Population development of the green peach aphid and beneficial insects in potato fields in British Columbia

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Abstract—Using 4 years of potato monitoring data containing insect counts, population development of the green peach aphid (*Myzus persicae* (Sulzer)) (Hemiptera: Aphididae), ladybird beetles (*Harmonia axyridis* (Pallas) and *Coccinella septempunctata* L.) (Coleoptera: Coccinellidae), and hymenopterous aphid parasitoids is described and used to consider revisions to current sampling plans. Depending on the year, field monitoring for aphids commenced between early May and early June. Aphid populations typically increased after 1 July and fluctuated until the end of the monitoring period (September). Winged *M. persicae* began to appear in sweep-net samples in late May, well in advance of the detection of aphids in visual samples. Aphid counts from field edge and interior sample sites were correlated and edge population levels were slightly and significantly greater than interior levels over the period 10 June – 14 July in 2 of the 4 years analyzed, suggesting a mild but inconsistent edge effect approaching mid season. Using an action threshold of 1 aphid/leaf to restrict the aphid-mediated spread of potato leaf roll virus (PLRV), the earliest whole-field action threshold was exceeded during 18–24 June in 1997. Using an action threshold of 10 aphids/leaf to address aphid-induced yield loss in fields not at risk to PLRV, the earliest whole-field action threshold was exceeded during 16–22 July in 1997. Therefore, monitoring for aphids can begin much later than the time it is currently commenced. A case is presented for monitoring only the edges of potato fields for an action threshold of 10 aphids/leaf, as interior samples rarely exceeded this action threshold when edge samples were below. This would further reduce the effort in sampling potato fields for aphids. Population development of ladybird beetle adults and larvae showed peaks occurring at different times during the growing season, depending on the year. Parasitism of aphids by hymenopterans occurred at low to moderate levels throughout the growing season (13% of total aphids in visual samples, on average), with peak parasitism appearing toward the end of the growing season in each year.

Résumé—À l'aide de données de surveillance de la pomme de terre sur 4 ans comprenant des dénombrements d'insectes, nous décrivons l'évolution de populations du puceron vert du pêcher, *Myzus persicae* (Sulzer) (Hemiptera : Aphididae), de coccinelles (*Harmonia axyridis* (Pallas) et *Coccinella septempunctata* L.) (Coleoptera: Coccinellidae) et d'hyménoptères parasitoïdes de pucerons et nous considérons des révisions possibles des plans actuels d'échantillonnage. Selon l'année, la surveillance des pucerons dans les champs commence entre le début de mai et le début de juin. Les populations de pucerons augmentent normalement après le premier juillet et fluctuent jusqu'à la fin de la période de surveillance (septembre). Les ailées de *M. persicae* commencent à apparaître dans les échantillons au filet fauchoir à la fin de mai, beaucoup plus tôt que leur détection dans les échantillons visuels. Il existe une corrélation entre les dénombrements de pucerons à la lisière et à l'intérieur des champs; les densités de population en lisière sont légèrement mais significativement plus élevées que les densités à l'intérieur des champs durant la période du 10 juin au 14 juillet dans deux des 4 années de l'étude, ce qui laisse croire à un léger, mais instable, effet de lisière vers la mi-saison. Avec un seuil d'action de 1 puceron/feuille pour enrayer la propagation du virus de l'enroulement de la feuille de la pomme de terre (PLRV) transmis par les pucerons, la période la plus hâtive à laquelle le seuil d'action est dépassé pour

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tout un champ est entre les 18–24 juin (en 1997). Avec un seuil d'action de 10 pucerons/feuille pour contrer les pertes causées par les pucerons dans les champs non menacés par le PLRV, le seuil d'action est dépassé pour la première fois dans un champ entier entre les 16–22 juillet (en 1997). On peut donc commencer la surveillance des pucerons beaucoup plus tard qu'on le fait actuellement. Nous examinons la possibilité de surveiller seulement les lisières des champs de pommes de terre avec un seuil d'action de 10 pucerons/feuille, puisque les échantillons de l'intérieur des champs dépassent rarement le seuil d'action lorsque les échantillons de lisière sont inférieurs au seuil. Cela réduirait encore plus l'effort nécessaire pour échantillonner les pucerons dans les champs de pommes de terre. L'évolution des populations d'adultes et de larves de coccinelles accuse des sommets qui se produisent à différents moments de la saison de croissance selon les années. Il y a un parasitisme des pucerons par les hyménoptères de niveau faible à modéré (en moyenne 13 % de tous les pucerons dans les échantillons visuels) avec un maximum vers la fin de la saison de croissance chaque année.

[Traduit par la Rédaction]

Introduction

The green peach aphid, *Myzus persicae* (Sulzer, 1776) (Hemiptera: Aphididae), is a primary pest of potatoes worldwide, causing both direct damage through feeding and indirect damage through the spread of viruses (*e.g.*, potato leaf roll virus, PLRV) (van Emden *et al.* 1969). In the lower Fraser Valley of British Columbia (BC), *M. persicae* was once considered the main pest of potatoes, and production guides from the 1970s suggest that growers apply insecticidal sprays every 7–10 days from mid-July through to harvest each year (Anonymous 1978). Growers following the suggested spray routines for aphids and applying additional early-season sprays for the tuber flea beetle, *Epitrix tuberis* Gentner, 1944 (Coleoptera: Chrysomelidae), in May and June (Finlayson 1950; Vernon *et al.* 1990) could apply as many as 10 insecticidal sprays per season (R.S. Vernon, personal observation).

Two events occurred in BC that together dramatically reduced the threat, or perceived threat, of *M. persicae* as a key pest of potato. The first was the establishment of the certified seed potato growing region in the Pemberton Valley of BC in the 1950s, which provided the majority of Fraser Valley growers with seed that was virtually free of all aphid-borne viruses, including PLRV. The second event was the development and implementation of an integrated pest management (IPM) program for potato insect pests that was introduced to the lower Fraser Valley in 1979. This program, now provided by private IPM consultants to the majority of Fraser Valley potato growers, is based on weekly surveys of key insect pests (aphids, tuber flea beetles, lepidopterans) and beneficials (ladybird beetles and aphid parasitoids) in individual potato fields from crop emergence to harvest (Cusson *et al.* 1990; Vernon *et al.* 1990; Kabaluk and Vernon 2000).

Aphid monitoring consists of a combination of direct plant inspections and sweep-net samples. For efficiency, the sampling path for aphids follows that for the tuber flea beetle, which must be sampled along field edges as well as in the field interior because of strong edge effects (Cusson *et al.* 1990). The mean number of *M. persicae* (unparasitized alates and apterae) counted on bottom leaves is used to determine the need for selective (*e.g.*, pirimicarb) or broader spectrum (*e.g.*, methamidophos) sprays. A two-tiered action spray threshold is used, where well-rotated fields (low in potato volunteers) planted with certified seed (*i.e.*, highest likelihood of being virus-free) have a more tolerant threshold (10 aphids/leaf) than fields with poor rotation and (or) uncertified seed (1 aphid/leaf). The lower spray threshold reflects inherent field conditions (poorly rotated fields, volunteers, uncertified seed) favourable for the current-season spread of PLRV by aphids. The two-tiered action threshold developed for the lower Fraser Valley has reduced spraying for aphids in over 2000 fields sampled since 1979 (usually less than 1 aphid spray/field·season) without incurring economic aphid-related damage (*i.e.*, yield losses through feeding, current-season PLRV spread, and net necrosis).

Green peach aphid populations are generally observed to increase to damaging levels in the lower Fraser Valley around mid-July, and the formation of alates greatly increases the risk of PLRV spread in fields already at risk. The potato IPM program begins monitoring for *M. persicae* early, with visual inspections of lower leaves conducted when plants are about 30 cm tall. This coincides with the time that scouts switch from conducting visual plant inspections for tuber flea beetles to using sweep nets (Kabaluk and Vernon 2000), commonly in May and June. Pest managers believe that sampling for aphids during this period might unnecessarily increase the time and cost required to survey fields, as it appears that aphid populations are often low or absent altogether. There has never been a formal analysis of the aphid monitoring data, so we observe and describe the population trends of *M. persicae* in lower Fraser Valley potato fields over four growing seasons and use these observations to determine whether it is reasonable to delay aphid sampling by identifying a generic time when aphid levels approach, but never exceed, the action thresholds. We look at these trends in both field edges and interiors to consider whether sampling for aphids could be limited to field edges to further save sampling time and costs. Finally, we describe the seasonal occurrence of two beneficial insects, ladybird beetles and hymenopterous parasitoids.

Materials and methods

Pest and beneficial insect data from potato fields in the lower Fraser Valley were provided by E.S. Cropconsult Ltd., Vancouver, BC. Monitored fields ranged in size from 0.4 ha to 30 ha, and data were provided for 1992 (45 fields), 1995 (101 fields), 1996 (113 fields), and 1997 (91 fields). An analysis of the number of sample sites per field visit for 1992, 1995, and 1997 showed that, on average, the pest management company counted insects at 42 ± 19 sites per field; for 54% of the field visits, the number of sampled sites fell in the range of 31–50 (Kabaluk *et al.* 2006). Monitoring began as early as 6 May (1995) and ended as late as 23 September (1995 and 1996). Two standardized methods were used to enumerate aphids and beneficial insects. Visual samples of the three terminal leaflets from leaves on the bottom third of the plant for alate, apterous, and parasitized *M. persicae* were taken when plants were 30 cm high, coinciding with the onset of sweep-net sampling (parasitized aphids were not recorded in 1992). Leaves were selected and removed from two adjacent plants at locations where tuber flea beetle (see Kabaluk and Vernon 2000) and aphid sweep-net samples were taken. Sweep-net sampling entailed taking 10 consecutive 180° sweeps using a 40 cm diameter sweep net and vigorously brushing the tops of potato plants over four adjacent rows. The numbers of alate *M. persicae* and ladybird beetle adults and larvae (predominantly *Harmonia axyridis* (Pallas, 1773) and *Coccinella septempunctata* L., 1758 (Coleoptera: Coccinellidae); D. Henderson, unpublished data) in the sweep net were recorded (ladybird counts were not recorded in 1992). The number of paces between sample sites within a field ranged from 25 to 50. Normally two scouts would sample each field; both would begin sampling at the same corner and move away from each other at 90°, sampling field edges (edge samples) to the far corners. They then turned 90° and sampled a second field edge until they met at the corner diagonal to their starting point. On their return, the field interior (interior samples) would be sampled, with scouts arbitrarily selecting transect rows on opposite sides of the field centre, between the centre and the edge of the field (Kabaluk and Vernon 2000). Interior samples were most often taken near the centre, but never within 20 m of the field edges.

The mean number of insects per site per field (for field edge, field interior, and whole field) was calculated for each sampling date by summing the number of insects from the edge, interior, or whole field and dividing by the corresponding number of leaves for visual samples or sample sites for sweep-net samples. Where required, the values from all monitored fields were used in the calculation of weekly aphid means. The monitoring data were compiled or analyzed using SAS (SAS Institute Inc. 1989) or Excel (Microsoft Corp.). Because day-degrees are an important determinant of aphid population development (Campbell *et al.* 1974), we calculated summer and winter day-degrees in 1992, 1995, 1996, and 1997 from temperature data, using the University of California (Davis) Web site http://www.ipm.ucdavis.edu/WEATHER/ddretrieve.html, to determine whether the day-degrees represented longer term averages. Lower and upper development thresholds for *M. persicae* of 4 °C and 30 °C (Liu and Meng 1999) were used in the calculations. The source of weather data was Environment Canada's Richmond Nature Park weather station, located within 15 km of the monitored potato fields. To adjust for the two leap years (1992 and 1996) and accurately compare weekly insect counts during identical time

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periods among years, dates were converted to Julian days and equal Julian day ranges were selected for each year. The Julian days, ranges, corresponding dates, and week numbers used in the graphs are shown in Table 1. Line graphs were constructed using Excel and lines were smoothed for clarity of presentation.

Results

The range of summer day-degrees (May–August, inclusive) for the years used in this study clustered closely around the 10-year average for 1992–2001, while the winter day-degrees (January–April, inclusive) varied more (Table 2). 1992 had the warmest winter and the second warmest summer, which likely contributed significantly to high *M. persicae* population levels through high survival of the overwintering generation and rapid population development throughout the summer (Campbell *et al.* 1974; Liu and Meng 1999). Therefore, 1992 represented a year when *M. persicae* levels could be expected to exceed average levels (and they did), according to the day-degree model. 1997 had the second coldest winter and relatively low summer aphid population levels. Other winter and summer day-degrees were within 5% of the 10-year average and could be considered representative of those of typical years.

Population development of *M. persicae*

The mean numbers of *M. persicae* (alates + apterae per leaf per potato field) counted in visual samples over four growing seasons are shown in Figure 1. Aphid populations were generally low during the first 8 weeks of monitoring (between 6 May and 1 July). This was true even if fields had been planted earlier (as in 1995 and 1997). Thereafter, the variations in populations were unique in each year. The highest overall population levels occurred in 1992, with peaks observed on weeks 14 (5–11 August) and 18 (2–8 September). In contrast, population levels were lowest in 1996, with a gradual increase in levels occurring over the last 4 weeks of sampling. Aphid population levels were moderate and fairly consistent over time in 1995 but were more variable over time in 1997.

The mean number of alate *M. persicae* occurring in sweep-net samples varied considerably over the four growing seasons (Fig. 2). Alates were recorded as early as week 3 (21–27 May) in 1995 and, on average, the highest numbers were observed throughout the middle and latter periods of the growing season (weeks 10–19 (8 July to 16 September)). Alate levels from sweep-net samples did not consistently correlate with mean total aphids from visual samples (1992, $r = 0.94$; 1995, $r = 0.83$; 1996, $r = 0.22$; 1997, $r = 0.38$), which may be due to differences in the sources of alates collected with the two sampling methods. Alates found in visual samples on lower leaves could represent new arrivals or late products of maturing leaf colonies, whereas alates found in sweep-net samples (taken from the upper canopy) could reflect immigration from other fields (possibly into relatively uninfested fields) and (or) late-season alate production from within the field itself.

Levels of *M. persicae* exceeding action thresholds

Mean aphid counts in edge and interior samples were quite similar on most sampling weeks (Fig. 3, Table 3). Although differences in mean aphid levels between edge and interior samples were apparent during some sampling weeks in each year, there was no overall bias toward edge or interior samples in any year. When data were grouped by range of weeks, edge means were significantly greater than interior means during weeks 6–10 (10 June – 15 July) in both 1996 and 1997, suggesting the possibility of an occasional edge effect during colonization in early-mid season.

The earliest occurrence of *M. persicae* exceeding 1 aphid/leaf in edge, interior, or whole-field leaf inspections was on week 7 (18–24 June) in 1997 (Table 4, Fig. 4), when only 2 of 29 fields were above threshold; the mean number of aphids in those fields was 1.1 and 2.6 aphids/leaf, respectively. In the other years, aphids first exceeded the 1 aphid/leaf threshold on week 9 (1–7 July) in 1992, week 8 (25 June – 1 July) in 1995, and week 9 (1–7 July) in 1996 (Table 4).

The earliest occurrence of *M. persicae* exceeding 10 aphids/leaf in edge, interior, or whole-field leaf inspections was on week 10 (9–15 July) in 1997 (Table 4, Fig. 4), when only 1 of 64 fields sampled was above threshold, and only in interior samples in that field. In the other years, aphids first exceeded the 10 aphids/leaf threshold on week 13 (29 July – 4 August) in 1992, week 11 (16–22 July) in

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Table 1. Standardized weeks based on Julian day ranges (*n* is number of potato fields used in most analyses).

Week	Julian day range	1992		1995		1996		1997	
		Dates	*n*	Dates	*n*	Dates	*n*	Dates	*n*
Week 1	127–133	6 May – 12 May	0	7 May – 13 May	2	6 May – 12 May	0	7 May – 13 May	0
Week 2	134–140	13 May – 19 May	0	14 May – 20 May	6	13 May – 19 May	0	14 May – 20 May	0
Week 3	141–147	20 May – 26 May	0	21 May – 27 May	10	20 May – 26 May	0	21 May – 27 May	2
Week 4	148–154	27 May – 2 June	0	28 May – 3 June	23	27 May – 2 June	0	28 May – 3 June	9
Week 5	155–161	3 June – 9 June	4	4 June – 10 June	44	3 June – 9 June	0	4 June – 10 June	19
Week 6	162–168	10 June – 16 June	7	11 June – 17 June	67	10 June – 16 June	1	11 June – 17 June	17
Week 7	169–175	17 June – 23 June	15	18 June – 24 June	86	17 June – 23 June	2	18 June – 24 June	29
Week 8	176–182	24 June – 30 June	20	25 June – 1 July	94	24 June – 30 June	7	25 June – 1 July	47
Week 9	183–189	1 July – 7 July	39	2 July – 8 July	100	1 July – 7 July	41	2 July – 8 July	58
Week 10	190–196	8 July – 14 July	29	9 July – 15 July	89	8 July – 14 July	78	9 July – 15 July	64
Week 11	197–203	15 July – 21 July	29	16 July – 22 July	101	15 July – 21 July	100	16 July – 22 July	73
Week 12	204–210	22 July – 28 July	30	23 July – 29 July	88	22 July – 28 July	113	23 July – 29 July	89
Week 13	211–217	29 July – 4 Aug.	22	30 July – 5 Aug.	88	29 July – 4 Aug.	96	30 July – 5 Aug.	60
Week 14	218–224	5 Aug. – 11 Aug.	22	6 Aug. – 12 Aug.	73	5 Aug. – 11 Aug.	104	6 Aug. – 12 Aug.	91
Week 15	225–231	12 Aug. – 18 Aug.	45	13 Aug. – 19 Aug.	73	12 Aug. – 18 Aug.	103	13 Aug. – 19 Aug.	81
Week 16	232–238	19 Aug. – 25 Aug.	21	20 Aug. – 26 Aug.	73	19 Aug. – 25 Aug.	85	20 Aug. – 26 Aug.	50
Week 17	239–245	26 Aug. – 1 Sept.	13	27 Aug. – 2 Sept.	48	26 Aug. – 1 Sept.	89	27 Aug. – 2 Sept.	37
Week 18	246–252	2 Sept. – 8 Sept.	11	3 Sept. – 9 Sept.	24	2 Sept. – 8 Sept.	65	3 Sept. – 9 Sept.	31
Week 19	253–259	9 Sept. – 15 Sept.	0	10 Sept. – 16 Sept.	9	9 Sept. – 15 Sept.	30	10 Sept. – 16 Sept.	8
Week 20	260–266	16 Sept. – 22 Sept.	0	17 Sept. – 23 Sept.	1	16 Sept. – 22 Sept.	6	17 Sept. – 23 Sept.	0

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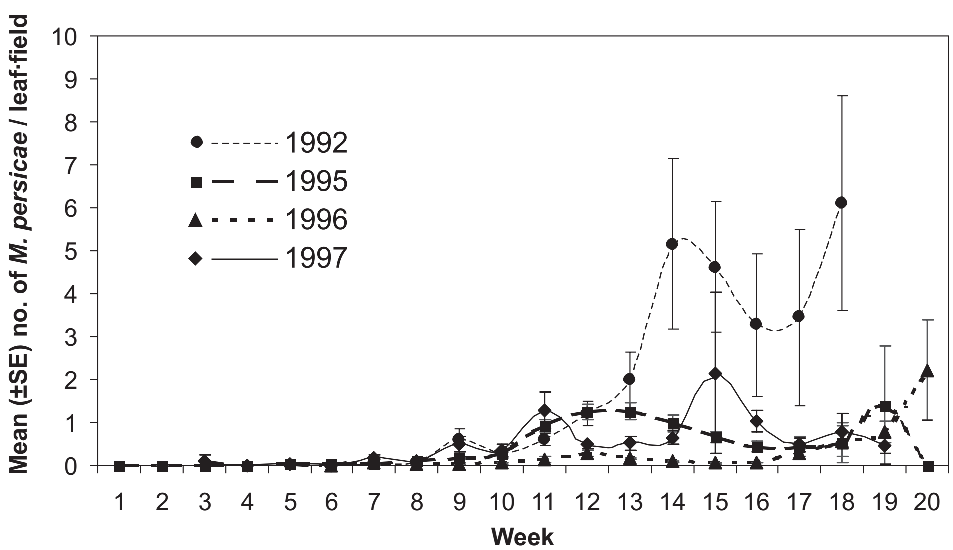
Table 2. Summer and winter day-degrees (DD) in a 10-year period, including the years used in the current study (in bold italics).

Year	DD (May–August), summer	DD, % of average, summer	Summer ranking	DD (January–April), winter	DD, % of average, winter	Winter ranking
1992	***1625***	***105***	***2***	***557***	***126***	***10*** (warmest)
1993	1529	99	6	394	89	3
1994	1559	101	5	483	109	8
1995	***1565***	***102***	***4***	***450***	***102***	***6***
1996	***1506***	***98***	***7***	***451***	***102***	***7***
1997	***1618***	***105***	***3***	***392***	***89***	***2***
1998	1676	109	1 (warmest)	499	113	9
1999	1420	92	10 (coolest)	401	91	4
2000	1480	96	8	409	93	5
2001	1435	93	9	375	85	1 (coolest)
Average	1541			441		

Fig. 1. Population development of *Myzus persicae* in potato fields over the growing season (May–September) in 4 years.



1995, and week 18 (2–8 September) in 1996 (Table 4).

The absence of a clear and consistent bias in aphid levels between field edges and interiors lead to consideration of abandoning interior samples altogether. Using a continuum of thresholds, the plotted sampling data showed that as the action threshold increased, edge samples more consistently represented interior samples in terms of classifying the values as being above or below the action threshold (Fig. 5), providing a case for abandoning interior samples for high thresholds.

Ladybird beetles

Mean numbers of ladybird beetle adults and larvae from sweep-net samples taken in 1995–1997 are shown in Figure 6. Adults occurred in samples early in the growing season, but larvae did not appear until after week 10. Ives (1981) showed that adult coccinellids increase their consumption of aphids with increasing temperature. After their maintenance requirements are satisfied, females convert excess food to egg production. The temporal abundance of larval coccinellids (Fig. 6) coincided well with the temporal abundance of *M. persicae* (Fig. 1)

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Fig. 2. Population development of alate *Myzus persicae* in potato fields over the growing season (May–September) in 4 years.

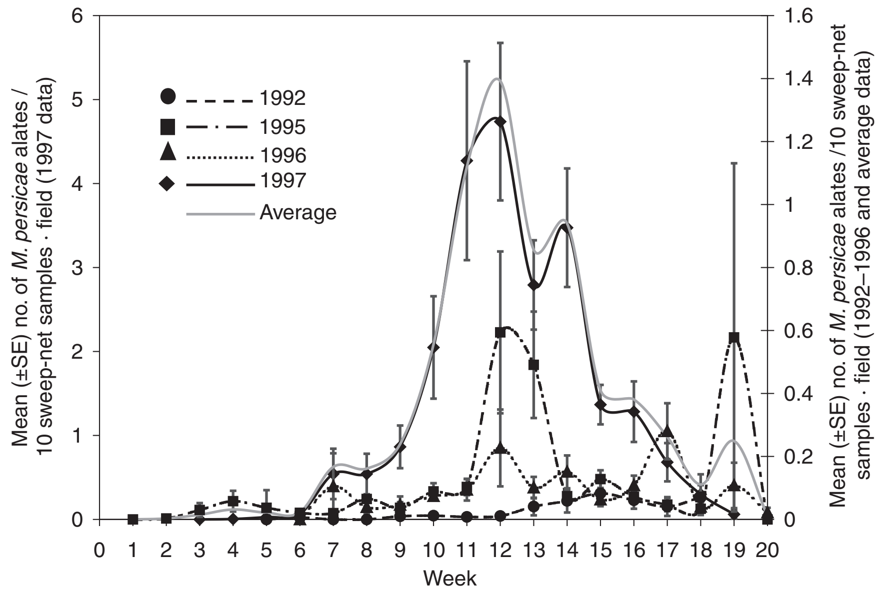
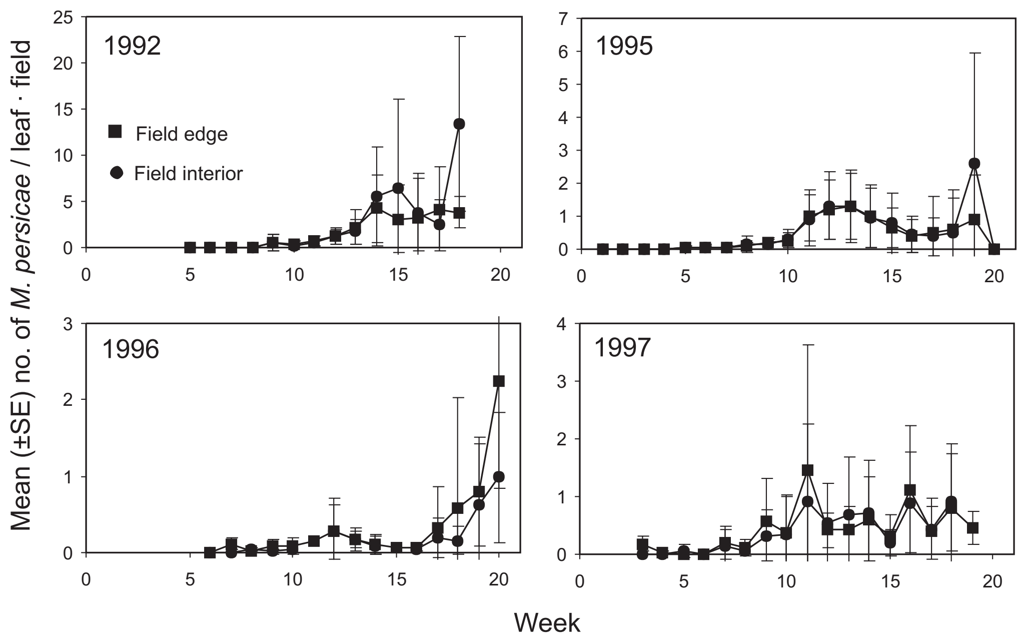


Fig. 3. Population development of *Myzus persicae* in potato field edges and interior regions over the growing season (May–September) in 4 years.



from 1995 to 1997. In 1996, when populations of *M. persicae* were quite low throughout the growing season, populations of larval coccinellids were also low despite a fairly consistent number of adults in the fields. In 1995, when aphid populations were highest between weeks 11 and 16, populations of both larval and adult coccinellids increased between weeks 11 and 13, and larval populations then declined to low levels by week 18. An increase in adults between weeks 14 and 16 in 1995 was likely due to the larvae reaching the adult stage during that time. In 1997, aphid populations peaked on weeks 11 and 15, while larval coccinellid levels

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Table 3. Differences and correlations between mean levels of *Myzus persicae* sampled from edge and interior rows in potato fields over four growing seasons.

		Mean no. of *M. persicae*/sample					
Year	Weeks	Edge rows	Interior rows	Difference in *M. persicae* levels (edge – interior)	*P* (*t* test)	Correlation (*r*) between *M. persicae* from edge and interior samples	df
1992	1–5	—	—	—	—	—	0
	6–10	0.35	0.29	+0.06	0.124	0.89	105
	11–15	2.23	3.14	–0.91	0.158	0.42	141
	16–20	3.84	5.62	–1.78	0.134	0.54	38
1995	1–5	0.03	0.03	0.00	0.497	0.80	77
	6–10	0.13	0.15	–0.02	0.128	0.60	413
	11–15	1.04	1.08	–0.03	0.334	0.62	405
	16–20	0.54	0.51	+0.03	0.392	0.81	137
1996	1–5	—	—	—	—	—	0
	6–10	0.08	0.04	+0.04	0.002*	0.61	117
	11–15	0.16	0.15	+0.01	0.151	0.89	490
	16–20	0.25	0.20	+0.05	0.122	0.58	251
1997	1–5	0.02	0.03	–0.01	0.403	0.11	28
	6–10	0.30	0.23	+0.06	0.035*	0.88	192
	11–15	0.69	1.48	–0.79	0.165	0.59	386
	16–20	0.72	0.72	+0.00	0.491	0.52	73

*Significant difference (α = 0.05) in mean number of *M. persicae*/sample between edge and interior rows.

Table 4. First occurrence during the growing season of *M. persicae* exceeding action-threshold levels in potato fields.

	First week that aphids exceeded threshold				
	1992	1995	1996	1997	Average
			Threshold = 1 aphid/leaf		
Field edges	9 (5/39)	8 (1/94)	9 (1/38)	7 (2/25)	8.25
Field interior	9 (3/37)	8 (4/92)	11 (1/95)	7 (1/23)	8.75
Whole field	9 (4/39)	8 (4/94)	10 (1/78)	7 (2/29)	8.5
			Threshold = 10 aphids/leaf		
Field edges	13 (1/22)	12 (1/87)	18 (1/64)	11 (3/73)	13.5
Field interior	14 (2/22)	11 (1/98)	*	10 (1/61)	13.75
Whole field	13 (1/22)	12 (1/88)	18 (1/65)	11 (2/73)	13.5

Note: Numbers in parentheses are number of fields exceeding threshold per number of fields sampled.

*Threshold was never exceeded and a default value of week 20 was used in the calculation of the average.

Fig. 4. Proportion of potato fields exceeding *Myzus persicae* action thresholds of 10 aphids/leaf and 1 aphid/leaf using edge, interior, and whole-field data over the growing season (May–September) in 4 years.

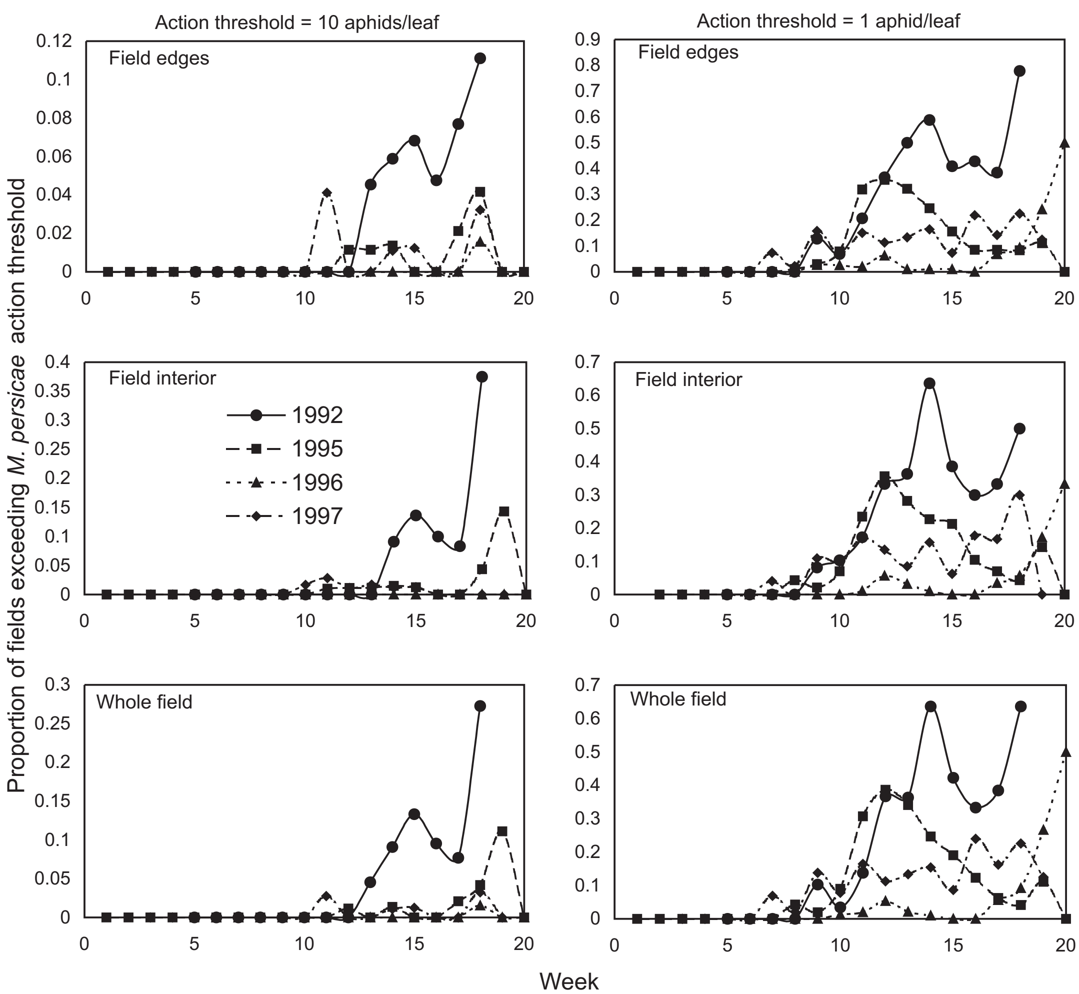

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Fig. 5. Percentage of interior samples exceeding the action threshold for *Myzus persicae* in potato fields when edge samples are below the threshold.

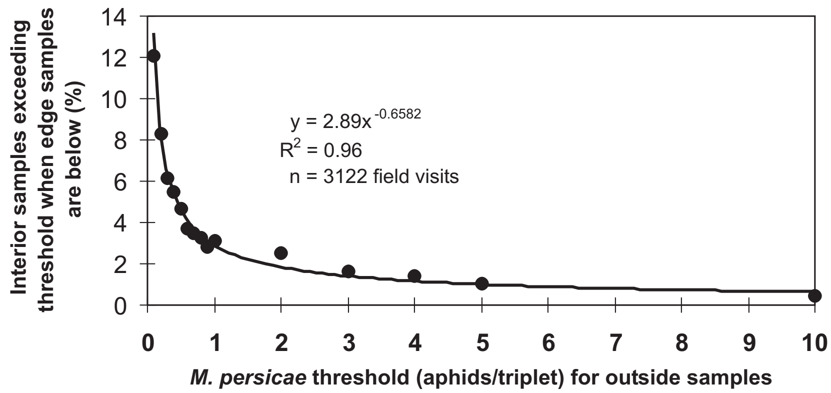


Fig. 6. Population development of ladybird beetles (*Harmonia axyridis* and *Coccinella septempunctata*) in potato fields over the growing season (May–September) in 3 years.

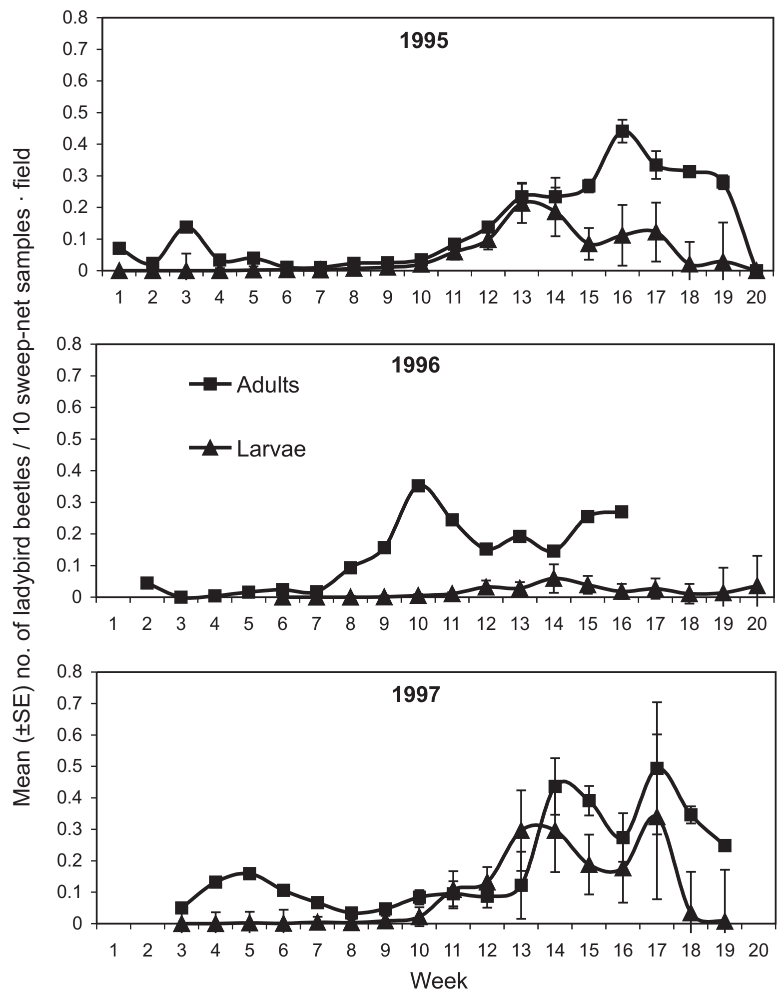
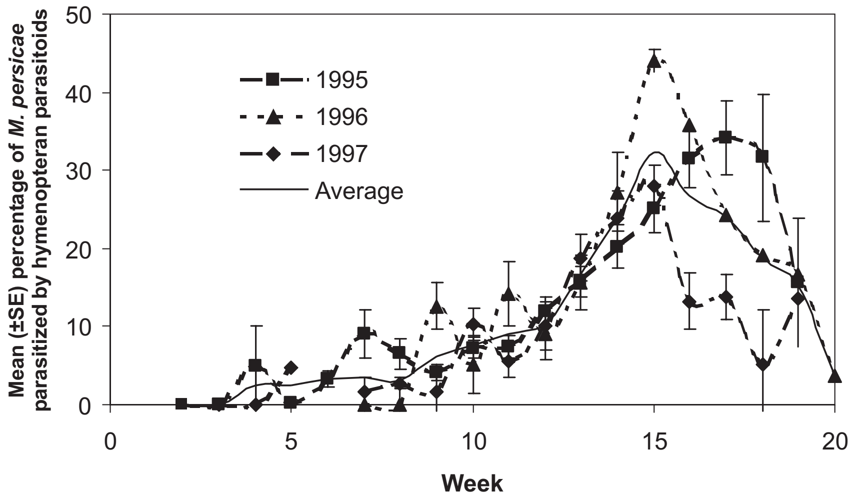


Fig. 7. Percentage of *Myzus persicae* parasitized by hymenopterans in potato fields over the growing season (May–September) in 4 years.



peaked on weeks 13 and 17. The variation in adult coccinellid levels among potato fields (as shown by the standard error bars in Fig. 6) was surprisingly small in all years, suggesting that the general area-wide population distribution of these insects is relatively uniform. The higher standard errors associated with counts of larvae among potato fields in all years suggest greater variability in larval populations among fields and (or) greater variability in sweep-net sampling efficacy. Greater variability in larval counts among fields is expected, since oviposition by ladybird beetles is linked to the relative abundance of aphid populations (Gutierrez *et al.* 1981), which in turn can be quite variable among fields (Fig. 1). In our data, ladybird beetle levels were not correlated with *M. persicae* levels, but an edge effect was observed, with a greater number of adult beetles occurring in samples from field edges (Σ(edge sample means – interior sample means) = 20.87 (1995), 31.25 (1996), and 33.68 (1997)). No edge effect was observed for larvae.

Aphid parasitism

The percentage of *M. persicae* parasitized by hymenopterans gradually and consistently rose to peaks in 1995 (34% during week 17 (27 August – 2 September)), 1996 (44% during week 15 (12–18 August)), and 1997 (28% during week 15 (13–19 August)) (Fig. 7). The first incidence of parasitism was recorded on week 4 in 1995 (28 May – 3 June), with parasitized aphids being recorded up to the last week of monitoring in each year. The degree of aphid parasitism was unexpectedly high in some years, with an average of 44% of *M. persicae* being parasitized in 92 fields during week 15 in 1996 (12–18 August).

Discussion

Fields monitored by professional pest managers in the lower Fraser Valley are rarely sprayed for insect pests (D. Henderson, unpublished data). When required, spraying for tuber flea beetles generally takes place during early crop establishment in late May or early June (plants less than 30 cm high) and usually only along one or more field edges (Kabaluk and Vernon 2000). These targeted early-season sprays are usually effective at controlling tuber flea beetles for the rest of the season and occur at a time when the crop has not yet been colonized by other pests or beneficial insects. Sprays for other pests such as aphids and various defoliating lepidopterans are applied thereafter only if and when these pests exceed threshold levels, usually later in the growing season. We do not believe that occasional edge sprays for aphids affected their spatial distribution, for two reasons: (1) aphid levels were generally similar in field edges and interiors in all 4 years, and when differences occurred, they were not similar from year to year; and (2) 10 m × 10 m grid sampling for green peach aphids in four organic (no aphid sprays) potato fields on 2 days (mid season and late season) revealed no bias toward either edge or interior samples (J.T. Kabaluk, unpublished data). In the case of lepidopterans,

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field sprays are rarely applied, and populations of early instars are effectively controlled with a single spray of *Bacillus thuringiensis*. Therefore, most potato fields are unsprayed or only partially sprayed (*i.e.*, edge sprays) during the period of initial establishment and development of aphid populations. Therefore, the onset and subsequent magnitude of aphid populations reflected in our data were likely influenced more by natural abiotic (*e.g.*, weather) and biotic (*e.g.*, predation and parasitism) factors than by the activities of growers (*e.g.*, insecticide spraying).

In our data set, an action threshold of 1 aphid/leaf was not exceeded until week 7 (18–24 June; 1997 data), and then only in 2 of 29 fields. This suggests that monitoring higher risk fields for aphids to restrict the spread of PLRV could conservatively begin much later than currently practiced. In delaying monitoring, the risk of not detecting aphids would increase; however, according to the data, this risk appears minimal up to week 7. If aphid sampling is delayed in the lower Fraser Valley (*e.g.*, to week 6 or 7), it would be prudent for pest managers to take into account aberrant years when aphid populations might advance earlier than observed in this study. This could occur, for example, in years with weather conditions favourable for *M. persicae* development or in years when PLRV-infected volunteer potatoes in high-risk fields are more numerous and further advanced because of mild winters.

The action threshold of 10 aphids/leaf was not reached until week 10 (9–15 July in 1997), and then only in 1 of 61 fields sampled, suggesting that monitoring could be conservatively delayed in low-risk fields until week 9, or early July. Consideration might be given to sampling a reduced number of leaves earlier than week 9 in years with higher than normal spring and summer temperatures. Dramatic increases in alate populations in sweep-net samples in advance of the onset of visual leaf sampling in atypical years could be used as a signal to begin leaf sampling earlier.

In general, we take a risk management perspective and state that the longer the delay in sampling, the greater the chance of leaving an above-threshold field undetected. We do not recommend delaying sampling into periods when above-threshold fields were encountered in this study, and we recognize that the sooner sampling begins, the lesser is the chance that a potato field will exceed the aphid threshold for more than a week. Delaying the starting dates for the sampling of aphids in high- and low-risk fields as suggested would reduce overall sampling effort while retaining an extremely low risk of crop damage due to PLRV spread. This approach would require that consultants determine the PLRV risk for each field (*i.e.*, assess the fields' rotational history, presence of volunteers, and seed source) by consulting monitoring records, talking to farmers, and performing pre-plant scouting at the beginning of the growing season. In the event that PLRV risk cannot be determined for certain fields, those fields could be assumed to be at high risk and sampled accordingly.

While pest managers in the lower Fraser Valley are using thresholds of 10 aphids/leaf and 1 aphid/leaf for aphid feeding loss and PLRV transmission, respectively, other researchers have found much lower thresholds to be valid in other regions of North America (*e.g.*, Byrne and Bishop 1979; Mowry 2001). The lower Fraser Valley thresholds have been established through more than 20 years of experience of pest managers and farmers, but there would be value in their verification through experimentation. The use of different thresholds would obviously affect when to commence sampling for *M. persicae*.

The edge versus interior field sampling results also provide a basis by which pest managers can better interpret monitoring data and make spray decisions. Aphid populations in general did not display an edge bias over the 4 years of study, although on some occasions an action threshold was exceeded in edge samples but not in field interiors (1996) or vice versa (1995). Nor was an *M. persicae* edge bias observed through observation of kriged surfaces and *t* tests after five potato fields ranging from 4 ha to 24 ha were grid-sampled for *M. persicae* every 10 m × 10 m in July and August 2001. Furthermore, semivariograms reached their sill at a 10 m lag, suggesting a random distribution when sampling at and beyond the lag distance during this time period (J.T. Kabaluk, unpublished data). Our findings justify combining the heterogeneous aphid sampling data from edge and interior samples and permit making recommendations based on the mean level of aphids throughout the entire field, although there could occasionally be significantly greater levels of aphids in field edges approaching mid season. To reduce sampling effort for aphids, pest managers may consider sampling

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the edges when the action threshold of 10 aphids/leaf is in effect. In doing so, it is recommended that a minimum of 25 sample sites be visited to ensure a high enough probability of correctly classifying the aphid population above or below threshold (Kabaluk *et al.* 2006). Sampling only the edges when a threshold of 1 aphid/leaf is in effect would be inappropriate because of the higher probability of the interior exceeding the threshold and the consequence of the error, *i.e.*, rapid spread of PLRV.

On average, 13% of visually observed aphids had been parasitized, with a much larger percentage generally occurring in August. In 1996, for example, the percentage of parasitized aphids reached 44% in mid-August, while aphid populations remained below the 10 aphid/leaf threshold throughout most of the growing season. However, the specific contribution of parasitoids to aphid mortality requires a more detailed study taking into account the phenology of both the host and the parasitoid (Van Driesche *et al.* 1991). The data also showed that coccinellid beetles were common in all fields monitored between 1995 and 1997, and levels of coccinellid larvae generally increased with increases in aphid populations. Although the actual effects of coccinellid predation on aphid populations were not measured, it is known that the presence and abundance of adults and larvae are directly related to levels of aphid predation (Ives 1981). The edge bias observed with coccinellid beetles (not larvae) likely reflects the fact that beetles actively immigrate to, reside in, and emigrate from fields at rates depending on temperature and field prey density (Baumgaertner *et al.* 1981). Counts of aphid predators and parasitized aphids are an established part of the IPM programme for potatoes in BC, and conservation of beneficial insects is the most important factor for managing aphids in potatoes. For this reason, full-field sprays for other pests are avoided. When assessing the need for control of aphids, the presence of beneficial insects is a key factor, although exact predator/parasitoid:aphid ratios have not been established. When pest managers consider predators and parasitoids to be present in sufficient numbers to reduce aphids to subthreshold levels, an insecticide application is not recommended. This occurs mainly during mid-late season. However, if aphid levels have been rising quickly despite the presence of predators and parasitoids, an insecticide application will be recommended. If other pests are below threshold, a product with minimal impact on the beneficial insects, even though it is not the most efficacious for the aphids, will be recommended. If aphid numbers are reduced even partially by such a product, predators and parasitoids are usually able to gain control over the remaining population and no further insecticides will be required (D. Henderson, personal communication). These results apply to the lower Fraser Valley of British Columbia, *i.e.*, a potato growing region with a unique climate, pest–predator complex, and pest sampling protocol. We believe that pest management companies in other potato growing regions might save time and costs by undertaking a similar analysis of pests and predators.

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References

Anonymous. 1978. Vegetable production guide for commercial growers. Province of British Columbia, Ministry of Agriculture and Fisheries, Victoria, British Columbia.

Baumgaertner, J.U., Frazer, B.D., Gilbert, N., Gill, B., Gutierrez, A.P., Ives, P.M., Nealis, V., Raworth, D.A., and Summers, C.G. 1981. Coccinellids (Coleoptera) and aphids (Homoptera): the overall relationship. The Canadian Entomologist, **113**: 975–977.

Byrne, D.N., and Bishop, G.W. 1979. Relationship of green peach aphid numbers to spread of potato leaf roll virus in southern Idaho. Journal of Economic Entomology, **72**: 809–811.

Campbell, A., Frazer, B.D., Gilbert, N., Gutierrez, A.P., and Mackauer, M. 1974. Temperature requirements of some aphids and their parasites. The Journal of Applied Ecology, **11**(2): 431–438.

Cusson, M., Vernon, R.S., and Roitberg, B.D. 1990. A sequential sampling plan for adult tuber flea beetles (*Epitrix tuberis* Gentner): dealing with “edge effects”. The Canadian Entomologist, **122**: 537–546.

Finlayson, D.G. 1950. The effects of certain insecticides on the biotic potential of *Epitrix tuberis* Gentner (Coleoptera: Chrysomelidae), on potato in British Columbia. M.Sc. thesis, University of British Columbia, Vancouver, British Columbia.

Gutierrez, A.P., Baumgaertner, J.U., and Hagen, K.S. 1981. A conceptual model of predator growth, development, and reproduction in the ladybird beetle, *Hippodamia convergens* (Coleoptera: Coccinellidae). The Canadian Entomologist, **113**: 21–33.

Ives, P.M. 1981. Feeding and egg production of two species of coccinellids in the laboratory. The Canadian Entomologist, **113**: 999–1005.

Kabaluk, J.T., and Vernon, R.S. 2000. Effect of crop rotation on populations of *Epitrix tuberis* (Coleoptera: Chrysomelidae) in potato. Journal of Economic Entomology, **93**(2): 315–322.

Kabaluk, J.T., Binns, M.R., and Vernon, R.S. 2006. Operating characteristics of full count and binomial sampling plans for green peach aphid (Hemiptera: Aphididae) in potato. Journal of Economic Entomology, **99**(3): 987–992.

Liu, S.-s., and Meng, X.-d. 1999. Modelling development time of *Myzus persicae* (Hemiptera: Aphididae) at constant and natural temperatures. Bulletin of Entomological Research, **89**(1): 53–63.

Mowry, T.M. 2001. Green peach aphid (Homoptera: Aphididae) action thresholds for controlling the spread of potato leaf roll virus in Idaho. Journal of Economic Entomology, **94**(6): 1332–1339.

SAS Institute Inc. 1989. SAS user's guide. SAS Institute Inc., Cary, North Carolina.

Van Driesche, R.G., Bellows, T.S., Jr., Elkinton, J.S., Gould, J.R., and Ferro, D.N. 1991. The meaning of percentage parasitism revisited: solutions to the problem of accurately estimating total losses from parasitism. Environmental Entomology, **20**(1): 1–7.

van Emden, H.F., Eastop, V.F., Hughes, R.D., and Way, M.J. 1969. The ecology of *Myzus persicae.* Annual Review of Entomology, **14**: 197–270.

Vernon, R.S., MacKenzie, J.R., and Bartel, D.L. 1990. Monitoring tuber flea beetle: *Epitrix tuberis* Gentner (Coleoptera: Chrysomelidae) on potato: parameters affecting the accuracy of visual sampling. The Canadian Entomologist, **122**: 525–535.