# AN ABSTRACT OF THE THESIS OF

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Laboratory and field studies investigated the effectiveness of *Geocoris pallens*
Stål as a predator of the green peach aphid, *Myzus persicae* (Sulzer).  The laboratory
study addressed consumption of alate and 1st and 2nd instar *M. persicae* on 'Russet
Burbank' potato and 'Lady Bell' pepper and the field study focused on the population
dynamics of *G. pallens* and *M. persicae* on potato.

Adult female *G. pallens* consumed significantly more alatae and 1st instar *M.
persicae* per day than males on potato and pepper.  All instars of *G. pallens*
consumed 1st and 2nd instar aphids on both plants, indicating that early *G. pallens*
instars can sustain themselves on live food.  In addition, adult *G. pallens* were able
to reduce the production of 1st instar aphids by alatae on potato.

Foliage dwelling arthropods, including *G. pallens* and *M. persicae*, were
averaged from beating cloth samples on transgenic potato expressing the *Bacillus
thuringiensis* ssp. *tenebrionis* (Btt) gene for resistance to Colorado potato beetle and
on plots treated with permethrin in 1992 and 1993.  The Btt treatment supported the
largest number of predators, primarily *G. pallens*, which were more abundant in Btt

plots than in permethrin treated plots from the earliest samples to the end of the season in 1992. Apterous *M. persicae* populations never exceeded 40 individuals per sample in the Btt potato plots, while the permethrin treatments dramatically reduced predator populations, allowing the proliferation of apterous *M. persicae* populations (as high as 3970 per sample during an August peak). In 1993, *Geocoris* spp. did not reproduce successfully in Btt transgenic potato, despite the presence of prey such as thrips, mites, and lygus bug nymphs. The late arrival of *M. persicae* and unusually cool temperatures were potentially responsible for the absence of *Geocoris* spp. and lack of reproduction after mid-season. Permethrin treatments contributed to the proliferation of *M. persicae* during both years by reducing predator populations, primarily *G. pallens*. The consumption of *M. persicae* by *G. pallens* in the laboratory compared with the population of *G. pallens* in the field suggest that this predator may be capable of suppressing *M. persicae* populations in the field. There was a strong inference that the absence of this predator contributed to the proliferation of the aphid population in Btt potato plots in 1993, and in permethrin treatments in both years. An evaluation of degree-day requirements, using a biofix date of emergence of 1st instar *G. pallens*, predicted adult *G. pallens* development within 4 days of the observed development in 1992. Using this biofix date for 1993 accurately predicted that *G. pallens* 1st generation nymphs would not develop to adult in potato. Using 1 April as an initiation for the degree-day model was unreliable as an indicator for *G. pallens* development in both years, predicting emergence 30 days earlier than observed emergence in 1992. Early presence,

successful reproduction, and an abundant population of *Geocoris* spp. appear to be
necessary to suppress *M. persicae* in potato.

Big-Eyed Bugs as Predators of

the Green Peach Aphid

by

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## CHAPTER I
## INTRODUCTION


The green peach aphid, *Myzus persicae* (Sulzer), has been identified as the

most important aphid pest on potato (Cancelado and Radcliffe 1979), and is an

efficient vector of potato leaf roll virus (PLRV) (Bacon et al. 1976). PLRV results

in net necrosis of stored tubers, which reduces or eliminates their market value. The

'Russet Burbank' variety, the predominant variety grown in the Hermiston, Or. area

of the Columbia Basin, is particularly susceptible to PLRV infection. Infection is

dependent on virus source plants and the abundance and activity of aphid vectors

(Bishop and Guthrie 1964).

Alate (winged) *M. persicae*, which develop on secondary hosts in the spring

and summer, are apparently the important stage in the spread of PLRV in crops

(Bacon et al. 1976). In the Yakima Valley of Washington, alate *M. persicae* develop

from eggs on peach trees each spring and subsequently disperse to secondary

summer hosts, including potato (Davis and Landis 1951; Tamaki 1973a). Each alate

aphid is capable of producing approximately 3 to 4 apterous (wingless) offspring per

day. Apterous aphids are produced parthogenetically by these alates. These

apterous aphids, in turn, also can produce 3 to 4 aphids per day, about 1 week after

being produced (Bishop et al. 1982). The potential for exponential aphid growth is

usually realized during July, soon after the arrival of the alates in the Hermiston

potato growing areas. PLRV is not transmitted by these alates to their offspring but

the offspring can become infective by feeding on infected plants.

While the control of *M. persicae* has typically depended on the use of

insecticides, the development of insecticide resistance (McClanahan and Founk 1983;

Cancelado and Radcliffe 1979) and limited availability of pesticides have led to

investigations of *M. persicae* suppression with biological control agents (Tamaki

1973b; Radcliffe 1973). In the past, *M. persicae* was effectively controlled with

aldicarb, a systemic insecticide; however, aldicarb was withdrawn for use on potato

in 1990 (Flanders et al. 1991). Other insecticides tend to provide inadequate control

(Bacon et al. 1976). Therefore, currently used insecticides need to be supplemented,

perhaps through the release or conservation of predators.

Mackauer and Way (1976) reported that natural enemies are unable to control

*M. persicae* as a virus vector once it has reached a potato crop but suggested that

more work needs to be done to evaluate generalist predators. Generalist predators

are often present in a crop prior to the arrival of a pest and may be able to control

that pest (Ehler, 1977). Evidence discussed by Ehler and Miller (1978) and Ehler

and van den Bosch (1974) suggested that generalist predators may have an advantage

over specialist predators in the exploitation of disrupted habitats. Ehler (1977)

presented examples of a suite of hemipteran predators, particularly *Orius tristicolor*

White, *Nabis* spp., and *Geocoris* spp., that function as efficient colonizers in

disturbed habitats such as annual crops.

*G. pallens* Stål, (big-eyed bug) is reported in the literature as a generalist predator in cotton (Smith 1942; van den Bosch and Hagen 1966; Gonzalez and Wilson 1982), alfalfa (Benedict and Cothran 1975), sugarbeet (Tamaki and Weeks 1973), and potato, peas, and broccoli (Tamaki and Weeks 1972).

Big-eyed bugs are known to feed on mites, thrips, aphids, and other small arthropods (Tamaki and Weeks 1972) and can persist when aphid densities are low (Tamaki 1981). Its ability to utilize plant material for fluid and nutrition also has been reported as an advantage during periods of low prey abundance (Stoner 1970). *G. pallens* also has been identified as an important predator of *M. persicae* and is among the most abundant natural enemies in potato (Tamaki 1981). However, the ability of *Geocoris* spp. to prey on alate and 1st and 2nd instar *M. persicae* in potato and other crops has not been investigated.

The following review is summarizes information from various crops and regions to illustrate the similarities and differences of *Geocoris* spp. and other common predators in these crop systems.

**Biology of *Geocoris pallens***

*G. pallens* is a member of the Lygaeidae family, subfamily Geocorinae, and tribe Geocorini. Slater (1964) reported *G. pallens* from British Columbia, Arizona, California, Colorado, Costa Rica, Kansas, Hawaii, Utah, Texas, Montana, and Mexico. It is the most prevalent *Geocoris* spp. found in the potato fields at the Oregon State University, Hermiston Agricultural Research and Extension Center,

Hermiston, Oregon (HAREC), where this research was conducted. *Geocoris bullatus* (Say), a larger species, which also occurs in the Hermiston area in open areas, emerges earlier in the spring (Tamaki and Weeks 1972), but does not seem to occur as often in potato. *G. pallens* superficially resembles *G. bullatus*, but Readio and Sweet (1982) described *G. pallens* as entirely macropterous and *G. bullatus* as occasionally brachypterous. Additionally, the hind lobe of the pronotum is evenly convex in *G. pallens*, and flattened and somewhat depressed in *G. bullatus*. Tamaki and Weeks (1972) stated that *G. pallens* is smaller than *G. bullatus*. In addition, they reported that *G. pallens* has straw colored legs and *G. bullatus* is sexually dimorphic with regard to leg color. That is, female *G. bullatus* have entirely dark brown legs and the males have legs with dark brown spots against a lighter background.

Male *G. pallens* are distinguished from females by their smaller size, white coloration on the dorsal side of the antennae, and periphallic lobes. The ventral abdominal section is dark brown in the male and light brown in the female. The female has an ovipositor and dark antennae. The systematics of *Geocoris* included studies by Stål (1874), McAtee (1914), Usinger (1935), Torre Bueno (1946), and Readio and Sweet (1982). Slater (1964) includes a list of 20 *Geocoris* spp. from the United States, of which three are listed for Oregon. These three species are *G. atricolor*, *G. bullatus*, and *G. decoratus*. The subject of the present study, *G. pallens*, has been reported in the Yakima Valley of Washington State (Tamaki and Weeks 1972; Tamaki and Olsen 1977), which is near the HAREC.

*G. pallens* biology is discussed at length in the U.S. Department of Agriculture Technical Bulletin, 1446 (Tamaki and Weeks 1972) and will be summarized below.

The diminutive size of the first of the 5 instars, approximately 1 mm. in length, makes identification in the field difficult. It is tan colored, slender and cigar shaped, with red eyes. The second instar has a light red pigmentation in its abdomen and light tan legs. This red pigmentation is a useful distinction between the first and second instar. The third instar differs from the second in that it has rudimentary wing pads, seen under magnification. The abdomen is light red with silverish or whitish pigments covering portions of the head and thorax. The fourth instar differs from the third in that the wing pads are slightly longer than half the width of the thorax. The scutellum is light tan with small, light brown spots on the anterior lateral portion and the background color of the abdomen is light red with silverish pigmentation extending to the head and thorax. The fifth instar has wing pads almost as long as the width of the thorax. The legs are light tan, and the abdomen has yellow specks on a light-red background. The head, thorax, and wing pads have a silvery appearance.

The tan colored egg is ovoid with chorionic processes, which are a circle of notches around the blunt end of the egg. At a constant temperature of 26.7 C, the eggs of *G. pallens* hatch in about 8 to 12 days. Butler (1966), working in Arizona, found that *G. pallens* developed more rapidly than *G. punctipes* eggs and nymphs, although the diets were different for the two populations.

Dunbar and Bacon (1972) studied *G. pallens* and two other *Geocoris* spp. in the laboratory at various constant temperatures in the laboratory and found that temperatures between 30.0 and 35.0 C were optimal for rearing *G. pallens*, and that *G. pallens* was tolerant of high temperatures but not low temperatures. Oviposition did not occur at or below 23.9 C but did at 35.0 C for *G. pallens* and fertility was low at 23.9 C and higher at 30.0 and 32.0 C.

The following behavior was observed by the author in the field and in the laboratory. Mating was initiated when the male approached another individual *G. pallens* from the side and slightly behind the head. The male's antennae were extended to touch the abdomen of the other bug. If the bug was a male, the first male withdrew and searched for another bug. If the bug was a female, and receptive, the male mounted the female and the genitalia were connected in an opposing manner (at 180° angles to each other). Duration of copulation lasted from 10 minutes to more than 3 hours (Dunbar 1971). Egg laying patterns by *Geocoris* may differ depending on the crop and prey. In sugarbeet, eggs were usually deposited singly or in groups on the underside of the leaf, and sometimes on the upper side (Tamaki and Weeks 1972). Outside of cultivated crops, eggs were laid in decaying plant matter (Tamaki and Weeks 1972). The reason for laying eggs singly may be to prevent cannibalism. Cannibalism is common among the early instars of *Geocoris* (Champlain and Sholdt 1966) and adults (Yokayama 1980), McGregor and McDonough (1917), van den Bosch and Hagen (1966). Tamaki and Weeks (1972) found that more eggs were laid in areas of spider mite infestations than in other

areas. Tamaki and Weeks (1972) observed that large numbers of mating *G. pallens* on potato were associated with high numbers of mites, more than 20 mites per leaf, and *Geocoris* eggs were found on these leaves.

Studies of *Geocoris* spp. physiology have revealed information about feeding behavior and processes. Cohen (1990) investigated the mandibular physiology of *Geocoris*, using scanning electron microscopy to examine the two mandibular stylets of *G. punctipes*. One of the stylets was rasp-like with recurved teeth, the other also toothed but knifelike. Cohen (1990) also used thin layer chromatography to show the paths of various digestive proteinases used to break down prey tissues. Through radio-labeling, the path of these digestive enzymes was found to originate in the salivary glands.

Investigations of nutritional aspects of consumption (Cohen 1984; Cohen 1989) indicated that *G. punctipes* was highly efficient in metabolizing prey as a protein source. In a 6-hour feeding period (Cohen 1989), *G. punctipes* consumed pea aphid, *Acyrthosiphon pisum* (Harris), body material consisting of nearly 80% of the nutritionally available aphid material and 65% of the total aphid weight, which amounted to 25 to 50% of the predators' body weight.

An insect allelochemical, rutin, was fed to *G. punctipes* to measure the metabolic rates, survival, and egg weights and discover whether this bug was affected by an accumulation of this compound (Cohen and Urias 1987). Success by plant-feeding insects in ingesting allelochemicals may confer protection against predators that can not tolerate the toxic chemicals. No differences in survival or

growth rates were found when newly molted 3rd instar *G. punctipes* were fed different concentrations of rutin. These results suggest that this allelochemical is a neutral compound for *G. punctipes* and that *G. punctipes* may be able to tolerate allelochemicals.

Chamberlain and Tenhet (1923), observed *G. punctipes* attacking tobacco flea beetles. An early report of *Geocoris* as a predator of aphids (Smith 1923) listed *G. bullatus* and *O. tristicolor* as the most important species attacking the clover aphid, *Nearctaphis bakeri* Cowen, in clover crops in Idaho. The young nymphs were reported to be phytophagous but older nymphs and adults were mainly predaceous. Eggs were deposited "promiscuously in the crowns of the plants" and the bug overwintered as an adult in the clover. Accounts of *Geocoris* spp. in Utah, including *G. decoratus* Uhler, *G. atricolor* Montandon, and *G. pallens*, described feeding on pests such as the potato psyllid, *Paratriòza cockerélli* (Sulc), the beet leafhopper, *Eutettix tenellus* (Baker), the willow psyllid, *Trioza maura* Forster, the false chinch bug *Nysius ericae* (Schil.), and aphids *M. persicae*, *A. pisum*, *Euroleucon escalantii* Knowlton, *Acyrthosiphon zerozalphum* Knowlton, and *Acyrthosiphon pisi* (Kaltenbach) (Knowlton 1933; Knowlton 1935; Knowlton 1936; Knowlton 1942; Knowlton 1947). An adult *G. atricolor* was collected from an infested pea field in Utah and brought into the laboratory for a description of its feeding behavior on a 2nd instar pea aphid, *A. pisum* (Knowlton and Stains 1941). The geocorid grasped the aphid with its front tibiae and tarsi and inserted its stylet "at a point along the suture between the third and fourth segments of the abdomen."

The aphid was soon extended by the rostrum of the geocorid, and the contents were drained after 22 minutes. The stylet was seen moving throughout the aphid, including the legs and eyes, and there was evidence that a digestive fluid was injected. The presence of digestive fluid has been confirmed by Cohen (1990) who noted that it emanated from the salivary glands. The use of the tibiae and tarsi, however, was apparently not typical for *Geocoris*. Smith (1942) reported that *G. pallens* and *Geocoris* spp. were very numerous but were not found to injure cotton plants; they fed on cotton dauber and fleahopper nymphs and cotton dauber eggs.

In the Yakima Valley of Washington state, *Geocoris* spp. were the most abundant predators in potato, sugarbeet, broccoli, second most abundant on peas, and third on alfalfa (Tamaki and Weeks 1972). Tamaki and Weeks (1972) reported that *G. bullatus* had a shorter development time, higher egg production, and the greatest survival when fed a combination of sunflower seeds, green plants, and insects than if it was fed any one or two of these foods (both *G. pallens* and *G. bullatus* died after 24 days on a diet of pea aphids). *Geocoris* spp. also were able to suppress caged populations of *M. persicae* on sugarbeet.

Tamaki and Weeks (1972) also observed that: 1) *Geocoris* eggs were more frequently found on the underside of leaves than on the top leaves in sugarbeet. 2) More eggs were found in areas of heavy mite infestations than in other areas of a sugarbeet field. 3) Daily high temperatures above 24.0 C increased *Geocoris* flight activity. 4) Overwintering adults of *G. bullatus* emerged after several days of temperatures above 24.0 C. 5) *G. bullatus* had three generations per year and *G.*

*pallens* had two generations in alfalfa. 6) *G. bullatus* laid overwintering eggs in the fall.

*Geocoris* spp. are almost unanimously regarded as beneficial insects, although there are a few exceptions. King and Cook (1932) reported internal plant damage by *G. punctipes* feeding on cotton plants in cage tests but detected no external swelling. Lockwood (1933) associated the loss of cotton squares with the presence of *Geocoris* spp. (along with other plant bugs) and suggested that removing off-season vegetation would reduce these pests. *G. pallens* has been implicated in the predation of two weevils, *Microlarinus* spp., and *M. lypriformis* (Wollaston) that were used for biological control of puncture vine, *Tribulus terrestris* L. (Goeden and Ricker 1967). Since this weevil was introduced in 1961, *G. pallens* appeared to have widened its host range to include the eggs of these weevils. Other beneficial hemipteran predators such as *Orius* spp. (Whitcomb and Bell 1964), and the nymphs of *Nabis alternatus* (Parshley) (Atim and Graham 1984) were reported as prey of *Geocoris*.

**Geocoris as prey**

The striped lynx spider, *Oxyopes salticus* (Heinz), has been implicated as a predator of *Geocoris* spp. (Guillebeau and All 1989; and Nyffeller et al. 1987) as have *Nabis alternatus* (Atim and Graham 1984) and a reduviid, *Sinea confusa* (Fye 1979). Even lygus bugs have been observed feeding on early instars of *G. punctipes* (Champlain and Sholdt 1967; Dunbar and Bacon 1972).

**Geocoris plant feeding**

An unusual feature of hemipteran predators, particularly *Geocoris* spp., is their ability to use plants as a source of moisture (York 1944; Ridgway and Jones 1968), and food (Stoner 1970; Tamaki and Weeks 1972; Naranjo and Stimac 1985). Sunflower seeds also have been proven to be effective in sustaining *Geocoris* for extended periods (Sweet 1960; Tamaki and Weeks 1972). This adaptability to plant material may sustain *Geocoris* during periods of low prey numbers (Sweet 1960; Stoner 1970) and may be more useful for the less mobile nymphs than adults (Naranjo and Stimac 1985). This suggestion is supported by De Lima and Leigh (1984) who found that extrafloral nectaries in certain cotton genotypes extended the longevity of *G. pallens* in the absence of prey compared to plants without extrafloral nectaries.

The variety of prey and food plants that *Geocoris* spp. are associated with has been reported by Crocker and Whitcomb (1980), who observed *G. bullatus*, *G. uliginosus*, and *G. punctipes* feeding on 67 species of arthropods encompassing 3 classes and a variety of plants.

**Biological control of spider mites**

An early reference reported that *G. punctipes* was a beneficial insect not previously known as a mite predator (McGregor and McDonough 1917). *G. punctipes* eggs were seen in spider mite colonies in cotton, and after hatching, the

*Geocoris* nymphs readily ate spider mites and even the mite eggs, but only if other live prey was unavailable. Although the percent mortality rate of *Geocoris* fed red spider mites was high, adult *Geocoris* consumed an average of 47 spider mites per day. About 1,600 spider mites may be consumed during the life cycle of *Geocoris* spp. in California alfalfa, and an adult *Geocoris* spp. may consume about 80 mites per day (Smith and Hagen 1956). Wilson et al. (1991) indicated that mid-to-late season increase of spider mites was negatively correlated with early season *Geocoris* spp. eggs, *Orius* spp. nymphs, and *Frankliniella occidentalis* larvae, and that both *Geocoris* and *Orius* had the highest correlation ($r^2 = 0.62$) with early season mite populations.

References indicated that *Geocoris* spp. either prey on or respond to increases in spider mite populations (Gonzalez et al. 1982; Oatman and McMurtry 1966; van den Bosch and Hagen 1966; Wilson et al. 1991), but the nutritional value appeared to be inadequate for survival and reproduction (Dunbar and Bacon 1972).

## Biological control of lygus bugs

Van den Bosch and Hagen (1966) ranked *G. pallens* and *G. punctipes* as primary enemies of lygus bugs, leafhoppers, spider mites, and potentially cotton bollworm larvae as well as the eggs of certain pests. They also noted that *Geocoris* spp. are often mistaken for lygus bugs and needless chemical treatments are applied as a result. Field observations of *Geocoris* feeding on lygus bugs have been recorded by Stitt (1940), and Champlain and Sholdt (1967). Cage evaluations in the

field (Leigh and Gonzalez 1976) and laboratory (Tamaki et al. 1978) demonstrated

that *Geocoris* spp. readily fed on lygus bug eggs and nymphs. Tamaki and Weeks

(1972) indicated that *Geocoris* spp. populations were positively correlated with lygus

bug populations in sugarbeet. *G. pallens* appears to be the most effective predator of

*Lygus hesperus* adults and eggs in cotton in the San Joaquin Valley (Leigh and

Gonzalez 1976) due to their numerical response to lygus populations.


**Biological control of Lepidoptera**

Early and mid-season population peaks of *Geocoris* spp., *Nabis* spp., *O.*

*insidiosus*, and spiders were consistently found in soybean in Missouri, Arkansas,

South Carolina, and Mississippi (Pitre et al. 1978). These arthropods were cited as

predators of *Heliothis virescens* and *H. zea* in cotton and soybean. *G. punctipes* and

*G. uliginosus* adults consumed an average of 5.27 and 4.83 *Pseudoplusia includens*

(Walker) larvae per day, respectively, in field cage tests (Richman et al. 1980).

Adult *Geocoris* spp. reduced field populations of *P. includens* larvae by 67% after

13 days, and were more effective (88%) when combined with the neuropteran,

*Chrysopa carnea* Stephens. Greater quantities of *P. includens* were consumed by

later instars of *G. punctipes*, and an increase in temperature resulted in higher

predation rates in the laboratory (Crocker et al. 1975).

G. pallens reduced a field caged population of *H. zea* larvae by 50%, where

the ratio of *G. pallens* to *H. zea* was 4 to 1 (van den Bosch et al. 1969). The

authors stated that due to numerical superiority early in the season, *G. pallens* impact

was greater than that of the other predators. Lingren et al. (1968) recorded a 67%

reduction in larval *H. virescens* population by adult *G. punctipes* in the field.

Laboratory experiments indicated that adult *G. punctipes* consumed about 29 1st

instar *H. virescens* per day and, in a separate experiment, about 18 *H. virescens* eggs

per day. However, *C. carnea* was judged to be a superior predator and more easily

reared for use in biological control.

Size of prey was apparently a factor in the ability of *Geocoris* to control a

population of *Heliothis* since they were unable to prey on 3rd instars (Lopez et al.

1976). Lawrence and Watson (1979) claimed that 1st instar *G. punctipes* were

almost exclusively egg predators, and the other stages of *G. punctipes* were

unsuccessful at feeding on 3rd and 4th instar *H. virescens*. Chiravathanapong and

Pitre (1980) found that 1st, 2nd, and 3rd instar *G. punctipes* could successfully feed

on newly hatched, mid, and late 1st instar *H. virescens*, but the defensive actions of

the larger *H. virescens* larvae prevented adult *Geocoris* from feeding on them.

Increases in size of *Heliothis* prey increases *Geocoris* mortality, which may be a

result of aggressive defensive behavior (Lawrence and Watson 1979;

Chiravathanapong and Pitre 1980).

In field samples, *G. pallens* was implicated with *O. tristicolor*, *N.

americoferus*, and *C. carnea* as a major predator of the cabbage looper, *Trichoplusia

ni* (Hubner) (Ehler et al. 1973).

**Biological control of aphids**

A variety of foods was fed to *G. punctipes* to assess mortality and reproduction (Dunbar and Bacon 1972). Tubermoth, *P. operculella* (Zeller) larvae and green beans caused the lowest nymphal mortality (35.6%) and pea aphids alone imposed the highest mortality on *Geocoris* (100%). The high *G. punctipes* nymphal mortality on a diet of pea aphids was duplicated by Tamaki and Weeks (1972) with *G. bullatus*. Interestingly, pea aphids (along with lygus bugs) were the preferred prey of adult field-reared and *in vitro G. punctipes* over three lepidopteran species and the Oleander aphid, *Aphis nerii* (Hagler and Cohen 1991). First instar *G. punctipes* were unable to consume immature cotton aphids, *Aphis gossypii* (Staten 1970), while aphid mortality of 100% was associated with third and fifth instar *G. punctipes*.

*G. decoratus* (Uhler) was ranked lower in effectiveness as a predator of the spotted alfalfa aphid, *T. maculata* (Buckton), than *O. tristicolor* and *N. alternatus* in alfalfa in Utah (Goodarzy and Davis 1958), mainly due to *G. decoratus* low abundance.

In replicated cage experiments, *G. decoratus* Uhler consumed an average of 5.0 apterous adult spotted alfalfa aphids per day, compared to *O. tristicolor* adults (3.0 aphids consumed), and *N. alternatus*, (5.3 aphids consumed) (Goodarzy and Davis 1958). Smith and Hagen (1956) estimated that adult *Geocoris* spp. (*G. pallens*, *G. punctipes*, and *G. atricolor*) eat about 3 to 4 spotted alfalfa aphids per day. In Arizona, *G. punctipes sonoraensis* Van Duzee adults consumed an average

of 29 spotted alfalfa aphids per day in glass tubes (Nielson and Henderson 1959).
The differences in the results of these two experiments could have been due to the
size of the aphids (adult apterous aphids were used in the former experiment and no
indication of stage was given in the latter experiment).

G. *bullatus* raised from eggs produced fewer eggs when fed *M. persicae* on
sugarbeet leaves but had a higher survival rate than *G. bullatus* fed beet leafhoppers,
*Circulifer tenellus* (Baker) (Tamaki and Weeks 1972).

The behavior of *G. bullatus* during the fall in the Yakima Valley of
Washington is noteworthy because it appears to be associated with *M. persicae* on
peach trees (Tamaki 1972). These arboreal aphids feed on peach leaves that later
fall to the ground in October. *G. bullatus*, which does not inhabit or visit peach
trees, was found in great abundance underneath the peach trees in the fall during 4 of
the 6 years of sampling, but not earlier in the season. The numbers of *G. bullatus*
found under apricot and pear trees, which do not harbor *M. persicae*, were
considerably lower. The only time that *G. bullatus* is able to feed on *M. persicae*
during this period is when the leaves fall and the aphids crawl back to the tree.

G. *bullatus* decreased growth rates of *M. persicae* in caged sugarbeet and
decreased the rates even more when the temperatures were high (above 29.0 C)
(Tamaki et al. 1981b). Using *Geocoris* spp. and *Nabis* spp. in cages on sugarbeet,
Tamaki and Weeks (1973) found that the combined predators reduced the population
of *M. persicae* by 1/3 over that of the control cage. Coccinellids were more

effective in controlling *M. persicae* than the other predators, but keeping the coccinellids in the field was a problem.

There is evidence to suggest that *G. bullatus* has plant preferences unrelated to prey density, which Tamaki et al. (1981a) suggested might limit interspecific competition.

In potato, geocorids were reported to be effective aphid predators due to their early presence in the field, ability to survive during periods of low aphid numbers, and ability to survive on plant foods (Tamaki 1981). This effectiveness could result in delaying the accelerated growth phase of the *M. persicae*.

Among the biological control attributes of *Geocoris* spp. is its abundance and early presence in crop systems. Crops in which the numerical superiority of *Geocoris* among predators has been reported include cotton: Ehler and van den Bosch (1974), Ehler et al. (1973), Ehler (1977), Dinikins (1970), and Leigh et al. (1974), soybean: Funderburk et al. (1988), Shepard et al. (1974), tobacco: Gilmore (1936), alfalfa: Benedict and Cothran (1975), Tamaki and Weeks (1972), cantaloupe: Bugg et al. (1991), strawberry: Oatman and McMurtry (1966), and potato: Tamaki and Weeks (1972). The abundance of *G. punctipes* in subterranean clover may be useful in intercropping the clover in cantaloupe for the control of the fall army worm, *Spodoptera frugiperda* (J.E. Smith) (Bugg et al. 1991).

It is apparent from the phenology of *Geocoris* in soybean in many regions of the south and eastern United States that *Geocoris* is present early and throughout the

growing season (Funderburk and Mack, 1987; Mcpherson et al. 1982; Shepard et al. 1974).

In Washington, *G. pallens* and a larval parasite, *Encarsia coquilletti* How., were listed as the most important natural enemies of the iris whitefly, *Aleyrodes spiraeoides* Quaint., which inhabits potato and many other hosts (Landis et al. 1958). It also has been demonstrated that *G. punctipes* has potential as a biological control agent of the sweet potato whitefly, *Bemisia tabaci* (Genn.) in Arizona (Cohen and Byrne 1992).

**Eggs as food**

Early references of egg predation by *G. punctipes* included eggs of spider mites (McGregor and McDonough 1917), tobacco hornworm (Gilmore 1936), and the cotton bollworm (Ewing and Ivy 1943). Adult *Geocoris* spp. were still alive at the conclusion of an experiment (55 days) to determine the diet suitability of leafhopper, *Eutettix tenellus* (Bak.), eggs embedded in beet tissue, whereas all of the *Geocoris* spp. fed only beet tissue were dead (York 1944). More than half of the *G. punctipes* nymphs raised on tubermoth, *Phthoramaca operculella* (Zeller), eggs developed into adults and more than half of those females produced viable eggs (Dunbar and Bacon 1972). The authors concluded that the high percentage egg production and viability of *G. punctipes* raised on an egg diet was an indication that *G. punctipes* was basically an egg predator in nature. Laboratory studies involving eggs or larvae of *H. virescens* as food for *G. punctipes* instars indicated that 1st

instars were almost exclusively egg predators, and all instars maintained a survival

rate of 96% when raised on eggs (Lawrence and Watson 1979). First instar *H.*

*virescens* as food for *G. punctipes* resulted in much higher rates of mortality. *G.*

*punctipes* and *G. uliginosus* were reported to be effective predators of eggs of the

soybean looper, *Pseudoplusia includens* in Florida soybean field cage evaluations

(Richman et al. 1980). *G. bullatus* was reported to have consumed 4.80 eggs per

day.

In Mississippi, a higher percentage (8.5%) of *G. punctipes* was recovered in

cotton that had fed on *H. virescens* eggs labeled with phosphorous-32, compared to

nabids (2.1%), *Hippodamia convergens* Guerin-Meneville (0.8%), and *Coleomegilla*

*maculata* (DeGeer) (2.7%) (Thead et al. 1987).

However, observations of *Geocoris* spp., including *G. punctipes*, in natural

settings in Florida indicate that arthropod eggs or pupae accounted for only 3% of

the total diet of *Geocoris* (Crocker and Whitcomb 1980).


**Pesticide effects on *Geocoris* spp.**

Gonzalez and Wilson (1982) evaluated two mite predators, *G. pallens*, and *O.*

*tristicolor* and found higher predator numbers on untreated cotton plants with

abundant food sources than on insecticide-treated plants. The authors cited the need

to evaluate the impact of insecticides on non-target arthropods that serve as food for

the predators. They suggested that four components should be included in the

computation of an economic threshold: "1) the plants, 2) the complex of key pests,

3) the complex of beneficial arthropods, and 4) sources of food in the form of minor pests required to support significant numbers of predaceous arthropods in agricultural crops."

Field experiments involving the application of five insecticides in cotton suggested that certain predators, particularly hemipterans, were extremely susceptible (Lingren and Ridgway 1967). Hemipteran predators, including *Geocoris*, also were affected by applications of systemic insecticides (Ridgway et al. 1967), and higher populations of *Heliothis* spp. were associated with lower populations of hemipteran predators in these treatments.

The organophosphates were the most toxic group of insecticides tested on cotton leaf residues on *G. pallens* (Yokayama et al. 1984), with mortality reaching 100% in 5 of 7 organophosphate compounds tested.

Wilkinson et al. (1979) found that fenvalerate was less toxic than permethrin (Pounce or Ambush), Sulprofos, or Profenofos to *G. punctipes* exposed to residues by tarsal contact on filter paper.

In fields studies involving insecticides, hemipteran populations, including *Geocoris* spp., *Nabis* spp., and *O. insidiosus*, were reduced by methyl parathion and aldicarb applications in soybean (Morrison et al. 1979). The increase of *H. zea* larvae was attributed to the reduction of hemipteran predators.

Lentz et al. (1983) observed reductions in populations of *Geocoris* and *Nabis* spp. 44 and 46 days after treatment in soybean, respectively, with the nematicides

aldicarb and carbofuran. The authors suggested that these beneficials would probably reestablish prior to the next expected pest population increase.

Methomyl, carbaryl, and methyl parathion had no significant influence on maturation and fecundity of a *Geocoris* spp. on South Carolina soybean (Walker et al. 1974).

Field soybean pesticide tests including aldicarb, acifluorfen, bentazon, and benomyl, revealed no reduction in the density of arthropod populations, which included *G. punctipes* and *G. uliginosus* as one of the three major predators (Farlow and Pitre 1983a).

The herbicides acifluorfen and bentazon actually increased fecundity of mixed age adult populations of *G. punctipes* in Mississippi soybean (Farlow and Pitre 1983b). The result was apparently an example of hormoligosis (Luckey 1968), due to stimulation by exposure to a sublethal stressing agent. Hormoligosis also was noted in *M. persicae* populations in potato treated with carbaryl, and the delayed coccinellid and chrysopid populations had little impact on the aphids (Ferguson and Chapman 1993). However, hemipteran predators were not accounted for, and their absence may have contributed to the aphid population explosion.

Increased mortality of *G. punctipes* nymphs occurring in pest-resistant soybean cultivars has demonstrated that even non-pesticide approaches can adversely effect natural enemies (Rogers and Sullivan 1986).

## Objectives

The objectives of my study were to:

1) quantify consumption of alate green peach aphids by *G. pallens* adults on potato and bell pepper in the laboratory and quantify the number of 1st instar green peach aphids produced by alates on potato in the presence of adult *G. pallens*.

2) quantify consumption of 1st and 2nd instar aphids by adults and nymphs of *G. pallens* on potato and bell pepper.

3) determine the population dynamics of *G. pallens* and *M. persicae* in Btt transgenic and permethrin treated potato.

4) assess two starting points for accumulation of degree-days for development of 1st generation of *G. pallens*.

The four objectives are discussed in Chapter II - Effectiveness of *Geocoris pallens* (Hemiptera: Lygaeidae) as a predator of *M. persicae* (Homoptera: Aphididae).

# CHAPTER II
## EFFECTIVENESS OF *Geocoris pallens* (HEMIPTERA: LYGAEIDAE)
## AS A PREDATOR OF *Myzus persicae* (HOMOPTERA: APHIDIDAE)

## Abstract

Laboratory and field studies were conducted to determine the effectiveness of

*Geocoris pallens* Stål as a predator of the green peach aphid, *Myzus persicae*

(Sulzer). The laboratory study focused on predation of alate and 1st and 2nd instar

*M. persicae* in containers with 'Russet Burbank' potato or 'Lady Bell' pepper. The

field study focused on the relationships between *G. pallens* and *M. persicae* on

potato.

Adult female *G. pallens* consumed significantly more alatae and 1st instar *M.*

*persicae* per day than males on potato and pepper. All instars of *G. pallens*

consumed 1st and 2nd instar aphids on both plants, which indicates that early instars

can sustain themselves on live food. In addition, adult *G. pallens* were able to

reduce the number of 1st instar aphids produced by alatae on potato.

The impact of predators, including *G. pallens*, on *M. persicae* was compared

on transgenic potato expressing the *Bacillus thuringiensis* ssp. *tenebrionis* (Btt) gene

for resistance to Colorado potato beetle and potato plots treated with permethrin in

1992 and 1993. Beating cloth samples were used to monitor foliage dwelling

arthropod populations, including *Geocoris* spp. and *M. persicae*. Predators,

predominantly *G. pallens*, were more abundant in Btt potato than in permethrin

treated potato from the earliest samples to the end of the season in 1992. Apterous *M. persicae* populations peaked in July and August and never exceeded 40 individuals per sample. The permethrin treatments dramatically reduced predator populations and allowed the proliferation of apterous *M. persicae* populations (as high as 3970 per sample during an August peak). In 1993, *Geocoris* spp. did not reproduce successfully in Btt transgenic potato, despite the presence of prey such as thrips, mites, and lygus bug nymphs. The late arrival of *M. persicae* and unusually cool temperatures were possible reasons for the absence of *Geocoris* spp. and lack of reproduction after mid-season. Permethrin treatments contributed to the proliferation of *M. persicae* during both years by reducing the predator population, primarily *G. pallens*. Comparing the consumption of *M. persicae* by *G. pallens* in the laboratory with field population densities of *G. pallens* suggests that this predator may be capable of suppressing *M. persicae* population growth in the field. There was a strong inference that the absence of this predator contributed to the proliferation of the aphid population in Btt plots in 1993, and in permethrin treatments in both years. A degree-day evaluation of extrapolated laboratory data, using a biofix date of emergence of 1st instar *G. pallens*, accurately predicted the development of 1st generation adults in potato within 4 days of observed development in 1992 and the lack of development in 1993. The use of 1 April as a starting date was not reliable for either year. Early presence, successful reproduction, and an abundant population of *Geocoris* spp. appear to be necessary to suppress *M. persicae* in potato.

Introduction

The development of transgenic potato with the *Bacillus thuringiensis* ssp. *tenebrionis* (Btt) gene to control Colorado potato beetle (CPB) has provided an unique opportunity to study the relationships between pest and predators in the potato ecosystem. The use of transgenic potato permits ecology to be studied in an agroecosystem without the overwhelming influence of the CPB or the effects of conventional insecticides on non-target organisms. Because of the effectiveness of Btt in controlling the CPB, its use could be a valuable tool in potato IPM. Next to CPB, the most serious pest in potato is the green peach aphid, *M. persicae*. *M. persicae* vectors potato leaf roll virus (PLRV), which causes net necrosis in stored tubers, particularly in 'Russet Burbank' potato (Bacon et al. 1976). Only very low levels of PLRV are tolerated in seed or fresh market potato, making the early suppression of the virus important. The only way to suppress PLRV is to suppress aphid populations. An economic threshold of 3-10 apterae per 100 leaves for seed potato (Flanders et al. 1991) and 30 apterae per 105 leaves for fresh market potato (Cancelado and Radcliffe 1979) was suggested for control of PLRV. While natural enemies are unlikely to adequately control *M. persicae* at these thresholds, it is important to understand their ability to impact *M. persicae* populations.

Since the withdrawal of Aldicarb in 1990 (Flanders et al. 1991), an adequate insecticide to control *M. persicae* has not been registered. The withdrawal of aldicarb puts an added burden on other methods to control *M. persicae*.

Previous quantitative predator/prey studies have considered only late stage apterous adult or non-alate aphid prey. In the Pacific Northwest potato ecosystem, there are three distinct phenological events that are important for aphid suppression: The spring alate migrants, the initial apterae produced by these migrants, and the initial offspring of these individuals. If aphid populations are adequately suppressed during these periods, the potential for exponential population growth is prevented. In order for generalist predators, whose populations are never excessive, to achieve prey suppression they must be present in the field at the time that the pest invades the crop and must effectively suppress the initial populations of the pest. In the case of *M. persicae*, this means control of alate migrants, the initial apterae, and their initial offspring. Predators present during the early periods of these aphid life stages represent the greatest potential for biological control. Tamaki (1981) speculated that the success of a predator in suppressing its prey may depend as much on the predators abundance and time of arrival in relation to its prey, as on its capacity to consume the prey.

*Geocoris* spp. are frequently reported in the literature as a generalist predator in many crop systems (Atim and Graham 1984; Crocker and Whitcomb 1980; Ehler 1977; Funderburk et al. 1988; Naranjo and Stimac 1985; Stoner 1970). Tamaki and Weeks (1972) studied two *Geocoris* spp., *G. pallens* Stål and *G. bullatus* (Say), in five crops and found these species to be the most abundant predators on potato in the Yakima Valley of Washington. As an important predator of *M. persicae*, *G. pallens*

is known to persist when aphid densities are low (Tamaki 1981). Early presence and abundance of *G. pallens* may help prevent outbreaks of *M. persicae*.

The goal of the laboratory experiment was to develop a better understanding of the role of *Geocoris* spp. in suppressing *M. persicae* on potato and bell pepper. Specifically, this investigation focused on consumption of alate *M. persicae* by *G. pallens* adults and of 1st and 2nd instar *M. persicae* by all stages of *G. pallens* on potato and bell pepper. In order to utilize feral *G. pallens*, the timing of the experiment coincided with the natural occurrence of *G. pallens* and *M. persicae* in the field. Production of 1st instar *M. persicae* by alatae in the presence of male and female *G. pallens* or no predators was measured. Pepper was included in the experiment because it provided a comparison of feeding rates on a different host plant of *M. persicae*. It was expected that there would be no difference in the number of aphids consumed by *G. pallens* on potato and pepper. If differences were detected, it would suggest that something about the nature of the plants, i.e., surface area, plant compounds, plant structure, or *G. pallens* host preferences, affected the consumption of *M. persicae*. Potato leaflets have a surface covered with trichomes that may interfere with a predators ability to catch prey. In comparison, pepper leaves are smooth, possessing few trichomes.

An investigation also was conducted in the field to determine the impact of *Geocoris* spp. on *M. persicae*, and the abundance of other arthropods in Btt transgenic potato. The reasons for using Btt transgenic potato were two-fold: 1) the abundance of natural enemies in Btt transgenic potato was greater than any of the

other treatments compared during a 2 year period; and 2) without the detrimental effects of the CPB, no insecticides were needed, eliminating the effect of pesticides on aphids and other non-target arthropods.

Laboratory mean consumption values were compared with beating cloth samples taken in Btt transgenic potato plots to evaluate the effectiveness of *G. pallens* as a biological control agent. This study was done to provide information on predation during the important aphid phenological events. The knowledge gained from these studies may allow pest management professionals to better implement the use of biological control of *M. persicae* by selecting insecticides that protect populations of *G. pallens*.

Because of the contrast between the 1992 and 1993 *G. pallens* populations, a study was conducted to determine whether degree-day requirements could be used to predict development of 1st generation adults. In order to predict emergence of adult *G. pallens* in the field, temperature data must be combined with degree-day requirements determined from laboratory studies. Studies on the development of eggs and nymphs of *Geocoris* spp. in the laboratory have contributed to our understanding of the biology of these lygaeids (Butler (1966), Champlain and Sholdt (1967), Tamaki and Weeks (1972), and Dunbar and Bacon (1972)), but actual degree-day requirements of *G. pallens* have not been determined. However, extrapolation of a lower developmental threshold and degree-day requirements from constant temperature experiments (Dunbar and Bacon 1972) provided a useful approximation for prediction. The accurate prediction of adult development would

1) support the validity of the laboratory extrapolated degree-day requirements and 2) help explain the presence or absence of *G. pallens* in the potato ecosystem.

Degree-day models usually have a biofix date that is used to initiate heat-unit accumulation. A biofix date has been defined as "an identifiable event that signals when to begin degree-day accumulation" (Flint 1991). Emergence of 1st instar *G. pallens* emergence in potato was used as the biofix date for heat unit accumulation for 1992 and 1993. An initiation date of 1 April was used as a comparison to the biofix date, since temperatures exceeding the lower developmental threshold usually occur after 1 April and no insect sampling is required to obtain a starting point for degree-day accumulation.

## Materials and Methods

For the laboratory portion of this investigation, which investigated *G. pallens* consumption of *M. persicae*, ten 2 l plastic containers (16.50 cm H x 11.50 cm w at base x 14.0 cm w at top) were fitted with plastic lids that had an organdy cloth center. A 1.27 cm hole was cut through the center of the bottom of the container so an Eppendorf tube, with the end cut away, would fit snugly into it. A potato plant with three leaflets and petiole, or an entire 'Lady bell' pepper plant, ca. 45 days old, was wrapped in non-absorbent cotton and placed through the Eppendorf tube. The stem protruded through the tube into an identical container filled 2.54 cm high with water. The laboratory where the experiment was conducted averaged 23.3 C (range

of 18.8-25.5 C) and relative humidity was 50%. Laboratory temperatures varied because of external influence by summer temperatures and fluctuated when florescent lights turned on and off. Photophase was 16L:8D hours.

Alate *M. persicae* aphids were collected from the field in mid-July, 1993, within days of their immigration to the potato field, by tapping the plants onto a beating cloth and picking the aphids up with a fine paint brush. These alatae also were placed in containers with pepper plants. *G. pallens* was collected from an area immediately adjacent to the potato plots. *G. pallens* nymphs were collected and identified to instar after emerging in the field. The 1st and 2nd instar *M. persicae* used for the consumption tests were produced by field collected alatae, which were brought into the greenhouse and fed on pepper or potato. In each container, 1st and 2nd instar aphids were placed on the potato and pepper leaflets. Two hours later, individual *G. pallens* adult or nymphs were added. A sufficient and consistent number of aphids added to the containers was determined by preliminary tests. *G. pallens* always had at least 50% more aphids than they could consume in a 24 hour period, thus avoiding problems of density dependent responses.

Laboratory experiments were timed to coincide with the appearance of *M. persicae* and *G. pallens* in the potato plots and adjacent areas. Adult *G. pallens* were tested with the alatae, but *G. pallens* instars were not present when alatae immigrated to potato, so nymph predation of alatae was not evaluated. Ten replications of each instar of *G. pallens* were tested; the control containers had only aphids and potato leaflet. In the alate study, 12 alatae were placed in each of the

potato and pepper containers. Adult *G. pallens* (male or female) were placed into the container two hours after the introduction of the aphids to allow time for the aphids to acclimate to the plant. At 24 hour intervals over 4 days, the containers were inspected for live alatae and 1st instar aphids they may have produced. After examination, 1st instar aphids and dead or injured alatae were removed and alatae were replaced to total 12. A net consumption value was determined by subtracting aphid mortality in the control containers from the containers containing *G. pallens*. *G. pallens* individuals that molted during experiments were replaced with the same instar being studied. If the number of molting individuals was excessive (greater than three per day per experiment), the experiment was repeated.

An ANOVA test was used for repeated potato experiments with adult *G. pallens* and when comparing the production of 1st instar *M. persicae* by alatae with and without *G. pallens*. Two-sample analyses were performed for all other experiments. When non-normal distributions were encountered, the Wilcoxon unpaired ranked sum test was performed. Statistical significance was designated at the 0.05 level.

The impact of *G. pallens* on *M. persicae* was studied by comparing field planted Btt transgenic 'Russet Burbank' potato and potato treated with permethrin at the Oregon State University, Hermiston Agricultural Research and Extension Center, Hermiston, Oregon. Six replications were planted in a latin square design. Potato foliage was monitored twice weekly using a 71 cm square beating cloth. An equal amount (71 cm) of foliage was bent over the beating cloth and beat firmly 8 times.

Immature and adult predators, prey, and non-target arthropods that inhabited foliage were counted in one sample per replication, twice a week. The plots were monitored from mid-June to late August during the 1992 and 1993 growing seasons. Arthropods collected in samples from the replications were averaged by sampling date. Potato plots treated with permethrin were used to estimate potential *M. persicae* population development, since *M. persicae* has shown resistance to permethrin (Ffrench et al. 1988) and predator populations were reduced.

Both degree-day accumulation and the lower developmental threshold were extrapolated from a linear regression equation, $y = 0.005x - 0.092$, of 5 constant temperatures (23.8, 26.6, 29.4, 32.2, and 35.0 C) (Dunbar and Bacon 1972). A total of 200 degree-days (threshold 18.4 C) was required for development of *G. pallens* from the 1st generation to adult. The lower developmental threshold was taken from the x-intercept (divided by the slope) and the degree-day requirement (200) from the inverse of the slope of the linear regression equation. Dunbar and Bacon (1972) noted that no development of *G. pallens* nymphs occurred at or above 37.8 C, and mortality of nymphs was 100%. Since 40% mortality occurred at 35.0 C, the upper developmental threshold would be between these two temperatures. An upper developmental threshold of 36.0 C was chosen for accumulation of degree-days. If a recorded high temperature was above 36.0 C, it was replaced by 36.0 C, since development presumably did not occur above this temperature. To evaluate the accuracy of a 1 April starting date to predict emergence of adult *G. pallens*, daily mean temperatures were subtracted from the lower developmental threshold (18.4 C)

and accumulated until 200 degree-days were reached. To evaluate the accuracy of the biofix date, degree-days were summed from the date that 1st instar *G. pallens* were initially observed in potato. The mean temperatures were collected from a site in Echo, Oregon, which is located approximately 16 km from the Hermiston Agricultural Research and Extension Center. The two degree-day starting dates (1 April and biofix) were compared with the actual emergence dates in potato during 1992 and 1993, determined by field sampling.

## Results and Discussion

### Consumption of alate *M. persicae* by adult *G. pallens*

Female *G. pallens* adults consumed more alate *M. persicae* than male *G. pallens* adults on both potato and pepper.

On potato, adult female *G. pallens* consumed significantly (F= 77.123, df =1, 36 p<0.0001) more alate *M. persicae* than male *G. pallens*. There was no evidence of differences between two repeated experiments (F= 3.322, df= 1,36 p= .077) or interaction of gender and experiment (F= 0.147, df= 1, 36 p= 0.707).

Adult female and male *G. pallens* consumed 2.8 ±0.3 and 0.7 ±0.2 alatae/day (mean subtracted from control ± sem), respectively, in the first experiment (Fig. II.1A). A mean consumption rate from the second experiment was not calculated due to excessive aphid mortality in control containers. However, the relative
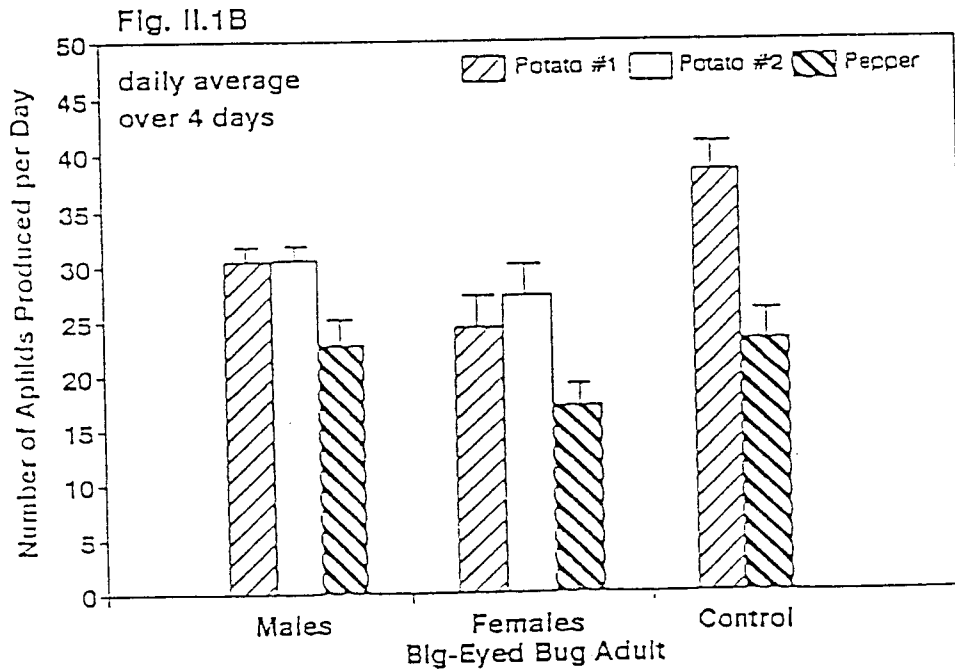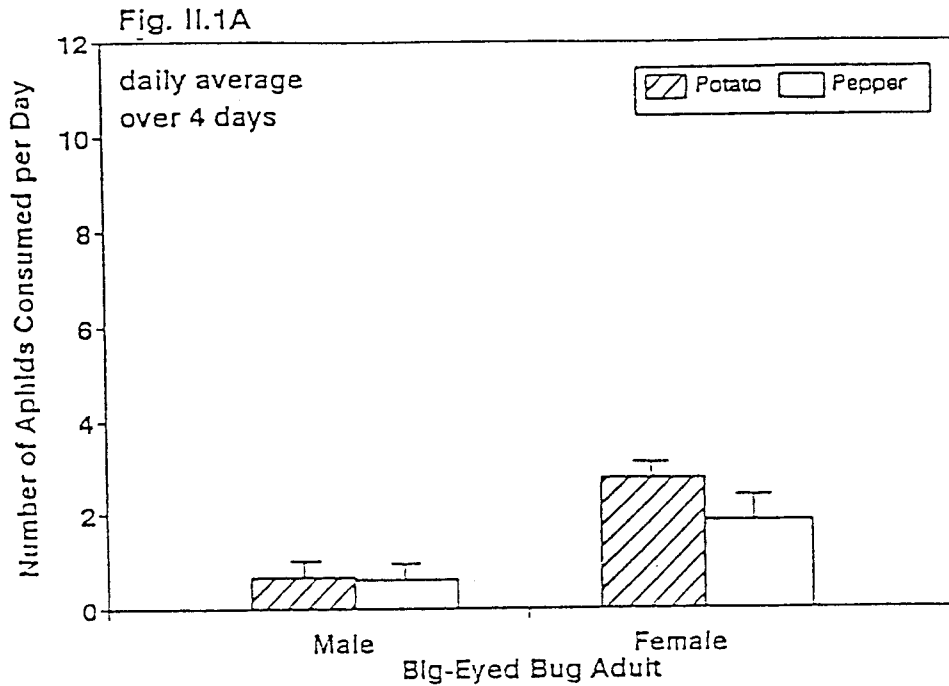
Figure II.1  A)  Daily consumption of alate *M. persicae* by adult *G. pallens* on potato and bell pepper in the laboratory and B) daily production of 1st instar *M. persicae* by alatae in cages with and without adult *G. pallens* on potato and bell pepper in the laboratory.  Error bars are for within-plant comparisons only.

consumption values of male and female *G. pallens* (without adjusting for mortality in the control containers) supported the results in the first experiment.

On pepper, the number of alate *M. persicae* consumed per day by adult female *G. pallens* was significantly (F= 4.503 df= 1,18 p= .048) greater than that by adult male *G. pallens* (Fig. II.1A). Females and males consumed an average of 1.9 ±0.4 to 0.6 ±0.2 *M. persicae*, respectively.

First instar *M. persicae* production

Alate aphids collected during the consumption experiments continually produced live 1st instars. *G. pallens* had the option of consuming both alates and 1st instar aphids. The number of 1st instars collected from the control (no *G. pallens*) provided a useful estimation of aphid reproduction in the absence of *G. pallens*. Comparing these numbers with the numbers where *G. pallens* was present allowed an assessment of predation on the young apterae or prevention of apterae production.

In experiment one on potato (Fig. II.1B), the number of 1st instar *M. persicae* produced by alatae was not significantly different between treatments with either male or female *G. pallens* but was significantly greater in the control (F=19.093 df= 2,27 p< 0.0001). The population of live 1st instar *M. persicae* recovered each day averaged 30.4 ±1.9 and 24.4 ±2.7 for treatments with male and female *G. pallens*, respectively, while the control averaged 38.5 ±3.2 first instar aphids. This indicated an average reduction of 8.1 and 14.1 1st instar aphids due to male and female *G. pallens*, respectively.

In experiment two, the number of 1st instar *M. persicae* recovered in the treatments with female or male *G. pallens* did not differ (t statistic= 1.475 p = 0.15). The mean values in the control were not included due to excessive mortality of alatae in the experiment two check. The average number of live 1st instar *M. persicae* recovered each day was 30.5 ±2.8 and 27.2 ±2.5 for male and female *G. pallens*.

On pepper, there was no difference in the number of live 1st instar *M. persicae* recovered each day with male or female *G. pallens* (22.9 ±2.2 and 17.5 ±2.0, respectively), or in controls with only alatae (23.3 ±2.4) (F= 1.696 df= 2,27 p= 0.202).

Consumption of 1st and 2nd instar *M. persicae* by adult *G. pallens*

Females consumed significantly more 1st and 2nd instar aphids than males in experiments one and two on potato (F= 51.460 df= 1, 36 p< 0.0001). Female and male *G. pallens* consumed an average of 6.9 ±0.8 and 2.2 ±0.3 1st and 2nd instar aphids per day, respectively, in experiment number one (Fig. II.2A). In experiment number two, female and male *G. pallens* consumed 9.6 ±1.0 and 4.0 ±0.5 1st and 2nd instar aphids per day, respectively. There were experimental differences (p< 0.001) but no interaction between experiment and gender (p< 0.747) was detected (F= 13.00 and 51.46, respectively, df= 1, 36). The increase in consumption for the second experiment conducted five days after the first experiment caused a significant difference between experiments, which was likely due to an increased

Fig. II.2A

daily average
over 4 days

Potato #1 ▭ Potato #2 Pepper

Number of Aphids Consumed per Day

Males          Females
Big-Eyed Bug Adult

Fig. II.2B

daily average
over 4 days

Potato ▭ Pepper

Number of Aphids Consumed per Day

1     2     3     4     5
Big-Eyed Bug Instar
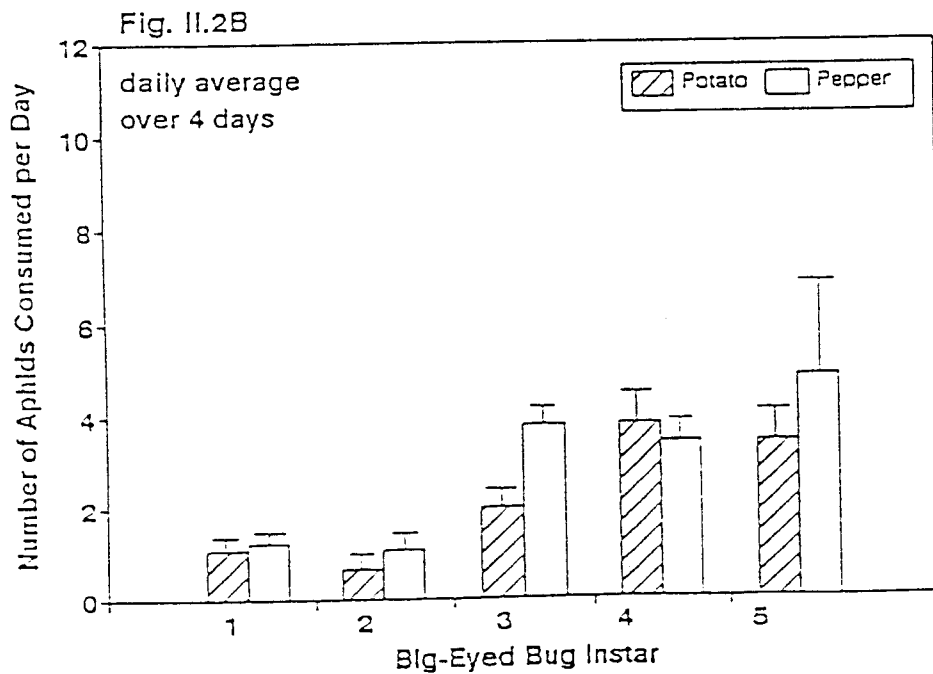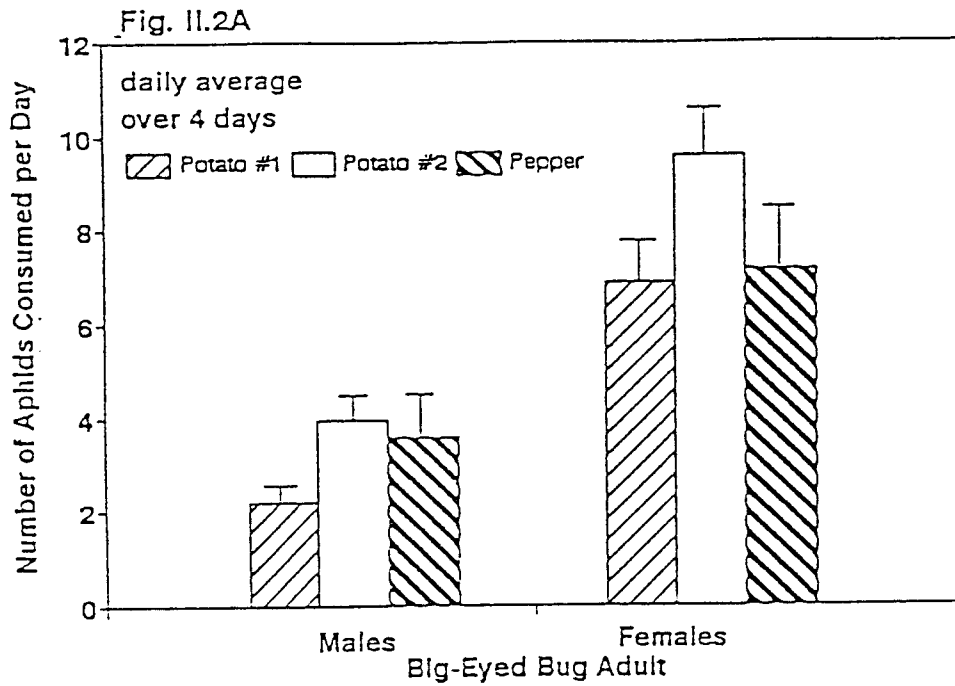
Figure II.2  Daily consumption of 1st and 2nd instar *M. persicae* on potato and bell pepper in the laboratory by A) adult *G. pallens* and B) nymphs.  Error bars are for within-plant comparisons only.

metabolism in *G. pallens* from warmer temperatures in the laboratory containers. Higher temperatures (between 30.0 and 35.0 C) have been shown to increase feeding rates in *G. punctipes* (Crocker et al. 1975).

On pepper, female *G. pallens* consumed significantly more 1st and 2nd instar aphids/day than male *G. pallens* (t statistic= -2.160 p= 0.044). Females consumed an average of 7.2 ±1.3 and males, 3.6 ±1.0) (Fig. II.2A) (t statistic = -2.160 p= 0.044).

Consumption of 1st and 2nd instar *M. persicae* by *G. pallens* nymphs

In two-sample analyses on potato, mortality of 1st and 2nd instar *M. persicae* was significantly greater in the presence of instars 1 and 5 of *G. pallens* than in their controls (for instar 1, $p < 0.0001$; 5, $p < 0.0001$). An analysis of variance (Tukeys HSD) of the 2nd, 3rd, and 4th instars of *G. pallens* and common control indicated that significantly greater mortality of *M. persicae* occurred in the presence of 3rd and 4th instars than in the control containers ($p < 0.05$) but the 2nd instar was not significantly different ($p > 0.05$). In comparing other instars, no significant differences were found between *G. pallens* instars 1 and 2 (p= 0.15) or instars 4 and 5 ($p < 0.05$). *G. pallens* instars 1 through 5 consumed an average of 1.1 ±0.2, 0.7 ±0.2, 2.0 ±0.2, 3.8 ±0.9, and 3.4 ±0.7 1st and 2nd instar aphids, respectively, on potato (Fig. II.2B). Since no significant differences were detected between 1st and 2nd or 2nd and 3rd instars, the non-significance of aphid mortality in the presence of

2nd instar *G. pallens* and the control container can not be easily explained biologically, and may be attributed to the differences in control mortality.

On pepper, mortality of 1st and 2nd instar *M. persicae* was significantly greater in the presence of any *G. pallens* instars than in their controls (for instar 1, $p< 0.001$; 3, $p< 0.0001$; 4, $p< 0.0001$; 5, $p< 0.0001$) except instar 2, which did not differ from the mortality in its control ($p< 0.064$). In comparing adjacent instars, no significant differences were found between *G. pallens* instars 1 and 2 ($p= 0.09$), instars 3 and 4 ($p = 0.19$), or instars 4 and 5 ($p = 0.21$). *G. pallens* instars 1 through 5 consumed an average of 1.2 ±0.3, 1.1 ±0.4, 3.8 ±0.4, 3.4 ±0.5, and 4.9 ±1.9 1st and 2nd instar aphids, respectively, on pepper (Fig. II.2B).

The results of these experiments indicated that *G. pallens* nymphs consumed 1st and 2nd instar *M. persicae* on both potato and pepper. Due to their small size and reduced consumption rates, a much larger sample size would have been desirable. However, labor constraints limited the number of samples possible.

The number of 1st instar *M. persicae* consumed per day by adult female *G. pallens* was 6.9 ±0.8, which agrees closely with the 6.5 ±0.5 reported by Tamaki and Olsen (1977) from adult female *G. pallens* on sugarbeet (using 3rd, 4th instars and apterous adult *M. persicae*). The temperature of 24 C (range of 19-33 C) used in their experiments was similar to the temperature used in my experiments (23.8 C and range of 18.8-25.5 C), but apparently they did not have a control to account for non-predator mortality.

Results from an experiment involving *G. punctipes* suggested that cooler temperatures were responsible for non-significant differences and some lower consumption rates in later instars compared with earlier instars (Crocker et al. 1975). At higher temperatures, later *G. punctipes* instars consumed significantly more prey than earlier instars. Dunbar and Bacon (1972) reported that *G. pallens* preferred temperatures between 30 and 35 C. The average laboratory temperature of 23.3 (range of 18.8-25.5 C) used in my experiment was an attempt to duplicate the conditions in the potato field in 1993. The temperatures of 1993 were unusually cool for the arid climate of Hermiston, Oregon. Temperatures within the range of 30 to 35 C probably would have resulted in higher consumption rates and larger differences between the *G. pallens* instars. It was possible that the temperature used in the laboratory for my tests could reflect conditions during cool years for *G. pallens* predation. During many years, the average temperatures would be higher than 23.3. This indicates that more research needs to be done to determine the effect of temperature on consumption during warmer years.

The consumption rates reported in this thesis for both adult and nymphs of *G. pallens* suggested that those rates are good estimations and that *G. pallens* is capable of consuming alatae and apterae on both potato and pepper. The similarity of aphid consumption rates on both plants suggested that differences in plant compounds or physical structure did not differentially effect *G. pallens* ability to prey on aphids.

Assessment of *Geocoris* spp. population to *M. persicae* population in potato

The most common herbivores in the study were the CPB and aphids (primarily *M. persicae*) and the most common predators were *Geocoris* spp. (predominantly *G. pallens*), Spiders, *Nabis* spp., and *Orius tristicolor* White. During both 1992 and 1993, plots with transgenic CPB resistance had the highest numbers of predators, including *Geocoris* spp., while plots treated with permethrin insecticide had the lowest number of predators, including *Geocoris* spp. Since permethrin insecticide is ineffective in controlling *M. persicae*, these two treatments were compared to measure the impact of predators (of which *G. pallens* was the most common) on *M. persicae*.

During 1992, *Geocoris* spp. were the most numerous predators from 22 June through 27 August in the Btt plots. Adult populations were abundant from 19 June through 16 July (Fig. II.3A). Even though adults were most numerous in the plots during June and early July, they were present all season and increased in population in August as nymphs matured. Nymph populations were abundant (range 4.5 to 8 per beating cloth sample) from 19 July to 16 August. In all treatments, alate *M. persicae* populations were low until 22 June, peaking on 2 July and declining rapidly thereafter. Alate populations increased again in mid-August. Where *Geocoris* spp. were abundant (Btt plots) both populations of alate and apterous aphids were moderately low. The highest *M. persicae* densities of apterae never exceeded 40 per beating cloth sample in the Btt plots. Where *Geocoris* spp. populations were reduced in the permethrin treated plots, the average densities during the season of both alate
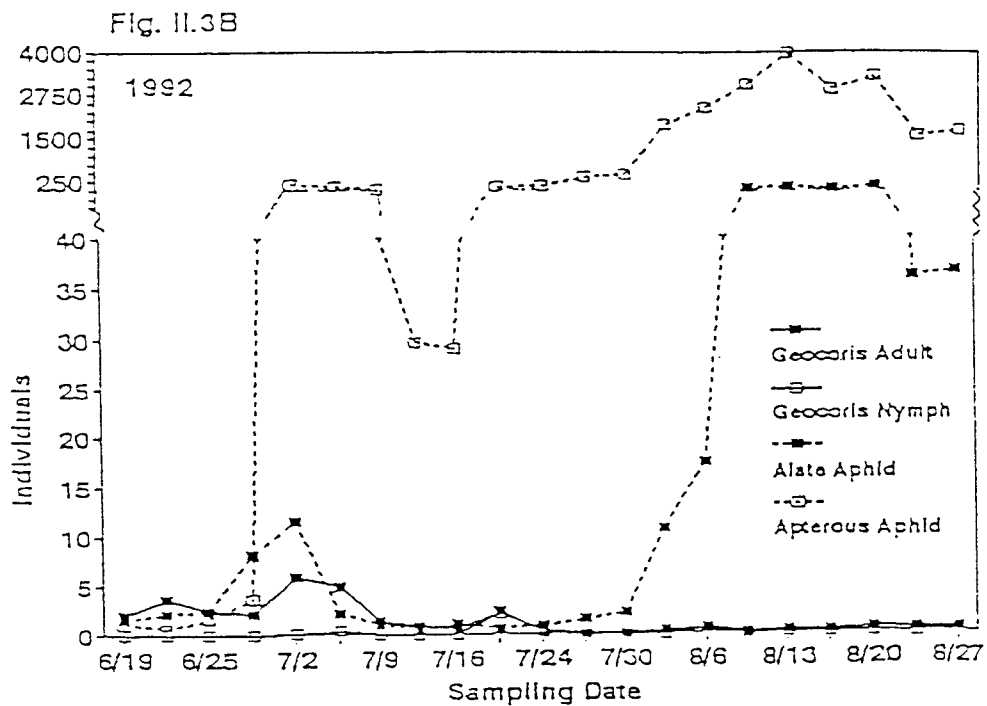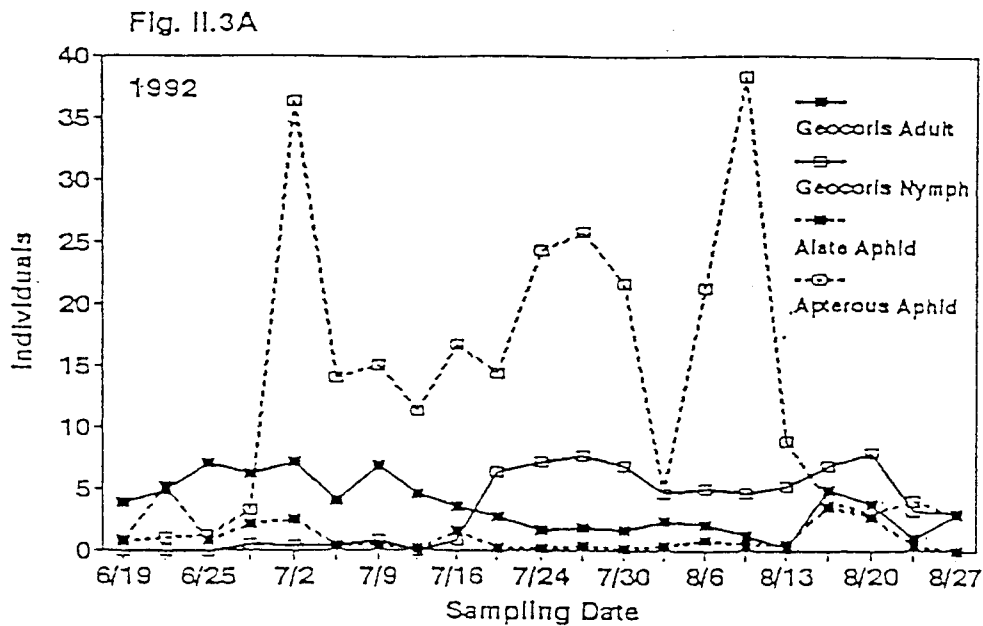
Fig. II.3A



Fig. II.3B



Fig. II.3 Average twice-weekly beating cloth samples of nymph and adult *Geocoris* spp. and alate and apterous *M. persicae* in 1992 in A) Btt transgenic potato and B) potato treated with permethrin at the Hermiston Agricultural Research and Experiment Center. Permethrin treatments on 23 June, 7 and 21 July, and 14 and 18 August.

and apterous aphids were substantially higher than in transgenic plots where *Geocoris* spp. were abundant (permethrin to transgenic: alate 5.2 ±1.2 to 2.3 ±1.2; apterae 40.2 ±29.9 to 11.1 ±6.3 - Table II.1A and II.1B). Apterous *M. persicae* populations in the permethrin plots were as high as 3970 per beating cloth sample during the August peak (Fig. II.3B).

During June and early July, 1993, *Geocoris* spp. were the most numerous predators in the field (Fig. II.4A). This population consisted almost entirely of adults. Low densities (range 0.8 to 1 per beating cloth sample) of nymphs were present from Mid-July through late August. Alate *M. persicae* first became numerous in the plots 15 July and peaked 22 July, then declined through the end of the study on 23 August. Apterous populations were very low in the plots until 22 July at which time they expanded rapidly but never reached the extreme numbers which occurred in 1992. The population of *Geocoris* spp. adults declined steadily from 18 June to 12 July. The initial presence of alate aphids on 15 July was accompanied by a secondary peak of *Geocoris* spp. adults; however, the adult population then declined steadily for the remainder of the season. Again, the comparison between transgenic and permethrin plots may be used to illustrate the impact of *Geocoris* spp. on aphid population. In 1993, the population of apterous aphids in the permethrin plots (for measuring the potential for unrestricted population growth) reached approximately 500 per beating cloth sample, a decrease of 87% of the peak population in 1992. Conversely, apterous aphid populations in the transgenic plots reached approximately 160 per beating cloth sample (in the near

Table II.1 Twice-weekly beating cloth samples of predators in Btt and permethrin (Perm) treated potato and A) alate aphids from 19 June to 2 July, 1992 and 17 July to 1 July, 1993 and B) initial apterous aphids from 19 June to 16 August, 1992 and 15 July to 2 August, 1993 at the Hermiston Agricultural Research and Extension Center.

| A | 1992 (19 June-2 July) | | 1993 (17 June-1 July) | |
| --- | --- | --- | --- | --- |
| | Btt mean s.e. | Perm mean s.e. | Btt mean s.e. | Perm mean s.e. |
| Aphid Alatae | 2.3 ±0.6 | 5.2 ±1.2 | 0.1 ±0.1 | 0.1 ±0.2 |
| Predator | | | | |
| *Geocoris* spp. | | | | |
| Adult | 5.8 ±1.2 | 3.2 ±1.4 | 3.5 ±1.1 | 3.7 ±1.4 |
| Nymph | 0.2 ±0.2 | 0.0 ±0.1 | 0.0 ±0.0 | 0.0 ±0.0 |
| Spider Immature | 1.9 ±0.7 | 0.8 ±0.6 | 1.0 ±0.7 | 1.0 ±0.6 |
| *Nabis* spp. | | | | |
| Adult | 0.6 ±0.4 | 0.9 ±0.4 | 0.4 ±0.4 | 0.4 ±0.3 |
| Nymph | 0.0 ±0.0 | 0.1 ±0.1 | 0.0 ±0.0 | 0.0 ±0.0 |
| *Orius tristicolor* | | | | |
| Adult | 0.6 ±0.2 | 0.6 ±0.2 | 0.6 ±0.4 | 0.6 ±0.4 |
| Nymph | 0.1 ±0.1 | 0.0 ±0.0 | 0.0 ±0.0 | 0.0 ±0.0 |

| B | 1992 (19 June-16 July) | | 1993 (15 July-2 August) | |
| --- | --- | --- | --- | --- |
| | Btt mean s.e. | Perm mean s.e. | Btt mean s.e. | Perm mean s.e. |
| Aphid Apterae | 11.1 ±6.3 | 40.2 ±29.9 | 61.8 ±26.4 | 137.0 ±85.6 |
| Predator | | | | |
| *Geocoris* spp. | | | | |
| Adult | 5.3 ±1.4 | 2.6 ±1.4 | 2.6 ±1.1 | 2.2 ±1.0 |
| Nymph | 0.3 ±0.3 | 0.1 ±0.1 | 0.1 ±0.1 | 0.1 ±0.2 |
| Spider Immature | 2.5 ±1.0 | 1.0 ±0.7 | 2.6 ±0.9 | 1.4 ±0.7 |
| *Nabis* spp. | | | | |
| Adult | 0.9 ±0.4 | 0.1 ±0.2 | 0.4 ±0.3 | 0.4 ±0.3 |
| Nymph | 0.2 ±0.3 | 0.1 ±0.1 | 0.6 ±0.4 | 1.0 ±0.7 |
| *Orius tristicolor* | | | | |
| Adult | 0.5 ±0.4 | 0.5 ±0.4 | 1.5 ±0.7 | 1.6 ±0.8 |
| Nymph | 0.5 ±0.4 | 0.2 ±0.2 | 2.3 ±1.1 | 0.4 ±0.4 |
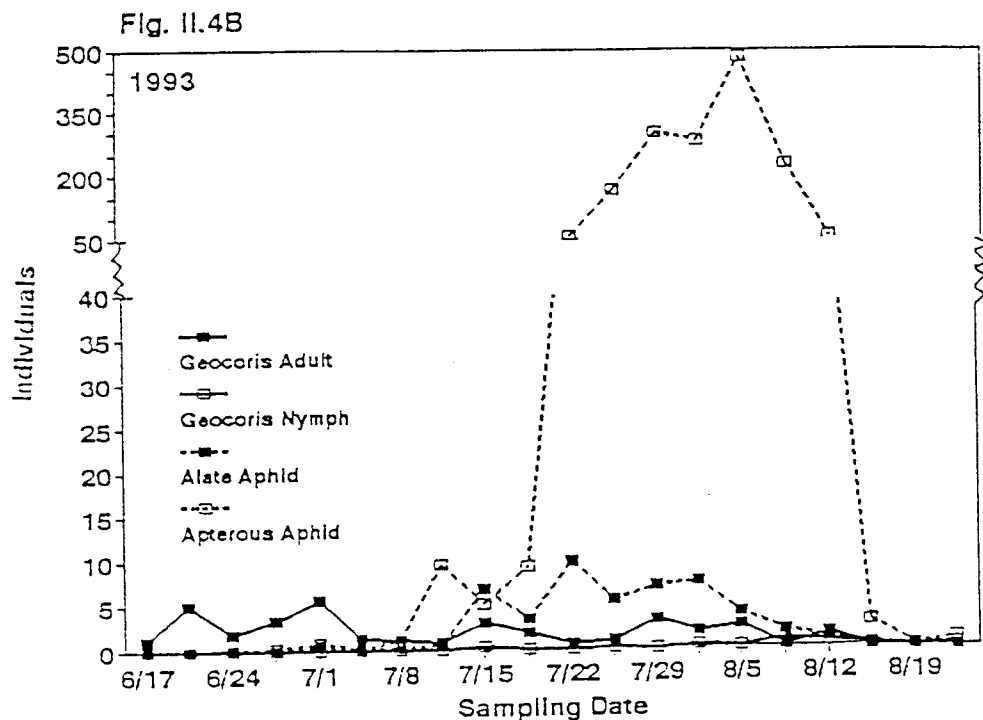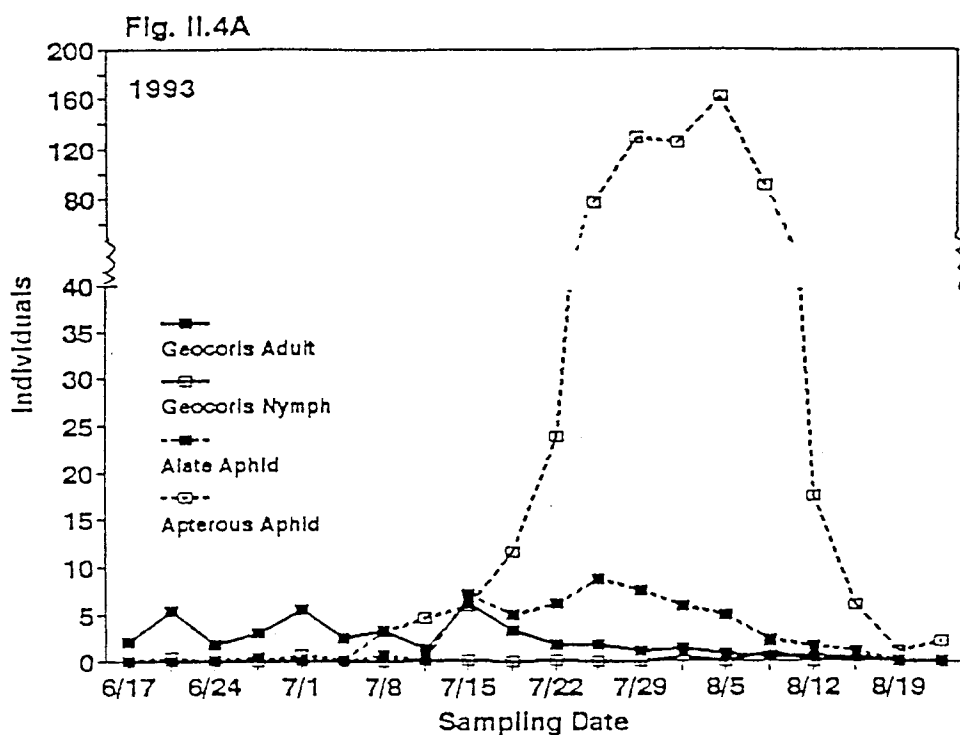
Fig. II.4 Average twice-weekly beating cloth samples of nymph and adult *Geocoris* spp. and alate and apterous *M. persicae* in 1993 in A) Btt transgenic potato and B) potato treated with permethrin at the Hermiston Agricultural Research and Experiment Center. Permethrin treatments on 9 and 23 July, 6 and 20 August.

absence of *Geocoris* spp. nymphs) an increase of 400% over the 1992 peak population (Fig. II.4B).

Successful reproduction of *Geocoris* spp. did not occur in the plots in 1993. This may be explained by the obvious disparity in seasonal occurrence of alate aphids and *Geocoris* spp. adults that year. While *Geocoris* spp. adults were present in nearly equal densities at the same time (mid-June) both years, both initial and peak alate aphid densities in the plots occurred 20 days later in 1993 than in 1992. This disparity may have been caused by differential exposure to winter environment. *Geocoris* spp. overwinter as adults in ground litter where they are protected by snow cover from a harsh environment such as occurred most of the 1992-1993 winter. Conversely, green peach aphid overwinters as eggs on scaffold branches of peach and thus was exposed to the 1992-1993 harsh winter conditions, which may have resulted in later seasonal development than exhibited by *Geocoris* spp. adults.

In 1992, a substantial population of *Geocoris* spp. nymphs emerged from eggs deposited approximately 6 July - after the major population of alate aphid had been present in the plots for 16 days. Since the seasonal population distributions of adult *Geocoris* spp. were very similar both years, it is likely that the adult population in 1993 was prepared to deposit eggs about 6 July of that year. Either these eggs were deposited in potato and some unknown factor caused high mortality in the nymph population or eggs were deposited outside potato plots where abundant suitable prey existed. It is likely that a mortality factor occurring in the plots also would have affected individuals hatching in the immediate vicinity. Since there were

abundant numbers of nymphs on puncturevine and other weeds in the transitional zone surrounding the potato plots, mortality may not explain the absence of *Geocoris* spp. in Btt plots.

This project also monitored populations of lygus bug nymph, thrips, leafhopper, and looper which are known prey of *Geocoris* spp. Populations of lygus bug nymphs, thrips, and leafhopper were more numerous in 1993 and looper nearly equal to those observed in 1992 (data not shown). This may indicate that *Geocoris* spp. are much more dependent on aphids than on other suitable prey. Therefore, while other explanations may account for the lack of *Geocoris* spp. reproduction, the lack of aphid prey at the time of egg deposition was the only salient factor measured in this research. Regardless of the reason for poor reproduction, a dramatic increase in apterous aphid population occurred in Btt in 1993 compared to 1992.

Assessment of *Geocoris* spp. predation capabilities

An attempt has been made to interpolate the consumption data in terms of population estimates gathered during 1992 and 1993. Predation potential for *G. pallens* was estimated using the following model:

Predation Potential = (Individual Consumption X Population Density).

The following assumptions were made in this model:

1) sex ratio was 1:1,
2) temperature did not affect consumption rate,
3) density of aphids in the laboratory resembled that of aphids in the plots,
4) *G. pallens* was the only predator in the field,

5) all *Geocoris* spp. were *G. pallens*, and

6) *G. pallens* only fed on alate and 1st instar *M. persicae*.

The impact of *G. pallens* adults on alatae was estimated using consumption data from experiment one on potato. An average laboratory male:female ratio of 1:1 was used, with each adult *G. pallens* able to consume 1.8 alate aphids/day (the average of male and female consumption rates per day). *G. pallens* was the numerically dominant species of *Geocoris* in the potato plots, while another species, *G. bullatus*, was less abundant. Since *G. bullatus* is larger and is known to consume greater amounts of late instar aphids than *G. pallens* (Tamaki and Olsen 1977), the assumption was that *G. pallens* represented the minimum predation capability of *Geocoris* spp. in the potato plots.

In the field at the HAREC in 1992, alate *M. persicae* averaged 2.3 ±.6 per beating cloth in Btt potato plots and 5.2 ±1.2 per beating cloth in permethrin treated potato plots during their arrival in potato (Table II.1A) (*M. persicae* constituted more than 98% of all aphids in the potato plots in 1992 and 1993). The average of 5.8 ±1.2 *Geocoris* spp. collected from each Btt beating cloth sample during this same period had the potential of consuming a total of 10.4 alatae/day (5.8 adult *Geocoris* spp./sample * 1.8 alatae consumed/day), which could easily account for the difference of 2.9 alatae per beating cloth sample that was found between the Btt and permethrin plots. Based on this estimate, adult *Geocoris* spp. had the potential to more than suppress the difference in aphid numbers between alate *M. persicae* populations in Btt and permethrin plots during 1992. With the exception of spiders

(1.9 ±0.7 per beating cloth sample), all other predators averaged less than one individual per beating cloth sample during the period of alate activity.

In the field during 1993, from 17 June to 1 July, the number of alatae in Btt and permethrin plots averaged less than 1 per beating cloth sample (Table II.1A). It should be noted that permethrin was initially applied on 9 July because CPB populations had not reached application thresholds for treatment until that time. Adult *Geocoris* spp. averaged 3.5 ±1.1 in Btt plots and 3.4 ±1.4 in the permethrin plots. The overwintering adult generation of *Geocoris* spp. began to decline prior to the arrival of alatae, which occurred on 15 July. Thus, *Geocoris* spp. had little impact on the alate aphid population in 1993.

The second phenological period of *M. persicae* infestation, the initial apterae produced by alatae, occurred from approximately 19 June to 16 July in 1992 (Table II.1B). The daily average mean consumption value of 1st and 2nd instar *M. persicae* by *G. pallens* adults was 5.7/day. A total of 30.2 1st and 2nd instar *M. persicae* could have been consumed by adult *Geocoris* spp. (5.3 adult *Geocoris* spp./sample * 5.7 1st and 2nd instar aphids consumed/day). The daily average consumption rate of *G. pallens* instars 1 through 5 was 2.2 1st and 2nd instar aphids. Thus, the potential number of 1st and 2nd instar aphids consumed by *Geocoris* spp. nymphs in Btt plots from 13 July to 24 August, 1992 was 1.5 1st and 2nd instar aphids/day) (5.1 *Geocoris* spp. nymphs/sample * 0.3 1st and 2nd instar aphids consumed/day). The combined potential of nymph and adult *Geocoris* spp. was 31.7 1st and 2nd instar *M.*

*persicae* consumed/day, which could account for the difference in apterae of 29.1 between permethrin and Btt treatments (40.2 apterae - 11.1 apterae).

There was a 72% reduction of apterae in the permethrin plots compared with the Btt treatments from 19 June to 16 July, 1992. Since spiders were the only other predator that averaged more than 1 per sample (2.5 ±1.0) from 19 June to 16 July in Btt plots, it is likely that the adult *Geocoris* spp. population had a greater impact on the initial apterae than the other predators.

During the production of subsequent generations of apterae produced from the initial apterae in 1992, the third phenological event of *M. persicae* (Table II.2), adult and nymphs of *Geocoris* spp. were capable of consuming 13.7 and 11.2 apterae/day, respectively (2.4 adult *Geocoris* spp./sample * 5.7 1st and 2nd instar aphids consumed/day and 5.1 *Geocoris* spp. nymphs/sample * 2.2 1st and 2nd instar aphids consumed/day). The combined potential of adult and nymph *Geocoris* spp. was 24.9 1st and 2nd instar *M. persicae* consumed/day. The difference between Btt and permethrin treatments could be explained if the initial predation by *Geocoris* spp. suppressed further reproduction of *M. persicae*.

The population of apterae (1563.0 ±0.1 to 15.3 ±8.6 in the permethrin and Btt treatments, respectively) during this second phenological event in 1992 suggests that predators were important in control, not only by direct consumption of aphids but indirectly by suppression of aphid reproduction. Spiders and *Nabis* spp. adults and nymphs were 68% and 45% as numerous as *Geocoris* spp., suggesting that these predators also contributed substantially to the control of *M. persicae*.

Table II.2 Twice-weekly beating cloth samples of predators and apterous aphids in Btt and permethrin (Perm) treated potato from 13 July to 24 August, 1992 and 12 July to 23 August, 1993 at the Hermiston Agricultural Research and Extension Center.

| | 1992 (13 July-24 August) | | 1993 (12 July-23 August) | |
|---|---|---|---|---|
| | Btt mean s.e. | Perm mean s.e. | Btt mean s.e. | Perm mean s.e. |
| Aphid Apterae | 15.3 ±8.6 | 1563.0 ±742 | 50.2 ±27.5 | 123.1 ±94.0 |
| Predator | | | | |
| *Geocoris* spp. | | | | |
|     Adult | 2.4 ±1.1 | 0.5 ±0.5 | 1.5 ±0.9 | 1.4 ±0.9 |
|     Nymph | 5.1 ±2.2 | 0.3 ±0.4 | 0.2 ±0.3 | 0.3 ±0.4 |
| Spider Immature | 5.1 ±1.6 | 0.7 ±0.5 | 4.2 ±1.5 | 1.6 ±0.8 |
| *Nabis* spp. | | | | |
|     Adult | 1.1 ±0.5 | 0.4 ±0.4 | 0.7 ±0.5 | 0.8 ±0.6 |
|     Nymph | 2.3 ±1.1 | 0.3 ±0.3 | 1.4 ±1.1 | 1.4 ±0.8 |
| *Orius tristicolor* | | | | |
|     Adult | 0.2 ±0.3 | 0.5 ±0.5 | 2.3 ±1.1 | 1.8 ±1.0 |
|     Nymph | 0.3 ±0.3 | 0.0 ±0.1 | 4.5 ±2.0 | 2.8 ±1.8 |

During this period in 1993, from 12 July to 23 August (Table II.2), *G. pallens* adults and nymphs were capable of consuming 8.6 and 0.4 apterae/day, respectively (1.5 adult *Geocoris* spp./sample * 5.7 1st and 2nd instar aphids/day and 0.2 *Geocoris* spp. nymphs/sample * 2.2 1st and 2nd instar aphids consumed/day). The combined potential consumption of adult and nymph *Geocoris* spp. was 9.0 1st and 2nd instar *M. persicae*/day, which is insufficient to explain the difference in population between permethrin treated potato and Btt potato. This would also suggest that suppression of reproduction and the impact of other predators was

necessary to explain the reduction in aphid population between Btt and permethrin treated potato. As mentioned earlier, the absence of reproduction of *Geocoris* spp. was the main difference in aphid densities in Btt between 1992 and 1993.

The population dynamics of *M. persicae* in the Pacific Northwest potato ecosystem is complex. Even when direct comparisons of the impact of predators on aphid populations (in Btt plots) are made with unrestricted aphid population growth (in permethrin plots), predator-prey dynamics are not easily explained. The impact of predators and parasites is difficult to separate and simplistic conclusions should be avoided. Not only do these organisms cause direct aphid population reduction, but they also cause further population suppression by reducing the potential for reproduction. Therefore, much of the evidence of the impact of *Geocoris* spp. on the aphid population must remain inferential.

The comparison of aphid population growth in Btt and permethrin treatments shows a definite decrease which can only be explained by biological factors. Included among these factors are generalist predators, such as *Geocoris* spp., spiders, nabids, *O. tristicolor*, other foliage and ground dwelling predators, and parasites. *Geocoris* spp. were the most numerous of the natural enemies observed in the plots during 1992 and initially in 1993. *Geocoris* spp. consume *M. persicae* throughout their nymph and adult life spans. Specific predators, such as coccinellids and lacewings, which are commonly found in potato ecosystems in other parts of North America, are noticeably scarce in the PNW potato ecosystem. When specific

natural enemies were present in our plots, they invariably followed the exponential

population growth of *M. persicae.*

The generalist predators, including *Geocoris* spp., apparently inhabit niches

that more specific natural enemies occupy in other potato ecosystems. Because the

presence of generalist predators usually precedes that of the pest, they are able to

impact pest populations before exponential growth can occur - both by direct

predation and by suppressing reproduction. This suggests that generalist predators

are of greater benefit in PNW potato IPM than specific natural enemies, which

predominate elsewhere. Perhaps their early impact on pest species precludes

development of substantial populations of specific natural enemies. It also should be

noted that other prey such as mites, thrips, and lygus nymphs, were present in the

potato ecosystem. When aphid populations were low, alternate food was available

for *Geocoris* spp.


Assessment of degree-day requirements

The evaluation of degree-day accumulation for the development of *G. pallens*

(Fig. II.5) presents the dates of predicted adult emergence of the 1st generation in

1992 and 1993, using both the biofix date of 1st instar emergence *G. pallens* and 1

April as a starting point for degree-day accumulation. These data indicated that,

using a 1 April starting date, predicted completion of development occurred 30 days

prior to the observed completion in 1992. In 1993, using the 1 April starting date,

completion of predicted development occurred on 20 August. However,
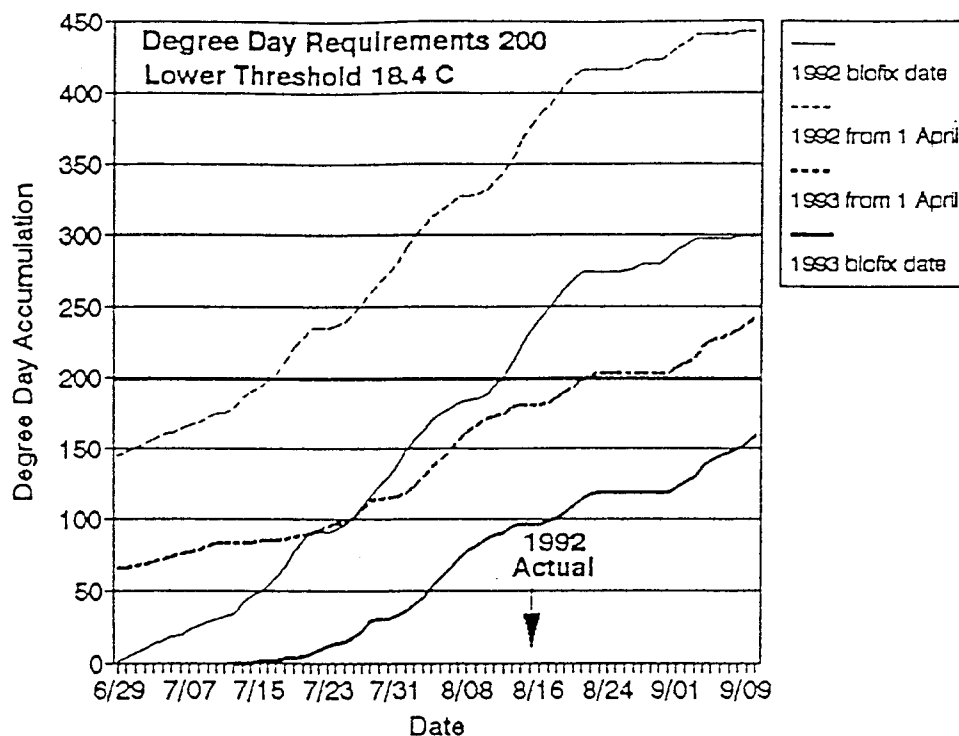
**Fig. II.5.** Degree-day comparison of *G. pallens* first generation development to adult beginning on 1 April (1992 and 1993), or on 1st instar emergence, 29 June and 12 July (biofix dates for 1992 and 1993). 'Actual' on x-axis refers to adult emergence in potato in 1992. Data from Hermiston Agricultural Research and Extension Center.

development did not occur in potato in 1993. Using the biofix date as a starting point for degree-day accumulation, the model predicted that adult emergence in 1992 would occur 4 days prior to the actual observed emergence. Heat units accumulated from the biofix date for 1993 indicated that *G. pallens* nymphs would not develop to adults, as was actually the case in 1993. Thus, using a biofix date was more accurate in predicting adult *G. pallens* emergence (and lack of emergence) for both 1992 and 1993 than an 1 April starting point.

Evaluation of adult emergence should use a relevant biological event, such as 1st instar emergence, to accurately predict adult emergence.

The superior abundance, early arrival, and reproduction of *G. pallens* in potato in 1992 contributed to its exceptional value as a predator of *M. persicae*, and potentially in suppressing potato leafroll virus. The value of *Geocoris* spp. and other generalist predators should direct consultants to manage insecticide programs to protect this resource. It also indicates a strong need for research on techniques to enhance populations of generalist predators in agroecosystems everywhere.

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## SUMMARY AND CONCLUSIONS

A big-eyed bug, *G. pallens*, is an important predator of several important pests in cultivated crops. It has been investigated in various crops (Smith 1942; van den Bosch and Hagen 1966; Gonzalez and Wilson 1982; Benedict and Cothran 1975; Tamaki and Weeks 1973; Tamaki and Weeks 1972) and preys on a variety of arthropods, including thrips, mites, aphids, and other small arthropods (Tamaki and Weeks 1972). The ability of adult *G. pallens* to consume late instar *M. persicae* on sugarbeet has been investigated by Tamaki and Weeks (1972), but the ability of all instars of *G. pallens* to consume *M. persicae* on pepper and potato has not been determined.

Three important phenological stages of *M. persicae* in potato are 1) migrant alatae 2) initial apterous progeny of alatae and 3) apterae produced by the initial apterae. Laboratory studies demonstrated that all stages of *G. pallens* consumed 1st and 2nd instar *M. persicae* on both potato and bell pepper. Adult *G. pallens* consumed alate aphids on potato and bell pepper, with females consuming more alatae than males on both plants. Female and male *G. pallens* limited the production of 1st instar *M. persicae* by alatae on potato.

An investigation of predators and *M. persicae* in the field grown Btt transgenic potato plots showed that *Geocoris* spp. were the most numerous predator throughout the growing season and during the three important phenological periods of aphid growth. Both adult and nymphs of *Geocoris* spp. were present during the production of apterae by alate *M. persicae* and during the production of apterous

aphids from the initial apterae. Conversely, nymphs of *Geocoris* spp. were absent in 1993, resulting in low numbers of *Geocoris* spp. after mid-season. The scarcity of 1st generation *Geocoris* spp. in 1993 corresponded with higher numbers of *M. persicae* relative to 1992, when an abundant population of *Geocoris* spp. was present. The summer of 1993 was unusually cool and may have been responsible for the absence of the reproduction of *Geocoris* spp. Another explanation for the absence of the reproduction of *Geocoris* spp. in 1993 could be the low population of *M. persicae* prior to *Geocoris* spp. oviposition. If *M. persicae* was an important source of nutrition for *Geocoris* spp. reproduction, their low densities in 1993 may explain why adult *Geocoris* spp. did not reproduce in the potato plots. In 1992, the Btt potato plots, which had a season long population of aphids, harbored greater numbers of *Geocoris* spp., including nymphs, than in 1993.

Laboratory consumption data was compared with data from beating cloth samples in both Btt and permethrin treated potato to assess the predation capabilities of *Geocoris* spp. From this analysis, it was apparent that *G. pallens* was capable of suppressing *M. persicae* during the three important phenological periods of *M. persicae* development, through direct predation and indirectly through limiting aphid reproduction.

The degree-day requirements extrapolated from Dunbar and Bacon (1972), when combined with the biofix date of 1st instar *G. pallens* emergence, was successful in predicting the development of the 1st generation of adults for both 1992 and 1993. The use of 1 April as a degree-day initiation was not useful for

prediction, indicating that some biologically relevant event should be used for accurate prediction.

Since *M. persicae* often occurs at a low density in potato (Mackauer and Way 1976), and the suggested threshold for *M. persicae* is 30 apterae per 105 leaves for fresh market potato (Cancelado and Radcliffe 1979), adequate control of *M. persicae* by parasites and specific predators is not feasible. In a study of numerical response of predators to *M. persicae*, coccinellids and chrysopids were more likely to oviposit in areas of high aphid density compared to low aphid density (Tamaki and Long 1978). *Geocoris* spp. and *Nabis* spp. oviposited only slightly more at higher densities of *M. persicae* than lower densities in the same experiment. Thus, a generalist predator like *Geocoris* spp. may have an advantage over specific predators as biological control agents of *M. persicae* because 1) they are present early in the growing season in potato, prior to the arrival of alate *M. persicae* 2) they are abundant and 3) they can exist on alternate prey when the density of aphids is low. These attributes are useful for *M. persicae* suppression in potato, and indicate that particularly *G. pallens*, as well as other generalist predators, have a role in reducing the increase of potato leafroll virus.

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APPENDICES

APPENDIX I

Table AI.1   Alate <u>M</u>. <u>persicae</u> and adult <u>G</u>. <u>pallens</u> on potato (two trials)

Anova Summaries
Square-root transformed

| Source of Variation | df | MS | F | P |
|---|---|---|---|---|
| Experiment | 1 | 1.079 | 3.322 | 0.077 |
| Gender | 1 | 25.058 | 77.123 | <.0001 |
| Exp X Gen | 1 | .048 | .147 | .707 |
| Residual | 36 | .325 | | |
| Total | 39 | | | |

Without interaction

| Source of Variation | df | MS | F | P |
|---|---|---|---|---|
| Main effects | | | | |
|   Experiment | 1 | 1.079 | 43.40 | .073 |
|   Gender | 1 | 25.058 | 278.94 | <.00001 |
| Residual | 37 | .3174 | | |
| Total | 39 | | | |

Table AI.2   Two-sample analysis of alate <u>M</u>. <u>persicae</u> and adult <u>G</u>. <u>pallens</u> on potato (experiment number 1)

Square-root transformed

| | Males | Females | Pooled |
|---|---|---|---|
| Observations | 10 | 10 | 20 |
| Average | 2.015 | 3.529 | 2.773 |
| Variance | 0.375 | 0.381 | 0.378 |
| Std. Dev. | 0.612 | 0.618 | 0.615 |
| Median | 2 | 3.658 | 2.914 |

Computed t statistic = -5.505
Sig. level = 0.00003

Table AI.3   Alate M. persicae and adult G. pallens on pepper

Square-root transformed
Source of

| Variation | df | MS | F | P |
|-----------|-----|-------|-------|------|
| Gender | 1 | 2.975 | 4.503 | .048 |
| Residual | 18 | .661 | | |
| Total | 19 | | | |

Table AI.4   1st and 2nd instar M. persicae and G. pallens adults on potato (two trials)

Square-root transformed
Source of

| Variation | df | MS | F | P |
|-----------|-----|--------|--------|---------|
| Experiment | 1 | 10.475 | 13.800 | <0.001 |
| Gender | 1 | 39.060 | 51.460 | <0.0001 |
| Exp X Gen | 1 | .082 | .108 | .747 |
| Residual | 36 | .325 | | |
| Total | 19 | | | |

Table AI.5   Two-sample analysis of 1st and 2nd instar M. persicae and adult G. pallens on potato (experiment number 1)

Square-root transformed

| | Males | Females | Pooled |
|--------------|-------|---------|--------|
| Observations | 10 | 10 | 20 |
| Average | 3.121 | 5.188 | 4.155 |
| Variance | 0.508 | 0.869 | 0.688 |
| Std. Dev. | 0.713 | 0.932 | 0.830 |
| Median | 3.240 | 5.338 | 3.936 |

Computed t statistic = -5.570
Sig. level = 0.00003

Table AI.6  Two-sample analysis of 1st and 2nd instar M. persicae and adult G. pallens on potato (experiment number 2)

Square-root transformed

|             | Males  | Females | Pooled |
|-------------|--------|---------|--------|
| Observations | 10     | 10      | 20     |
| Average     | 4.235  | 6.121   | 5.178  |
| Variance    | 0.624  | 1.035   | 0.829  |
| Std. Dev.   | 0.790  | 1.017   | 0.911  |
| Median      | 3.998  | 6.000   | 5.044  |

Computed t statistic = -4.630
Sig. level = 0.0002

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Table AI.7  1st and 2nd instar M. persicae and adult G. pallens on pepper

|             | Males    | Females | Pooled  |
|-------------|----------|---------|---------|
| Observations | 10       | 10      | 20      |
| Average     | 24.7     | 39      | 31.85   |
| Variance    | 180.233  | 258     | 219.117 |
| Std. Dev.   | 13.425   | 16.062  | 14.802  |
| Median      | 22.5     | 41.5    | 33      |

Computed t statistic = -2.160
Sig. level = 0.044

APPENDIX II

Table AII.1  Production of 1st instar M. persicae in cages with and without G. pallens adults on potato (experiment 1)

Square-root transformed

| Source of Variation | df | MS | F | P |
|---|---|---|---|---|
| Treatment | 2 | 16.437 | 19.093 | <0.0001 |
| Residual | 27 | .861 | | |
| Total | 29 | | | |

Multiple range analysis of treatments
Square-root transformed
Tukeys HSD

| | Count | LS Mean | Homogeneous Groups |
|---|---|---|---|
| Male | 10 | 9.832 | X |
| Female | 10 | 10.852 | X |
| Control | 10 | 12.379 | X |

Table AII.2  Two-sample analysis of production of 1st instar M. persicae in cages with G. pallens adults on potato (experiment number 2)

Square-root transformed

| | Males | Females | Pooled |
|---|---|---|---|
| Observations | 10 | 10 | 20 |
| Average | 11.018 | 10.373 | 10.695 |
| Variance | 0.567 | 1.345 | 0.956 |
| Std. Dev. | 0.753 | 1.160 | 0.978 |
| Median | 11.158 | 10.292 | 10.840 |

Computed t statistic = 1.475
Sig. level = 0.15
Note: Probable improper handling of alates in control cages prevented their use in this analysis

Table AII.3  Two-sample analysis of production of 1st
instar <u>M</u>. <u>persicae</u> in cages with <u>G</u>. <u>pallens</u> adults on
pepper

Square-root transformed

| Source of Variation | df | MS | F | P |
|---|---|---|---|---|
| Treatment | 2 | 25.059 | 1.696 | <0.202 |
| Residual | 27 | 14.778 | | |
| Total | 29 | | | |

APPENDIX III

Table AIII.1  1st and 2nd instar M. persicae consumption by 1st instar G. pallens vs control on potato.

Wilcoxon unpaired ranked sum test

Sample 1:  1st instar G. pallens
Sample 2:  control
Average rank of males = 15.45 based on 10 values
Average rank of females = 5.55 based on 10 values
Z = -3.770
One-tailed probability of equaling or exceeding z = 0.00005

Table AIII.2  1st and 2nd instar M. persicae control and 2nd, 3rd, and 4th instar G. pallens on potato

Analysis of Variance
Square-root transformed

| Source of Variation | df | MS | F | P |
|---|---|---|---|---|
| Between groups | 3 | 11.904 | 13.985 | <0.0001 |
| Within groups | 36 | 0.851 | | |
| Total | 39 | | | |

Table AIII.3  Multiple range analysis of 2nd, 3rd, and 4th instars

Square-root transformed
Tukeys HSD

| | Count | LS Mean | Homogeneous Groups |
|---|---|---|---|
| Control | 10 | 2.700 | X |
| Second | 10 | 5.400 | XX |
| Third | 10 | 10.700 | XX |
| Fourth | 10 | 18.000 | X |

Table AIII.4  1st and 2nd instar M. persicae consumption by
5th instar G. pallens vs control on potato


Wilcoxon unpaired ranked sum test

Sample 1:  5th instar G. pallens
Sample 2:  control
Average rank of males = 15.45 based on 10 values
Average rank of females = 5.55 based on 10 values
Z = -3.712
One-tailed probability of equaling or exceeding z = 0.0001

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Table AIII.5  Comparison of 1st and 2nd instar G. pallens
1st and 2nd instar M. persicae consumption on potato


Wilcoxon unpaired ranked sum test

Sample 1:  1st instar G. pallens
Sample 2:  2nd instar G. pallens
Average rank of males = 11.9 based on 10 values
Average rank of females = 9.1 based on 10 values
Z = -1.024
One-tailed probability of equaling or exceeding z = 0.15

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Table AIII.6  Comparison of 4th and 5th instar G. pallens
1st and 2nd instar M. persicae consumption on potato


Wilcoxon unpaired ranked sum test

Sample 1:  4th instar G. pallens
Sample 2:  5th instar G. pallens
Average rank of males = 10.9 based on 10 values
Average rank of females = 10.1 based on 10 values
Z = 0.791
One-tailed probability of equaling or exceeding z = 0.400

---

Table AIII.7  Pepper experiments with G. pallens instars
1st and 2nd instar M. persicae consumption by 1st instar
G. pallens vs control on pepper


Wilcoxon unpaired ranked sum test

Sample 1:  1st instar G. pallens
Sample 2:  control
Average rank of males = 14.65 based on 10 values
Average rank of females = 6.35 based on 10 values
Z = -3.124
One-tailed probability of equaling or exceeding z = 0.00085

---

Table AIII.8  1st and 2nd instar M. persicae consumption by
2nd instar G. pallens vs control on pepper

Wilcoxon unpaired ranked sum test

Sample 1:  2nd instar G. pallens
Sample 2:  control
Average rank of males = 12.55 based on 10 values
Average rank of females = 8.45 based on 10 values
Z = -1.56
One-tailed probability of equaling or exceeding z = 0.064

---

Table AIII.9  1st and 2nd instar M. persicae consumption by
3rd instar G. pallens vs control on pepper


Wilcoxon unpaired ranked sum test

Sample 1:  3rd instar G. pallens
Sample 2:  control
Average rank of males = 15.5 based on 10 values
Average rank of females = 5.5 based on 10 values
Z = -3.752
One-tailed probability of equaling or exceeding z = 0.00085

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Table AIII.10  1st and 2nd instar $\underline{M}$. $\underline{persicae}$ consumption
by 4th instar $\underline{G}$. $\underline{pallens}$ vs control on pepper


Wilcoxon unpaired ranked sum test

Sample 1:  4th instar $\underline{G}$. $\underline{pallens}$
Sample 2:  control
Average rank of males = 15.5 based on 10 values
Average rank of females = 5.5 based on 10 values
Z = -3.765
One-tailed probability of equaling or exceeding z = 0.0008

---

Table AIII.11 1st and 2nd instar $\underline{M}$. $\underline{persicae}$ consumption by
5th instar $\underline{G}$. $\underline{pallens}$ vs control on pepper


Wilcoxon unpaired ranked sum test

Sample 1:  5th instar $\underline{G}$. $\underline{pallens}$
Sample 2:  control
Average rank of males = 15.5 based on 10 values
Average rank of females = 5.5 based on 10 values
Z = -3.746
One-tailed probability of equaling or exceeding z = 0.0009

---

Table AIII.12  1st and 2nd instar $\underline{M}$. $\underline{persicae}$ consumption
by 1st and 2nd instar $\underline{G}$. $\underline{pallens}$ on pepper.


Wilcoxon unpaired ranked sum test

Sample 1:  1st instar $\underline{G}$. $\underline{pallens}$
Sample 2:  2nd instar $\underline{G}$. $\underline{pallens}$
Average rank of males = 5.7 based on 10 values
Average rank of females = 15.3 based on 10 values
Z = -3.602
One-tailed probability of equaling or exceeding z = 0.001

---

Table AIII.13   1st and 2nd instar <u>M</u>. <u>persicae</u> consumption by 3rd and 4th instar <u>G</u>. <u>pallens</u> on pepper.


Wilcoxon unpaired ranked sum test

Sample 1:   3rd instar <u>G</u>. <u>pallens</u>
Sample 2:   4th instar <u>G</u>. <u>pallens</u>
Average rank of males = 11.7 based on 10 values
Average rank of females = 9.3 based on 10 values
Z = -0.870
One-tailed probability of equaling or exceeding z = 0.19

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Table AIII.14   1st and 2nd instar <u>M</u>. <u>persicae</u> consumption by 4th and 5th instar <u>G</u>. <u>pallens</u> on pepper.


Wilcoxon unpaired ranked sum test

Sample 1:   4th instar <u>G</u>. <u>pallens</u>
Sample 2:   5th instar <u>G</u>. <u>pallens</u>
Average rank of males = 9.4 based on 10 values
Average rank of females = 11.6 based on 10 values
Z = -0.794
One-tailed probability of equaling or exceeding z = 0.4272