Impact of Low-Spray Mating Disruption Programs on Aphidophagous Insect Populations in Virginia Apple Orchards

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Impact of Low-Spray Mating Disruption Programs on Aphidophagous Insect Populations and *Platynota idaeusalis* Resistance in Virginia Apple Orchards

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(Abstract)

The populations of aphidophagous insects in low-spray and conventional programs were surveyed in Virginia apple orchards. Two sampling methods were utilized; aphid colony collection and beating tray collection. The low-spray blocks employed the use of mating disruption for control of the key direct pests, codling moth, *Cydia pomonella* (Linnaeus), and leafrollers. The abundance and diversity of aphid predators in low-spray mating disruption programs and conventionally controlled apple orchards was compared. Both sampling methods suggested that aphid predators were more plentiful in the mating disruption blocks. Several mating disruption blocks were found to accumulate significantly more predator-days and diversity than the matched control blocks. The reduction of insecticide input into the low-spray blocks may have allowed higher populations of aphidophagous insects to occur. Aphid populations in mating disruption blocks sometimes declined faster and had less resurgence than those in the conventionally controlled blocks.

The tufted apple bud moth (TABM), *Platynota idaeusalis* (Walker), populations in four apple orchards in Winchester, Virginia, were compared for resistance to azinphosmethyl. These orchards were suspected by the growers to have resistant populations of TABM. Pheromone traps with insecticide incorporated into the adhesive were used to collect and test the moths. The results were not analyzed due to the low number of moths collected and high variability in mortality.

To Randy Mortimer,

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CHAPTER 1

Literature Review

Impact of Low-Spray Programs on Aphidophagous

Insect Populations and Insecticide Resistance in Leafrollers

The purpose of this research project was to compare the populations of

aphidophagous insects in low-spray and conventional pest management programs in

Virginia apple orchards. The low-spray programs employ the use of mating disruption

for control of the key primary pests, codling moth, *Cydia pomonella* (Linnaeus), and a

complex of leafroller species from the family Tortricidae. The conventional programs

control these primary pests through the use of organophosphorus insecticides such as

azinphosmethyl, and carbamates such as methomyl. A promising alternative to the

conventional pesticide control of crop pests is mating disruption (Pfeiffer et al. 1993).

Unfortunately, mating disruption is more expensive than conventional control

methods.   For example, Brunner (1991) listed mating disruption expenses for codling

moth alone to be $156/acre compared to $96/ acre for sprays. To help promote

acceptance of this method, it is therefore necessary to evaluate the potentially positive

impact of mating disruption on the arthropod community of orchards. The evaluation of

potential effects, such as higher densities of natural enemies and slowing the rate of

resistance development, may help to persuade growers to adopt this tactic (Brunner

1991). This evaluation is especially important because conventional spray programs can

cause outbreaks of a wide range of secondary pests, including spirea aphids, *Aphis*

spiraecola Patch. The insecticide sprays used in the conventional programs for primary

pests often kill the aphid predators thus allowing the aphid population to rise above

damaging levels. A spray specifically targeted towards these secondary pests must then

be applied.   Spirea aphids have displaced apple aphids as the most common aphid in

the orchard environment and are better able to survive common orchard insecticides

(Pfeiffer et al. 1989a).

Resistance management is a driving force in the development of alternative low-

spray methods such as mating disruption. Azinphosmethyl, known commercially as

Guthion, is the most widely used insecticide in Virginia apple orchards (Pfeiffer et al.

1989b). Reports of tortricid resistance to azinphosmethyl are increasing (Helle et al.

1991). Light brown apple moth (*Epiphyas postvittana* (Walker)) larvae were reported to

be resistant to azinphosmethyl in New Zealand (Suckling et al. 1984). The variegated

leafroller, *Platynota flavedana* (Clemens), and the tufted apple bud moth, *Platynota*

idaeusalis (Walker), were reported to be resistant in the mid-Atlantic region by Hull et al.

(1995). *P. idaeusalis* was found to be resistant in North Carolina by Bush et al.(1993)

and in Pennsylvania by Knight and Hull (1989a & b). In fact, the reports of *P. idaeusalis*

resistance in the mid-Atlantic area have lead to Section 18 requests for the insect growth

regulator, tebufenozide (Confirm) in 1996 for Virginia, Pennsylvania, West Virginia, and

New Jersey. Mating disruption, although already commercially available, is still priced

too high for consideration by most growers.

Mating Disruption & Primary Pests

In mating disruption, the crop area is permeated with the synthetic sex pheromone of the target pest. This permeation disrupts location of potential mates by the males. There are several proposed mechanisms for mating disruption. These include: habituation, adaptation, false trail following, masking, and imbalanced sensory input (Brunner 1991, Beers et al. 1993). In habituation and adaptation, theories the insect's olfactory system does not work correctly due to the exposure to high levels of pheromone. Adaptation occurs when the sensory cells become accustomed to the high levels of pheromone and no longer respond to it. Habituation occurs when sensory cells still fire, but the insect's CNS adapts to ignore the continual signal it receives (Brunner 1991). The false trail theory proposes that there are so many false trails from the pheromone dispensers that the male cannot find the female (Beers et al. 1993). The masking theory suggests that the insect's sensory system still works, but background level of the pheromone masks the female's position by overwhelming the relatively weak natural trail (Brunner 1991). The theory of imbalanced sensory input states that the species-specific blend of the insect is disrupted by pheromone permeation (Beers et al. 1993). The blend perceived by the male is distorted by permeation with an incomplete or improper blend. In reality, more than one theory may be involved (Campion 1984, Brunner 1991, Beers et al. 1993).

Mating disruption may be used by organic growers. It is most successful in suppressing low to moderate pest populations, and can help to significantly reduce pesticide input into a system (Brunner et al. 1991, Pfeiffer et al. 1993). For example, using mating disruption in apple orchards may decrease post bloom pesticide applications from once every two weeks to two applications per season (Pfeiffer et al. 1993). As a

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result, less insecticide is put into the environment. This drastic reduction in insecticide input into the apple orchard may affect the insect fauna of the orchard (Gronning 1995).

C. pomonella and *P. flavedana* are the most economically important direct pests of apple orchards in the central and southern Virginia regions. Other leafrollers present in this region include *P. idaeusalis*; redbanded leafroller, *Argyrotaenia velutinana* (Walker); and occasionally the obliquebanded leafroller, *Choristoneura rosaceana* (Harris) (Hull et al. 1995). *P. idaeusalis* is considered the most important leafroller pest in northern Virginia and Pennsylvania. Mating disruption is commercially available for *C. pomonella* and *P. idaeusalis.*

Primary pests are the insects that consistently cause the most damage to the fruit. Spray programs are targeted to kill these primary pests. Secondary pests are insects that are not always a serious problem in the orchard. Sprays do not always have to be applied to control them. In fact outbreaks of secondary pests are sometimes triggered by sprays for primary pests. These sprays often kill the natural enemies of the secondary pests. In fruit crops the terms direct & indirect are also used to classify pests. Direct pests feed on the fruit. Examples of direct pests in apple orchards include *C. pomonella* and *P. idausalis.* Indirect pests feed on the tree, but generally do not cause injury to the fruit. Aphids and European red mites are examples of indirect pests in apple orchards.

Aphids and aphidophagous insects in apple orchards

Aphids are secondary pests in apple orchards. They feed on the phloem tissue of

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growing shoot tips (Minks & Harrewijn 1987). Leaves on shoot tips are a preferred and

major food source, because they are high in food quality (Pfeiffer 1991). There are at

least 20 species of aphids found on apple (Blackman & Eastop 1984, Pfeiffer 1991).

Aphids of economic importance in Virginia apple orchards include: the spirea aphid,

Aphis spiraecola Patch; apple aphid, *Aphis pomi* (DeGeer); rosy apple aphid, *Dysaphis*

plantaginea (Passerini); apple grain aphid, *Rhopalosiphum fitchii* (Sanderson); and the

woolly apple aphid, *Eriosoma lanigerum* (Hausmann) (Beers et al. 1993). The spirea

aphid, which is morphologically similar to the apple aphid, is currently the most

common aphid found in Virginia apple orchards (Pfeiffer et al. 1989a). Spirea and apple

aphids can be found in the same colony; this complex is commonly referred to as green

aphids (Pfeiffer et al. 1995).

Aphids have varying effects on apple trees. The amount and kind of damage

caused depends on the species and the number of aphids present. Apple and spirea

aphids may stunt shoot growth on young trees: they affect the tree in a similar fashion

(Beers et al. 1993, Kaakeh et al. 1993). Spirea aphids are known to reduce

photosynthesis and foliar nitrogen content (Pfeiffer 1991). The honeydew produced by

aphids may have an economic impact in the orchard. This is because a black fungus,

Fumago vagaus (Fries), may grow in honeydew on the apple (Beers et al. 1993). This is

especially noticeable around the stem of the apples. The presence of this fungus can

reduce the value of the apple and suppress photosynthesis of leaves (Kaakeh et al.

1993). Conversely, honeydew may also attract aphid predators to the tree (Hofsvang 1990).

In Virginia, spirea aphid populations generally peak in mid-June. The suggested monitoring protocol for growers is as follows: "Select ten actively growing shoots per tree. On each shoot, determine the number of leaves that have wingless aphids. Calculate the average number of leaves per shoot infested with aphids across all trees. If an average of four or more leaves per shoot are infested with one or more wingless aphids an application of an insecticide is warranted." (Hogmire 1995). The following is a general list of some of the sprays recommended for aphids: methomyl (Lannate), esfenvalerate (Asana), azinphosmethyl (Guthion), imidacloprid (Provado), dimethoate (Cygon), endosulfuran (Thiodan), and chlorpyrifos (Lorsban) (Pfeiffer 1996). Some of these sprays may be timed to provide control for other pests as well. However, some are considered detrimental to populations of orchard predators (Pfeiffer 1996). Aphids, especially rosy apple aphid, may sometimes be hard to control with sprays after silver-green tip stage of the apple tree, because the leaves they feed on begin to curl inward, and the spray does not contact them (Pfeiffer 1996).

Natural enemies may be used to help control aphid populations in apple orchards. They can be divided into three general categories--predators, parasitoids, and pathogens. In this review, I focused on predators. Families of aphidophagous insects noted in apple orchards include: Anthocoridae, Cantharidae, Cecidomyiidae, Chamaemyiidae,

Chrysopidae, Coccinellidae, Hemerobiidae, Miridae, Nabidae, Phlaeothripidae,

Reduviidae, and Syrphidae (Parella 1980, Peterson 1982 (Part I & II), Minks & Harrewijn

1988, Beers et al. 1993, Pfeiffer & Hogmire 1995). When monitoring aphid colonies it is

suggested that if there are predators in greater then twenty percent of the colonies then

biological control is possible (Hogmire 1995). Natural enemy populations tend to vary

with the site surroundings and management practices used. For example, in pear orchards,

natural enemies tend to be more common in orchards bordered by natural habitats. They

appear to be less plentiful in orchards bordered by well-sprayed orchards (Riedl 1991).

Gronning (1995), utilized pitfall sampling to find that arthropod communities in the

orchards undergoing mating disruption were more diverse than communities in

conventionally-managed orchards. Azinphosmethyl is the most widely used insecticide

in Virginia apple orchards (Pfeiffer et al. 1989b). Thus, it may be relevant to note which

natural enemies have shown resistance or tolerance to azinphosmethyl.

Green lacewings (Chrysopidae) can be important natural enemies of aphids in

apple orchards. They are generalist predators. The eggs are laid on stalks near aphid

colonies. The stalk is thought to help protect the egg from predation (Smith 1922). The

larvae are predaceous and eat aphids. They pierce the aphids with their elongated

mandibles and maxillae that are modified to form sucking tubes. Then they raise the

aphids in the air and suck the body fluids from them (Smith 1922). Depending on the

species of chrysopid, the adults may be predaceous or feed primarily on honeydew and

pollen. However, even the adults that feed primarily on honeydew and pollen

occasionally consume aphids, possibly resulting in increased reproductive success

(Pfeiffer & Hogmire 1995).

Three Chrysopid species that have been reported in orchards of the mid-Atlantic

region include: *Chrysopa oculata* Say*, Chrysoperla carnea* (Stephens)*,* and *Chrysoperla*

rufilabris (Stephens). Other species have been reported but less abundant (Pfeiffer &

Hogmire 1995). *C. carnea* has been noted to consume an average of 393 aphids during

development (Hofsvang 1990). Green lacewings tend not to be present in the early stage

of the growing season due to a high developmental threshold temperature (Minks &

Harrewijn 1988).

Beating trays have been noted as the best monitoring method for adult chrysopids

(Smith 1922, Riedl 1991, Beers et al. 1993). The cooler morning hours result in better

collections and better monitoring. Larvae can be monitored by visual inspection of active

aphid colonies, and Chrysopid larvae may also be found in beating trays (Szabo &

Szentkiralyii 1981, Canard et al. 1984, Beers et al. 1993). Two to four generations of

Chrysopidae can occur each year in Virginia (Pfeiffer & Hogmire 1995). In the Pacific

Northwest green lacewings are often plentiful in orchards practicing methods of integrated

pest management (Beers et al. 1993). Azinphosmethyl has been shown to be moderately

to very harmful to lacewing larvae and adults (Riedl 1991, Pfeiffer 1996). However, Pree

et al. (1989) noted that resistance to azinphosmethyl has been found in larvae from

sprayed apple orchards in Ontario, Canada.

Brown lacewings (Hemerobiidae) may also be found in Virginia apple orchards. The adults and larvae of this family are generalist predators, but larvae are noted to feed mainly on aphids (Beers et al. 1993). The developmental threshold of brown lacewings is often less than that of aphids. This can make brown lacewings important in early season control (Minks & Harrewijn 1988, Tauber 1991, Pfeiffer & Hogmire 1995). Eggs are laid directly on twigs or apple buds near active aphid colonies (Tauber 1991, Beers et al. 1993, Pfeiffer & Hogmire 1995). Species identified in Pennsylvania vineyards include: *Micromus posticus* (Walker), *M. subanticus* (Walker), *Hemerobius humulinus L., H. stigmaterus* (Fitch)*,* and *Sympherobius amiculus* (Fitch). Brown lacewing larvae can eat around 20 aphids a day (Pfeiffer & Hogmire 1995). The suggested monitoring plan for brown lacewings is the same as listed above for green lacewings. Szabo and Szentkiralyii (1981) noted that Chrysopidae and Hemerobiidae communities in apple orchards under various management practices (commercial, abandoned, & experimental) typically have low diversity. Azinphosmethyl was noted to be highly toxic to lacewings (Pfeiffer 1996).

Hover flies (Syrphidae) are predators of aphids and other soft-bodied insects. The adults, often bee or wasp mimics, are not predaceous. However, larvae are predaceous and each individual may kill hundreds of aphids during its life. Syrphid larvae have exhibited a high voracity in the lab (Heiss 1938, Minks & Harrewijn 1988). *Syrphus ribesii* (L.) has been noted to eat an average of 562 aphids during development (Hofsvang

1990). Syrphid flies can be more active in cooler temperatures than most other aphid

predators (Beers et al. 1993). Syrphid females lay eggs in the middle of aphid colonies.

The first evidence of aphid predators in the spring is often the presence of syrphid eggs,

which eggs are white and resemble a small grain of rice (Beers et al. 1993, Pfeiffer &

Hogmire 1995). The three larval instars are maggot-shaped and yellowish-green. Five to

seven generations of syrphids have been noted per year (Pfeiffer & Hogmire 1995) Beers

et al. (1993) noted that syrphid flies are highly susceptible to insecticides. Larval

monitoring of syrphids should be done while visually inspecting for aphid colonies (Beers

et al. 1993). Adults may be collected in beating tray samples. *Syrphus rectus* (Osten

Sacken), *Allograpta obliqua* (Say), and *Metasyrphus americanus* (Weidemann) are three

species common in this region (Pfeiffer & Hogmire 1995).

   Aphidoletes aphidimyza (Rondani), the aphid midge, is a predaceous cecidomyiid.

Most cecidomyiids feed on plants and cause gall formation in which the larvae live.

However, the larvae of this species are free-living, feeding on aphids by sucking the fluids

out of them. The larvae may kill more aphids than they consume, especially when aphid

densities are high (Minks & Harrewijn 1988). Eggs may be laid singly or in groups inside

aphid colonies. The larvae are bright orange or pink, and able to develop at low prey

densities (Minks & Harrewijn 1988, Pfeiffer & Hogmire 1995). Monitoring of larvae

during visual counts of aphid colonies is the recommended survey method as larvae are

obvious in the colonies due to their bright color (Beers et al. 1993). Adults are nocturnal

and not usually observed. Aphid midges can be plentiful in this region, particularly in

low-spray blocks (Pfeiffer & Hogmire 1995). Resistance to some organophosphorus

insecticides has been noted in the East (Beers et al. 1993, Pfeiffer 1996). However,

Pfeiffer (1996) noted that midges were highly susceptible to azinphosmethyl.

The family Coccinellidae contains many important aphid predators. The larvae

and adults of most species in the sub-family Coccinellinae prey on aphids (Hofsvang

1990). The larvae are typically the most voracious and may consume hundreds of aphids

while developing (Beers et al. 1993). The fourth instars are noted be more voracious than

the other instars and adults (Hodek 1973, Minks & Harrewijn 1988). *Adalia bipunctata*

(L.) was reported to eat 45.7% of its larval food as a fourth instar (Hodek 1973). The

voracity of these insects is limited by temperature (Minks & Harrewijn 1988). Low

humidity combined with high temperatures may cause increased feeding (Hodek 1973).

*Coccinella s*eptempunctata (L.) has been noted to eat an average of 420 aphids during

development (Hofsvang 1990). Coccinellids may be able to suppress even large

populations of aphids.   At least twelve species of coccinellids have been noted in

mid-Atlantic apple orchards (Brown 1988). A newly introduced species, *Harmonia*

axyridis (Pallas), has been noted in Virginia (Kidd et al. 1995). Pfeiffer (1996) noted

azinphosmethyl to be moderately toxic to lady beetles. Beating tray sampling is

recommended for adults, and visual inspection has been advised for larvae by Beers et al.

(1993). Coccinellid sampling methods generally seem to underestimate the actual number

of insects present.   In a study cited by Minks & Harrewijn (1988) only 10% of a known

number of caged coccinellids were reported in daily samples.

There are several families of Coleoptera, other than Coccinellidae, that are known

to feed on aphids. The carabid, *Harpalus rufipes* (DeGeer), was found to eat aphids in

apple orchards (Minks & Harrewijn 1988). In a recent survey of the Carabidae fauna of

Virginia orchards, carabids in the genus *Harpalus* were found to be quite common

(Gronning 1994). Members of the families Cantharidae and Staphylinidae are also known

to eat aphids (Bland 1978, Minks & Harrewijn 1988).

Predatory bugs (Hemiptera) in apple orchards include members of the families

Anthocoridae, Nabidae, Reduviidae, and Miridae. These bugs are generalist predators that

may feed on aphids.   Both nymphs and adults of these families are predatory. Nabidae

and Reduviidae may also feed on other predators. The suggested monitoring method for

adults and nymphs of these families is beating tray sampling (Beers et al. 1993, Pfeiffer &

Hogmire 1995) *Anthocoris* and *Orius* are the two most common genera of Anthocoridae

feeding on aphids (Minks & Harrewijn 1988). Species of predaceous bugs noted in apple

orchards include: Anthocoridae: *Orius insidiosus* (Say); Miridae: *Deraeocoris*

nebulosus (Uhler), *Hyaliodes vitripennis* (Say), *Hyaliodes harti* Knight, *Phytocoris*

canadensis (Van Duzee), *Phytocoris sp.*, and *Plagiognathus politus* (Uhler); Nabidae:

Nabis roseipennis (Uhler); Reduviidae: *Acholla multispinosa* (DeGeer) (Brown 1988,

Pfeiffer & Hogmire 1995). The minute pirate bug, *Orius insidiosus* (Say), is commonly

found in Virginia apple orchards (Pfeiffer & Hogmire 1995). Some mirids are noted to be

sensitive to organophosphous insecticides (Beers et al. 1993). Tolerance to

azinphosmethyl and chlorpyrifos has been noted in some anthocorids (Beers et al. 1993).

Leptothrips mali (Fitch) (Thysanoptera: Phlaeothripidae) is known to feed on

aphids. They also feed on European red mites, *Panonychus ulmi* (Koch) (Parella 1980,

Pfeiffer & Hogmire 1995). *L. mali* are noted to have a tolerance to azinphosmethyl

(Pfeiffer 1996).

Mite days and Community measurements

European red mite is a secondary pest in apple orchards (Pfeiffer et al. 1995).

European red mites need to be monitored to determine if the population has reached

damaging levels. Mite days are calculated to determine if a control spray is warranted.

These calculations incorporate the number of mites per leaf and the time the mites have

spent feeding, and can be used to determine if and when a spray if necessary to control

the mites. In Hogmire (1995), the formula is defined as follows:

Mite days = (The number of mites from consecutive sample dates X and Y)/2*(Julian

date of sample Y- Julian date of sample X)).

Aphid-day and predator-day formulas were adapted from this mite-day formula. This

approach was used to attempt to quantify relative differences in aphid and

aphidophagous insect populations between blocks.

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Diversity indices are used to evaluate community structure. Indices measuring the richness (the number of taxa collected), the evenness or equability (distribution of individuals in the taxa collected), or both can be calculated. Taxa richness indices describe the number of taxa present in the community. The simplest of all these is simply the number of taxa collected in the community (Brower et al. 1990). Taxa evenness describes the distribution of the individuals across the taxa. Pielou's J', also called Simpson's evenness, is a widely accepted measure of evenness (Pielou 1984, Brower et al. 1990). Neither richness nor evenness indices are adequate by themselves. The Shannon index takes into account the number of individuals in each taxon and the total number of taxa present; essentially, this diversity index evaluates both the richness and evenness of the community (Shannon 1948, Brower et al. 1990). Both the Shannon index and Pielou's J' were recently used in a similar ecological study design in apple orchards by Pearsall and Walde (1995). Formulas used are noted in materials and methods.

Tufted Apple Bud Moth

The tufted apple bud moth , *Platynota idaeusalis* (Walker) (Tortricidae) is the most economically important leafroller pest of apple orchards in the mid-Atlantic region. *P. idaeusalis* populations are lower in the central and southern regions of the Virginia. Other Tortricid leafrollers present in this region include the variegated leafroller , *Platynota flavedana* (Clemens); redbanded leafroller , *Argyrotaenia velutinana* (Walker); and the obliquebanded leafroller , *Choristoneura rosaceana* (Harris) (Hull et al. 1995)

Tufted apple bud moth is a primary pest in apple orchards. The larva webs one leaf to another or to a fruit to form a protective shelter. Economic damage occur s when the fruit is injured. The typical damage appears as a shotgun pattern of tiny feeding holes on the apple . The apple may also rot in areas due to damage by the larvae. The second generation typically occurs in greater numbers than the first and causes a higher level of economic damage. The adults do not cause injury (Helle et al. 1991). *P. idaeusalis* injury cannot be distinguished from *P. flavedana* damage when evaluating damge to the crop (Howitt 1993, Hull et al. 1995).

The *P. idaeusalis* is described as a generalist feeder. It has been found in a variety of hosts including apple, blackberry, black haw, osage orange, goldenrod, and clover (Chapman & Lienk 1971, Howitt 1993). Its range is transcontinental extending from northern United States to Southern Canada(Chapman & Lienk 1971, Howitt 1993, Hull et al. 1995).

P. idaeusalis is generally bivoltine in Virginia, although a third generation may occur. (Chapman & Lienk 1971, Hull et al. 1995). It overwinters in the larval stage in ground cover and feed on such weeds as narrowleaf plantain, smartweed, and dandelion (Hull et al. 1995). First generation of *P. idaeusalis* adults emerge in early to late May, generally 7-10 days before the first flight of *P. flavedana* in the same region (Hull et al. 1995). Second flight usually occurs in mid-July to late August.

Adult females tend to be slightly larger than the males, averaging 11 mm in length.

Both sexes are a mottled gray/brown color and have two or three patches of tufted scales

on their wings (Howitt 1993). Eggs masses of up to 150 eggs are usually found on the

upper side of leaves (Howitt 1993, Hull et al. 1995). Around 24 hours before hatch the

black head capsules of the first instars become visible. The egg stage lasts between 9 and

13 days (Hull et al. 1995).

There are typically five larval instars over a period of 20-42 days (Hull et al.

1995). The first and second instars are greenish-yellow in color, while older instars tend

to be light brown in color with a brown stripe on the dorsal section. The head capsule of

older larvae is a dark brown color. Approximate length of the full grown larva is 19 mm

(Chapman & Lienk 1971, Hull et al. 1995). The pupa is brown in color. A life stage

model is available for the *P. ideausalis* that can be used to predict the timing of

insecticide sprays. It is based catches in pheromone traps during first flight.

Azinphosmethyl (Guthion) is the most widely used insecticide in Virginia apple

orchards; 89.1% of orchards were reported to be treated with azinphosmethyl each year

(Pfeiffer et al. 1989a). Most of these orchards received multiple applications. According

to Hassell (1990) azinphosmethyl is a persistent contact or loco systemic

organophosphous insecticide. This means the compound may diffuse a short distance

into the surface of the leaf, but cannot move throughout the sprayed plant. The activated

form of azinphosmethyl phosphoralates the enzyme, acteylcholinesterase, persistently

disabling it (Hassell 1990). Acteylcholinesterase is an enzyme that hydrolyzes the

neurotransmitter acetylcholine in the synaptic region of the insect central nervous

system. Proper neural transmission cannot occur when cholinesterase is not functioning.

Objectives

1 a. Compare the abundance and diversity of aphid predators between mating disruption

and conventionally -managed orchard blocks by collecting aphid colonies.

1 b. Compare abundance and diversity of aphid predators in mating disruption and

conventionally -managed orchard blocks collected with beating trays.

2. Compare azinphosmethyl resistance of the tufted apple bud moth, *P. idaeusalis* in

four commercial orchards in Winchester, Virginia.

Chapter 1

Impact of Low-spray Mating Disruption Programs on Aphidophagous

Insect Populations

Introduction

Commerically available mating disruption is more expensive than conventional

control methods.   For example, Brunner (1991) listed mating disruption expenses for

codling moth alone to be $156/acre compared to $96/ acre for sprays. To help promote

acceptance of this method, it is necessary to evaluate the potentially positive impact of

mating disruption on the arthropod community of orchards, via reduced pesticide

application. The evaluation of potential effects, such as higher densities of natural

enemies and slowing the rate of resistance development, may help to persuade growers to

adopt this tactic (Brunner 1991).

This evaluation is especially important because conventional spray programs can

cause outbreaks of a wide range of secondary pests, including spirea aphids, *Aphis*

spiraecola Patch. The insecticide sprays used in the conventional programs for primary

pests often kill the aphid predators thus allowing the aphid population to rise above

damaging levels. A spray specifically targeted towards these secondary pests must then

be applied. Azinphosmethyl is the most widely used insecticide in Virginia apple

orchards (Pfeiffer et al. 1989b). Thus, it may be relevant to note which natural enemies

have shown resistance or tolerance to azinphosmethyl (Table 1).

Some of the aphidophagous insects noted in apple orchards include:

Anthocoridae, Cantharidae, Cecidomyiidae, Chamaemyiidae, Chrysopidae, Coccinellidae,

Hemerobiidae, Miridae, Nabidae, Phlaeothripidae, Reduviidae, and Syrphidae (Parella

1980, Peterson 1982, Minks & Harrewijn 1988, Beers et al. 1993, Pfeiffer & Hogmire

1995.   Suggested sampling methods for aphidophagous insects are listed in Table 1.

Table 1. Recomended collection methods for common aphidophagous insects.

Visual Inspection of Active Aphid Colonies	Beating Tray Collection	Possible Resistance to an Organophosphorus Insecticide
Cedcidomyiid Larvae	Chrysopid Adults & Larvae	Chrysopid Larvae (Pree et al. 1989)
Chrysopid Larvae	Coccinellid Adults	Cecidomyiid Larvae (Beers et al. 1993, Pfeiffer 199)
Coccinellid Larvae Hemerobiid Larvae Syrphid Larvae	Hemerobiid Adults & Larvae Hemipterians	Anthrocoids (Beers et al. 1993)

Natural enemy populations tend to vary with the site surroundings and

management practices used. For example, in pear orchards, natural enemies tend to be

more common in orchards bordered by natural habitats. They appear to be less plentiful

in orchards bordered by well-sprayed orchards (Riedl 1991). Gronning (1995), using

pitfall traps, found that arthropod communities in the orchards undergoing mating

disruption were more diverse than communities in conventionally managed orchards.

Objectives

1 a. Compare the abundance and diversity of aphid predators between mating disruption

    and conventionally -managed orchard blocks by collecting aphid colonies.

1 b. Compare abundance and diversity of aphid predators in mating disruption and

    conventionally -managed orchard blocks collected with beating trays.

Materials and Methods

Four apple orchards in Virginia --Sprinkle (Botetourt Co.), Tyro (Nelson Co.),

Glaize (Frederick Co.) and Solenburger (Frederick Co.) -- were sampled in Virginia during

the 1994 and 1995 growing seasons (Figure 1). One block in each orchard utilized mating

disruption for codling moth and leafroller control; this block was matched with a

conventionally-managed block in the same orchard. In the conventionally-managed

blocks, each grower followed their normal insecticide spray program. In 1995, Sprinkle

was undergoing its sixth consecutive year of mating disruption, while Tyro was in its

fourth. In 1995, Glaize and Solenburger orchards were both undergoing their second

consecutive year of mating disruption. Each block in the orchards contained the following

number of hectares: Sprinkle-2, Tyro-4, Glaize-10, Solenburger-10. Both blocks in the

Sprinkle and Tyro orchards were sampled weekly for the presence of aphids and

predators. Each block in the Glaize and Solenburger orchards were sampled every two

weeks for the presence of aphids and predators. Sampling continued as long as aphids
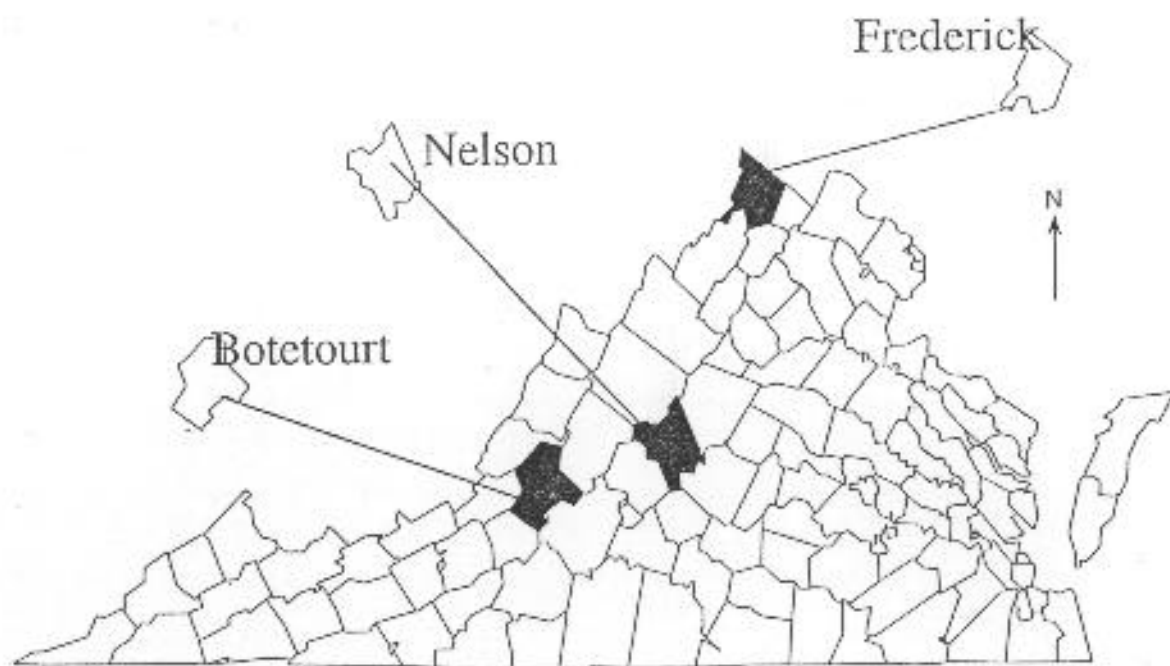
Fig. 1 Map of Virginia showing the locations of the counties where samples were collected.

were present. Two different sampling techniques were utilized--aphid colony collection

and beating tray sampling.

Publications that were useful in the identification of aphid predators include:

 Borror et al. 1989, Bland & Jacques 1978, Peterson 1982, Kelton 1983, Gordon 1985,

Hogmire 1995, Tauber 1991, Gage 1921, Rhoades 1995, and Gordon & Vandenburg 1991.

Sampling Technique A--Aphid Colony Collection

In 1994, six trees were sampled in each block each week. Ten terminal shoots

were examined on each tree for the presence of aphids. If aphids were present, up to

three shoots with aphids were collected in plastic bags. In the lab, these shoots were

inspected for predators.

In 1995, the same sampling technique was used except that the number of shoots

collected was increased to five in an attempt to obtain larger numbers of predators. This

sampling method mainly targeted the less mobile aphidophagous insects such as the

larvae of coccinellids, syrphids, cecidomyiids, chrysopids, and hemerobiids.

Data Analysis

Predator and aphid-days were calculated using the following formulas:

Predator-days = (sum of the average predators per colony from consecutive sample

dates X and Y)/2*(Julian date of sample Y- Julian date of sample X)

Aphid-days = (sum of the average number of aphid colonies from consecutive sample

dates X and Y)/2*(Julian date of sample Y- Julian date of sample X)

Predator and aphid-day formulas are based on mite-day calculations (Hogmire 1995).

This approach was used to attempt to quantify relative differences between blocks in

aphid density combined with length of infestation.   Predator and aphid-days in each

orchard were compared using a two-tailed t-test with unequal variance and an alpha level

of 0.10.

Diversity of the orchard predator communities was quantified using indices for general

diversity, richness, and evenness (Brower et al. 1990). The Shannon index formula is:

$$H' = - S\ p_i \log p_i \qquad\qquad (1)$$

where $p_i = n_i / N$ (p_i= the proportion of individuals of the ith taxa in the community)

n_i= number of individuals in taxon i

N= total number of individuals collected.

This may be computed using log base 10, 2, or e. It does not matter which base is used as

long as one is consistent. A higher Shannon index value reflects greater diversity in the

community (i.e., the lower the probability that two individuals sampled from the

community will belong to the same species).

Shannon diversity measurements for two communities can be compared using the

following procedure. First variance must be calculated for each H' value:

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$$s^2 = \underline{Sp_i (\log p_i)^2 - (Sp_i \log p_i)^2 / n} \qquad (2)$$

$$n^2 \; .$$

The Student t-value is then computed:

$$t = \quad (H'_1 - H'_2) \; / \; [\text{square root}(s^2_1 + s^2_2)]. \qquad (3)$$

The degrees of freedom must also be calculated:

$$DF = (s^2_{H'1} + s^2_{H'2})^2 \; / \; [(s^2_{H'1})^2 / \, n_1 + (s^2_{H'2})^2 / \, n_2]. \qquad (4)$$

A *P* value can then be obtained from a student t critical value table (Brower et al 1990).

Pielou's J', the evenness measure based on the Shannon index, can be calculated using H' (as defined above). The formula follows:

$$J' = H' / H_{max} \qquad (5)$$

where

$$H_{max} = \log s$$

s = number of taxa.

(Pielou 1984, Brower et al. 1990). A community with a J' value of 1 would have the same number of individuals in each taxon collected. A value of J' closer to zero indicates that the community has an uneven distribution of individuals in the taxa.

Horn's index of similarity, based on Shannon's index, can be useful to compare communities. The following equations are used to calculate Horn's index (R_0):

H'_1 (as defined in equation 1) for community 1

H'_2 (as defined in equation 1) for community 2

$$H'_3 = [N \log N - S(x_i + y_i) \log (x_i + y_i)] / N$$

where $N = N_1 + N_2$

x_i = number of individuals in Taxon i in community 1

y_i = number of individuals in Taxon i in community 2

H'_3 is essentially a calculation of a H' value after combining all of the data.

$$H'_4 = (N \log N - S\, x_i \log x_i - S\, y_i \log y_i)/ N$$

$$H'_5 = (N_1 H'_1 + N_2 H'_2) / N$$

and finally,

$$R_0 = H'_4 - H'_3 / H'_4 - H'_5 \qquad\qquad (6)$$

(Horn 1966, Brower et al. 1990). An R_0 value of 1.0 indicates that the samples from the two communities are identical. The similarity between the communities decreases as the R_0 value declines.The indices were calculated using the program 'Ecological Analysis Tools' with the exception of the calculation of the variance, t-test, and degrees of freedom used to compare Shannon indices (Eckblad, 1989). These were calculated in Excel (Microsoft 5.0). An analysis of varience was used to determine differences between blocks (SAS Institute Inc. 1995). This was performed on the data using Proc GLM (SAS Institute 1985). I received advice on the model, program, and the interpretation of results from the Statistical Consulting Center at Virginia Tech.

Sampling Technique B--Beating Tray Collections

Ten trees were sampled in each block. Three limbs were jarred on each tree. A 1 m^2 cloth beating tray was held under the limb. The insects were collected using an aspirator. This method mainly targeted the more mobile stages of aphid predators that do not necessarily live in the aphid colonies. The following aphidophagous insects were collected by this method: coccinellids, chrysopids, hemerobiids, cecidomyiids, and hemipterans.

Data Analysis

Predator-days were calculated using the following formula:

Predator-days = (The sum of predators per total sample from consecutive sample dates

X and Y)/2*(Julian date of sample Y- Julian date of sample X)

Predator-day formulas are based on mite-day calculations (Hogmire 1995). This approach was used to attempt to quantify relative differences between blocks. Predator-days in each orchard were compared using a two-tailed t-test with unequal variance and an alpha level of 0.10. An ANOVA was used to determine differences in predator abundance between blocks (SAS Institute 1995). These samples were also analyzed using to determine diversity of the predators collected. Diversity was quantified using indices for general diversity, richness, and evenness (Brower et al. 1990).

Results & Discussion

Aphid colony collections were targeted towards gathering information on aphid populations and predators that usually live in the aphid colonies. Tables 2 and 3 show the total number of predators and aphid colonies observed from aphid colony collections in 1994 and 1995. Sampling by beating tray collection was used to try to capture predators that might not be collected in the aphid colony collections.

Aphid Colony Collection Results

Abundance of Aphids and Aphidophagous Insects

Sprinkle Orchard

In both 1994 and 1995, more predators were observed in the Sprinkle pheromone block than in the matched conventionally-managed block. In 1994, almost twice as many predators were collected in the pheromone block (124 vs. 67) (Table 2); the next year, five times as many predators were collected in the pheromone block (120 vs. 22)(Table 3).

These results were as hypothesized for a low-spray block versus a conventionally managed block. During the 1994 growing season in the Sprinkle pheromone block, aphid populations peaked shortly before the predatory population peaked at 4.5 predators per aphid colony (Fig. 2-A). The data suggest that aphids were controlled by their natural enemies in this block. Population decline may also have been induced in part to decreased tree vigor. In late summer the tender shoot tips of the trees begin to harden. This is correlated with a decrease in the aphid population in the orchard. In the conventionally-

Table 2. Aphids and predators[1] observed in aphid colonies in mating disruption and conventionally-managed apple orchards in 1994.

Aphid Data	Sprinkle		Tyro		Glaize		Solenburger	
	Pheromone	Conven. Managed	Pheromone	Conven. Managed	Pheromone	Conven. Managed	Pheromone	Conven. Managed
#of colonies	196	195	203	199	55	97	91	80
#leaves inspected	499	585	614	559	215	222	204	174
Syrphid Eggs	50	34	22	13	7	7	3	1
Syrphid Larvae	12	5	3	2	0	0	0	0
Lacewing Eggs	2	1	35	0	11	0	0	1
Chyrsopid Larvae	7	9	7	2	0	0	1	0
Hemerobiid Larvae	0	0	1	0	0	0	0	0
Cecidomyiid Larvae	69	10	0	7	8	11	0	0
Coccinellid Adults	7	7	4	4	4	2	2	2
Coccinellid Larvae	0	1	0	1	4	0	7	0
Anthocorids	17	35	12	17	9	8	8	4
Chamaemyidae Larvae	2	0	0	1	0	0	0	0
Thrips	10	0	0	2	0	0	0	0
Chrysopid Adult	0	0	0	0	1	0	0	0
Total Predators	124	67	27	36	26	21	18	6

[1] Totals over season.

Table 3. Aphids and predators[1] observed in aphid colonies in mating disruption and conventionally-managed apple orchards in 1995.

Aphid Data	Sprinkle		Tyro		Glaize		Solenburger	
	Pheromone	Conven. Managed	Pheromone	Conven. Managed	Pheromone	Conven. Managed	Pheromone	Conven. Managed
#of colonies	289	330	254	275	129	226	134	246
#leaves inspected	1108	1643	1191	1383	567	589	434	915
Syrphid Larvae	5	1	2	5	3	1	2	0
Chrysopid Larvae	6	0	6	0	8	1	2	2
Hemerobiid Larvae	4	3	2	1	0	0	4	0
Cecidomyiid Larvae	80	0	0	8	13	1	0	0
Coccinellid Adults	4	0	6	1	0	2	0	1
Coccinellid Larvae	0	3	2	1	8	0	0	0
Anthocorids	20	14	40	8	7	3	16	5
Chrysopid Adults	1	1	0	0	0	0	0	0
Hemerobiid Adults	0	0	0	0	3	0	0	0
Total Predators	120	22	58	24	42	8	24	8

[1] Totals over season.

Figure 2. Predators and Aphids observed in Sprinkle Orchard-1994. (A). Aphid colonies and predators per aphid colony in Sprinkle Pheromone Block. (B). Aphid colonies and predators per aphid colony in Sprinkle Conventionally- Managed Block. (C). Mean number of predators collected on beating trays (Bars are 95% CI.)(** denotes a significant difference)

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managed block, the predatory population did rise in response to the aphid population, but reached a lower density (1.6 predators/colony) than in the pheromone block (Fig. 2-B). It appeared to take 1 week longer for the aphid population to begin to decline in the conventionally-managed block relative to the pheromone block. In the conventionally-managed block, this may be due to possible deleterious effect of the higher insecticide input on the aphidophagous population.

In 1995, the predatory population in the Sprinkle pheromone block appeared to rise in response to the increase in prey availability (Fig. 3-A); although there was not as high a response as the previous year (cf. Fig. 2-A). The aphid population in the pheromone block (Fig. 3-A) collapsed earlier than the aphid population in the conventionally-managed block (Fig. 3-B), indicating that the aphids in the pheromone block appeared to be impacted more by their natural enemies, possibly in combination with declining host vigor. During the 1995 growing season, the predatory population in the Sprinkle conventionally-managed block did not seem to respond to the increase in the aphid population (Fig. 3-B). As a result, the aphid population was sustained at high levels for a longer period of time than in 1994 (Fig. 2-B). This general lack of predatory buildup in the conventionally-managed blocks may be due to the higher insecticide input.
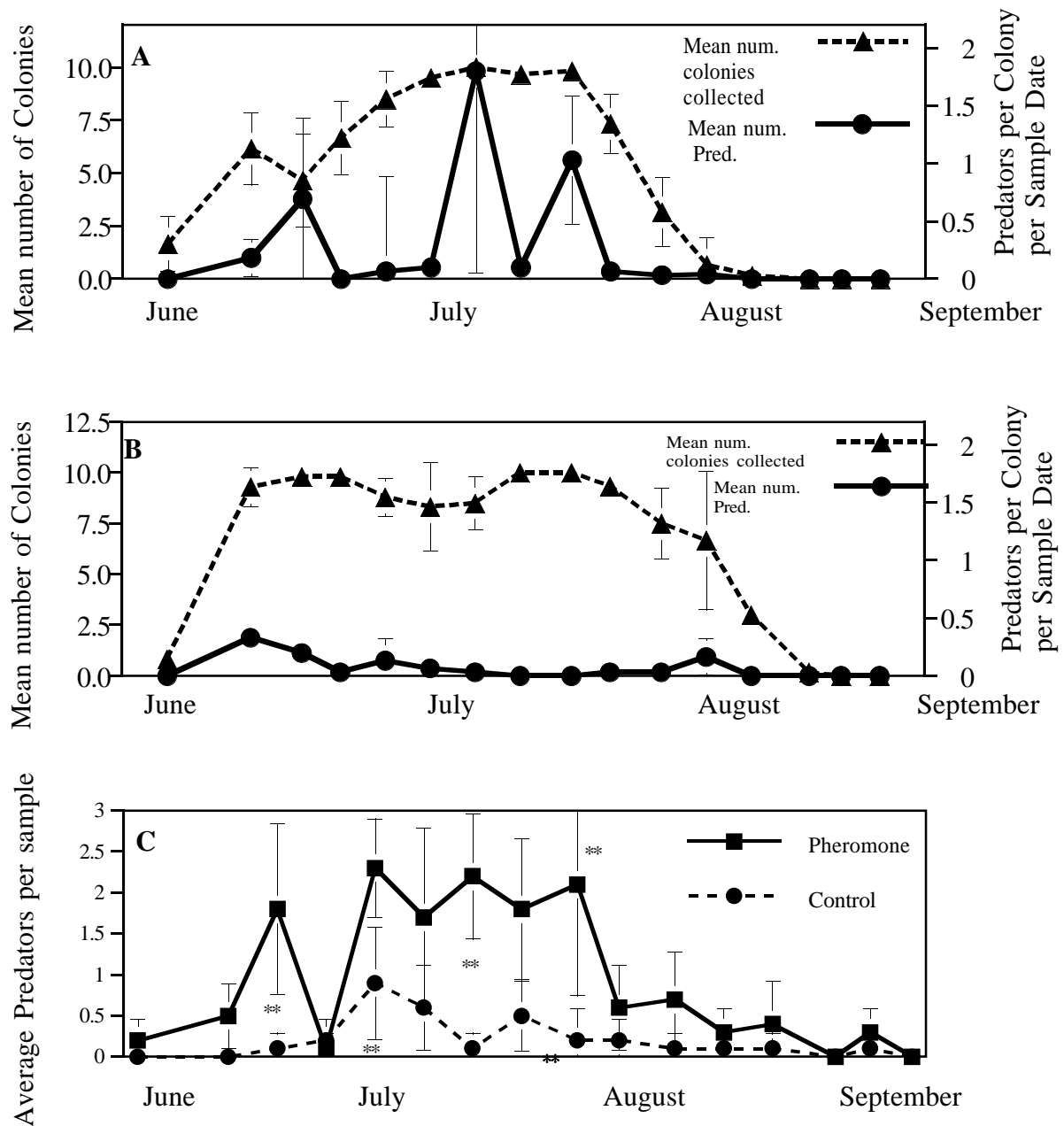
Figure 3. Predators and Aphids observed in Sprinkle Orchard-1995. (A).
Aphid colonies and predators per aphid colony in Sprinkle Pheromone Block.
(B). Aphid colonies and predators per aphid colony in Sprinkle
Conventionally- Managed Block. (C).Mean number of predators collected
on beating trays (Bars are 95% CI.)(∗∗ denotes a significant difference)

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Tyro Orchard

Variable results were obtained from this orchard. In 1994, 36 predators were collected in the conventionally-managed block, while only 27 were caught in the pheromone block (Table 2). However, twice as many predators were collected in the pheromone block than in the conventionally-managed block in 1995 (58 vs. 24) (Table 3). Even though the pheromone block had undergone disruption for 3 years, a possible explanation for the larger number of predators collected in the conventionally-managed block in 1994 could be due to the surrounding habitat. The Tyro pheromone block is adjacent to a conventionally-managed orchard and hay fields. Spray drift may have impacted the predator population in the pheromone block. These environments might have reduced the likelihood of immigration of predatory insects into the pheromone block.   Figures 4-A and 4-B show the mean number of aphid colonies and predators (per colony collected) found in the Tyro orchard over the 1994 growing season. In the conventionally-managed and pheromone blocks, the predatory population showed a slight response to the aphid population. The pheromone block peaked at .83 predators per colony, while the conventionally-managed peaked at .77 predators per colony.

In the 1995 growing season, the aphid predators in the Tyro pheromone block again slight ly responsedboth times the aphid population increased (Fig. 5-A). Natural enemies may have impacted aphid population density in the pheromone block. Natural

Figure 4. Predators and Aphids observed in Tyro Orchard-1994. (A). Aphid colonies and predators per aphid colony in Tyro Pheromone Block. (B). Aphid colonies and predators per aphid colony in Tyro Conventionally-Managed Block. (C). Mean number of predators collected on beating trays (Bars are 95% CI.)(∗∗ denotes a significant difference)
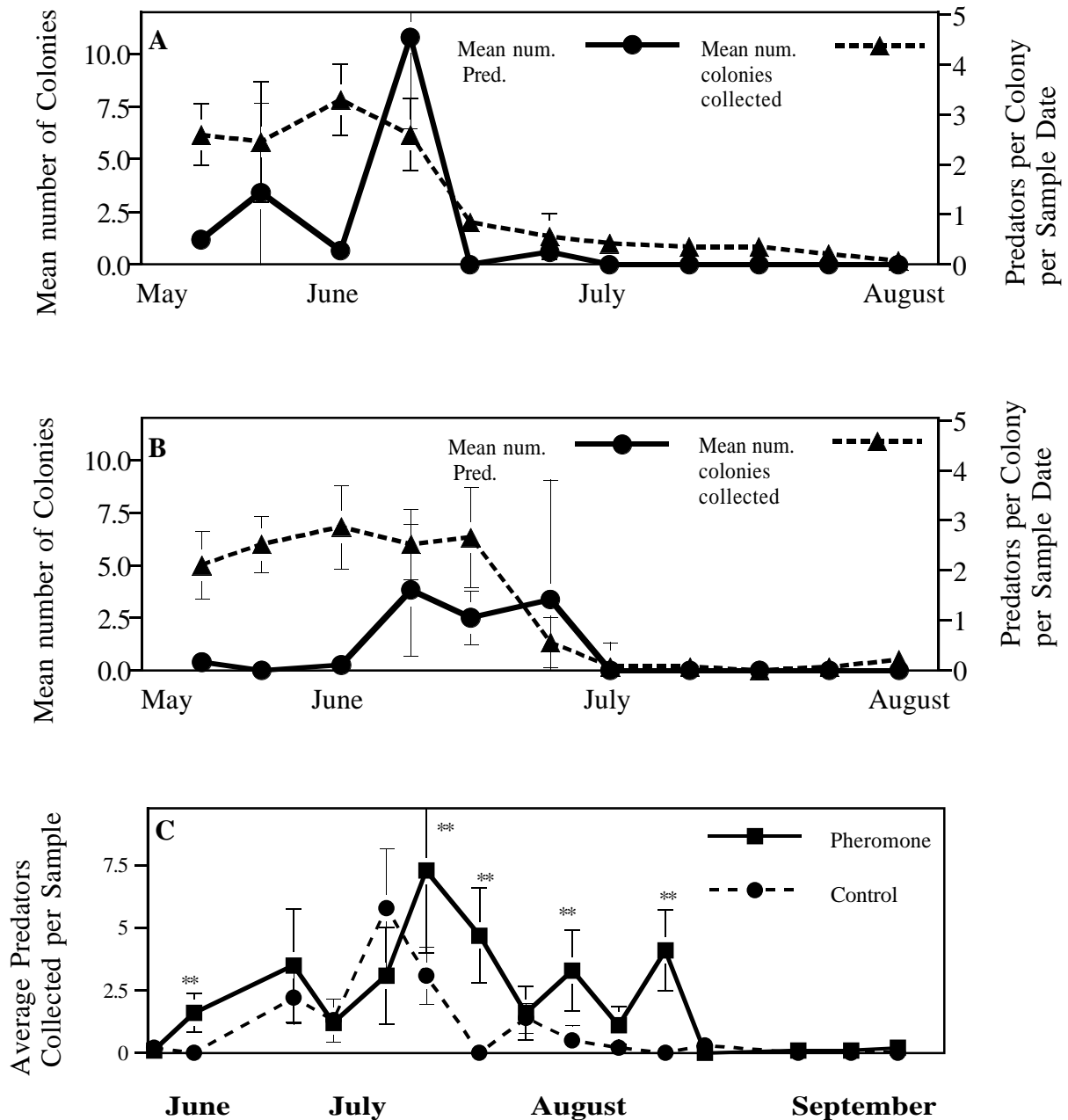
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Figure 5. Predators and Aphids observed in Tyro Orchard-1995. (A).   Aphid colonies and predators per aphid colony in Tyro Pheromone Block.   (B). Aphid colonies and predators per aphid colony in Tyro Conventionally-Managed Block. (C). Mean number of predators collected on beating trays (Bars are 95% CI.)(** denotes a significant difference)

enemies rose slightly in response to the population increase of aphids in the

conventionally-managed block (Fig. 5-B), possibly due to higher insecticide input.

Glaize Orchard

Mixed results were also obtained from the Glaize orchard. Similar numbers of

predators were collected from the pheromone and conventionally-managed blocks (26 vs.

21) in 1994 (Table 2). However in 1995, the pheromone block produced 42 predators,

while only 8 were collected from the conventionally-managed (Table 3). Several factors

may have influenced these results. First, 1994 was the first year the Glaize orchard was

under mating disruption. The populations of predators may not have had the

opportunity to build up in only one growing season. This factor is especially relevant

because the Glaize pheromone block is surrounded by environments not likely to be good

sources for immigration of natural enemies (bordered on three sides by conventionally-

managed orchard and one side by a road and yard).

Increased prey availability appeared to result in increased predator response in

both the pheromone and conventionally managaed blocks at Glaize in 1994. In 1994,

both the pheromone and conventionally-managed blocks at Glaize showed response to

the increased prey availability (Figs. 6-A & 6-B). The peak response was around 1.2

predators per aphid colony. In 1995, the Glaize conventionally-managed block did not

have a predator increase at all (Fig. 7-A). The pheromone block did show an increase in

predators as the aphid population rose (0.9 predators per colony) (Fig. 7-B). A late
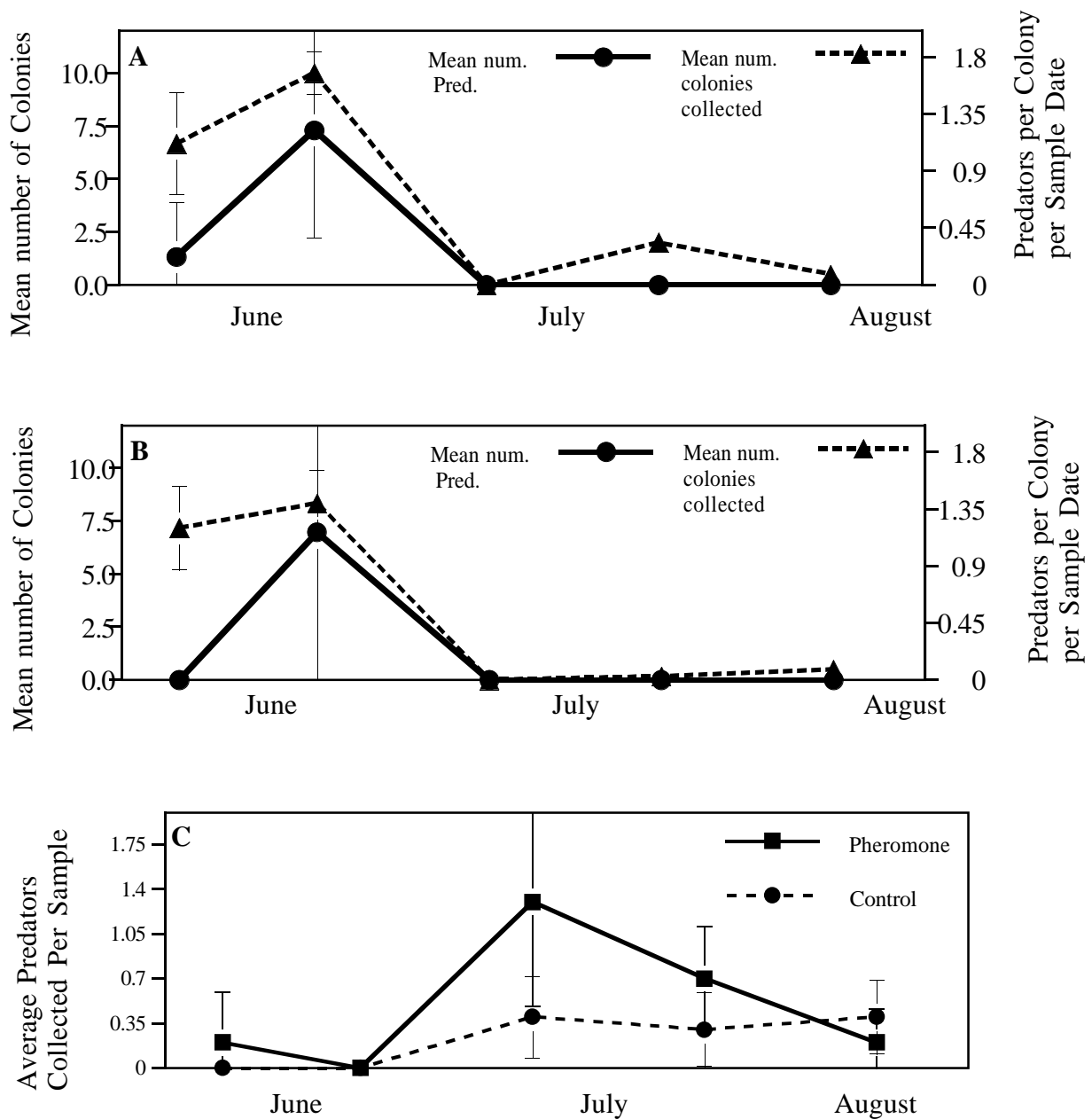
Figure 6. Predators and Aphids observed in Glaize Orchard-1994. (A). Aphid colonies and predators per aphid colony in Pheromone Block. (B). Aphid colonies and predators per aphid colony in Conventionally Managed Block. (C). Mean number of predators collected on beating trays (Bars are 95% CI.)(** denotes a significant difference)
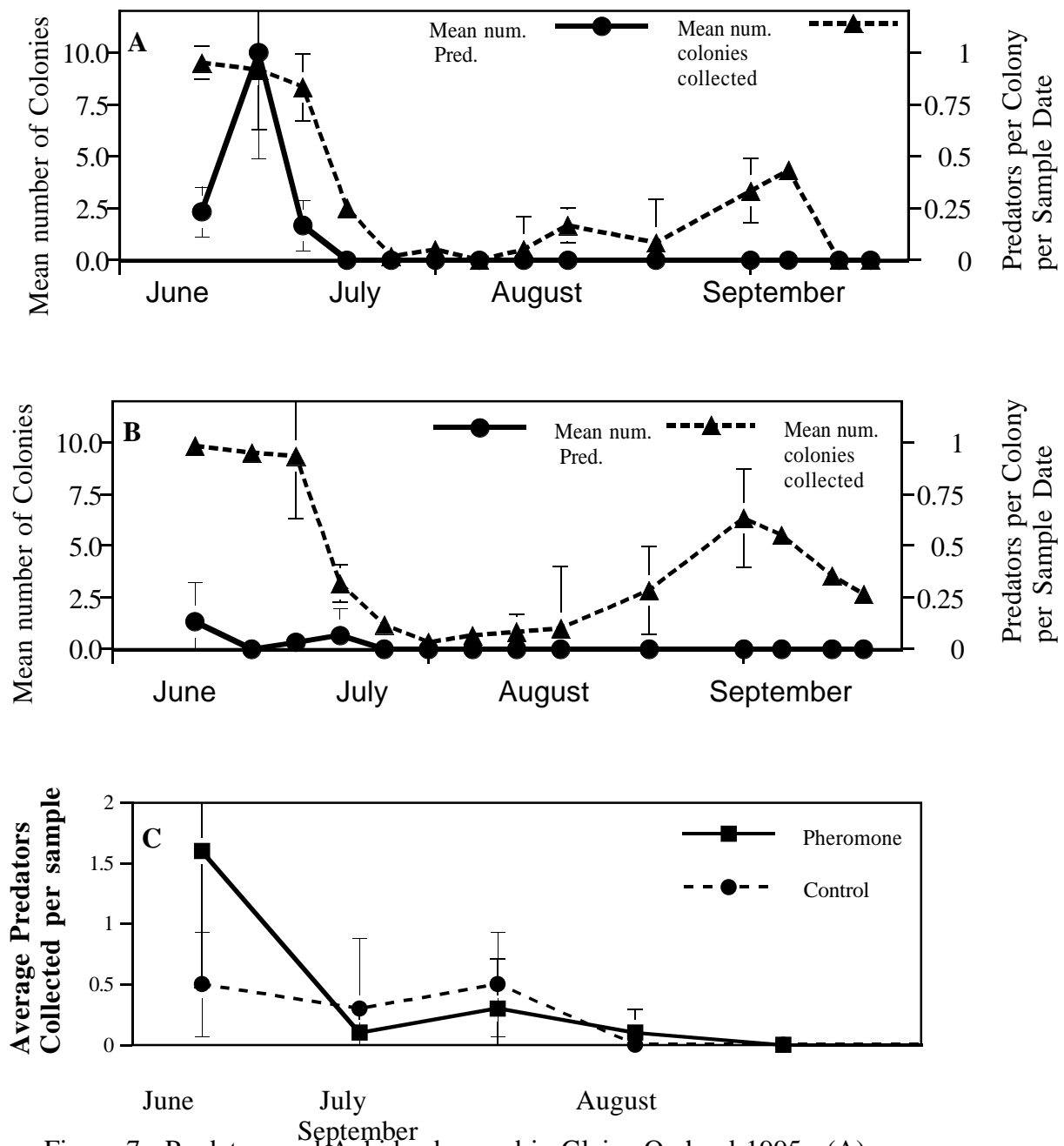
Figure 7. Predators and Aphids observed in Glaize Orchard-1995. (A). Aphid colonies and predators per aphid colony in Pheromone Block. (B). Aphid colonies and predators per aphid colony in Conventionally-Managed Block. (C). Mean number of predators collected on beating trays (Bars are 95% CI.)(** denotes a significant difference)

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season resurgence of aphids was greater in the conventionally-managed block (Figs.7-A & 7-B).

Solenburger Orchard

In both 1994 and 1995, more predators were observed in the Solenburger pheromone block than in the matched conventionally-managed block (Tables 2 & 3). Yet, oeverall numbers were lower then at the other three orchards. In 1994, 18 predators were collected in the pheromone block compared with only six in the conventionally-managed block; the next year, the pheromone block again yielded three times as many predators as the conventionally-managed block. In 1994, both the pheromone and the conventionally-managed blocks exhibited a slight rise in predators in response to the presence of prey (Figs.8-A & 8-B). The pheromone block had a higher peak of predators, rising to 0.75 predators per colony versus only 0.2 predators per colony in the conventionally-managed block. In 1995, the aphid population peaked twice in both blocks, though there was not as large an aphid resurgence in the pheromone block (Figs. 9-A & 9-B). The number ofpredators in each block increased following the aphids (Figs. 9-A & 9-B). Predators in the pheromone block peaked during the high point of the aphid population and were present for longer than those in the conventionally-managed block. It should be noted that while the Solenburger orchard contained fewer predators than the other orchards, it also had lower populations of aphids. This may possibly be a result of its' being a processing block, pruned only every other year and therefore of lower vigor.
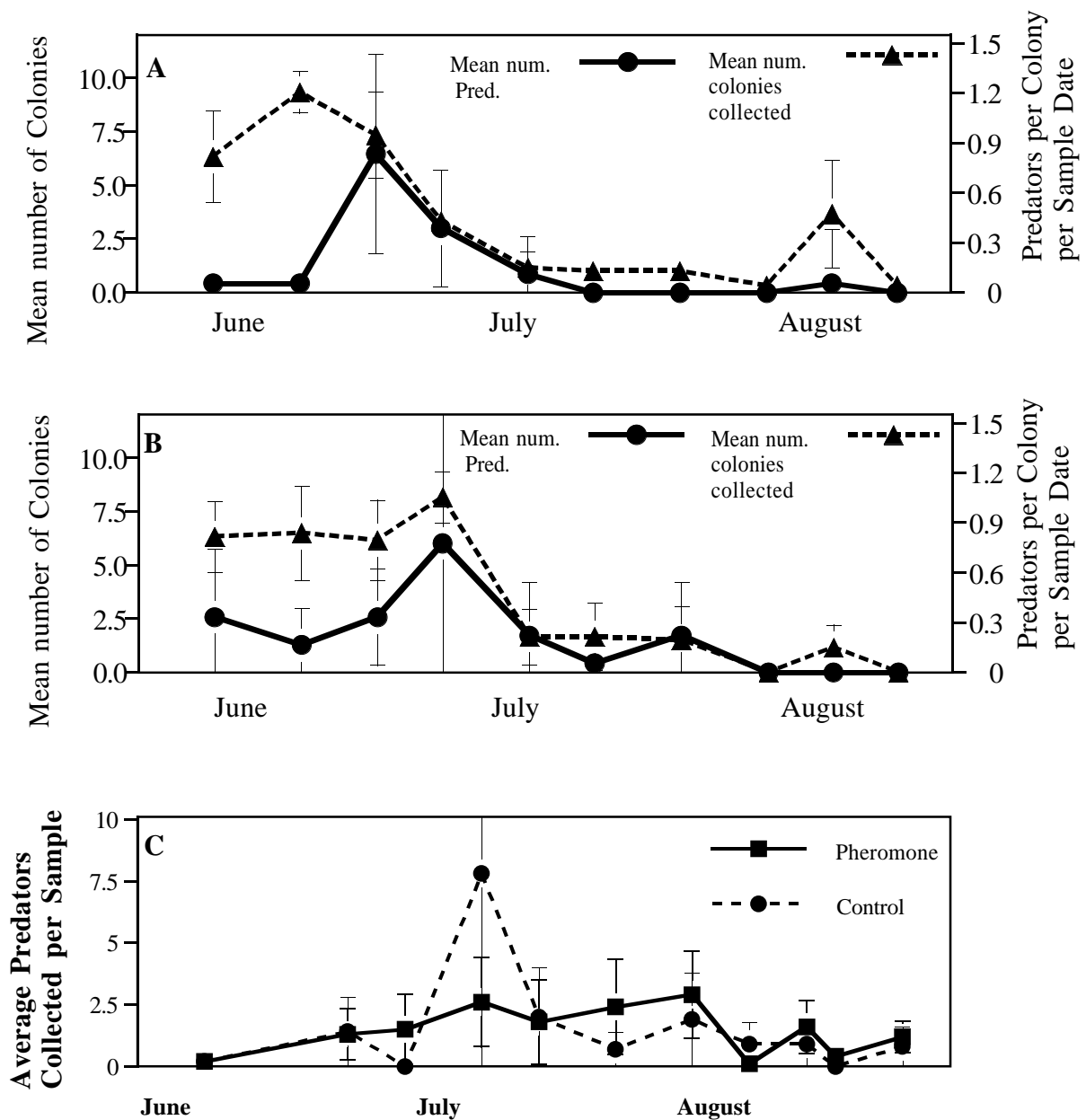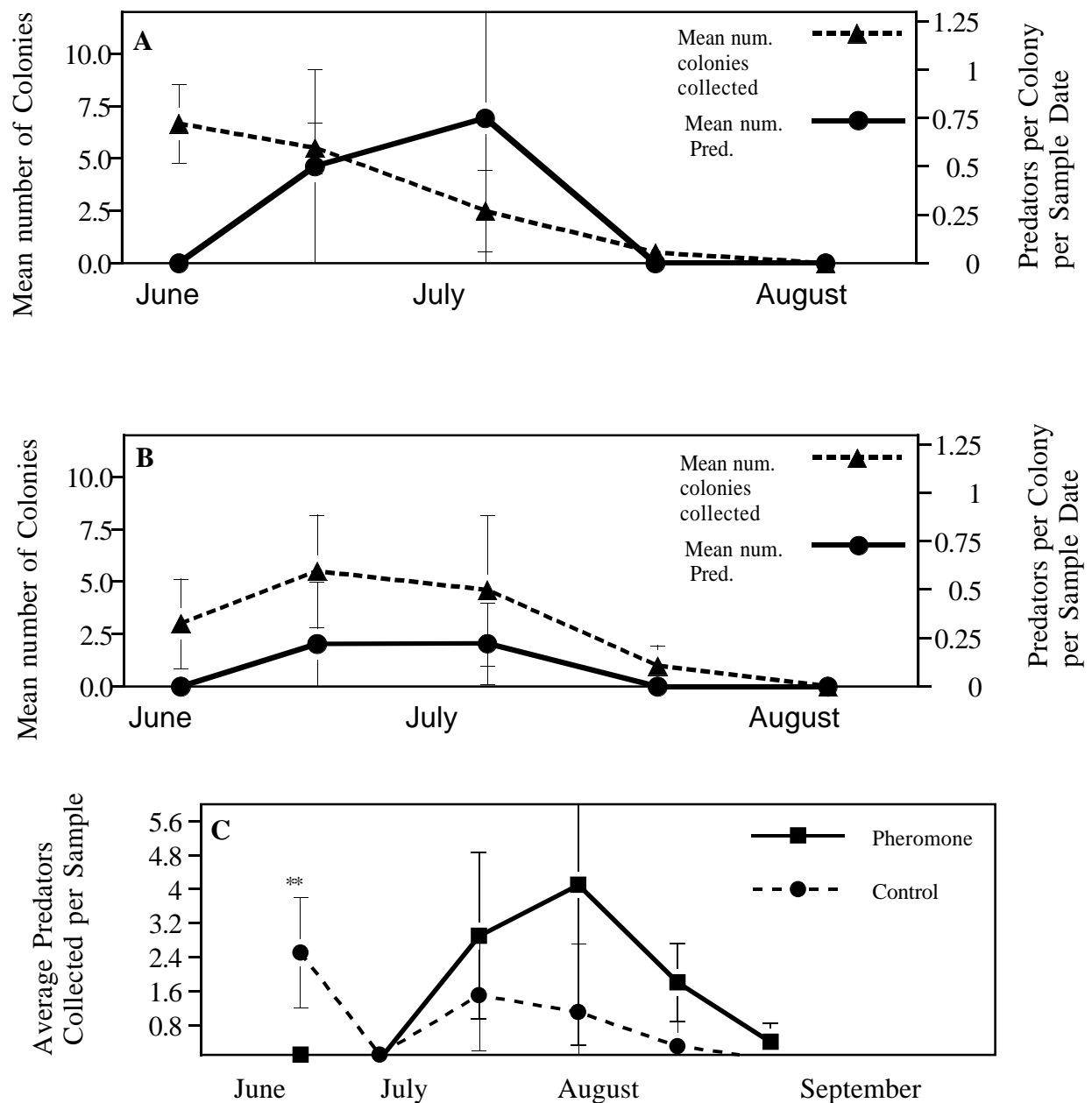
Figure 8. Predators and Aphids observed in Solenburger Orchard-1994. (A). Aphid colonies and predators per aphid colony in Pheromone Block. (B). Aphid colonies and predators per aphid colony in Conventionally Managed Block. (C). Mean number of predators collected on beating trays (Bars are 95% CI.)(** denotes a significant difference)
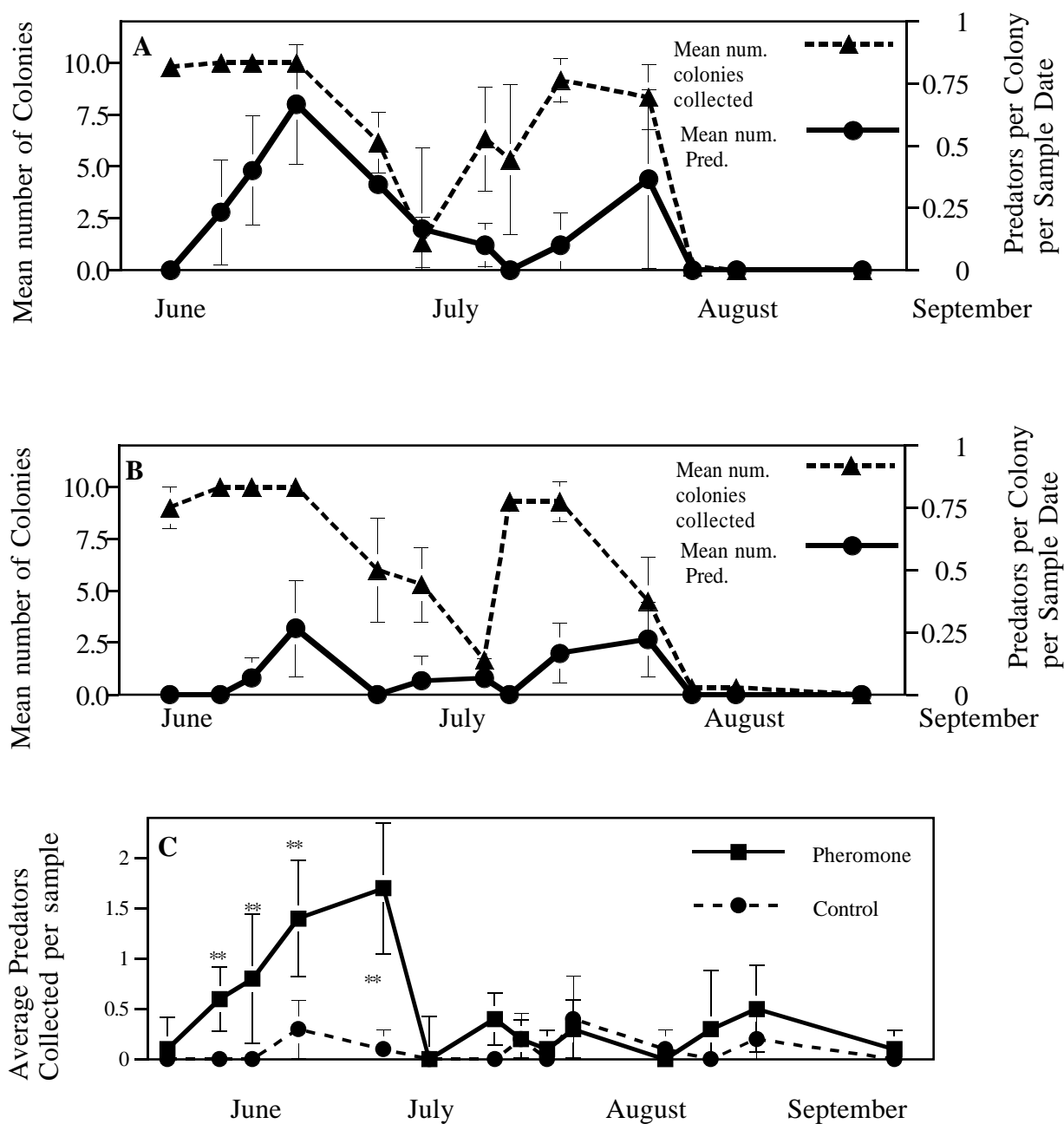
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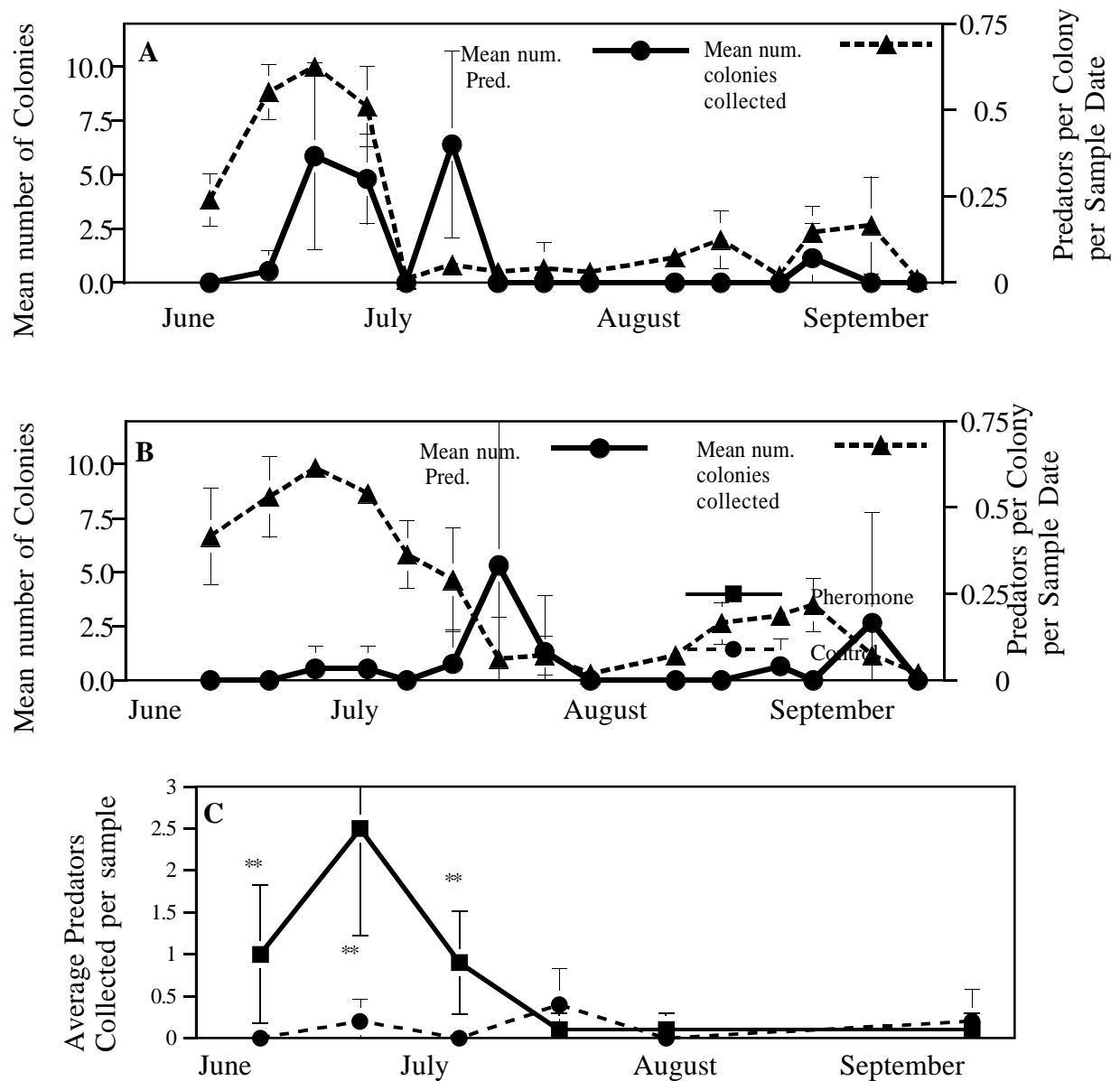
Figure 9. Predators and Aphids observed in Solenburger Orchard-1995. (A). Aphid colonies and predators per aphid colony in Pheromone Block. (B). Aphid colonies and predators per aphid colony in Conventionally Managed Block. (C). Mean number of predators collected on beating trays (Bars are 95% CI.)(** denotes a significant difference)

Pruning results in the more new growth on the trees. This new tender growth is the preferred food of green aphids.

Comparison of Abundance and Duration of Aphids and Aphidophagous Insects

Sprinkle Orchard

In an attempt to quantify the differences between predatory and aphid populations in the pheromone and conventionally-managed blocks, predators and aphid-days were calculated. It is important to note that these incorporate the time the aphids and predators were present in the orchard. My hypothesis was that there would be more predator-days and fewer aphid-days in a low-spray block versus a conventionally-managed block. These values were compared using a two-tailed t-test with unequal variance. The total aphid-days for the pheromone (207.1) and conventionally-managed (207.4) blocks were virtually the same for the Sprinkle blocks in 1994 (Table 4-A), and there was not a significant difference in the predator-days accumulated in each block (Table 4-A). In 1995, the conventionally-managed block did not accrue significantly more aphid-days than the pheromone block (741.9 vs. 574.9) (Table 4-B). However, the pheromone block had a significantly greater number of predator-days than the conventionally-managed block ($P = 0.01$) (Table 4-B).

Table 4. A. Aphid days, Predator days, and P-values from the t-test performed on 1994 aphid colony collection data.

Orchard	Treatment	Aphid Days	P-Value	Predator Days	P-Value
Sprinkle	Pheromone	207.1		47.3	0.45
	Conv. Managed	207.4	0.99	31.5	
Tyro	Pheromone	213.4		13.8	0.50
	Conv. Managed	214.6	0.99	9.8	
Glaize	Pheromone	73.6		17.8	0.42
	Conv. Managed	161.7	0.19	15.7	
Solenburger	Pheromone	159.2		17.9	0.16
	Conv. Managed	164.7	0.95	6.3	

B. Aphid days, Predator days, and P-values from the t-test performed on 1995 aphid colony collection data.

Orchard	Treatment	Aphid Days	P-Value	Predator Days	P-Value
Sprinkle	Pheromone	574.9		29.8	0.01
	Conv. Managed	741.9	0.24	4.9	
Tyro	Pheromone	598.5		18.3	0.08
	Conv. Managed	610.9	0.95	7.9	
Glaize	Pheromone	299.6		10.4	0.16
	Conv. Managed	398.9	0.45	1.9	
Solenburger	Pheromone	307.4		8.4	0.60
	Conv. Managed	409.4	0.44	6.3	

Tyro Orchard

Aphid-days for the two blocks were similar in both 1994 and 1995 (Table 4-A & 4-B). In neither year were there significantly different populations in the pheromone and conventionally-managed blocks. The Tyro pheromone block did not have significantly more predator-days in 1994 than the conventionally-managed block, 13.8 vs. 9.8, respectively (Table 4-A). In 1995, the pheromone block accumulated significantly more predator-days than the conventionally-managed block ($P = 0.08$) (Table 4-B).

Glaize Orchard

The pheromone block consistently accumulated fewer total aphid-days than the conventionally-managed block. In fact in 1994 the conventionally-managed block had twice as many aphid-days (161.7 vs. 73.6) (Table 4-A). These differences were not significant ($P = 0.19$). The pheromone block also produced more predator-days than the matched conventionally-managed block in both 1994 & 1995 (Table 4-A & 4-B). In 1995, the pheromone block had 10.4 predator-days versus only 1.9 for the conventionally-managed block (Table 4-B). However, the difference was not significant at the $P = 0.10$ value with which we tested.

Solenburger Orchard

In both 1994 and 1995, the Solenburger pheromone block consistently accumulated more predator-days and fewer aphid-days than the matched conventionally-

managed block (Tables 4-A & 4-B). This is what was expected to occur in a low-spray environment versus a conventionally-managed block. However, these differences were not significant. In 1994 predator-days became significant only at $P = 0.16$; other differences were not significant

Diversity of Aphidophagous Communities

Sprinkle Orchard

Diversity measures were calculated to determine if the reduction of sprays in the pheromone blocks had allowed a greater variety of predators to become established. In 1994, the pheromone block showed greater richness (number of taxa, 7 vs. 6), but a less even distribution of individuals across the taxa (Pielou J', 0.729 vs. 0.773) (Table 5-A). The evenness of the pheromone block may have been lowered because of the high number of ceccidomyiid larvae collected. The Shannon index, incorporating both community richness and evenness, showed that the pheromone block in the Sprinkle orchard was slightly more diverse than the conventionally-managed block (1.419 vs. 1.385) (Table 5-A). These values were compared using a t-test method specifically designed for comparing Shannon H' values and were found to be significantly different only at $P = 0.11$. Cecidomyiid larvae were the most dominant group in the pheromone block, accounting for 55.6% of the predators collected (Table 2). Anthocorids (13.7 %), predatory thrips (8.1%), and syrphid larvae (9.7%) were also common in the pheromone block. It is interesting to note that two chamaemyid larvae, a rare family of aphid

Table 5. A. Aphidophagous community composition analysis for mating disruption and conventionally-managed apple orchards using aphid colony collection -1994.

	Sprinkle		Tyro		Glaize		Solenburger	
	Pheromone	Control	Pheromone	Control	Pheromone	Control	Pheromone	Control
Total Individuals	124	67	27	36	26	21	18	6
Total taxa	7	6	5	8	5	3	4	2
Shannon-H'	1.419	1.385	1.359	1.597	1.431	0. 930	1.179	0. 637
Pielou J'	0. 729	0. 773	0. 468	0. 536	0. 889	0. 847	0. 850	0. 918
df	113		60		47		10	
Student t	1.22		3.19		6.55		4.05	
p-value	0. 111		0.002		< 0.001		0. 001	
Horn	0. 758		0. 775		0. 882		0. 799	

B. Aphidophagous community composition analysis for mating disruption and conventionally-managed apple orchards using beating tray collection-1995.

	Sprinkle		Tyro		Glaize		Solenburger	
	Pheromone	Control	Pheromone	Control	Pheromone	Control	Pheromone	Control
Total Individuals	120	22	58	24	42	8	24	8
Total taxa	7	5	6	6	6	5	4	3
Shannon-H'	1.118	1.112	1.074	1.456	1.670	1.494	.983	0. 900
Pielou J'	0. 574	0. 691	0. 599	0. 813	0. 932	0. 928	0. 709	0. 819
df	24		32		9		8	
Student t	0. 0899		0. 310		0. 888		0. 478	
p-value	0. 464		0. 379		0. 200		0. 322	
Horn	0. 521		0. 656		0. 687		0. 656	

predators, were collected from the pheromone block. The dominant taxon in the conventionally-managed block in 1994 was Anthocoridae, comprising 52% of the total. Cecidomyiid larvae (14.9%) and chrysopid larvae (13.4%) were also common. Horn's index showed the pheromone and conventionally-managed block to be 75.8% similar in composition and distribution of predators (Table 5-A).

The results for the 1995 growing season were very similar, with the pheromone block having a higher richness, lower evenness, and a higher diversity (Table 5-B). However, the difference in diversity between the two blocks was not significant. As in 1994, cecidomyiid larvae were dominant in the pheromone block, comprising 66.7% of all predators collected. Anthocorids were also common (16.7%). Similar to 1994, Anthocoridae were the dominant taxon in the conventionally-managed block (63.6%). The Horn index showed a 52.1% similarity between blocks (Table 5-B).

Tyro Orchard

In 1994, the aphidophagous community in the conventionally-managed block exhibited greater evenness, diversity and richness (Table 5-A). The difference between the Shannon diversity indices was significant ($P = 0.002$) (Table 5-A). The dominant taxon in the conventionally-managed block was Anthocoridae (47.2%). The dominant taxa in the pheromone block also was Anthocoridae (44.4%), followed by Chrysopidae larvae (25.9%). The Horn's index of similarity showed the communities to be 77.5%

similar.

In 1995, the conventionally-managed block had greater evenness than the matched pheromone block (Table 5-B). The difference between the Shannon diversity indices was not significant. The richness was the same for both blocks. In 1995, the Anthocoridae were the most dominant taxon in the pheromone block, accounting for 68.9% of the predators collected (Table 3). This was an increase from the previous year, and the anthocorids accounted for most of the increase in predators in the pheromone block from 1994 to 1995 (27 to 58). In the conventionally-managed block, anthocorids and cecidomyiid larvae were equally common (33.3%). The overall number of anthocorids and predators collected from the conventionally-managed block decreased from 1994 to 1995. The Horn index showed these communities to be 65.6 % similar (Table 5-B).

Results from the Tyro orchard did not support my hypothesis that the reduction of sprays in the orchard would allow predatory populations to build up and diversify. In addition to its being surrounded by fields and sprayed orchards, the ground cover management differs from the other orchards sampled. The grass in this orchard is cut very short several times during the season; while the grass in Sprinkle, Glaize, and Solenburger is not cut as frequently. This difference in length could be a factor, because the longer grass provides habitat and refuge for some of the adult forms of the predators. However , the results in 1995 did appear more promising. The pheromone block contained a larger number of aphid predators that the conventionally-managed block

(Table 2). It is possible that this orchard's aphidophagous population would continue to increase with the continued use of mating disruption.

Glaize Orchard

In 1994, the pheromone block had greater richness, evenness, and diversity (Table 5-A). The Shannon diversity values of the two blocks were significantly different (Table 5-A). Cecidomyiid larvae (30.8%) and anthocorids (34.6%) were the dominant taxa in the pheromone block. They were also the dominant taxa in the conventionally-managed block; however, they demonstrated different levels of dominance (anthocorids-38.1%, cecidomyiid larvae-52.4%) (Table 2). The Horn index showed these communities to be 88.2% similar (Table 5-A).

In 1995, the pheromone block had slightly greater richness than the conventionally-managed block.   The difference in the diversity indices was not significant. The evenness was almost the same in the two blocks (Table 5-B). In the 1995 growing season there were four common taxanomic groups in the pheromone block: cecidomyiid larvae (31.0%), chrysopid larvae (19.0%), coccinellid larvae (19.0%) and anthocorids (16.7%). The predators in the conventionally-managed block decreased by approximately half from 1994 to 1995, while the predators in the pheromone block almost doubled in number. In 1995, this orchard was undergoing its second consecutive year of mating disruption. The predators may have built up over time, as insecticide

sprays were reduced.

Solenburger Orchard

The pheromone block had greater richness and diversity than the conventionally-managed block in 1994 (Table 5-A). The difference between the Shannon diversity indices was significant ($P = 0.001$). Anthocorids (42.1%) and coccinellid larvae (36.8%) were the most prevalent predators in the pheromone block in 1994. Anthocorids accounted for 66.7% of the predators in the conventionally-managed block. The Horn's index showed these communities to be 79.9% similar.

The community compositions changed in 1995. Richness and overall diversity were greater in the pheromone block, while the conventionally-managed block had a more even distribution (Table 5-B). The diversity indices were not significantly different. Anthocorids alone accounted for 66.7% of the predators collected in the pheromone block, and no coccinellid larvae--a common taxon in 1994-were collected in 1995. Anthocorids were also the most prevalent predator in the conventionally-managed block (62.5%).

Combined Data Analysis of the Sprinkle, Tyro, Glaize and Solenburger Orchards

Comparing Shannon index values of communities from which there is a large difference in the number of samples is not valid (Brower et al. 1990). The Sprinkle and Tyro orchards are similar in number of samples, size and years under mating disruption and were therefore grouped together. The Glaize and Solenburger orchards were similar in

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number of samples, size, mating disruption history, and locations and were therefore grouped together. Fewer samples were obtained from the Glaize and Solenburger orchards because of their far away location. A t-test was performed on the Shannon diversity index values obtained when the two orchards were evaluated at the same time. The results were not significantly different for the combined pheromone blocks versus the combined conventionally-managed blocks in 1994 or 1995 for Sprinkle and Tyro. Significant differences were obtained when the Glaize and Solenburger blocks were grouped. The pheromone blocks in 1994 were significantly more diverse than the matched conventionally-managed blocks ($P = 0.058$). The values were not significantly different in 1995.

When the analyses of variance was performed on the predators collected in the aphid colonies, the orchards were grouped in the same manner as for the tests for diversity. For the aphid colony collection in Sprinkle and Tyro there were no significant differences in the treatment effects except for the number of aphid colonies. There were significantly fewer aphid colonies in the pheromone blocks than in the matched conventionally-managed blocks ($P = 0.0910$) (Table 6). The year and location were not significant when evaluating aphid colonies; however, as expected, sample date was significant ($P = 0.05$). The year and location were not significant when evaluating predators per colony; sample date was significant ($P = 0.04$). The comparison of the pheromone and conventionally-managed blocks of Glaize and Solenburger orchards

Table 6. ANOVA results comparing the numbers of predators collected in mating disruption and conventionally-managed apple orchards using aphid colony collection.

Orchard	Treatment		
	P -value		
Sprinkle & Tyro		Glaize & Solenburger	
Aphid colonies	0.0910	Aphid colonies	0.3031
Leaves with aphids	0.4520	Leaves with aphids	0.2148
Predators/colony	0.2584	Predators/colony	0.1647
Syrphid Larvae	0.2352	Syrphid Larvae	0.0001
Chrysopid Larvae	0.2136	Chrysopid Larvae	0.6333
Hemerobiid Larvae	0.3113	Hemerobiid Larvae	0.4689
Coccinellid Larvae	0.3909	Coccinellid Larvae	0.3701
Coccinellid Adult	0.6435	Coccinellid Adult	0.2972
Cecidomyiid Larvae	0.2033	Cecidomyiid Larvae	0.7650
Anthocorids	0.7472	Anthocorids	0.0540
Other	0.7303	Other	0.5770

showed no significant differences in the number of aphids and predators per colony; the year, location, and sample date were not significant when evaluating predators per colony; sample date was significant when evaluating aphids ($P = 0.0001$). However, syrphid larvae and anthocorids were significantly more numerous in the pheromone blocks ($P = 0.0001$ and 0.0540, respectively) (Table 6). Year and location were not significant, but sampling date was significant for the anthocorids ($P = 0.0085$). For the syrphid larvae location was significant ($P = 0.0001$). More syrphid larvae were collected from the Glaize orchard than the Glaize orchard. Also, the low overall number of syrphid larvae collected from these orchards may have influenced the significance level.

By far the most common predators captured in this study were the aphid midge (Cecidomyiidae) and the anthocorids. They respectively accounted for 29.7% and 29.8% of all predators collected. Their dominance in the community varied slightly from conventionally-managed block to pheromone. The pheromone block communities were comprised of 38.7% aphid midges and 29.4% anthocorids; while the conventionally-managed block communities were comprised of 19.3% aphid midges and 48.9% anthocorids. Aphid midges have been noted to be sensitive to Guthion (Pfeiffer 1996). This may account for their increased numbers and a higher percent dominance in the low-spray blocks. Anthrocorids are generalist feeders. They are also known to be efficient predators of European red mite (ERM); ERM maybe present in the orchards in large numbers while the aphid population is high in the orchard (Pfeiffer & Hogmire 1995).

Insecticide sprays for primary pest often trigger outbreaks of European red mite, because they may harm the natural enemy population. This large alternative food source may contribute to the maintenance of high numbers of anthocorids in the orchards.

The overall percentage of each of the predatory taxa collected in the pheromone blocks did not vary much from year to year .   However, slightly fewer hemerobiid and anthocorid adults were collected in 1995 relative to 1994 (Tables 2 & 3). The conventionally-managed blocks seemed to fluctuate more with only the dominant anthocorids accounting for the same percentage in 1994 and 1995. The overall number of predators collected was greater in 1994 than in 1995.

Beating Tray Sampling Results

Abundance of Aphids and Aphidophagous Insects

Sprinkle Orchard

In 1994, twice as many predators were collected from the pheromone block as from the conventionally-managed block (320 vs. 151) (Table 7). In 1995, the difference increased, with five times as many predators collected in the pheromone block as in the conventionally-managed block (150 vs. 33) (Table 8). Figs. 2-C & 3-C show the predators collected over the growing seasons in the orchard; in 1994, both blocks demonstrated a buildup of predators during the peak of the aphid population (Figs. 2 A-C). The pheromone block had a significantly greater number of predators than the conventionally-managed block on four sampling dates ($P = 0.05$). The next year, the

Table 7. Predators[1] collected using beating trays in mating disruption and conventionally-managed apple orchards in 1994.

Beating Tray Data	Sprinkle		Tyro		Glaize		Solenburger	
	Pheromone	Con. Managed	Pheromone	Conven. Managed	Pheromone	Conven. Managed	Pheromone	Conven. Managed
Chrysopid Larvae	96	94	55	58	5	3	25	23
Chrysopid Adults	4	3	1	1	0	0	2	0
Hemerobiidae Larvae	8	1	0	0	0	0	0	0
Hemerobiidae Adults	9	6	2	3	0	0	1	1
Coccinellid Adults	32	10	8	9	9	3	1	5
Coccinellid Larvae	1	0	0	0	2	1	4	0
Anthocorids	142	36	61	84	1	0	51	25
Syrphid Larvae	0	0	1	0	0	0	0	0
Mirids	10	0	2	1	0	0	2	0
Carabids	2	0	0	0	0	0	0	0
Nabids	0	1	0	1	1	0	0	0
Reduviids	4	0	0	0	0	0	0	0
Thrips	12	0	31	5	6	4	7	0
Total Predators	320	151	161	162	24	11	93	54

[1] Totals over the season.

Table 8. Predators[1] collected in beating trays in mating disruption and conventionally-managed apple orchards in 1995.

Beating Tray Data	Sprinkle		Tyro		Glaize		Solenburger	
	Pheromone	Conven. Managed	Pheromone	Conven. Managed	Pheromone	Conven. Managed	Pheromone	Conven. Managed
Chrysopid Larvae	60	11	17	8	14	6	19	2
Chrysopid Adults	3	1	1	0	0	0	2	0
Hemerobiid Larvae	15	7	10	0	3	1	5	0
Hemerobiid Adults	9	7	5	0	1	0	2	1
Coccinellid Adults	29	1	18	4	2	1	3	4
Coccinellid Larvae	0	0	6	0	0	0	6	0
Anthocorids	26	5	10	1	1	3	10	1
Syrphid Larvae	1	1	1	0	0	0	0	0
Mirids	2	0	0	0	0	1	0	0
Carabids	3	0	1	0	1	0	0	0
Nabids	1	0	0	0	0	0	0	0
Reduviids	1	0	0	0	0	0	0	0
Total Predators	150	33	69	13	22	12	47	8

[1]Totals over season.

aphid numbers peaked for a greater duration (Figs. 3 A-C). The predatory population in

the pheromone block appeared to have built up in response to the rise in prey population

in 1995 (Fig. 3-C) while the predators in the conventionally-managed block did not

appear to respond. The pheromone block had significantly more predators on five

sample dates in 1994 ($P = 0.05$) (Fig. 2-C). The buildup of predators in the pheromone

block probably contributed to the earlier collapse of the aphid population in that block in

both 1994 (Figs. 2 A-C) and 1995 (Figs. 3 A-C).

Tyro Orchard

As in the aphid colony collection experiment, this orchard produced inconsistent

results. In 1994, the conventionally-managed block had virtually the same number of

predators as the pheromone block (162 vs. 161) (Table 7); however, in 1995 the

pheromone block had more than five times as many predators as the conventionally-

managed block (69 vs. 13) (Table 8). Figure 4-C shows the collection of predators in

1994 for the Tyro orchard. Almost half of the predators collected from the Tyro

conventionally-managed blocked were gathered on a single sample date. The predators in

both blocks seemed to respond to the buildup of prey. In 1995, the pheromone block had

significantly more predators than the conventionally-managed block on five sample dates,

and the predators in the pheromone block rose as the prey increased (Figs. 5 A-C) ($P =$

0.05). The pheromone block peaked at an average of 1.7 predators per sample, while the

conventionally-managed block reached only an average of 0.4 predators per sample, and did not seem to respond to the rise in the prey population(Figs. 5 A-C).

Glaize Orchard

The Glaize pheromone block consistently yielded twice as many predators as the associated conventionally-managed block. The numbers of predators also remained consistent from 1994 to 1995; 24 predators were collected in the pheromone block in 1994 and 22 in 1995 (Tables 7 & 8). In 1994, the predators sampled on trays in the pheromone block peaked right after the aphids peaked at an average of 1.3 predators per sample (Fig. 6-A & Fig. 6-C). The conventionally-managed block predator population also peaked after the aphid population did, but the peak was not as great as in the matched pheromone block (0.4 predators per sample) (Fig. 6-B & 6-C).

In 1995, the aphid population showed two peaks, the first as expected in June and July, and a second rise in population in August (cf. Figs. 7-A & 7-B). The predators on beating trays in the pheromone block responded to the first aphid peak (1.6 predators per sample), but not the second (Fig. 7-C). The conventionally-managed block predators increased slightly in population as the aphids peaked (0.5 predators per sample) (Fig. 7-C).

Solenburger Orchard

Predators were more numerous in the pheromone block than in the conventionally-managed block. In 1994, 1.75 times as many predators were collected

from the pheromone block (93 vs. 54) (Table 7), and in 1995, almost six times as many

predators were collected from the pheromone block (47 vs. 8) (Table 8). The predators in

both blocks in 1994 peaked slightly after the aphid population did (Figs. 8 A-C). In

1995, the pheromone block showed a peak during the height of the aphid infestation. The

pheromone block had significantly more predators than the conventionally-managed

block for three consecutive sample dates during its peak ($P = 0.05$). The conventionally-

managed block showed only a slight peak after the aphid population had already crashed

(Figs. 9 A-C).

Comparison of Abundance and Duration of Aphidophagous Insects

Sprinkle Orchard

Predator-days were calculated for both 1994 and 1995. The difference between

the blocks was not significant in 1994 (Table 9-A). However, in 1995 the pheromone

block accrued significantly more predator-days than the conventionally-managed block (P

$= 0.0007$) (Table 9-B). This showed that the pheromone block had more predators

present for a longer time than the conventionally-managed block, possibly contributing

to reduced aphid population density in the pheromone block (Figs. 3-A & 3-B).

Tyro Orchard

In 1994, the difference between the predator-days accumulated in the blocks was

not significant (Table 9-A); yet in 1995, it was (Table 9-B). In 1995 the pheromone block

Table 9. A. Predator days and *P*-values from the t-test performed on 1994 beating tray data collected from mating disruption and conventionally-managed orchards.

Orchard	Treatment	Predator Days	P-Value
Sprinkle	Pheromone	232.5	0.23
	Conv. Managed	145.5	
Tyro	Pheromone	109.95	0.90
	Conv. Managed	115.95	
Glaize	Pheromone	33.75	0.14
	Conv. Managed	13.5	
Solenburger	Pheromone	134.5	0.19
	Conv. Managed	59.7	

B. Predator days and *P*-values from the t-test performed on 1995 beating tray data collected from mating disruption and conventionally-managed orchards.

Orchard	Treatment	Predator Days	P-Value
Sprinkle	Pheromone	107.6	0.0007
	Conv. Managed	21.9	
Tyro	Pheromone	50.9	0.037
	Conv. Managed	13.5	
Glaize	Pheromone	19.95	0.74
	Conv. Managed	14	
Solenburger	Pheromone	64.8	0.123
	Conv. Managed	12.9	

had more predators present for a longer amount of time than the associated

conventionally-managed block.

Glaize Orchard

The pheromone block did not accumulate significantly more predator-days than the

conventionally-managed block in either 1994 or 1995 (Tables 9-A & 9-B).

Solenburger Orchard

There was no significant difference between the number of predator-days in

pheromone block and conventionally-managed block in 1994 (Table 9-A). Again, there

was no significant difference between the number of predator-days in pheromone block

and conventionally-managed block in 1995 (Table 9-B).

Diversity of Aphidophagous Communities

Sprinkle Orchard

Diversity statistics were calculated to determine if the reduction of sprays in the

pheromone blocks had allowed a greater variety of predators to become established. In

1994, the pheromone block showed greater richness, evenness, and diversity (Table 10-

A). The pheromone block had 11 taxa collected, compared to only 7 in the

conventionally-managed block. A t-test showed the pheromone block had a significantly

higher Shannon diversity index value than the conventionally-managed block (Table 10-

A). The reduction of insecticide sprays was predicted to allow for a greater diversity of

predators to become established in the orchard. Anthocorids (44.4%), chrysopid larvae

(30 %), and coccinellid adults (10%) were the dominant predators collected in the pheromone block (Table 7). Chrysopid larvae (62.2%) and anthocorids (23.8%) accounted for the majority of predators in the conventionally-managed block (Table 7). The Horn similarity index showed the communities to be 88.7% similar in composition (Table 10-A).

In 1995, the pheromone block again showed greater richness and diversity (Table 10-B). The pheromone block had a significantly higher diversity than the matched conventionally-managed block ($P = 0.100$). The overall number of predators collected in 1995 was lower than in 1994. As in 1994, chrysopid larvae (40%), coccinellid adults (19.3%) and anthocorids (17.3 %) were again the most dominant taxa in the pheromone

Table 10. A. Aphidophagous community composition analysis for mating disruption and conventionally-managed apple orchards using beating tray collection-1994.

	Sprinkle		Tyro		Glaize		Solenburger	
	Pheromone	Control	Pheromone	Control	Pheromone	Control	Pheromone	Control
Total Individuals	320	151	161	162	24	11	93	54
Total taxa	11	7	8	8	6	4	8	4
Shannon-H'	1.533	1.078	1.398	1.230	1.513	1.295	1.275	1.017
Pielou J'	0. 639	0. 554	0. 672	0. 560	0. 844	0. 934	0. 613	0. 734
df	261		293		18		114	
Student t	39.9		0.137		1.87		9.07	
p-value	< 0.001		0. 446		0. 0389		< 0.001	
Horn	0. 887		0. 904		0. 949		0. 897	

B. Aphidophagous community composition analysis for mating disruption and conventionally-managed apple orchards using beating tray collection-1995.

	Sprinkle		Tyro		Glaize		Solenburger	
	Pheromone	Control	Pheromone	Control	Pheromone	Control	Pheromone	Control
Total Individuals	150	33	69	13	22	12	47	8
Total taxa	11	7	9	3	6	5	7	4
Shannon-H'	1.701	1.628	1.778	.859	1.128	1.199	1.467	1.213
Pielou J'	0. 710	0. 837	0. 855	0. 782	0. 630	0. 865	0. 754	0. 875
df	36		17		21		9	
Student t	1.30		10.89		0.55		1.49	
p-value	0. 100		< 0.001		0. 293		0. 087	
Horn	0. 880		0. 805		0. 757		0. 654	

block (Table 8). The composition of the conventionally-managed block varied from the previous year with chrysopid larvae (33.3%) being dominant. Hemerobiid larvae and adults and anthocorids comprised the majority of the other predators collected (Table 8). The Horn similarity index showed the communities to be 88% similar in composition.

Tyro Orchard

In 1994, the conventionally-managed block had lower evenness than the pheromone block (Table 10-A). There were no significant differences between the diversity indices. The dominant predators in the pheromone block were chrysopid larvae (34.1%), anthocorids (37.8%), and predatory thrips (19.3%) (Table 7).   Anthocorids (51.8%) and chrysopid larvae (35.8%) accounted for most of the predators in the conventionally-managed block (Table 7).

In 1995, the pheromone block had greater richness, evenness, and diversity than the conventionally-managed block (Table 10-B). The pheromone block had significantly greater diversity than the conventionally-managed block (Table 10-B). The overall number of predators collected decreased from the previous year. The community composition of the pheromone block changed.   Coccinellid adults (26.1%), chrysopid larvae (24.6%), and hemerobiid larvae and anthocorids (14.5%) were the dominant predators, and no predatory thrips were collected (Table 8). Chrysopid larvae accounted for the majority of predators in the conventionally-managed block (61.5%), and no anthocorids were collected (Table 8).

Glaize Orchard

In 1994, the Glaize pheromone block had greater richness, but lower evenness than the conventionally-managed block (Table 10-A). The pheromone block also had significantly more diversity than the conventionally-managed block ($P = 0.0389$). Coccinellid adults, chrysopid larvae, and predatory thrips accounted for the majority of the predators in both blocks (Table 7). Likewise, the Horn's similarity index showed a 94.9% similarity in community composition. Again, in 1995 the Glaize pheromone block had greater richness, but less evenness than the conventionally-managed block (Table 10-A). These was no significant difference in the diversity of aphidophagous communities between the two blocks (Table 10-B). Chrysopid larvae were the dominant predators in both blocks (Table 8).

Solenburger Orchard

In both 1994 and 1995, the pheromone block was greater in richness and diversity, but lower in evenness than the conventionally-managed block (Tables 10-A & 10-B). The pheromone block had significantly greater diversity than the conventionally-managed block (Tables 10-A & 10-B). Anthocorids and chrysopid larvae were the dominant predators both years in the pheromone block (Tables 7 & 8). However, anthocorids were the most dominant in 1994 (55%), and chrysopid larvae were the most dominant in 1995 (40%). Anthocorids (45%) and chrysopid larvae (42%) were the

dominant predators in 1994 in the conventionally-managed block, while coccinellid adults (50%) were dominant in 1995.

Combined Data Analysis of the Sprinkle, Tyro, Glaize and Solenburger Orchards

The Shannon index is affected by sample size (Brower et al. 1990). The Sprinkle and Tyro orchards are similar in number of samples, size and time under mating disruption and were therefore grouped together. The Glaize and Solenburger orchards were similar in number of samples, size, time under mating disruption and location and were therefore grouped together. A t-test was performed on the Shannon diversity index values obtained when two orchards with similar numbers of samples were combined. The pheromone blocks were significantly more diverse than the matched conventionally-managed blocks for Sprinkle and Tyro ($P = 0.05$), and Glaize and Solenburger ($P = 0.07$).

When the analyses of variance were performed on the predators collected in beating trays, the orchards were grouped in the same manner as for the tests for diversity. The ANOVA for the Sprinkle and Tyro orchards showed one significant difference (Table 11). The pheromone blocks were found to have significantly more of the predators I placed in the category "other" ($P = 0.0075$). Year, location, and sample date effects were not significant. Predators that were found in very low numbers were lumped in this category

for the ANOVA; these included: predatory mirids, nabids, carabids, reduviids, and thrips. For the evaluation of all predators, the year and location effects were not

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Table 11. ANOVA results comparing the numbers of predators collected in mating

disruption and conventionally-managed apple orchards using beating tray collection.

Orchard	Treatment			
	P - value			
Sprinkle & Tyro			Glaize & Solenburger	
All predators	0.2797		All predators	0.1842
Chrysopid Larvae	0.1501		Chrysopid Larvae	0.2018
Hemerobiid Larvae	0.3023		Hemerobiid Larvae	0.0243
Chrysopid Adults	0.2553		Chrysopid Adult	0.2104
Hemerobiid Adults	0.1676		Hemerobiid Adult	0.0226
Coccinellid Larvae	0.7078		Coccinellid Larvae	0.2050
Coccinellid Adult	0.3386		Coccinellid Adult	0.8693
Anthocorids	0.7879		Anthocorids	0.4191
Other	0.0075		Other	0.1953

significant, but the sample date was (P = 0.0001). The Glaize and Solenburger blocks also

showed significant differences in the ANOVA (Table 11). Hemerobiid larvae and adults

were more prevalent in the pheromone blocks (P = 0.0243 and 0.0226, respectively). In

the ANOVA of the hemerobiid larvae, year, location, and sample date were not

significant. In the analysis of the hemerobiid adults, location was significant (P = 0.02).

By far the most dominant predators captured in this study were chrysopid larvae

and the anthocorids, accounting for 37.3% and 34.3% of all predators collected,

respectively. Their dominance in the community varied slightly between both treatment

blocks. The pheromone block communities were comprised of 32.8% chrysopid larvae

and 34.1% anthocorids, while the conventionally-managed block communities were

comprised of 46.2% chrysopid larvae and 34.9% anthocorids. Coccinellid adults

comprised 10.5% of all predators collected. Minks & Harewijn (1988) noted that current

sampling methods of coccinellids generally underestimates the total population present.

Pree et al. (1989) noted that resistance to azinphosmethyl has been found in

chrysopid larvae from sprayed apple orchards in Ontario, Canada. Although this has not

been determined in eastern N. America, it is possible that tolerance to azinphosmethyl

allowed the chrysopid larvae to establish a dominant population in the conventionally-

managed blocks (Pfeiffer 1996). Nevertheless, more chrysopid larvae were collected from

the pheromone blocks (496 vs. 291). Anthocorids are polyphagous and they are efficient

predators of European red mite; This mite maybe present in the orchards in large

numbers concurrently with the aphids (Pfeiffer & Hogmire 1995). Mite populations in

the Tyro and Sprinkle orchards in 1994 were known to be large (Knowles et al. 1994).

This large alternative food source may have contributed to the maintenance of high

numbers of anthocorids in the orchards. Beers et al. (1993) previously noted that

anthocorids have tolerance to azinphosmethyl and chlorpyrifos.

The overall community composition of predators collected in the pheromone

blocks did change from 1994 to 1995. Anthocorids were much more dominant in 1994

(42% to 16%). The conventionally-managed blocks also seemed to fluctuate with the

dominance of anthocorids decreasing from 1994 (38%) to 1995 (15%). The overall

number of predators collected was greater in 1994 than in 1995.

Coccinellids

Coccinellids were of special interest in this study, particularly because of the

presence of a species previously not collected from Virginia apple orchards, *Harmonia*

axyridis (Pallas). Chapin and Brou (1991) first reported the establishment of this

multicolored Asian lady beetle in Louisiana and Mississippi. *H. axyridis* was first

collected in Virginia in August 1993 (Kidd et al. 1995). It was collected near a colony of

green apple aphids, reportedly *Aphis pomi* DeGeer, in a dwarf apple tree in Canada in

August 1994 (Coderre et al. 1995). *H. axyridis* is known to be an effective biological

control agent against *A. pomi* (Coderre et al. 1995). *H. axyridis* were identified using

the field guide to recently introduced species of Coccinellidae (Coleoptera) in North

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America (Gordon et al 1991). The multicolored Asian lady beetle was not only present in the orchards, but it dominated the coccinellids collected.

Aphid Colony Collection: In 1994, *H. axyridis* comprised 40.6% of all adults collected and 84.6% of larvae. *Coccinella septempunctata* L., the introduced European sevenspotted lady beetle, was also numerous in 1994 (53.1% of adults) (Table 12). However, in 1995 the sevenspotted lady beetle comprised only 21.4% of adults collected; while the Asian lady beetle represented 78.6% of the adults collected (Table 13).

Beating Tray Collection: In 1994, *H. axyridis* comprised 55.8% of all adults collected and 62.5% of larvae (Table 14). *C. septempunctata* was also numerous in 1994 (36.4% of adults). However, in 1995 the sevenspotted lady beetle comprised only 11.3% of adults collected, while the Asian lady beetle made up 69.4% of the adults collected (Table 15). These results were very similar to the aphid colony collection data.

These data suggest that it would be worthwhile to perform further studies to see if *Harmonia* continues to displace the established coccinellid fauna. The total number of *C. septempunctata* collected decreased from 45 in 1994 to only 13 in 1995; while the number of *H. axyridis* remained almost constant (73 in 1994, 70 in 1995) and more abundant than the *C. septempunctata* (Tables 12-15). It is interesting to note that the sevenspotted lady beetle recently replaced the native ninespotted lady beetle, *Coccinella novemnotata*, in Virginia apple orchards (Pfeiffer & Hogmire 1995). *C. novemnotata* is rarely collected now.

Table 12. Coccinellids observed in aphid colonies in mating disruption and conventionally managed apple orchards in 1994.

Aphid Data	Tyro		Sprinkle		Glaize		Solenburger	
	Pheromone	Control	Pheromone	Control	Pheromone	Control	Pheromone	Control
Adults								
Harmonia axyridis (Pallas)	2	3	4	4	0	0	0	0
Coccinella septempunctata L.	2	1	3	2	4	2	2	1
Hippodamnia convergens Guerin	0	0	0	0	0	0	0	1
Cycloneda munda (Say)	0	0	0	1	0	0	0	0
Larvae								0
Harmonia axyridis (Pallas)	0	0	0	0	4	0	7	0
Hippodamnia parenthesis (Say)	0	1	0	1	0	0	0	0

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Table 13. Coccinellids observed in aphid colonies in mating disruption and conventionally managed apple orchards in 1995.

Aphid Data	Tyro		Sprinkle		Glaize		Solenburger	
	Pheromone	Control	Pheromone	Control	Pheromone	Control	Pheromone	Control
Adults								
Harmonia axyridis (Pallas)	5	0	4	0	0	1	0	1
Coccinella septempunctata L.	1	1	0	0	0	1	0	0
Hippodamnia convergens Guerin	0	0	0	0	0	0	0	0
Cycloneda munda (Say)	0	0	0	0	0	0	0	0
Larvae								
Harmonia axyridis (Pallas)	0	0	0	0	8	0	0	0
Hippodamnia parenthesis (Say)	1	0	0	3	0	0	0	0
Coccinella septempunctata L.	1	1	0	0	0	0	0	0

Table14 . Cocinellids observed in mating disruption and conventionally-managed apple orchards in beating trays in 1994.

	Tyro		Sprinkle		Glaize		Solenburger	
Aphid Data	Pheromone	Control	Pheromone	Control	Pheromone	Control	Pheromone	Control
<u>Adults</u>								
Harmonia axyridis (Pallas)	4	5	20	7	1	2	1	3
Coccinella septempunctata L.	3	3	11	2	7	1	0	1
Hippodamnia convergens Guerin	0	0	0	0	0	0	0	0
Cycloneda munda (Say)	1	0	1	0	0	0	0	1
Psyllobora vigintimaculata (Say)	0	0	0	0	1	0	0	0
Anatis labiculata (Say)	0	1	0	1	0	0	0	0
<u>Larvae</u>								
Harmonia axyridis (Pallas)	0	0	1	0	0	0	4	0
Coleomegilla maculata (DeGeer)	0	0	0	0	2	1	0	0
Hippodamnia parenthesis (Say)	0	0	0	0	0	0	0	0
Coccinella septempunctata L.	0	0	0	0	0	0	0	0

Table 15. Cocinellids observed in mating disruption and conventionally-managed apple orchards in beating trays in 1995.

	Tyro		Sprinkle		Glaize		Solenburger	
	Pheromone	Control	Pheromone	Control	Pheromone	Control	Pheromone	Control
Adults								
Harmonia axyridis (Pallas)	7	3	24	0	2	1	2	4
Coccinella septempunctata L.	6	0	1	0	0	0	0	0
Hippodamnia convergens Guerin	2	0	2	0	0	0	0	0
Cycloneda munda (Say)	2	0	0	0	0	0	1	0
Psyllobora vigintimaculata (Say)	1	1	2	1	0	0	0	0
Anatis labiculata (Say)	0	0	0	0	0	0	0	0
Larvae								
Harmonia axyridis (Pallas)	2	0	0	0	0	0	6	0
Coleomegilla maculata (DeGeer)	0	0	0	0	0	0	0	0
Hippodamnia convergens Guerin	3	0	0	0	0	0	0	0
Hippodamnia parenthesis (Say)	0	0	0	0	0	0	0	0
Coccinella septempunctata L.	1	0	0	0	0	0	0	0

Summary

The following significant differences were found:

Aphid Colony Collection: In 1994, the Glaize and Solenburger pheromone blocks showed greater diversity than the conventionally-managed blocks ($P = 0.001$). In 1995, the Sprinkle and Tyro pheromone blocks accumulated more predator-days than the associated conventionally-managed blocks ($P = 0.01$ and $P = 0.08$). In 1994 and 1995, the Sprinkle and Tyro pheromone blocks had slightly fewer aphid colonies than the conventionally-managed blocks ($P = 0.09$). The Glaize and Solenburger pheromone blocks had significantly more syrphid larvae and anthocorids ($P = 0.0001$ & $P = 0.0540$). In 1994 the Tyro conventionally-managed block showed greater diversity than the pheromone block ($P = 0.002$)

Beating Tray Collection: In 1994, the pheromone blocks of Sprinkle, Glaize, and Solenburger contained more diverse fauna than the matched conventionally-managed blocks ($P < 0001$, $P = 0.039$, $P < 0.001$, respectively). In 1995, the pheromone blocks of Sprinkle, Tyro, and Solenburger were more diverse than the matched conventionally-managed blocks ($P = 0.100$, $P < 0.001$, $P = 0.087$, respectively). In 1995, the Sprinkle and Tyro pheromone blocks accumulated significantly more predator-days than the conventionally-managed blocks ($P < 0.001$ & $P = 0.037$). Over the 1994 and 1995 growing seasons, the Sprinkle pheromone block had a greater number of predators on nine

sample dates than the conventionally-managed block ($P = 0.05$). In the 1995 growing season, the Tyro pheromone block had a greater number of predators on five sample dates than the conventionally-managed block ($P = 0.05$). In the 1995 growing season, the Solenburger pheromone block had a greater number of predators on three sample dates than the conventionally-managed block ($P = 0.05$). The Sprinkle and Tyro pheromone blocks had significantly more of the predators in the category "other" (mirids, nabids, carabids, reduviids, and phlaeothripids) ($P = 0.008$). The Glaize and Solenburger pheromone blocks had significantly more hemerobiid larvae and adults than the conventionally-managed blocks ($P = 0.002$ & $P = 0.002$).

Conclusions

The reduced insecticide input due to the use of mating disruptions appeared to allow the aphid predators to build up to higher and more diverse populations than in the conventionally-managed blocks. Over the two years of aphid colony collecting, 69.6% of all predators were collected from the pheromone blocks (439 vs. 192), and in all but one case (Tyro 1994), more predators were collected from the pheromone block than the matched conventionally-managed block. Again, over the two years of beating tray collections, 66% of all predators were collected from the pheromone blocks (886 vs. 444), and in all but one case (Tyro 1994) more predators were collected from the pheromone block than the matched conventionally-managed block. The Tyro pheromone

block accumulated significantly more predator-days than the conventionally-managed blocks in the aphid colony and beating tray collections. In the aphid colony collection, the Glaize and Solenburger pheromone blocks all showed significantly greater diversity than the conventionally-managed blocks. In the beating tray collections, all of the pheromone blocks showed significantly more diversity than the conventionally-managed blocks, and significantly more predators were collected from the pheromone blocks on a total of seventeen sample dates.

I believe this increase in the numbers and diversity of aphidophagous insects resulted in adequate control of aphid populations in the low-spray blocks . The aphid-days accumulated were virtually the same in the pheromone blocks as in the conventionally-managed blocks, while the Sprinkle and Tyro pheromone blocks accumulated significantly more predator-days than the matched conventionally-managed blocks. The pheromone block was not receiving sprays such as Guthion and Lannate that could help to control the aphids. The natural enemies seemed to have provided at least as effective a control as the insecticide sprays. While aphid populations often reached as high densities in pheromone blocks as in controls, populations often declined faster and were less likely to show resurgence.

For future study I suggest:

Recommendations for sampling procedure:

     1. Sampling time be limited from the end of May to the end of July. This would cut down on the time and expense of the experiment. These sampling dates would usually include all of the time that the aphids are potentially causing economic damage in the orchard.

     2. Retain the higher number of trees sampled (6-aphid colony, 10-beating trays) and high number of branches inspected per tree (10) per sample date. Aphid and predator populations varied greatly within tree and from tree to tree. Also, continue random sampling of trees. Predators seemed to vary in different regions of the orchard.

     3. Increase the number of replicated blocks. This would greatly increase time and expense of the experiment. However, I feel that if there were more replications in this experiment more positive significant results would have been obtained. The high variability in predatory populations made it difficult to obtain significant results. The increase in time and expense could be partially offset by suggestion number 1.

Future Experiments:

     1. It would be interesting to monitor aphid predators in Virginia blocks using the new insecticide tebufenozide (Confirm). A Section 18 permit was granted in June of 1996. Tebufenozide is an insect growth regulator that causes premature molting and death in lepidopteran larvae. It is very selective towards the targeted pests, and therefore

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not deleterious to beneficial insects.   It may possibly be in widespread use in the

northern Virginia area within a few years. It would be worthwhile to monitor predatory

numbers, and be able to advise growers to take this into account when considering control

methods for aphids and European red mite.

 2. Monitoring of *Harmonia axyridis* populations should continue.   This Asian

lady beetle seems to be taking over a large portion of the community niche of the

established coccinellid fauna in Virginia apple orchards. Both larvae and adults were

collected in the orchards. An investigation into its possibly dominant role as an aphid

predator in Virginia apple orchards would be worthwhile.

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Appendix

Comparison of Tufted Apple Bud Moth Resistance to Azinphosmethyl in Four Virginia Apple Orchards

Introduction

Azinphosmethyl (Guthion) is the most widely used insecticide in Virginia apple orchards; 89.1% of orchards were reported to be treated with azinphosmethyl each year. Most of these orchards received multiple applications (Pfeiffer et al. 1989a). This pesticide is used in apple orchards to control primary insect pests such as *P. idaeusalis.* Reports of tortricid resistance to azinphosmethyl are increasing (Helle et al. 1991). Helle et al. (1991) noted azinphosmethyl resistance in *P. flavedana* in North America.

More specific examples of Tortricid resistance has been noted. *P. flavedana* and *P. idaeusalis* were reported to be resistant in the mid-Atlantic Region by Hull et al. (1995). *C. rosaceana* larvae in the field were found to be resistant in New York (Reissig et al. 1986). *P. idaeusalis* was reported to be resistant in North Carolina by Bush et al. (1993) and in Pennsylvania by Knight & Hull (1989a, 1989b). Light brown apple moth [*Epiphyas postvittana* (Walker)] larvae were reported to be resistant to azinphosmethyl in New Zealand (Suckling et al. 1984).

Resistance of *P. idaeusalis* to azinphosmethyl has been detected in Pennsylvannia. Knight & Hull (1989a) found the resistance levels of field collected *P. idaeusalis* neonates to be around 17 times greater than of a susceptible laboratory strain. Neonates were evaluated in direct spray and leaf residue bioassays. In the direct spray

test the LC_{50} was reported at 410.8 ppm. LR_{50} was 0.36 $\mu g/cm^2$, and the LR_{90} was 1.59 $\mu g/cm^2$.

Resistance has also been monitored in adult male field populations using sex pheromone traps (Knight & Hull 1989b). Two methods of testing were employed. In one, azinphosmethyl was incorporated into the adhesive of the sticky card of the traps. The other method involved the topical application of the pesticide to the trapped moths. These results were compared to the evaluation of male and female lab populations. The site of application (dorsal vs. ventral), the length of the bioassay, and the sex of the insect were found to be significant factors affecting resistance levels. In the trial in which azinphosmethyl was incorporated into the adhesive, the moths were more susceptible when exposed to the adhesive ventrally. In a trial lasting only 24 hours the LD_{50} and LD_{90} were approximately twice that of the trial lasting 48 hours. In tests using lab populations, female moths were found to be from 1.5 to 2 times more resistant than males. The age and mating status of the moth were not found to be important.

Areawide resistance of *P. idaeusalis* to azinphosmethyl in Pennsylvania was studied by Knight & Hull (1990). Resistance ratios of adult males were found to vary from 1.8 to 6.4 fold (compared to susceptible lab strain). Adult males were collected in the field using sex pheromone traps, and topical applications of 0.5 to 1.0µl were applied to their dorsal side. Concentrations between 0.1 and 4.0µg/l were tested. The LD_{50}'s for the populations were highest in the apple orchards evaluated, lower in the peach orchards and wooded areas.

Bush et al. (1993) studied azinphosmethyl resistance in North Carolina populations of *P. idaeusalis*, and found that resistance was 41 times greater in adult males. They evaluated the field moths with sex pheromone traps. Bush determined the LC_{95} and LC_{99} of susceptible strains to be 340 and 760 µg(AI)/g adhesive, respectively. These concentrations were used to evaluate resistance in the field population. A colony of resistant *P. idaeusalis* from the field was kept. The resistance level of neonates and adult males declined in the lab, and after 17 generations, the resistance level was near that of the susceptible strain. Bush tested neonates using a filter-paper bioassay.

Reissig (1986) used a topical method to evaluate *C. rosaceana* larvae. Their weights were recorded, and analysis of results used a probit regression with weight as a factor. Resistance was noted. The mechanism of resistance to azinphosmethyl in tortricids has not yet been established (Bush et al. 1993).

Objective

1. Compare azinphosmethyl resistance of the tufted apple bud moth, *P. idaeusalis ,* in four commercial orchards in Winchester, Virginia.

<u>Materials and Methods</u>

In August of 1995, adult *P. idaeusalis* males were collected from four commercial orchards near Winchester, Virginia; the orchards were catergorized as follows:

Solenberger (1), Barley (2), Brown (3), and Brumbach (4). All orchard owners had

reported suspected *P. idaeusalis* resistance in their orchard blocks. Sex pheromone traps

were used to collect the males. Insects were not collected until 48 hours after the last

insecticide application.

Technical azinphosmethyl was serially diluted in acetone, then incorporated into

tanglefoot (adhesive used to trap insects) to obtain the following four concentrations: 125,

250, 500, and 1000 µg(AI)/g adhesive [modified from concentrations used by Bush et al.

(1993)]. One gram of adhesive was spread on a 9.5 x 17 cm wax-covered cardboard card,

and the card was placed in the bottom of a wing style trap. During each trial, two traps

of each concentration were placed in each block. Trapping took place during peak flight.

Traps were placed the evening, and retrieved in the early morning. An environmental

chamber was not available. Therefore, the moths were placed in a closed plastic container

in a room with the temperature set at 27 degrees C and observed every 24 hours for three

days. Adult mortality was assessed by probing with a fine pin. If the moth did not

respond with sustained movement of a body part it was considered dead. Three trials

were conducted.

Statistics

Mortality curves (mortality versus concentration) could not be accurately

generated due to the low number of moths collected and the high variability of the results.

Therefore, statistics were not performed on this data.

Results & Discussion

As noted above the total number of moths collected was very low (Table 1). The results of trials in which there was >= three moths collected are shown in figures 1-7. There appeared to be a cause of mortality other than the insecticide. This prevented the generation of an accurate mortality curve for each orchard. Possible causes for the mortality include: unregulated temperature and humidity due to the unavailability of an environmental chamber, and unknown experimental error. The low number of moths in the test and small size of the orchard blocks (1 acre) may have magnified the variability of the mortality. The blocks in which the traps were placed was not sprayed for 48 hours prior to collection; however, immigration of adult males from other sprayed parts of the orchard might have occurred.

Recommendations for future study

1. A study comparing the *P. idaeusalis* populations in orchard 1 and 2 to susceptible lab populations, because of their typically lower mortality than the other two orchards.

2. Due to the small number of moths obtained in this experiment, I would suggest an alternative collection method. Preferably one that collects the moths in a manner so they may be equally divided among the treatments. I would suggest the use of a light trap or possibly modifying the pheromone trap design and timing to achieve higher catches. Perhaps an alternative method used by Knight & Hull (1989b) would be appropriate. They collected moths in pheromone traps and then took the traps back to the lab and topically applied insecticide to them. This would enable the equal division of moths

between concentrations and a control, and also would allow the moths to be transported

back to VPI & SU where an environmental chamber could be utilized.

3. I would recommend that an environmental chamber be utilized in the experiment. Due

to the location of the collection of the moths, it was not possible to use one.

Table 1. Number of TABM males caught in each trial in apple orchards nearWinchester, Virginia.

		Orchard			
	Conc. (AI)	**1**	**2**	**3**	**4**
Trial 1	125	15	8	6	1
	250	5	8	3	0
	500	8	10	5	2
	1000	11	10	2	2
Trial 2	125	4	11	3	7
	250	3	13	0	11
	500	4	11	2	3
	1000	15	7	2	3
Trial 3	125	4	0	3	3
	250	1	0	3	4
	500	1	0	0	2
	1000	1	0	3	5
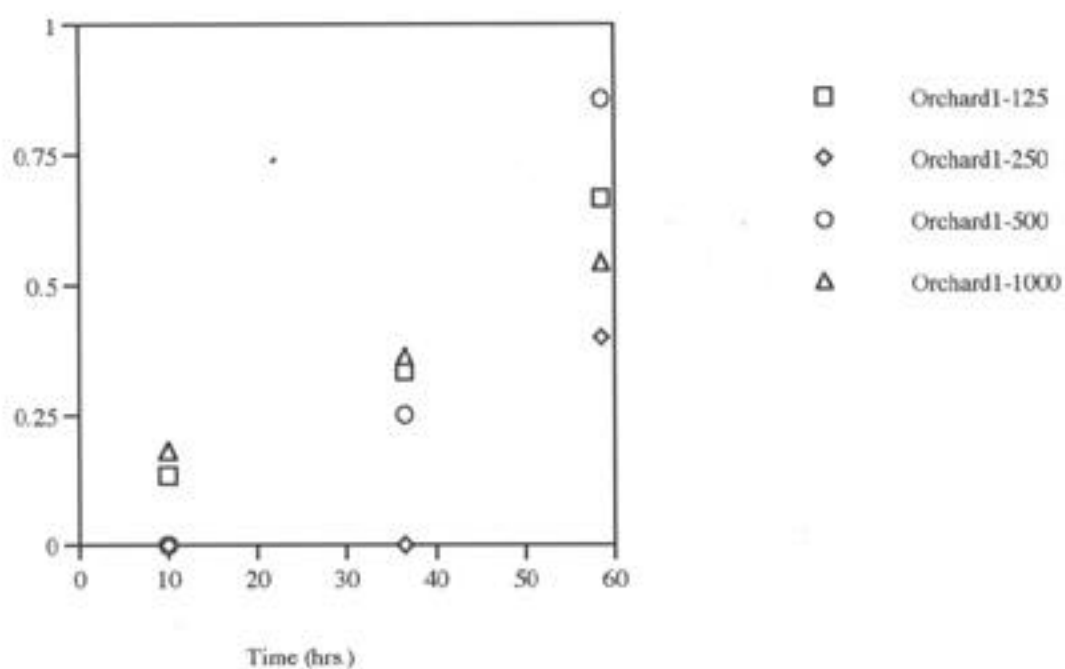
Figure 1. Mortality over time for moths collected from Orchard 1 in the first trial. (sample size >=3).
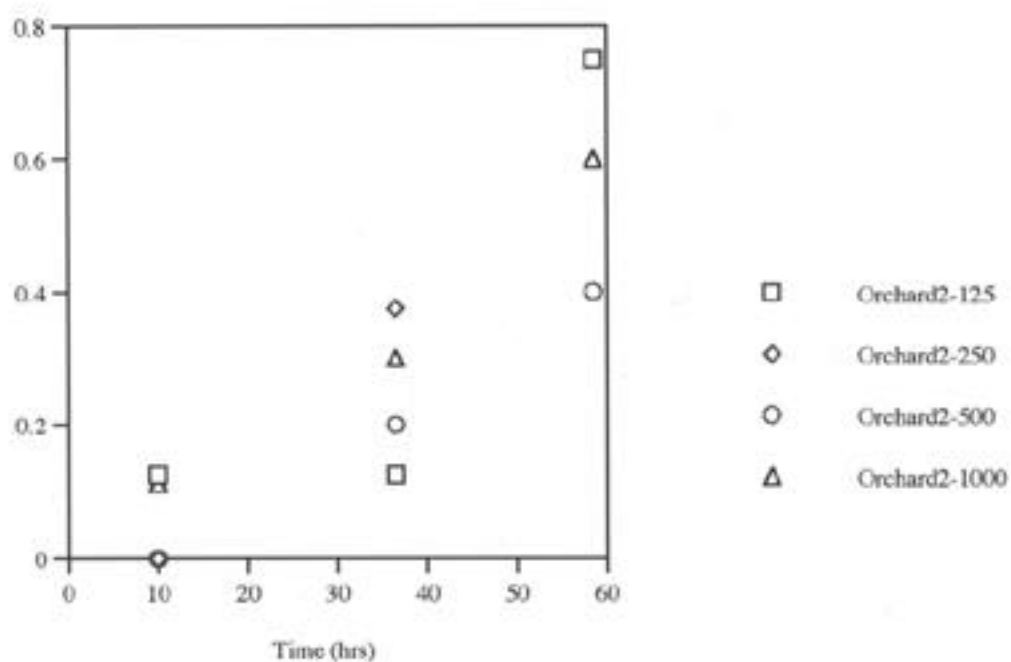
Figure 2. Mortality over time for moths collected from Orchard 2 in the first trial. (sample size >=3).
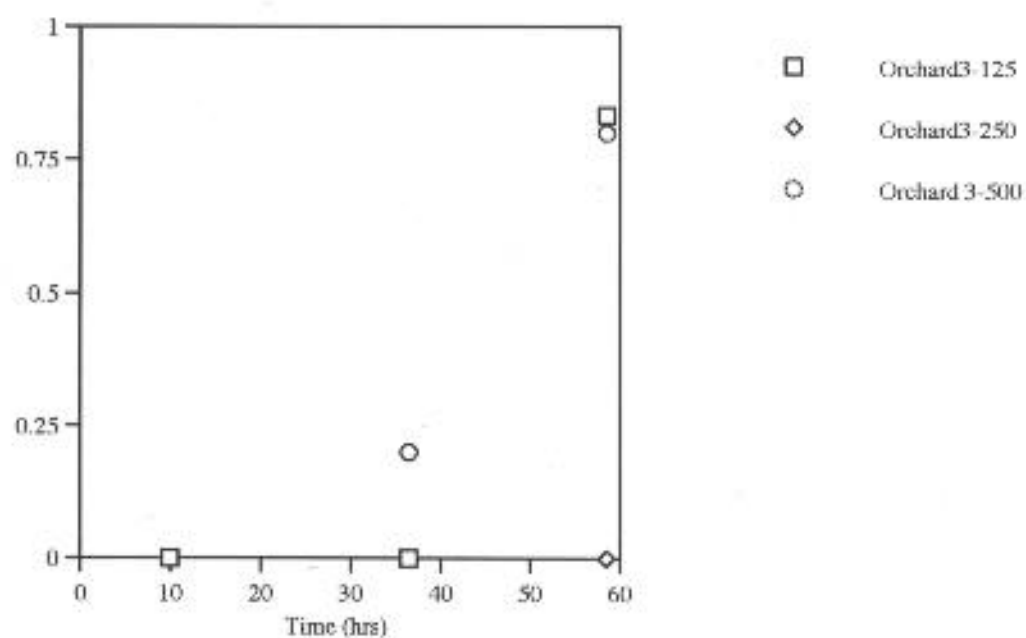
Figure 3. Mortality over time for moths collected from Orchard 3 in the first trial. (sample size >=3).
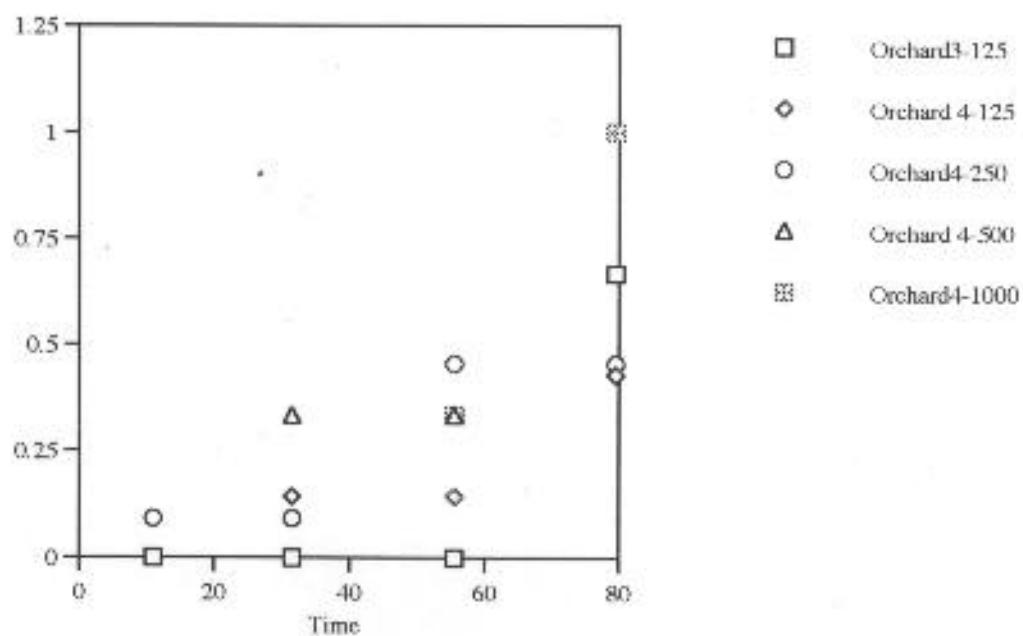

Figure 4. Mortality over time for moths collected from Orchard 3 & 4 in the second trial. (sample size >=3).
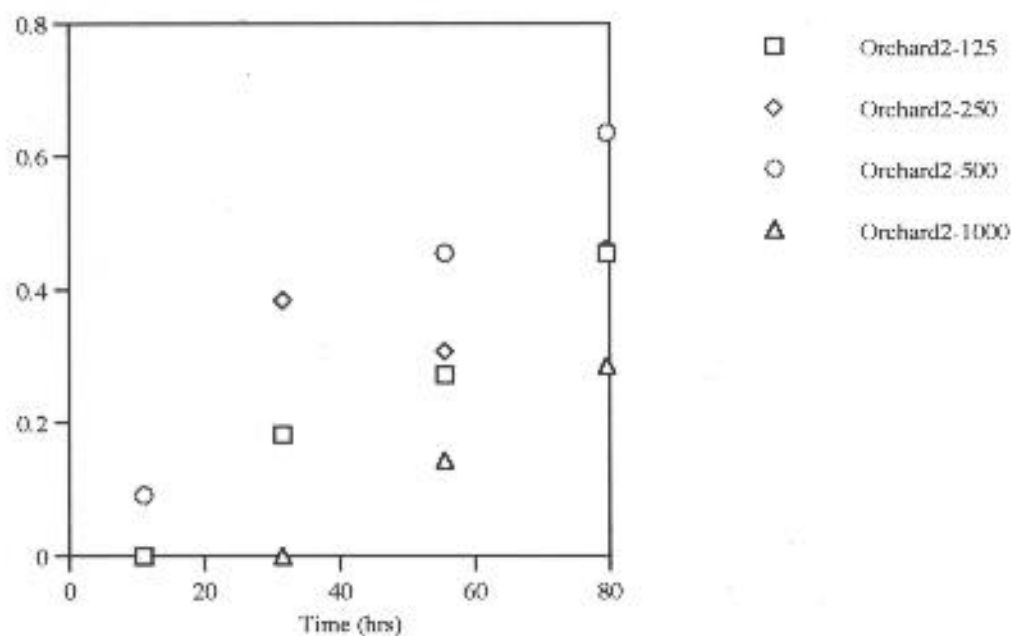
Figure 5. Mortality over time for moths collected from Orchard 2 in the second trial. (sample size >=3).
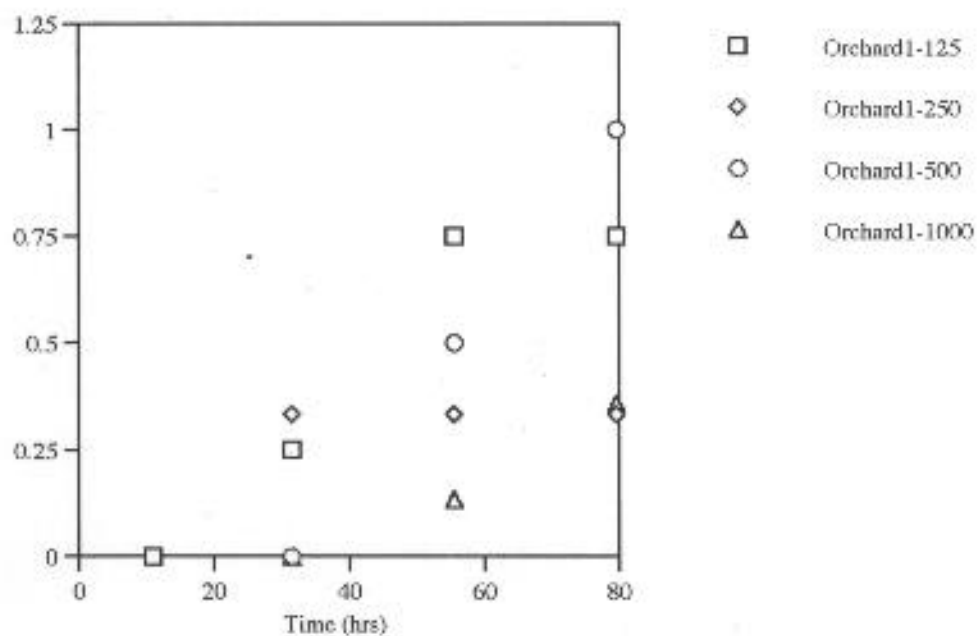

Figure 6. Mortality over time for moths collected from Orchard 1 in the second trial. (sample size >=3).
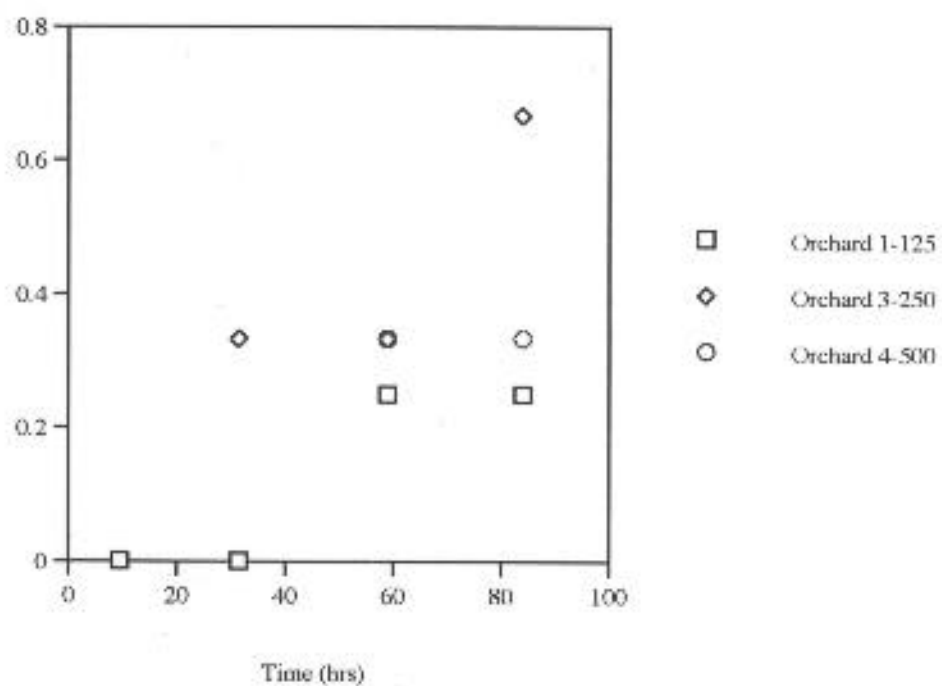
Figure 7. Mortality over time for moths collected from all orchards in the third trial. (sample size >=3).

VITA

Kathy Knowles was born on September 27, 1971, in Alexandria, Virginia. She attended Woodbridge Senior High School. She then attended James Madison University in Harrisonburg, Virginia. She graduated with a B.S. in Biology in 1993. She worked with the use of mating disruption for apple pests in Virginia for her graduate work at the Virginia Tech Department of Entomology.