



## AN ABSTRACT OF THE THESIS OF

Matthew L. Klein for the degree of Master of Science in Crop Science presented on November 4, 2016.

Title: Seasonal Occurrence and Abundance of Insect Pests and Natural Enemies in the Columbia Basin

Abstract approved:

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Silvia I. Rondon

Potato (*Solanum tuberosum* L.) is the fourth largest food crop in the world following rice (*Oryza sativa* L.), wheat (*Triticum* spp.), and maize (*Zea mays* subs. *mays*). Potatoes arrived in the United States in the early 1600s and over the following centuries, the crop was subsequently cultivated across the country and world. The highest productive potato region in North America is in the Columbia Basin of Eastern Oregon and Washington. The Columbia Basin (OR and WA) and Idaho account for close to 60% of United States production of both fresh and processed potatoes. This thesis, entitled “Seasonal occurrence and abundance of insect pests and natural enemies in the Columbia Basin” is divided in three chapters, the first being an overarching introduction that ties together the common themes of the following research based chapters. In the second chapter we document a field experiment we conducted on the potato psyllid, *Bactericera cockerelli* Sulc (Hemiptera: Trioziidae), a key potato pest that has the ability to vector the plant pathogenic bacterium *Candidatus Liberibacter solanacearum* (Lso). In this study, we also collected data on insect predators (natural enemies), specifically the taxa: *Geocoris* spp., *Nabis* spp., and *Orius* spp. The literature indicates that the potato psyllid has a close affinity for solanaceous crops and weeds and our hypothesis was that the presence of potato psyllids in crops such as maize or wheat was due to the presence of volunteer potatoes. In

the region, potatoes are in rotation with both maize and wheat. Thus, the objectives of this study were to (1) evaluate the role of potato, maize, and wheat, as well as maize planted with volunteer potatoes and wheat planted with volunteer potatoes on the population dynamics of potato psyllids and natural enemies and (2) compare two sampling techniques: sticky traps and inverted leaf blowers, for monitoring potato psyllids adults and natural enemies. Data collected in this study suggested that potato psyllids have an affinity for potato crops even in the presence of a diverse crop landscape and also that differences may occur between trapping methods. Potato psyllids were rarely found in maize and wheat and were more likely to be found in plots containing volunteer potatoes. Little association was found between crop treatment and natural enemy presence. However, there were differences in potato psyllid and natural enemy captures when using both collection methods and they were present in all crop treatments tested. These results have implications for potato psyllid management as well as utilizing natural enemies for suppression of key pests.

The third chapter was designed to provide regional information on aphids (Hemiptera: Aphididae) in the Columbia Basin (Umatilla and Morrow Counties) and Eastern Oregon (Union and Baker Counties). The potato aphid (PA) *Macrosiphum euphorbiae* Thomas, the green peach aphid (GPA) *Myzus persicae* Sulzer, and various other aphids (OA) were the focus of this study. The objectives were to (1) determine spatial, yearly, and weekly trends in GPA, PA, and OA populations in the Columbia Basin and (2) determine abiotic environmental variables that could potentially have a significant impact on population levels in the following growing season. In our analysis, we observed that aphid populations were distributed heterogeneously both spatially and temporally with large differences in aphid numbers between species, year, and trapping locations. We also found that aphids were influenced by previous season dew point, previous season temperature, and to a lesser extent by elevation. This data supports the conclusion that aphid populations respond in a complex fashion to environmental variables and that managing aphid populations requires the collection of ample data. These results indicate the difficulty in managing aphid pests.

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Seasonal Occurrence and Abundance of Insect Pests and Natural Enemies in the  
Columbia Basin

by  
Matthew L. Klein

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Matthew L. Klein, Author

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## CONTRIBUTION OF AUTHORS

Matthew L. Klein and Dr. Silvia I. Rondon designed the field experiments presented in Chapter 2. Matthew L. Klein collected the data presented in Chapter 2 and conducted statistical and data analysis with some assistance from Tim Skalland of the Oregon State University Statistics Department. Dr. Rondon, Darrin Walenta and Qamar Zeb organized and compiled the data analyzed in Chapter 3, Drs. Alexzandra Murphy and Andy Jensen provided aphid identification, and Matthew L. Klein conducted statistical and data analysis with some assistance from Alyssa Pedersen of the Oregon State University Statistics Department. Dr. Rondon provided support with writing and editing. This work was supported partially by the Oregon Potato Commission and by the Irrigated Agricultural Entomology Research Program at the Oregon State University Hermiston Agricultural Research and Extension Center. Matthew L. Klein was supported by the NIFA Grant 2012-04150. Aphid species data and identification was supported by funding from a NIFA-AFRI Fellowship and the Northwestern Potato Consortium.



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**Seasonal Occurrence and Abundance of Insect Pests and Natural Enemies in the  
Columbia Basin**

**General Introduction**

Matthew L. Klein

### **History and current metrics of potato (*Solanum tuberosum* L.) production**

Potatoes (*Solanum tuberosum* L.) are one of the most widely cultivated food crops in the world with a total harvestable biomass of 385,000,000 metric tons and a total value exceeding \$48 billion USD (Camire et al. 2009, Birch et al. 2012, Obidiegwu et al. 2015, FAOSTAT 2016). Potato cultivation originated in Peru roughly 8,000 years ago, and was first introduced into Western Europe during the late 16<sup>th</sup> century (Brown 1993, Camire et al. 2009, Birch et al. 2012, FAOSTAT 2016). Potatoes are relatively adaptable to diverse growing conditions and a wide range of climates; they can be grown in temperate, tropical, and subtropical regions (Hawkes 1990, Rondon 2012). Currently, potatoes are grown in more than 160 countries on every continent except Antarctica (Birch et al. 2012, Obidiegwu et al. 2015, FAOSTAT 2016). The United States (US) is fifth in potato production with 18.3 million metric tons (FAOSTAT 2016). The Columbia Basin which includes eastern Oregon, Washington, and Idaho is a hub for potato production producing close to 60% of the US fresh and processing market (NASS 2016).

### **Potato production in the Columbia Basin**

Potato production is a mainstay of the agricultural industry in both Oregon and Washington where yields in the lower and upper Columbia Basin can range from 51,000 kg ha<sup>-1</sup> (22.75 US tons/acre) to as high as 79,000 kg ha<sup>-1</sup> (35.24 US tons/acre) (NASS 2016). Columbia Basin yields are rarely matched by any other growing region in the world (Lang et al. 1999, Dung et al. 2015). In 2015, approximately 16,187 ha (40,000 ac) of potatoes were planted in Oregon with a value of roughly \$176,000,000 USD which accounts for 6% of total US production (USDA 2014, Beeles 2016, NASS 2016). Most of Oregon's potato production occurs in Umatilla and Morrow counties where potatoes are used for high quality processing and value-added products such as French fries and chips (Hopkins et al. 2007, Dung et al. 2015). However, northeastern Oregon (Union and Baker counties) also contributes significantly (approx. \$20.4 million USD in 2015) to the agricultural economy via the production of certified seed and conventional/organic fresh pack potatoes (Union) and high quality processing potatoes (Baker) (NASS 2016). The potatoes produced in Oregon are of high value, selling for approximately \$109 USD per metric ton, but the high

yields are possible due to intense pest management, fertilizer, and irrigation inputs. However, Hopkins et al. (2007) found that growers were able to generate greater profits when input costs were factored in to the calculation of net crop value. These conservative measures have come to be known as ‘best management practices’ a.k.a BMPs (i.e. minimizing insecticide, fertilizer, and fossil fuel use). The BMPs have generated more profits than that of comparable operations where potatoes were solely managed for maximum yield (Hopkins et al. 2007). Of the myriad management costs associated with potato production, insecticide applications to control insect pests rank as one of the top inputs and are typically made many times throughout a growing season to achieve adequate yields (Knutson et al. 1967, Chen and Halterman 2011).

### **Other important crops in the Columbia Basin**

The Columbia Basin encompasses 668,000 km<sup>2</sup> of land area in the US Pacific Northwest. A subset of this region, known as the Lower Columbia Basin, includes parts of Morrow, and Umatilla counties and is host to a major area for the production of potatoes, maize, onions (*Allium cepa* L.), melons (*Cucurbitaceae* spp.), and a number of other vegetables, herbs, and seeds crops (FAOSTAT 2016). Crops are produced for both fresh market and processing. In addition to potatoes, barley (*Hordeum vulgare* L.), wheat (*Triticum* spp.), and several species of grasses are key components of the Columbia Basin agriculture (Machado et al. 2006). Maize is another mainstay of agriculture in the state with roughly 80,000 acres planted across the state in 2015, between 6,400 and 7,700 acres are planted in Morrow and Umatilla Counties annually (USDA 2008, Beeles 2016).

### **Insect pests**

Insects, have been studied by entomologists for decades and only a fraction cause problems for crops and humans (Rondon 2012). Many pests infest at specific stage of crop growth (e.g., seed maize maggot damage is more severe at planting), while others are permanent residents before planting, at planting and during crop development (e.g., wireworms). A number of pests are important to various crops in the Columbia Basin. For instance, aphids, vector diseases such as leaf roll virus, PVY in potatoes; or barley yellow dwarf virus in

wheat or maize dwarf virus in maize. Other pests are important in specific regions such as beet leafhoppers *Circulifer tenellus* Baker in Northeastern Oregon and Southeastern Washington, or corn rootworms, *Diabrotica* spp. in the Midwest (Gray et al. 2009).

### **Spatial analysis of insects and its relationship to pest management**

To mitigate insect damage, commercial potato growers, and especially those in seed potato production, have relied on insect monitoring as part of integrated pest management (IPM) programs (SI Rondon personal communication). However, the ability of aphids and psyllids to transmit diseases into potatoes, as well as the overall perceived risk from insect infestation, typically leaves growers with no option other than insecticide control (DiFonzo et al. 2015). Because one of the theoretical foundations of IPM is that control measures are taken only when and where a pest population reaches or exceeds an economic threshold, the geographic distribution of the target pest population must be determined in order to estimate economic levels of the pest and for growers to take action when such levels are reached (Castrignanò et al. 2012).

Determination of a pest geographic distribution requires quantification of the pest's population dynamics in time and space. The data for this quantification comes from extensive sampling networks deployed throughout growing regions. In order to inform pest management practitioners on the economic impact of insects surveyed in a trapping network, these data must be complemented with pest damage estimates determined through adequate sampling and record keeping (Castrignano et al. 2012). Consequently, efficient site-specific management tools can only be implemented if spatial distribution and temporal dynamics are sufficiently determined and modeled (Park and Tollefson 2005). A challenge in large scale settings is that geographic distributions are difficult to predict because the quantification of developmental rate, within-species behavior, resource use patterns, and environmental variability are difficult to correlate with pest presence (Nestel et al. 2004, Fievet et al. 2007). Additionally, the monitoring efforts necessary to produce adequate spatial data can be limited by geography, and available resources such as time, well-trained personnel, cost of traps, fuel, and other services (Cullen et al. 2000). Despite the costs of collecting the data necessary for precision management, in some production



regions such as the US Midwest, significant insect monitoring efforts have led to the successful development of economic thresholds to reduce both insecticide use and disease incidence in crops such as maize and soybeans (Radcliffe et al. 1991, Flanders et al. 1992, DiFonzo et al. 1995).

Developmental thresholds have not been estimated for some key pests in the Columbia Basin, but some of the data needed to do so have been collected (Thomas et al. 1997). For instance, the timing and number of aphids collected was found to correlate significantly with heat unit accumulation, and also to vary significantly but predictably throughout a growing season (Thomas et al. 1997). This and other data on insect population dynamics suggests that the movement of insects depends on abiotic variables, which has been documented in many insect species (Stinner et al. 1983). Additionally, it was noted that the fragmented distribution of resources influences the interactions between population dynamics and biotic/abiotic factors (Fleischer et al. 1997). At the same time, biotic and abiotic factors play a large role in determining when and where insect populations increase or decrease (Mazzi and Dorn 2012). Therefore, a quantitative analysis of how key pests of potato vary spatially will likely provide valuable information that can be applied towards developing precise management tactics.

The two projects within this thesis represent two different approaches to collecting spatial data necessary for managing potato pests. The first project (Chapter 2) focuses on small-scale within-field sampling methods and the effect of diverse cropping systems on the population dynamics and distributions of potato psyllid *Bactericera cockerelli* Sulc (Hemiptera: Triozidae) and its natural enemies (i.e. *Orius spp.*, *Geocoris spp.*, and *Nabis spp.*). The second project (Chapter 3) focuses on regional scale population dynamics and spatial-temporal dynamics of the green peach aphid (GPA) *Myzus persicae* Sulzer (Hemiptera: Aphididae), potato aphid (PA) *Macrosiphum euphorbiae* Thomas (Hemiptera: Aphididae), and over 30 species of other aphids (OA).

### **Potato psyllid: a new emerging pest**

Since the early 2000s, the potato psyllid has been considered one of the most serious pests of solanaceous crops in North America (Munyanenza 2012). The potato psyllid was first

documented in the early 1900s in the US from an insect sample taken from a potato plant in Colorado by T. D. Cockerell (Abdullah 2008). In 1909, the insect was described and named *Trioza cockerelli* by Sulc, and then allotted to the genus *Paratrioza* by Crawford (Crawford 1911). Recently, the insect has been moved to the genus *Bactericera*. The first record of the potato psyllid associated with plant damage was made in 1915 in both San Francisco and Sacramento California, where the insect was found to cause feeding damage on False Jerusalem Cherry (*Solanum capsicastrum* L.) (Compere 1915). Large scale damage to potatoes due to feeding, known as ‘psyllid yellows’, was recorded as early as 1927 in the US in Utah and several other Rocky Mountain states (Richards 1973). Psyllid yellows is typically attributed to psyllid feeding behavior where the psyllid releases a toxin which causes a reaction by the plant. Psyllid yellows has been associated with the largest potato crop losses in the US during widespread outbreaks in 1927 and 1938 (Linford 1928, Jensen 1939, Morris 1939). Growers began specifically managing the potato psyllid with insecticides following the 1938 outbreak (Pletsch 1947, Wallis 1955, Cranshaw 1994). Organophosphates and carbamates were primarily used to control the potato psyllid and were successful at suppressing psyllid numbers from the 1940s up until the mid-1990s.

### **Potato psyllids and Zebra Chip disease: an overview of insect-pathogen interactions**

In 1994, ‘Zebra Chip disease’ (ZC) was identified in Mexico (Munyaneza et al. 2007b). The disease was determined to be caused by a bacterium *Candidatus Liberibacter psyllarous* (Lso) (*Ca. L. solanacearum*) and transmitted through direct feeding by the potato psyllid (Munyaneza et al. 2007a, Crosslin, et al. 2012, Goolsby, et al. 2007a, Munyaneza 2012). In the following years, the negative impacts of ZC became more apparent and widespread; infections were found to render tubers unmarketable, even in late season infections, and were found to be damaging to potatoes in cold storage (Crosslin et al. 2010). The ZC disease was reported for the first time in 2011 in the Columbia basin (Crosslin et al. 2012). This event prompted extensive use of insecticides in the region to control the potato psyllid (Guenthner et al. 2012).

The potato psyllid is known to affect a wide range of solanaceous crops including tomato (*Solanum lycopersicum* L.), tamarillo (*Solanum betaceum* L.), *Capsicum* spp., and

eggplant (*Solanum melongena* L.) (Martin 2008). The insect causes direct feeding damage to plants causing ‘psyllid yellows’ but more importantly, the insect vectors the bacteria (Lso) ZC disease (Hansen et al. 2008, Liefting et al. 2008, 2009). Zebra chip disease was first described in the mid-1990s in Mexico where sliced tubers were observed to have unique dark stripes and discoloration which had a negative effect on both fresh market potatoes and those processed for fries or chips (Secor et al. 2006, De Boer et al. 2007, Gudmestad and Secor 2007, Crosslin et al. 2010). The disease was incorrectly first thought to be related to another known potato disease known as ‘purple top disease’ or Beet leafhopper transmitted virescence agent (BLTVA), which is caused by phytoplasmas vectored by the beet leafhopper, *Circulifer tenellus* Baker (Hemiptera: Cicadellidae). Purple top disease exhibits similar foliar symptoms of upward rolling leaflets, leaf scorch, early senescence, and purple tops (Crosslin et al. 2010). Purple top infected tubers also exhibit symptoms of brown discoloration; however, ZC tubers upon frying, produce chips or fries with extreme dark blotches, stripes, and streaks, a symptom not seen in BLTVA infections (Crosslin et al. 2010). The presence of these streaks led to the development of the name ZC disease. These symptoms were first described in the US in 2000 in the Pearsall and Lower Rio Grande valley areas of Texas (Abad et al. 2008). By 2004 to 2005, significant crop losses and economic damages were reported in the area (CNAS 2006). Similar symptoms were first reported in 2006 in New Zealand (Kale 2011) and 2007 in Arizona, California, Colorado, Kansas, Nebraska, New Mexico, and Nevada (Goolsby, et al. 2007a, Munyaneza 2012). Disease symptoms were reported in Honduras in 2009 (Rehman et al. 2010). Munyaneza et al. (2007a) and Navarre et al. (2009) proved that ZC was a separate phenomenon from that of purple top disease. Additionally, grafting experiments conducted in 2005-2006 showed that healthy foliage would acquire disease symptoms in roughly four weeks when grafted to a symptomatic plant (Secor et al. 2009). More progress was made on isolating the cause of ZC in 2008 when researchers in New Zealand used transmission electron microscopy of symptomatic tomato leaf tissue and identified phloem-limited bacterium-like organisms (Liefting et al. 2009). In May 2008, a unique PCR amplicon was produced from symptomatic plants that further facilitated the detection of the bacterium in ZC symptomatic potatoes (Abad et al. 2008, Liefting et al.

2009, Lin et al. 2009, Munyaneza et al. 2009, Secor et al. 2009). Additionally, *Ca. Liberibacter* was isolated from the potato psyllid using universal prokaryote rRNA primers and qPCR techniques (Hansen et al. 2008). The potato psyllid was determined to transmit ZC horizontally – from plant to plant – through feeding and also vertically (transovarially) by transmitting the bacterium to offspring (Hansen et al. 2008, Sengoda et al. 2010).

Since the discovery of ZC, the potato psyllid/pathogen complex has caused hundreds of millions of dollars in damages from crop loss, reduced yield, and increased insect management costs (Muyaneza 2012). The 2003-2005 potato psyllid outbreak in Texas caused over \$100 million USD loss (NASS 2006, Kale 2011). In Oregon, previous to the 2011 the potato psyllid was largely ignored (Rondon personal communication). The vector was considered a “nuisance pest” and undesirable due to the possibility of feeding damage. Since 2011, to reduce the cost of ZC control, substantial vector management practices have been implemented in most growing regions but more research is needed to understand the long term impact of this disease in potato production.

### **Monitoring the potato psyllid: quantifying population dynamics through sampling**

Monitoring for the potato psyllid on both cultivated and non-cultivated host plants has been carried out in a concerted fashion using a wide range of techniques (Pletsch 1947, Wallis 1955, Cranshaw 1994, Al-Jabr 1999, Al-Jabr and Cranshaw 2007, Goolsby, et al. 2007a). Multiple trapping methods have been used including: suction traps (a.k.a inverted leaf blowers or vacuum sampling), sweep netting, collection of plant material, and colored sticky traps (Butler and Trumble 2012). Sweep nets have seen widespread use especially in the development of a “psyllid index” in the late 1940s whereby the number of psyllids per 100 sweeps was correlated with the severity of psyllid yellows (Pletsch 1947, Cranshaw 1994). Studies incorporating sweep netting elucidated patterns in potato psyllid within a potato field where psyllids were typically first detected on the edges of fields, but as season progressed, the number of psyllids collected increased towards the field’s center (Jensen 1939, Wallis 1955, Cranshaw 1994). Sticky traps are a commonly used and important component of potato psyllid monitoring programs, and are used regularly in the US (Al-Jabr 1999, Goolsby et al. 2007a, 2007b). The potato psyllid was found to be significantly

attracted to standard yellow sticky traps as well as neon-green and neon-orange when traps were placed a few centimeters above the potato crop canopy and in the shade (Al-Jabr 1999). Yellow sticky cards were also successfully used to monitor potato psyllids in Texas potato fields and it was suggested that the cards could be a cost effective tool to detect the insect (Goolsby et al. 2007a, 2007b). However, sticky traps and other collection methods have not been compared systematically under Columbia Basin field settings.

Several studies have been conducted on the population dynamics of the potato psyllid in the Columbia Basin and elsewhere, but, little is known about the interactions between the potato psyllid and its environment and non-cultivated hosts such as volunteer potatoes (Goolsby et al. 2012). Multiple studies have documented that the potato psyllid overwinters on several native plants primarily bittersweet nightshade *Solanum dulcamara* L. and matrimony vine (*Lycium* spp.) in the arid region along the US – Mexico border (Pletsch 1947, Wallis 1955, Abernathy 1991, Ferro and Boiteau 1993, Cranshaw 1994, Capinera 2001, Cranshaw and Kramer 2001, Murphy et al. 2013). Others have reported that the potato psyllid breeds and overwinters on these plants between January – May and then later migrates into potato crops (Pletsch 1947, Wallis 1955, Abernathy 1991, Cranshaw 1994, 2001, Murphy et al. 2013). Also, natural ZC infection was found in bittersweet nightshade which is thought to be an important source of annual Lso in the area (Murphy et al. 2014).

Studies on potato psyllid dispersal have also been conducted. Psyllids have been found to disperse readily within crop fields through jumping and flying (Henne et al. 2010, 2012). Longer distance movement, on the order of hundreds of meters per day, has also been measured (Cameron et al. 2013). Psyllids have a high propensity to jump and fly when plants are disturbed and prevailing winds have also been shown to be influential on psyllid movement (Henne et al. 2010, Cameron et al. 2013). Local movement may partially explain how psyllids colonize fields on the within-field scale, but it is also currently thought that long distance northward migration accounts for a significant quantity of the psyllids in the Columbia Basin every year (Butler and Trumble 2012, Munyaneza 2012). This theory is supported by high altitude insect collections, where psyllids are routinely found (Glick 1939, Papp 1978, Chapman et al. 2011). Until recently, the origin of the potato psyllid in

the Columbia Basin was not fully understood. Through genetic haplotyping using High Resolution Melting it was determined that there are different sub-populations of psyllids in the region primarily the western haplotype and the northwestern haplotype (Swisher et al. 2012). The Northwestern haplotype was found to be the majority haplotype on bittersweet nightshade in the Columbia Basin (Murphy et al. 2013). Part of the differentiation in these haplotypes is due in part to a response to abiotic variables. It is commonly thought that psyllid outbreaks are due to conditions such as size of the spring population, wind patterns, temperature during migration, and quality of potato plants and other hosts at the new location that affect late spring and early summer movement from overwintering hosts into potatoes (Blood et al. 1933, Pletsch 1947, Wallis 1955, Abernathy 1991, Cranshaw 1994, Capinera 2001, Cranshaw and Kramer 2001). Even though potato psyllids' main hosts are solanaceous plants, they have been observed in crops such as wheat and maize in the Columbia Basin (SI Rondon, personal observation). The primary hypothesis proposed to explain potato psyllid presence in non-solanaceous crops is the presence of volunteer weeds. Because of late maize planting allows volunteer potatoes to develop, this green bridge could serve as a host for psyllids. In this thesis, I provide evidence that potato psyllids are able to utilize volunteer potatoes in maize and wheat as refugia thus increasing their chances of survivorship in diverse landscapes.

## **Summary of chapter 2**

This project was designed to (1) evaluate potato psyllid and natural enemy population in diverse cropping systems which include potatoes, maize, wheat, potatoes + volunteer potatoes, and wheat + volunteer potatoes and (2) compare the use of sticky traps and vacuum traps for monitoring potato psyllids adults and natural enemies. Data collected in this study suggested that potato psyllid has an affinity for potato crops even in the presence of a diverse crop landscape and also that differences may occur between trapping methods. Potato psyllids were found in maize and wheat but only when volunteer potatoes were present. There were differences in captures of natural enemies when using both collection methods and they were present in all crop treatments tested. These results have implications

for potato psyllid management as well as providing information regarding natural enemies that can potentially play a role in psyllid control.

### **History and background of aphids as potato pests**

While the potato psyllid is considered one of the top potato pests in the United States, aphids in general, are considered to have the greatest economic impact on potatoes worldwide (Radcliffe 1982). The green peach aphid (GPA) *Myzus persicae* Sulzer (Hemiptera: Aphididae), was first described as *Aphis persicae* in 1776 by the Swiss entomologist Johann Heinrich Sulzer and Remaudière and Remaudière (1997) compiled synonymous species names, Blackman and Paterson (1986) and Blackman et al. (1984) reviewed its taxonomy. The origins of GPA are unknown, but its primary host, the peach *Prunus persica* L. is of Asian origin, which suggests an Asian origin for the GPA as well (Van Emden et al. 1969). The potato aphid (PA) *Macrosiphum euphorbiae* Thomas (Hemiptera: Aphididae), is also considered one of the key insect pests of potato (Tamaki et al. 1979, Radcliffe 1982, Alvarez and Srinivasan 2005). Potato aphids are thought to have originated in North America and was first described by Cyrus Thomas in 1878 from samples obtained in Illinois, US, and is now considered highly cosmopolitan and found globally (Davis 1913). The GPA and PA have been known to cause significant crop losses to potatoes in the Columbia Basin, but were not considered major pests in the region until 1938 when potato leafroll virus (PLRV; family Luteoviridae, genus Polerovirus), transmitted by GPA and PA through feeding, first occurred in the area (Locke 1948). In the early 1900s, aphid transmitted potato viruses were studied due to their economic impact (Radcliffe 1982). It took until 1920 for Oortwijn Botjes to prove that PLRV was transmitted by aphids (Lambers 1955). Potatoes are in fact subject to at least 33 distinct viruses and virus-like diseases, 13 of those vectored by aphids (Radcliff and Ragsdale 2002). The green peach aphid is known to vector over 100 viral diseases of plants in roughly 30 different plant families including many economically important crops such as beans (*Phaseolus* spp.), sugar beet (*Beta vulgaris* L.), sugar cane (*Saccharum* spp.), brassicas, tobacco (*Solanum nicotiana* L.), and citrus (*Citrus* spp.). In 1990, aphids ranked as either the top

or second most important potato pest in all production regions in the US (Van Emden et al. 1969, Radcliffe and Ragsdale 2002).

### **Aphid transmitted viruses**

Significant effort is made in the Columbia Basin to control potato viruses that can cause serious crop loss. Management of these viruses is difficult due to the disease life cycle which depends on viral species, form of transmission (e.g. mechanical, seed borne, or insect vectored), and environmental conditions (Radcliffe and Ragsdale 2002). Because aphid transmitted viral pathogens must be acquired by an insect intermediary to be transferred between susceptible plants, the relationships between insect, virus, plant, and environment exhibit a much more complex relationship than that described by the classic disease triangle (Ragsdale et al. 1994), and although aphids are a key component of viral epidemiology, their role in virus transmission remains poorly understood (Radcliff and Ragsdale 2002). This knowledge deficiency is especially true with regards to long term population dynamics and spatial-temporal distribution; although research has been conducted on viral occurrence, insecticide management, species diversity, and migration (Crosslin et al. 2006, Murphy et al. 2014, Thomas et al. 1997).

In the US, Potato Virus Y (PVY; family Potyviridae, genus Potyvirus), and Potato Leafroll Virus (PLRV; family Luteoviridae, genus Polerovirus), are considered highly important with PVY being considered the most economically significant virus of potato (de Bokx and Van der Want 1987, Coutts and Jones 2015). PVY is largely vectored in a non-persistent manner by multiple species of colonizing and non-colonizing aphids (Gibson et al. 1988, Shattock 2002, Karasev and Gray 2013, Coutts and Jones 2015) and naturally occurs in a wide range of host plants mainly in the Solanaceae including tomato, pepper, tobacco, and weeds such as lambsquarters (*Chenopodium album* L.), prickly lettuce (*Lactuca serriola* L.), redstem filaree (*Erodium cicutarium* L.), tumble mustard (*Sisymbrium alissimum* L.), and bittersweet nightshade (*Solanum dulcamara* L.) – all of which are also suitable hosts for both GPA and PA (Kazinczi et al. 2004, Kaliciak and Syller 2009). PLRV, like PVY, can also seriously impact yield and tuber quality and can cause complete crop loss (Nolte et al. 2004). At least 10 colonizing aphid species are known



to transmit PLRV in a persistent, circulative, and non-propagative manner (Kassanis 1952, Nault 1997, Rouze-Jouan et al. 2001).

Insecticide applications are the primary control measure taken against both GPA and PA, however, their use is typically only considered effective in reducing disease spread when the insecticide takes effect before the disease is transmitted (Perring et al. 1999). Similarly, insecticides have been shown not to reduce viral spread even when aphids were effectively controlled (Till 1971, Bacon et al. 1976, Collar et al. 1997). This discrepancy is due to a lag period between insecticide contact and lethal action and to alate viruliferous aphids continuously entering fields after applications are made (Holbrook 1977, Radcliffe and Ragsdale 2002). Concerns have also been raised over the slow mode of action of systemic insecticides such as imidacloprid which may have little effect on reducing virus transmission by alates (Boiteau and Osborn 1997). Pymetrozine, a pyridine azomethine, has been shown to quickly and selectively knock down aphids on contact and inhibit stylet insertion soon enough after contact to prevent virus spread (Harrewijn and Kayser 1997).

These management complications arise partly due to the success of off-farm aphids in moving between hosts and colonizing cash crops in unpredictable ways. Information on PA and GPA basic biology in the Columbia Basin has helped to alleviate some of these issues, but has also potentially led to a disproportionate focus on these two species over other aphids (OA). It is known that PA has a broad host range which includes many Solanaceae, apples (*Malus domestica* L.), clover (*Trifolium* spp.), maize, and roses (*Rosa* spp.) (Murphy et al. 2013) and that it is a dominant early colonizer of potato (Murphy et al. 2013). GPA is considered the most efficient vector of PVY according to MacGillivray (1981) and Piron (1986), but OA, typically considered less efficient vectors, are often observed in greater abundance, which could make them more important in regard to viral epidemiology (Van Hoof 1980, Piron 1986, Lowery and Boiteau 1988, Weidemann 1988, Harrington and Gibson 1989, Sigvald 1992). While over 30 species of other aphids have been identified on potatoes in the Columbia Basin, the bird cherry-oat aphid *Rhopalosiphum* spp., mint aphid *Ovatus crataegarius* L., and mealy plum aphid *Hyalopterus pruni* Geoffroy make up the majority of the aphid community (Murphy 2013).

### **Aphid population dynamics**

Aphids such as Potato Aphid (PA) *Macrosiphum euphorbiae* Thomas, Green Peach Aphid (GPA) *Myzus persicae* Sulzer, Bird cherry oat aphid *Rhopalosiphum padi* L., and over 30 species of other aphids (OA) are routinely considered among the most important insect sucking pests (Tamaki et al. 1979, Radcliffe 1982, Alvarez and Srinivasan 2005). Aphids can cause direct feeding damage but their ability to efficiently transmit viruses makes them a top priority of study. Potato Virus Y (PVY; family Potyviridae, genus Potyvirus), and Potato Leafroll Virus (PLRV; family Luteoviridae, genus Polerovirus), are considered the most damaging aphid transmitted viruses (de Bokx and Van der Want 1987, Coutts and Jones 2015). Both species are not exclusively potato pests; GPA and PA both have a broad host range that largely overlaps with the list of plants able to carry PVY and/or PLRV (Murphy et al. 2013). The pest status of aphids is due in part to a combination of polyphagous feeding behavior and high spatial mobility. GPA and PA are also known to overwinter in many plants which can also carry PVY (Murphy et al. 2013). Thomas et al. (1997) found that the timing and number of aphids collected correlated significantly with heat unit accumulation, and also that it varied significantly but predictably throughout a growing season. This suggests that the movement of aphids depends on abiotic variables as has been documented previously (Barlow et al. 1980, Stinner et al. 1983). Additionally, the fragmented distribution of resources and the influence of interactions between population dynamics and biotic/abiotic factors plays a large role in determining when and where insect populations increase and where they go locally extinct (Fleischer et al. 1997, Mazzi and Dorn 2012). With aphid management, complications also arise due to aphids having overlapping generations and unstable population age structures (Dixon 1998). Aphid populations rarely exhibit changes in density in response to natural enemy populations which suggests that predation is only a weak regulator of population size (Radcliffe and Ragsdale 2002). Multiple aphid trapping surveys have found that captures of aphids are cyclic and follow a pattern consistent with that of time-lagged density-dependent regulation (Bagnall 1992, Woiwod and Hanski 1992). Surveys give little to no information on the underlying mechanisms of such patterns, but modeling results have suggested that weather variables are a major factor in stimulating aphid migration and

determining peak densities (Barlow et al. 1980). Therefore, a quantitative analysis of how aphid pests of potato vary spatially will likely provide valuable information that can be applied towards developing precise management tactics.

Unique complications for aphid management, when compared to other insect pests, arise due to the variable colonization patterns that these wing dimorphic insects produce. GPA flight dynamics have been studied in the Columbia Basin where it has been determined that the species commonly overwinters on peach trees (*Prunus persica* L.), but that it can also overwinter in apterous form in specific microclimates where warmer than ambient air temperatures exist (Walis and Turner 1969, Powell and Mondor 1976, Tamaki et al. 1979, Thomas et al. 1997). GPA engages in a small scale spring flight from overwintering sites to winter annuals, herbaceous plants, and other early spring hosts, after this, a movement to summer hosts occurs as spring hosts mature and senesce; this summer movement typically correlates with higher numbers in economic crops (Thomas 1997). The role of aphid flight patterns and alternate hosts in virus acquisition has been widely studied (See Thomas 1983, Hassan 1985, Fox et al. 1993, Thomas et al. 1997) but landscape and spatio-temporal dynamics of aphids in the Columbia Basin have yet to be analyzed and as of this publication, no data exists to map aphid presence on a large scale.

### **Summary of chapter 3**

This project was designed to provide information on GPA, PA, and OA abundance, population dynamics, and response to environmental variables throughout the two primary potato growing regions of Oregon: the Columbia Basin (Umatilla & Morrow Counties) and Eastern Oregon (Union, Baker, and Wallowa Counties). Aphids have been monitored in the Columbia Basin through a trapping network that was established in the mid-1970s to monitor multiple potato pests and serve as an early warning system for growers. Starting in 2006, a more concerted effort was taken where the geographic coordinates of traps throughout the Columbia Basin were recorded along with weather data from several nearby weather stations. Previous researchers proposed that aphid populations may be sensitive to environmental variables. Thus, the objectives of this study were to (1) determine trends in GPA, PA, and OA populations in the Columbia Basin and (2) determine abiotic

environmental variables that could potentially have a significant impact on population levels in the following growing season. Aphids were found to have a heterogeneous distribution in most years; a few sites had high aphid populations while low numbers were observed at most sites; aphids were also found to correlate with several abiotic variables namely elevation, previous season temperature, and previous season dew point.

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**Effect of Crop Diversity on Distributions of Potato Psyllid *Bactericera cockerelli*  
Sulc (Hemiptera: Triozidae) and its Natural Enemies**

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### Abstract

The potato psyllid, *Bactericera cockerelli* Sülc (Hemiptera: Triozidae), is a key potato (*Solanum tuberosum* L.) pest that has the ability to vector the plant pathogenic bacterium *Candidatus Liberibacter solanacearum* (Lso). The literature indicates that this insect has an affinity for solanaceous crops and weeds and our hypothesis is that the presence of the potato psyllid in crops such as maize (*Zea mays* L.) or wheat (*Triticum* spp) was due to the presence of volunteer potatoes. In the region, potatoes are in rotation with both, maize and wheat. Thus, the objectives of this study were to (1) evaluate the role of potato, maize, wheat, maize + volunteer potato, wheat + volunteer potato on potato psyllid and natural enemy population dynamics and (2) compare two sampling techniques such as sticky traps and inverted leaf blowers, for monitoring potato psyllids adults and natural enemies. Data collected in this study suggested that potato psyllid has an affinity for potato crops even in the presence of a diverse crop landscape and also that differences may occur between trapping methods. Potato psyllids were found in maize and wheat but only when volunteer potatoes were present. There were differences in captures of natural enemies when using both collection methods and natural enemies were present in all crop treatments tested. These results have implications for potato psyllid management as well as providing information regarding natural enemies that can potentially play a role in psyllid control.

**KEY WORDS:** Potato Psyllid, *Bactericera cockerelli*, natural enemies, *Orius*, *Nabis*, *Geocoris*, population dynamics, volunteer potatoes.

## Introduction

The potato psyllid, *Bactericera cockerelli* Sülc (Hemiptera: Triozidae) is a serious economic pest of solanaceous crops such as pepper (*Capsicum* L.), tamarillo (*Solanum betaceum* Cav.), tomato (*Solanum lycopersicum* L.), and potato (*Solanum tuberosum* L.). Immature and adult potato psyllids have the ability to vector the plant pathogen *Candidatus Liberibacter solanacearum* (Lso), the causal agent of Zebra Chip (ZC) disease in potatoes. The disease can reduce yield and render tubers unmarketable by causing internal discoloration that is more pronounced after cooking, especially in fries or chips (Abad et al. 2008, Hansen et al. 2008, Liefting et al. 2008, 2009). Zebra Chip was first identified in Mexico in 1994 (Munyanze et al. 2007b, Abad et al. 2008) and by the early 2000s, it reached the potato production area of Texas (Secor and Rivera-Varas 2004, Munyanze, et al. 2007a). Currently, ZC has been documented in North America in Arizona, California, Colorado, Idaho, Kansas, Nebraska, Nevada, New Mexico, Oregon, Washington, and Wyoming; also in Canada, Honduras and Nicaragua (Munyanze et al. 2013); ZC has also been reported in New Zealand (Thomas et al. 2011).

Industry efforts to control the potato psyllid began in Oregon, Washington, and Idaho in 2011 when the ZC disease was first reported in the region (Hamm et al. 2011, Crosslin et al. 2012). This area produces close to 60% of the potatoes in the US (NASS 2016). Prior to this finding, potato growers in the Pacific Northwest did not monitor or take management action against potato psyllids and the insect was considered a “nuisance pest” or undesirable due to the possibility of direct feeding damage that causes “psyllid yellows” (Rondon et al. 2016). Significant yield losses have been associated with the presence of the potato psyllid alone but losses are higher when the potato psyllid vectors Lso (Munyanze, et al. 2007b).

Researchers have been studying potato psyllid basic biology for decades and have identified and described the insect on other crops besides solanaceous (Knowlton and Thomas 1934, Romney 1939, Pletsch 1947, Wallis 1955, Martin 2008, Murphy et al. 2013). According to Wallis (1955) and Martin (2008), psyllids can often be found on plants in 20 other families that are known to not be true hosts, but the role of those plants related to psyllid biology is unknown. Potato psyllids have only been confirmed to breed on plants

from 3 families: Solanaceae (37 species), Convolvulaceae (3 species), and Lamiaceae (1 species) (Horton et al. 2016). There have also been anecdotic reports of the potato psyllid being collected in other economic crops such as wheat (*Triticum* spp.) and maize (*Zea mays* L.) in the Columbia Basin (S. I. Rondon, personal communication). It is speculated, that the presence of this insect in these crops is due to the insect locating and feeding on volunteer potatoes or weeds. Volunteer potatoes are prevalent in the Columbia Basin. Approximately 25,000 – 190,000 tubers per acre (62,000 – 470,000 tubers per hectare) can be left in the soil and survive into the next growing season (Steiner et al. 2005). If volunteers survive the winter and germinate in the early spring, they can harbor insect pests, nematodes, and disease. Thus, we were interested in studying the potential role of volunteer potatoes as a potato psyllid host when occurring in non-host primary crops like wheat and maize. Since potatoes are in a three year rotation with wheat or maize in the Columbia Basin, volunteer potatoes are a likely to be an issue.

The role of natural enemies, especially predators, in potato psyllid control is another aspect of pest management that has not been fully examined in the Columbia Basin. While research indicates that potato psyllids have a strong preference for solanaceous crops and weeds, including plants like bittersweet nightshade (*Solanum dulcamara* L.) (Murphy et al. 2013), less is known about the use of these plants by natural enemies (Castillo-Carillo et al. 2016). Weeds can serve as a green bridge, not only for pest, but also for natural enemies, providing them with crucial habitat and hunting grounds which can potentially support their populations before migrating into potato fields (Szendrei and Weber 2009). A wide range of predatory arthropods are known to exist in the Columbia Basin. Castillo-Carillo et al. (2016) identified over 25 species of predators on bittersweet nightshade alone. Of these, several species of *Geocoris* spp., *Nabis* spp., and *Orius* spp. made up large portions of the beneficials found (Castillo-Carillo et al. 2016).

A robust, cost effective, and efficient insect sampling plan is necessary to make timely decisions. Psyllid monitoring programs have been developed for this purpose in several states (Pletsch 1947, Wallis 1955, Cranshaw 1994, Al-Jabr 1999, Goolsby, et al. 2007a, 2007b). However, potato psyllid phenology, density and distribution vary significantly which can limit the effectiveness of general monitoring programs (Walker et

al. 2013). Thus, there is the need to study and validate a monitoring program under Columbia Basin conditions, a process that has not yet been fully undertaken. Since the first outbreak of ZC in 2011, potato psyllids have been monitored extensively in the area during the potato growing season, as well as during winter months (S. I. Rondon personal communication). However, many questions remain such as the role of overwintering habitats, flight dynamics, and host preference. Potato psyllids adults can be collected using beating sheets, sweep netting, water traps, sticky traps, Malaise traps, and inverted leaf blowers (a.k.a. DVAC) (Yen et al. 2013). Immature stages can be collected mainly by sampling foliage (Butler and Trumble 2012). Sweep nets have seen widespread use, especially in determining potato psyllid relative populations and in determining a “psyllid index” whereby the number of psyllids per 100 sweeps was correlated with the severity of psyllid yellows incidence (Pletsch 1947, Cranshaw 1994). Studies incorporating sweep netting also detected patterns in potato psyllid distributions within a potato field (Jensen 1939). Psyllids are typically first detected on the edges of fields, and as the number of psyllids collected increases, the population tends to be found spreading towards the field’s center (Jensen 1939, Wallis 1955, Cranshaw 1994). However, in the lower Columbia Basin, Echegaray and Rondon (not published) did not observe this pattern. In addition to netting, sticky traps are commonly used and they are important components of potato psyllid monitoring programs (Al-Jabr 1999, Goolsby et al. 2007a). Potato psyllids were found to be attracted to standard yellow sticky traps as well as neon-green and neon-orange when traps were placed a few centimeters above the potato crop canopy and in the shade (Al-Jabr 1999). Yellow sticky cards were successfully used to monitor potato psyllids in Texas potato fields where it was suggested that the cards could be a cost effective management tool (Goolsby, et al. 2007a, 2007b). Leaf samples have also been collected and analyzed to determine egg and nymph populations although such collections were labeled as tedious and time-consuming. In California, leaf sampling methods are currently being used to develop economic levels (Butler and Trumble 2012). In the Columbia Basin, management recommendations are made based on yellow sticky traps (Goolsby, et al. 2007a). Even though inverted leaf blowers were found to effectively sample first potato psyllids landing in potatoes (Echegaray and Rondon unpublished) and weak fliers such as



aphids in other commercial crops (Teulon et al. 2006, 2009), inverted leaf blowers are rarely used.

Prior to the arrival of potato psyllids in the Columbia Basin, insecticides were typically applied to potatoes for control of Colorado potato beetle *Leptinotarsa decemlineata* Say (Coleoptera: Chrysomelidae), several aphid species including potato aphid *Macrosiphum euphorbiae* Thomas (Hemiptera: Aphididae) and green peach aphid *Myzus persicae* Sulzer (Hemiptera: Aphididae); beet leafhopper *Circulifer tenellus* Baker (Hemiptera: Cicadellidae) and potato tuber moth *Phthorimaea operculella* Zeller (Lepidoptera: Gelechiidae). Since the arrival of potato psyllids in the region, the number of insecticide applications per season has increased (Guenthner et al. 2012). The recent presence of the potato psyllid has led to the disruption of established IPM strategies (Horne and Page 2009), thus there is the need to reevaluate pest management practices in the area as well as the impacts of natural enemies' populations. This study sought to analyze potato psyllid and natural enemies in a two-year field experiment conducted in the potato-growing region of the Lower Columbia River Basin of eastern Oregon. The objectives of this study were to (1) evaluate the role of potato, maize, wheat, maize + volunteer potato, wheat + volunteer potato on potato psyllid and natural enemy population dynamics and (2) compare the two sampling techniques, yellow sticky traps and inverted leaf blowers, for monitoring potato psyllids and natural enemies.

## Materials and Methods

### Field Site

In 2014 and 2015, the potato psyllid and its natural enemies were monitored in experimental plots at the Oregon State University Hermiston Agriculture Research and Extension Center (HAREC) located in Hermiston, OR (Lat 40.7127837; Lon -74.0059). The experimental plots were arranged in a five by five Latin square design and included: 1) potato, 2) maize, 3) wheat, 4) maize + volunteer potato, and 5) wheat + volunteer potato. Each plot was 7.62 m X 7.62 m (25 ft<sup>2</sup>) (Appendix Photo 1). Row spacing for all crops

were the most commonly used in Oregon. Standard agronomic practices were followed (Table 2.1). No insecticides were used at any time during the 2-year study with the exception of Rynaxypyr (Coragen®) to control Colorado potato beetles. The arrangement of the five treatments in 2014 is illustrated in Fig. 2.1A. The Latin square design, which allows for comparison of randomly assigned  $t$  treatments blocked off in  $t$  rows and  $t$  columns which leads to no repetition of treatments within rows or columns. In 2015 (Fig. 2.1B) treatments were rotated with respect to 2014. All plots were separated by one meter alleys and the entire experiment was surrounded by 12 rows of potatoes to attract potato psyllids to plots. Most herbicide control was done with spot treatments of glyphosate (Glystar Plus @ 0.008 gallons or 6.5 fl oz per gallon) and manual weed control was also used as needed throughout the growing season. Care was taken to minimize insecticide use on experimental plots in order to avoid confounding variables. Potatoes (var. ‘Russet Ranger’) were planted with a potato pick planter (John Deere®, INC) on 15 April in 2014 and 18 April in 2015. Potatoes were planted with standard plant and row spacing: 22.86 cm (9 in) between plants within a row and 91.44 cm (36 in) between rows. Potato pieces were pre-treated with an insecticide/fungicide mix (Cruiser Maxx: thiomethoxam, fludioxonil) to control Colorado potato beetle, aphids, beet leafhopper, and fungal diseases. The potato experimental plots were also amended with a broadcast fertilizer (Osmocote® Smart-Release® 14-14-14; The Scotts Miracle-Gro Company) at 45 grams (0.099 lb) per four ft<sup>2</sup> or roughly 500 grams per plot, the recommended rate for vegetable and row crops. Maize (var. ‘Serendipity’) was planted in 2014 on 3 June and in 2015 on 29 May. Maize seed was pre-treated against southern maize leaf blight *Bipolaris maydis* (Y. Nisik. & C. Miyake) Shoemaker. Maize was planted with a handheld push-operated garden seeder (Earthway® Precision Garden Seeder Model# 1001B) and inserted seed plate (#18100). There were a total of 8 rows per plot and plants were spaced at 30.48 cm (12 in) and rows were 91.44 cm (36 in) apart. Maize experimental plots were also amended with Osmocote® 14-14-14 at a rate of 500 grams per plot. Wheat (var. ‘WB 6341’ soft white spring wheat; Monsanto Company) was planted in 2014 on 20 April and in 2015 on 22 April. Wheat was planted with a John Deere® 450 grain drill which had 26 openers and 15.25 cm (6 in) row spacing to achieve 50 rows of wheat per plot. WB 6341 is a Medium-Early maturity variety

that possesses significant tolerance to Fusarium head blight (*Fusarium graminearum* L.) and Hessian fly *Mayetiola destructor* Say (Diptera: Cecidomyiidae). Wheat experimental plots were also amended with Osmocote® 14-14-14 at a rate of 500 grams per plot. Volunteer potatoes were planted by hand in the wheat + volunteer potatoes and maize + volunteer potato treatments on 25-27 March 2014 and 30 March 2015. Volunteer planting preceded the planting of maize or wheat. A soil auger was used to dig approximately 30 cm (12 in) below the soil surface to plant potatoes (var. 'Russet Ranger') seed pieces. A single potato piece was placed in the bore hole, and then soil was replaced to bury the piece. Volunteer potatoes were planted at a rate of 25,000 per acre or 350 volunteer potatoes per plot. This rate of volunteers was chosen based off of field data on volunteer prevalence on commercial farms (Steiner et al. 2005).

### **Sampling**

Potato psyllids and natural enemies sampling was initiated in 2014 on 10 June and was terminated on 12 August. Sampling was initiated in 2015 on 2 June and terminated on 18 Aug. Target insects were collected using yellow sticky cards (Alphascent, Inc.) (Appendix Photo 2) and inverted leaf blowers (Appendix Photo 3) (STIHL® BG-50 gasoline powered handheld blower, 27.2 cc displacement, 0.7 kW power engine). One sticky card per plot was attached with a binder clip to 1 meter stakes in the center of each plot; stakes were hammered into the ground and sticky cards were kept at canopy level throughout the growing season. As plants in all crop treatments grew, cards were subsequently placed higher up on the stakes leading to a maximum height of roughly 20 cm (7.78 in) in potato plots, 30 cm (11.81 in) in wheat, and 1 meter (39.37 in) in maize plots. Sticky cards were positioned following a north/south direction. Sticky cards were stored in the lab in 2.25 cm slats that were cut into on 8.9 by 3.8 cm wooden beams; boards were custom made and were used to minimize contact between cards that damage delicate insects. Sticky card samples were processed the same day by counting potato psyllids and natural enemies under a dissecting scope (Leica S8). Inverted leaf blowers were constructed by reversing the blower to induce suction at the end of the vacuum tube; vacuums were fitted with custom sewn ultra-fine mesh sleeves that were secured over the vacuum tube with rubber

bands. Samples were collected by strafing the tube over plants while walking across each experimental plot in a straight line for one minute. Sampling was carried out in the direct vicinity of the sticky traps, but sticky cards were always collected first by walking into plots as carefully as possible to minimize disturbing insects. Inverted leaf blower samples were transferred to plastic bags, and brought to the freezer in the laboratory to kill all insects. Inverted leaf blower samples were processed under dissecting scope 48 h after collection. Potato psyllids and natural enemies were counted and sorted.

Potato psyllids, and natural enemies (*Orius* spp., *Geocoris* spp., and *Nabis* spp.) were sampled with both sampling methods. Natural enemies were monitored to see if they correlated with either/or crop treatments and psyllid presence. These natural enemies were chosen since they are known to predate psyllids (Castillo-Carillo et al. 2016).

### **Data Analysis**

Spatial and temporal distribution of the potato psyllid and natural enemies was compared within each growing season (2014 – 2015) by plotting the number of insects collected per crop over time and also by statistically analyzing the number of insects collected per week crop treatment and collection method using a generalized linear mixed effects model (PROC GLIMMIX; SAS institute 2016). The generalized linear mixed effects model used was developed through standard model selection procedure and was informed by the study design and nature of the response variable. In the first model, it was determined that there was no effect of either the row or column in the Latin square design. Therefore, we were able to condense the statistical test down to a simple two-way ANOVA with, crop, collection method, and a crop\*collection method interaction term. We also conducted a standard Tukey's HSD to make all comparisons between treatments. The ANOVA and Tukey's HSD tests were conducted in Rstudio (RStudio 2016). Mean insects per trap per week was calculated from the data and compiled into bar plots with respect to trapping method and year. Data were also compiled into scatterplots of mean insects per trap per week with respect to collection date, again separately for each insect and year. These line graphs were not differentiated by collection method, but rather were a combination of both. This was done in order to efficiently represent the data, as very few insects were collected

on sticky card traps. Scatterplots were developed in Rstudio using the package ggplot2 (Wickham et al. 2013).

## Results

### Potato psyllids

The poisson and negative binomial models had both *fixed effects* (crop treatment and collection method) and *random effects* (row and column effects of the Latin Square as well as the random whole-plot variation component that was modeled with a *crop\*column* identifier (data not shown). After finding no effect of either row or column, the results were modified with a simple two-way ANOVA with the fixed effects of crop treatment, collection method, and the crop\*collection method interaction term.

In 2014, mean potato psyllids per trap per week over both collection methods were greatest in potato (0.60 potato psyllid per trap per week) followed by mean number of potato psyllids per trap per week in wheat + volunteer potato (0.46), maize + volunteer potato (0.22), wheat (0.08) and maize (0) (Fig. 2.2). Differences were found among crop treatment ( $F = 3.5691$ ;  $df = 4$ ;  $P = 0.007$ ) but no differences were found between collection type or crop \* collection type interaction (Table 2.2). There were no differences in the number of potato psyllids caught with the two trapping methods. On sticky traps over the duration of sampling (n=34) potato psyllids were collected, while (n=33) potato psyllids were collected using inverted leaf blowers.

In 2015, mean potato psyllids per trap per week were the greatest in potato (2.2), followed by wheat (0.4), wheat + volunteer potato (0.33), maize + volunteer potato (0.18); and maize (0.07) (Fig. 2.3). Differences were found between collection methods and crop treatments ( $F = 2.60$ ;  $df = 1, 4$ ;  $P = 0.0351$ ) (Table 2.2). More potato psyllids were collected, with both collection methods, on potatoes than other crops. No significant differences were found in the collection rate of psyllids in other crops. Also, significantly more potato psyllids were collected in potato with inverted leaf blowers than sticky cards.

### Population dynamics of potato psyllids

During the 9-wk period of the study in 2014 (Fig. 2.4A) and 10-wk period in 2015 (Fig. 2.4B), in all crop treatments, first captures of the potato psyllid occurred in mid-June to early July. Peak captures of psyllid adults occurred somewhat sporadically, with a tendency to occur in August. In 2014, the first capture of potato psyllids was made on 8 July on a sticky card in potato. The first inverted leaf blower capture was made the following week on 18 Jul. In 2014, it was particularly difficult to extract any trends given the very low psyllid numbers and the degree of heterogeneity observed. For 2014, within each week, no differences were found among crop treatments. No psyllids were found in maize plots.

In 2015 (Fig. 2.4B), potato psyllids were detected on the first day of sampling, 2 June; this collection was made with a sticky card. Trapping rates appear highly sporadic (Fig. 2.4B) however, distinct differences exist between the two years of study. In general, more potato psyllids were found in 2015 compared with 2014 captures (Fig. 2.4B;  $F = 4.37$ ;  $df = 4, 543$ ;  $P = 0.0018$ ). Also, in 2015 numbers appear to exhibit a somewhat cyclic pattern of increasing and crashing, a pattern not evident in the 2014 data. Similarly to 2014, collections in maize were the lowest with only one psyllid found in maize plots, and one psyllid in maize + volunteer potato plots. Numerous psyllids were collected in all other treatments.

### Natural enemies

Natural enemies such as *Orius* spp., *Geocoris* spp., *Nabis* spp. varied by both crop treatment and collection method in 2014 (Figs. 2.5A, B, C) and 2015 (Figs. 2.6A, B, C). Separate comparisons were made between crop treatment and collection method for each natural enemy category, with differences in both 2014 and 2015 (Table 3.2). The three natural enemy families were rarely collected on sticky cards in 2014 with a total number of 6 *Orius* spp., 5 *Geocoris* sp., and 1 *Nabis* spp. However, the same year, large numbers of natural enemies were collected using the inverted leaf blowers with 331 *Orius* spp., 33 *Geocoris* spp., and 519 *Nabis* spp.

In 2015, numbers were greater across all treatments with 243 *Orius* spp., 323 *Geocoris* spp., and 176 *Nabis* spp. on sticky cards compared to 203 *Orius* spp., 1445

*Geocoris* spp., and 657 *Nabis* spp. collected with the inverted leaf blower (Appendix Photo 3). Consistent differences were seen both years with more natural enemies being collected in inverted leaf blower samples.

### **Population dynamics of natural enemies**

In 2014 and 2015, all natural enemy groups exhibited heterogeneous numbers over the course of the sampling period (Figs. 2.7 A, B, C). In 2014, *Orius* spp. population dynamics in each crop were similar with the exception of maize + vol. potato and potato. Geocorid trends for 2014 also tended to follow a similar pattern between crops with a somewhat consistent large peak on 8 July. Nabids however seem to show no consistency in trapping among crop treatments. In 2015, trends seem to be more consistent (Figs. 2.8 A, B, C). *Orius* spp. showed several distinct peak-crash cycles with peaks occurring on 10 June, 7 July, and 28 July in each crop treatment. A similar but slightly weaker trend appears in *Geocoris* spp. with a slightly flattened peak occurring from 9 June to 23 June and on 7 June and 21 June. Nabids again appear to show the least consistency when compared counts in all crop treatments although general peaks did occur between 9 June and 23 June, 7 July and 21 July.

### **Discussion**

Data collected in the present study suggest that potato psyllid has an affinity for potato crops even in the presence of a diverse crop landscape and also that differences occur between trapping methods. Similar trends were observed in data on natural enemies where large differences were seen between collection methods. The fact that some potato psyllids are collected in wheat, maize, and intercrops with volunteer potatoes confirms multiple grower reports of finding this insect in non-host crops. This study found mixed results for the comparison of sticky cards and inverted leaf blowers for the collection of potato psyllids showing no difference in 2014 but showing a slight advantage to inverted leaf blower use in 2015. This study also found strong evidence of inverted leaf blowers outperforming sticky cards for the collection of three groups of beneficial insects and this

trend held for each crop. Interestingly, the ratios between numbers of natural enemies collected were similar regardless of collection method, the main difference was the higher numbers collected in inverted leaf blowers. An exception was Nabids collections in 2015 where collection rates exhibited a near inverse pattern between card and inverted leaf blower collections.

The temporal dynamics of target insects in this study were highly variable and our concluding analysis of these trends illustrates that sampling rates differed between weeks. However, the trends in natural enemies tended to parallel each other when looking at the data from a seasonal perspective. Natural enemy lines tended to peak in mid-season in all species, and often several peaks occurred. In some instances, these peaks represent large differences in collection rates. For example, weekly average *Orius* spp. in 2015 ranged from roughly 2-4 per trap on 16 June and then dropped to under 1 per trap two weeks later. Then next week, 7 July, rates increased again to over 1 per trap. Such boom-bust cycles suggest the presence of multiple, possibly lurking variables, for example, natural enemy numbers could be highly dependent on populations of other prey insects besides potato psyllids movement in search of prey, and/or due to the influence of abiotic variables like temperature and humidity. Numbers of most insect collections were peaking and crashing over most of the sampling period.

Such trends make prediction of future insect numbers difficult, and for growers this translates into a lack of knowledge on how many traps to place as well as when to take control measures. The trends in natural enemy numbers also illustrate the difficulty in relying on natural enemies for pest suppression (Szendrei and Weber 2009). In the future, further data should be collected on an expanded list of natural enemies.

The differences between collecting pest insects and collecting natural enemies may mandate that growers utilize 2 or more collection methods. Insects respond to different cues in nature in order to find hosts/prey and the results of this study indicate that while yellow sticky traps may indeed work for herbivorous insects (Horne and Page 2009), they do not attract predatory insects with the same strength. Despite their inability to collect natural enemies at a high rate, sticky traps are widely used, relatively inexpensive, and easy to set up and service, making them a common primary method for collecting insects in



agronomic settings. They also can be collected quickly at the end of a sampling period and transported without worry of damaging insects. There are potential downsides. Namely the traps can get covered in dust and/or dislodged during high winds. Also, insects can get so ensconced in adhesive that identification becomes difficult.

Inverted leaf blower sampling also is easy to conduct, but requires significantly more labor. Several commercial options exist, however, several units are often needed to expedite sampling times which in turn increases the up-front costs of this collection method. An additional downside is that inverted leaf blowers often disturb resting insects within a wide area which could cause a significant amount of insects to leave sampling range. However, the benefit of inverted leaf blowers seems to be in the fact that they collect natural enemies at a high rate, insects that are rarely seen on sticky cards. Our results from 2015 indicated that inverted leaf blowers outperformed sticky cards at collecting potato psyllids, a rare occurrence as sticky cards have been typically thought to be superior. Growers in the Pacific Northwest rarely use inverted leaf blowers, but our results may indicate the need to further evaluate the effectiveness of this method on a larger commercial scale as they may be able to significantly improve monitoring for potato psyllids while simultaneously sampling natural enemies.

Monitoring for pests and natural enemies is a key aspect of integrated pest management, as the potential exists for natural enemies to significantly impact pest levels. The results of this study suggest that multiple trapping methods should probably be utilized by those interested in sampling both potato psyllids and natural enemies. A program of surveillance with yellow sticky cards will provide useful information on psyllid numbers in relevant crops, while inverted leaf blower will provide information on natural enemies. Some uncertainty still exists on the comparative effectiveness of sticky cards and inverted leaf blowers as both of these methods are easy to implement and yield a high probability of detecting target insects. Those deciding to utilize one or both of these methods in either research or commercial settings will likely have to factor in multiple aspects of cost, labor requirements and insect collection rates.

### **Acknowledgements**

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Table 2.3. ANOVA results for natural enemies in 2014 and 2015.

**Table. 2.1.** Chemicals used for control of Colorado potato beetle, weeds and diseases in experimental plots, 2014- 2015.

Trade Name	Active Ingredient(s)	Class / Chemical Family	Mode of Action	Rate	Source
Cruiser Maxx Potato	Thiamethoxam; Fludioxonil	Neonicotinoid; fungicide	Nicotinic acetylcholine receptor competitive modulator (IRAC 4A)	0.27 fl. oz/100 lbs of tubers	Syngenta AG, Basel, Switzerland
Calypso	Thiacloprid	Neonicotinoid	Nicotinic acetylcholine receptor competitive modulator (IRAC 4A)	4.0 oz/a	Bayer CropScience, Research Triangle Park, North Carolina
Keystone NXT	acetochlor; atrazine	Chloroacetamide; triazine	Long chain fatty acid inhibitor; photosystem II inhibitor	2.4 qt/a	Dow Agrosciences, Indianapolis, Indiana
Matrix SG	Rimsulfuron	Sulfonylurea	ALS inhibitor	1.5 oz/a	DuPont, Wilmington, Delaware
Blackhawk	Spinosad A & D	Spinosyn	Nicotinic acetylcholine receptor allosteric modulator (IRAC 5)	5.0 oz/a	Dow AgroSciences, Indianapolis, Indiana
GlyStar Plus	Glyphosate	phosphonate	EPSP synthase inhibitor	6.5 fl. oz./gal	Albaugh, LLC Ankeny, Iowa
Dual II Magnum	5-metolachlor	Chloroacetamide	Long chain fatty acid inhibitor	2.5 pt/a	Syngenta AG, Basel, Switzerland





**Table. 2.3.** ANOVA results for natural enemies in 2014 and 2015.

<b>Response</b>	<b>Df</b>	<b>Sum Sq.</b>	<b>Mean Sq.</b>	<b>F value</b>	<b>Pr(&gt;F)</b>	<b>signif.</b>
<b>Geocoris 2014</b>						
Crop	4	231.1	57.78	2.233	0.06535	.
Collection.Type	1	865.9	865.94	33.4643	<0.0001	***
Crop*Collection	4	105.1	26.27	1.0153	0.39955	
Residuals	315	8151.1	25.88			
<b>Nabis 2014</b>						
Crop	4	379.21	94.8	13.0102	<0.0001	***
Collection.Type	1	477.25	477.25	65.4943	<0.0001	***
Crop*Collection	4	164.54	41.14	5.6452	<0.0001	***
Residuals	315	2295.35	7.29			
<b>Orius 2014</b>						
Crop	4	161.22	40.305	5.564	<0.0001	***
Collection.Type	1	137.85	137.855	19.031	<0.0001	***
Crop*Collection	4	68.67	17.168	2.37	0.0524921	.
Residuals	315	2281.81	7.244			
<b>Geocoris 2015</b>						
Crop	4	2744.8	686.19	12.0795	<0.0001	***
Collection	1	3016.5	3016.55	53.1022	<0.0001	***
Crop*Collection	4	2261.9	565.48	9.9545	<0.0001	***
Residuals	540	30675.5	56.81			
<b>Nabis 2015</b>						
Crop	4	142.1	35.53	2.2949	0.05818	.
Collection	1	568.2	568.23	36.6985	<0.0001	***
Crop*Collection	4	191.8	47.94	3.096	0.01547	*
Residuals	540	8361.3	15.48			
<b>Orius 2015</b>						
Crop	4	29.97	7.4927	1.6245	0.1666	
Collection	1	1.46	1.4561	0.3157	0.5744	
Crop*Collection	4	18.9	4.7256	1.0246	0.3939	
Residuals	540	2490.62	4			

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

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**Fig. 2.1.** Experimental plot layout for trials conducted at HAREC, Hermiston, OR. (A) 2014, (B) 2015.

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**Fig. 2.5.** Mean ( $\pm$  SE) number of *Orius* spp. (A), *Geocoris* (B), and *Nabis* spp. (C), 2014.

**Fig. 2.6.** Mean ( $\pm$  SE) number of *Orius* spp. (A), *Geocoris* (B), and *Nabis* spp. (C), 2015.

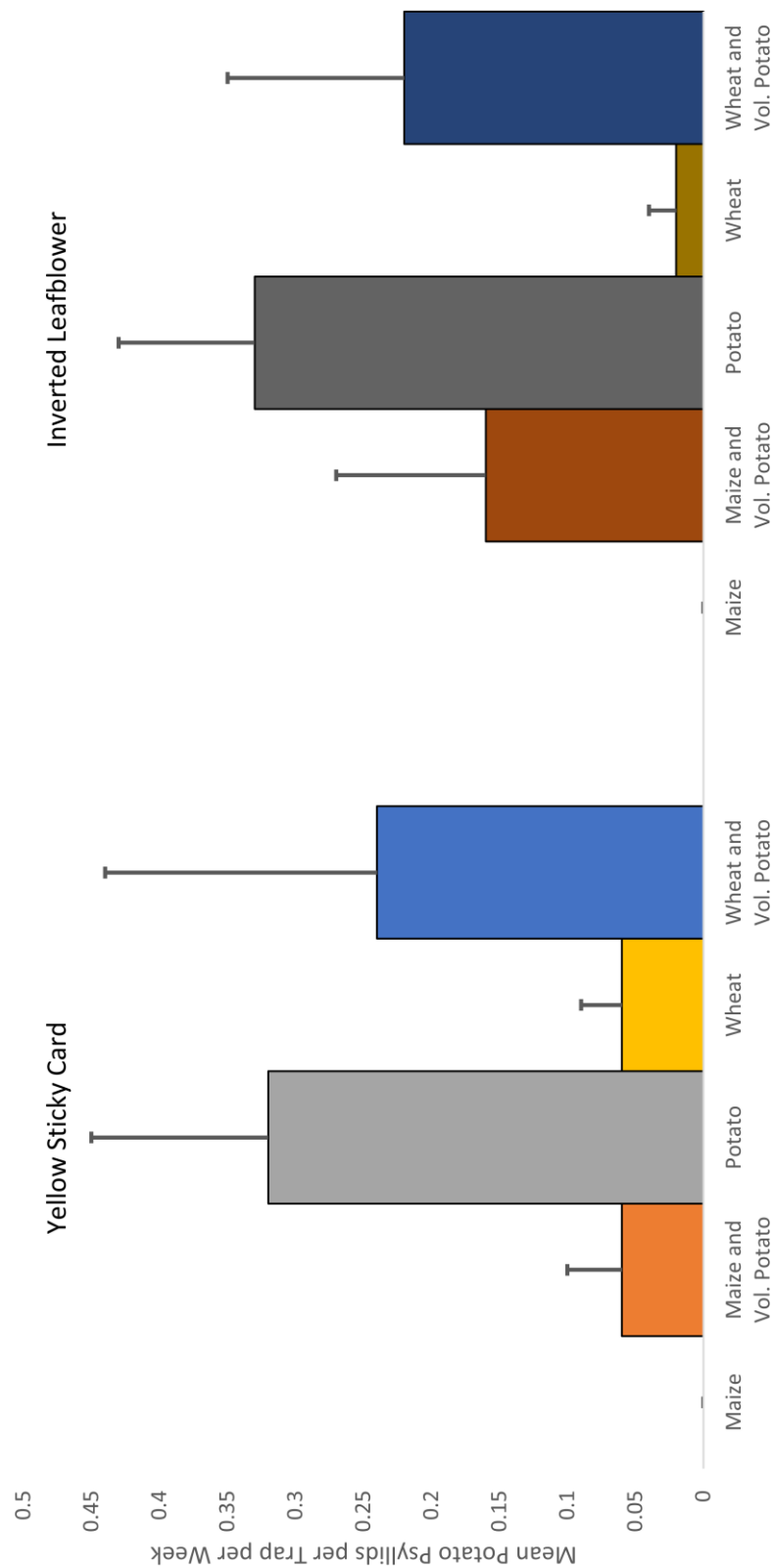
**Fig. 2.7.** Population dynamics of *Orius* spp. (A), *Geocoris* (B), and *Nabis* spp. (C), 2014.

**Fig. 2.8.** Population dynamics of *Orius* spp. (A), *Geocoris* (B), and *Nabis* spp. (C), 2015.

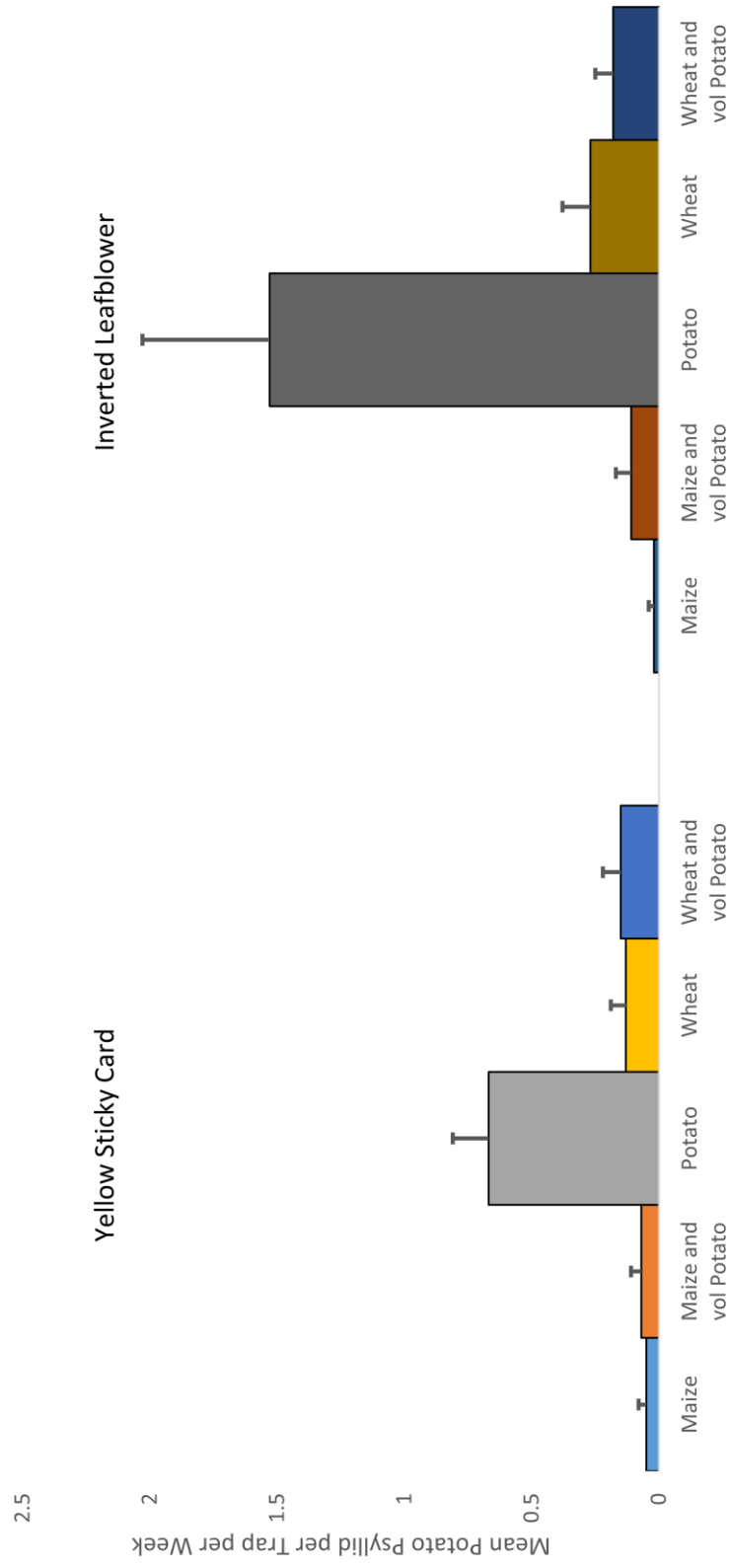
**Fig. 2.1.** Experimental plot layout 2014-2015



**Fig. 2.2.** Mean ( $\pm$  SE) number of potato psyllids per trap per week in five crop systems in 2014.

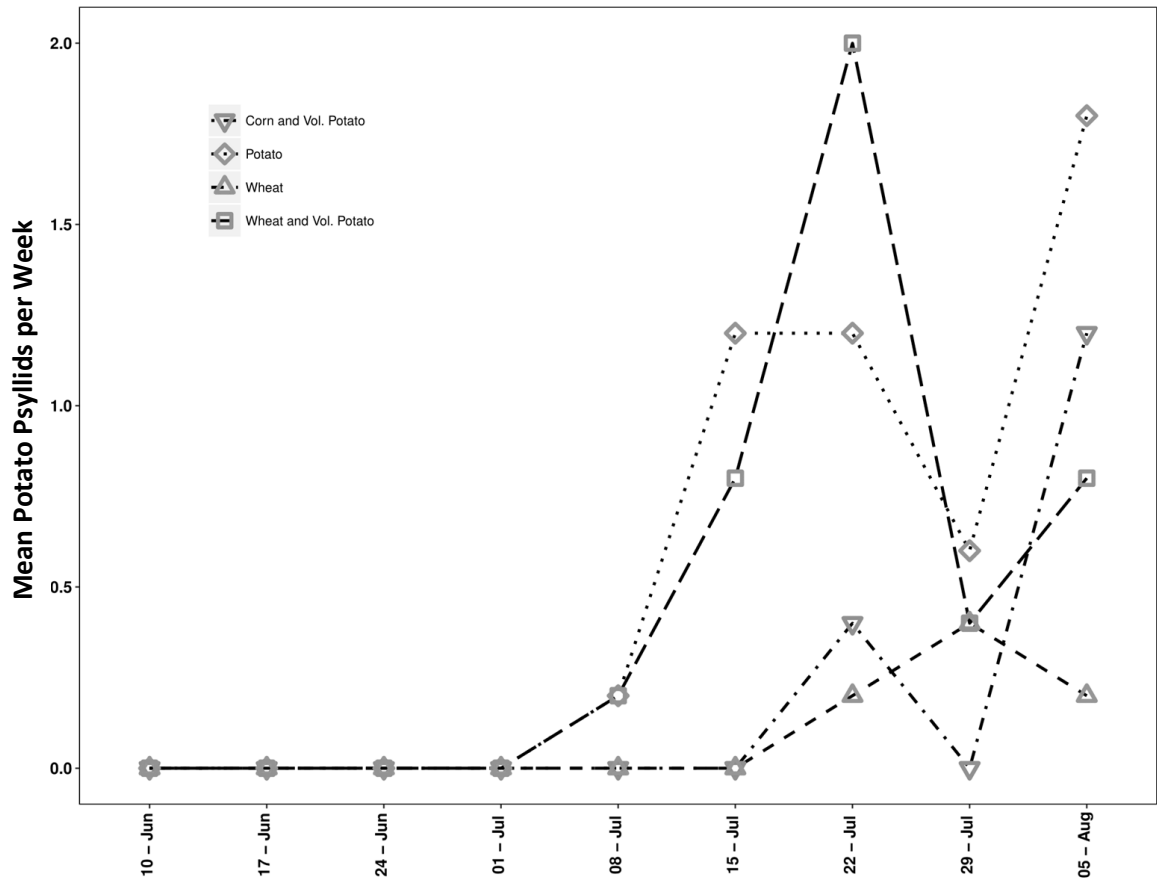


**Fig. 2.3** Mean ( $\pm$  SE) number of potato psyllids per trap per week in five crop systems in 2015.

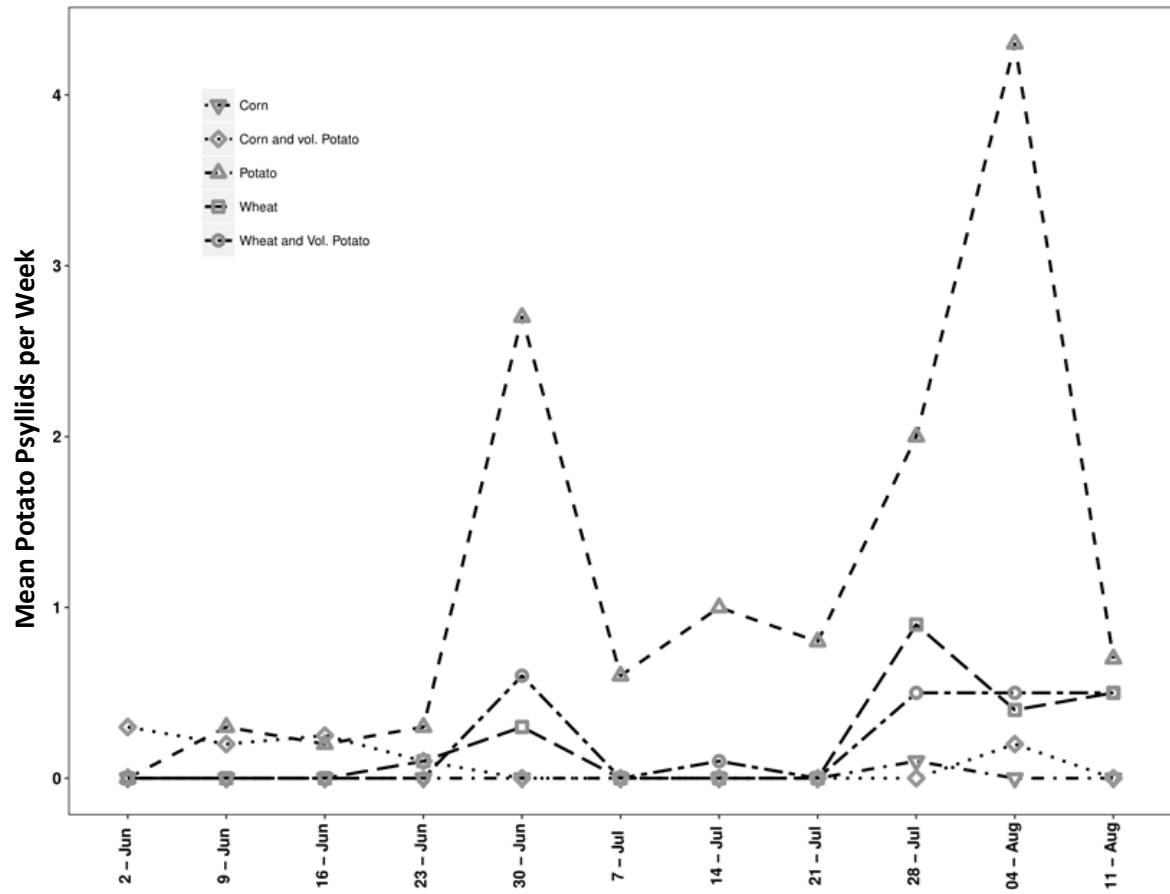


**Fig. 2.4** Population dynamics of potato psyllids in 2014 (A) and 2015 (B).

(A)

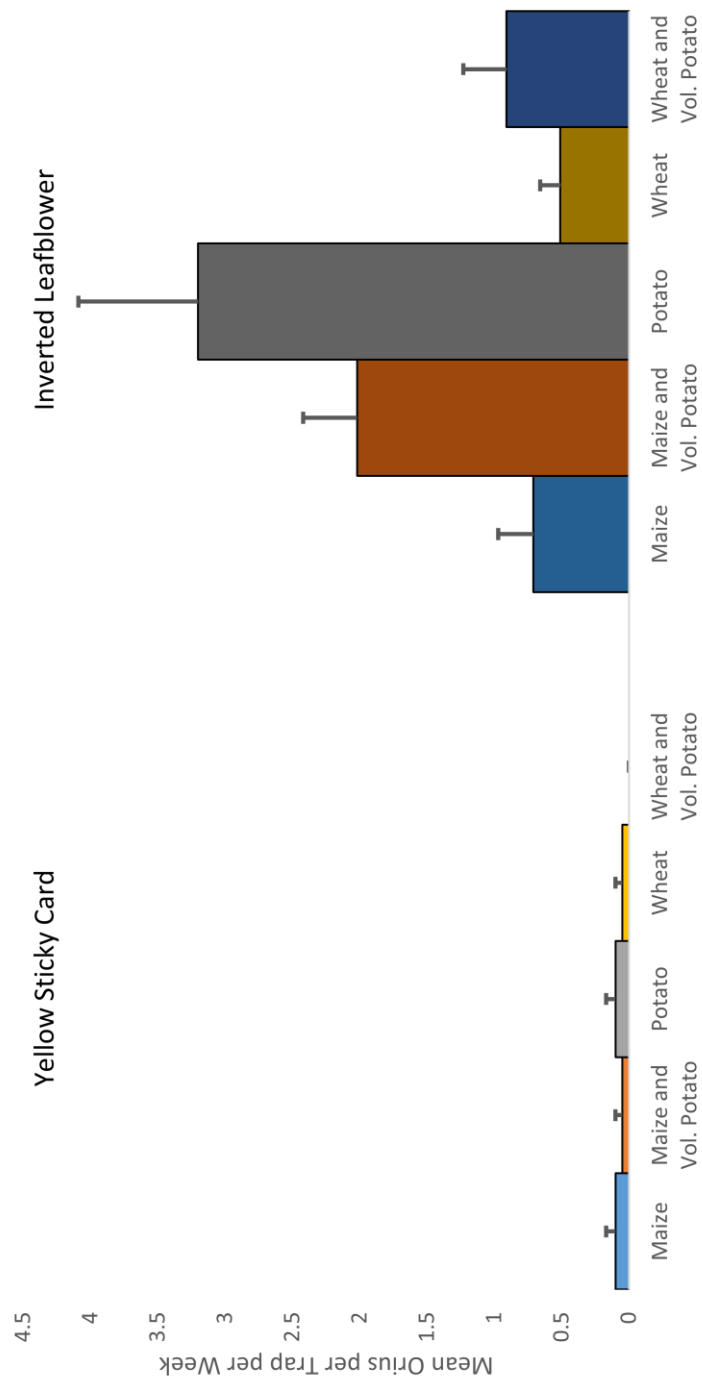


(B)



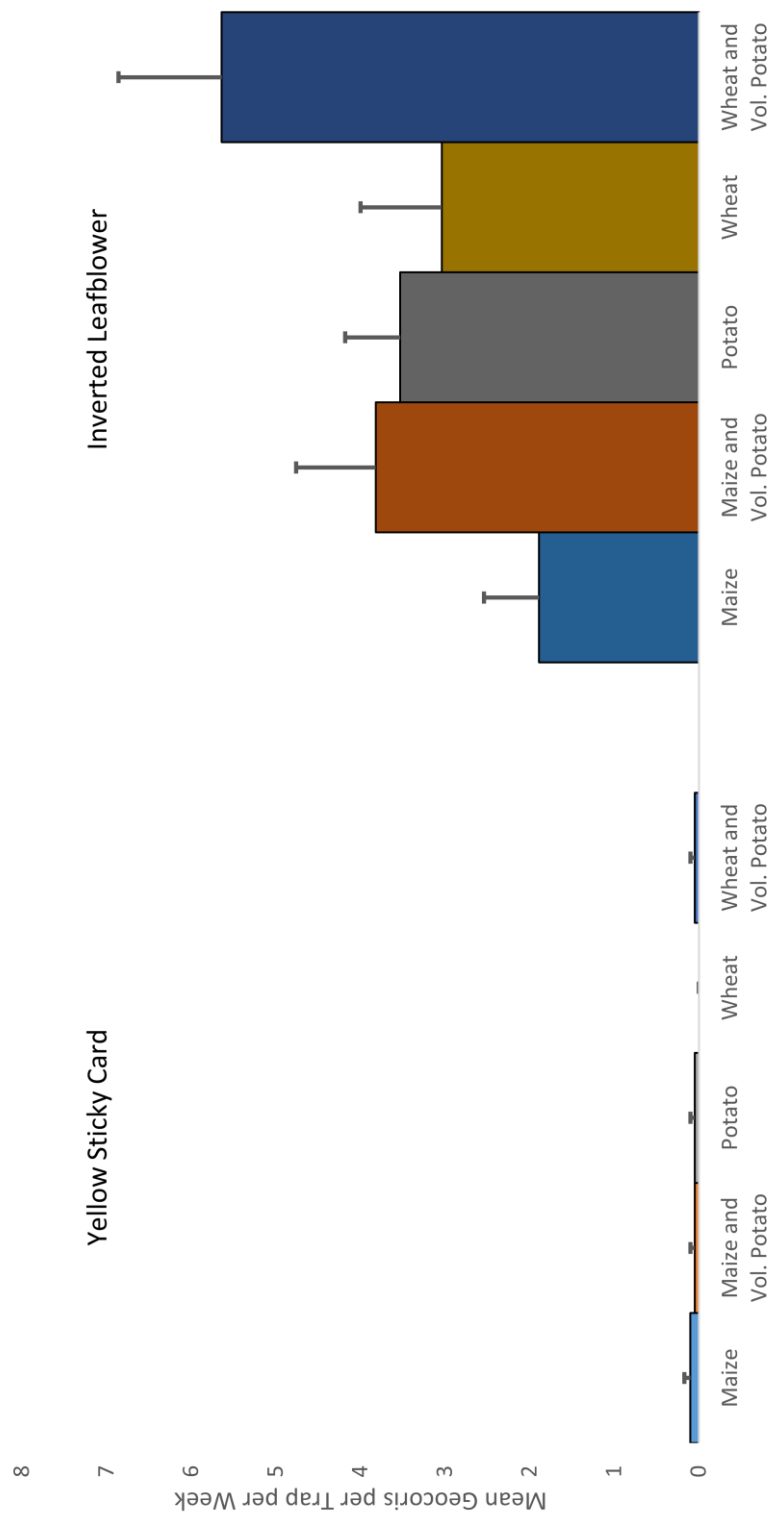
**Fig. 2.5** Mean ( $\pm$  SE) number of *Orius* spp. (A), *Geocoris* (B), and *Nabis* spp. (C), 2014.

(A)

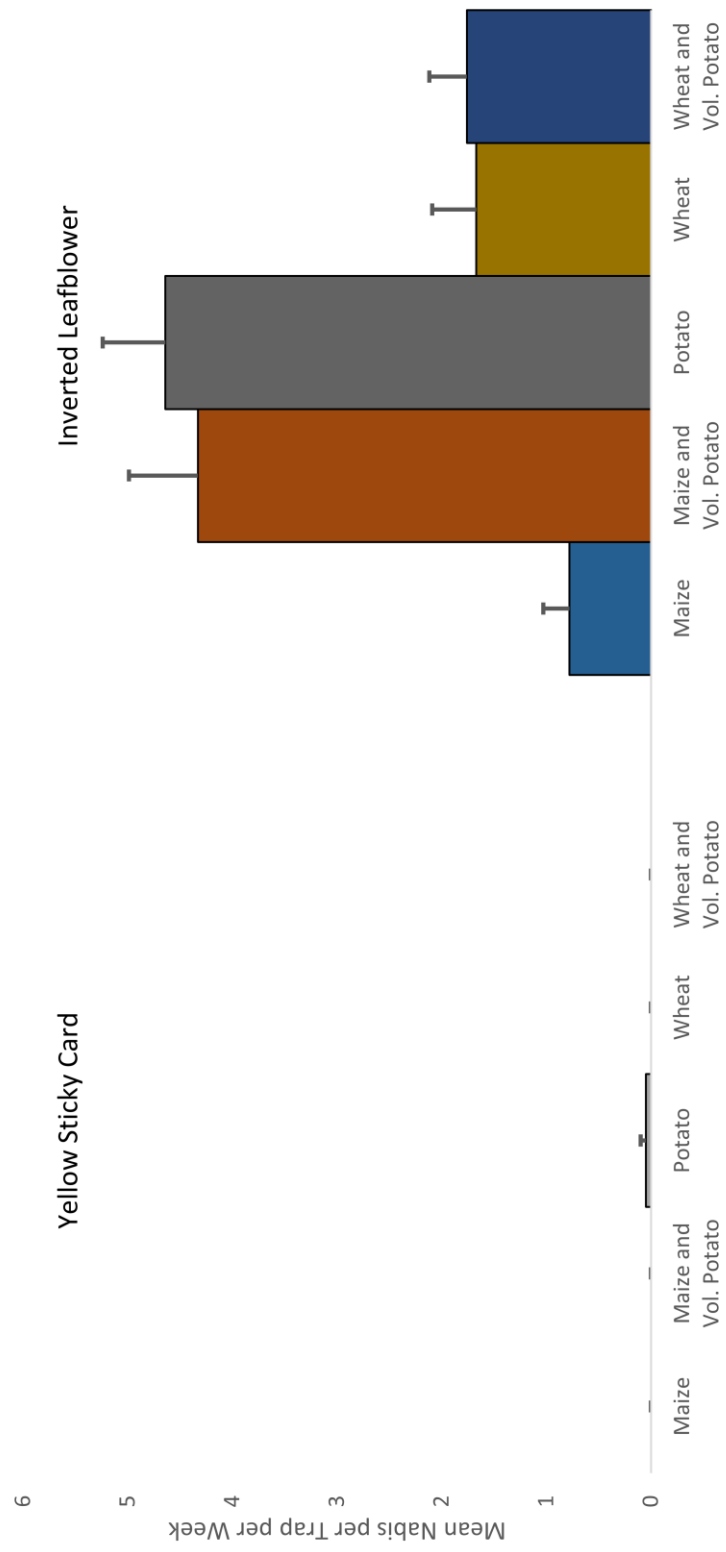




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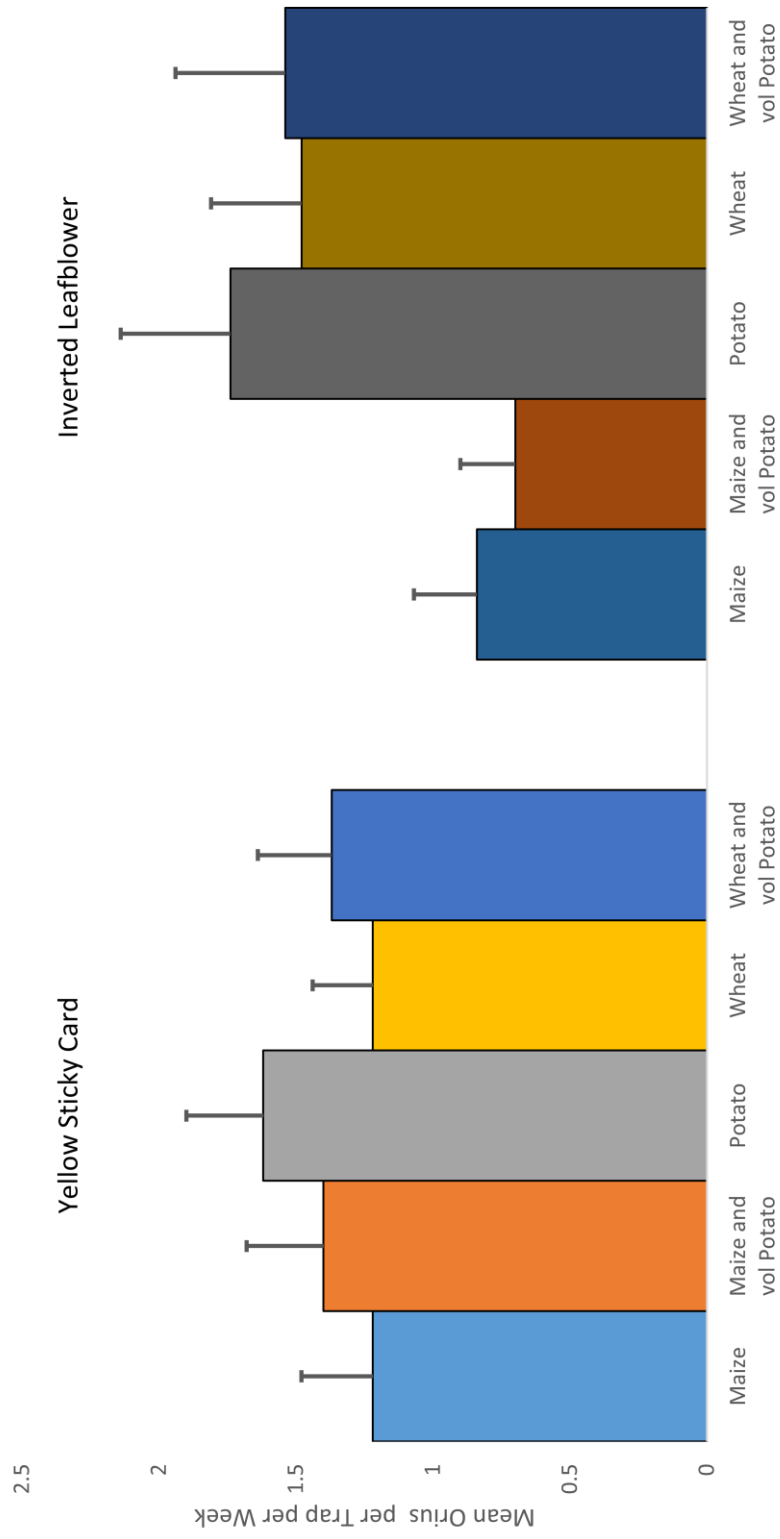


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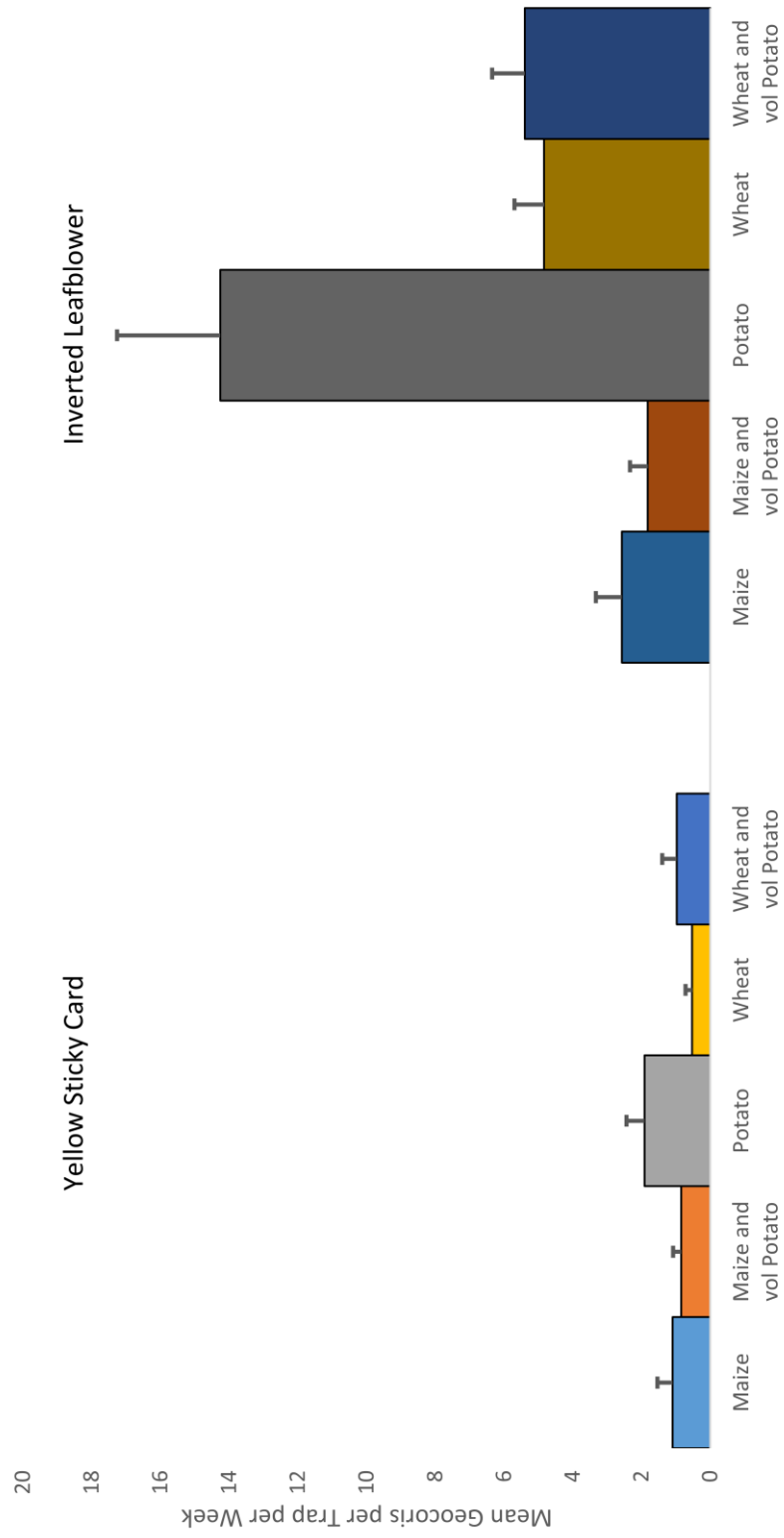


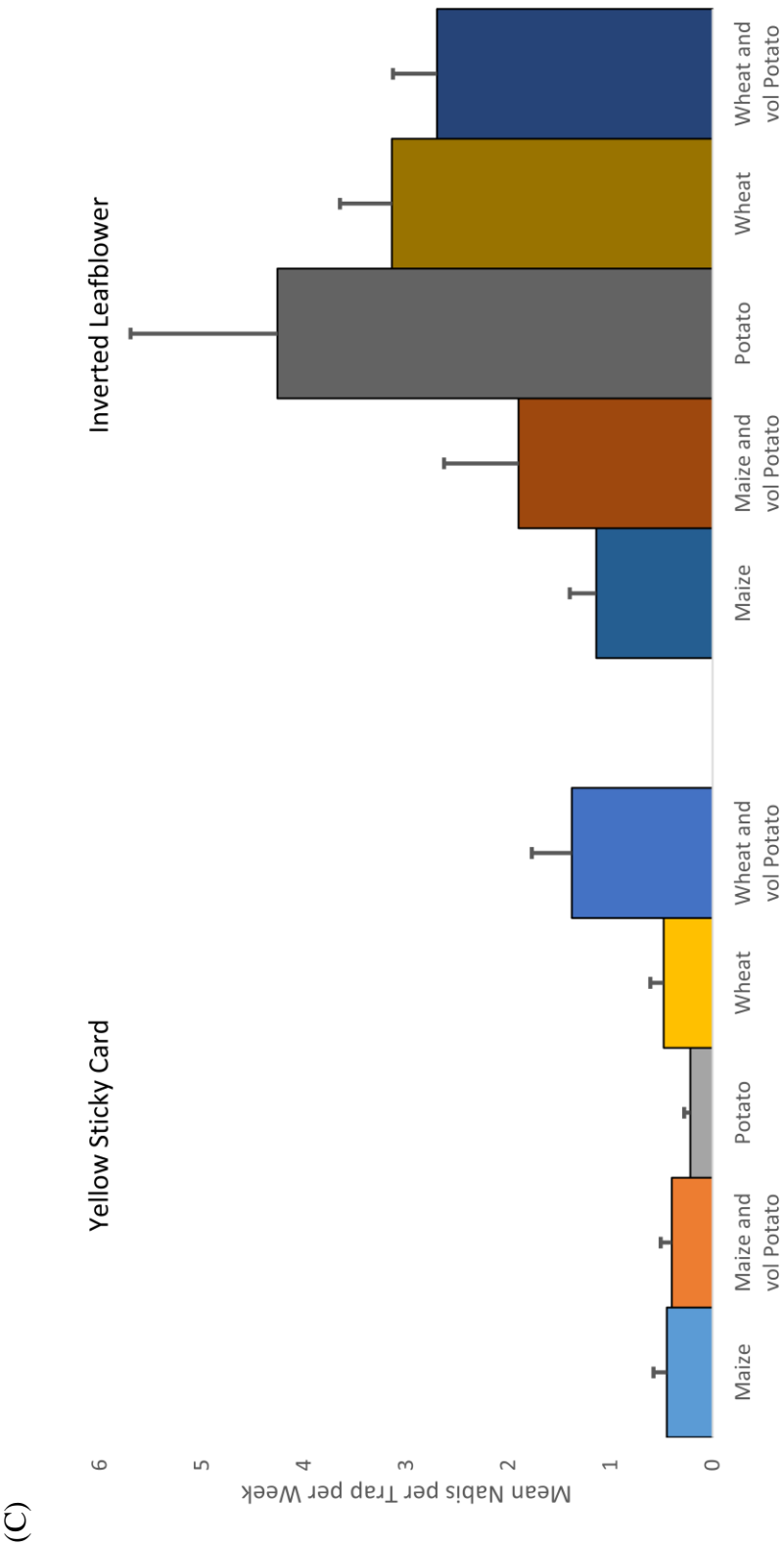
**Fig. 2.6** Mean ( $\pm$  SE) number of *Orius* spp. (A), *Geocoris* (B), and *Nabis* spp. (C), 2015.

(A)



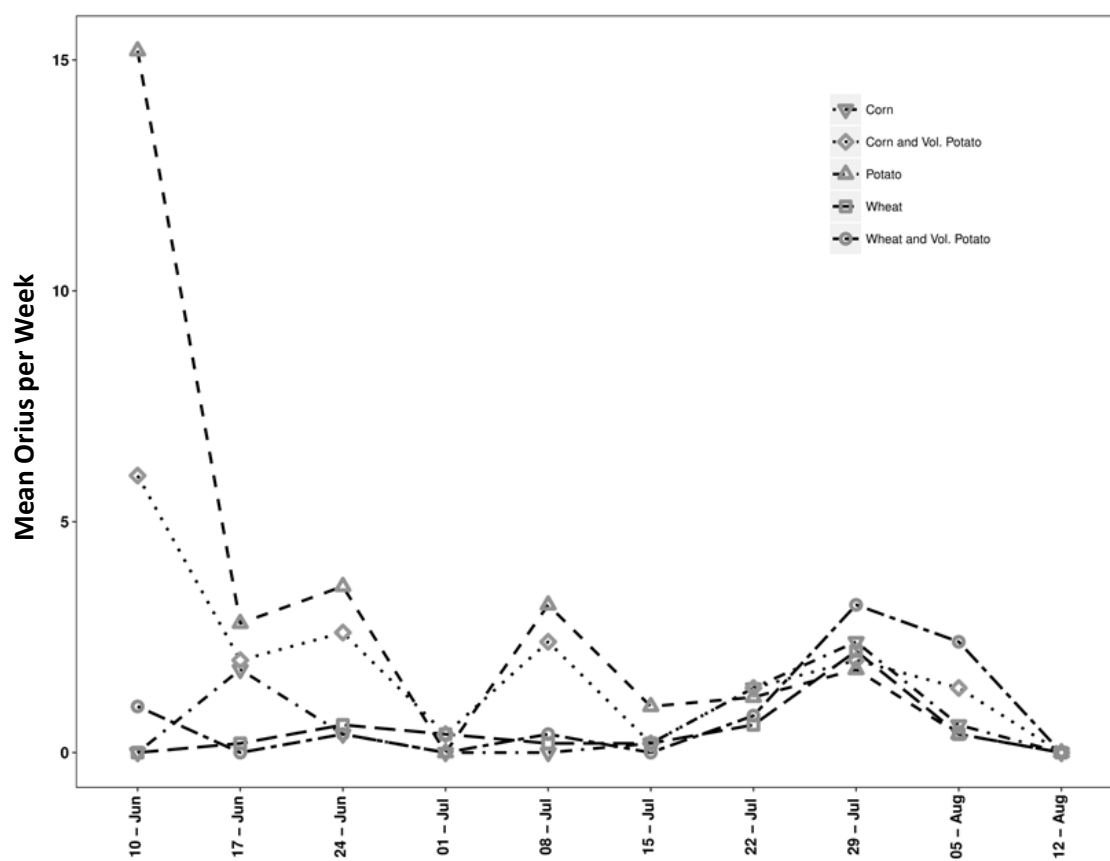
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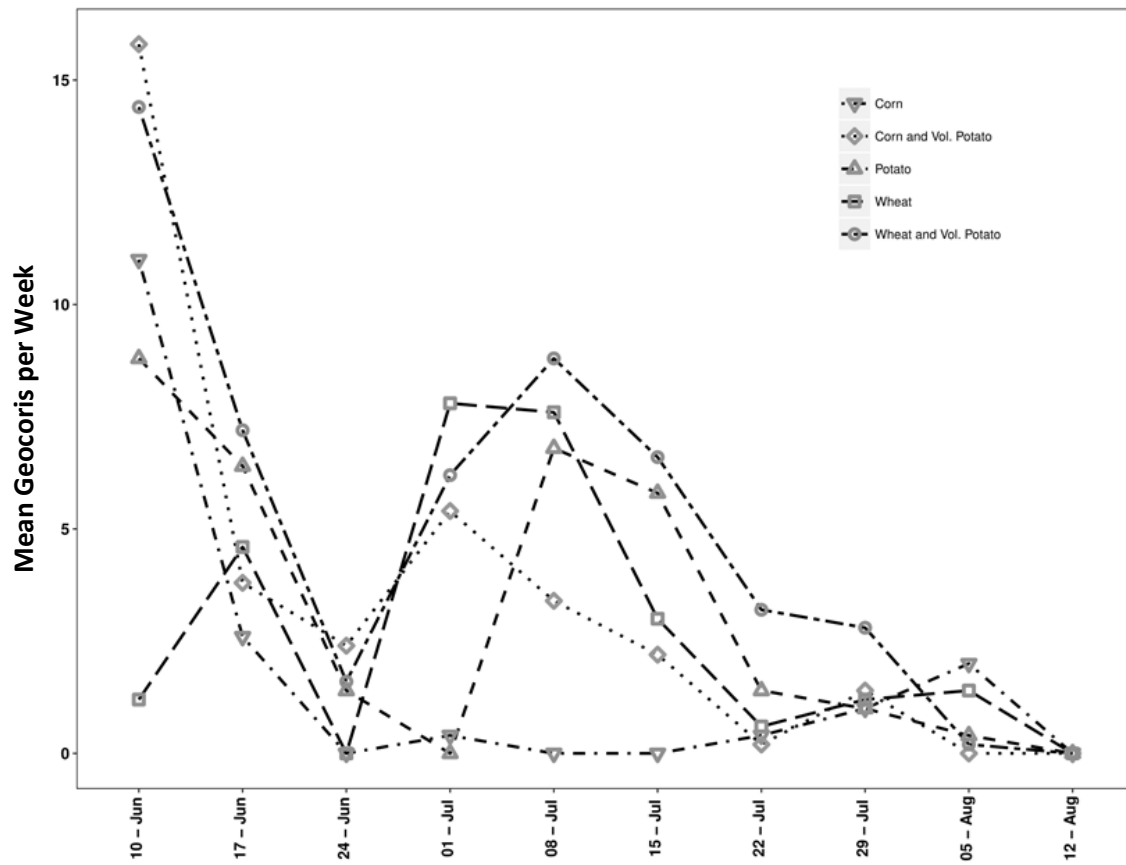


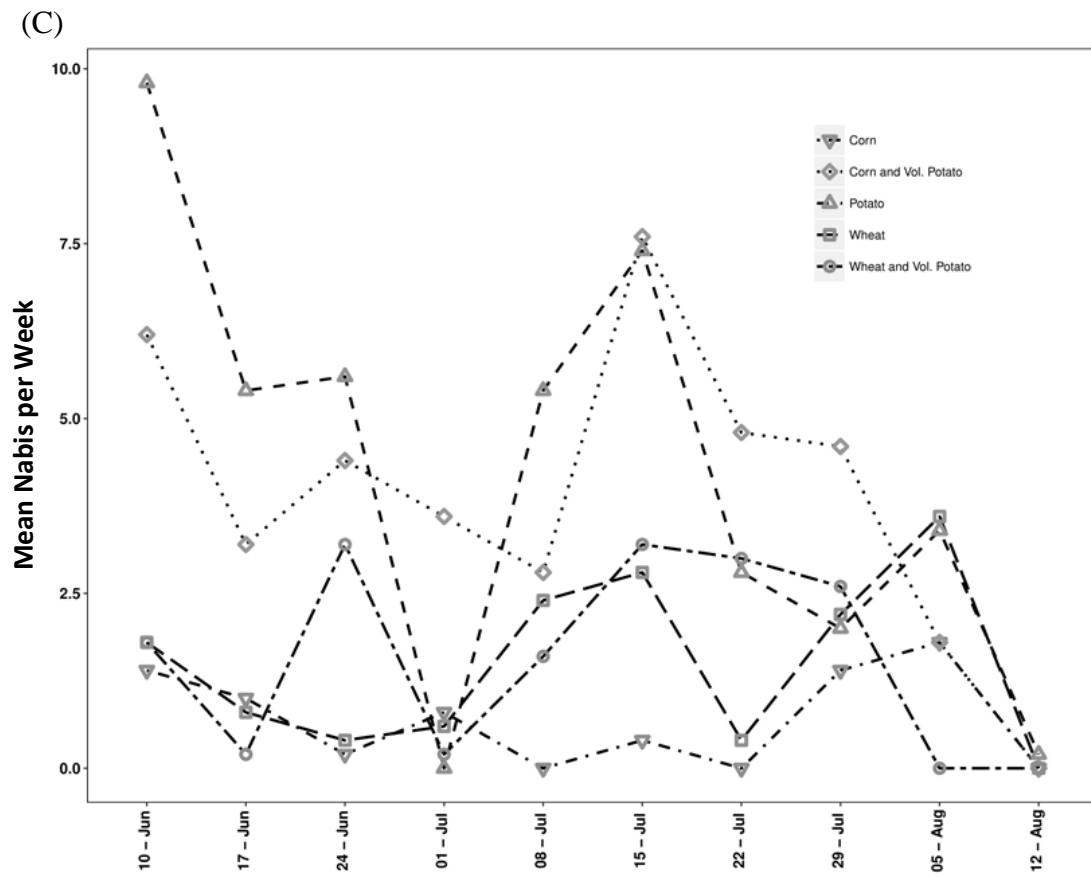
**Fig. 2.7** Population dynamics of *Orius* spp. (A), *Geocoris* (B), and *Nabis* spp. (C), 2014.

(A)



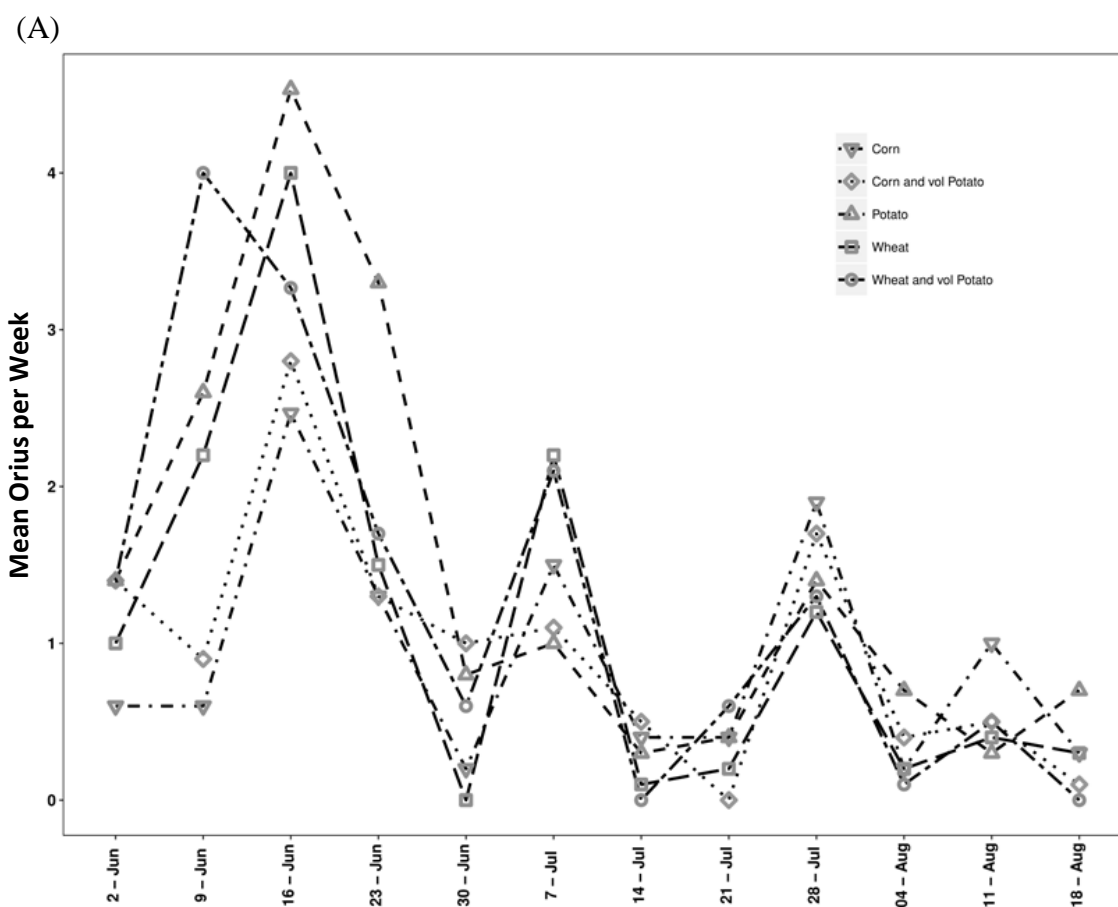
(B)



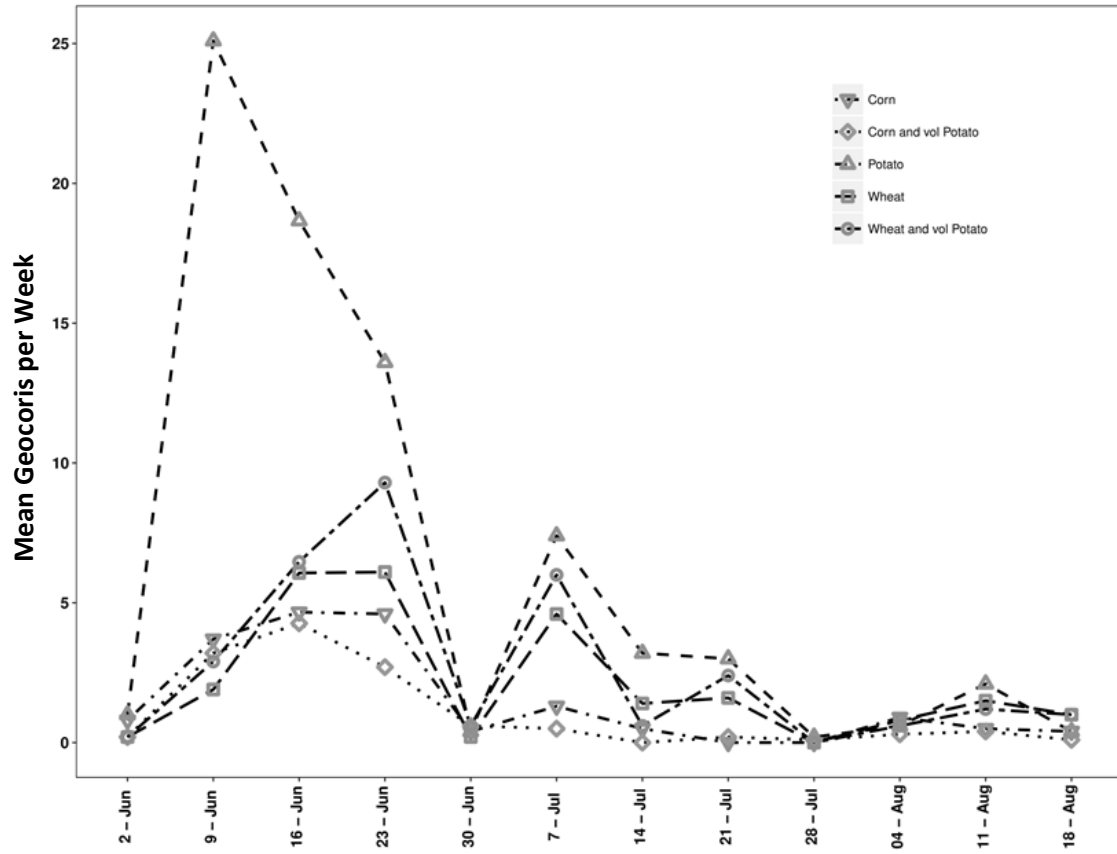




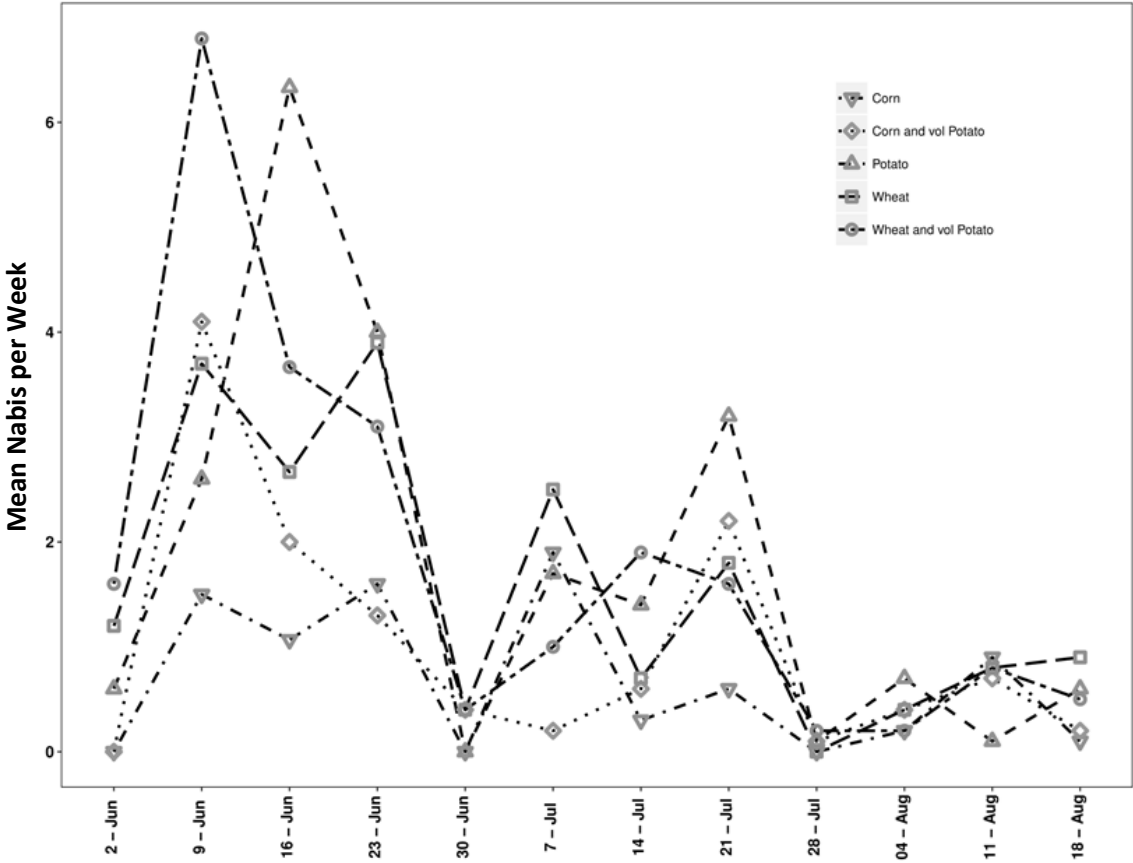
**Fig. 2.8** Population dynamics of *Orius* spp. (A), *Geocoris* (B), and *Nabis* spp. (C), 2015.



(B)



(C)



**Spatial and Temporal Dynamics of Aphids (Hemiptera: Aphididae) in the Columbia  
Basin and Northeastern Oregon**

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### Abstract

Aphid species such as the potato aphid (PA) *Macrosiphum euphorbiae* Thomas and the green peach aphid (GPA) *Myzus persicae* Sulzer are routinely considered the most important pests of potatoes. PA, GPA, and more recently, other aphids (OA) such as the bird cherry-oat aphid *Rhopalosiphum padi* L. have been identified as vectors of multiple plant pathogenic viruses in potatoes, specifically *Potato virus Y* (family *Potyviridae*, genus *Potyvirus*) and *Potato leafroll virus* (family *Luteoviridae*, genus *Luteovirus*). Both of these viruses can cause significant yield losses and reduced tuber quality. Since 2006, an area-wide trapping network consisting of ~60 sites was developed to monitor aphid populations in the Columbia Basin of Oregon (Umatilla and Morrow counties), and in northeastern Oregon (Union and Baker counties). The network was developed through collaboration among researchers, extension faculty and stakeholders. Over a 9-yr period (2006 to 2014), weekly aphid specimens were collected using yellow bucket traps and were then identified and counted to determine population levels during the growing season (May-Sept.). Thus, aphid population data were compiled and subjected to spatial and temporal distribution analysis. Weather data were obtained from an established network of weather stations located in the monitoring areas and were used in a nonparametric multiplicative regression analysis to determine which abiotic variables may impact aphid populations. Weather conditions were characterized using confidence intervals established based on weather data from 1999 to 2005 for each environmental variable. Aphids were found to have a heterogeneous distribution in most years; a few sites had high aphid populations while low numbers were observed at most sites; aphids were also found to correlate with several abiotic variables namely elevation, previous season temperature, and previous season dew point.

**KEY WORDS:** Potato Aphid, *Macrosiphum euphorbiae*, Green Peach Aphid, *Myzus persicae*, population dynamics, nonparametric multiplicative regression, bird cherry-oat aphid, *Rhopalosiphum padi*

## Introduction

Potato production is a mainstay of the agricultural industry in the Columbia Basin of both Oregon and Washington where yields can range from 51,000 kg ha<sup>-1</sup> (23 ton/ac) to 95,000 kg ha<sup>-1</sup> (43 ton/ac) yields rarely matched by any other growing region (Lang et al. 1999, Dung et al. 2015). Approximately 16,187 ha (40,000 ac) of potatoes are planted in Oregon annually with a net worth of roughly \$176,000,000 in 2015 which accounts for 6% of total US production (USDA 2014, Beeles 2016, NASS 2016). Most of Oregon's potato production occurs in Umatilla and Morrow counties; these potatoes are used for high quality processing and value-added products such as French fries and chips (Hopkins et al. 2007, Dung et al. 2015). However, northeastern Oregon (Union and Baker counties) contributes significantly (approx. \$20.4 million in 2015) to the agricultural economy via the production of certified seed and conventional/organic fresh pack potatoes (Union) and high quality processing potatoes (Baker) (NASS 2016).

Many pests affect potato crops, however, aphids (Hemiptera: Aphididae) such as Potato Aphid (PA) *Macrosiphum euphorbiae* Thomas, Green Peach Aphid (GPA) *Myzus persicae* Sulzer, and over 30 species of other aphids (OA) are routinely considered among the most important insect sucking pests (Tamaki et al. 1979, Radcliffe 1982, Alvarez and Srinivasan 2005). Aphids can cause direct feeding damage but their ability to efficiently transmit viruses makes them a top priority of study. *Potato virus Y* (PVY; family *Potyviridae*, genus *Potyvirus*), and *Potato leafroll virus* (PLRV; family *Luteoviridae*, genus *Luteovirus*), are considered the most damaging aphid transmitted viruses (de Bokx and Van der Want 1987, Coutts and Jones 2015). PVY is largely vectored in a non-persistent manner by multiple species of colonizing and non-colonizing aphids, including GPA and PA (Gibson et al. 1988, Shattock 2002, Karasev and Gray 2013, Coutts and Jones 2015). PVY is a latent virus with several different strains which can cause tuber necrosis and yield loss (Crosslin 2013).

GPA and PA are polyphagous and both have a broad host range that largely overlaps with the plants able to carry PVY and/or PLRV, moreover, multiple potato virus species in the field may interact with each other making this insect-plant interaction troublesome (Hameed et al. 2014, Booth and Alyokhin 2016). The pest status of aphids

can be due in part to a combination of polyphagous behavior and high spatial mobility. For instance, GPA commonly overwinters in alate form on peach trees (*Prunus persica* L.) that are uncommon in both the Columbia Basin and Northeastern Oregon (SI Rondon personal communication). They can also overwinter in apterous form in specific microclimates and in weed hosts, where warmer than ambient air temperatures often persist throughout the winter (Walis and Turner 1969, Powell and Mondor 1976, Tamaki et al. 1979, Thomas et al. 1997). PA are additionally known to overwinter in many plants including nightshades (Solanaceae spp.), apples (*Malus pumila* Miller), clover (*Trifolium* spp.), maize (*Zea mays* L.), and several species of roses (*Rosa* spp.) (Walker et al. 1984). GPA have been found to engage in small scale spring flights from overwintering sites on herbaceous winter hosts and peach trees, and subsequently move to key summer hosts as the winter hosts mature and senesce by early summer. Typically, such migration correlates with high populations in valuable crops (Thomas et al. 1997). The role of aphid flight patterns and alternate hosts in virus acquisition has been widely studied (Thomas 1983, Hassan 1985, Fox et al. 1993, Thomas et al. 1997), however such data have been minimally applied to aphid management in the area.

To mitigate virus transmission, area-wide monitoring and in-field scouting programs are widely used in conjunction with insecticide application programs due to low/zero tolerance of processors and/or consumers for damaged tubers (DiFonzo et al. 2015). Aphid control is even more critical, however, in certified seed potato production areas in order to produce disease-free seed stock and to meet Oregon Seed Certification Service standards (<http://seedcert.oregonstate.edu/potatoes>). Implementation of effective integrated pest management (IPM) based on economic thresholds is directly or indirectly related to spatial population dynamics data. The collection of sufficient data on pest geographic distributions and basic biology and ecology enables researchers to recommend more efficient control methods before reaching or exceeding an economic threshold (Kogan 1998). Currently, there are insufficient data on aphid distributions and ecology specifically in the Columbia Basin and Northeastern Oregon for researchers to determine precise economic thresholds.

The trapping network described within this paper already contributes significantly to grower decisions on insecticide use. Growers use the weekly reports as an “alert system” in order to increase their own trapping efforts; they routinely add or subtract traps based on data available. Information is provided via the Potato update (<http://oregonstate.edu/dept/hermiston/trap-reports>) and a newly developed map (<https://andersongeog.maps.arcgis.com/apps/webappviewer/index.html?id=e857a721431642188fa27b04c2f7c270>) presents spatial information but lacks quantitative information. Area-wide potato insect pest monitoring efforts in the Columbia Basin and Northeastern Oregon (Union and Baker Co.) began with establishment of a trapping network in the mid-1970s to provide growers with a tool to track population dynamics, which would serve as an early warning system. Starting in 2006, a more concerted effort was taken where the geographic coordinates of traps throughout the region were recorded along with weather data from several nearby weather stations. Previous researchers have determined that aphid populations are sensitive to environmental variables (Taylor 1977, 1986, Radcliffe and Ragsdale 2002, DiFonzo et al. 2015) but to date such information has not been collected and applied to aphids in the Pacific Northwest, nor has spatial-environmental data been used to augment management practices. Understanding what factors contribute to aphid outbreaks in the Pacific Northwest is necessary to determine the risk, specific to this region that these pests pose to growers. Thus, the objectives of this study were to (1) determine trends in the spatial and temporal dynamics of GPA, PA, and OA populations and (2) examine the relationship between aphids and abiotic environmental variables that could potentially have a significant impact on population levels.

## **Materials and Methods**

### **Trapping network**

The trapping network coordinated by the Oregon State University Irrigated Agricultural Entomology Program is also described by DeBano et al. (2010) and Murphy et al. (2012). Although the trapping network has monitored aphids since the late 1970s, data presented



herein cover the 2006-2014 period where traps were deployed during the potato growing season. GPA and PA were the main sampling focus; a representative sample of the species composition of OA was determined (Table 3.1). Over the course of the study, OA were grouped into one category and undifferentiated because they were not our primary focus. Aphid traps consisted of single, uncovered 18.9 liters (5 gal) yellow buckets filled with 11.4 liters (3 gal) of water plus 2-5 g (0.004-0.011 lb) of copper sulfate used as a preserving agent. Buckets were placed 2 m (2.2 yd) away from the edges of commercial potato fields and captured predominantly winged aphids. On a weekly basis, aphids were filtered out with a fine mesh net, transferred to 20 ml vials containing 70% ethanol and returned to the lab for sorting, counting, and identification using a Leica S8 dissecting scope. Buckets were refilled with water and copper sulfate weekly.

Number of traps deployed, sampling date initiation, and sampling date secession information are presented in Table 3.2. Traps were located in ~50-60 locations in Umatilla, Morrow (Fig. 3.1.) and Union and Baker (Fig. 3.2.) in Northeastern Oregon and were within  $0.05 \pm 0.02$  km ( $0.03 \pm 0.012$  mi) from commercial irrigated crop fields and  $0.58 \pm 0.07$  km ( $0.36 \pm 0.04$  mi) away from roads (Figs. 3.1 and 3.2.). Trapping locations and numbers remained within close proximity between years, but logistical issues resulted in different total number of traps and length of sampling season (Table 3.2).

### **Annual weather trends**

Data from five AgriMet weather stations were collected each year from stations in close proximity to trapping efforts as described above. AgWeatherNet data can be accessed for any station at the U.S. Department of the Interior, Bureau of Reclamation AgriMet site (<http://www.usbr.gov/pn/agrimet/wxdata.html>) or Washington State University AgWeatherNet (<http://www.weather.wsu.edu/>). A list of the environmental variables used are presented in Table 3.3. The 5-yr 95% Confidence Intervals (CIs) for mean monthly temperature, precipitation, and dew point (Figs. 3.3 A, B, and C) were generated from weather data from the 5-yr preceding the study (2001-2005) and values for these variables from the study period (2006-2014) were graphed alongside these 5-yr intervals in order to observe any deviations or trends (Fig. 3.3). Statistically different seasonal averages were

determined when their values fell outside of the CIs. Intervals for minimum temperature, maximum temperature, and mean temperature were calculated by season which consisted of summer (Jul, Aug, Sept), fall (Oct, Nov, Dec), winter (Jan, Feb, Mar), and spring (April, May, Jun). These CIs were used to compare seasonal averages among months for the range of sampling years (2006 – 2014).

### **Exploratory analysis and population dynamics**

In this stage of analysis, aphid count data were considered with no predetermined hypotheses of their spatial distribution and were described with classical descriptive statistics. Statistics were applied to determine the mean, median, range, and metrics of spread. Exploratory analysis was conducted in RStudio (RStudio 2016). Average aphid counts per week were calculated and weekly population trends for traps in the Columbia Basin (Umatilla and Morrow) and Northeastern Oregon (Union and Baker) were graphed to identify temporal differences between the two growing regions. In this analysis, aphids were grouped by mean GPA, PA, and OA and each year was graphed separately.

### **Nonparametric multiplicative regression**

Local mean nonparametric multiplicative regression (LM-NPMR) models were generated to estimate the response of aphid populations to various environmental variables within each season. Environmental data were collected from AgWeatherNet as described above. Gaussian functions were used in LM-NPMR to weight and smooth data points in close proximity to each mean. Since many insect species, aphids included, do not respond to abiotic environmental factors in a linear fashion, but rather a function described by McCune as “hump-shaped,” these nonlinear regression tactics can produce valid results even when many variables are added to the model (Murphy et al. 2012). Additionally, other forms of regression limit responses by assuming linearity or logarithmic associations, LM-NPMR does not. These characteristics allow for examination of complex systems with many potentially influential environmental variables. Weather data were associated with each trap site based on minimum distance between each trap and weather station. These

distances were determined by Murphy et al. (2012) using GPS tools accessible via GPS Visualizer (<http://www.gpsvisualizer.com>). Trap sites were on average 11.5 km away from weather stations and distance ranged from as close as 0.1 km to as far away as 25.6 km. Models were selected based on simplicity,  $xR^2$  values, and biological relevance. The next most complicated model was selected if it produced a greater than 5% increase in  $xR^2$  value over the previous model. Selected models were analyzed for significance with a Monte-Carlo test using 100 iterations. All multiplicative regression analyses were conducted with HyperNiche 2 software (McCune 2011, Murphy et al. 2012).

### **Spatial distribution and abundance**

Mean aphid counts collected at each location were mapped for each year using GPS coordinates and the R package scatterplot3d (Ligges and Mächler 2002, Ligges et al. 2015). The mean numbers of aphids captured at each site over the sampling period were compared to determine the degree of heterogeneity of aphids between trap locations. A Kruskal-Wallis test was used to compare populations of GPA, PA, and OA by trap location (no between species comparisons) because we were unable to transform the data to meet the assumption of normality for a standard analysis of variance (ANOVA). However, the mean abundance of GPA, OA, and PA collected per trap was compared between years using a standard ANOVA as these data did meet the assumptions of ANOVA. These analyses were conducted using RStudio.

## **Results**

### **Annual weather trends**

The relationships between mean monthly temperatures, mean monthly dew point, and mean monthly precipitation from 2006 to 2014 and their 5-yr means (2001-2005) are shown in Fig. 3.3. In general, values outside of the 5-yr CI can be thought of as being different from the preceding five years. Fig. 3.3 A. shows the mean monthly precipitation for each month of the year. Based on the 5-yr data, with the exception of 2012, July follows

a typical pattern (low precipitation); however, in general, there are extreme lows and highs depending on the year. Most years had higher precipitation than the 5-yr average from October to June. Fig. 3.3B. shows the mean monthly temperatures. Some significantly different low temperatures were observed in several years, and especially in Dec-Feb, while few significant highs were observed. With the exception of December and January, most points fell close to the 5-yr CI. Coldest temperatures were observed in December-January, while warmest temperatures were typical in July. Mean dew point (Fig. 3.3C.) follows mean temperature patterns, however dew point shows more variability than temperature, with most years exhibiting significantly lower dew points from Dec-Apr.

### **Exploratory analysis**

In the exploratory analysis stage, we sought to determine structural metrics of the dataset. Data were highly skewed with the mean always being greater than the median, indicating a skewed right frequency distribution and significant deviation from normality (Table 3.4). A right skewed distribution indicates that high aphid captures were only observed at a few locations across all years. The median was 0 for most years and species with a few exceptions, while mean aphid counts (among all species and years) ranged from a minimum of 0.06 (GPA in 2014) to a maximum of 8.54 (OA in 2007) aphids per trap (Table 3.4). Maximum aphid counts also ranged widely, from a maximum count of 3 PA in 2008 to a maximum count of 970 OA in 2007. No data transformations were carried out to address these issues as the Kruskal-Wallis test (discussed in the spatial distribution and abundance section) is a nonparametric test that is resistant to deviations from normality.

Mean counts of GPA, PA, and OA per trap per week of all 9-yr of data are shown in Table 3.5 which contains data from Columbia Basin and Northeastern Oregon traps for 2006-2014. Data show significant differences in collection rate of GPA, PA and OA species ( $F = 17.615$ ;  $df = 8$ ;  $P < 0.0001$ ). In the Columbia Basin, more OA ( $2.88 \pm 0.27$ ) were collected than GPA ( $1.01 \pm 0.14$ ) or PA ( $0.20 \pm 0.03$ ); similarly in northeastern Oregon, more OA ( $6.84 \pm 0.46$ ) were collected than GPA ( $0.21 \pm 0.02$ ) or PA ( $0.59 \pm 0.03$ ). Table 3.4 shows the same data broken down by year. The highest GPA mean number ( $\pm$ SD) was found in 2006 ( $2.06 \pm 12.95$ ) compared to the lowest in 2014 ( $0.06 \pm 0.33$ ); highest

PA mean number ( $\pm$ SD) was found in 2014 ( $1.27 \pm 2.76$ ) compared to the lowest in 2008 ( $0.06 \pm 0.31$ ); highest OA mean number ( $\pm$ SD) was found in 2007 ( $8.54 \pm 53.12$ ) compared to the lowest in 2012 ( $2.27 \pm 5.99$ ).

### **Population dynamics**

In both regions, the population dynamics of GPA, PA and OA were highly variable with definitive peaks in GPA, PA, and OA in some years, however most data show significantly smaller or nonexistent peaks for GPA and PA. Also in both regions, OA population counts tend to dominate the population trends.

In the Columbia Basin, each year exhibits one or more large peaks in aphid numbers (Fig. 3.4.) with first detections usually occurring on the first sampling date and higher numbers occurring by mid-July. Differences between years are evident. For example, in 2010, distinct GPA, PA, and OA peaks occurred in synchrony, while in 2009 peaks occurred discordantly. In most years GPA populations remained extremely low, with the exception of 2012 where in the third week of collecting, significantly more GPA were captured than OA or PA. PA populations followed a similar pattern to GPA with capture rates tending to be similar in most years.

In northeastern Oregon (Fig. 3.5.), aphids were found on the first sampling date or by late June and peaks occurred in most years by late July. OA was collected at a higher rate than GPA and PA in almost every week of sampling. OA collection rates in northeastern Oregon showed more definitive peaks than those in the Columbia Basin, and after each peak, OA collections tended to decrease. GPA were rarely collected in most weeks while more PA were collected than GPA for stretches of several weeks (i.e. 2011, 2012, and 2013). The time of peak aphid capture was highly variable between years, species, and locations. Peak capture of OA usually occurred between mid-July to mid-August in northeastern Oregon, whereas in the Columbia Basin it occurred variably between June and August depending on the year.

### **Nonparametric multiplicative regression**

Final nonparametric multiplicative regression models for each year and species along with sensitivities,  $xR^2$ , and  $P$  values are shown in Table 3.6. Final models were selected on the basis of an additional variable explaining less than 5% of the existing model's variation. Final models explained between 25 and 56% of the variability in aphid counts, and all 7 significant models had one variable solution (Table 3.6). When species were analyzed separately, OA was found to correlate with environmental variables in the years 2008-2012, PA was found to correlate with environmental variables in 2010 and 2011, and GPA was not found to correlate with any environmental variables. Previous season mean dew points, mean temperature, and in 2009, elevation, were the only environmental variables found to explain a portion of spatial variation in aphid trap numbers. In 2008, previous fall temperatures and in 2011 preceding spring temperatures were correlated with OA spatial variation; from 2010 to 2012, previous season dew point correlated significantly with counts of OA and PA (Table 3.6). Correlations with dew point and temperature were positive associations; as dew point and temperature rose we were more likely to collect a higher number of aphids. Traps located in regions with higher temperatures preceding that season's sampling were also associated with higher capture rates. In 2009, elevation correlated significantly; traps at higher elevations were associated with higher capture rates. Spatial variation in OA counts was more likely to correlate with environmental variables than PA (significant models in 2010 and 2011) or GPA. GPA were not found to correlate with any variables. In 2006, 2007, 2013, and 2014 no significant models were generated at an  $xR^2$  cutoff of 25%.

### **Spatial distribution and abundance**

The spatial distribution of aphids appears to be highly variable, the trap counts varied significantly between trapping locations for multiple species-year combinations as determined by a Kruskal-Wallis test (Table 3.4). However, some species-year combinations showed no differences between trap locations, which indicates that collection rates were homogeneous in those years. GPA were found to have differences between sites at the  $\alpha = 0.05$  level in 2006-2008, 2010, and 2013; PA were found to have differences between sites in 2006, 2007, and 2009-2013; OA were found to have differences in all

years (2006-2014) (Table 3.4). These differences were mapped in 3 dimensional scatterplots with X and Y as latitude and longitude of traps and Z as mean aphids. Scatterplot maps can be seen in Appendix Figs. 1 and 2.

### Discussion

Aphid populations exhibit a complex response to environmental variables. In our analysis, they are influenced principally by previous season dew point, previous season temperature, and to a lesser extent by elevation, and are also distributed heterogeneously both spatially and temporally. Based on these data, aphid populations are greater when previous season dew point and temperature are higher and at higher elevations. For the two years where previous season temperature had the greatest correlation with OA, the temperatures in those previous seasons were higher than most other years and within the 5-yr CI. For years where previous season dew point correlated significantly with aphids, those dew points also tended to be higher and within the 5-yr CI. For 2006, 2007, 2013, and 2014, we did not find any correlations between variables and aphid numbers. Of all the variables tested, high previous season mean dew point showed the strongest correlation with aphid incidence in multiple years. Studies by DeBano et al. (2010) and Murphy et al. (2012) showed similar trends in the Columbia Basin for the potato tuber worm (*Phthorimaea operculella* Zeller) and the beet leafhopper (*Circulifer tenellus* Baker) respectively. Based on the averages of 2006 to 2014, GPA, PA, and OA showed significant correlation specifically with previous spring mean dew point. However, when broken down into individual years the trend weakened for GPA and PA substantially.

The temporal dynamics of target aphids in this study were highly variable and our concluding analysis of these trends illustrates the difficulty in managing aphid pests on a weekly basis. For example, weekly average OA were over 100 aphids per trap on July 24, 2007 in northeastern Oregon traps and then decreased to under 20 aphids per trap the next week. And in years like 2007 and 2009 in the Columbia Basin, aphid collections were peaking and crashing over most of the sampling period. Such a trend makes prediction of future aphid numbers difficult, and for growers this translates into a lack of knowledge on how many traps to place as well as when to take control measures.

Data that follow such a trend are often considered to be ‘auto-correlated’ where one week’s collection is highly dependent and conditional on the previous week. The potential exists to model these temporal dynamics as a Hawkes process, which could produce hypothetical future counts based on existing data, but the development of such a model was outside of the scope of this study.

However, inference can still be made from our analysis, specifically that trapping rates are highly variable and that previous fall, winter, and/or spring conditions have the greatest influence on aphid populations. Most years had particularly cold winters, which may have been detrimental to aphids the following year and could potentially have led to the extremely low trapping rates of GPA and PA. When a dominant variable leads to lower populations, this allows for other less significant variables (elevation) to come to the forefront. Elevation and dew point are closely linked with temperature but differ enough that their correlations are not surprising and may suggest correlations with such linked variables. There was a trend for increased aphid population levels at higher elevations (~250 m above sea level in Columbia Basin traps and ~850 m above sea level in Northeastern Oregon) and dew points (~2.5-8 C) conditions that likely coincide with agricultural areas as the majority of potatoes in the Columbia Basin are grown further from the Columbia River (high elevation) and are also managed with center pivot irrigation where the added moisture likely raises local dew point.

A number of issues also may limit the explanatory power of our results. The lack of correlation in GPA and PA populations was particularly surprising, but may be due to the low number of aphids collected and the high frequency of zero counts of GPA and PA. This may have inhibited findings of significance even though nonparametric analysis is considered robust to such distributions (McCune 2011). However, some trends seem to emerge from qualitative data analysis. Peak aphid populations for GPA, PA, and OA tended to occur sporadically, sometimes occurring in the same weeks, other times occurring quite disparately. Such findings suggest that aphid numbers, regardless of species, may be due to highly localized conditions that could not be explained by our weather data. If true, this would be in agreement with previous observations on aphid population dynamics and biology (Radcliffe and Ragsdale 2002). Aphids possess the



ability to disperse widely in alate form often in response to overcrowding on a particular host and are highly dependent on wind speed and direction, although they do exhibit some flight control especially on initiation and cessation of flight (Radcliffe and Ragsdale 2002). Environmental variables can potentially serve as a proxy for aphid flight responses but a precise measure of behavioral traits is not considered by an analysis of environmental variables. Given the heterogeneity observed here, it is likely that the level of precision achieved in our analysis was inadequate at estimating the conditions and aphid numbers at individual trapping locations, but we were able to identify some variables at the regional level (e.g. previous season high temperature and dew point) that correlated with aphid collections in our traps. The nature of this study was not to estimate numbers at individual traps but rather to determine such region-wide ends.

Our results may have opened the door to further analyses and potentially to improved pest management in the future. Seed potato production demands a near 0% rate of disease incidence which almost always requires insecticide applications to achieve, even at extremely low capture rates (DiFonzo et al. 2015). Given the heterogeneous distributions of aphids and high degree of temporal variability, growers should be encouraged to maintain adequate sampling rates even when aphid numbers are low. Our findings may also indicate the overall success growers have in controlling GPA and PA as the low numbers may represent successful suppression of these insects with insecticides, and the heterogeneity may be influenced by individual applications. It was beyond the scope of this study to account for grower insecticide use.

Our results highlight the need to study the impacts of OA on virus transmission and crop damage, as OA were often collected at a rate 10 times that of GPA and PA. If indeed insecticides were controlling GPA and PA and explain the low numbers observed, in most years insecticides were potentially having a much smaller effect on OA. OA have until recently been largely ignored in pest management programs in potato production areas, but recent findings suggest they are capable of transmitting potato viruses, albeit at a lower rate (Mondal et al. 2016). High OA population numbers however, may compensate for their inefficient transmission. Of the OA collected, mint aphids (*Ovatus crataegarius* Walker) make up roughly 14%, mealy plum aphids (*Hyalopterus pruni* Geoffroy) 12%,

and bird cherry-oat aphids (*Rhopalosiphum padi* L.) 10% (Murphy 2013). These other aphids are rarely categorized as potato pests, and rarely if ever are specific management tactics taken against them in potatoes. The role of OA in potatoes has yet to be fully determined, but given the prevalence of aphid-transmitted viruses and the low collection rates of GPA and PA, it seems possible that OA are a significant contributor to potato damage in the area.

Given the generally weak correlations observed with abiotic variables, we have little predictive power to determine aphid distributions based off a given set of environmental conditions. Another possibility is that our observed variables were a proxy for some other unmeasured variable, which is confounding the results. This is quite often the case in studies where many variables are accounted for; one or more important variables are left out. However, this finding is the first quantitative assessment of such variables in the area, and could potentially provide the foundation for future monitoring programs. Given a predictive model, economic thresholds could be developed, and growers could potentially use field dew point and temperature variables to modify management efforts at the field level. For example, higher dew point could indicate to growers to deploy more aphid traps or to scout fields for apterous aphids.

Further research is necessary to identify whether other aphids preferentially feed on potatoes during the growing season, whether they are contributing significantly to virus spread in the field, and whether they are collected in our traps in their search for other hosts. Also, the extent of aphid migration within the Columbia Basin and origin of collected aphids are both important areas of future study. In our design, it is unclear where collected aphids originate; they could be making short flights on the order of < 1 km or they could be appearing from long-range migration. Detailed studies on ecology and migration could provide a better understanding of aphid biology and help researchers to predict population outbreaks.

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**Table 3.1. Other aphids found in the Columbia Basin and Northwestern Oregon**

<b>Genus / Species</b>	<b>Common Name</b>
<i>Acyrtosiphon pisum</i>	pea aphid
<i>Anoecia spp.</i>	-
<i>Aphis craccivora</i>	cowpea aphid
<i>Aphis fabae</i>	bean aphid
<i>Aphis spp.</i>	-
<i>Aulacorthum spp.</i>	-
<i>Brachycaudus spp.</i>	-
<i>Brevicoryne brassicae</i>	cabbage aphid
<i>Capitophora spp.</i>	-
<i>Carolinaia spp.</i>	-
<i>Cavariella aegopodii</i>	carrot-willow aphid
<i>Ceruarphis spp.</i>	-
<i>Diuraphis noxia</i>	Russian wheat aphid
<i>Dysaphis spp.</i>	-
<i>Eucallipterus spp.</i>	-
<i>Forda spp.</i>	-
<i>Hayhurstia atriplicis</i>	chenopodium aphid
<i>Hyadaphis spp.</i>	-
<i>Hyalomyzus spp.</i>	-
<i>Hyalopterus pruni</i>	mealy plum aphid
<i>Hyperomyzus spp.</i>	-
<i>Macrosiphoniella spp.</i>	-
<i>Macrosiphum euphorbiae</i>	potato aphid
<i>Metopolophium spp.</i>	-
<i>Mindarus spp.</i>	-
<i>Myzaphis spp.</i>	-
<i>Myzus persicae</i>	green peach aphid
<i>Myzus spp.</i>	-
<i>Nearctaphis spp.</i>	-
<i>Ovatus crataegarius</i>	mint aphid
<i>Rhopalomyzus spp.</i>	-
<i>Rhopalosiphum spp.</i>	-
<i>Schizaphis spp.</i>	-
<i>Sitobion spp.</i>	-
<i>Tetraneura spp.</i>	-
<i>Thecabius spp.</i>	-
<i>Therioaphis spp.</i>	-
<i>Tinocallis spp.</i>	-
<i>Uroleucon spp.</i>	-



**Table 3.2.** Number of traps and dates of activity from the trapping network, 2006-2014.

Year	No. traps per region	Date trapping began		Date trapping ended	
		Columbia Basin	Northeastern Oregon	Columbia Basin	Northeastern Oregon
<b>2006</b>	67 (35, Columbia Basin; 32, Northeastern Oregon)	25-May	10-Jun	7-Sep	5-Sep
<b>2007</b>	30 (15, Columbia Basin; 15, Northeastern Oregon)	1-Jun	12-Jun	29-Aug	4-Sep
<b>2008</b>	57 (35, Columbia Basin; 22, Northeastern Oregon)	5-Jun	10-Jun	4-Sep	2-Sep
<b>2009</b>	60 (35, Columbia Basin; 25, Northeastern Oregon)	11-Jun	9-Jun	13-Aug	1-Sep
<b>2010</b>	64 (36, Columbia Basin; 28, Northeastern Oregon)	17-Jun	7-Jun	12-Aug	30-Aug
<b>2011</b>	61 (34, Columbia Basin; 27, Northeastern Oregon)	16-Jun	14-Jun	11-Aug	29-Aug
<b>2012</b>	61 (34, Columbia Basin; 27, Northeastern Oregon)	16-Jun	6-Jun	11-Aug	29-Aug
<b>2013</b>	59 (34, Columbia Basin; 25, Northeastern Oregon)	2-May	5-Jun	27-Sep	26-Aug
<b>2014</b>	25 (36, Columbia Basin; 25, Northeastern Oregon)	NA	3-Jun	NA	25-Aug

**Table 3.3.** List of abiotic environmental variables used to conduct non-parametric multiplicative regression analysis of aphid population data, 2006-2014.

Spring (14 variables)	Summer (18 variables)	Fall (22 variables)
Latitude	Latitude	Latitude
Elevation	Elevation	Elevation
Previous fall:	Previous fall:	Previous fall:
Mean temp	Mean temp	Mean temp
Mean precipitation	Mean precipitation	Mean precipitation
Mean dew point	Mean dew point	Mean dew point
Mean wind speed	Mean wind speed	Mean wind speed
Previous winter:	Previous winter:	Previous winter:
Minimum temp	Minimum temp	Minimum temp
Mean precipitation	Mean precipitation	Mean precipitation
Mean dew point	Mean dew point	Mean dew point
Mean wind speed	Mean wind speed	Mean wind speed
Current spring:	Previous spring:	Previous spring:
Max temp	Max temp	Max temp
Mean precipitation	Mean precipitation	Mean precipitation
Mean dew point	Mean dew point	Mean dew point
Mean wind speed	Mean wind speed	Mean wind speed
	Current summer	Previous summer
	Mean temp	Mean temp
	Mean precipitation	Mean precipitation
	Mean dew point	Mean dew point
	Mean wind speed	Mean wind speed
		Current fall
		Mean temp
		Mean precipitation
		Mean dew point
		Mean wind speed
Spring: Mar., April, and May; Summer: June, July, and Aug; Fall: Sept., Oct., and Nov.; Winter: Dec., Jan., and Feb.		

**Table 3.4.** Summary statistics and Kruskal-Wallis chi-square values for aphids differentiated by species and year.

Species	Year	N	Min	Max	Mean	Med.	Std. dev.	Skewness	Kurtosis	SE	X <sup>2</sup>	df	P value
GPA	2006	860	0	307	2.06	0	12.95	16.84	363.85	0.44	152.03	65	<0.0001
GPA	2007	390	0	38	0.58	0	2.36	11.08	161.34	0.12	46.374	29	0.02153
GPA	2008	768	0	15	0.22	0	0.92	8.33	102.3	0.03	177.72	57	<0.0001
GPA	2009	660	0	4	0.12	0	0.46	4.82	28.32	0.02	75.544	60	0.08506
GPA	2010	660	0	9	0.13	0	0.56	8.13	102.09	0.02	91.543	63	0.01090
GPA	2011	601	0	3	0.09	0	0.32	3.9	18.79	0.01	71.246	60	0.15180
GPA	2012	593	0	53	0.46	0	2.99	12.12	179.76	0.12	50.754	60	0.79670
GPA	2013	838	0	71	1.1	0	4.79	9.92	124.35	0.17	108.15	57	0.00005
GPA	2014	288	0	4	0.06	0	0.33	7.69	76.13	0.02	22.266	24	0.56340
Species	Year	N	Min	Max	Mean	Med.	Std. dev.	Skewness	Kurtosis	SE	X <sup>2</sup>	df	P value
OA	2006	837	0	340	8.33	2	22.72	7.49	77.54	0.79	381.18	65	<0.0001
OA	2007	386	0	970	8.54	1	53.12	15.98	278.39	2.7	153.04	29	<0.0001
OA	2008	767	0	150	3.43	0	9.78	7.73	85.48	0.35	509.72	57	<0.0001
OA	2009	651	0	56	3.23	1	6.56	3.81	18.61	0.26	363.13	60	<0.0001
OA	2010	660	0	112	2.92	0	8.17	7.07	69.66	0.32	293.27	63	<0.0001
OA	2011	603	0	52	2.33	0	5.19	4.81	32.14	0.21	340.11	60	<0.0001
OA	2012	595	0	87	2.27	0	5.99	7.81	88.86	0.25	217.99	60	<0.0001
OA	2013	837	0	412	5.69	2	18.72	14.73	285.43	0.65	130.72	57	<0.0001
OA	2014	295	0	183	6.02	1	16.72	7.08	63.2	0.97	59.783	24	0.00007
Species	Year	N	Min	Max	Mean	Med.	Std. dev.	Skewness	Kurtosis	SE	X <sup>2</sup>	df	P value
PA	2006	490	0	16	0.35	0	1.11	7.88	90.72	0.05	80.896	34	<0.0001
PA	2007	210	0	5	0.12	0	0.53	5.87	41.16	0.04	5.1626	14	0.98340
PA	2008	746	0	3	0.06	0	0.31	5.93	39.25	0.01	66.876	57	0.17410
PA	2009	660	0	8	0.13	0	0.69	7.54	67.32	0.03	81.055	60	0.03643
PA	2010	660	0	11	0.36	0	0.94	5.36	44.34	0.04	166.09	63	<0.0001
PA	2011	603	0	8	0.5	0	1.11	3.23	12.97	0.05	227.03	60	<0.0001
PA	2012	595	0	15	0.45	0	1.28	5.9	49.13	0.05	143.8	60	<0.0001
PA	2013	844	0	73	0.38	0	2.62	25.32	695.01	0.09	138.98	57	<0.0001
PA	2014	300	0	24	1.27	0	2.76	4.2	23.3	0.16	32.989	24	0.1043

**Table 3.5.** Collection rates of target aphids with respect to regional trapping networks.

Species	Common name	Location	Mean Count	SE
<i>Myzus persicae</i> (Sulzer)	Green Peach Aphid	Columbia Basin	1.012321012 ±	0.138154 a <sup>1</sup>
<i>Macrosiphum euphorbiae</i> (Thomas)	Potato Aphid	Columbia Basin	0.198468198 ±	0.027889 e
Several spp.	Other Aphid	Columbia Basin	2.878756115 ±	0.274382 c
<i>Myzus persicae</i> (Sulzer)	Green Peach Aphid	Northeastern Oregon	0.212869435 ±	0.014616 b
<i>Macrosiphum euphorbiae</i> (Thomas)	Potato Aphid	Northeastern Oregon	0.591039085 ±	0.032304 f
Several spp.	Other Aphid	Northeastern Oregon	6.83623298 ±	0.45785 d

Means within a column marked by the same letter are not significantly different (ANOVA,  $P < 0.001$ )

**Table 3.6.** Environmental factors for aphids determined by nonparametric multiplicative regression, 2006-2014.

Year	Species	Environmental Factors	Sensitivities	Tolerances	$\chi^2$ ; P
2008	Other	Previous Fall Mean Temperature	0.2921, 0.4709	1.0721	0.566, $P < 0.01$
2009	Other	Elevation	0.3301, 0.5172	153.84	0.4475, $P < 0.01$
2010	Other	Fall 2009 Mean Dew Point	0.1205, 0.1320	0.5916	0.2859, $P < 0.01$
2010	Potato Aphid	Fall 2009 Mean Dew Point	0.0453, 0.0505	1.3607	0.2504, $P < 0.01$
2011	Other	Spring 2010 Mean Temperature	0.2103, 0.2318	3.7856	0.4355, $P < 0.01$
2011	Potato Aphid	Winter 2010 Mean Dew point	0.3834, 0.6484	1.3717	0.4754, $P < 0.01$
2012	Other	Spring 2011 Mean Dew Point	1.3631, 1.7788	0.193	0.2783, $P < 0.01$

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**Fig. 3.1.** Map of the Columbia Basin (Umatilla-Morrow Counties) trapping network sites, Agrimet, and AgWeatherNet stations, 2006-2014

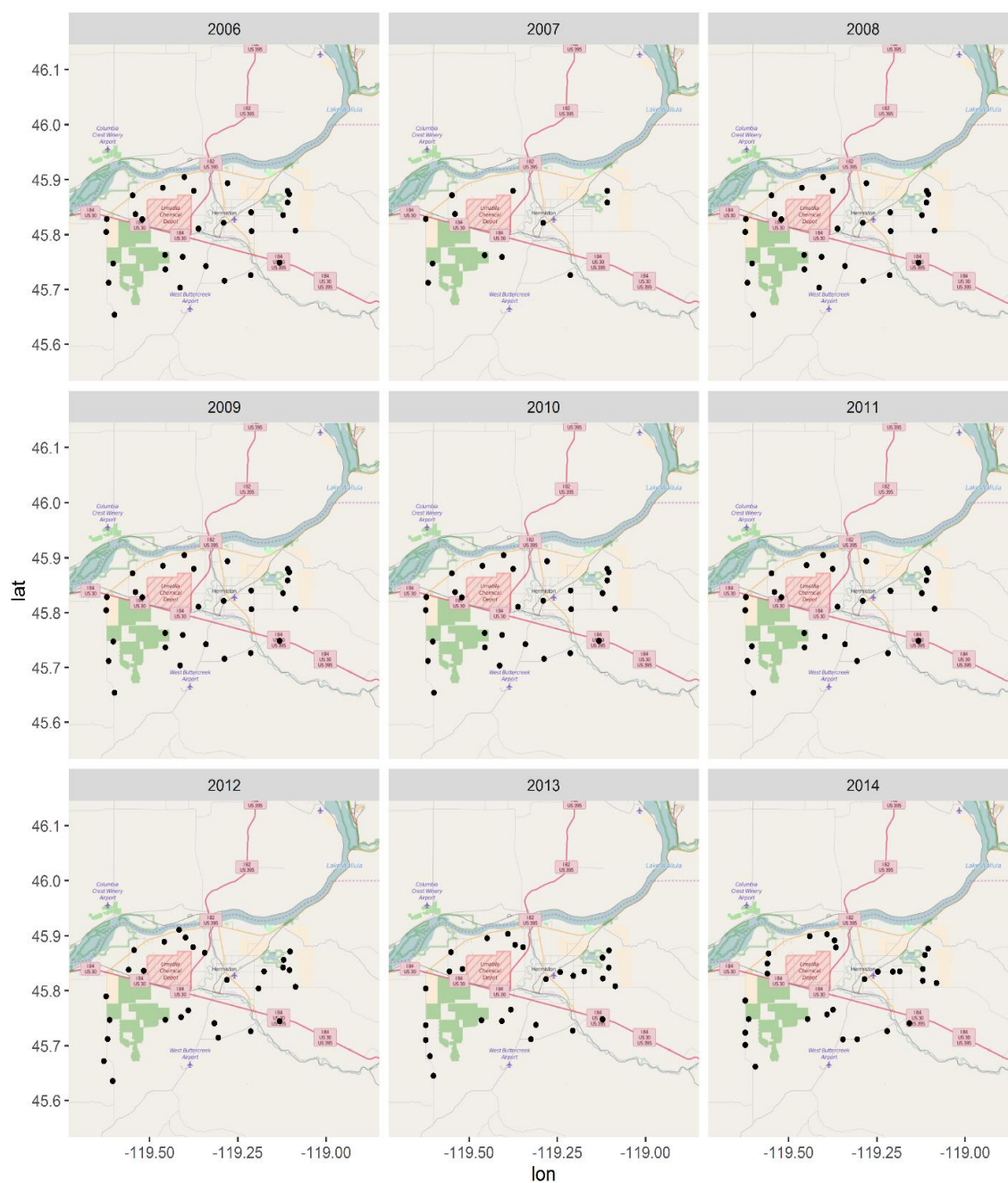
**Fig. 3.2.** Map of the Northeastern Oregon (Union-Baker counties) trapping network with location of trapping sites and Agrimet and AgWeatherNet stations, 2006-2014

**Fig. 3.3.** Means and 95% CIs for environmental variables across all weather stations and locations for each month, 2006-2014 (a) precipitation, (b) monthly temperature, and (c) mean dew point.

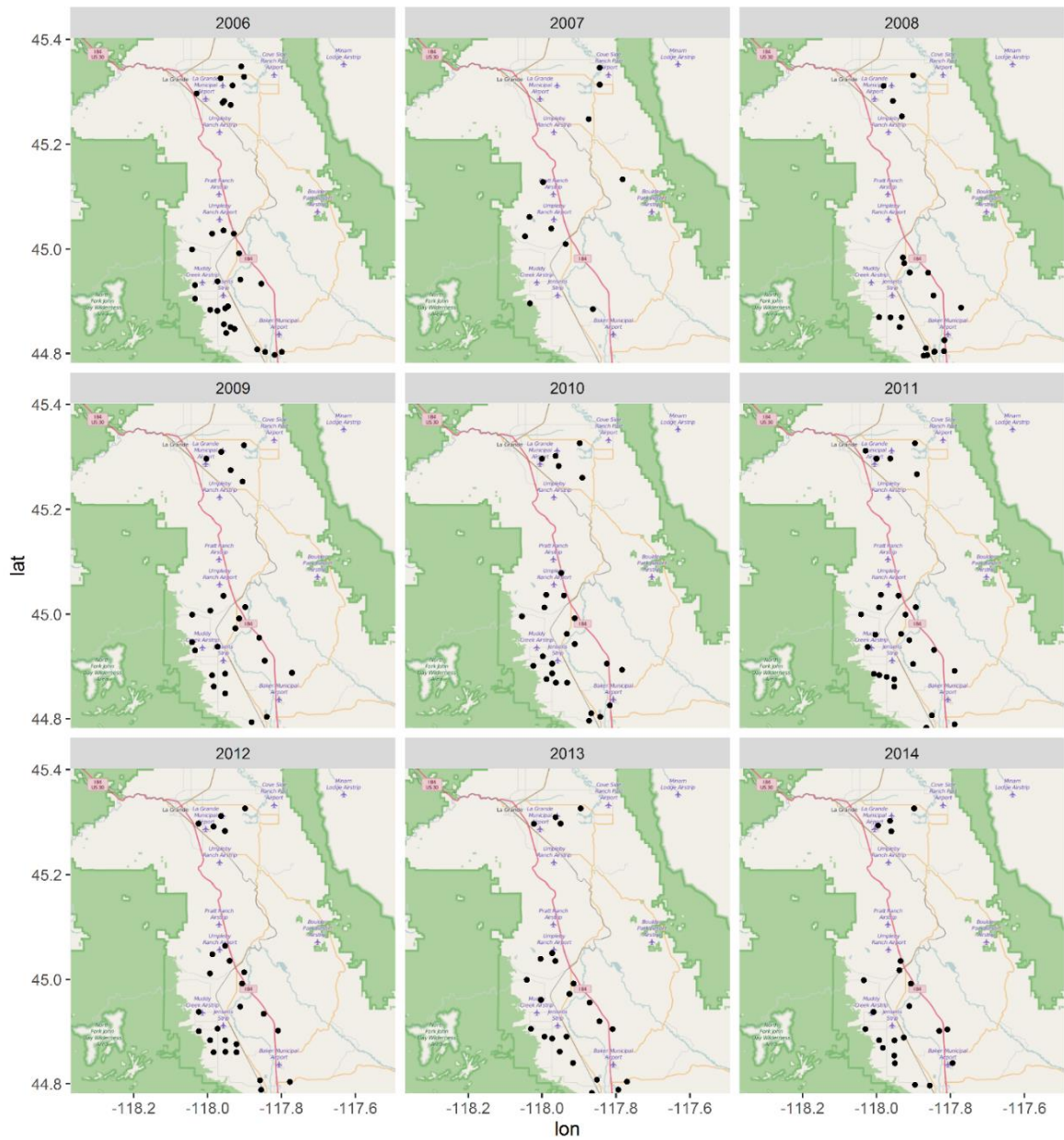
**Fig. 3.4.** Population dynamics (mean  $\pm$  SEM) of Green Peach Aphid, Potato Aphids and Other Aphids in Umatilla and Morrow counties, 2006-2014.

**Fig. 3.5.** Population dynamics (mean  $\pm$  SEM) of Green Peach Aphid, Potato Aphids and Other Aphids in Union-Baker, 2006-2014.

**Fig. 3.1.** Map of the Columbia Basin (Umatilla-Morrow Counties) trapping network sites, Agrimet, and AgWeatherNet stations, 2006-2014



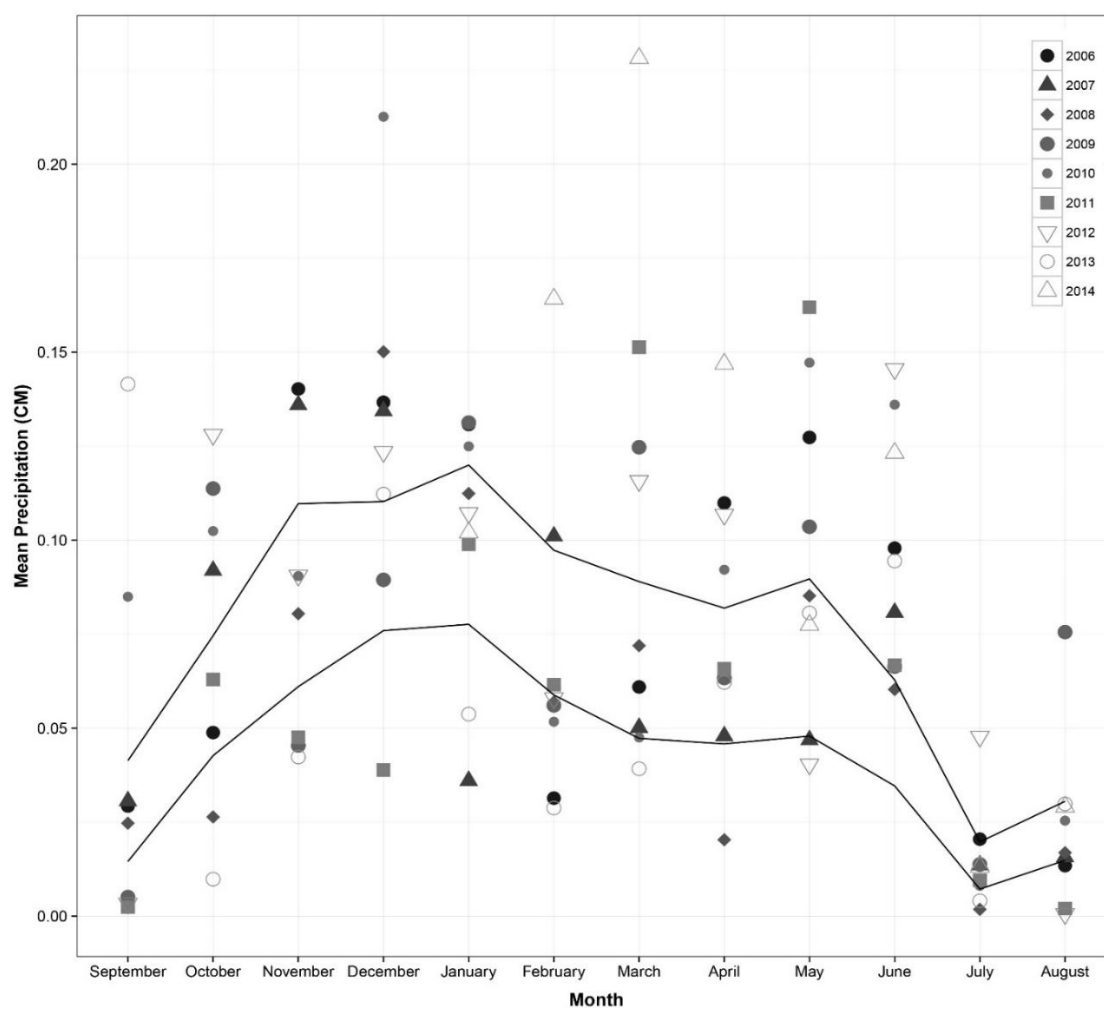
**Fig. 3.2.** Map of the Northeastern Oregon (Union-Baker counties) trapping network with location of trapping sites and Agrimet and AgWeatherNet stations, 2006-2014.



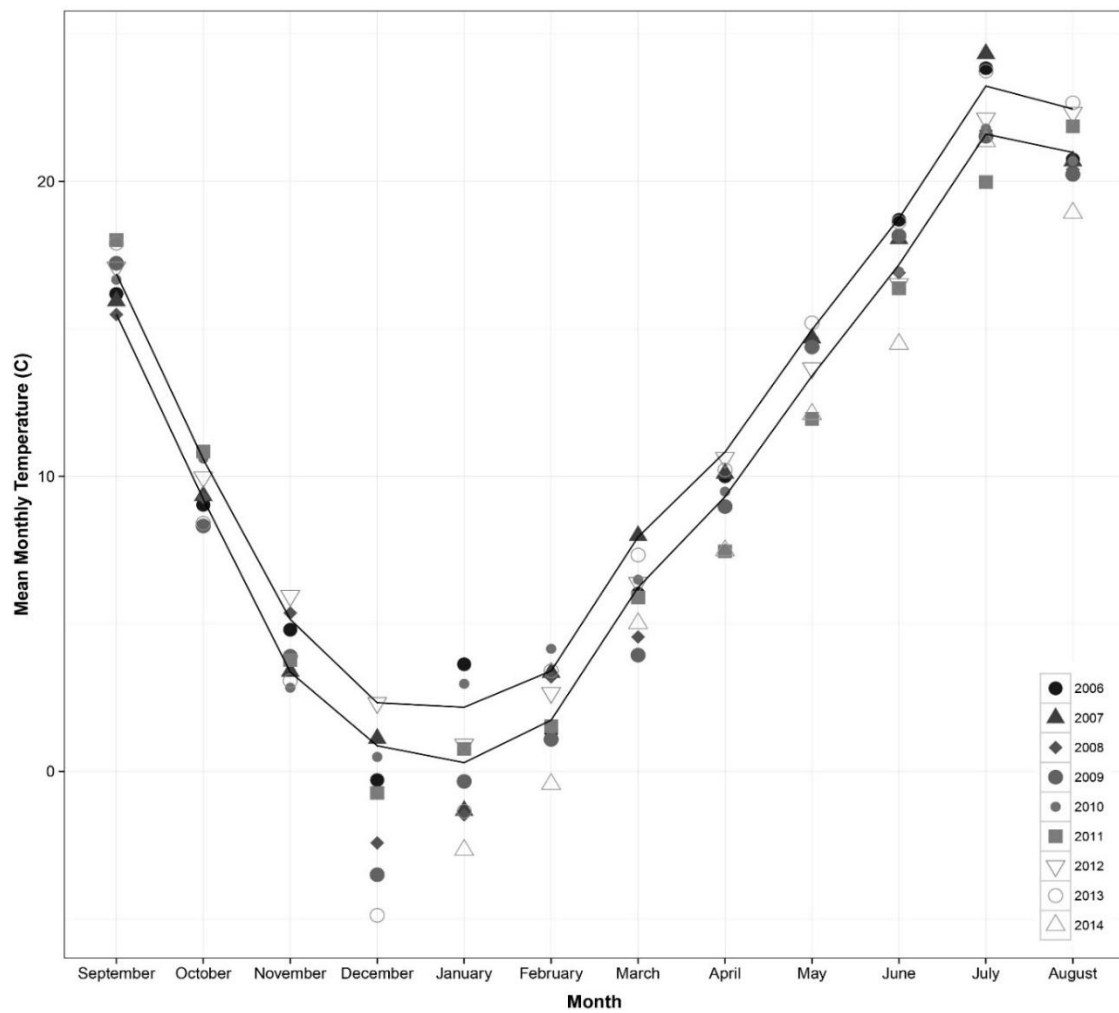


**Fig. 3.3.** Monthly means for weather variables in 2006-2014  $\pm$  95% CI (A) precipitation, (B) monthly temperature, and (C) dew point.

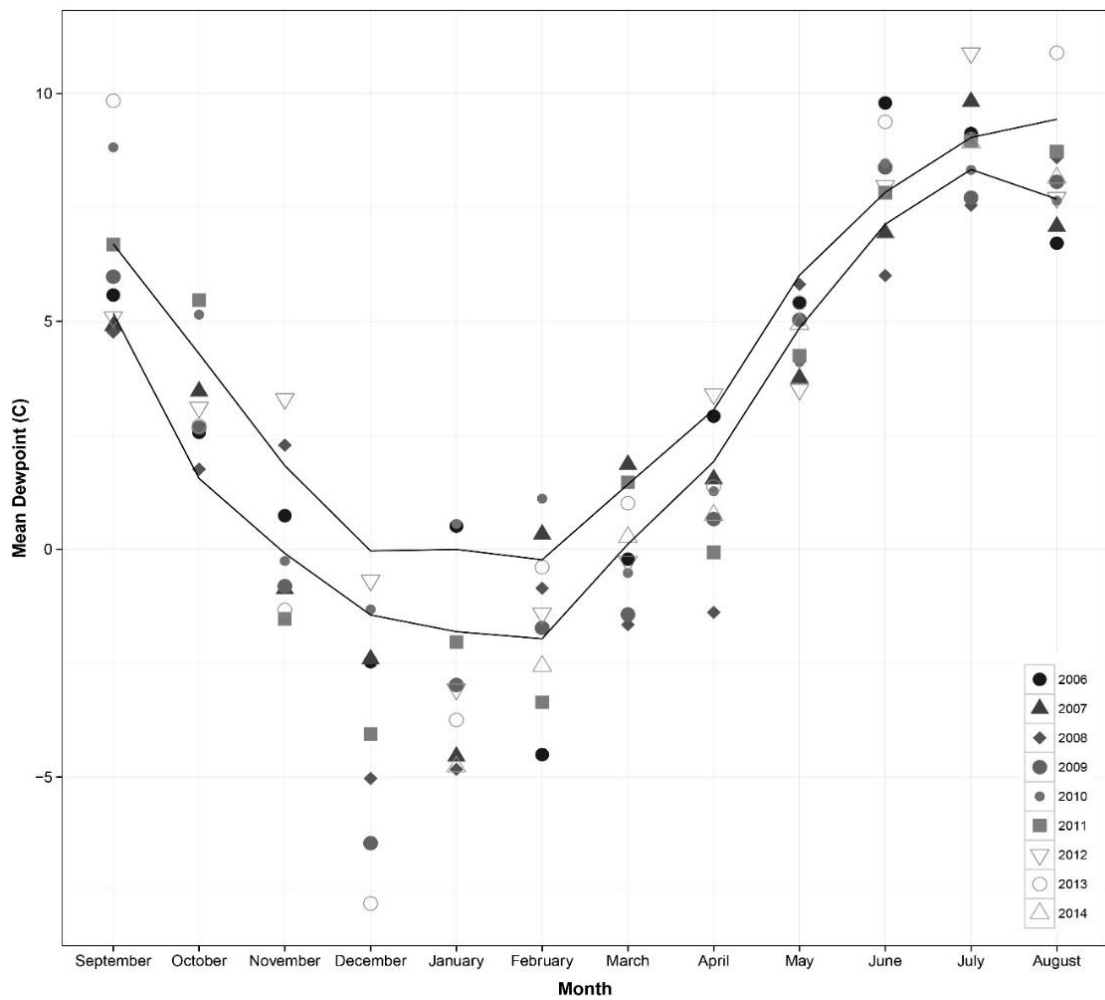
(A)



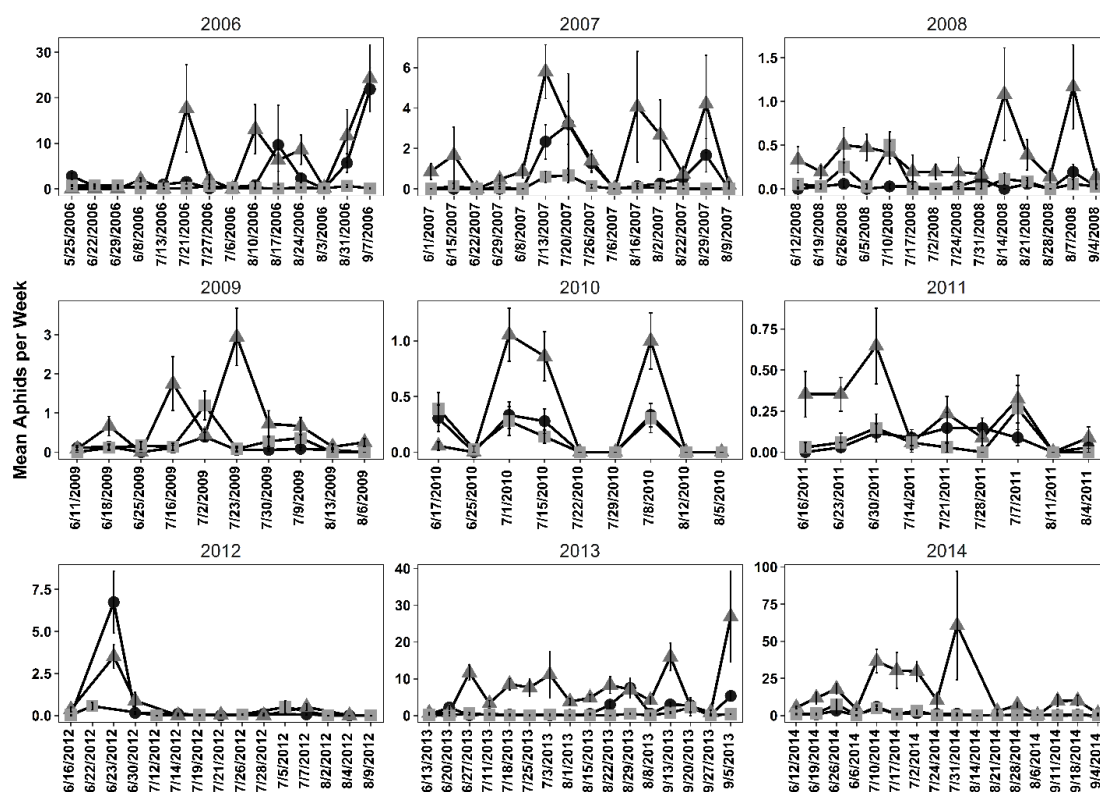
(B)



(C)



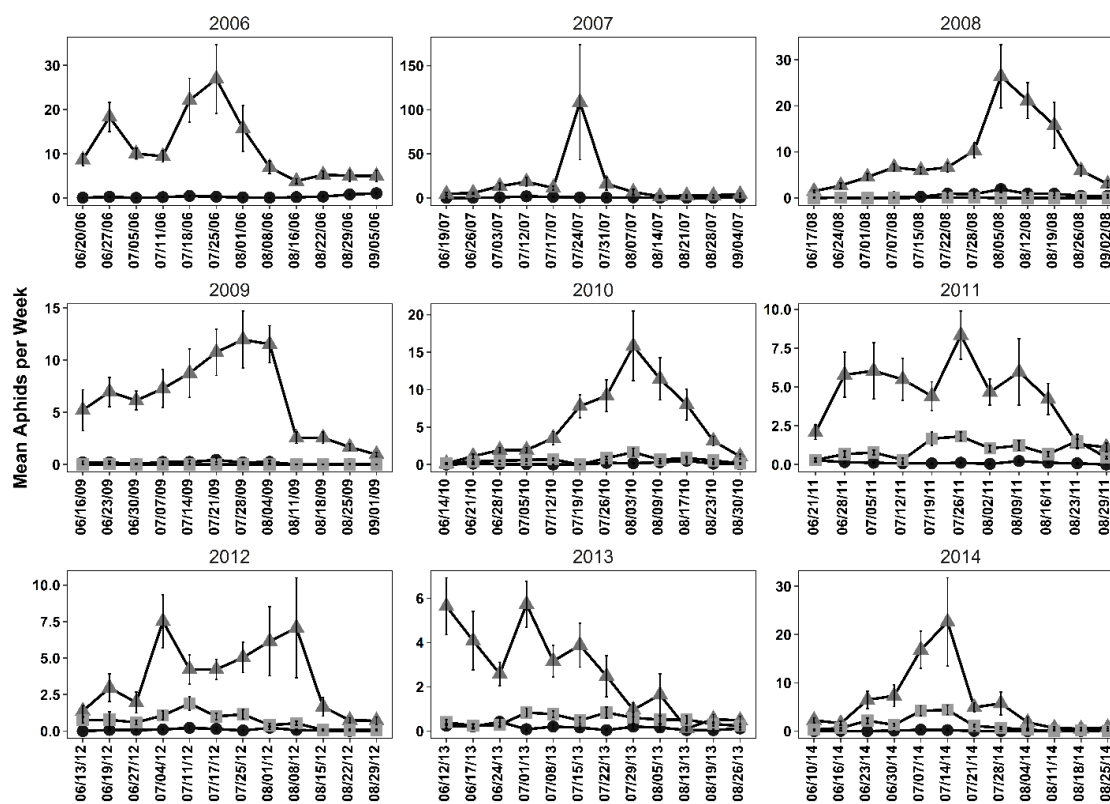
**Fig. 3.4.** Population dynamics (mean  $\pm$  SEM) of Green Peach Aphid, Potato Aphids and other aphids in Umatilla and Morrow counties.



**Legend:**



**Fig. 3.5.** Population dynamics (mean  $\pm$  SEM) of green peach aphid, potato aphids and other aphids in Union and Baker counties.



## **GENERAL CONCLUSIONS**

Matthew L. Klein

The results of this research provide the foundation of scientific information that could help management programs. Despite some inconsistencies in our findings on potato psyllid sampling, we did find that inverted leaf blowers were more effective at collecting potato psyllids when compared with sticky cards, although the effect was small. We cannot conclusively state that inverted leaf blowers should be recommended as a primary sampling tool for potato psyllids; further research is needed to confirm whether a real difference in collection rate exists between leaf blowers and sticky cards. Furthermore, studies could compare the various other methods used to collect psyllids. As for natural enemy sampling, we can confidently state that inverted leaf blowers are far superior to sticky cards. However, the usefulness of such data remains to be determined. Natural enemy presence does not mean they are predating on key pests like the potato psyllid; they could be feeding on other pests, benign insects, or even other natural enemies. To date little research has been carried out on the feeding preferences of these insects with regards to potato psyllids, largely due to the recent classification of potato psyllid as a key pest.

The results of this field trial also shed some light on the role of volunteer potatoes. Potato psyllids were indeed found in treatments containing volunteer potatoes, albeit at a very low rate and with little differences from other crops (except potato) which may be due to the small size of plots. However, in a field setting, such numbers may accumulate into a meaningful number of potato psyllids migrating through acres of seemingly non-host crop material through the use of volunteers. ZC disease pressure is a serious management concern to growers; since entire fields of potato may be rejected from processing if ZC is detected. If only a few infected psyllids entering a potato field transmit ZC, and begin reproducing, they may produce a detectable infection level and in turn could lead to field rejection and loss of profit.

Our study of spatial and temporal dynamics of aphids produced some interesting results. Primarily of note was the fact that other aphids routinely make up an overwhelming portion of aphid collections in both the Columbia Basin and Northeastern Oregon. This result has been found by others, but has not been quantified consistently over such a timespan. Our findings on OA prevalence highlight the need to evaluate the effectiveness

of OA at transmitting and acquiring potato viruses as they may in fact be an important source of viral infections in the region. Historically, green peach aphid and potato aphid have typically been considered the primary sources. Our results indicate that OA may have been overlooked in pest management programs in the area.

We also found that aphids correlated with environmental variables. Complex population models may be possible to develop in the future given a robust insect and weather relationship. Also if modeled correctly, it could lead to predictions of future aphid numbers and could lead to an even more effective early warning system for growers.

The two studies presented here represent two unique methods for sampling insects in agricultural settings with the goal of acquiring information that can improve pest management practices. In small scale studies, deliberate manipulations of the crop environment can be used to study insect responses and they can also allow for efficient data collection. In our landscape analysis of aphids, collecting data from all traps routinely took between 6-8 hours, which represents a large time, money, and resource commitment. The benefit of such an approach is that these data are more robust to local conditions, by sampling the entire area of interest we can avoid generalizing site specific data to regions where that data do not apply. Instead, for example, if a few traps were affected by some variable that increased aphid numbers compared to other regions, we can observe those differences and warn growers with nearby operations, while those outside of that region would consult that increased control measures are not yet necessary. The main limitation here was that our weather data were of low precision compared to our trapping data, which likely contributed to the lack of correlations. Both small and large scale studies have a place in insect pest management and our results illustrate the benefits and downsides of each.



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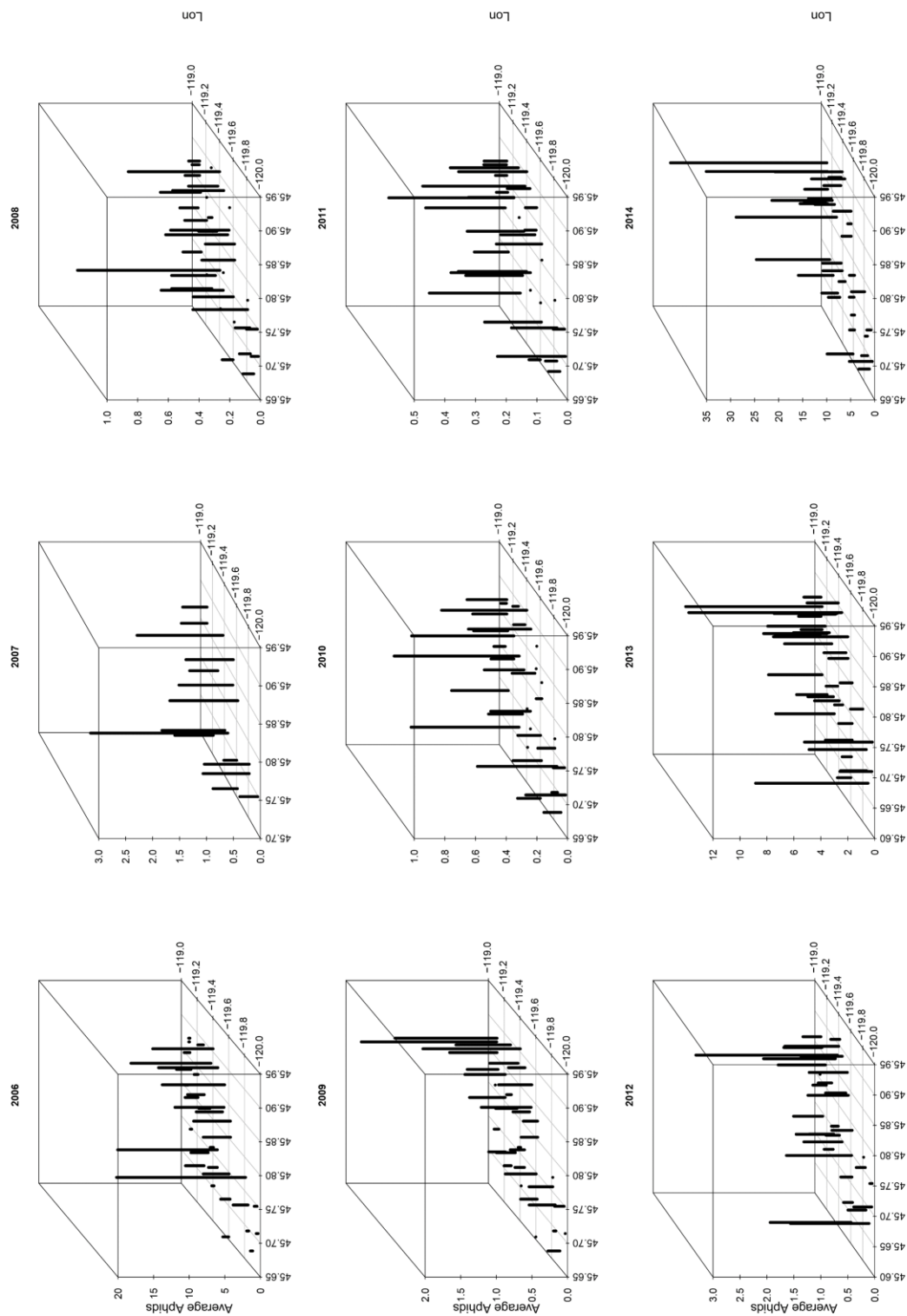
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## **APPENDIX**

**Fig. 1.** Spatial distribution of average number of aphids per trap per week. Columbia Basin 2006 – 2014.



**Fig. 2.** Spatial distribution of average number of aphids per trap per week in northeastern Oregon 2006 – 2014.

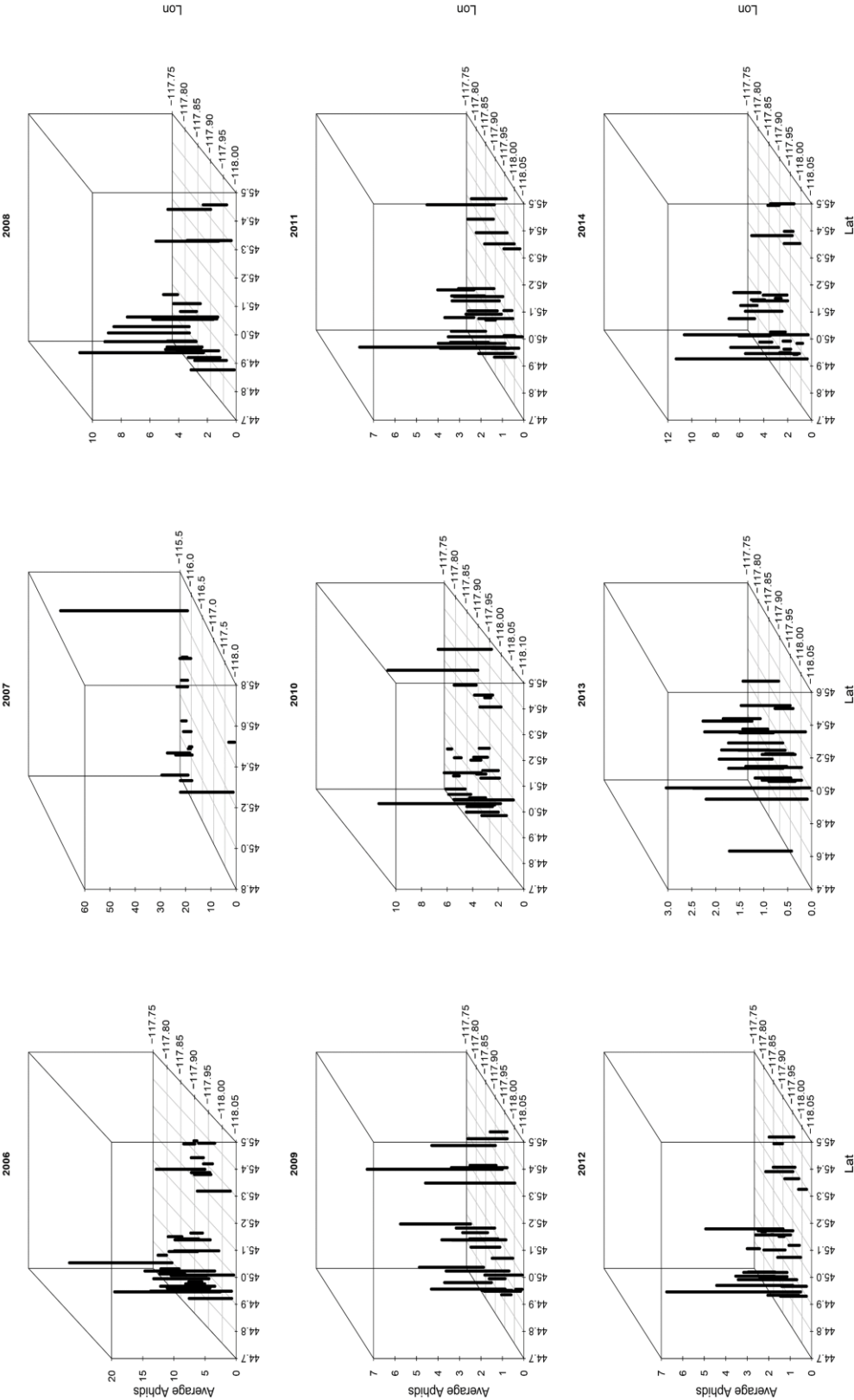


Photo 1. Aerial view of the field plots at the Hermiston Agricultural Research and Extension Center.



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Harec Test Plot Jul 19, 2015

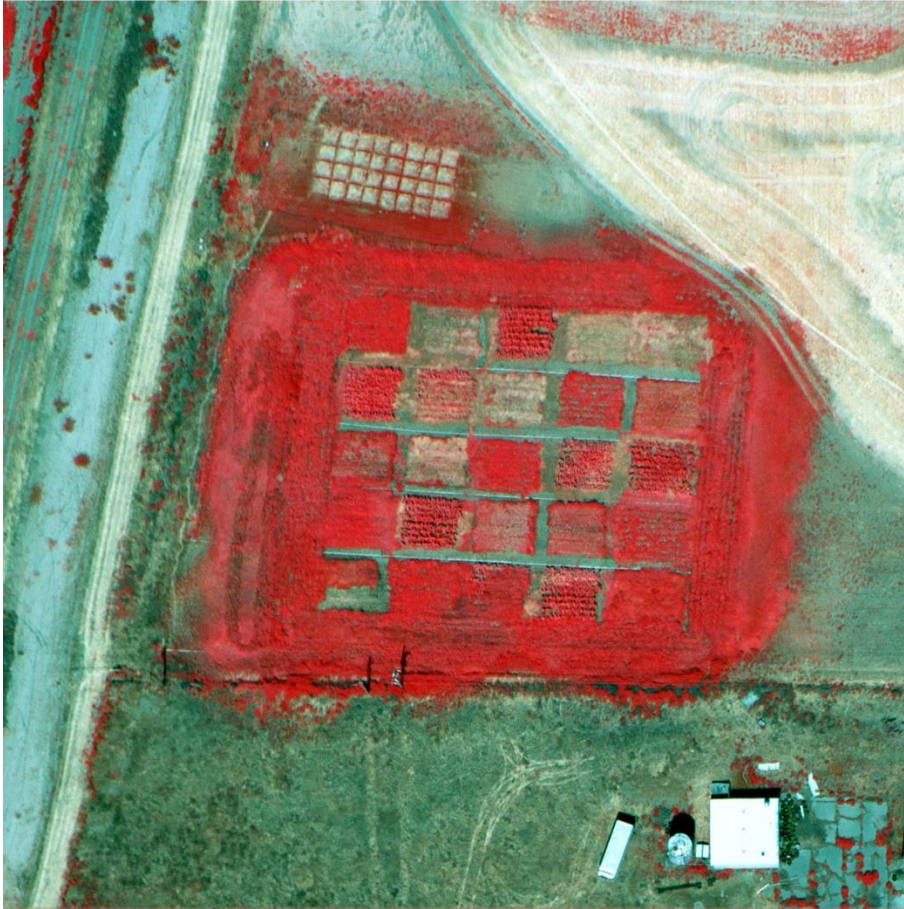




Photo 2. Sticky cards





Photo 3. Inverted Leaf Blower

