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Organic farming research project report submitted to the Organic Farming Research Foundation:

Project Title:

Biological control of Delia spp. in cole crops with the rove beetles, Aleochara spp. and other natural enemies

FINAL PROJECT REPORT

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Funding provided by OFRF: $1,300

OFRF funding cycle: Awarded spring 2001

Project period: 2001/2002

Report submitted: December 2002

Executive Summary

The overall objective of this research was to further understand how natural enemies can be utilized to enhance biological control of root maggots, *Delia* spp., which are important cole crop pests. We have determined that there is a truly complex web of insects that are potential natural enemies of *Delia* spp. in southwestern BC and northwestern Washington. This community of natural enemies includes six species of beetles (ground and rove) that are predators of *Delia* spp. eggs, and also several species of parasitoid wasps and *Aleochara* spp. rove beetles that attack the larval and pupal stages of this pest. Our first objective was to determine if certain types of field margins, those with primarily grassy vegetation and high percentage of ground cover, could conserve this community of natural enemies on farmland. In both 2001 and 2002, we did not find any significant differences in natural enemy density between the grassy good margins and bare ground poor margins. We did, however, find that natural enemy - in particular rove beetle densities - were higher in May and June in good margins. In 2002, we found that natural enemy densities remained higher in the margin than in the field. However, we also found that early in the season - May 2002 - the diversity of the predatory beetles, measured as activity density and species richness, was higher 20m into organic fields that were adjacent to grassy ('good') margins. This increase in natural enemy diversity only occurred in organic fields with good margins and was not observed in conventional fields or in organic field with poor margins. It is during this early part of the growing season that biocontrol of root maggots is most crucial because in-field natural enemy activity is low. This is especially the case for the rove beetles, *Aleochara* spp. which are effective biocontrol agents of root maggots, but are not active early enough to control early season maggot populations. Our second objective was to determine if increases in predator diversity resulted in increased in egg predation. In an experimental manipulation, we found that overall predator diversity did not correlate with predation of fly eggs in the field. It is unlikely that the relationship between predator diversity and pest control would be so straightforward, given the complexity of the community of organisms. Our overall conclusions are that certain attributes of field margins (grassy perennial vegetation, high percentage of ground cover, relatively undisturbed) can provide a refuge for natural enemies, but that dispersal of enemies from margins to the field may be limited. Future efforts on natural enemy conservation should focus on enemy activity and conservation within the field.

Introduction

In southwestern BC and northwest Washington, cole crops are an important component of many small and large organic farms. Depending on the specific crop, transplants and/or direct seeding can begin as early as April, provided that ground is dry enough. Repeated plantings can extend harvest through to September or October. Among the many pests of cole crops, root maggots (*Delia* spp.) are especially problematic as they are active starting in April when young seedlings or transplants are very susceptible to root maggot attack. Later in the summer, natural enemy populations tend to be higher and root maggot eggs tend to desiccate more easily in hotter and drier conditions so plant mortality due to maggot attack tends to be lower (Finch 1989, Howard 1997).

The challenge then is to provide protection to early season, i.e. April to early June, cole crop plantings. Floating row covers are effective control tools for protecting crops from root maggot attack, but weed and fungal problems tend to be higher under row covers. Our original focus was on biological control of root maggots by rove beetles in the genus *Aleochara*. These beetles attack root maggots at two different life stages: the adult stage of the beetle is a predator of root maggot eggs and the larval stage is a parasitoid of the root maggot pupae (Whistlecraft et al. 1985, Royer and Boivin 1999). Naturally occurring populations of *Aleochara* spp. are quite high in organic farms in our study area, and our findings of parasitism levels between 50 to 65% are consistent with those of other researchers (Turnock *et al*. 1995). However, adults of these beetles are not active until late May and thus their impact on the root maggot population is minimal in the early season. Researchers have suggested that inundative releases of *A. bilineata* could be a promising biocontrol tactic for root maggots (Whistlecraft et al. 1985, Royer and Boivin 1999). However, our experience with the beetle in 2001 and 2002 indicates that mass-rearing beetles is difficult and thus obtaining a sufficient number of individuals for a biological control program may be impractical.

While inundative biological control with *Aleochara* spp. may prove to be an ineffective tactic for root maggot control, conservation biological control appears to be more practical. Conservation biological control is the enhancement of endemic or naturally occurring species of beneficial arthropods (Barbosa 1998). In addition to *Aleochara* spp., several other species of rove beetles (Staphylinidae) and ground beetles (Carabidae) are predators of root maggot eggs (Finch 1989, Coaker and Williams 1963). These species are for the most part generalists and so consume a wide variety of organisms. Generalist beetles could also attack a variety of other cole crop pests including aphids, caterpillars, flea beetles and slugs. Also, many of these generalist predators are active in the early part of the season when effective root maggot control is crucial.

Since root maggot control is crucial in the beginning of the season, it is important to get predators into fields earlier. One tactic to enhance the early season activity and abundance of natural enemies in fields is to provide refuges adjacent to or even inside the field (Denys and Tscharntke 2002, Dennis and Fry 1992, Wissinger 1997). These refuges provide an overwintering habitat to beneficial arthropods adjacent to the field, thus in theory decrease the amount of time required for recolonization of fields. Further, natural enemies move back and forth from the margin/refuge and the field as the season progresses and food availability in the field changes (Wissinger 1997, Lee et al. 2001). Field margins are an ideal location for natural enemy refuges since they do not obstruct farming practices and growers are currently being urged to surround their fields with wide margins for other environmental reasons, including reducing agricultural run-off into waterways and providing habitat for small vertebrates and birds (Merkens 1999).

The original objective of our study was to continue to monitor the activity and impact of native rove beetles and focus on *Aleochara* spp. We also wanted to learn more about the wasp parasitoids of *Delia* spp. We continued to pursue these objectives, but within the context of a much broader perspective on root maggot natural enemies. We examined all of the commonly caught beetles and spiders for root maggot egg predation activity. We also focused on the role of the field margin as a source for natural enemies that colonize the field. This study was expanded to two field seasons. The specific objectives, methods and results for each field season are provided below. This is followed by a summary discussion of our results.

2001 Field Sampling

Objective

In 2000, we determined that different types of field margins support different densities of ground dwelling rove beetles (Prasad and Henderson, unpublished). More rove beetles were caught in field margins that had grasses as the primary vegetation. In 2001 we wanted to examine this issue further by comparing the season long activity of natural enemies in two types of field margins. We compared margins that were primarily grass vegetation with a high percentage of ground cover (>80%) at the beginning of the season ('good margins') with margins that had less ground cover and more exposed soil ('poor margins'). Vegetation along poor margins was also more variable with more annual forbs and shrub cover. Also, we expanded the scope of the survey to include an examination of ground beetles and spiders, both of which are known to be important predators in agroecosystems (Kromp 1999, Thiele 1977, Riechert and Lockley 1984, Wise 1993). Several ground beetle species have been identified as important predators of *Delia* spp. eggs (Kromp 1999) and the species *Bembidion lampros* has been the focus of many root maggot biocontrol studies in the past (see Kromp 1999, Humphreys and Mowat 1993, Coaker and Williams 1963). We continued to examine the level of parasitism of *Delia* spp. pupae by *Aleochara* spp. and also by hymenopteran (wasp) parasitoids.

Methods

Pitfall traps were placed along field margins, within 50 cm of the margin-field interface. The location of the trap along each margin was haphazardly selected. In each field, traps were placed along one or two margins, usually those closest to the field entry point. At least three traps were placed along each margin that was surveyed. However, as the season progressed many traps were destroyed by farm machinery. A total of eight fields were surveyed in the Ladner area. Seven of these fields were organic and one was conventional. Cole crops were part of the rotation for all seven of the fields. Table 1 summarizes the field information. Trapping started on May 11 and continued throughout the summer until August 30, 2001. Only four of the fields were sampled during this entire period. Sampling in the remaining four began later or ceased sooner.

Table 1. Summary of fields surveyed in 2001, Ladner BC.

Farm/field	Management	Margin Quality	2001 Crop	Sampling period
Fraser-64th*	Organic	Poor	Corn (2000 broccoli)	May 11-Aug 30
Fraser-Kamlah*	Organic	Good	Cauliflower	May 11-Aug 30
Fraser-Seed*	Organic	Good	Cole crop seedlings	May 11-Aug 30
Fraser-Twassen*	Organic	Poor	Broccoli	May 11-Aug 30
Snows	Organic	Poor	Beans (2000 fallow)	May 31-Aug 30
Chong	Organic	Good	Broccoli	June 21-Aug 30
Singh	Organic	Good	Broccoli	June 28-Aug 30
Husband	Conventional	Poor	Cabbage	May 31-Aug 30

* Four fields used for comparison of predator activity in good versus poor margins.

Pitfall traps consisted of a one-liter mason jar buried into the ground to the upper edge of the rim. The jar was filled with a soap and water solution (50ml) used as a killing agent for captured arthropods. Jars were covered with a 20-cm^2 piece of plywood and raised 5-cm off the ground. These covers prevented rainfall and plant debris from interfering with traps but did not obstruct arthropod activity. Trap contents were collected weekly and a fresh soap and water solution was added to the jar. Trap contents were returned to the lab for sorting and identification of arthropods. All captured specimens were recorded and preserved in alcohol. Beetles were identified to the level of order, family, or genus (for the beetles), arachnids were classified as Opiliones (daddy long legs), Aranae (spiders) or mites. Other arthropods, e.g. millipedes and sowbugs, were also identified but were not saved.

Statistical analysis was only performed on the data from the four fields (two with good margins and two with poor margins) that were sampled for the entire field season. Data were analyzed using repeated measures MANOVA. Data analysis was performed using Systat 9 software.

We sampled pupae to measure percent parasitism in May, July, September and November. Pupae were also collected in March 2002. Pupae were collected from the soil by pulling up roots and sifting through soil. All pupae were held at 20^oC until adults emerged. All pupae were collected from organic farms in the Ladner BC area. Previous experience indicated that pupae are difficult to find on conventional farms.

Results-Predator Sampling

There was no significant difference in the activity of predators (spiders, ground and rove beetles) in good versus poor margins (df=1, F=1.289, p=0.374). There was a significant effect of time (df=15, F=3.005, p=0.005), however the interaction of margin by time was not significant (df=15, F=1.541, p=0.152). The season long activity pattern of arthropods in margins of these four fields is summarized in Figure 1. Natural enemy activity levels were similar in good and poor margins in the beginning of the season and at the end of the season. However, the density of beneficial arthropods is higher in good margins than poor margins during the middle of the field season.

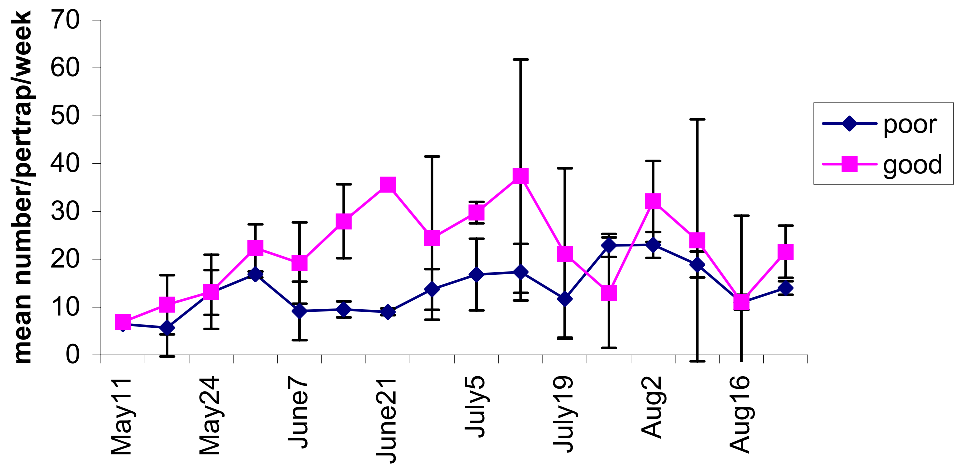

Figure 1. Natural enemies in good and poor margins 2001

The abundance of each type of natural enemy (spiders, ground and rove beetles) was also compared in the good and poor margins. There was no significant effect of either margin type (F=2.046, df=1, p=0.289) on the activity density of rove beetles. However, both time (F=2.304, df=16, p=0.022) and the interaction of margin type x time (F=3.119, df=16, p=0.003) had significant effects on rove density. As can be seen from Figure 2, rove beetle densities rise early in good margins and are significantly higher than densities in poor margins during May and June. Later in the season however, the rove beetle densities in good margins decline to the same level as in poor margins. Rove densities in poor margins rose slightly towards the end of the season.

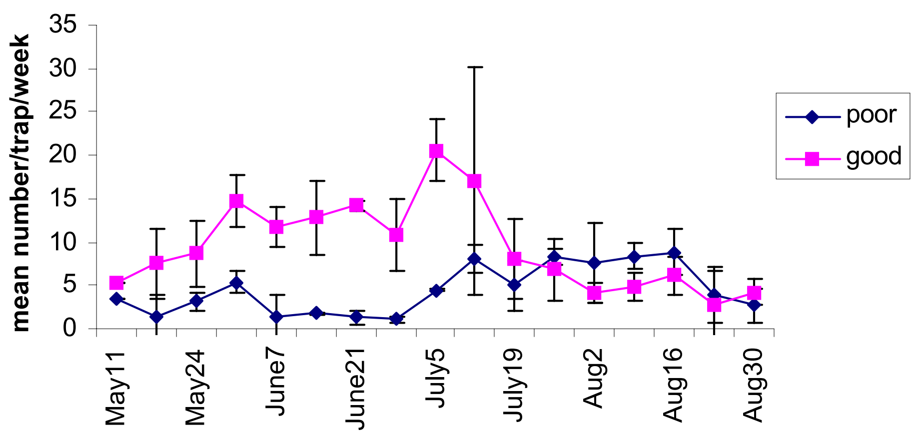

Figure 2. Rove beetles in good and poor margins 2001

Ground beetle densities were not significantly affected by margin type (F=0.246, df=1, p=0.669). Time had a significant effect on ground beetle densities in the two kinds of margins (F=2.450, df=16, p=0.015), but the interaction of margin x time was not significant (F=1.265, df=16, =

0.277). Ground beetle densities increased in both types of margins over the course of the summer.

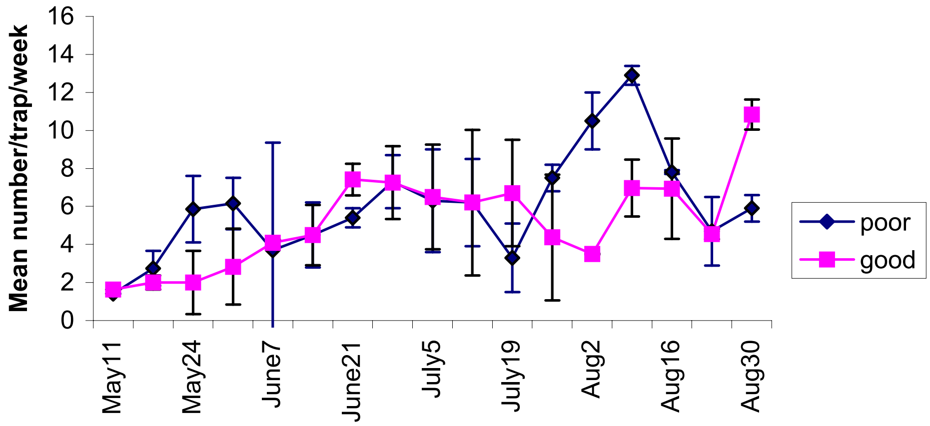

Figure 3. Ground beetles in good and poor margins

Spider densities were not significantly affected by either margin type (F=2.044, df=1, p=0.289), time (F=0.879, df=16, p=0.597) or the interaction of margin type x time (F=1.089, df=16, p=0.403). Spider densities fluctuated a great deal in the good margins but remained fairly constant in poor margins (Fig. 4).

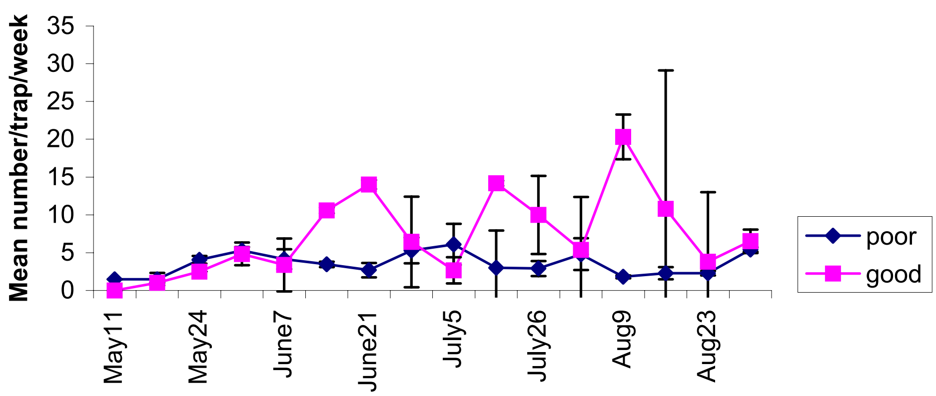

Figure 4. Spider densities in good and poor margins. 2001

Results-Parasitism

Table 2 summarizes the results of the parasitism observations. As expected, parasitism by *Aleochara* spp. increased as the season progressed. Parasitism by hymenopterans was only observed in the pupae collected in September through to November. During collections made in September both adult *Aleochara* spp. and hymenopterans were observed at the base of plants. This suggests that competition between these two species may occur at this time of year. There were two different types of hymenopteran parasitoids. One species was larger and only one adult developed per pupa. The other species was smaller and 5 to 8 adults emerged from each pupa. Specimens from each type of wasp have been collected and are awaiting positive identification to species by a wasp taxonomist. The large proportion of un-emerged pupae from the fall and spring collections is also interesting. Upon dissection, all un-emerged pupae appeared to be discolored and foul smelling. It is possible that a fungus or other pathogen infected these pupae. Also, pupae may have died due to handling and storage in laboratory conditions.

Table 2. Parasitism of *Delia* spp. pupae collected at different times of the year.

Collection period	Total # Pupae	*Aleochara* spp. emergence	Wasp emergence	Fly emergence	Unemerged	% parasitism (*Aleochara*+ wasp)
May 2001	32	0	0	32	N/a	0%
July 2001	50	32	0	18	N/a	64%
September-November 2001	75	21	8	10	36	53.8%*
March-April 2002	110	4	14	26	59	40.9%

* percent parasitised based on total that emerged

2002 Field Sampling/Experiments

Objective

Results from 2001 showed that rove beetles were higher along field margins with a high percent ground cover (good margin) during certain periods of the growing season. Overall there were no significant differences between the two kinds of margins. These sampling efforts, however, did not provide information about the effect of margins on the activity of predators in the adjacent fields. Also our methods did not provide information about predation of *Delia* spp. eggs in the field, by ground and rove beetles. Thus, the objective of the 2002 sampling program was to determine the in-field activity of natural enemies in fields with different kinds of field margins. We were especially interested in the in-field activity of natural enemies in the early part of the field season, April to July. Although cole crops are planted all season long in our study area, egg mortality is usually quite high at the end of the summer because of the hotter, drier conditions (Finch 1989, Howard 1997). Also, crops are usually past the susceptible early transplant stage by the end of the summer. A small prey enrichment experiment was also conducted in order to assess if egg predation and predator activity, based on pitfall trap catches, was correlated. Our specific questions for the 2002 field season were

1. Are the in-field populations of natural enemies affected by the type of field margin and/or management practices (organic versus conventional)?
2. Does increased predator density or richness result in more egg predation?

Methods-Sampling

Ground-dwelling arthropod activity was assessed in 12 fields, six organic and six conventional. Seven of these fields grew cole crops as part of the normal crop rotation for that field and were planted with cole crops in either 2001 or 2002. Five of these fields were polycultures and grew cole crops yearly, but in different locations. The fields were located between Ladner, BC and Carnation, WA. Six of these fields had margins that were classified as “good”, i.e. winter ground cover was over 60%. In the good margins overwinter vegetation was primarily grasses with margin width of at least 1 meter. Six of these fields had margins that were classified as “poor”, i.e. winter ground cover was less than 60%. In poor margins overwinter vegetation was primarily weedy dicots and horsetail. The poor margins were less than 1 meter. In total there were four different types of fields: organic with good margins, organic with poor margins, conventional with good margins, and conventional with poor margins. We located 3 replicate fields for each of the 4 management/margin quality combinations (total number of fields = 12; Table 3). Fields were sampled once every three weeks between April 4, 2002 and July 20, 2002. A total of six sampling sessions were conducted during the survey period.

Predator activity was assessed using pitfall traps. Traps consisted of a 12-cm long piece of PVC pipe that was buried into a 14-cm deep hole in the ground. A plastic cup, cut to a length 10-cm, was placed inside the PVC pipe. 50 ml of a soap and water solution were placed in the cup to act as a killing agent for trapped arthropods. To prevent rainfall or plant debris from interfering with the trap contents, a Styrofoam bowl was placed over the pitfall trap, supported with metal wires 10 cm above the opening of the pitfall trap. Pitfall traps were set up in fields and collected three days later. For each sampling session a new pitfall trap hole was dug and all traps were removed from the field after three days. Trap contents were poured into clean plastic containers and stored in the refrigerator until they could be processed, usually within 2 weeks. The arthropods collected in pitfall traps were sorted and identified to species or morphospecies. Arthropods were preserved in a 70% alcohol solution.

Table 3. Twelve fields were surveyed from April to July 2002. Pitfall trap data from these fields were used to run the analysis of effect of margin quality, management type and field location on predator density and richness.

Field	Management	Margin Quality	Crop 2002
Harris-Kamlah	Organic	Good	Broccoli/Potatoes
Frogsong	Organic	Good	Polyculture
Westcoast	Organic	Good	Polyculture
Harris-64	Organic	Poor	Beans (Broccoli 2000)
Chong-Westham	Organic	Poor	Beans (Broccoli 2001)
Harris-Twassen	Organic	Poor	Peas (Broccoli 2001)
Husband-West	Conventional	Good	Fallow (Cabbage 2001)
Hedlin-Alverson	Conventional	Good	Polyculture
Hedlin-Market	Conventional	Good	Polyculture
Hedlin-Landing1	Conventional	Poor	Cauliflower
Lee	Conventional	Poor	Rutabaga seed
Husband-Home	Conventional	Poor	Beans (Rutabaga 2001)

Pitfall traps were placed along the field-margin interface, 10 m and 20 m into the field. Two pitfall traps, 10 m apart, were placed in each of these three locations. Each of the three transects, (along margin, 10 m and 20 m into field) were parallel. Only one margin was sampled per field. The margin to be sampled was randomly selected and was usually the margin closest to the field entrance. The location of transects along the margin was haphazardly chosen, however was usually near the middle of the margin, in order to minimize any interference from adjacent margins.

Analysis of activity-density The effect of the field margin and management (organic versus conventional) on in-field predator density was analysed using repeated-measures MANOVA (Wilk's Lambda). We used data from the margin and from samples collected 20-m in-field for this analysis. Profile analyses were conducted for each of the six sampling dates using two-way ANOVA. Data were analyzed using Systat 9 software.

Analysis of richness Predator species richness was compared between four organic/good margin fields and four conventional/poor margin fields. We used data from the same three organic/good and conventional/poor fields for this analysis as described in Table 1. We also added one organic/good and one conventional/poor field to increase replicate size for each field category. These two additional fields were sampled in exactly the same manner as the previously described 12 fields and for the same length of time. Only these two categories of fields were compared since our *a priori* prediction was that predator diversity would be most different between these two types of fields. We compared species richness in these eight fields using data from April 4, May 20 and July 22. We examined richness of the 12 most common species of carabids and staphylinids caught over the course of the study. Then we examined the diversity of the six species of predators that we found to be the more effective consumers of *Delia* spp. eggs in petri dish trials ('focal predators'). We calculated species richness first for the entire field (margin and both sets of in-field samples, 10m and 20m) and then only the in-field data (samples from 10m and 20m in-field). Data were analysed using Systat 9 software.

Methods-Prey Enrichment Experiment

In order to address our second question - do more diverse predator communities eat more eggs? - we conducted a prey enrichment experiment. A correlation approach could have been used, where *Delia* spp. density in the different types of fields would have been assessed and compared to pitfall trap catches of predators. However, we chose an experimental approach for several reasons. First, not all of the fields that were sampled for predator activity had cole crops planted in them in 2002. Second, fields that were planted with cole crops were planted at different times in the season, so that *Delia* spp. density could be affected by planting date. Finally, all farms used different methods for controlling *Delia* spp., including pesticides on conventional farms and row covers on transplants on some organic farms. An experimental approach allowed us to control for all of these multiple sources of variation.

The experiment was conducted on six farms. Three were organic farms with good margins (WestCoast, FrogSong and Jubilee). These farms were all polycultures and had cole crop beds that were planted in mid June to early July. The other three farms were conventional cabbage seed fields that were planted in early September. We chose to work on these two types of farms because of the *a priori* prediction that predator densities would be extremely different in the two types of systems. On each farm, eight random locations were selected in the field or in the cole crop beds specified above for the organic farms. At each position two egg cards with 5 freshly laid *Musca domestica* eggs were placed at the base of two adjacent plants. *Musca domestica* eggs were used instead of *Delia* spp. eggs because *M. domestica* eggs were more readily available from an insectary colony than *Delia* eggs. In a previous study we determined that there was no significant difference in the consumption of *M. domestica* and *D. radicum* eggs by the eight most commonly occurring species of carabid and staphylinid beetles (Prasad and Snyder, unpublished). The egg card consisted of moistened 2cm square of peat, cut from a peat pot. Egg cards were covered with a thin layer of soil. A Styrofoam bowl raised 10 cm above the card with wires was used to cover the egg cards and prevent eggs from being washed off of cards. A pitfall trap (see description above) was also placed in the vicinity of the two plants. The experiment was run for 48 hours. Egg cards were collected and the number of remaining eggs was determined. In previous laboratory trials we determined that predation of *M. domestica* eggs results in complete removal of the egg, including egg case from the egg card. Predators will also eat empty egg cases, left behind after maggots hatch (Prasad and Snyder, unpublished). Thus, the absence of eggs on an egg card can reasonably be attributed to predation.

The number of arthropods caught in pitfall traps and their identities were also determined. Effects of predator density and richness on egg predation-measured as eggs remaining on cards- at each farm were examined using linear regression. All data were analyzed using Systat 9 software.

Results-Sampling

Focal Predator Phenology

In 2002 we commonly collected 12 species of carabid and staphylinid beetles (Table 4). Six of the predator species that ate large numbers of D. radicum eggs in petri dishes (Table 4) were active in fields for most of the growing season (Fig. 5a). The data for this figure are based on the results of pitfall sampling in three organic fields in 2002. Focal predators are present in fields during the entire period of *Delia* spp. activity in agricultural fields (Fig. 5B).

Table 4. The commonly caught species or morphospecies of ground (carabidae) and rove (staphylinidae) beetles, caught in pitfall traps in all of our survey fields in 2002.

Species or Morphospecies*	Order	*Delia* spp. predator?
Pterostichus melanarius	Carabidae	No
Amara spp.	Carabidae	Yes
Clivinia spp.	Carabidae	Yes
Bembidion spp. 1	Carabidae	Yes
Bembidion lampros	Carabidae	Yes
Carabus spp.	Carabidae	Not tested
Poecilus spp.	Carabidae	Not tested
Bradycellus spp.	Carabidae	Yes
Pterostichus spp. 2	Carabidae	Not tested
Aleochara spp.	Staphylinidae	Yes
Staphylinid 1	Staphylinidae	Yes
Staphylinid 2	Staphylinidae	Yes

*Morphospecies identifications to be confirmed

Predator Density

Repeated measures MANOVA

There was an overall time x management x margin x location effect on predator density (df=5, F=7.627, p=0.002). Of all the possible two and three way interactions only time x location (df=5, F=13.352, p=0.000) had a significant effect on predator density; except for the third and sixth sample date predator density was higher in the margins than in-field (Fig.6). Finally there was a significant effect of time (df=5, F=7.627, p=0.002) on predator density; the total number of predators caught in pitfall traps increased as the season progressed, and peaked during June (Fig 6). See Table 5 for complete analyses results.

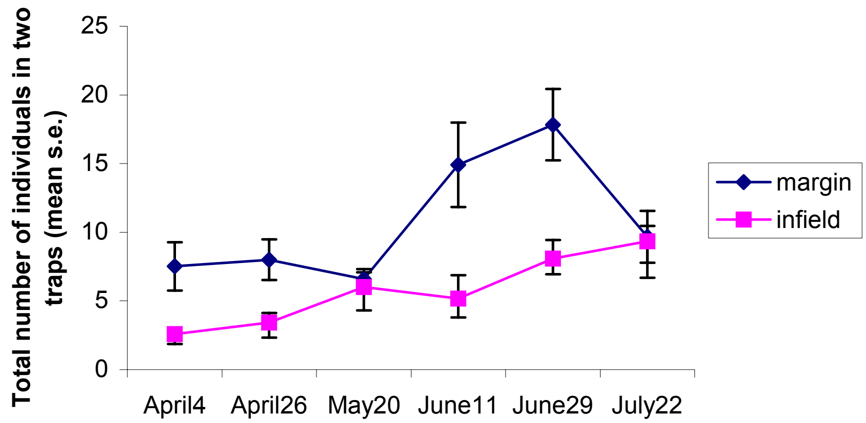

Figure 6. The effect of location and time on predator activity density. N=12 for each point.

Table 5. Results of Multivariate repeated measures analysis of variance of predator activity density data for 2002, α=0.05.

Source	Wilk's Lambda	Hypothesis df.	Error df.	F	p
time	0.213	5	12	8.870	0.001
time x management	0.452	5	12	2.912	0.060
time x margin	0.590	5	12	1.670	0.216
time x location	0.152	5	12	13.352	0.000
time x management x margin	0.658	5	12	1.246	0.347
time x management x location	0.506	5	12	2.346	0.105
time x margin x location	0.707	5	12	0.997	0.460
time x margin x location x management	0.239	5	12	7.627	0.002

Profile analysis

Profile analyses were conducted for each sample date in order to tease apart the meaning of a significant four-way interaction of all three of our variables with time. This analysis examines which of the three variables (location, management and margin) had significant effects on predator density for each sample date. At the beginning of the field season there was a significant effect of location on predator density, (df=1, F=5.495, p=0.032) (df=1, F=6.634, df=0.02) for April 4 and 26, respectively. More predators were in the margins (Fig. 6). By May 20, the interaction of management x margin x location had a significant impact on predator activity (df=1, F=5.256, p=0.036). This can be seen best in Figure 7a: the in-field activity of predators is highest in organic fields with good margins during two of the early sampling dates. The interaction of management x margin x location continued to have an impact on predator density on June 11 (df=1, F=12.033, p=0.003), in particular predator density was highest in conventional fields with poor edges (Fig. 7b). Overall there were more predators in margins than in-fields on this date. For data collected on June 29, only location (df=1, F=10.650, p=0.005) had significant effects on predator density; again, more predators were found in margins than in-field (Fig. 6). By July 22 none of the three variables had a significant effects on predator density. Predator densities were similar in both locations for all four types of fields (Figs. 6, 7a and 7b) on the last sampling date.

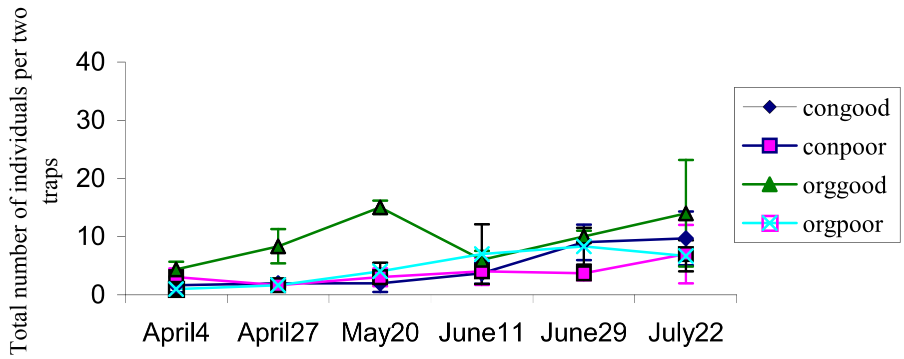

Figure7a. In-field predator activity density. Categories represent each of the four combinations of management type (organic or conventional) and margin (good or poor). Points represent mean of 3 fields, bars represent one standard error.

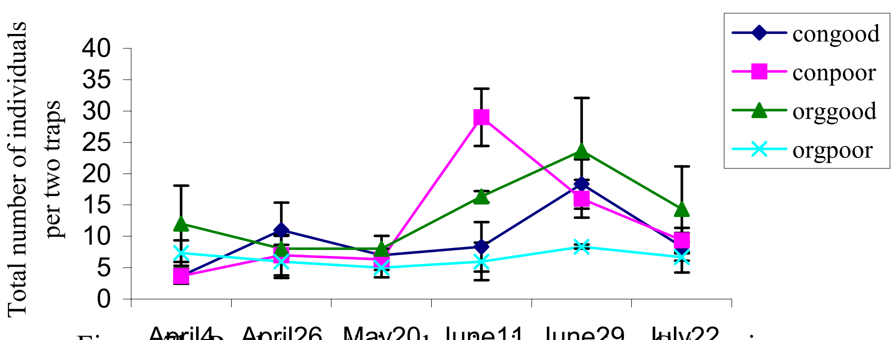

Figure 7b. Predator activity density in margins. Categories represent each of the four combinations of management type (organic or conventional) and margin type (good or poor). Points represent mean of 3 fields, bars represent one standard error.

Predator Species Richness (S)

<u>(Margin+In-field)</u> Whole field richness of the 12 most common species was not significantly affected by field type (between subjects F=4.807, df=1, p=0.071). There was a significant time effect; richness of the 12 common species increased over the season (Wilk's Lambda F=11.079, df=2, p=0.015). There was no significant interaction between time and field type (Wilk's Lambda F=1.321, df=2, p=0.346). Whole field richness of the six focal species was significantly affected by field type; organic/good fields had more of these species than conventional/poor fields (between subjects F=8.138, df=1, p=0.029) (Fig. 8). Neither time (Wilk's Lambda

F=0.817, df=2, p=0.493) nor the interaction of time and field type (Wilk's Lambda F=1.202, df=2, p=0.375) had significant effect on richness of the focal species.

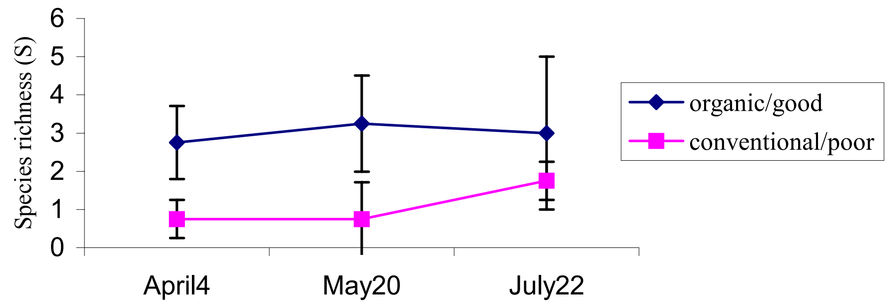

Figure 8. Whole field richness of focal species. Each point represents mean richness for four fields, bars one standard error. Fields compared were organic with good margins and conventional with poor margins.

(In-field) In-field richness of the 12 most common species did not differ between the two types of fields (between subjects F=4.50, df=1, p=0.078). Richness of the 12 most common species increased through the first and last sample dates (Wilk's Lambda F=6.463, df=2, p=0.041). There was no significant time X field type interaction (Wilk's Lambda F=0.044, df=2, p=0.958). In-field richness of the six focal predators was significantly higher in organic/good than conventional/poor fields (between subjects F=6.897, df=1, P=0.039), and significantly affected by time (Wilk's Lambda F=6.037, df=2, p=0.046). In-field diversity of focal species peaked in organic/good fields on May 20 with a significantly higher richness of focal species than conventional/poor margins (see Fig. 9). The interaction of field type and time was not significant (Wilk's Lambda F=0.996, df=2, p=0.432).

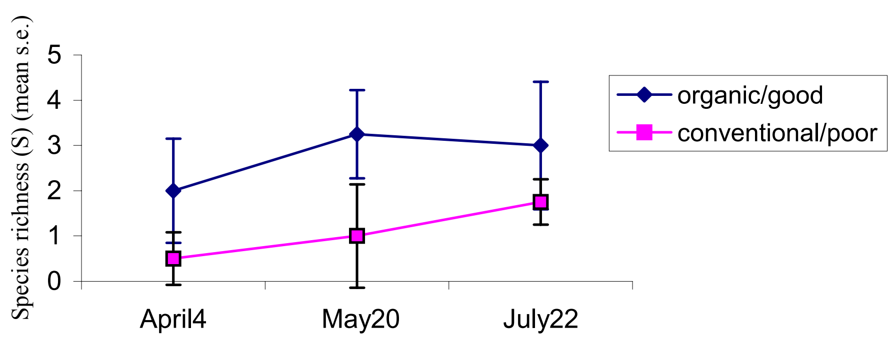

Figure 9. In-field richness of focal species. Each point represents mean richness for four fields, bars represent one standard error. Fields compared were organic with good margins and conventional with poor margins.

Results-Prey Enrichment Experiment

Regressions were run comparing the number of eggs remaining on cards with predator density, focal predator density and predator richness (Table 6). Of all the comparisons on the farms only predator richness was significantly correlated with the number of eggs remaining on cards, but only on one farm. At this farm, Jubilee, as predator species richness increased number of eggs left on cards decreased, i.e. more eggs were eaten. However this trend was not observed on the other five farms, including the other two organic farms.

Table 6. Results for prey enrichment experiment. Results for each farm were analysed separately. For each farm, *eggs left* was the dependent variable and three separate analyses were run with *predator density*, *focal predator density*, and *predator richness* as the independent variable for each analysis.

Farm	Category	Eggs Left mean±s.e.	Predator density mean±s.e.	Predator density R^2 and p-value	Focal density mean±s.e.	Focal density R^2 and p-value	Richness mean±s.e.	Richness R^2 and p-value
Jubilee	Organic Poly	4.63±1.77	28.5± 12.18	0.369 0.110	0.88±0.99	0.466 0.062	1.88±1.13	0.554 **0.034**
FrogSong	Organic Poly	7.25±1.28	6.13±3.36	0.050 0.594	1.25±1.75	0.122 0.369	1.88±1.36	0.122 0.396
WestCoast	Organic Poly	5.13±2.64	1.25±1.28	0.069 0.528	1.13±1.36	0.197 0.271	0.88±0.64	0.107 0.429
Hedlin-Home	Convent .Seed	8.13±1.13	2.13±2.30	0.046 0.610	0.5±1.07	0.004 0.889	1±0.76	0.028 0.691
Hedlin-Burlington	Convent .Seed	6.75±2.71	1.38±1.69	0.172 0.308	0.88±1.25	0.070 0.527	0.75±0.89	0.199 0.268
REU	Convent .Seed	9.25±0.89	1.13±1.36	0.043 0.621	1±1.31	0.136 0.368	0.75±0.71	0.013 0.788

Discussion

The density of ground dwelling natural enemies (ground, rove beetles and spiders) did not differ significantly in good versus poor margins in either 2001 or 2002. In 2001, we examined the activity density of each of three groups individually and did find that rove beetle activity densities were higher in good margins at the beginning of the season. Ground beetle and spider densities were not different in the two types of margins. Our results contradict those of other studies which demonstrated higher densities of beneficial arthropods in margins with dense perennial grass cover than in margins that lack these characteristics (Dennis and Fry 1992, Thomas *et al*. 1991). Habitats with thick layers of perennial grass cover have been shown to provide more stable microclimates than do other types of habitat (Desender 1982, Honek 1988). Stable microclimates are important for arthropod overwintering success (Thomas et al. 1992, Sotherton 1985). The differences between our study and previous studies may be due to differences in margin ages. Older margins have been shown to support a different group of species than younger margins, that is older margins were more favoured by disturbance intolerant beetles (Thomas et al. 1992, 1991). Higher densities of predators, mostly spiders, have also been observed in 6-year old margins than in 1-year old margins (Denys and Tscharntke 2002). Our good margins were all of varying ages, e.g. 2 to 10 years since the last disturbance. The high variability of our predator data in good margins (Fig. 1, 3, 4 and 7b) could therefore be reflective of differences between good margins in age. These differences between the good margins could have thus obscured any differences between good and poor margins in our study.

Although the overall predator activity density may not have been significantly different between the two types of margins we wondered if the in-field density and richness of predators was influenced by margin type. Wissinger (1997) has suggested that refuges for natural enemies adjacent to agricultural fields will be important sources for beneficial fauna. Our results suggested that the relationship between the type of margin, management (organic versus conventional), time and the in-field density of natural enemies is complicated. The results from this study indicated that the in-field density of beneficial arthropods was higher in the early part of the season (late April to late May) in fields that were organic and had good margins. This benefit of good margins, however, was not observed in conventional fields. Twelve species of beetles (carabid and staphylinid) were categorized as commonly occurring, i.e. found in all of our different fields. Six of these species were considered "focal predator" species because we identified them to be the more effective predators of *Delia* spp. eggs, in petri dish assays (Prasad and Snyder, unpublished). When species richness data was examined using these focal species, we found that the peak in predator density in organic fields with good margins also corresponded to a peak in the proportion of individuals from focal species in these fields. This suggests then that not only predator density but also the richness of the specific group of focal predators (consumers of *Delia* spp. eggs) peaks in the field, during the early season, in organic fields with good margins.

What is thought to be especially valuable about a refuge adjacent to the field is that natural enemies will begin to colonize fields sooner than if they were to have to disperse to the field from more distant locations (Dennis and Fry 1992, Wissinger 1997). The earlier the colonization of the field by natural enemies, the sooner biological pressure can be applied to pest organisms (Wiedenmann and Smith 1997). Increasing the speed with which predators of root maggot eggs colonize fields would be advantageous for the management of this pest. Although we did find higher in-field activity densities in organic/good fields at the beginning of the season, overall our results from 2002 indicate that predator activity densities were higher in the field margins than in the field. In-field predator activity densities never exceeded those found in the margins, but were similar to activity densities in margins on two of the four sample dates. These results, along with the findings in other studies (Thomas et al. 2001, Frampton et al. 1995, Dennis and Fry 1992) suggest that even where margins support higher densities of natural enemies, dispersal from the margin is limited. These limitations are primarily due to the dispersal differences among species. Thomas et al. (2001) found that dispersal in some ground beetle species is limited to the area adjacent to margins, while other species disperse more readily from the margin into the field, and others remain almost exclusively in the field. Since it is in-field density of natural enemies that is crucial for pest control, efforts should shift from the margin habitat to agricultural practices within the field that are affecting natural enemy populations.

All twelve fields in our survey were managed differently and thus it is not surprising that our results are not straightforward. For example, although several of the farms were classified as conventional, no chemical insecticides were applied to at least one of these fields during the trapping period. The effect of cultivation, used as a common method for weed control especially on larger organic farms, may have been detrimental to the ground-dwelling beetles. Cultivation has been shown to have a negative impact on some rove beetle species (Krooss and Schaefer 1998) and ground beetles (see Kromp 1999). It is possible that mechanical cultivation for weeds in organic farms may have been more destructive to the ground-dwelling arthropod fauna than chemical weed control on conventional farms that did not apply insecticides. However, some beneficial species may be enhanced by tillage. For example, in a study of effects of tillage in cereal fields, Andersen (1999) found that certain beetle species preferred open soil, i.e. tilled, to non-tilled soil. Among these were *Bembidion lampros*, one of our focal predators. These results, along with our own, suggest that there may be factors other than application of insecticides that impact the diversity of natural enemies in agricultural fields.

Currently, community ecologists are trying to understand the role of predator diversity on predator impact on pests. One of the difficulties in answering these questions is designing appropriate field experiments. In our experimental enrichment of the prey/pest population via *M. domestica* eggs, we observed that predator species richness does increase egg predation but only on one of the six farms, an organic farm. On the other five farms there was no correlation between any aspect of predator diversity and egg predation. The balance of our results then suggests that diversity does not enhance biocontrol. However, this experiment needs to be repeated with more replicates and at different times in the growing season, since predators in September (when experiment was conducted) may have reduced foraging as a result of physiological changes for overwintering. Alternately, other sources of food may have limited predation of our introduced eggs. The methodology of this experiment should also be further modified to increase the predator-trapping efficiency, for example by adding more pitfall traps or by conducting the experiment in cages where predators are either excluded or allowed access to egg cards. Finally, predator densities in our fields may not have been high enough to observe increases in egg predation. Diversity (richness) of predator species is not in itself sufficient for biological control. Sufficient densities of the important predator species are required in order to control specific pests.

When the natural enemy population of a field is examined in terms of the overall community of arthropods, it becomes apparent that there is a myriad of complicated interactions that go on between the individual species. These interactions can enhance or detract from the biocontrol activity of beneficial predators (Rosenheim et al. 1993). The community of natural enemies that attack *Delia* spp. in our study area is diverse (Fig. 10). Further study may reveal additional focal species; Finch (1996) compiled a list of ground beetle species that consumed *Delia radicum* eggs in petri dishes. Many of the top predators, or related species, in that study are known to occur in our study area. Thus the food web presented in Figure 10 is likely over-simplified. Also Figure 10 represents a ***potential*** web of interactions. Actual field consumption of root maggot eggs by these beetles could vary considerably. Three of the six focal predators identified in this study are present concurrently with the flies from the beginning of the season to the end. Parasitoids however, were most abundant only at the end of the season. Our six focal predators are classified as generalists: they consume a wide range of organisms. The parasitoids, including *Aleochara* spp., are more specialized since part of their life cycle is dependent on the presence of *Delia* pupa. The rove beetles in the genus *Aleochara* are interesting since the adult stages appears to be generalist, feeding on an array of organisms including *Delia* eggs, and the larval stage is a *Delia* specialist. The advantage of generalist natural enemies is that other pests can also be controlled. For example in polycultures growing carrots, generalist beetles can also eat eggs of carrot rust fly (Ramert 1996). Generalist beetles also attack other cole crop pests, such as aphids and lepidopterans (Kromp 1999, Hassall et al. 1992, Thomas et al. 1992). So while not all the species in Figure 10 may contribute to *Delia* biocontrol in the field, as generalists they will consume other pests in the system.

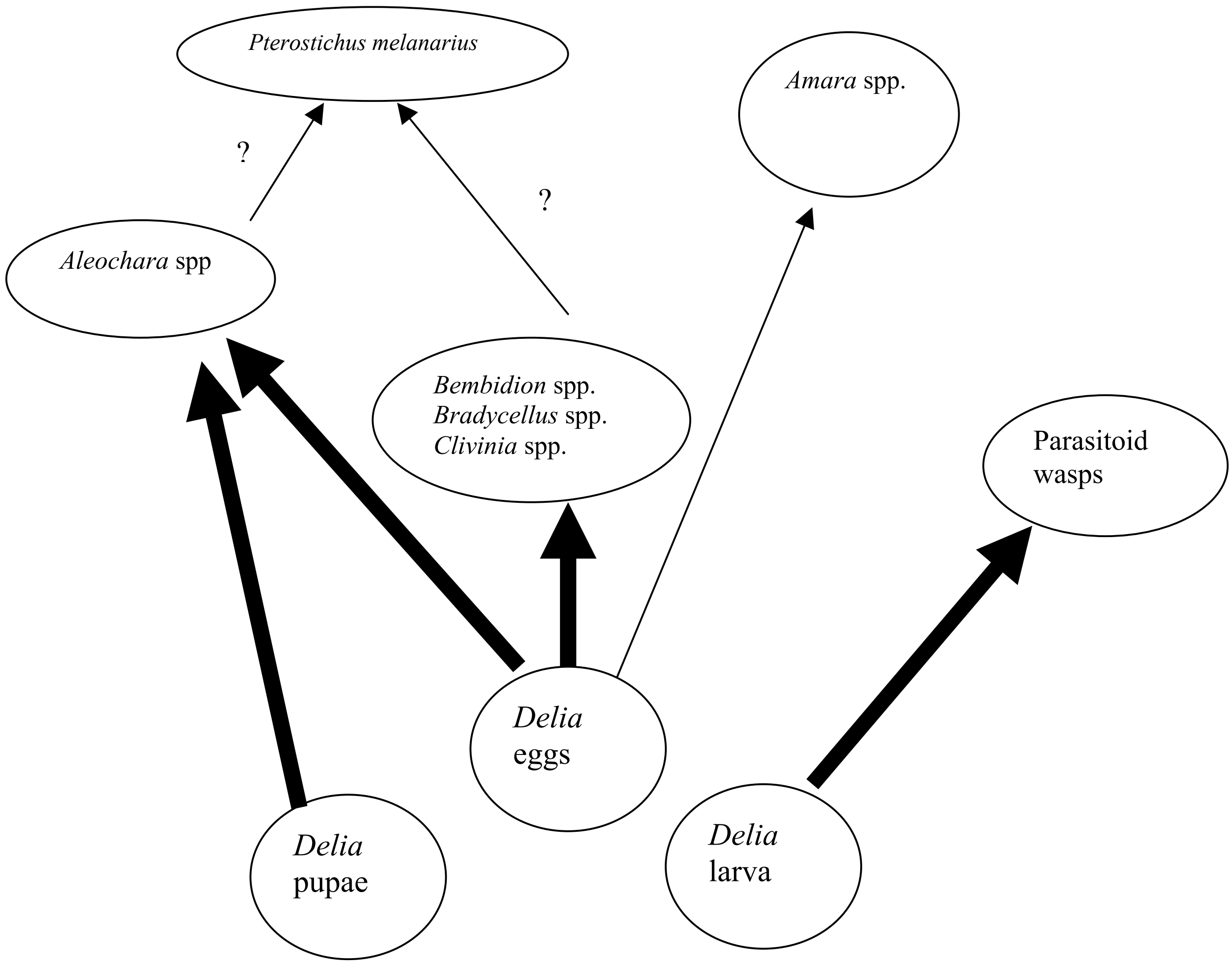

Figure 10. The food web of interacting species that consume *Delia* spp. eggs, larvae or pupae. Arrows indicate the flow of energy (i.e. from prey to predator). Arrow thickness represents our hypothesized impact on *Delia* populations in the field (e.g. *Amara* spp. not as impactful as *Bembidion* spp.). Also included is the possible role of *Pterostichus melanarius,* a common predator, especially abundant on one of our organic farms but not found to consume *D. radicum* eggs in petri dish assays. *P. melanarius* may act as a predator of our focal predators (intraguild predation) thus disrupting biocontrol of *Delia* spp.

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Outreach

Results of this last two years of study will be presented at the Washington Tilth Grower's conference on November 8, 2002. Also we will be presenting results at the Western Washington Horticultural Association Conference on January 9, 2003. All growers who participated in this research will be provided with a color flyer describing the focal species of root maggot predators. We will also discuss natural enemy conservation tactics in these flyers. We are also planning to discuss some of the key aspects of our results in an article for the Tilth Producers Quarterly (Washington State), a presentation will be made to organic growers in British Columbia (COABC), finally a presentation will also be made to a community of non-commercial organic growers (Coquitlam Community Organic Growers Association) regarding many of the findings of this study and natural enemies in general. This research is ongoing and we will continue to provide growers with information and resources to allow them to utilize their beneficial arthropod resources.