

Chapter Eleven

Discussion: Major Findings and Future Research.

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Major Findings

Predator population dynamics at the landscape scale

Predator movement (in terms of dispersal) was assessed at the landscape scale using water traps that captured ballooning spiders positioned in crop and non-crop areas (Chapter three). In the water traps 66 percent of the spiders caught were immatures and 34 percent were adults. The most abundant families collected from the water traps were Linyphiidae (23%), Araneidae (14%) and Lycosidae (10%). In the pitfall traps 71% of the spiders caught were adults and 29% immatures. The Lycosidae (38%) and the Linyphiidae (33%) were the most abundant families caught in the pitfall traps. Family level composition of the ballooning spider fauna is different to that of the cursorial spider fauna. The highest ballooning rate was recorded in a soybean field with an average of nearly 15 spiders per metre squared per day. In comparison mungbean fields and non-crop areas experienced much lower levels of ballooning activity. Ballooning in soybean increased throughout the season and exhibited a wave-pattern with peaks and troughs. Peaks in ballooning activity were synchronised across habitat types and some spider groups. It is difficult to determine if the higher ballooning activity in soybean fields is a cause or an effect of increased spider populations on the ground. Regardless, unsprayed, irrigated soybean fields appear to be ideal for spider reproduction and more spiders balloon than in comparison to surrounding non-crop areas.

The seasonal pattern in ground-dwelling spider movement across a field edge was investigated using directional pitfall traps and directional sticky traps positioned on all four sides of a soybean field (Chapter three). No directional movement of ground-dwelling spiders across the field border was detected even for the edge adjacent to lucerne (see below). On the sticky traps the peak time for ballooning activity was at the start and the end of the season but again no directional movement was detected. The field edge does not appear to be a strong barrier to movement of ground-dwelling and ballooning spiders. Population exchanges across the field border appeared to be a common practice, however immigration and emigration events were not identified. This conclusion is supported by the mark-recapture study on Lycosidae (Chapter five), which showed that they are capable of travelling between fields within the same area and between areas within a larger field. The average straight-line distance travelled by Lycosidae was 3.2 ± 0.82 metres per day ($n = 4$). These active, ground-dwelling spiders were not restricted by vegetation changes such as one crop (soybean) to a different crop (lucerne) or a crop habitat to a weedy edge.

Immigration and emigration of predators between adjacent crops or non-crop may influence the within-field abundance of predators. In particular, the practice of planting lucerne as a refuge crop to increase predator abundance within an adjacent target crop has been encouraged in IPM programs (Mensah 1999, 2002a,b). I found that the cutting of lucerne was followed by a decrease in plant-dwelling pests and predators in the lucerne crop (Chapter four). No corresponding increase in abundance in pests or predators was observed in the adjacent soybean field. Grid data was used to investigate trends with distance from the soybean/lucerne interface directly after cutting (Chapter four). Strong positive and negative linear correlations existed for a few parameters in each grid, but the parameters were not consistent. Despite the high abundance of predators (and other arthropods) in lucerne, the cutting of lucerne alone does not guarantee movement of predators into the adjacent target crop. This conclusion is supported by the results of the insecticide use experiment (Chapter six). Predator populations did not recover to pre-treatment levels even 20 days after spraying despite the presence of large lucerne fields near the sprayed crop that may have provided a source of colonising arthropods. The presence of lucerne fields within a cropping area may have some impact on regional predator populations but this has yet to be critically tested.

Predator population dynamics within-fields

Factors that contribute to variability in the abundance of predators, both spatially and temporally within-fields was investigated using an intensive grid sampling scheme positioned across the lucerne/soybean interface (Chapter eight). Predators were not evenly distributed within soybean fields but rather exhibited some degree of spatial patterning with regions of increased and decreased abundance. Ground-dwelling and foliage-dwelling predators were often aggregated in patches of up to 40m across. Lycosidae spiders showed a consistent pattern of increased abundance in the lucerne and adjacent soybean traps up to 50m from the interface in some instances. A pattern supported by the mark-recapture experiment results (see above) in Gilbert A and C fields (Chapter five).

Spatial variability is often overlooked when farms are managed as a uniform area. The recent development in precision farming techniques stems from the realisation that it is impractical to view a field as homogeneous in terms of yield potential, crop, soil and growth characteristics (Blackmore 1994). The results from this study suggest that arthropod abundance is not uniform or randomly distributed within soybean fields. Whole-field averages of arthropod abundance (pests and predators) and activity (egg predation and plant damage) can be very misleading given that there was a great deal of spatial variability within the field.

Precision farming uses GIS and monitoring technologies to map yield gross margins within a field so that more accurate management decisions can be made. Similarly more accurate and cost effective pest management decisions could be made if we had a greater understanding of spatial variability in predator abundance and activity.

Predators and *Helicoverpa* spp. control

This study aimed to determine if the naturally occurring predators within unsprayed grain crops are of use for the control of *Helicoverpa* spp. From the observations and experiments conducted throughout this thesis the answer to this question would have to be yes. The naturally occurring assemblage of predators provides a valuable ecosystem service to growers that often goes unappreciated. This is best illustrated by results of the exclusion experiments (Chapter nine). Larval survival was greatest in the closed cage treatments from which predators were excluded. Overall larval survival was very low within soybean fields (mean proportion surviving = 0.10 ± 0.03) when all mortality factors were combined. Average predator mortality estimates for larvae were similar across seasons, 23-33 percent (2001/02) and 21-30 percent (2002/03). The maximum predator mortality imposed on *H. armigera* eggs on cards ranged from 28 to 56 percent. This figure is supported by the results from the spatial pattern analysis (Chapter eight), which found uncorrected egg predation on cards ranged from the lowest average of 16 percent to the highest average of 56 percent. For growers these results suggest that if maximum predator mortality (33% egg and 56% larval mortality) occurs during egg and first instar stage, 20 eggs per square metre will result in 5.9 small larvae per square metre. Still below the economic threshold of six small larvae per square metre suggested by Colton *et al.* (1995) during flowering and pod formation. If minimum predator mortality (21% egg and 28% larval mortality) occurs a soybean crop can withstand up to 10 eggs per square metre (resulting in 5.7 larvae per square metre). If growers use the more conservative threshold of two larvae per square metre suggested by Lucy and Mills (2002), with maximum predator mortality, up to five eggs per square metre should not cause concern (resulting in 1.5 larvae per square metre). With minimum predator mortality only three eggs per square metre can be supported (resulting in 1.7 larvae per square metre). The large range of possible egg densities (three to 20 eggs per square metre) make spray decision making difficult and support the need for further work on threshold development and predator mortality estimates. Despite problems with calculating economic thresholds, predator mortality estimates obtained without the costs associated with insecticide application, or the introduction of mass reared beneficials I would argue are of use to many growers.

Spiders and *Helicoverpa* spp. control

Unsprayed soybean fields support a diverse and abundant spider fauna. The spider assemblage in Australian agroecosystems has been relatively less studied than in other cropping areas around the world. The composition of the spider assemblage appears to be similar to that found in the United States where the active hunters (Oxyopidae, Salticidae, Clubionidae, Thomisidae and Lycosidae) are numerically dominate. In comparison, European agroecosystems are strongly dominated by the small Linyphiidae (greater than 90% of all individuals) (Nyffeler & Sunderland 2003). The inability to identify many of the spiders collected to species limits the ecological conclusions that can be drawn from this thesis. For example, the wolf spiders, Lycosidae, have been treated as a homogenous group throughout this study but research in the United States has shown that two Lycosidae species inhabiting soybean fields display very different ecological characteristics. The more common species, *Pardosa milivina* Hentz, has one population peak per year and is active during the day, whereas the less common *Hogna helluo* (Walckenaer) may have one or two population peaks per year and is nocturnally active (Marshall *et al.* 2002). There is evidence that *H. helluo* is influenced by habitat quality because it has been found to emigrate from no-till soybean more often than mulched (with straw) soybean than in comparison to *P. milivina* (Buddle & Rypstra 2003).

The predatory potential of spider groups was estimated in the laboratory using no-choice feeding tests with *H. armigera* eggs and larvae as prey (Chapter ten). The field-collected spiders tested ate two to five eggs per 24 hours per spider (10-25% of those available) depending on level of starvation. Few spider groups consumed eggs in the laboratory with the exception of Clubionidae spiders that eat eight to 18 eggs in 24 hours. The fact that Clubionidae spiders are excellent egg predators was further confirmed by observations of this spider on egg cards at night in the field (Chapter seven). All spider groups collected from the field readily consumed first instar larvae in the laboratory. Starved spiders consumed nine first instar larvae per 24 hours per spider (90% of those available). We are unable to assume that these results are indicative of predation rates that occur in the field. The results suggest that Lycosidae, Clubionidae, Oxyopidae, Salticidae and Thomisidae have the capacity to contribute to control of *Helicoverpa* spp. and warrant further investigation. This was attempted for Clubionidae spiders (Chapter ten) using molecular methods to detect *Helicoverpa* spp. in the spiders guts (see below).

Predator abundance and impact in the field

It is often assumed that an increase in abundance of predators within a grain crop results in a reduction in crop damage due to insect pests. However, it is clear from this study that not all naturally occurring predators are equally useful for control of *Helicoverpa* spp. (see the spider example discussed early). Even a very large increase in the abundance of certain predator species may have little impact of *Helicoverpa* spp. populations. In only a few instances was there evidence of significant within-field spatial associations between egg predation on cards and predator abundance (Chapter eight, table 5). Which predator groups should be the focus of conservation efforts is hard to determine given that prey consumption in the field is difficult to measure quantitatively (Mills 1997, Knutson & Gilstrap 1989). With this problem in mind a molecular technique was developed to detect *Helicoverpa* spp. remains in the guts of Clubionidae spiders using ITS2 primers (Chapter ten). The nested PCR protocol was able to successfully amplify *H. armigera* DNA (eggs and first instar larvae) from the guts of Clubionidae spiders. The assay was specific within the Heliiothine sub-family but not species specific to *H. armigera* or *H. punctigera*. Eight hours after feeding on one *H. armigera* egg 50 percent of the assayed spiders tested positive and *H. armigera* egg remains could be detected for a maximum of 48 hours post feeding. Clubionidae spiders were then collected from field crops and tested using the protocol developed and 30 percent tested positive for *Helicoverpa* spp. remains. Field collections need to be conducted in crops with a range of *Helicoverpa* spp. densities to better estimate the proportion feeding.

Molecular techniques, such as the protocol investigated here, may be used in the future to quantify predation rates of generalist predators in the field without confounding effects (e.g. cage effects, alternative prey and a complex search arena, Symondson 2002). A selection of predators could be collected from the field, taken back to the laboratory, and tested to determine which species had fed on the target prey and how much they had consumed in the previous 24 hours. Further studies could focus on those predators known to consume the greatest quantities of prey in the field and go on to investigate factors that limit prey consumption in the field (e.g. presence of alternative prey). We currently have an idea of which predator species may be important for pest control (see Scholz 2000, table 8.3). However the ranking of these predators in terms of pest control potential is still based on abundance records and inconsistent field observations of prey capture. Molecular techniques may be costly and time-consuming to develop to a stage that can be useful in the field but the information that can be obtained through their use is vital and, I think, impossible to obtain using more traditional approaches.

Future research

Throughout this thesis I have tried to highlight further research necessary to resolve the questions addressed in each chapter. Below is a more general discussion on research areas of high priority for Australian agroecosystems. Further suggestions can be found in Johnson *et al.* (2000).

Predator ecology

For many of the predator species and groups investigated throughout this thesis we lack basic biological and ecological information. Their use in an IPM system is dependent on a sound knowledge of how these animals will react to management decisions. With the increasing areas of land sown with genetically modified crops an understanding of how these animals live in a “simplified” cropping environment is essential. Within grain crops I suggest that future research on generalist predators should focus on key areas that include prey choice and how predators find prey in a field situation on different crop plants.

In the laboratory generalist predators will eat most prey that they are capable of killing and consuming. In a more complex field situation it is not what they can eat, but what they can find which limits their ability to survive and reproduce. There are many cues that predators use to locate prey in complex habitats such as the movement of prey, odours emitted from the prey and prey products (frass and silk) and volatiles emitted from the plants in response to herbivore attack. The production and reception of these cues will vary according to crop type, prey species and predator species. For example, studies on damsel bugs, *Nabis kinbergii* Reuter, have shown that they are relatively inefficient at searching the lucerne crop for prey. Damsel bugs searched the habitat at random, whether or not prey was present and chance appeared to play a major role in prey location (Siddique 1985). Alternatively my observations of Clubionidae spiders suggest they are capable of quickly finding *H. armigera* egg cards amongst dense soybean foliage. Perhaps their searching strategy (orbital probing with their fore-legs and low reliance on vision) is more efficient in the soybean environment. It would be interesting to test if the efficiency of a predators searching strategy changes with different plant architecture or crop type.

The target prey species and stage has been known to affect the predators’ ability to find and consume prey. The no-choice spider feeding experiment in the laboratory (Chapter nine) demonstrated that not all spiders recognise *H. armigera* eggs as prey and consume them even

after a period of starvation. In contrast *H. armigera* larvae were consumed by most spider species. Perhaps this response is due to the stationary nature of an egg, making it less noticeable to some spiders. Awan *et al.* (1989) showed that *Oechalia schellebergii* (Guérin-Méneville) took less time to locate wandering than stationary *H. punctigera* larvae, and dead, but artificially moved larvae were more prone to attack than stationary larvae. Studies have shown that egg parasitoids are attracted to plant volatiles emitted in response to oviposition, however a similar response has not been shown for egg predators (see review by Hilker & Meiners 2002). The generalist predator *Geocris pallens* (Stal) was attracted by volatiles emitted by a plant in response to larval feeding but consumed both eggs and larvae once at the site (Kessler & Baldwin 2001). Studies on the different attractants used by predators to find different pest stages, such as *Helicoverpa* spp. eggs versus larvae, are important for a complete understanding conservation biological control in the field. Furthermore the identification and understanding of predator attractants and cues may lead to commercial opportunities for producing new formulations that attract and retain predators in fields (similar to Envirofeast®).

Some predatory arthropods have been shown to exploit volatile organic compounds emitted from plants in response to larval herbivore damage (Baldwin *et al.* 2001, Pichersky & Gershenzon 2002). The predatory mite *Phytoseiulus persimilis* Athias-Henriot is attracted to volatiles from bean plants infested with *Spodoptera exigua* (Hbn.) caterpillars despite the fact that it does not prey on this herbivore (*P. persimilis* is a specialist that feeds only on spider mites) (Shimoda & Dicke 2000). Shimoda and Takabayashi (2001) demonstrated that the specialist predatory staphylinid *Oligota kashmirica benefica* responded to herbivore-induced plant volatiles from spider mite infested lime beans in both laboratory and field conditions. Similar responses have been demonstrated in generalist predators (Kessler & Baldwin 2001). Reddy (2002) found that the generalist predator *Chrysoperla carena* Stephens (Neuroptera: Chrysopidae) which preys on spider mites was attracted to volatiles emitted from mite-infested eggplant, okra and pepper leaves but not tomato leaves. Dicke *et al.* (2003) compared the response of the predatory mite *P. persimilis* to caterpillar infested brussel sprouts and spider mite infested lima beans and found no response to the brussel sprout odours. This suggests that certain odour blends emitted by particular plants differ in their attractiveness to predators, and predators that may be able to use specific cues to locate prey in one crop type may be unable to do so in other crop types. Laboratory based studies

investigating long and short distance cues that predators use to find their prey in different crop types would provide some interesting insights.

Predator dispersal and movement is a key process that affects within field and between field population dynamics, however it has been relatively ignored by Australian researchers. Novel approaches to directly detect and quantify movement such as mark-release-recapture techniques, pollen markers, and even molecular based methods should be investigated (Johnson *et al.* 2000). It is still a common misconception that the predators, which exist within a field, are isolated from populations in surrounding fields or non-crop areas. This simplification of an agroecosystem may be intended to allow researchers to design neat experimental units. In fact it only serves to provide confounding and noisy experimental results. This is particularly well illustrated by insecticide exclusion experiments (see Chapter six). I have no original solution to this problem, except to reiterate that for predators to exist successfully in a dynamic cropping region they must be capable of high rates of movement and dispersal.

Spider ecology

I believe that spider friendly farming systems within southeast Queensland are possible given a few minor and inexpensive changes to cultural practices within the crop. There are many simple techniques that may potentially increase spider (and insect predator) abundance within fields. It should be noted that the unsprayed soybean fields examined in this thesis did not have any major pest problems with the naturally occurring predator densities. Stubble retention is a technique that may increase or maintain spider abundance and diversity within the crop. In southeast Queensland some cotton growers plant directly into cereal stubble to reduce soil erosion, pesticide runoff and nutrient movement (Waters & Sequeira 2000). The benefits of stubble retention for pest management are currently being investigated (Cleary *et al.* 2002a,b). Previous studies have shown that the depth and complexity of the litter layer can affect ground-dwelling spiders (Rypstra *et al.* 1999). Reichert and Bishop (1990) found that the addition of a mulch layer between rows of vegetables increased spider densities by 30 times that of the un-mulched plots. They attributed this increase in abundance to the altered humidity and temperature conditions in the mulch plots. Stubble retention may produce similar changes in environmental conditions near the soil surface. Comparisons could be made of spider abundance and diversity between stubble planted fields, traditional cultivated fields and fallow fields. Conservation tillage regimes, that also result in a more complex understorey layer (in terms of leaf litter and weed density) have been shown to increase the

abundance of Lycosidae in comparison to conventionally tilled soybean fields (Marshall & Rypstra 1999). Buddle and Rypstra (2003) demonstrated that emigration of one Lycosidae species was influenced by habitat quality (no-till soybean, conventional tilled soybean and mulched soybean) but another species (*P. milvina*) was unaffected. Many other habitat manipulations have been shown to successfully increase spider abundance (Rypstra *et al.* 1999). These studies have provided some interesting empirical insights into the effects of top-down control on pest populations. However many, such as the introduction of wooden crates into soybean fields (Carter & Rypstra 1995), are of limited use in commercial situations.

The Lycosidae may be important for pest control early in the season when other predator numbers are low. There is some evidence from this study (see Chapter five, Kiss & Samu 2000, L. Silberbauer personal communication) that Lycosidae spiders are affected by rainfall and soil water logging. Perhaps due to their habit of building burrows. Studies that examine the abundance of Lycosidae (and other ground-dwelling predators) under different irrigation strategies (pivot or flood) may provide methods for increasing abundance. Further studies on the diet range of Lycosidae in the field is necessary for a full understanding of their pest control potential. This cannot be achieved without greater taxonomic resolution to genus and species level.

The diet of web-building spiders was not assessed in detail throughout this study. It was clear from observations in the field that orb webs did not readily capture *Helicoverpa* spp. eggs and larvae and only occasionally grew big enough to capture adults. However other prey items were often caught in great numbers by the webs. Studies that record and quantify the amount of prey (both pests and beneficials) caught in orb webs (in relation to the size of the web) are necessary to further clarify their role in pest control. The architecture of the crop itself appeared to affect the abundance of orb-web building spiders and the size of the web itself. Experiments aimed at determining which crop types (with different plant heights) and row spacings encourage orb-weaving spiders should be attempted. Row spacing and the time to canopy closure are believed to have an impact on outbreaks of *H. zea* in soybeans (Anderson & Yeorgan 1998). Anderson & Yeorgan (1998) could not attribute the differences in egg mortality between open and closed canopy fields to the actions of generalist predators, whose abundance did not noticeably change. However influence of canopy closure and row spacing on web-building spider activity was not thoroughly assessed.

More information is required on factors that control spider distribution and movement within agroecosystems in order to fully exploit their pest control potential. Ballooning is essential for the movement of immature stages of many spider species found in agroecosystems. Studies that examine how area-wide insecticide use affects this fragile but essential component of the spider fauna are crucial. The selective insecticides currently in use may be non-lethal to adult spiders and other predators however they are rarely tested on immatures.

The fact that commercial grain growers are aware of predators in their crops and some attempt to use predator counts when making spray decisions (see appendix one) suggests that naturally occurring predators can become a useful component of IPM programs. Since the introduction of IPM in the mid 1960's there has been widespread and rapid implementation of the rational use of pesticides in response to pest thresholds (Zalucki & Norton 1999). Despite this success the truly integrated use of biological control with selective pesticides remains rarely used. Zalucki and Norton (1999) suggest that for IPM to move away from the 'sample, spray and pray' approach that is the common form of IPM in most crops greater emphasis must be placed on understanding beneficials and modifications to the environment which make it less suitable for pest populations. Natural biological control in crops is a process that can keep pests below economic thresholds however it is often thought of as a 'black box' (Waage 1996) by growers. A key to improving the implementation of conservation biological control is a greater understanding of the abundance and impact of naturally occurring predators across the greater agricultural landscape.

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