72 and 98% of the eggs deposited in sampled blossom clusters, depending upon blossom stage (Fig. 3). By the time fruit reached approximately 10 mm in size, they had become moderately attractive as oviposition sites. Eggs in fruit ovary tissues never ex-

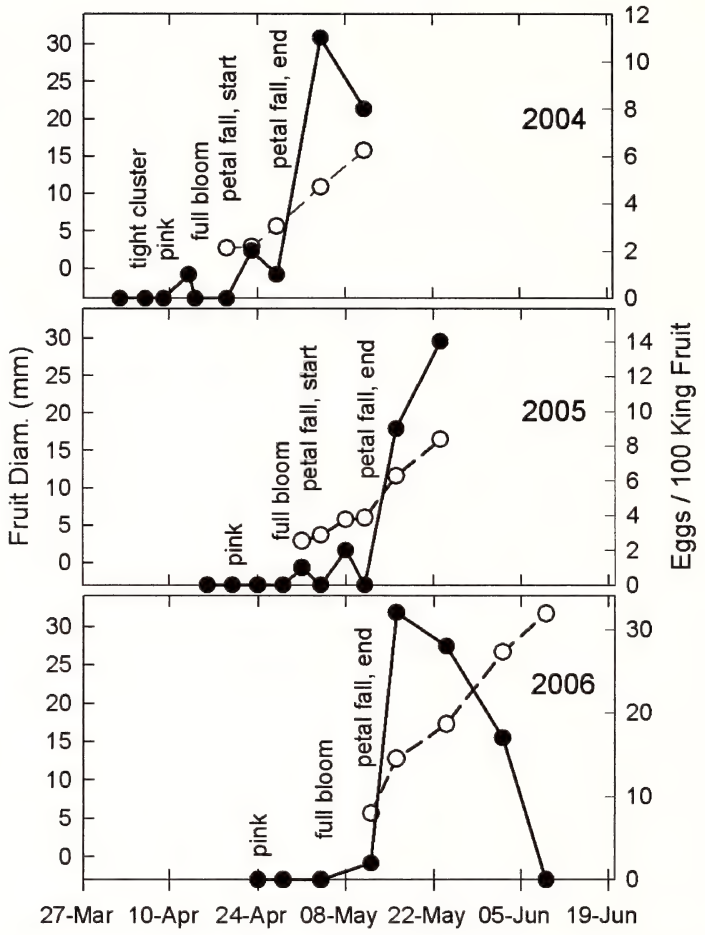


**Figure 2.** Thrips egg densities in king fruit ovary tissues (•) and king fruit size (○).

ceeded 13% of the total eggs found at any blossom stage. Some oviposition also occurred in leaves and floral reproductive parts (stamens and styles), but this comprised a small proportion of the total eggs.

This study provides insight into several issues regarding thrips damage to apple. In the fruit oviposition timing studies, where only eggs laid in fruit ovary tissues were assessed, the larvae appeared to be out of sequence with the eggs (Fig. 1). The larvae may have been hatching from eggs laid in structures not monitored during that study. The second issue deals with predicting the amount of fruit damage from adult density estimates. The high percentage of eggs being laid in non-fruit tissues may be responsible for the overall poor correlation between densities of adult flower thrips and fruit damage in apples (Terry 1991, Bradley and Mayer 1994).

**2004 Insecticide Timing Trial.** The timing of formetanate hydrochloride applications affected the percentage of fruit damaged ($F = 4.45$; df = 9,96; $P < 0.0001$). Applications were most effective in reducing pansy spot during the period from the start of petal fall to 5.6 mm fruit; applications before or after this timing were less effective (Table 1). An application at king bloom, for example, was clearly too early. The optimum timing was, as would be expected, just before the peak oviposition that occurred some time between 5.6 and 10.9 mm fruit size (Fig. 2). The results indicated that prevention of the oviposition surge at the end of petal fall was key for pest management, but that the entire period of oviposition was not of interest. In fact, one well-timed spray at petal fall was equiva-

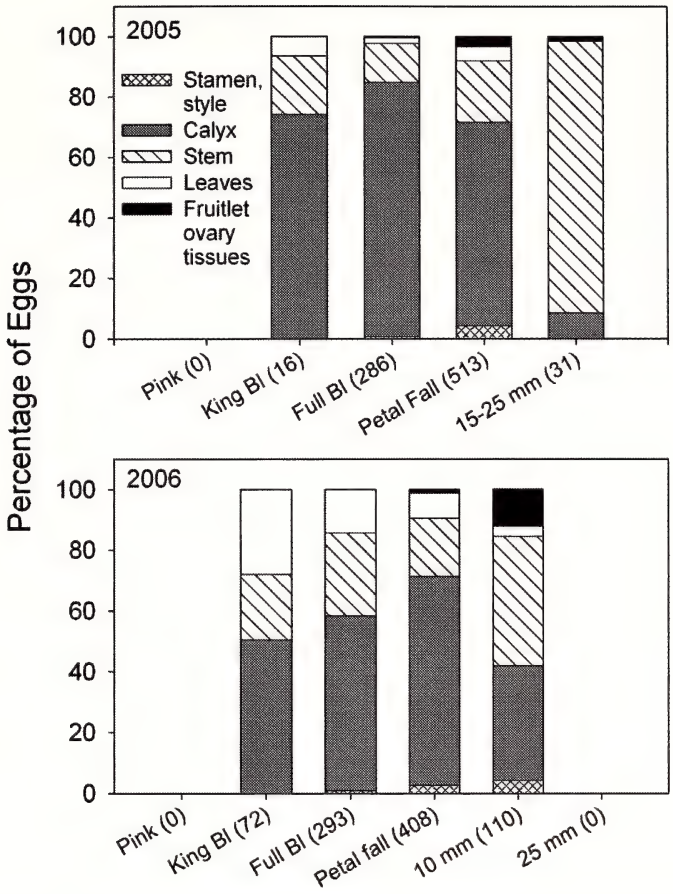


**Figure 3.** Percentage of eggs deposited in various flower and fruit parts as a function of blossom and fruit stage (2005-06). Numbers in parentheses are total eggs counted in the subsamples.

lent to multiple applications made over the 39-d period when adults were present in blossom clusters.

**2006 Insecticide Timing Trial**. Fruit damage was affected by timing of spray application ($F$ = 5.74; df = 5,36; $P$ = 0.0005), but not by the type of insecticide used ($F$ = 0.05; df = 1,36; $P$ = 0.83). The interaction term was not significant ($F$ = 0.34, df = 5,36; $P$ = 0.89), thus the main effects means are of most interest (Table 2). Fruit injury on trees treated at full bloom or the end of petal fall (5.7 mm diameter king fruit) was significantly lower than injury on trees treated at all other times (Table 2). Mean percentage of fruit with pansy spot on trees treated at king bloom or any time after 5.7 mm diameter king fruit varied between 3.1 and 3.8% (Table 2), compared to a mean damage of 2.6% in the unsprayed check (data for check plots not shown). Thus, insecticides applied at king bloom or at any interval after the fruit had attained a diameter of 5.7 mm provided no benefit.

In summary, data reported here support a revision of the recommended spray timing for managing western flower thrips in central Washington apple orchards. The current recommendation that insecticides should be applied at pink (Smith *et al.* 2005) is clearly too early for preventing damage, although it may reduce adult thrips populations. There is an optimal spray window from full bloom to 5 mm fruit diameter, similar to that described by Madsen and Jack (1966) for British Columbia, Canada, but later than that described by Terry (1991) for Arizona, USA. The period of optimal timing extended from 8 - 13 d in 2004 - 2006, giving some flexibility in orchard operations. The

**Table 1.**

Mean percentage of fruit (SEM) with pansy spot from apple tree branches treated with formetanate hydrochloride on different blossom or fruit growth stages, 2004

| Stage treated | Application date | % damage[1] |
|---|---|---|
| Tight cluster | 5 April | 11.4 (3.0)ab |
| Pink | 9 April | 20.1 (4.4)a |
| King bloom | 13 April | 10.3 (3.7)abc |
| Full bloom | 16 April | 7.0 (2.5)bcd |
| Petal fall, 2.7 (0.15) mm | 20 April | 2.5 (1.7)cde |
| Petal fall, 2.9 (0.18) mm | 23 April | 1.7 (1.7)de |
| Petal fall, 5.6 (0.31) mm | 27 April | 0.0 (0.0)e |
| 10.9 (0.78) mm | 4 May | 12.5 (4.3)ab |
| 15.8 (0.61) mm | 11 May | 11.8 (4.7)abc |
| All stages | All dates | 0.0 (0.0)e |

[1] Means followed by the same letter are not significantly different, Least Significant Difference test, $\alpha$=0.05.

**Table 2.**

Mean percentage of fruit (SEM) with pansy spot from apple trees treated with either formetanate hydrochloride or spinosad on different blossom or fruit growth stages, 2006[1]

| Stage treated | Application date | Formetanate HCl (1 kg AI/ha) | Spinosad (0.14 kg AI/ha) | Pooled means |
|---|---|---|---|---|
| King bloom | 28 April | 3.5 (1.8) | 2.8 (1.4) | 3.1 (1.1)a |
| Full bloom | 4 May | 0.5 (0.3) | 0.7 (0.5) | 0.6 (0.3)b |
| Petal fall, 5.7 mm | 12 May | 0.6 (0.4) | 1.0 (0.2) | 0.8 (0.2)b |
| 12.8 mm | 17 May | 4.1 (1.9) | 3.3 (0.9) | 3.7 (1.0)a |
| 17.3 mm | 25 May | 4.2 (1.1) | 3.4 (0.9) | 3.8 (0.7)a |
| 26.7 mm | 1 June | 3.4 (0.7) | 3.1 (1.2) | 3.3 (0.6)a |
| Pooled means | | 2.7 (0.5)a | 2.4 (0.4)a | |

[1] Means within columns (dates) or between columns (insecticide) followed by the same letter are not significantly different, Least Significant Difference test, $\alpha$ =0.05.

beginning of this period (full bloom) coincides with the timing of blossom thinning sprays, suggesting the possibility of combining materials. The latter part of the spray window coincides with early fruit thinning sprays that are applied at 80% petal fall, or 3-5 mm fruit diameter (Smith *et al.* 2005). A petal-fall or post-petal-fall spray, which would be after bee hives had been removed from the orchard, would minimize damage potential to bees and eliminate the need to apply insecticides in the late evening or at night. The latter timing also opens up the potential use of materials that are effective on thrips, but could not otherwise be used because of bee hazard.

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# Mortality of five wireworm species (Coleoptera: Elateridae), following topical application of clothianidin and chlorpyrifos

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## ABSTRACT

Five wireworm species (*Agriotes obscurus*, *A. sputator*, *Limonius canus*, *Ctenicera destructor*, and *C. pruinina*) were exposed to clothianidin and chlorpyrifos at various concentrations using a Potter Spray Tower to compare larval susceptibilities to these compounds. Wireworms were stored in containers with soil at 15 °C after insecticide exposure, and their post-application health was evaluated weekly for up to 140 days. Where possible, $LC_{50}$, $LC_{90}$, $LT_{50}$, and $LT_{90}$ values were calculated and the $LC_{90}$ and $LT_{90}$ values of chemical concentrations compared between species. Considerable differences in susceptibility to both chlorpyrifos and clothianidin were observed among species, with the $LC_{90}$ of *L. canus* exposed to clothianidin being significantly higher than *A. obscurus* or *A. sputator*. Similarly, while the $LC_{50}$ of *A. sputator* exposed to chlorpyrifos was similar to that of *C. pruinina* and *A. obscurus* assayed in previous studies (0.05, 0.10, 0.10%, respectively), there was low (12.5%) mortality of *L. canus* at the highest concentration tested (0.15%). There were considerable differences in the survival of various wireworm species after exposure to clothianidin at 0.15%, with the $LT_{90}$ of *L. canus* (66.5 days) similar to those of *C. pruinina* and *C. destructor* (52.5, 59.5 days, respectively), but much shorter than those for *A. obscurus* or *A. sputator* (122.5, 115.5 days, respectively). Considerable differences in the induction of and recovery from morbidity induced by the chemicals were observed among species. Most larvae of *A. sputator* and *A. obscurus* exposed to chlorpyrifos were moribund before *C. pruinina* larvae (4, 7, 42 days after exposure, respectively). Most (proportion = 0.86) larvae of *L. canus* recovered from morbidity induced by chlorpyrifos, but a high proportion (>0.8) of moribund *A. sputator*, *A. obscurus*, and *C. pruinina* died. Larvae of *C. destructor* and *C. pruinina* which were moribund after exposure to clothianidin at 0.15% died or recovered sooner than larvae of *L. canus* and *A. obscurus*. Together these results suggest that the efficacy of both clothianidin and chlorpyrifos for wireworm control in the field are affected by the wireworm species present.

**Key Words:** *Agriotes obscurus*, *Limonius canus*, wireworm, contact toxicity, insecticide, survival time

## INTRODUCTION

Wireworm problems are increasing across North America and Europe. In North America, the most important pest species include the Pacific Coast wireworm, *Limonius canus* LeConte, found from British Columbia (BC) to California (Horton and Landolt 2001), the dusky wireworm, *Agriotes obscurus* L. in BC, Washington and the Atlantic provinces (Eidt 1953, Vernon *et al.* 2001, Lagasa *et al.* 2006), the common click beetle, *A. sputator* L. in Atlantic Canada (Eidt 1953), and the prairie grain wireworm, *Ctenicera destructor* (Brown) in the Canadian prairies (Burrage 1963). A closely related species, the Great Basin wireworm, *C. pruinina* (Horn), is an increasing pest in the US Pacific Northwest (Kuhar *et al.* 2003). The increase in wire-

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worm problems, especially in Canada, is due at least in part to the loss of effective organochlorine (OC) and organophosphate (OP) insecticides, and the increased use of newer chemistries which are not as effective at reducing wireworm populations (van Herk *et al.* 2007, Vernon *et al.* 2007). Recent work has demonstrated that neonicotinoid (including thiamethoxam, clothianidin, acetamiprid, and imidacloprid), pyrethroid (e.g. tefluthrin) and spinosyn (i.e. spinosad) insecticides can cause long-term morbidity from which wireworms can eventually make a full recovery (van Herk *et al.* 2007, Vernon *et al.* 2007). In addition, tefluthrin, registered for wireworm control on corn in Canada, has been shown to be repellent to *A. obscurus* and *L. canus* in laboratory studies (van Herk and Vernon 2007b).

The efficacy of new insecticides for wireworm control is usually inferred from improvements in crop stand and marketable yield (van Herk and Vernon 2007b) and not from assessment of their direct effects on wireworms (exceptions are Hall and Cherry 1985, van Herk *et al.* 2007). This scarcity of toxicity data for wireworms is understandable, as subterranean insect larvae are often difficult to study *in situ*, and wireworms are difficult and costly to rear in the laboratory or collect from the field. Wireworm toxicity studies are complicated further by their recently discovered ability to make a full recovery after extensive periods of morbidity (van Herk and Vernon 2007a, Vernon *et al.* 2007). Wireworms exposed to sublethal doses of insecticide may appear dead and show no detectable movement to the unaided eye for up to 300 days (van Herk *et al.* 2007). Prematurely removing these "dead" wireworms from the study can easily lead to overestimations of an insecticide's effectiveness. Wireworms exposed to other insecticides (e.g. fipronil) may not show symptoms of intoxication for several weeks before becoming moribund and dying (van Herk *et al.* 2007). Failure to conduct long-term observations of these wireworms can easily lead to underestimations of an insecticide's effectiveness. Although time consuming and expensive, laboratory bioassays in conjunction with field efficacy studies now appear to be requisite in developing a complete understanding of how candidate wireworm insecticides will work in practice.

Previous work has shown that the insecticide concentration required to kill 50% ($LC_{50}$) and 90% ($LC_{90}$) of *A. obscurus* are similar for clothianidin and chlorpyrifos, but the time required to kill 90% ($LT_{90}$) of larvae when exposed at near-$LC_{90}$ concentrations is much longer for clothianidin (123 days) than for chlorpyrifos (25 days) (van Herk *et al.* 2007). Preliminary work has also suggested that there may be differences in the toxicity of chlorpyrifos to *A. obscurus* and an additional species, *C. pruinina* (van Herk, unpublished data).

Bousquet (1991) lists some 369 known wireworm species in Canada, of which at least 30 are of economic importance (Glen *et al.* 1943; Wilkinson 1963). These species differ considerably in size and cuticle hardness (van Herk and Vernon 2007b). Thus the efficacy of various candidate insecticides for wireworm control may differ depending on the species present in the field. In this paper we present the $LC_{50}$, $LC_{90}$, and $LT_{90}$ values of clothianidin and/or chlorpyrifos topically applied to five wireworm species. The implications of differences in the relative toxicities and in the ability of these wireworms to recover from a moribund state are discussed.

## MATERIALS AND METHODS

**Wireworm collection and preconditioning.** Five collections of wireworm larvae were made from different regions of North America. Late instar larvae of *C. pruinina* were collected in June 2004 from an organic vegetable field near Boardman, Oregon (45°41'N, 119°50'W). Larvae were identified according to Glen (1950). Late instar *C. destructor* larvae were collected in July – August 2004 near Wainwright, Al-

berta (52°49'N, 110°52'W), and identified according to Glen et al. (1943). Larvae of *A. obscurus* were collected in March 2005 from a fallow field in Agassiz, BC, (49° 14'N, 121°46'W) and identified according to Becker (1956). These larvae were at least 15 mm long when used in bioassays and thus three to four years old based on length criteria developed by Subklew (1934) for *A. obscurus*. Larvae of *L. canus* were collected in July 2005 from an organic vegetable farm in Kelowna, BC (49°49'N, 119° 26'W), and identified according to Lanchester (1946). All *L. canus* were at least 14 mm long and therefore three to four years old (Wilkinson 1963). Late instar *A. sputator* larvae were collected in November 2005 near Kentville, Nova Scotia (45°06'N, 64°29'W), and identified according to Eidt (1953) and Becker (1956).

Larvae were stored, by species, at the Pacific Agri-Food Research Centre (PARC) in Agassiz, BC, in Rubbermaid® tubs (Newell Rubbermaid Inc, Atlanta, GA) filled with Agassiz soil at 15 – 20 °C until used. Agassiz soil (sandy-clay loam) was taken from a field at PARC, screened through 2 x 2 mm mesh to remove organic material, and dried to approximately 20% soil moisture by weight. Potato slices (cv. Russet Burbank) placed cut-face down on the soil provided food, as well as a means of selecting feeding wireworms for bioassays. Wireworms found feeding on potato slices were removed from the tubs, weighed, and placed in 150 ml plastic sample cups (Fisher Scientific Ltd, Ottawa, Ontario) filled with approximately 130 g Agassiz soil (for *A. obscurus*, *A. sputator*, and *L. canus*) or 170 g of a 2:1 mixture of Agassiz soil and clean sand (for *C. destructor* and *C. pruinina*). Five wireworms were placed in each cup no more than seven days prior to insecticide applications (see below).

A single piece (approximately 1 $cm^3$) of peeled organic potato (cv. Russet Burbank), was placed in each wireworm storage cup. Lids were placed on cups after wireworms were inserted. Thereafter, wireworms were transported in Coleman® coolers (Sunbeam Corporation (Canada) Ltd., Brampton, ON) to the Southern Crop Protection and Food Research Centre (SCPFRC) in London, ON. HOBO® H8 data loggers (Onset Computer Corporation, Pocasset, MA) placed inside the coolers indicated that the temperature remained between 8.5 and 20 °C during transport.

**Insecticide application**. Insecticides were applied directly to wireworms using a Potter Spray Tower (Burkhard Manufacturing Co Ltd, Rickmansworth, United Kingdom) at SCPFRC. Insecticides were dissolved in a 19:1 solution of acetone (histology grade, minimum 99% purity) and olive oil (Maestro® 100% Extra Virgin) (van Herk *et al.* 2007). Olive oil prevents the insecticides from coming out of solution and crystallizing on the insect cuticle, as sometimes occurs when insecticides are dissolved at high concentrations in pure acetone (van Herk, personal observation).

Just prior to insecticide applications, wireworms were removed from the cups and placed in an arena to check their health (see below). Healthy wireworms were placed in a 50 mm diameter x 4 mm deep sterile plastic Petri dish (Gelman Sciences, Ann Arbor, Michigan) in the tower, and are hereafter referred to as a single "batch" (four to five wireworms). Wireworms that were writhing were discarded. The shallow Petri dish used ensured that all wireworms in the batch received the same amount of spray. The tower was calibrated before the experiment to deliver 5.0 ml of insecticide solution in a uniform (11.9 cm diameter) application pattern (van Herk *et al.* 2007). Uniformity of spray deposition was visualized by applying 5.0 ml of a 0.01% (in acetone) red dye solution onto filter paper. This application indicated that the spray did not resolve into individual droplets, confirming that the olive oil did not interfere with the spray application.

For *L. canus*, *A. sputator*, and *A. obscurus*, eight to ten batches were exposed to each of five concentrations of clothianidin (0.005, 0.01, 0.05, 0.1, 0.15%) or chlorpyrifos (0.05, 0.075, 0.1, 0.125, 0.15%), or to the solvent alone. When one of these spe-

cies was selected for study, different batches were exposed to all concentrations of clothianidin or chlorpyrifos (plus solvent controls) on the same day. Due to the limited number of *C. pruinina* wireworms available, eight batches were exposed to clothianidin at 0.15% and eight batches to the control solution. Similarly, six batches of *C. destructor* were exposed to each of clothianidin at 0.15% and the control solution.

In a previous study, conducted in 2004, larvae of *C. pruinina* were exposed to chlorpyrifos (van Herk *et al.* 2007). Larvae of *C. pruinina* assayed in 2004 were collected at the same time, and preconditioned, selected and treated like *C. pruinina* assayed in 2006 (van Herk *et al.* 2007). Except for *C. pruinina* exposed to chlorpyrifos, all insecticide applications were conducted in January 2006.

**Post-application observations.** Treated wireworms were allowed to air-dry for approximately 1 minute, after which they were placed on the soil surface in their cups. Several minutes later, when the wireworms had burrowed into the soil, a fresh potato piece was placed in each cup, lids replaced, and the cups placed in a dark environmental chamber at 15 ± 0.2 °C. This temperature was selected to simulate the temperature of soil in spring, when pesticides would normally be applied in BC. Wireworms were inspected 1, 4, and 7 days after treatment (DAT) and every week thereafter for up to 140 days. After the first health check, done at SCPFRC, wireworms (except *C. pruinina* exposed to chlorpyrifos in 2004) were transported (as above) back to PARC where they were stored in growth chambers at 15 ± 0.2°C. All subsequent health checks were conducted at PARC; health checks of *C. pruinina* exposed to chlorpyrifos in 2004 were conducted at SCPFRC (van Herk *et al.* 2007).

For each health check, wireworms were carefully removed from their cups with soft-touch forceps, and placed in the center of a 15 cm Petri dish lined with moistened filter paper (Whatman No.1, Whatman International Ltd., Maidstone, England). Wireworm health was assessed according to Vernon *et al.* (2007), using the following criteria. Wireworms that could move out of a 10 cm circle drawn on the center of the filter paper within two minutes were designated as "Alive". Wireworms that were incapable of directed movement but capable of clearly visible movements were designated "Writhing". All wireworms that made no visible movements when gently prodded with forceps were inspected under a dissecting microscope and designated as "Leg & Mouthparts" if they were able to move their legs and mouthparts or "Mouthparts" if that was all they could move. Wireworms that were incapable of movement were considered to be dead. In all cases, wireworm death was confirmed by subsequent signs of decomposition which became visible within two weeks of death (van Herk, personal observation). Wireworms were removed from the study as soon as decomposition was evident; to ensure that morbidity did not recur, larvae that recovered from insecticide-induced morbidity were observed for two or more weeks after they had made a full recovery. Control wireworms were checked until the last insecticide-exposed wireworms of the species were removed from the study. Potato cubes were replaced each time wireworms were checked.

**Statistical methods.**

*$LC_{50}$ and $LC_{90}$ analysis.* The estimated concentrations required to kill 50% ($LC_{50}$) and 90% ($LC_{90}$) of larvae was computed, along with 95% confidence intervals, from the probit model (Southwood 1978, SAS Institute 2002). Due to the small number of wireworms per batch, the goodness of fit (GOF) of the probit model could not be computed from the standard chi-square distribution. *P*-values (with standard error (SE) estimates) were therefore computed using a parametric bootstrap procedure as described by van Herk *et al.* (2007). To accommodate data overdispersion, the variance of the binomial distribution was multiplied by a scale parameter (i.e. the deviance statistic computed for a concentration of a chemical divided by its degrees of freedom). Control wireworm mortality was

incorporated in LC analyses.

*$LT_{50}$ and $LT_{90}$ analysis.* Survivorship was modeled separately for each chemical with non-parametric Kaplan-Meier survival curves (Cox and Oakes 1984) using Proc LIFETEST (SAS Institute 2002). The time required for 50% ($LT_{50}$) and 90% ($LT_{90}$) of larvae susceptible to die at a certain concentration was estimated using these models. Standard errors were computed using a non-parametric bootstrap procedure as described by van Herk *et al.* (2007). The standard error of the LT values was then approximated by the standard deviation of the bootstrap LT values. Parametric models with survival times following a Weibull distribution were tested, but provided a poor fit.

*Comparisons.* Pair-wise comparisons were made between various $LC_{50}$s and $LC_{90}$s by comparing the difference between two values to 0 with a Z-test. Tests were considered significant if $P \leq 0.05$. Comparisons between Kaplan-Meier curves were made using the log-rank test. Comparisons between individual $LT_{90}$ values were made with Wald tests.

## RESULTS AND DISCUSSION

**General observations.** The wireworm species used in this study varied significantly in size, ranging from 13.7 mg (*A. sputator*) to 81.5 mg (*C. pruinina*) (Table 1). While some larvae were stored longer than others, the similar response of the same population of *A. obscurus* exposed to clothianidin in 2004 and 2006 (see below) suggested that storage did not affect wireworm susceptibility to insecticides.

**Chlorpyrifos.** The $LC_{50}$ and $LC_{90}$ of chlorpyrifos applied to *A. sputator* (Table 2) were similar to those previously calculated for *A. obscurus* (0.10, 0.14%, respectively; van Herk *et al.* 2007). Similarly, the $LC_{50}$ of chlorpyrifos applied to *A. sputator* was close to that calculated for *C. pruinina* (Table 2). However, there was low (12.5%) mortality of *L. canus* at the highest concentration tested (0.15%). Considering that *L. canus* is similar in size to *A. obscurus*, and much smaller than *C. pruinina* (Table 1), the lower susceptibility of *L. canus* to chlorpyrifos suggests that there may be differences in the efficacy of this chemical against different species when used in the field.

Considerable differences among species in the induction of and recovery from chlorpyrifos-induced morbidity were observed. All larvae of *A. sputator* and *A. obscurus* that died after exposure to chlorpyrifos at 0.10% were moribund (Writhing, Leg & Mouthparts, or Mouthparts) seven DAT, but most *C. pruinina* that died showed no signs of morbidity until 42 DAT (Vernon *et al.* 2007). As wireworms can continue to feed on certain insecticides until they become moribund (van Herk *et al.* 2007), larvae that do not immediately become moribund during feeding may continue to damage crops. This suggests that for minimal wireworm damage and optimal population management, insecticides may need to be applied at concentrations that will induce morbidity quickly. A high proportion (>0.8) of moribund *A. sputator*, *A. obscurus*, and *C. pruinina* ultimately died (Vernon *et al.* 2007; data not shown for *A. sputator*), but most (12/14) moribund *L. canus* recovered, suggesting that morbidity alone is not always a reliable indicator of an insecticide's effectiveness.

**Clothianidin.** While the $LC_{50}$ of clothianidin applied to *A. obscurus* in 2006 was slightly lower than in 2004 (0.02, 0.07%, respectively; Table 2, van Herk *et al.* 2007), the $LC_{90}$ values were nearly identical (0.13, 0.15%, respectively; Table 2, van Herk *et al.* 2007), confirming previous results and justifying comparisons between the 2004 and 2006 studies. Similarly, the $LC_{50}$ and $LC_{90}$ values for *A. obscurus* (2006) were nearly identical to those for *A. sputator* (Table 2). In contrast, the $LC_{90}$ for *L. canus* was significantly higher than those for either *A. obscurus* or *A. sputator* ($P = 0.006$, $P = 0.019$, respectively), indicating

**Table 1.**
Mean (standard error) weight of wireworms used in toxicity studies. Weight of *C. pruinina* includes wireworms exposed in 2004 study.

| Species | *n* | Weight (mg) |
|---|---|---|
| *C. pruinina* | 209 | 81.5 (2.31) |
| *C. destructor* | 60 | 52.1 (2.72) |
| *L. canus* | 440 | 21.4 (0.41) |
| *A. obscurus* | 240 | 32.4 (0.59) |
| *A. sputator* | 440 | 13.7 (0.25) |

**Table 2.**
Toxicity of clothianidin and chlorpyrifos topically applied to various wireworm species in 2004 (*C. pruinina*) and 2006 (*L. canus*, *A. obscurus* and *A. sputator*). CL denotes 95% confidence limits.

| Insecticide | Species | *n* | Slope (SE) | LC50 (CL) | LC90 (CL) | $\chi^2$ (df) | *P* (SE) |
|---|---|---|---|---|---|---|---|
| clothianidin | *L. canus* | 240 | 7.27 (1.77) | 0.12 (0.08 – 0.16) | 0.30 (0.18 – 0.41) | 80.71 (54) | 0.05 (0.007) |
| clothianidin | *A. obscurus* | 240 | 12.25 (2.43) | 0.02 (0.001 – 0.04) | 0.13 (0.09 – 0.16) | 85.54 (51) | 0.009 (0.003) |
| clothianidin | *A. sputator* | 240 | 9.92 (1.37) | 0.02 (0.01 – 0.04) | 0.15 (0.12 – 0.19) | 29.04 (47) | 0.998 (0.001) |
| chlorpyrifos | *C. pruinina* | 130 | 6.58 (1.39) | 0.10 (0.07 – 0.13) | 0.30 (0.22 – 0.37) | 13.81 (23) | 0.907 (0.009) |
| chlorpyrifos | *A. sputator* | 240 | 11.20 (1.65) | 0.05 (0.04 – 0.07) | 0.17 (0.14 – 0.20) | 39.64 (48) | 0.965 (0.006) |

that the efficacy of this chemical in the field may also vary with species composition.

The $LT_{90}$ of *A. obscurus* exposed to clothianidin at 0.15% in 2006 (Table 3) was similar to the $LT_{90}$ of *A. obscurus* exposed to 0.1% and 0.25% in 2004 (143.5, 122.5 days, respectively; van Herk *et al.* 2007). The $LT_{90}$s of *A. obscurus* (2006) and *A. sputator* exposed to clothianidin at 0.15% were similar (Tables 3 and 4). While *L. canus* exposed to clothianidin at 0.15% died more quickly (66 days) than the two *Agriotes* spp., there was no significant difference in $LT_{90}$s between the species (Table 4). The difference in survival curves between *A. sputator* and *L. canus* (Table 4) reflects the faster initial rate of dying of *A. sputator* (Fig. 1). The $LT_{90}$s at 0.15% were significantly longer for both *Agriotes* species than for both *Ctenicera* species (Tables 3, 4). These results suggest that there are considerable differences between wireworm genera in the time required to kill them after exposure to clothianidin, which may affect the effectiveness of the chemical when used for wireworm control.

While nearly all wireworm species were either moribund (writhing or appendage movement) 1 day after exposure to clothianidin at 0.15% 1 DAT (Fig. 1), differences in recovery from morbidity were observed. Initial recovery from the writhing or appendage movement stages took longer for larvae of *A. obscurus* and *L. canus* (56, 28 DAT, respectively) than for *C. pruinina* and *C. destructor* (4 DAT) (Fig. 1), suggesting that clothianidin applied at sublethal rates may be less effective in providing crop stand protection in fields infested with *C. pruinina* and *C. destructor*.

These laboratory assays demonstrate that the wireworm species tested differ in

**Table 3.**
Time (days) required for 90% mortality (LT90) for various wireworm species exposed dermally to clothianidin at 0.15%, as calculated from Kaplan-Meier survival curves. CL denotes 95% confidence limits.

| Species | LT90 (CL) |
|---|---|
| *C. destructor* | 59.5 (31.5 – 80.5) |
| *C. pruinina* | 52.5 (45.0 – 66.5) |
| *L. canus* | 66.5 (52.5 – 122.5) |
| *A. sputator* | 115.5 (87.5 – 136.5) |
| *A. obscurus* | 122.5 (66.5 – 136.5) |

**Table 4.**
Comparison of LT90 values and Kaplan-Meier survival curves calculated for various wireworm species exposed dermally to clothianidin at 0.15%. LT90 values were compared with Wald tests; statistics shown are Z and *P*-values (respectively). Survival curves were compared with log-rank tests; statistics shown are Chi-square and *P*-values (respectively).

| | *C. pruinina* | *L. canus* | *A. sputator* | *A. obscurus* |
|---|---|---|---|---|
| | | | LT90 values | |
| *C. destructor* | 0.52, 0.60 | 0.23, 0.82 | 3.34, 0.0008 | 2.48, 0.013 |
| *C. pruinina* | x | 0.49, 0.62 | 4.80, < 0.0001 | 3.02, 0.003 |
| *L. canus* | x | x | 1.63, 0.10 | 1.57, 0.12 |
| *A. sputator* | x | x | x | 0.28, 0.78 |
| | | | Kaplan – Meier survival curves | |
| *C. destructor* | 0.70, 0.40 | 0.94, 0.33 | 12.11, 0.0005 | 4.70, 0.03 |
| *C. pruinina* | x | 2.39, 0.12 | 23.13, <0.0001 | 10.28, 0.0013 |
| *L. canus* | x | x | 6.70, 0.009 | 2.36, 0.12 |
| *A. sputator* | x | x | x | 1.29, 0.26 |

the onset and recovery of morbidity and the occurrence of mortality following exposure to certain insecticides (chlorpyrifos and clothianidin). Since several wireworm species are known to attack many agricultural crops worldwide, field efficacy trials should be carried out on as many economic species as possible to establish application rates that will provide crop damage and/or wireworm population control for all species.

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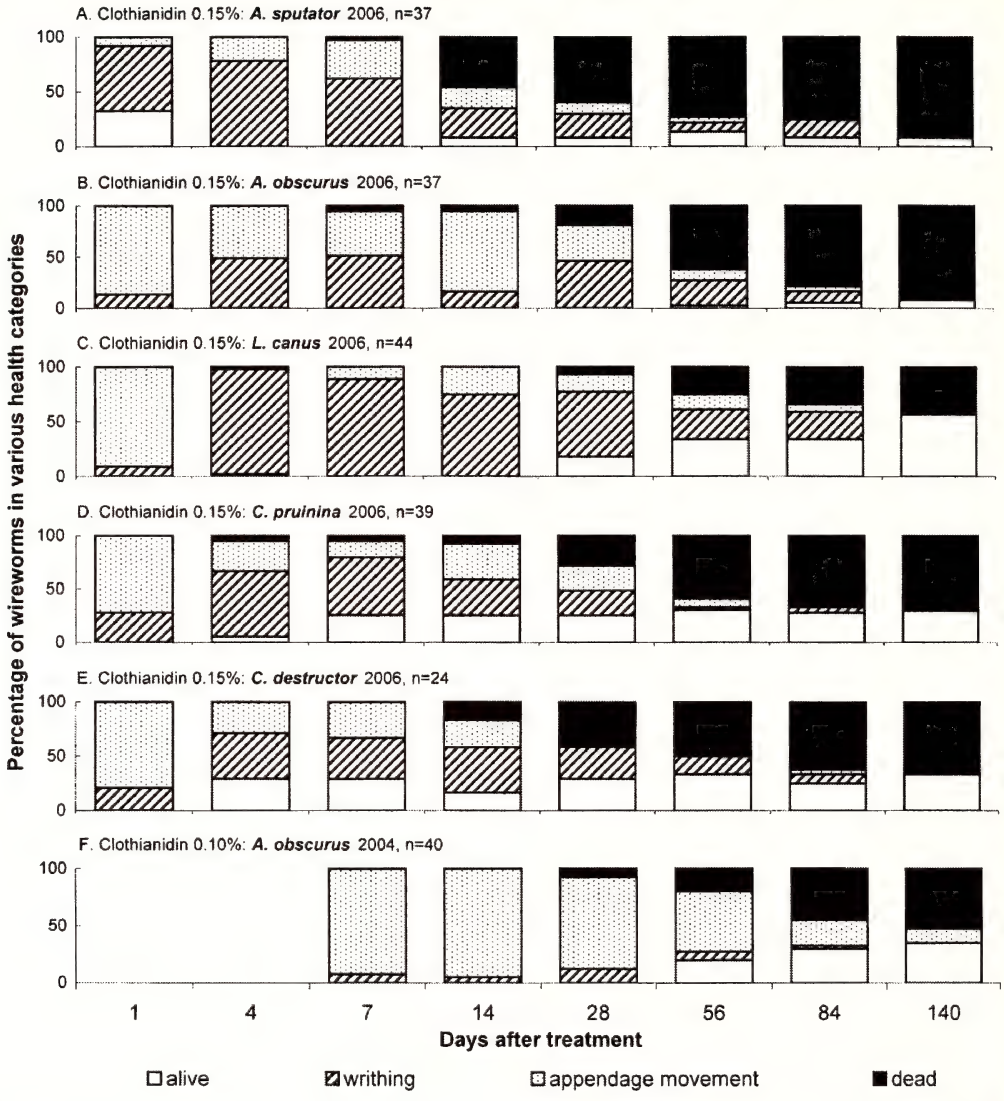


**Figure 1.** Transitional stages of toxicity in *A. sputator, A. obscurus, L. canus, C. pruinina,* and *C. destructor* wireworms exposed dermally to clothianidin in a Potter Spray Tower in 2006, and in *A. obscurus* wireworms exposed to clothianidin in 2004. The percentage of wireworms Alive, Writhing, with Leg and/or Mouthpart Movement (Appendage Movement), or Dead are shown on various dates of observation. Data for *C. pruinina* exposed to clothianidin 0.15% first appeared in Vernon *et al.* 2007.

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# Effect of kaolin clay on migrant alate aphids (Hemiptera: Aphididae) in blueberry fields in the context of *Blueberry scorch virus*

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## ABSTRACT

The efficacy of kaolin clay (Surround® WP) in reducing the number of migrant aphids on blueberry, *Vaccinium corymbosum* L. (Ericaceae) and the incidence of *Blueberry scorch virus* (BlScV) was determined. Two applications of kaolin clay reduced the number of alatae collected on treated 'Berkeley' plants by as much as a factor of eight between 4 June and 16 August. However, five of 100 test plants located near infected fields and exposed only to migrant alatae between 10 May and 16 August became infected with BlScV: three controls and two treated with kaolin clay. The work demonstrates the importance of migrant alatae in the spread of BlScV; 5% transmission is consistent with previous estimates of annual virus spread by winged and non-winged aphids. Three of the plants became infected between 10 and 27 May (one control and two treated with kaolin clay), indicating the importance of aphid flights in May for virus transmission. Rainfall removed much of the kaolin clay and this may have affected its efficacy. The aphid data demonstrated that migrant alatae are able to discriminate between untreated and kaolin-treated blueberry plants, and that *Ericaphis fimbriata* (Richards), which utilizes blueberry as a host, discriminates better than other migrant species. Water trap data do not necessarily reflect the total migrant aphid composition found on plants in the field. Plant growth was not affected by the kaolin clay, but the fruit had clay residues amongst the bracts of the calyx limiting the use of this product on producing fields to the period before fruit set. Kaolin clay may be best suited to protection of nursery stock, but further work is needed to improve efficacy during wet weather and determine optimal application frequency.

**Key Words:** *Ericaphis fimbriata*, aphid behaviour, virus transmission

## INTRODUCTION

*Blueberry scorch virus* (BlScV) was detected in 20 fields of blueberry, *Vaccinium corymbosum* L. (Ericaceae), in southwestern British Columbia (BC), Canada in 2000, and this increased to 140 fields by 2004 (Wegener *et al.* 2006). Symptoms

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depend on virus strain (Wegener *et al.* 2006) and blueberry cultivar, and can include severe blighting of flowers and young leaves, twig dieback, and yield reductions of more than 85% in the third year of symptom expression (Bristow *et al.* 2000). The virus is a member of the genus *Carlavirus* and is thought to be transmitted by *Ericaphis fimbriata* (Richards) (= *Fimbriaphis fimbriata*) (Hemiptera: Aphididae) (Remaudière and Remaudière 1997) in a non-persistent fashion (Bristow *et al.* 2000).

Raworth *et al.* (2006) showed that alatae of 87 aphid species out of a known 412 species in BC (Chan and Frazer 1993) fly over blueberry fields. Given the mode of transmission, these alatae may land on an infected plant, probe, then move to an uninfected plant and transmit the virus. Lowery *et al.* (1990) showed that whitewash could be used on rutabaga, *Brassica napobrassicae* (L.) (Brassicaceae), to reduce field populations of *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) and incidence of *Turnip mosaic virus*, another non-persistently transmitted virus. Liang and Liu (2002) showed in laboratory assays that kaolin particle film applied to the upper surface of melon leaves, *Cucumis melo* L. (Cucurbitaceae), reduced the number of adult silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring (Homoptera: Aleyrodidae), an important vector of viruses. Here, we present the results of an experiment to determine the efficacy of kaolin clay (Surround® WP, Engelhard Corp., Iselin, New Jersey) in reducing the number of alatae found on blueberry plants in the field and the incidence of BlScV.

## MATERIALS AND METHODS

'Berkeley' blueberry test plants were shipped from Fall Creek Farm & Nursery Inc. (Lowell, Oregon) in closed bulk containers in the spring of 2004. The plants were potted in 8-litre pots and held under insect screening at Agassiz, BC, an area isolated from BlScV. On 10 May 2004, 100 plants 42.4 ± 8.5 (SD) cm tall were transported in an enclosed cube truck from Agassiz to a field with BlScV-infected plants in Surrey, BC where they were placed in an open area within the field. One-hundred-forty plants from the same lot were grown in a screenhouse near Abbotsford, BC and served as non-field-exposed controls. Before exposure to the field, half the test plants were sprayed with kaolin clay (50 g per litre of water). The material was applied to the upper leaf surface using a Solo® backpack sprayer with an adjustable plastic nozzle (Solo, Newport News, Virginia) and was re-applied after inspection to ensure adequate coverage. The plants were placed in the field 65 cm above the ground on 7 mm diameter rebar driven 50 cm into the ground. A hose clamp, fastened to the rebar 5 cm from the top, prevented a 20 x 20 x 0.7 cm piece of plywood, a water catch tray, and the 8 litre pot (each with a hole in the centre) from sliding down the rebar. The hole in the water catch tray was sealed with silicone so that excess water applied by hand to the soil in the pot would remain in the catch tray. The rebar was coated every 2 weeks with Stickem Special® (Seabright Enterprises, Emeryville, California) between the ground and the pot to ensure that only flying alatae could reach the plants. Groups of five treated or five untreated plants were established with the supporting rebar posts at the corners of a 60 x 60 cm square and one post in the centre. Groups were placed in a completely randomized design separated by at least 2 m. Because the grower was removing infected plants as they were identified, the experiment was dismantled on 27 May. The test plants were taken back to Agassiz and treated with thiamethoxam (Actara® 25% WG) to kill any aphids. The experiment was then re-established with the same plants on 4 June in an open area 10 m east

of a field in Richmond, BC that had BlScV-infected plants that were not being removed in 2004. The same kaolin-treated and control test plants were placed in groups of five as before. Groups were completely randomized and kaolin clay was applied on 4 and 22 June. In addition, one water trap, a 35 cm diameter x 7 cm deep metal pan coated with Tremclad® yellow paint, was set 1.4 m above the ground, 15 m east of the trial. The trap was maintained weekly by replacing the water and adding 10 ml of extran® 300 detergent (EM Science, Gibbstown, New Jersey) to reduce surface tension, and 50 g of salt as a preservative. The test plants were removed from the field on 16 August, sprayed with thiamethoxam to kill aphids on the plants, and maintained in a screenhouse near Abbotsford, BC.

Alatae observed on the test plants were counted, removed, and stored in 70% ethanol weekly from 8 June until 6 July, then every 2 weeks until 3 August, for a total of seven samples. Alatae from the water trap were collected weekly from 8 June until 15 August and stored in 70% ethanol. The aphids were identified to species; voucher specimens are maintained at the Eastern Cereal and Oilseed Research Centre, Ottawa, Ontario. Colonies of apterae observed on 6 July were removed so that production of alatae on the plants would not confound the estimates of migrant alatae. Plant growth was monitored on one test plant selected at random from each group of five. One stem from each plant was marked and leaves greater than 1 cm long were counted every 2 weeks; on kaolin-treated plants, the numbers of new untreated leaves were estimated by subtracting the leaf counts when the plants were sprayed from the leaf counts at later dates. Rainfall data for the fields at Surrey and Richmond were obtained from Environment Canada meteorological stations at the Surrey Municipal Hall and Vancouver International Airport, respectively.

Because the latency period for BlScV could be as much as 3 years (Bristow *et al.* 2000), the test plants were sampled on 15 March and 16 May 2005, 18 May 2006, and 28 March 2007. Five to seven leaves (buds for the March samples) were collected from each test plant and analyzed for BlScV by double-antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA). The March 2005 sample was also analyzed using reverse transcription polymerase chain reaction (RT-PCR), and thereafter each ELISA-positive plant was confirmed by RT-PCR. All BlScV positive material was analyzed for the virus strains BC-1 (GenBank Accession No. AY941198) and BC-2 (GenBank Accession No. AY941199) (Bernardy *et al.* 2005) using RT-PCR. The plants were inspected for virus symptoms — flower blighting and leaf and stem dieback — when sampling.

Because the test plants had been exposed to two fields and there can be different virus strains in different fields (Wegener *et al.* 2006), the field at Richmond was sampled to determine the dominant virus strain; removal of BlScV-infected plants precluded such sampling at the Surrey field. On 9 August 2005, 100 field plants were sampled in a regular pattern from a block of about 800 plants just west of the kaolin clay trial at Richmond, BC, and on 15 May 2007, 13 field plants were sampled from a block of about 60 plants just north of the trial; there were no commercial blueberry plants to the east or south. These samples were analyzed for BlScV in general and specifically for the strains BC-1 and BC-2, using RT-PCR.

ELISA was conducted according to the method described by Clark and Adams (1977) with the exception that borate grinding buffer (Martin and Bristow 1988) was substituted. Positive and negative controls were included in each test and samples were considered positive for BlScV if absorbance values were at least three times greater than the mean absorbance value of the negative control samples (Sutula *et al.* 1986; Pataky *et al.* 2004).

The RT-PCR assay utilized a rapid, direct one-tube-RT-PCR procedure (Rowhani *et al.* 2000) for virus detection. For sample preparation, leaf tissue from test plants was homogenized in sample bags (Agdia Inc., Elkhart, Indiana) with grinding buffer, pH

9.6 (carbonate ELISA coating buffer containing 2% PVP-40, 0.2% BSA, 0.1% sodium meta bi-sulfite, and 0.05% Tween 20®, all from Sigma Aldrich Canada, Oakville, Ontario) at a dilution factor of 1:20. A 2 µl aliquot of this plant extract was pipetted into a 0.2 ml PCR tube containing 25 µl of filter-sterile GES buffer (0.1 M glycine-NaOH, pH 9.0, 50 mM NaCl, 1 mM EDTA, 0.5% Triton® X-100, all from Sigma Aldrich Canada, Oakville, Ontario). The sample was heated in a thermal cycler (iCycler, Bio-Rad Laboratories (Canada) Ltd., Mississauga, Ontario) at 95 °C for 10 minutes, and then chilled in an ice bath for 5 minutes. For the one-tube-one-step RT-PCR procedure, all components for RT and PCR were assembled in 25 µl final volume of reaction mix containing 2.5 µl of 10 X PCR buffer (GeneSys Ltd., Surrey, UK), 0.5 µl of dNTP mixture (10 mM), 0.1 µl of RNaseOUT™ inhibitor (40 U/µl, Invitrogen Corp., Burlington, Ontario), 0.035 µl of MMLV-RTase (200 U/µl, Invitrogen Corp.), 0.25 µl of Taq DNA Polymerase (5 U/µl, GeneSys Ltd. ), 1.25 µl dithiothreitol (0.1 M, Invitrogen Corp.), 1.25 µl of each BlScV-specific primer BS32F, CAACCCGACGTTCATATTCA (10 µM) and BS506R, TCTTCAATGCACGATGTTCC (10 µM), and 2 µl of sample extract. RT-PCR was conducted using the following profile: 30 min for RT at 52 °C, followed by 35 cycles of 94 °C for 30 s, 53 °C for 45 s and 72 °C for 60 s and a final extension step at 72 °C for 7 min. The amplified fragment (478 bp) was analysed in a 1.5% agarose gel by electrophoresis in 1 X TBE buffer (90 mM Tris-borate, 2 mM EDTA), using 2 µl of the PCR mixture, followed by staining with ethidium bromide (0.5 µg/ml) and visualized with a UV transilluminator (260 nm). Virus strain assays utilized the primers BlScV-BC1-ORF2-F2, AAGGTGAAATCGGGGTTTTG and BlScV-BC1-ORF5-R1, GACTCGGGCAGGGACCTC for strain BC-1, and BlScV-BC2-ORF2-F1, ACCTTCTCTCGACCGAGATC and BlScV-BC2-ORF5-R1, GAGCTTGGACCAGCATCC for strain BC-2, with an annealing temperature of 50-55 °C.

The mean number of alatae per plant and the number of leaves per stem for each group of five plants ($n$ = 20) on every sample date ($n$ = 7), were analyzed by repeated measures ANOVA (SAS 1990) after transformation by square-root ($x$ + 0.5) and ln ($x$ +1.0), respectively, to stabilize the variance (Southwood 1966). The number of alatae per plant was plotted against day-degrees (dd) above 4.1 °C, the developmental temperature threshold for *E. fimbriata* (Raworth and Schade 2006), to determine the potential for the earliest progeny of *E. fimbriata* alatae to contribute to the population of alatae given that all aphids were removed by hand on 6 July. Chi-square was used to compare numbers of alate *E. fimbriata* with other migrant aphids as a group on treated versus control plants, or on blueberry plants versus yellow water trap samples.

The number of alatae found on the test plants at weekly intervals was a function of numbers attracted to the plant and rate of departure after landing. To distinguish between the two effects, alatae behaviour on kaolin-treated leaves and controls was examined in the laboratory at Agassiz, BC in a windowless room at 20-24 °C, with overhead fluorescent lighting (6.1 $\mu E \cdot m^{-2} \cdot s^{-1}$; 1 µE = 1 µmol of photons), and 56-67% RH. Alate *E. fimbriata* from an organic blueberry field and from a laboratory colony on 'Berkeley' blueberry were starved for 3-5 h on moist filter paper. An alate aphid was then placed in the centre of a 'Berkeley' blueberry leaf (6.8 ± 0.8 (SD) x 3.8 ± 0.5 cm, abaxial side down) in a glass Petri dish. The aphid was observed for 5 min, recording time settled. Three treatments were run simultaneously: leaves were either dipped in kaolin clay (50 g per litre reverse osmosis [RO] water), sprayed with kaolin clay on the upper side, or dipped in RO water (control). There were 20 replicates of the three treatments, and 15 additional replicates of the kaolin-sprayed versus control leaf. Treatment position was randomized

among replicates. The data were analyzed by ANOVA without transformation. A 24 h variation of the experiment was conducted, examining 14 replicates of kaolin-sprayed versus control leaves (9.1 ± 0.7 x 5.2 ± 0.5 cm, abaxial side down) simultaneously for alatae position (upper or lower leaf surface, or off leaf) 20 times, at various intervals from 15 min to 10 h. When an aphid was found off the leaf, it was placed back on the leaf. The experiment was repeated with 15 replicates of kaolin-sprayed versus control leaves. The proportion of observations of alatae in each position was arcsine square-root transformed and analyzed by ANOVA for differences among treatments, trials, and the interaction treatment by trial.

## RESULTS AND DISCUSSION

Kaolin clay significantly ($P < 0.001$) reduced the number of alatae found per plant on groups of five plants at Richmond (Fig. 1), even though rainfall (5, 7, 10-13 June, total 21.8 mm; 2, 6, 10 July, total 16.6 mm; and 3, 4, 6 August, total 19 mm) removed much of the clay, reducing the whiteness of the leaves, and despite the fact that new untreated foliage increased in surface area after application of kaolin clay (6.1 to 49.6 new leaves per stem between 15 June and 3 August). A total of 409 alatae was found on untreated controls and 71 on kaolin-treated plants.

It may be argued that the alatae were not discriminating with respect to attraction, but were discriminating with respect to rate of departure. However, the laboratory experiments provided no evidence that alatae behaved differently on kaolin-treated than on control leaves. In the first experiments, there was no difference in time settled on leaves treated with kaolin clay compared with controls during a 5 min period ($P > 0.05$). In the second experiments conducted during 24 h, alatae tended to move to the underside of the leaves and remain there regardless of treatment. There was no trial by treatment interaction or difference between kaolin-treated leaves and controls with respect to the position of the alatae on the leaf ($P > 0.05$), and the proportion of observations with alatae feeding on the abaxial surface was 0.79 -0.045 +0.042 (back-transformed mean ± SE) versus 0.082 -0.025 +0.029 on the upper surface. There was a trial by treatment interaction with respect to the proportion of observations in which alatae were found off the leaf ($P = 0.037$), but this weak effect merely suggests an inconsistency in the pattern from one trial to the next because there was no overall difference in the proportion off the leaf between treated and control leaves.

It might also be argued that the progeny of the earliest *E. fimbriata* contributed to later populations of alatae found on the test plants, producing biased results. However, alatae generally do not produce alatae directly (Lees 1961), therefore two generations were required for production of alatae on the test plants. Developmental time from birth to adult in June and July requires about 175 dd above 4.1 °C (Raworth and Schade 2006), so alatae would not arise on the test plants until after the fourth sample (Fig. 1), potentially contributing to the counts in the fifth sample, but this effect would be small because few migrant alatae were found in the first 80 dd, and progeny of alatae produced after 80 dd would have been removed on 6 July.

Five field-exposed test plants, three control and two kaolin-treated plants, were infected with BlScV; none of the non-field-exposed plants was infected. This showed that the infections were due to field exposure (5:95 versus 0:140, $\chi^2 = 7.0$, 1 df, $P < 0.01$), and as applied under the prevailing conditions, kaolin clay did not prevent virus transmission. All five plants were BlScV-positive in the first, and subsequent leaf samples during 3 years, and all were symptomatic. The infection rate, 5%, was consistent with the annual rate due to both alate and apterous aphids observed by Wegener

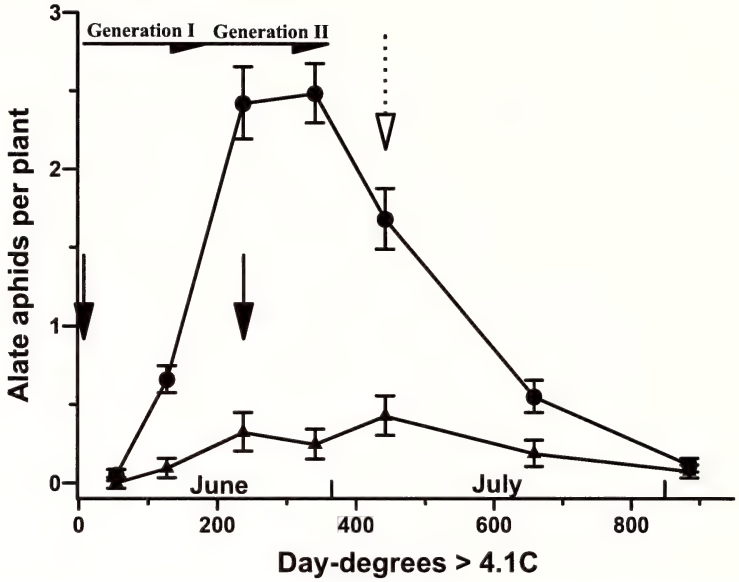


**Figure 1.** Mean number of alate aphids (± SE, back-transformed data) per control plant (circles) and kaolin-treated plant (triangles) versus time, 2004. Day-degree summations start the day the experiment was set up at Richmond, BC. Dark vertical arrows mark the application of kaolin clay; open vertical arrow marks the removal of all aphids by hand; horizontal arrows mark the first and second aphid generations arising from the earliest alatae to land on the plants.

*et al.* (2006) in three commercial fields from 2001-2004. Our result therefore demonstrates the importance of alate aphids in the spread of BlScV.

Two of the five BlScV-positive test plants were infected with the BC-2 strain and were negative for BC-1. The remaining three plants were negative for both BC-1 and BC-2 and were therefore infected with unknown BlScV strains. This contrasts with the survey of crop plants just west and north of the trial in Richmond where 46 out of 113 plants were BlScV-positive, all with BC-2 and none with BC-1. There were no BlScV-positive plants with unknown strains. We conclude that the infections in the test plants with unknown BlScV strains probably did not come from the Richmond field (46:0 versus 2:3, Fisher's Exact Probability test $P < 0.001$, 1 df). They probably came from the Surrey field. The Surrey field was known to have plants infected with BC-2 (Wegener, pers. comm.) and BC-5 (Wegener *et al.* 2006). Therefore, at least three of the infections — one control and two kaolin-treated plants — occurred in the Surrey field between 10 and 27 May, a period of 17 days, whereas the two BC-2 infections (both controls) may have occurred during the 17 days in the Surrey field, or between 4 June and 16 August, a period of 73 days in the Richmond field. This demonstrates that May is an important period for virus transmission. During the spring in some years, there are significant flights of *Euceraphis betulae* (Koch) and *Periphyllus testudinaceus* (Fernie) (Raworth *et al.* 2006), but perhaps more importantly, *E. fimbriata*, a known vector of BlScV (Bristow *et al.* 2000) and the dominant aphid on blueberry, produces a high proportion of alatae in May (Raworth 2004).

There were 320 *E. fimbriata*, 28 *Aphis fabae* Scopoli, 8 *E. scammelli* (Mason), 11 *Euceraphis betulae* (Koch), 23 *Wahlgreniella nervata arbuti* (Davidson) and one or two individuals of 10 other species collected from the test plants at Richmond. *Ericaphis fimbriata* was affected more by the kaolin clay than the other aphids taken as a group; 284 and 36 *E. fimbriata* alatae were collected on controls and kaolin-treated plants, respectively, but 60 and 21

alatae of other species were collected on the respective plants ($\chi^2$ = 11.5, 1 df, $P$ < 0.001). Assuming that the effect of kaolin clay on alatae departure was equal among species, this result suggests that *E. fimbriata*, which utilizes blueberry as a host, can better differentiate between untreated and kaolin-sprayed blueberry than other species which do not utilize blueberry as a host.

Only nine *E. fimbriata* alatae were found in the water trap compared with 232 alatae of other species. This was different from the pattern on blueberry (320 *E. fimbriata* and 81 other species; $\chi^2$ = 339.6, 1 df, $P$ < 0.001), reflecting lower attraction to blueberry, a higher turnover rate, or both, for migrant species that don't utilize blueberry as a host compared with *E. fimbriata* which does. In the water trap, there were 35 *A. fabae*, 12 *Brachycaudus helichrysi* (Kaltenbach), 77 *Calaphis flava* Mordvilko, 12 *E. betulae*, 16 *Myzocallis coryli* (Goeze) and fewer than 10 individuals for each of 29 other species, a different mix of aphids than on the test plants. Only one *B. helichrysi* and no *C. flava* or *M. coryli* were collected on the test plants, suggesting that either they are not attracted to blueberry, or that their residence time on blueberry is very short. Studies of the attraction and alighting behaviour of several aphid species with respect to blueberry would be useful. Using water trap data, Raworth *et al.* (2006) suggested that *B. helichrysi* requires study as a vector of BlScV, however, this would not be necessary if the aphid is rarely attracted to blueberry. On the other hand, no *E. scammelli* were collected in the water trap in this study, or in a more extensive 2-year study (Raworth *et al.* 2006), but this species was found on the test plants. This result shows that water trap data do not necessarily reflect the total migrant aphid composition.

Plant growth was not affected by the kaolin clay ($P$ > 0.05). The number of leaves per stem increased from 30.3 ± 3.0 (SE) on 11 May to 131.8 ± 16.2 on 10 August ($P$ < 0.0001), and the interaction of time and treatment was not significant. Spiers *et al.* (2004) observed increased plant growth in blueberry treated with Surround WP. However, their study was conducted in Mississippi, and they speculated that the clay protected the plants from heat stress and insect pests.

Given the low virus transmission rate in the blueberry system, further work is needed on a much larger scale — in the order of 5000 plants — to determine the efficacy of kaolin clay with respect to virus transmission. However, it is clear that even if a difference is detected, BlScV will still be transmitted to kaolin-treated plants unless efficacy can be improved by repeated applications or addition of an effective surfactant-sticker. Lowery *et al.* (1990) applied whitewash weekly, significantly reducing aphid numbers and infection rates of *Turnip mosaic virus*, which is transmitted in a non-persistent manner. In our study, kaolin clay was applied only three times in nearly 13 weeks. This consideration is particularly important in May when rainfall tends to be higher than the subsequent 3 months (66.6 versus 49.6, 44.1, and 28.8 mm, respectively, ± 8.6 overall SE; data from the Vancouver International Airport 1997-2006). In our study, rainfall at Surrey on 21, 22, and 25 May removed most of the clay film on the leaves. However, weekly sprays later than bloom in May would not be practical in commercial fields because clay residues which we observed on the fruit amongst the bracts of the calyx from our sprays in June would render the fruit unmarketable. In the final analysis, unless an effective surfactant-sticker is added, kaolin clay may not be a useful IPM tool for this crop, except perhaps on nursery stock where repeated sprays are possible throughout the spring and summer. The difference in numbers of alatae collected on kaolin-treated plants compared with controls suggests that further studies to determine efficacy and optimal application frequency for nursery stock are warranted. These studies should also examine the effect of plant-group size, and distance between treatment and control groups, on the numbers of alatae collected from each group.

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# Recent range expansion of the Praying Mantis, *Mantis religiosa* Linnaeus (Mantodea: Mantidae), in British Columbia

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## ABSTRACT

The Praying Mantis, *Mantis religiosa*, was introduced into eastern North America in the 1890s and is now a common species throughout much of the eastern United States and southern Ontario and Quebec. It was introduced from Ontario into the southern interior of British Columbia to control grasshoppers in 1937 and 1938. These introductions became established only in the southern Okanagan Valley where populations have persisted from Okanagan Falls south to Osoyoos. Since the late 1990s, the species' range has expanded from the South Okanagan north at least to Kamloops and east to Nelson. In addition, in the core of its traditional British Columbia range, the South Okanagan, this mantid has become more commonly encountered during the past decade. *M. religiosa* has also been collected on Vancouver Island. Specimen, photograph and sight records that document this change in status are listed and discussed and a distribution map is included. Characters used to distinguish *M. religiosa* from the native Ground Mantis, *Litaneutria minor*, and the exotic Chinese Mantis, *Tenodera aridifolia sinensis*, which is available commercially as a biocontrol agent, are summarized.

## INTRODUCTION

The Praying Mantis, *Mantis religiosa* Linnaeus, was introduced into the eastern United States and Canada from Europe, being first reported in New York State in 1899 and in Prince Edward County, Ontario in 1914 (McLeod 1962). It appeared in Quebec by about 1940 (Kevan 1979). It was introduced from Ontario into the Okanagan and Thompson valleys in the southern interior of British Columbia (BC) to control grasshoppers in 1937 and 1938 (Baird 1938, 1939; Buckell 1941; Vickery and Kevan 1983). Mantid oothecae (egg cases) were found in Salmon Arm orchards as late as 1940 (Buckell 1941); however, McLeod (1962) stated: "the insect has not been observed in recent years and there is no evidence of its permanent establishment in British Columbia". Currently, it is thought that the initial releases of *M. religiosa* became established only in the southern Okanagan Valley. Since the early 1970s, *M. religiosa* specimens regularly have been found between Okanagan Falls and Osoyoos (Cannings and Scudder 2001); both the green and brown colour phases occur there (Cannings 1987). More recently, especially since the late 1990s, I have collected reports from interested naturalists and the general public that indicate that the species' range has expanded in BC. It also is found in Washington and Idaho, although it is not clear how those populations arrived. Although most of the BC records are not museum specimens, the photographs and written sight records are largely convincing. This paper documents the spread and present status of *M. religiosa* in the Province.

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## MATERIALS AND METHODS

Data were collected from adult specimens and oothecae of *Mantis religiosa* from the collections of the Royal British Columbia Museum, Victoria, BC (RBCM), the Spencer Entomological Museum, University of British Columbia, Vancouver, BC (UBCZ) and the Canadian National Collection of Insects, Agriculture and Agri-Food Canada, Ottawa, ON (CNCI) and the personal collection of Ward Strong, Vernon, BC (STRONG). The collections of the Pacific Forestry Centre, Canadian Forest Service, Victoria, BC and the Lyman Entomological Museum, McGill University, Ste. Anne de Bellevue, QC do not contain any specimens of *M. religiosa* from BC.

Photographs and sight records were compiled from personal communications to the author from colleagues and the general public.

## RESULTS

**Specimens examined** (all specimens are single adults unless otherwise noted):

Duncan, Maple Bay, 6139 Denali Place, near Quamichan Lake, 31.x.1999, L. Taylor (RBCM, ENT001-011034); Naramata, 27.viii.1998, R.C.H. Cannings (RBCM, ENT000-000416, ootheca and hatchlings in ethanol); Okanagan Falls, 22.v.1986, S. Orchard (RBCM, ENT991-014761, -014762, -014763, 3 oothecae); Okanagan Falls, White Lake, 49°17'58.8"N x 119°37'21.1"W, 29.v.2006, R.A. Cannings (RBCM, ENT006-004184, ootheca); Oliver, ix.1975, B. Francis (CNCI, in ethanol); Oliver, ix.1990, S. Orchard (RBCM, ENT991-066770); Oliver, 10 miles south, *Artemisia-Purshia* habitat, 1.x.1963, W.B. Preston (UBCZ); Oliver, UBC Geology Camp, 3.ix.1982, S.G. Cannings (UBCZ, 5 specimens); Osoyoos, 14.v.1972, no collector stated (CNCI, ootheca collected and reared to adult, in ethanol); Osoyoos, 29.viii.1976, no collector stated (RBCM, ENT991-014757); Osoyoos, at light, 23.viii.1982, J.A. Garland (RBCM, ENT991-014756); Osoyoos, Deadman Lake, 6.ix.1980, L. Vasington (UBCZ, 2 specimens *in copula*); Osoyoos, Haynes Ecological Reserve, 3.ix.1983, R.A. Cannings (RBCM, ENT991-017647); Osoyoos, Haynes Ecological Reserve, pitfall trap, 6.vii.-17.viii.2000, G.G.E. Scudder (UBCZ); Osoyoos, Haynes Ecological Reserve, pitfall trap, 25.vi.-22.vii.2003 (UBCZ); Osoyoos, Osoyoos Desert Society, 20.viii.1998, P. Liu (UBCZ); Osoyoos, Haynes Point Prov. Park, 20.viii.1977, C. Denbigh (RBCM, ENT991-014758, -014759, 2 specimens); Osoyoos, Road #22, 10.vii.1986, R.A. Cannings (RBCM, ENT988-001350, ootheca); South Okanagan Valley, vii-viii.1984, S.R. Cannings (UBCZ); Pend d'Oreille Valley, east of Waneta, 11U 463978 5432563, 700m asl, 26.iv.2004, J. Dulisse (RBCM, ENT007-002472, ootheca); Summerland, 19.viii.2005, D. Chan (UBCZ); Vaseux Lake, Hack's Ponds, 19.v.1980, R.A. Cannings (RBCM, ENT991-014433, ootheca); Vernon, Kalamalka Seed Orchards, 10.v.2004, W. Strong (STRONG); Vernon (50°17.909'N x 119°16.463'W), 24.viii.2007, G. French (RBCM, ENT007-001057, ootheca); Vernon, 4.ix.2007, B. Corbett (RBCM, ENT007-002457); Vernon, Middleton Mtn., 10.ix.2007, M. Fowler (RBCM, ENT007-002458); Vernon, Kalamalka Seed Orchard #307, 18.ix.2007, D. Hopkins (RBCM, ENT007-002459, ootheca); Vernon, 10.x.2007, W. Strong (RBCM, in ethanol, ENT007-002460).

**Photographs:**

Armstrong, near Tolko Lumber Mill, Hwy 97, south of town, 23.viii.2007, Karen Meggait (brown adult found on 18.viii.2007); Castlegar, side of house, 23.ix.2002, Lynn Westcott (green adult); Castlegar, in ornamental cedar tree, 27.ix.2002, Lynn Westcott (brown adult); Castlegar, 25.v.2005, Genevieve Lachance (ootheca with hatchlings); Kamloops, Knutsford, grassland and Ponderosa Pine

habitat, on garage door, 12.x.2006, Richard Suttie (green adult); Lake Country, backyard near grassland, 7.viii.1998, Steve Kidd (brown adult); Lake Country, 21.vii.1998, Steve Kidd (yellowish adult); Okanagan Falls, White Lake, 1.ix.2006, V. Skilton (brown adult); Oliver, 22.iii.2006, Werner Eigelsreiter (ootheca); Oliver, 23.ix.2006, Werner Eigelsreiter (green adult); Oliver, 24.ix.2006, Werner Eigelsreiter (brown adult); Osoyoos, Haynes Point Prov. Park, vii.1974, Sydney Cannings (brown adult); Taghum (west of Nelson), ix.2004, Rachel Holt *fide* Jakob Dulisse (green adult); Trail, Oasis Wetland, 26.viii.2007, Bruce Enns (green adult) (Fig. 1); Vernon (50°17.909'N x 119°16.463'W), 25.v.2007, Lea Gelling (ootheca, collected 24.viii.2007, RBCM, ENT007-1057);Vernon, 50°17.909'N x 119°16.463'W, 15.viii.2007, Gord French (green adult).

**Other records without specimen or photo:**

Deer Park, Lower Arrow Lake (11U 425791 5474447 NAD 83), 14.vi.2004, Jakob Dulisse (ootheca); Kelowna, on house, about 25.ix.2000, *fide* Tanis Stoltz (adult); Keremeos, road to Keremeos Columns, sagebrush grassland, early vii.2001, Malcolm Martin (green immature and oothecae); Oyama, on house, 30.ix.2000, Tanis Stoltz (adult); Osoyoos, East Bench, 28.viii.2007, G.G.E. Scudder (adult male); Osoyoos, East Bench, 29.viii.2007, G.G.E. Scudder (adult male and female); Peachland, 6412 Renfrew Road, 25.viii.1998, Bill Fleming (green and brown adults); Port Alberni, Sproat River, Seaton Park, on tent, vii-viii.1991, Dee Cullon (green adult); Vernon, garden on north side of Middleton Mountain, summer 1999 or 2000, *fide* Malcolm Martin (green adult).

Figures 2 and 3 map the records documented above.

**Figure 1.** *Mantis religiosa*: Trail, 26 August 2007. Photo: Bruce Enns. This green adult is feeding on a female dragonfly, *Sympetrum obtrusum* (Hagen) and represents one of the more easterly records of the species in BC. The black-ringed white spot on the inner base of the procoxa is diagnostic of *M. religiosa*.

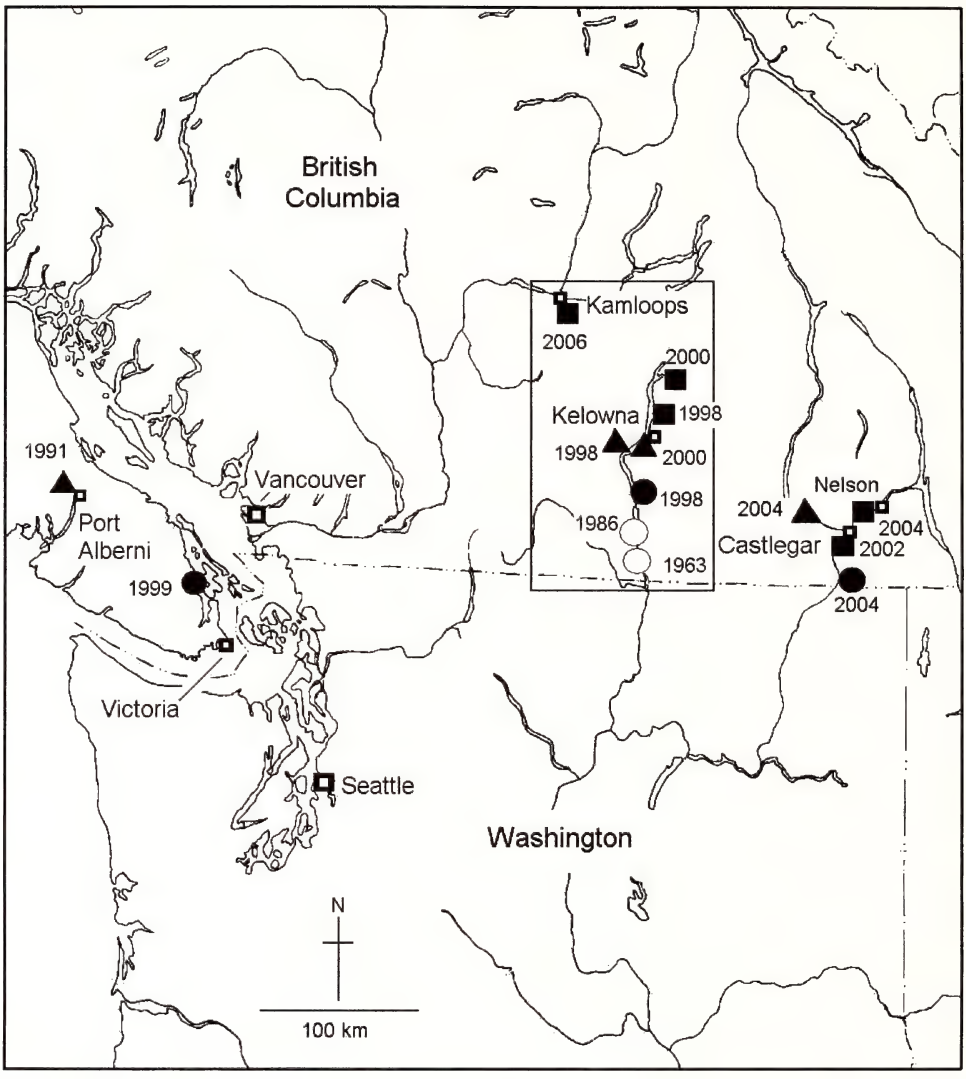


**Figure 2.** Map of southern British Columbia and northwestern United States showing selected distribution records of Mantis religiosa. Symbols: ● specimen records, including oothecae; ■ photographic records; ▲ sight records. Open symbols represent records before 1998. The dates represent the first records for the localities and illustrate the general geographical and temporal trend of range expansion. Rectangle shows area of Fig. 3.

## DISCUSSION

In 1937, 491 oothecae and 161 adult *Mantis religiosa* from Europe and Ontario were released in the Okanagan Valley and the Kamloops-Shuswap region (Baird 1938). The next year, at Salmon Arm and Vernon, 175 oothecae and 175 adults were introduced (Baird 1939). Buckell (1941), who was interested in grasshopper control, at first expressed hope that the introductions might succeed: "The finding of two fresh egg masses laid in apple boxes in the orchards at Salmon Arm [in 1940] shows that it is still present and may yet become thoroughly established." But Vickery and Kevan (1983) point out that even though this generalist predator favours Orthoptera prey in many situations, the slow rate of mantid reproduction makes it an unsuitable

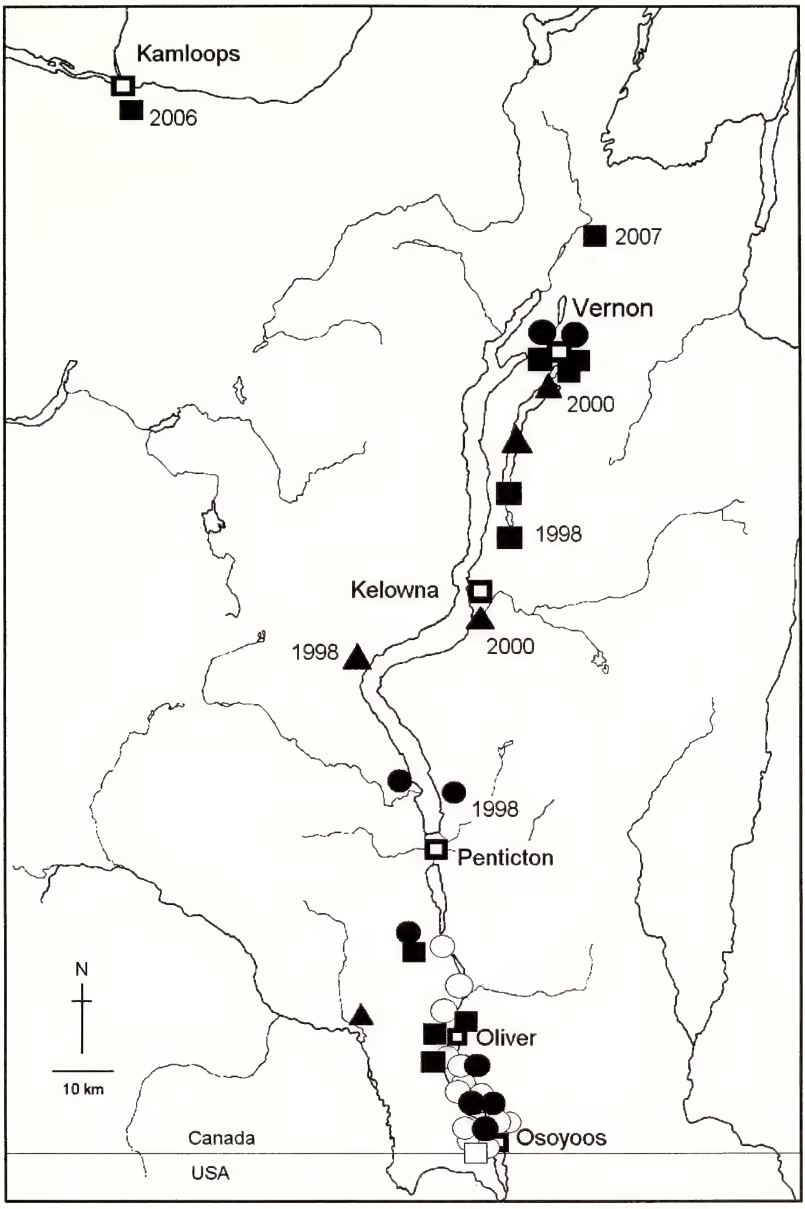


**Figure 3.** Map of the Okanagan Valley and part of the Thompson River drainage to the north showing some distributional details not given in Fig. 2. Symbols: • specimen records, including oothecae; ■ photographic records; ▲ sight records. Open symbols represent records before 1998. The dates represent the first records for the localities and illustrate the general geographical and temporal trend of range expansion.

biological control agent.

However, although no mantids were ever reported from most of the areas where these releases were made, by about 1962 periodic specimen sightings and collections were being made in the extreme southern part of the region. The first specimen known to me was from 10 miles south of Oliver in 1963. By the end of the 1970s, if one looked specifically for mantids, they could be found in small numbers in the Oliver-Osoyoos area, although few specimens were collected. Without evidence to support other origins for this population, it

has always been assumed that it derived from the releases of 1937-38.

As far as I am aware, since 1940, no *Mantis* specimens were collected and no observations were reported from the Thompson/Shuswap region or the Okanagan Valley north of Okanagan Falls until 1998 when specimens were recorded in Naramata, Peachland and Lake Country (=Winfield, north of Kelowna). In 2000, mantids were first reported from Kelowna and Oyama; to the north in Vernon, the first sightings were made about the same time. Jim Corrigan (pers. comm.) notes that he saw several mantids around the BC Ministry of Forests Kalamalka Seed Orchards at the southern edge of Vernon in 2006 and that staff there have seen specimens around Vernon for several years. The first Vernon specimen was collected in 2004 (Ward Strong, pers. comm.), and several specimens were taken at Vernon in 2007. There is also a photographic record from Armstrong in 2007. The only recent record in the Thompson/Shuswap was from Knutsford near Kamloops in 2006. This sequence of dates moves more or less from south to north (Fig. 3), suggesting that the mantid population expanded in this direction, the northern specimens descending from the long-standing South Okanagan population rather than resulting from recent independent introductions. This would also seem to be the most parsimonious explanation. The same goes for the numerous mantids now seen in the West Kootenays (Figs. 2), especially in the Castlegar region. The first two reports were from Castlegar in 2002; the next ones were all in 2004 – northwest in Deer Park, northeast in Taghum and south near Waneta. Figure 1 illustrates an adult from Trail in 2007. This expansion well north and east of the South Okanagan is probably the result of both natural dispersal and, more importantly, movement aided by human activity. Mantid adults are not strong wanderers but oothecae are laid on all sorts of solid substrates and can be transported long distances on trailers and other vehicles. It is unclear why, after decades of stability in the southern Okanagan Valley, this population has expanded almost 200 km, to both the north and east, in fewer than ten years.

Although few specimen collections have been made and the evidence is anecdotal, this range expansion has occurred at the same time that residents of the South Okanagan have observed an increase in mantid abundance from Osoyoos north to the Penticton region. My brothers and I were raised in the Penticton-Summerland area and since the 1950s we roved all over the countryside looking for animals and plants. Never once before the mid-1990s did we see a mantid anywhere north of Okanagan Falls, and south of there, they were uncommon. My brother Richard (pers. comm.), who now lives in Naramata, writes: "They are common in late summer and fall – you see them often while walking along the Kettle Valley Railway trail or similar trails in late August and early September and I often find egg cases. I can't say I've noticed an increase since we moved here in 1995 – I just remember that shortly after we arrived I realized that I was seeing them regularly". Geoff Scudder (pers. comm.) says he frequently sees adults, mostly gravid green females, around Osoyoos. He has observed them in the native steppe vegetation and in his garden, where he finds oothecae and two to three adults each year.

There are no coastal mainland records of *M. religiosa* in BC, but there are two from Vancouver Island – an early sight record from the Port Alberni area in 1991 and a specimen from Duncan in 1999 (Fig. 2). Presumably these are the result of long-distance, human-aided dispersal or purposeful release of adults from the BC interior or elsewhere. The Duncan specimen was the only one that was observed in 1999 and one more was seen in 2000 (no date). None has been seen there since. Laurie Taylor (pers. comm.), who made these observations in her garden, believes that the mantids originated from plants she bought at a local nursery.

There are also populations in Idaho and Washington State, including coastal ones,

that may be potential sources of additional introductions. Antonelli and Glass (2004) report specimens of introduced mantids (not necessarily *Mantis religiosa*) from western Washington counties such as Clark, Cowlitz, Pierce and King as well as from east of the Cascade Mountains; all specimens observed by colleagues in Washington seem to be *M. religiosa*. Kelly McAllister (pers. comm.) states that populations of *M. religiosa* in the prairies of south Puget Sound are large: "I've heard that there are literally thousands that fly about when Scot's Broom [*sic*] is being mowed at Scatter Creek Wildlife Area in late summer. I think the Nature Conservancy folks who mow Scot's Broom at places like McChord Air Force Base and Fort Lewis would probably attest to the widespread distribution and general abundance on prairie areas at least. It's my sense that they are very firmly established in appropriate habitat in the south Puget lowlands." Probably, *M. religiosa* could rather readily spread from northwestern Washington into coastal BC.

*Tenodera aridifolia* Stoll ssp. *sinensis* Saussure (Chinese Mantid) is an unrestricted and commercially produced species of mantid available as a biological control agent and in the pet trade in BC (David Blades, pers. comm.). It is released in gardens in attempts to control pests, although Don Elliott of Applied Bio-nomics (pers. comm.) considers it ineffective as it often feeds on other beneficial insects. Undoubtedly, releases of *T. a. sinensis* into greenhouses and gardens have occurred many times over the years in BC but no established populations are known. Experiments on the survival ability of the species in various locations in BC are required to determine whether this species is capable of becoming established here. Possibly, the development of *T. a. sinensis* requires more accumulated degree-days than are available on the BC coast (David Blades, pers. comm.).

In Canada, this Asian species is an exotic resident of extreme southern Ontario (the shores of lakes Erie and Ontario) and is recorded from, but not established in, southern Quebec (Vickery and Kevan 1983). It is also known from California. Adults are larger than those of *Mantis* (*Tenodera*: 83-104 mm long; *Mantis*: 47-56 mm long (Vickery and Kevan 1986)); the middle and hind femora have an apical spine lacking in *M. religiosa*; and the black-ringed white spot on the inner base of the procoxa characteristic of *M. religiosa* is absent (Vickery and Kevan 1986).

The Ground Mantis, *Litaneutria minor* (Scudder), Canada's only native mantid, also occurs in the southern Okanagan Valley where, in some habitats, such as antelope-brush (*Purshia tridentata* (Pursh) de Candolle) and big sagebrush (*Artemisia tridentata* Nuttall) grasslands it is sympatric with *Mantis religiosa* (Cannings 1987). However, it is easily distinguished from the latter; Cannings (1987) gives characters to separate the two species. Briefly, *Litaneutria* adults are grey to dark brown and less than 35 mm long while those of *Mantis* are green or pale brown and much longer than 35 mm. Females of the former have short, non-functional wings, one-third or less the length of the abdomen, while males are usually fully winged with a dark spot on the hindwing. Both sexes of *M. religiosa* are winged and have a black-ringed white spot on the inner base of the procoxa. Vickery and Kevan (1986) key the three species that occur in Canada.

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# Two alien Heteroptera (Hemiptera) new to Canada

G.G.E. Scudder[1]

## ABSTRACT

This paper reports two alien species of Heteroptera (Hemiptera), *Rhopalus tigrinus* (Schilling) (Rhopalidae) and *Plinthisus brevipennis* (Latreille) (Rhyparochromidae) new to Canada. The former is now known from British Columbia, the latter from British Columbia and Ontario.

**Key Words:** Canada, two new alien Heteroptera species

## INTRODUCTION

The distribution, spread, and adaptations of 81 alien heteropterous species recorded in Canada was summarized by Scudder and Foottit (2006). Recent research has revealed two additional alien species in the Canadian fauna. These are reported below, with Museum abbreviations as follows:

CNC: Canadian National Collection of Insects, Agriculture and Agri-Food Canada, Ottawa, ON.

RBCM: Royal British Columbia Museum, Victoria, BC.

USNM: United States National Museum of Natural History, Smithsonian Institution, Washington, DC.

## ALIEN HETEROPTERA NEW TO CANADA

FAMILY RHOPALIDAE

*Rhopalus tigrinus* (Schilling)

*Rhopalus tigrinus* was first reported from North America by Hoebeke and Wheeler (1982) with records from New Jersey, New York and Pennsylvania. Known breeding host plants are members of the Brassicaceae (= Cruciferae). Subsequently, Wheeler and Hoebeke (1999) recorded *R. tigrinus* from Arizona, California, Colorado, Nebraska, Oregon and Wyoming. Hoebeke and Wheeler (1982) provide a key to separate this alien Eurasian species from the other rhopalids known to occur in eastern North America, and give a dorsal view photograph.

The following characteristics will serve to identify this species: Dorsal coloration yellowish or greyish with black markings on head, anterior margin of pronotum, antero-lateral corners of scutellum, and spots on veins of hemelytra; abdominal dorsum black with yellow markings at apex; connexivum generally yellow, but sometimes with black spots posteriorly. Head short, more than 1.5 times as broad as long; rostrum short, not or barely extending to metasternum; pronotum without anterior collar; lateral margins of pronotum straight or slightly sinuate, without a distinct notch behind anterior margin; pronotal cicatrices not ending in a loop; pronotum anterior to cicatrices not smooth or polished, but always with numerous coarse punctures; metapleuron distinctly divided into episternum and epimeron; posterior margin of metasternum deeply concave, with dorsolateral angle distinctly produced caudad; metathoracic scent gland opening conspicuous. Total length (♂ 5.9-6.6 mm, ♀ 6.1-7.1 mm).

This species is now known to occur

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quite commonly in the southern interior of British Columbia. The species was previously reported from the province as *Liorhyssus hyalinatus* (Fabricius) by Blades and Maier (1996), based upon my misidentification. Canadian material has been compared with a colour photograph of a specimen from the USA kindly provided by Dr. T.J. Henry.

**Material examined.**

**BC**: 3♀, Barnhartvale, NW area, 50° 38'47"N 120°09'14"W, 23.vi.2003 (G.G.E. Scudder) [CNC, UBC]; 1♂, Boston Bar, 23.vi.1996 (G.G.E. Scudder) [CNC]; 2♂ 1♀, Chopaka, 27.viii.1986 (G.G.E. Scudder) [CNC, UBC]; 1♂, Chopaka, SATH habitat, BGxh1, SN, CH11, 26.v.1995, (J. Jarrett) [UBC]; 1♀, *id.*, CH 15, 19.vi.1995 (J. Jarrett) [UBC]; 1♀, Chopaka, BGxh1, SN, pitfall trap CH1-1, 23.vi-28.vii.1997 (J. Jarrett) [UBC]; 1♀, *id.*, CH1-3, 23.vi-28.vii.1997 (J. Jarrett) [UBC]; 1♂, *id.*, CH5-1, 23.vi.-28.vii.1997 (J. Jarrett) [UBC]; 1♀, *id.*, CH1-3, 28.vii.-18.viii.1997 (J. Jarrett) [UBC]; 1♀, *id.*, CH2-1, 28.vii.-18.viii.1997 (J. Jarrett) [UBC]; 1♀, *id.*, CH5-4, 28.vii.-18.viii.1997 (J. Jarrett) [UBC]; 2♀, Chopaka, Mariposa Conserv. Area, 3.vii.1996 (G.G.E. Scudder) [CNC]; 1♀, Fairview, White L., BGxh1, SWm, 7.vi.1996 (G.G.E. Scudder [CNC]; 1♀, Fairview, White L., SATH habitat, BGxh1, SWm, pan trap WL P-1, 4.vii.-11.vii.1995 (J. Jarrett) [UBC]; 1♀, *id.*, WL P-2, 13.vi.-20.vi.1995 (J. Jarrett) [UBC]; 1♂, Fairview, White L., SATH habitat, BGxh1, SWm, sweeping 9, 11.vii.1995 (J. Jarrett) [UBC]; 1♂, Hedley, 5 km W, 15.vi.1990 (G.G.E. Scudder) [CNC]; 1♀, Hedley, 7 km E on *Clematis*, 10.ix.1995 (G.G.E. Scudder) [CNC]; 4♂ 12♀, Kalamalka Lake Prov. Pk., 24.viii.1989 (G.G.E. Scudder) [CNC, UBC, USNM]; 1♀, Keremeos, 10.ix.1995 (G.G.E. Scudder) [CNC]; 2♀, Kilpoola L., 31.v.2006 (G.G.E. Scudder) [CNC]; 2♂, Merritt, 35 km S, 14.viii.1988 (G.G.E. Scudder) [CNC]; 1♀, Nicola, 1.ix.1993 (G.G.E. Scudder) [CNC]; 1♀, Okanagan Falls, Mandalay Ranch, McLean Cr., 49° ·20'52"N 119°31'29"W, collected on *Chenopodium album*, 31.viii.2004 (G.G.E. Scudder) [CNC]; 1♀, Okanagan Falls, Nature Trust Land, 49°18'54"N 119°31'33"W, 20.v.2004 (G.G.E. Scudder) [CNC]; 3♂ 3♀, Okanagan Falls, Vaseux Ranch, 49° 18'55"N 119°31'34"W, on *Sisymbrium altissimum* L. (Tumble mustard), 24.v.2004 (G.G.E. Scudder) [CNC, UBC]; 1♂, Okanagan Falls, Vaseux Ranch, 49° 18'55"N 119°31'34"W, 24.v.2004 (G.G.E. Scudder) [CNC]; 1♂ 1♀, *id.*, 20.viii.2004 (G.G.E. Scudder) [CNC]; 7♂ 9♀, Osoyoos, 29.viii.1988 (G.G.E. Scudder) [CNC, UBC, USNM]; 2♂ 3♀, *id.*, 23.viii.1989 (G.G.E. Scudder) [CNC]; 2♂, Osoyoos, Anarchist Mt., 26.viii.1989 (G.G.E. Scudder) [CNC]; 1♀, Osoyoos, Desert Centre, BGxh1, 8PD/2AN:P, pitfall trap DS3-1, 22.vii.-20.viii.1999 (G.G.E. Scudder) [CNC]; 1♀, Osoyoos, East Bench, 4.vi.1992 (G.G.E. Scudder) [CNC]; 1♀, *id.*, 15.ix.2000 (G.G.E. Scudder) [CNC]; 1♀, *id.*, 15.viii.2006 (G.G.E. Scudder) [CNC]; 1♀, *id.*, vane trap, 17.v.-12.vii.2007 (G.G.E. Scudder) [CNC]; 1♀, Osoyoos, Ecol. Res., 14.vi.1987 (S.G. Cannings) [UBC]; 1♀, *id.*, 8.v.1994 (G.G.E. Scudder) [CNC]; 1♀, Osoyoos, Haynes E.R., BGxh1, AN recovery after fire, pitfall trap B2, 8.vi.-9.vii.1994 (G.G.E. Scudder) [CNC]; 3♀, *id.*, E2, 26.v.-13.vii.1995 (G.G.E. Scudder) [CNC]; 1♀, *id.*, A1, 9.viii.-20.ix.1996 (G.G.E. Scudder) [CNC]; 1♂ 2♀, Osoyoos, Haynes E.R., BGxh1, AN recovery after fire, 9.viii.1995 (G.G.E. Scudder) [CNC]; 1♂ 1♀, *id.*, 23.v.1996 (G.G.E. Scudder) [CNC]; 1♀, Osoyoos, Haynes E.R., collected on *Sporobolus cryptandrus* (Torr.) Gray, 2.ix.1993 (G.G.E. Scudder) [CNC]; 1♀, *id.*, 5.ix.1993 (G.G.E. Scudder) [CNC]; 1♂ 1♀, *id.*, sweeping *Sisymbrium loeselli* L., 8.v.1994 (G.G.E. Scudder) [CNC]; 3♂ 3♀, *id.*, sweeping *Bromus tectorum* L., 8.v.1994 (G.G.E. Scudder) [CNC, UBC]; 2♂ 2♀, *id.*, sweeping *Stipa comata* T.&R., 2.vi.1994 (G.G.E. Scudder) [CNC]; 1♀, *id.*, sweeping *Sisymbrium loeselli* L., 2.vi.1994 (G.G.E. Scudder) [CNC]; 1♂, Osoyoos, Haynes Lease Eco. Reserve, "Throne area", 27.vii.1988 (C.S. Guppy) [RBCM]; 1♀, Osoyoos, nr. Haynes E.R., 28.ix.2001 (G.G.E. Scudder) [CNC]; 6♂ 7♀, Osoyoos,

8 km N, near canal, 49°05'32"N 119° 32'18"W, collected on *Berteroa incana* (L.) DC (Brassicaceae), 11.ix.1995 (G.G.E. Scudder) [CNC, UBC]; 1♀, Osoyoos, 8 km N, collected on *Rosa*, 21.ix.1995 (G.G.E. Scudder) [CNC]; 1♀, Osoyoos, Mt. Kobau, 1865 m, on *Artemisia tridentata*, 27.viii.1988 (G.G.E. Scudder) [CNC]; 1♀, Osoyoos, Mt. Kobau, 560 m, LM3, 8-13.vii.1991 (D. Blades, C. Maier) [RBCM]; 1♀, Osoyoos, Mt. Kobau Rd., PPxh1, WAw, pitfall trap K1B-4, 23.vi.-28.vii.1997 (J. Jarrett) [UBC]; 1♀, Osoyoos, Mt. Kobau Rd., km 1.8, 815 m, PPxh1, 4WAw:F/4WSw:F/2SS:F, 28.vii.1997 (G.G.E. Scudder) [CNC]; 1♀, Penticton, 5.ix.1982 (L. Vasington) [UBC]; 1♂, Penticton, Sage Mesa subdiv., grassland, 30.iv.1989 (R.A. Cannings) [RBCM]; 1♀, Penticton, West Bench, malaise, 29.iv.1989 (R.A. Cannings) [RBCM]; 1♂, Vaseux Cr., 'Kennedy bench', 49°16'N 119°30'W, *Purshia* assoc., BGxh1, AN, pitfall trap Z2-2, 12.viii.-6.ix.1995 (G.G.E. Scudder) [CNC]; 1♂ 1♀, Walhachin, 23.vi.2003 (G.G.E. Scudder) [CNC]; 3♀, White L., Observatory Jct., on *Sisymbrium altissimum* L., (Tumble mustard), 8.vi.2004 (G.G.E. Scudder) [CNC, UBC]; 1♀, White L., White L. Ranch, 49°18'N 119°40'W, *Lepidium perfoliatum* L. (Clasping peppergrass), 9.vi.2004 (G.G.E. Scudder) [CNC].

FAMILY RHYPAROCHROMIDAE

*Plinthisus brevipennis* (Latreille)

This alien European seed bug was first reported from North America by Asquith and Lattin (1991), who recorded the species from Oregon and Washington, with the first collection from near Seattle in 1964. Asquith and Lattin (1991) provide a fine illustration of this species, and note that it is easily distinguished from the three native western species of *Plinthisus* by its size (total length ♂ 2.45-3.00 mm, ♀ 2.98-3.20 mm), and the width of the fore femur, which in *P. brevipennis* is equal to, or greater than, the width of the vertex.

Canadian material has been compared with specimens of *P. brevipennis* in my own collection, collected by me in Jersey, Channel Islands in 1957. *P. brevipennis* is here reported new to Canada, with specimens collected in British Columbia and Ontario.

**Material examined.**

**BC**: 1♀, Victoria, Mary Hill, Site 1, 48° 20.6'N 123°33.0'W, low broom, grasses, pitfall trap 5, sample MH1PSA, 05-14.ix.2003 (A. Behennah, I. Behennah) [RBCM]; 1♀, *id.*, 21-28.ix.2003 (A. Behennah, I. Behennah) [RBCM]; 2♀, S. Gulf Islands, Tumbo Island, CDF, 48°47.602'N 123°03.143'W, pitfall trap, 8.vii.2004 (J. Heron, S. Lavallee, R. Bennett) [RBCM]; 1♂, *id.*, 48°47.650'N 123°03.721'W, [RBCM]; 1♀, *id.*, 48°47.754'N 123° 05.466'W, [RBCM].

**ON**: 2♀, Rondeau Pk., on sand beach, edge oak for., Int. trap 5, 14.vi.-2.vii.1985 (L. LeSage & D.M. Wood) [CNC].

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SCIENTIFIC NOTE

# Escape behaviour of cranberry girdler, *Chrysoteuchia topiaria* (Lepidoptera: Pyralidae), moths

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*Chrysoteuchia topiaria* (Zeller) (Lepidoptera: Pyralidae), the cranberry girdler, is a serious pest of cranberry, *Vaccinium macrocarpon* Aiton (Ericaceae), in North America (Kamm *et al.* 1990). *Chrysoteuchia topiaria* is univoltine, with moths emerging and flying in June and July (Kamm *et al.* 1990). The moths are dayfliers, but also come to light traps at night (Banerjee 1967).

When collecting gravid female *C. topiaria* moths for a laboratory colony, I observed that females were hard to catch because they behaved differently than males. When I approached with a handheld vacuum (Bioquip, Gardena, CA), female moths often dropped from plants, whereas male moths usually flew away. Moths that dropped landed on the trash layer (shed leaves and organic debris on the soil surface under the vines) where they lay motionless on their side until pursued further, when they scurried away by pushing the substrate with their legs.

To test the hypothesis that female *C. topiaria* moths respond to disturbance differently than males, escape behavior of male and female moths on a cranberry farm (cv. Stevens; 49°13'50.0"N, 122°43'33.0"W) was observed and recorded. Disturbance was defined as movement of the handheld vacuum toward the moth. Movement of the vacuum was often accompanied by a high-pitched crunching sound made by compression of cranberry vines underfoot. Observations were made by a team of two people between 1030-1230 h Pacific Daylight Time, on 28 and 29 June and 12 and 27 July 2000. An observer spotted a moth and kept it in view while a collector approached it with the handheld vacuum. The team followed the moth for five flights or until the moth dropped to the ground, whichever occurred first. The observer marked with a survey flag the locations where the pursued moth alighted or dropped. After the collector caught the moth, the observer recorded the number of flights and measured the distance between each set of flags to calculate the total distance flown. Air temperature was recorded by a shaded Hobo datalogger (Onset Computer Corp, Bourne, MA) and windspeed was recorded by the farm's anemometer. Captured moths were kept cool and transported to the laboratory, where females were dissected for spermatophores. Data are presented as mean ± standard error of the mean unless otherwise specified. Statistical tests were done with Systat 8.0 (SPSS Inc., Chicago, IL).

When disturbed, 37% of females (n = 33) dropped from the vines into the trash layer, in contrast to only 6% of males (n = 34) ($\chi^2 = 9.4$, P = 0.002). The median number of flights made by males was greater than that made by females (5 vs. 4; Mann-Whitney U = 362, P = 0.007). The median distance flown, measured for 27 males and 27 females, was 2.5 times greater for males (5.0 vs 2.0 m; Mann-Whitney U = 213, P = 0.009). Most (31) of the 32 captured females had mated at least once: 13 contained one spermatophore, 14 contained two, and 4 contained three. The number of spermatophores in females that dropped was similar to the number in females that did not drop (1.5 ± 0.2 vs. 1.8 ± 0.2; two-sample $t_{30}$ = 1.1, P = 0.3).

Female moths seemed larger than males. To test the hypothesis that females' wing

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load was greater than that of males, captured moths were weighed (before dissection) on a microbalance accurate to 0.01 mg (Sartorius Canada Inc., Mississauga, ON) and their wings were removed for area measurement by Scion Image software (Scion Corporation, Frederick, MD). To calculate total wing area, the areas of the most intact forewing and hindwing were measured, added together, then multiplied by two. Wing load was calculated by dividing moth weight by total wing area. Two-sample, one-tailed t-tests were used to analyse weight, wing area and wing load of females vs. males.

Females weighed more than males ($13.96 \pm 0.71$ vs. $9.33 \pm 0.44$ mg; $t_{64} = 5.6$, $P < 0.001$) and had larger abdomens. Wing area of females was similar to males' wing area ($96.51 \pm 2.49$ vs. $93.57 \pm 1.96$ mm$^2$; $t_{63} = 0.9$, $P = 0.4$). Wing load was $0.15 \pm 0.01$ mg/mm$^2$ for females, and $0.10 \pm 0.01$ mg/mm$^2$ for males ($t_{63} = 5.5$, $P < 0.001$). The wing load of females that dropped was not different than the wing load of females that flew ($0.13 \pm 0.01$ vs. $0.15 \pm 0.01$ mg/mm$^2$; $t_{30} = 1.2$, $P = 0.2$). There was no relationship between dropping and windspeed, which ranged from 2.7-13.6 km/h ($F_{1,2} = 0.5$, $P = 0.6$) or between dropping and temperature, which ranged from 20-28 °C ($F_{1,2} = 0.3$, $P = 0.6$).

To take off and maintain flight, wings of female *C. topiaria* moths must lift about 50% more body weight per unit area than male wings, thus the physiological cost of flight should be greater for females. A more extreme example of differences in wing load and flight behaviour is reported for the grasshopper *Phymateus morbillosus*. Females have large, heavy abdomens and wing loads three times greater than males; females escape by remaining motionless or hopping away to hiding places, whereas males take flight (Gade 2002). When thrown into the air by experimenters, females did not produce lift and simply plummeted to the ground (Gade 2002).

Both types of escape behavior (dropping or flying) put moths at risk of predation. Swallows, which prey on flying *C. topiaria* (Scammell, 1917), would catch males and mated females that had laid many eggs. Terrestrial predators, such as the hunting spiders commonly found in cranberry fields (Fitzpatrick *et al.* 1994, Bardwell and Averill, 1996), would likely prey on female moths that drop from the vines.

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SCIENTIFIC NOTE

# Further records for *Ochthebius* (Coleoptera: Hydraenidae) in British Columbia

REX D. KENNER[1]

The family Hydraenidae contains small aquatic beetles somewhat misleadingly called "minute moss beetles", as only a few species are found associated with moss (Perkins 2001). Hydraenids are commonly found on the margins of streams and can reach high densities in appropriate marginal substrates (Perkins 1976). However, these beetles are found in a wide variety of habitats and some species, particularly in the genus *Ochthebius* Leach, are typically found in lentic habitats (Perkins 1980, 2001).

During an ongoing survey of the aquatic insects of Jericho Park, Vancouver, BC (Needham and Kenner 2007), the author collected several hydraenids while sweeping with an aquatic insect net. Jericho Park is a very popular urban park with a large permanent "main pond" and an ephemeral "meadow pond". The main pond is in a relatively natural state, surrounded by short grass with trees along one side. It is filled mainly by rainwater and is subject to greatly reduced water levels in the summer months. It supports a large mixed flock of waterfowl in winter, with smaller numbers in the summer. It has a soft mud bottom and contains large amounts of detritus. Parts of the west end of the pond, where the hydraenid specimens were collected, are dominated by dense stands of *Typha* sp. although there are still significant areas of open water except in late summer.

Two of the hydraenids collected in Jericho Park are *Ochthebius brevipennis* Perkins. This species is "primarily a pond species" (Perkins 1980) and is found along the Pacific coast from northern California to southern British Columbia. Perkins lists only a single record for this species in Canada: BC, Agassiz, 07-iii-1931, H.B. Leech (1 specimen, California Academy of Science, San Francisco, CA). A search of the collections of the Canadian National Collection (Ottawa, ON), the Royal British Columbia Museum (Victoria, BC) and the Spencer Entomological Museum (University of British Columbia, Vancouver, BC) (SEM) yielded no additional records. The two Jericho specimens [CANADA, BC, Vancouver, Jericho Park, Main Pond, 49°16.26' N 123°11.70'W, 07-xi-2006, R.D. Kenner] have been deposited in the SEM.

Four specimens identified only as *Ochthebius* sp. were found in the collection of the SEM. Three of these are *O. kaszabi* Janssens, which is widespread in Canada (Perkins 1980). The remaining specimen [BC, Chilcotin (Riske Creek), Box 20-21 (now known as Lake Lye (Topping & Scudder 1977)), 52°1' N 122°29' W, 08-x-1968, G.G.E. Scudder] is *O. lecontei* Perkins. This species is associated with ponds but has an inland distribution extending from western Utah and northeastern Nevada to the southern interior of BC (Perkins 1980). Perkins lists only three Canadian localities for this species: Vernon (type locality), Kamloops and Cranbrook. The physical and chemical characteristics of Lake Lye, a saline lake (conductivity 2900 µS at 25 °C at the time of the collection), are described in Topping & Scudder (1977).

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SCIENTIFIC NOTE

# The Helicopsychidae, a caddisfly family new to British Columbia (Insecta: Trichoptera)

ROBERT A. CANNINGS[1,2] and GINA ROBERTS[3]

The Helicopsychidae is a small but distinctive family of the Trichoptera containing 10 genera (Morse 2007). It is found in most faunal regions around the world (Wiggins 1996a). The cosmopolitan genus *Helicopsyche* consists of about 238 described species (Morse 2007) and is the sole North American genus in the family. Although this genus is mostly tropical in distribution, it contains five known species north of Mexico (Morse 2007).

*Helicopsyche borealis* (Hagen) is the only species ranging north into Canada. Despite its name, it is not a typical transcontinental boreal species but is only distributed northerly relative to other species in the genus. It is widespread and common over much of North America (Wiggins 1996a) but has not been recorded from the Yukon (Wiggins and Parker 1999) or previously in British Columbia (BC) (Nimmo and Scudder 1978, 1983). It prefers clear, fast-flowing streams, but also inhabits the littoral zone of lakes (Wiggins 1996a, Schmid 1998) and is among the caddisflies most tolerant of high water temperatures (Wiggins 1996a), perhaps a reflection of the tropical origin of the genus (Williams *et al.* 1983).

The most striking feature of almost all species in the family is the larval case, which, finely built of sand grains and silk, strongly resembles a tightly coiled snail shell. Indeed, *H. borealis* was originally described as a gastropod (Lea 1834). This distinctive, compact and consolidated case probably is an adaptation for a larval life in beds of gravel and stones (Williams *et al.* 1983, Wiggins 1996a). The larvae feed on diatoms and plant detritus on the surfaces of the rocks or in the spaces between them (Williams *et al.* 1983).

This note records the first specimens of *H. borealis* and the family Helicopsychidae from BC. The main material examined was collected by Gina Roberts from the San Jose River, 2.4 km east of its mouth in Williams Lake (52°05'50"N x 121°59'52"W) on 9 November 1998. The water at the collection site was up to 50 cm deep and flowed at about 0.3 to 0.5 m/sec. During spring run-off, the river's water level rises 1 to 1.5 m. Larvae were abundant; over the 3 or 4 m of river examined, there were several hundred larvae per square decimetre. The specimens, about 100 in total, are housed in three ethanol lots in the Royal British Columbia Museum (ENT001-000978, 79, 80).

In addition, two small collections of specimens from the Chilcotin River were deposited as vouchers at the Royal BC Museum as part of Environment Canada's Fraser River Action Plan. Although the larval specimens were labeled and identified to family in the project, the Helicopsychidae was not listed in the benthic invertebrate report describing the collections and their analysis (Rosenberg *et al.* 1999). The data for the two sites on the Chilcotin River are: 52°12'41"N x 123°50'50"W, 21.x. 1994, 3040' asl, T.B. Reynoldson; and 52°18'52"N x 123°58'35"W, 22.x.1994, 3180' asl, T.B. Reynoldson. These sites are northwest of Redstone between Puntzi Creek and Chilcotin Lake.

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Wiggins (1996a) illustrated the larva and case. The mean maximum diameter of 30 cases from the San Jose River sample was 2.7 mm (range 2.2-3.3 mm). According to Ross (1944) and Wiggins (1996a) the diameter of the case of a full-grown larva ranges from about 5 to 7 mm, suggesting that these specimens were about half grown. Williams *et al.* (1983) summarized what little is known about the species' life history. They indicated that an Ontario population they studied was probably univoltine, with the adults emerging in the last half of June.

No adult *Helicopsyche* specimens were collected at the San Jose or the Chilcotin River sites. Adults of *H. borealis* should be looked for in BC. They are about 5-7 mm long and typically are pale yellow washed with various shades of brown. They lack ocelli, the mesotibiae do not have preapical spurs and the costa of the hindwing is broadly angled and bears a row of hooks on the basal half (Schmid 1998). The vertex has large setal warts extending from the mesal margins of the eyes to the mid-dorsal line and anteriorly to the middle of the head (Wiggins 1996b).

We thank Claudia Copley (Royal BC Museum, Victoria, BC) for locating the Chilcotin River specimens; and David Rosenberg (Department of Fisheries and Oceans, Winnipeg, Manitoba), Trefor Reynoldson (Acadia University, Wolfville, Nova Scotia) and Stephanie Strachan (Environment Canada, Vancouver, BC) for information about them.

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SCIENTIFIC NOTE

# *Meconema thalassinum* (Orthoptera: Tettigoniidae), a foreign katydid established in British Columbia

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*Meconema thalassinum* (De Geer), a katydid in the tettigoniid subfamily Meconematinae, is a European native established in northeastern North America since 1957 (Capinera *et al.* 2004). In the published literature it is known as far west as Michigan and extreme southwestern Ontario (Marshall *et al.* 2004).

Rather than stridulating by rubbing the forewings together, as most Ensifera do, males call at night by tapping their hind tarsi on leaf surfaces or other substrates, and thus *M. thalassinum* is known in North America as the Drumming Katydid. The drumming is quiet, but sometimes may be heard 3 to 4 m away (Capinera *et al.* 2004). The species is pale green with a dorsal yellow stripe on the head and prothorax. Adults range from 14 to 20 mm in length; both sexes are fully winged and have an exposed tympanum on each fore tibia. The female has a curved ovipositor as long as the abdomen (Fig. 1a); the male's subgenital plate is bifid, long and strongly upcurved (Fig. 1b). *Meconema thalassinum* lives mainly in deciduous trees and is mostly nocturnal; it eats insects as well as leaves (Johnstone 1970).

Although there are recent photographs posted on the Internet (BugGuide 2007) from southwestern British Columbia and one from King County, Washington, this paper documents the earliest western North American records of *M. thalassinum* and the subfamily Meconomatinae. They come from the Lower Mainland region of southwestern British Columbia (from the Greater Vancouver area east to Maple Ridge and Langley) between 1991 and 2007 (Collections deposited in RBCM – Royal British Columbia Museum, Victoria, BC; SFU – Simon Fraser University collection, Burnaby, BC; UBC – Spencer Entomological Museum, University of BC, Vancouver, BC). Most specimens (25 of 31) were collected by entomology students for class projects at Simon Fraser University and the University of British Columbia. The earliest records are from Surrey (16 September 1991, J. Mayer (SFU)) and Haney (22 September 1991, S. Chaabra (SFU)).

David Holden (pers. comm.), trapping Gypsy Moths with pheromone-baited delta traps, has found numerous *Meconema* specimens in the Vancouver and Lower Fraser Valley areas; the insects are apparently entering the traps for shelter or to eat dead insects trapped there. At 133 Powell Street in downtown Vancouver, Bruce Triggs captured a male in his apartment on 9 August 2006 (RBCM). Catrien Schiffer has observed the species for three years at her home on Puget Drive in Vancouver, a locality dominated by large trees and gardens. On 29 July 2005 a female appeared above the front door and both a male and female were seen there intermittently over the next two weeks. A male perched at the same place from 20 July 2006 until mid-August, when it was found dead (Fig. 1b)

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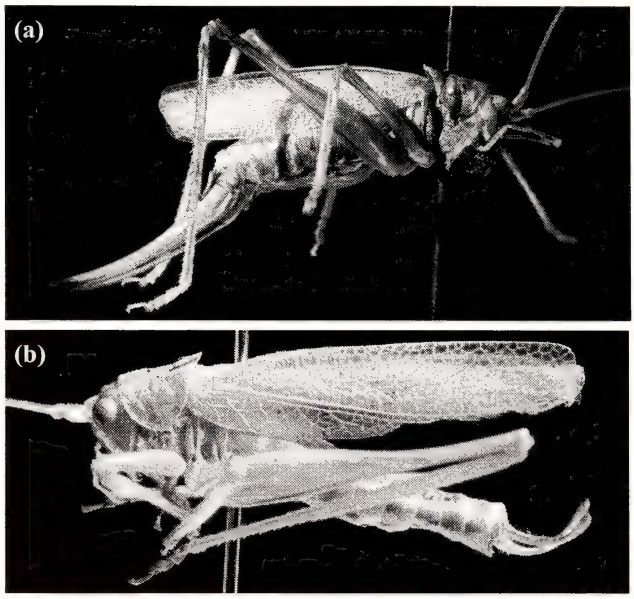


**Figure 1.** *Meconema thalassinum*. (a) Female. Vancouver, 5 September 2006, Murray Isman (Spencer Entomological Museum). (b) Male. Vancouver, 4015 Puget Drive, found dead, 19 August 2006, Catrien A.H. Schiffer (Royal BC Museum). Photos: Darren Copley.

(RBCM). Two females died in this garden in August (RBCM) and a third was photographed in September 2006. In 2007, both males and females were observed there between 8 August and 2 November. The closely timed appearance of adults at the same location in three consecutive years indicates that, although no courtship or mating behaviour has been observed at the site, breeding is occurring in the area.

*Meconema thalassinum* is clearly well established in the Vancouver and Lower Fraser Valley region of British Columbia and there is one photographic record from Issaqua, King County, Washington taken in August 2007 (BugGuide 2007). As far as is known, the Lower Mainland of BC is the only region west of Michigan where this exotic species is established. Whether this population is the result of specimens transported west from eastern North America, or if the founders came directly from Europe, is unknown. Vancouver is a major air, sea and land transportation hub and many routes for the immigration of *Meconema* are available. Its small size, attraction to human habitations and propensity for hiding in small spaces suggests that it may be an efficient traveller in human cargo. Although it has spread only slowly between New York and Michigan in the 50 years since its initial North American introduction, it appeared frequently in Toronto in 2007 (Steve Marshall, pers. comm.). The species feeds on a wide variety of deciduous trees and shrubs, but it has never been considered a pest in its native Europe or in eastern North America and it is unlikely to become one in British Columbia.

We thank Murray Isman and Yasmin Akhtar (University of BC), David Holden (Canadian Food Inspection Agency, Burnaby, BC), Steve Halford (Simon Fraser University), Bruce Triggs (Vancouver) and Steve Marshall (University of Guelph) for specimens and information.

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# Symposium Abstracts: Alien Invertebrate Species in B.C.

## Entomological Society of British Columbia Annual General Meeting, Pacific Forestry Centre, Victoria, BC, Oct. 20, 2007

### Back from the brink: pests, packaging and pathways

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Trade in wood and wood products has long been acknowledged as a pathway for the transport of bark- and wood-boring arthropods. Some of the species inadvertently moved have been able to successfully establish and breed well beyond their native ranges. In the last two decades, multiple non-indigenous Coleoptera, including *Agrilus planipennis* (Buprestidae), *Tetropium fuscum* and *Anoplophora glabripennis* (Cerambycidae) and *Tomicus piniperda* (Curculionidae: Scolytinae) and one hymenopteran, *Sirex noctilio* (Siricidae) have established in Canada. The primary pathway for most recent introductions is wood packaging and dunnage associated with the commercial transport of commodities. Examples are given of recent interceptions in British Columbia on wood packaging from Europe and Asia. To address the global movement of pests with wood-packaging, the global community under the auspices of the International Plant Protection Convention recently adopted an international standard that requires treatment of wood-packaging used in international trade to prevent future introductions associated with this pathway. The development and implementation of this standard (ISPM-15) as well as the research supporting the treatments employed are reviewed. This standard should significantly reduce the global movement of non-indigenous species associated with wood packaging.

### From all over the map: museums and the public's role in documenting new or expanding populations

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Members of the public constantly approach museum entomologists when an unfamiliar insect or other arthropod attracts their attention. The popularity of digital photography and the Internet has significantly increased these contacts. Although dealing with public inquiries is time consuming, the Royal BC Museum (RBCM) encourages them as an important part of the museum's work.

Unusual records regularly arrive at the RBCM or are posted on Internet sites and may initiate or support museum research, collections development and public programming. Inquiries about *Polistes dominulus* (Christ) (Hymenoptera: Vespidae), *Noctua pronuba* (Linnaeus) (Lepidoptera: Noctuidae), *Meconema thalassinum* (De Geer) (Orthoptera: Tettigoniidae) and *Exaireta spinigera* (Wiedemann) (Diptera: Stratiomyidae) stimulated the gathering of specimens for our collection and data for publications documenting the arrival or spread of these species in BC.

Frequently we enlist the public to help record the changing distribution and status of species (including invasive ones), especially if they are easily identified. A good example is *Mantis religiosa*, originally introduced to BC in the 1930s, but whose range has rapidly expanded in the Interior since the late 1990s. Light-producing lampyrid beetles have been documented in BC mainly with the help of naturalists; it is still unclear if one widespread species of *Photinus* is introduced or native.

As for other arthropods, the RBCM receives dozens of inquiries annually about spiders. Most spiders reported around

homes, especially some species of *Tegenaria*, *Xysticus, Pholcus, Aranea* and *Dysdera*, are alien introductions. *Dysdera crocata*, one of these introduced spiders, is almost cosmopolitan and specializes in feeding on terrestrial crustaceans of the Order Isopoda. These isopods (*Porcellio scaber*, *Armadillidium vulgare*, *Oniscus asellus* and others), so abundant in our gardens, are also aliens.

**When forest management and climate change collide: the eruption and spread of mountain pine beetle populations in western North America**

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The mountain pine beetle is native to the pine forests of western North America where it normally exists at very low densities, infesting only weakened or damaged trees. Under conditions conducive to survival, populations may temporarily increase allowing beetles to infest healthy trees. On rare occasions, these increases are rapid and widespread, leading to landscape-level outbreaks and the mortality of large numbers of trees. Although there have been four outbreaks during the past century in western North America, the ongoing epidemic is unprecedented in its size and severity, causing the mortality of mature pine in over 13 million hectares in British Columbia alone. In recent years, the mountain pine beetle has successfully breached the northern Rocky Mountains. Small populations are now scattered over the Alberta Plateau where lodgepole pine hybridizes with jack pine forming a corridor of susceptible hosts extending to the boreal forest. Given predictions of increasingly suitable climate for MPB across Canada, invasion of the boreal forest is a plausible threat. This paper will examine the independent and interacting influences of forest management practices and climate change on the mountain pine beetle and its potential for invasion of the boreal forest.

**Challenges in mitigating the risk of introduction of invasive alien species**

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The Canadian Food Inspection Agency (CFIA) has a long history of preventing pest introductions resulting from international trade. However, with increasing trade and movement of plant products internationally, invasive alien species are an immediate and growing threat to Canada's environment and economy. CFIA has the legal authority under the Plant Protection Act to prevent importation and exportation, reduce spread, and control plant pests. The Plant Health Division of CFIA prevents new pest introductions through science-based regulation and enforcement. The programs branch is responsible for developing import and domestic policies for movement of plants or plant products to prevent unintentional pest introduction or distribution. These policies are developed based on pest risk analysis of a commodity or pest. The operations branch implements policies through inspection, surveillance, control and eradication activities. Some of the challenges and solutions in mitigating the risk of introduction of invasives species are addressed using examples.

**Non-indigenous inter-tidal species in British Columbia**

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British Columbia (BC) has a long history of introduction of intertidal non-indigenous species (NIS) beginning with oysters and their fellow travellers deliberately introduced for culture, but also including species that arrived unintentionally

through shipping and live trade vectors, as well as northward dispersal from the US. The list of intertidal NIS is dominated by molluscs (25 species), followed by crustaceans (8), algae and plants (5), polychaetes (4), anemones and flatworms (1 of each). Invasive species diversity is highest in the Strait of Georgia (34 species) and decreases in outside waters (west Vancouver Island 17) and with increasing latitude (Johnstone Strait 5, North Coast 4, Queen Charlotte Islands 2). Twenty-two of 42 intertidal NIS recorded from BC were Atlantic in origin, 19 were from the Northwest Pacific and one from the South Pacific. Likely vectors of introduction include aquaculture (deliberate and unintentional; 30), shipping (hull fouling, ballast water or recreational vessels; 13), trade in live plants or food (4) and dispersal north from southern introductions (3). Although aquaculture was the predominant historical introduction vector, ballast water and hull fouling are currently of greater concern. Some species' distributions are limited by temperature; their range within and beyond BC will increase if climatic projections are accurate. Although most discussion of the impacts of non indigenous species is justifiably focussed on the negative, the establishment of Pacific oysters and Manila clams have led to the development of economically valuable culture and fishery industries.

**Challenging invasive species**

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Three approaches to invasive species are (1) to do nothing, (2) to attempt eradication and (3) to initiate a biological control program. History has shown that sometimes introduced species go through an initial phase of outbreak and spread, but that populations eventually decline to lower and less problematic densities. An example of this is the European cranefly that was a serious pest of pastures and lawns in the 1960s but declined in the 1970s and 1980s in association with the occurrence of protozoan disease. Eradication of introduced species is difficult and nearly impossible after they have become well established. Goals of area-wide suppression and slowing the spread are more attainable; changes to terminology could sometimes help with public relations. Finally, recent biological control of weed programs such as that for purple loosestrife and diffuse knapweed show that if an effective agent can be found, the reduction of weed densities can be dramatic.

**Aliens at your fingertips**

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A meta-database on forest alien insects and diseases is being developed from historical Canadian Forest Service survey data. Mapping and query applications are included as well as links to source data and biological information. This project is described briefly and its capability illustrated with analysis of the invasion of Canada by gypsy moth and future potential range under climate change. It appears that gypsy moth reached the climatic limits of its range in eastern Canada by 1990 and the range then remained relatively static. This will change little with climate-change projections over the next 50 yrs. The potential climatically-suitable range in west of the Great Lakes, however, will increase markedly over that same time period and overlap with suitable host plant ranges. Thus, the susceptibility and risk of gypsy moth to western Canada in increasing.

**Vector control pest management**

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The Tri-Cities Vector Control Department is a municipal agency that serves the

cities of Port Coquitlam, Coquitlam and Port Moody. We provide pest management information, education, advice and intervention programs for residents and municipal staff so that public health and community liveability is improved and protected.

The primary goal of our Northeast Sector West Nile Virus Mosquito Management Program is to reduce the human risk of contracting WNV by limiting populations of mosquito species implicated in transmitting the virus and thereby reducing the size of the infected bird reservoir. Program activities include mapping catch basins and surface water locations, sampling for mosquito larvae, species identification of larval and adult samples, applying larvicides, pre- and post treatment sampling, adult trapping, determining larvicide efficacy and GPS/GIS data management. *Culex pipiens,* a species introduced to North America in the late 1800's, is of great concern because it is found in high numbers in catch basins and poses a high risk for transmitting WNV to birds and humans. *Culex tarsalis* is another important species in transmitting the virus, however, we do not find this species in high numbers in the local area.

**Ticks and tick-borne diseases in BC**

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In North America, there has been a substantial interest in ticks and tick-borne diseases, such as Lyme, Relapsing fever, Anaplamosis/Ehrlichiosis, Babesiosis, Q fever, Rocky Mountain spotted fever (RMSF), tick-borne viral encephalitis, etc. Recently, there has been dramatically increased awareness of the role of human animal interaction, which is generating emerging infectious disease risk among B.C. residents. A variety of factors, such as the growth of wildlife populations, outdoor workers, outdoor recreational activities and wildlife rehabilitation, allow people to come into close contact with wild animals and insects directly and indirectly, which favours the transmission of vector-borne diseases.

BCCDC has engaged in identifying high-risk areas for ticks and tick-borne disease in B.C. since 1991. The data obtained from field studies and clinical samples showed that both hard ticks and soft ticks are present in BC. Among hard ticks, *Ixodes pacificus* and *Darmacentor andersoni* are the two predominant species found in BC. *I. pacificus* is found mostly in Fraser Valley and Vancouver Island and *D. andersoni* is found mostly in the Interior of BC. Other hard ticks found in BC are *I. angustus*, I. *soricis*, *I. auritulus*, *D. variabilis, Rhipicephalus sanguineus,* etc.

One of the most common tick borne diseases in BC is Lyme disease. A total of 68 cases was reported in BC from 1997 to 2006 and almost half of them are travel related. The causal organism for Lyme disease, *Borrelia burgdorferi,* is found in *I. pacificus* and *I. angustus* ticks (in very low numbers). In BC, *B. burgdoreferi* positive ticks are mostly found in the lower mainland and the south-east part of Vancouver Island

The next common tick-borne disease in BC is Relapsing fever caused by a soft tick *Ornithodoros hermsi*. This tick species has been mostly reported from the Interior of BC. It is very difficult to collect this tick because of its nocturnal nature. The causal pathogen for relapsing fever is *Borrelia hermsii.* A total of 32 cases was reported in BC from 1993 to 2005; all them were either residents or travelled to the Interior of BC.

In BC we have also found sporadic seropositive cases of Anaplasmosis/Ehrlichiois, Q fever and RMSF. Detection of antibodies against new and re-emerging tick-borne diseases will provide evidence of the presence of emerging pathogens in British Columbia. The result of this investigation will also help to create public awareness about the possible presence of different tick-borne diseases.

**Exotic terrestrial gastropods in southwestern British Columbia**

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Over 20 species of introduced slugs and land snails are known from British Columbia, and many species are ubiquitous in disturbed areas. Since 1999, we have surveyed hundreds of sites for terrestrial gastropods on Vancouver Island, Haida Gwaii (Queen Charlotte Islands), and southern mainland BC. Forests with limited public access, including Gwaii Haanas National Park, had a very low incidence of introduced gastropods. In contrast, Garry oak ecosystems on Vancouver Island and sand dune habitats on Graham Island, Haida Gwaii, supported high densities of introduced species. These habitats are vulnerable to invasion by introduced gastropods due to their semi-open nature and high human use and/or their location near population centres. Adverse effects on native species and ecosystems could occur through competition, predation, disease, and damage to plants but remain to be investigated.

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