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Biology of rosy apple aphid, *Dysaphis plantaginea* Passerini, (Homoptera: Aphididae) on its summer hosts in eastern Washington

Stephen D. Cockfield[1,2], Elizabeth H. Beers[1], Keith S. Pike[3], & George Graf[3]

[1]Tree Fruit Research & Extension Center, Washington State University, 1100 N. Western Ave., Wenatchee, Washington 98801

[3]Irrigated Agriculture Research & Extension Center, Washington State University, 24106 N. Bunn Rd., Prosser, Washington 99850

Abstract. In surveys of apple-production areas east of the Cascade Mountains of Washington, broadleaf plantain, *Plantago major* Linnaeus (Plantaginaceae) was common throughout while narrowleaf plantain, *P. lanceolata* Linnaeus, was most common south of Orondo, Douglas County (47.7° latitude). Rosy apple aphid was the most common aphid on these two herbaceous plants; however, colonies were scarce, on only 19% of broadleaf and 11% of narrowleaf plantain samples. Colonies were also generally small, fewer than 25 individuals. Adult rosy apple aphid was collected on plantain from late May through October. Adults reached their highest levels in July before declining in August. Colonies increased again in September and October. Relatively few predators (mainly syrphids) and parasitoids (two species of *Aphidius*) were found on plantain. On apple, the most common predators were the mirid *Campylomma verbasci* (Meyer-Dür), earwigs, coccinellids, cecidomyiids and syrphids; the most common primary parasitoid was *Lysiphlebus testaceipes* (Cresson). Secondary or hyperparasitoids consistently outnumbered the primary parasitoids. Plantains growing outside of orchards but within 1 km of apple trees had the highest incidence of RAA infestation. The potential for management of RAA on its summer hosts is discussed.

Key Words. Rosy apple aphid, *Dysaphis plantaginea*, host plant, phenology, predator, parasitoid.

Introduction

Rosy apple aphid, *Dysaphis plantaginea* Passerini, is a destructive pest of apple, *Malus* × *domestica* (Borkhausen) (Rosaceae), in the apple-growing regions of Europe and North America (Beers et al. 1993, Hemptinne et al. 1994, Brown and Mathews 2007, Brown and Myers 2010). While conventional orchards suffer sporadic damage, organic orchards can be severely affected by this pest. Aphid feeding causes distorted growth of leaves and shoots, misshapen and stunted fruit, as well as deposition of honeydew on healthy fruit. Infestations are difficult to detect at bud break when hatch of the overwintered eggs occurs. Colonies, however, can increase rapidly in size and number after apple bloom (late April-late May) and can severely damage trees by mid-summer. As colonies develop, the aphids induce leaf curling, which partially shelters the aphids from pesticide applications and natural enemies (Brown and Mathews 2007), making them more difficult to control.

Rosy apple aphid spends 2–7 generations on apple before producing winged forms which migrate to the summer host, plantain, *Plantago* spp. (Plantaginaceae) (Baker and Turner 1916). The common name ''rosy'' indicates the color of the aphids on apple (pinkish purple); on the summer host, a yellow-green color morph is produced. Three to eight generations develop on the summer host before migrants return to

[2]Corresponding author: PO Box 1461, Malott, Washington 98829, E-mail: pest@bossig.com

apple in the fall. Blommers (1999) divided the annual cycle into five periods critical for management and control, including development on the summer host, and noted that research focused on one period, the outbreak phase on apple. The period spent on the summer host has been rarely studied *in situ*, and the most detailed work has been done in Europe (Bonnemaison 1959, Blommers et al. 2004). Orchard management practices, such as mowing, have been shown to influence growth of the summer host and thus the summer population of rosy apple aphid, although this tactic has shown little impact on subsequent populations on apple (Brown and Myers 2010).

Agricultural land in the arid areas of western North America supports three species of plantain (*Plantago*): the perennial narrowleaf (*P. lanceolata* Linnaeus) and broadleaf (*P. major* Linnaeus) plantain, and the annual wooly plantain (*P. patagonica* Jacquin) (Whitson et al. 2002). Narrowleaf and broadleaf plantain originated in Europe while wooly plantain is native to western North America. The emergence of rosy apple aphid as a pest of apple in the arid interior regions of the Pacific Northwest appeared to follow the spread of narrowleaf plantain from the Atlantic coastal regions (Matheson 1919). In eastern North America, although broadleaf plantain is also a summer host, it is less preferred (Ross 1915, Brittain 1916). However, in the interior of British Columbia, rosy apple aphid occurs on broadleaf plantain, the most common species in apple orchards (Brown and Myers 2010). Wooly plantain has not been reported as a summer host. To date, there are no studies on the host status of the three plantain species in eastern Washington State.

Biological control of rosy apple aphid on apple trees has been studied in eastern North America (Brown and Mathews 2007) and Europe (Wyss et al. 1999, Miñarro et al. 2005, Dip et al. 2010). Research has been directed at the most common natural enemies such as the coccinellids *Harmonia axyridis* Pallas (Brown and Mathews 2007) and *Adalia bipunctata* L., the syrphid *Episyrphus balteatus* (DeGeer), the midge *Aphidoletes aphidimyza* (Rondani), and the braconid *Ephedrus persicae* Froggatt (Wyss et al. 1999, Peusens et al. 2006). Although natural enemies can considerably impact rosy apple aphid populations in apple trees (Brown and Mathews 2007, Stewart-Jones et al. 2008, Wyss et al. 1999), biological control as a management tool in commercial orchards has been elusive. There is little recent information on the natural enemies of rosy apple aphid in Washington State (Carroll and Hoyt 1986, Pike et al. 1996), and almost none on the natural enemies attacking this species on plantain.

The objectives of the present study were to survey narrowleaf and broadleaf plantain in the irrigated arid regions of eastern Washington State and determine the relative abundance of rosy apple aphid on these species; to determine the seasonal fluctuations in populations on the summer hosts; and lastly, to identify common predators and parasitoids of rosy apple aphid on apple and in association with the summer hosts.

Methods and Materials

Survey of Aphids on Plantain. A survey was conducted by sampling narrowleaf and broadleaf plantain for summer generations of rosy apple aphid in 2005 and 2006. One or both species were sampled per site depending on presence in the orchard. We also checked each site for wooly plantain. A total of 101 sites were sampled in Yakima (42 sites), Walla-Walla (1), Skamamia (6), Okanogan (6), Klickitat (7), Kittitas (2), Grant (3), Franklin (1), Douglas (7), Chelan (9), and Benton counties

(13) in Washington State and Umatilla County (4) in Oregon. Half of the sites (50) were in apple orchards. Most others (31) were in orchards other than apple, or in irrigated crops (4) such as blueberry, *Vaccinium* spp. (Ericaceae) or grape, *Vitis vinifera* Linnaeus (Vitaceae), within apple-growing areas. A few (12) were in irrigated lawns of city parks. The latitude and elevation were recorded to determine the pattern of distribution of each species.

Samples were collected at each site from May through October to survey aphid species. Sites were sampled once (68 sites) or two or more times (33). Each plant sample consisted of cutting plants at ground level, with sufficient material taken to fill a 4-liter plastic bag. A bag held up to a dozen small plants or one large plant. Aphids were obtained by extraction in a Berlese funnel (2 h exposure, with temperature at the top of funnel held at 40° C) and preserved in 70% ethanol. Only adult aphids could be identified to species. A chi-square test was performed on the number of samples of each plant species positive or negative for the presence of rosy apple aphid. The seasonal abundance of rosy apple aphid was determined by plotting the number of identified aphids (adults) and the date of collection.

Distance from Apple Trees. Sample sites were divided into three categories to determine the likelihood of rosy apple aphid living at a distance from its woody host (apple). Sites were categorized as within an apple orchard, outside an apple orchard but within 1 km from apple trees, or greater than 1 km from apple trees. Samples were counted as either positive or negative for the presence of adult rosy apple aphid. A chi-square test was conducted to detect any changes in the probability of positive samples with distance from apple trees.

Natural Enemies. Predators were extracted from the fresh plant samples with a Berlese funnel as described above. A duplicate sample was collected upon each site visit in Okanogan, Chelan, and Douglas Counties and held for rearing parasitoids from parasitized aphids. Plantains were collected in the same manner as the aphid survey samples and transferred to a 6-liter plastic box with a ventilated lid held at room temperature for one month. Rosy apple aphids were cryptic and uncommon in these samples, often consisting of a single specimen. Therefore, it is not known which species of aphids were parasitized; paired samples used for aphid extraction indicated possible aphid hosts. Parasitoids were identified using various keys and descriptions (Smith 1944, Gibson et al. 1997, and Pike et al. 1997) for primary parasitoids (Aphelinidae and Braconidae); Dessart 1972, Takada 1973, Fergusson 1980, Andrews 1978, Gibson et al. 1997 for secondary parasitoids (Megaspilidae, Charipidae, Pteromalidae) and by comparison with verified specimens. Voucher specimens of aphids and parasitoids are deposited in collections at Washington State University, Prosser, Washington.

Natural enemies of rosy apple aphid were also collected from infested apple trees from May through August at several locations in Okanogan (3), Douglas (4), Chelan (4), and Grant (1) counties in 2005 and 2006. Samples from apple consisted of 4-liter plastic bags filled with infested foliage, up to 1000+ aphids per sample. Predators and parasitoids were collected directly from the samples, and additional adult parasitoids were reared from samples as described above.

Results

Distribution of Plantain Species. Plantains were found growing in irrigated land throughout the areas of apple production (Fig. 1). The elevation of the sample sites

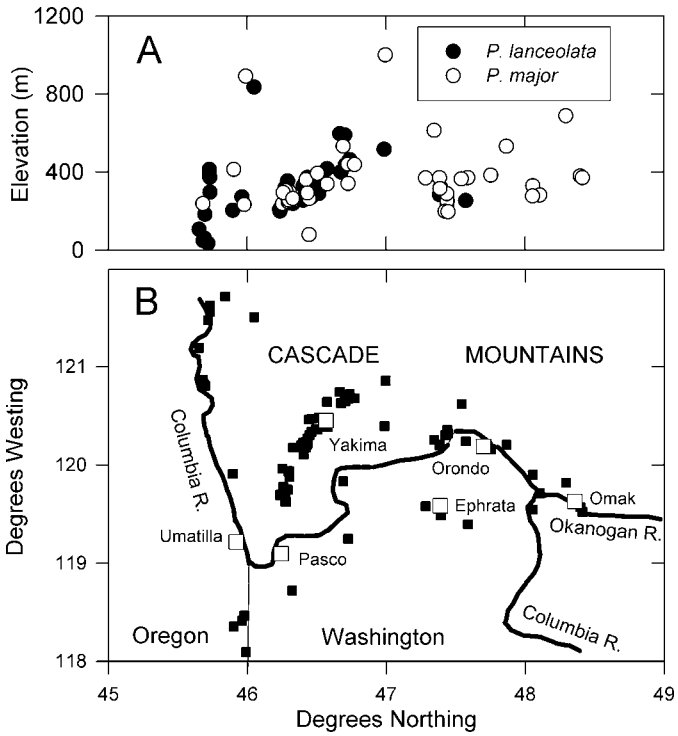

Figure 1. Plantains, *Plantago* spp., at 101 sample sites in apple-production regions of eastern Washington State and northern Oregon. A, elevation and species found at each site. B, location of the sites (filled squares), major towns (open squares), mountains, and rivers.

ranged from less than 100 m along the southwestern Columbia River Valley to greater than 800 m in the foothills of the Cascade Mountains. Broadleaf plantain was found throughout the Columbia and Okanogan River Valleys at a broad range of elevations. However, narrowleaf plantain was rarely found north of 47.7° latitude (near Orondo, Douglas County), although it occurred at a range of elevations south of Yakima (46.6).

Survey of Aphids on Plantain. Aphids in general were uncommon on plantains; only 24% of the samples were positive for aphids of any species. Rosy apple aphid was detected on 74 (19%) of the 387 samples of narrowleaf plantain. Six (2%) had a few specimens of *Aphis* spp., six (2%) had *Aulacorthum solani* (Kaltenbach), six (2%) had *Rhopalosiphum padi* (Linnaeus), five (1%) had *Pemphigine* sp., and three (1%) had *Myzus ascalonicus* Doncaster. Seven other species, most likely errant, were collected in single samples. The numbers of aphids in the samples was generally low (ca. 25 or fewer), but one sample contained an extremely high number of rosy apple aphid, estimated to be over 2000 individuals.

Of the 297 broadleaf plantain samples collected, 32 (11%) were positive for adult rosy apple aphid, or about half the percentage of positive samples found on narrowleaf plantain. The probability of encountering adult rosy apple aphid on the two species was not equal ($\chi^2 = 8.94$, df = 1, $P = 0.003$). Eight samples (3%) were infested with *Aphis* spp., six (2%) had *R. padi*, four (1%) had *Rhopalosiphum* spp., and three (1%) had *A. solani*. Six other aphid species were collected in single samples.

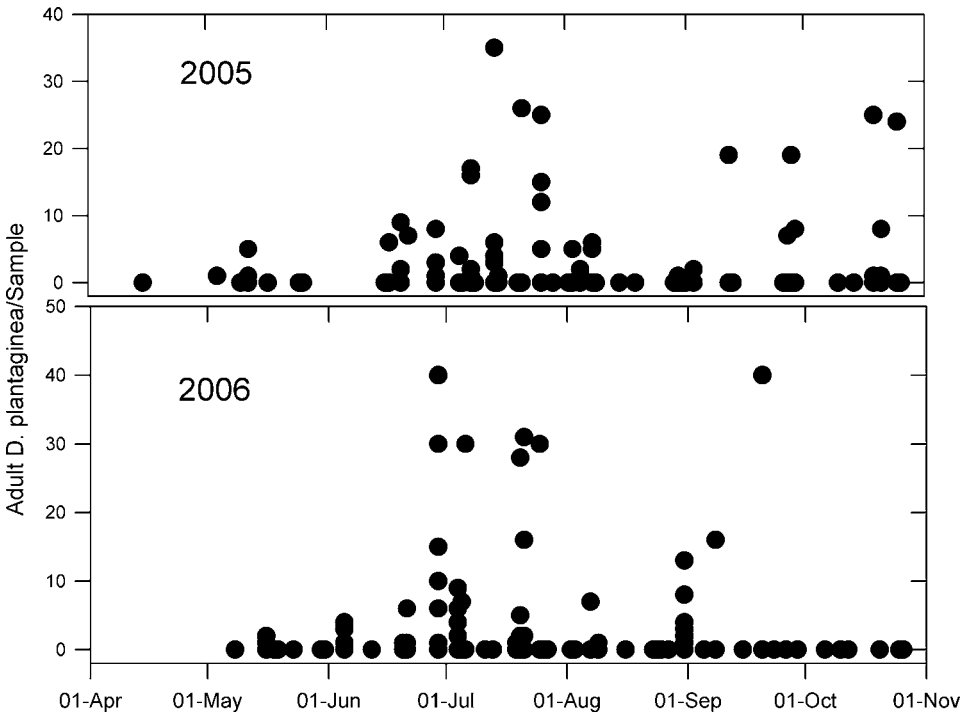

Figure 2. Number of adult rosy apple aphids extracted from a 4-liter volume of plantain vegetation collected from agricultural land on different dates in 2005 ($n = 201$) and 2006 ($n = 465$).

Seasonal Abundance. A total of 201 plantain samples were collected in 2005 and 465 in 2006. The sample with over 2000 rosy apple aphids, collected on 14 July 2005, was omitted from the graph. The pattern of seasonal abundance of rosy apple aphid on plantain was similar in both years (Fig. 2). Densities were low in May, when migration from the winter host was starting, peaking in late June and early July. Populations dipped in August, but rose again in September and October.

Distance from Apple Trees. Rosy apple aphid was found in 77 (13%) of 573 plantain samples (both species) taken in apple orchards. However, this species was found in 15 (31%) of 48 samples from sites outside orchards but within 1 km from apple trees and 11 (18%) of 62 samples from sites farther than 1 km. There was a significant difference in probability of infestation based on distance from the woody host ($\chi^2 = 11.35$, df = 2, $P = 0.0034$). Plantain found outside an apple orchard but within 1 km from apple trees had the highest probability of infestation.

Natural Enemies. Several groups of generalist predators were collected feeding on rosy apple aphid colonies on apple (Table 1). These included *Campylomma verbasci* (Meyer-Dür), which is both a direct pest and beneficial species on apple. Other immature Hemiptera were not identifiable past the ordinal level. Earwig nymphs were found quite commonly on apple, as were adult lady beetles; larvae of lady beetles were less common. Cecidomyiid larvae were also found frequently in the aphid colonies. The phytophagous cecidomyiid, *Dasineura mali* (Kieffer), does not yet occur in eastern Washington, thus all cecidomyiid larvae in the aphid colonies were presumed to be predatory. Syrphid larvae were the most commonly

Table 1. Predators and parasitoids collected from colonies of *Dysaphis plantaginea* on apple, May to August, and *Plantago* spp., June to October, 2005–2006

			Collected on apple						Collected on *Plantago*						
Order	Family	Species	May	June	July	August	Imm	Adl	June	July	August	September	October	Imm	Adl
Hemiptera	Miridae	*Campylomma verbasci* (Meyer-Dür)	X		X		5	9						—	—
		(unidentified species)					—	—			X			—	1
		(unidentified species)			X		2	—						—	—
	Anthocoridae	(unidentified species)					—	—				X		—	1
Dermaptera	Forficulidae	(unidentified species)	X				16	—						—	—
Neuroptera	Chrysopidae	(unidentified species)	X	X	X		3	1						—	—
Thysanoptera	—	(unidentified species)					—	—		X				—	1
Coleoptera	Coccinellidae	*Hippodamia convergens* Guerin	X		X	X	—	9						—	—
		Coccinella septempunctata (Linnaeus)	X	X			—	14						—	—
		Harmonia axyridis (Pallas)			X	X	—	2						—	—
		(unidentified species)	X	X	X	X	4	—			X			1	—
	Staphylinidae	(unidentified species)					—	—					X	—	1
Diptera	Syrphidae	(unidentified species)	X	X	X		20	—		X	X	X		8	—
	Cecidomyiidae	(unidentified species)		X			8	1			X	X		—	2
Hymenoptera	Braconidae	*Lysiphlebus testaceipes* (Cresson)	X	X	X		—	59		X	X			—	2
		Praon unicum Smith	X	X			—	5						—	—
		Aphidius matricariae Haliday					—	—		X				—	4
		Aphidius sp.					—	—		X	X	X	X	—	16
	Aphelinidae	*Aphelinus* sp.					—	—		X		X		—	2
	Charipidae	*Alloxysta* sp. (hyperparasitoid)	X	X	X		—	28		X				—	1
	Megaspilidae	*Dendrocerus* sp. (hyperparasitoid)	X	X	X		—	25						—	—
	Pteromalidae	(hyperparasitoid)		X	X		—	31	X	X	X			—	6

encountered predators. Many groups of predators and parasitoids were found on colonies in May, before the colonies became very large, including earwig nymphs, *C. verbasci*, the coccinellids *Hippodamia convergens* Guérin-Ménéville and *Coccinella septempunctata* (L.), and syrphid larvae. Rosy apple aphid colonies were less frequently encountered on apple in mid- to late July, and rarely encountered in early August as migration to the summer host was completed; thus, no natural enemies were collected from apple trees beyond early August.

Two primary parasitoid species, the braconids *Lysiphlebus testaceipes* (Cresson) and *Praon unicum* Smith, were collected on colonies from apple. *L. testaceipes* was by far the most common (Table 1). Hyperparasitoids from the families Charipidae, Megaspilidae and Pteromalidae collectively outnumbered the primary parasitoids. Parasitoids and hyperparasitoids were present in small colonies collected in May as well as in large colonies in June and July.

The composition of the natural enemy complex was different on plantain than on apple. Although rosy apple aphid was the most common aphid species on plantain, some predators and parasitoids could have been associated with other species. Predators were found only rarely on plantain, and few of the typical generalist predators (lady beetles, earwigs) found in apple colonies were present. It is likely that the low numbers of prey found on plantain were insufficient to attract these generalists. However, as on apple, syrphid larvae were the most common predators. *Aphidius* spp. (including *A. matricariae*), the most common parasitoids on plantain, were absent from apple. As on apple, *L. testaceipes* and some hyperparasitoids were encountered.

Discussion

Broadleaf plantain is the most widespread summer host of rosy apple aphid in the arid fruit-production regions of Washington State. In areas north of Orondo, Douglas County (47.7° latitude) along the Columbia and Okanogan River, it is the most common plantain species. It is also the most common in the Similkameen River Valley of British Columbia, Canada, just north of the U.S. border (49° latitude) (Brown and Myers 2010). In areas south of Orondo, both narrowleaf and broadleaf plantain occur. Broadleaf plantain is considered less preferred by rosy apple aphid than narrowleaf plantain (Ross 1915, Brittain 1916). However, Matheson (1919) believed that rosy apple aphid could fully adapt to broadleaf plantain where narrowleaf plantain is absent. We found broadleaf plantain less likely to be infested with rosy apple aphid in our samples, but it is known to host moderate colonies on leaves growing close to the ground (Brown and Myers 2010). We have also been able to rear summer-generation rosy apple aphid on the native annual wooly plantain in a greenhouse (unpublished data). This species does not survive after producing seed in midsummer and was not encountered during our survey of broadleaf and narrowleaf plantains in irrigated lands. Therefore, it probably can not support significant populations that return to apple trees in the fall.

Rosy apple aphids colonize plantain in spring and populations build until late June or early July, about the time when most migrants are leaving apple trees (Brittain 1916, Matheson 1919, Bonnemaison 1959). In contrast to the large colonies that develop on apple, densities on plantain were low and infrequent. The field population data from plantain were also in contrast to plantains grown in greenhouses, which supported large colonies that eventually debilitate the plants

(Matheson 1919, Blommers et al. 2004, unpublished data). The apparent population decline in early August was noteworthy because it preceded the typical period of fall migration, during which a second peak occurred (Bonnemaison 1959, Hemptinne et al. 2004). A decline may have been caused by the production of summer alates that spread to other plantain hosts (Matheson 1919), although we did not observe these forms in our samples. The most likely cause of the population decline is high temperatures in late summer, with daily maxima of 35–40°C. Other possibilities include pesticide applications, mowing, or a decline in the nutritional quality of plantain following flowering.

Midsummer may represent a vulnerable period in the aphid life cycle and additional stress on the population may aid in management in orchards. Summer mowing, an example of a cultural control method that can cause such stress, has not been evaluated in Washington State. Brown and Myers (2010) evaluated mowing in spring and found that it did not discourage rosy apple aphids on plantain. In addition to proper timing, mowing may also need to be coordinated over a broader scale than a single orchard, because Brown and Myers (2010) found no correlation between the population of plantain in individual orchards and the level of infestation in apple trees. We have found rosy apple aphids more commonly on plantain growing outside (but within 1 km) of orchards, and encountered some more than 1 km from the nearest woody host. This suggests they migrate great distances, and thus indicates the need for an area-wide approach.

The most common parasitoids collected from rosy apple aphid colonies on apple in this study, *L. testaceipes* and *P. unicum*, were the same as those found by Carroll and Hoyt (1986). Both species have a broad range of aphid hosts and are found in a variety of plant habitats. In apple orchards, they also develop on apple grain aphid, *Rhopalosiphum insertum* (Walker), and *R. padi* (Carroll and Hoyt 1986, Pike et al. 1996).

We found *L. testaceipes* also on plantain, but from unidentified aphid hosts. The plantain we studied supported two known hosts of this parasitoid, rosy apple aphid and *R. padi*. *Aphidius* spp. were also found on plantain, again from unknown hosts. This genus has not been previously linked to aphids on plantain but *Aphidius* has been recovered from *R. padi* (Pike et al. 1996). Based on our samples, rosy apple aphid is by far the most common aphid on plantain, suggesting that some *L. testaceipes* and *Aphidius* spp. adults likely came from mummies of rosy apple aphid.

The parasitoid community on apple differs from that in Europe, where *E. persicae* is the most common species (Peusens et al. 2006, Dip et al. 2010). *Ephedrus persicae*, although recognized in Washington State, is rare here and not associated with rosy apple aphid (Pike et al. 2000); its rarity suggests it may be a different biotype than in Europe and/or is poorly adapted to the central Washington apple-plantain areas studied where natural rainfall is relatively low. In eastern North America, an *Ephedrus* sp. has also been reported on rosy apple aphid (Brown and Mathews 2007). We encountered many hyperparasitoids in the colonies, a finding consistent with that of Carroll and Hoyt (1986). In general, parasitism of rosy apple aphid is not considered sufficient for population control based on reports from England (Stewart-Jones et al. 2008), Belgium (Bribosia et al. 2005), southern France (Dip et al. 2010) and eastern North America (Brown and Mathews 2007).

The predator taxa found on apple tree rosy apple aphid colonies and on plantain include many found in other growing regions (Brown and Mathews 2007, Dip et al.

2010, Stewart-Jones et al. 2008). Some of the predators, such as earwigs, may not have been important contributors to aphid mortality, but could have been using the curled leaves as a shelter. Brown and Mathews (2007) measured over 95% of colonies lost to predation and attributed the mortality to coccinellids such as *H. axyridis* and *Coccinella septempunctata*. These species are recently introduced in eastern Washington State. It is not known to what extent *C. septempunctata* could displace the native species *C. transversoguttata* Faldermann in apple orchards (Carroll and Hoyt 1984), as it has in other agricultural crops (Snyder et al. 2004). *Harmonia axyridis*, the most recent introduction, could also displace species, including *C. septempunctata*, and may even improve biological control of the introduced aphids such as rosy apple aphid (Brown and Miller 1998).

The most striking difference between the biology of rosy apple aphid on apple and plantain was the lack of a conspicuous outbreak phase on plantain. Rosy apple aphid populations on 4-liter samples of foliage rarely exceeded 25 adults. Possible causes of low populations include biological control, unfavorable climatic conditions summer mowing, and differences in the nutritional quality of host plants. Another possibility is that other plant species, as yet unidentified, could be serving as summer hosts. We sampled a variety of common orchard weed species (including members of the genera *Rumex, Lactuca, Taraxacum Amaranthus, Polygonum, Solanum, Trifoium, Medicago, Stallaria, Chenopodium, Malva, and Achillea*; data not shown), but there was no evidence that rosy apple aphid used these as a summer host. This, and the near-absence of mention in the literature of non-*Plantago* hosts indicates this is not a likely explanation, Further research is needed to determine the actual causes of low densities of rosy apple aphid on plantain, especially if these causes can be exploited for pest management during the summer generation.

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