Chapter One

Introduction and Thesis Outline.

Introduction

Integrated pest management

The use of chemical insecticides for the control of herbivorous insect populations in crops has been a common practice since the 1950’s. The rapid expansion in insecticide (and other pesticide) use has been a result of the need to boost productivity as well as consumer demand for high quality food (Dann *et al*. 1994). Insecticides were quickly integrated into faming systems worldwide due to their effectiveness, relatively low cost, and versatility (Dent 1995). Since that time there has been a growing realization of the undesirable side effects of wide spread insecticide use. In the mid 1990’s Sweden, Denmark and the Netherlands passed legislation to reduce the total use of agricultural pesticides by 50 percent or more by the year 2000 (Matteson 1995). Pesticide usage in these countries was causing a range of environmental problems including pollution of ground water (which supplies 98% of Danish drinking water). The indiscriminate use of insecticides reduces beneficial insect populations within the crop, leading to a rapid resurgence of the pest species, and secondary outbreaks of previously harmless insects (Stern *et al.* 1959). Many pest species now show resistance to certain insecticides as a result of field selection pressures. Australian agriculture generally uses lower levels of pesticides than similar industries in Europe and the United States (Dann *et al.* 1994, Commonwealth of Australia unpublished report 1991) due in part to the Australian government not providing price subsidies that encourage higher inputs in other countries. I have not been able to find any statistical comparisons to support this proposition.

From the mid 1960’s the growing concern by the general public for the environment, and more recently a move toward sustainable land use, has lead to the development of a range of alternative control measures for use in integrated pest management (IPM) programs. IPM aims to limit economic damage to crops from pests and simultaneously minimize the effects on non-target organisms within the crop, the surrounding environment and consumers (Gullan & Cranston 1994). This can be achieved by combining the effective use of selective pesticides with biological control to provide the farmer with a variety of pest management options.

Biological control

King and Coleman (1989) define biological control as the management of predators, parasites, microbial organisms and their products to reduce pest population densities. Successful biological control requires a thorough knowledge of both the impact of the biological control agent on pest mortality, and the ecology of the agent itself.

A dramatic example of successful biological control was the introduction of the Vedalia beetle, *Rodolia cardinalis* Mulsant, from Australia in the 1880's. The beetle was able to control the Cottony Cushion Scale, *Icerya purchasi* Maskell, which was decimating citrus crops in California (DeBach & Bartlett 1951, Caltagirone & Doutt 1989, Dent 1995). This type of biological control is known as "classical" biological control because it involves the introduction of an exotic natural enemy for the control of an introduced pest (Caltagirone 1981). There are additional types of biological control strategies that have all had some success. Augmentation can be used when natural enemies are absent or population levels are too low to be effective. Their abundance is augmented by the use of laboratory cultured natural enemies (King *et al.* 1985). Inoculation is a special case of augmentation and involves the inoculative release of natural enemies at the beginning of the season to colonize the area for the duration of the season and prevent pest build-up (New 2002). Inundation involves the release of large numbers of native or introduced natural enemies in a similar way to the application of chemical pesticides (New 2002). Conservation aims to encourage the natural populations of beneficial insects so that sufficient numbers are present to exert a controlling influence on a developing pest population (Dent 1995, Gurr & Wratten 1999). The conservation strategy is the least studied and implemented (Landis *et al.* 2000), and is of most relevance to this study.

Conservation biological control

A reduction in insecticide use, or the use of a selective insecticide may in some cases be sufficient to encourage, or at least not decrease, the presence and population growth of natural enemies. In situations where this is not the case manipulation of the crop environment is required to provide conditions favourable for beneficials to become established, or increase in numbers (Landis *et al.* 2000).

Establishment of "refuges" within the crop or around the crop boundary has been used to increase the abundance of predators within the crop. Mensah (1999a) investigated a number of different strip crops (sunflower, safflower, sorghum, lucerne and tomato) as a refuge for predatory insects of *Helicoverpa* spp. in cotton fields. Lucerne showed the most dramatic result with the number of predators in cotton being highest adjacent to the lucerne strip and decreasing with distance from the strip to 300m within the cotton crop. Lucerne strips in cotton have also been used as a trap crop for green mirids (Mensah & Khan 1997). The mirids oviposited on the lucerne instead of the cotton and mirid numbers within the cotton were reduced to levels similar to fields that had been sprayed with conventional insecticides.

Non-crop habitats bordering agricultural fields have been found to have favourable effects on beneficial abundance and diversity (Coombes & Sotherton 1986, Hickman & Wratten 1996, Dyer & Landis 1997). These non-crop habitats may include stands of native vegetation, herbaceous crop edges, or weed strips. Hickman and Wratten (1996) found that flowering strips around the margins of wheat fields led to higher numbers of adult hoverflies within the crop. In contrast, studies by Bugg *et al.* (1987) found that common knotweed, despite its attractiveness to numerous species of predators, has limited use in enhancing biological control in adjoining crops. The authors concluded that predators were unlikely to forage in the nearby crop because the weed habitat provided such a hospitable environment. Williams *et al.* (1995) also found that intercropping of soybean with sorghum had little impact on green clover worm mortality from parasitism and disease.

Food sprays have been investigated for attracting beneficial arthropods to crops early in the season when food is scarce. Investigations into the use of the food supplement Envirofeast® have shown that the spray attracts predators into cotton crops (Mensah 2002a,b). Envirofeast® has also been found to deter *Helicoverpa* spp. females from ovipositing on sprayed cotton plants (Mensah 1996). Applications of artificial honeydews (Evans & Swallow 1993) and sucrose sprays (Schiefelbein & Chiang 1966, Carlson & Chiang 1973) have proved useful in attracting and concentrating beneficial arthropods. For food sprays to be effective there must be a source area within the farm from which beneficial arthropods can move into the crop (Mensah & Harris 1995). If the populations of beneficial arthropods have been significantly reduced by prior repeated use of insecticides, food sprays can do little good. Despite promising results from investigations into conservation biological control very few techniques of habitat manipulation have been implemented in the field. Furthermore, the majority of habitat manipulation experiments in Australia utilising strip-crops have been tested only within cotton.

What makes for good biological control agents?

A number of attributes are considered to be desirable for an organism to be a successful biological control agent, at least in theory. These are:

1. A high degree of prey (host) specificity
2. A high searching ability
3. A rapid increase in density when prey (host) densities increase, and
4. Seasonal activity synchronous with that of the pest (host) (DeBach 1974, Seymour & Jones 1991).

Results from an increasing number of laboratory and field experiments have lead to debate over how essential some of these characteristics are to biological control in a field situation. According to conventional biological control theory a successful biological control agent should display a high degree of prey specificity. Huffaker and Messenger (1976) stated that theoretically generalist predators tend to serve as regulators of community stability while the specialists tend to regulate single species stability. However, this does not preclude the use of generalist predators as biological control agents. In fact some authors argue that generalist predators are potentially better because they can sustain their population levels during periods of low pest abundance by utilising alternative prey species (Newsome 1978, Hassell & May 1986, Murdoch *et al.* 1985). Rice and Wilde (1988) concluded that in sorghum and wheat, generalist predators, not parasitoids, are the prominent biological control agents of green bugs, *Schizaphis graminum* (Rondani). Experimental studies showed that natural enemies, primarily coccinellids, consistently reduced artificial greenbug populations (Rice & Wilde 1988).

Parasites as biological control agents

Parasitoids develop as larvae on or in a single host individual from eggs generally laid on, in, or near the host insect (DeBach 1974). The majority of successful biological control programs have been as a result of the introduction of parasitoids (Seymour & Jones 1991, New 1991). *Trichogamma* spp. are good examples of wasp parasitoids that oviposit inside the eggs of over 200 moth species whose larvae attack crops (Seymour *et al.* 1994, Scholz *et al.* 1998). *Microplitis demolitor* Wilkinson is a common larval parasitoid of *Helicoverpa* spp. in Australian cotton (Annetts *et al.* 1998, Annetts 2000). The female wasp inserts an egg into the body cavity of small host larvae, and after hatching, the parasite larva consume the host as it grows (Murray & Zalucki 1994). Unlike predators, which require many prey throughout their lifetime to survive, complete development and reproduce, parasitoids have to attack only one host in order to oviposit an egg in their life span. The close association that parasitoids have with the life stages of their host results in greater synchronisation between parasitoids and pests than has been shown for predators (Murdoch *et al.* 1985, Hassell & May 1986, Johnson *et al.* 2000).

Pathogens as biological control agents

Pathogenic micro-organisms that attack insects include various fungi, viruses, protozoa and nematodes. Pathogens are limited as biological control agents as they do not actively search for the prey or host like predators and parasites (DeBach 1974). Despite this significant levels of pest mortality have been associated with diseases. An economically important outbreak of the tobacco looper, *Chrysodeixis argentifera* (Guenée) in soybeans was completely controlled by the fungus *Nomuraea rileyi* (Shepard *et al.* 1983). Thirteen nuclear polyhedrosis virus (NPV) diseases have been recorded from field collected Lepidoptera larvae in Queensland (Teakle 1973a). NPV can be a significant mortality agent of *Helicoverpa* spp. pests (Teakle 1973b). Titmarsh (1992) estimated that NPV accounted for 28 percent of the *Helicoverpa* spp. larval mortality in crops on the Darling Downs. In recent years a greater emphasis has been placed on the mass production of pathogens and application in the field as microbial insecticides; often without the harmful side effects of chemical insecticides (Teakle 1977, Forrester 1994, Johnson *et al.* 2000).

Predators as biological control agents

Predators are defined as organisms that consume more than one individual prey in order to reach maturity. Despite the fact that the majority of successful biological control cases have involved parasitic insects, the effectiveness of predators should not be underestimated. Their importance as biological control agents is illustrated when indiscriminate use of insecticides reduces the naturally occurring predator populations, resulting in an increase in pest abundance. Outbreaks of citrus pests such as the cottony cushion scale were associated with the elimination of native predators through the use of DDT (DeBach & Bartlett 1951). Wilson *et al.* (1998) found that outbreaks of aphids occurred on cotton treated with thiodicarb. A significant negative relationship between final aphid abundance and the abundance of aphid-specific natural enemies suggests that the outbreaks of aphids in thiodcarb treated cotton developed because of reduced abundance of predators.

Holmes (1984) provides a good example of the biological control of aphids in winter wheat by the combined predation of *Tachyporus* sp. and syrphid larvae. The characteristic that made these predators successful biological control agents was that they were present in the crop before the aphids arrived. Synchronization of the abundance of predator and prey species, both within the crop and throughout the season is essential for effective biological control (Chambers *et al.* 1983). Knuston and Gilstrap (1989) used exclusion cage experiments combined with life table analysis to evaluate the effect of natural enemies of the Southwestern corn borer, *Diatraea grandiosella* (Dyar) in Texas corn. Predation by spiders and *Orius insidiosus* (Say) significantly reduced the early-instar survival of the corn borer. However, in some years of the study predator densities were insufficient to suppress larval densities.

Spiders as biological control agents

Spiders are among the most abundant predators recorded in grain crops in Australia (Whitehouse & Lawrence 2001). Adult spiders are all predaceous, and may play an important role in the reduction of pest populations (Greenstone 1999, Riechert 1999). Individual spider species lack many of the characteristics suggested as necessary for a successful biological control agent (Murdoch *et al.* 1985). They feed on a variety of prey and do not exhibit density dependent tracking of prey populations (table 1). Nonetheless, spider assemblages as a whole impose high levels of mortality on pest populations in various crops (Riechert & Bishop 1990, Nyffeler *et al.* 1994, Carter & Rypstra 1995). The significance of spider assemblages for biological control of pests in Australian agroecosystems is largely unknown, and spiders have been the subject of very few investigations (e.g. Bishop 1978, Bishop 1980). In the majority of studies that set out to examine predators in crop systems spider species are grouped together or given cursory treatment (Bishop & Milne 1986, Stanley 1997). As a result, our knowledge of the biology and ecology of spiders in Australian crops is limited.

Table 1. Characteristics of spiders that influence their potential as biological control agents of field crop pests (adapted from Wise 1993, Greenstone 1999, Riechert 1999).

Positive Attributes	Negative Attributes
High dispersal ability. Ballooning allows spiders to re-colonise fields early in the season.	
Generalist predators. Prey includes a wide range of pest species.	Generalist predators. Prey includes other spiders and beneficial insects as well as pest species.
Predaceous throughout all life stages.	
Long-lived and resistant to starvation and desiccation.	Long generation times relative to the pests, slow temporal numerical response.
The spider assemblage can exhibit density-dependent tracking of prey.	Individual spider species seldom exhibit density-dependent tracking of prey.
High abundance. Often numerically the most dominate component of the predator complex.	Exhibit some territorial behaviour (both within species, and within-guild) that may limit maximum population size.

Quantifying predator abundance

A number of techniques such as sweep net, visual observation, vacuum sampling, whole plant removal, beat bucket and ground cloth can be used alone or in combination to measure predator abundance in the field. Each technique has advantages and disadvantages that must be considered when sampling. The sampling efficiency of each of these techniques has been evaluated in cotton (Stanley 1997, Scholz *et al.* 2001), soybean (Evans 1985, Evans 1987) and mungbean (Brier 1997). Visual sampling, beat cloth, and vacuum sampling are the commonly used collection techniques for scouting in commercial crops (Schulze & Tomkins 2002, see Appendix 1). These methods are favoured because they require little operator expertise and, with the exception of vacuum samplers, are inexpensive. Although the abundance of predators can be reliably estimated in the field their impact on prey survival is harder to quantify (see following section). In contrast, parasitoid abundance is much more difficult to determine in the field. Adult parasitoids are generally small and highly mobile and parasitised eggs and larvae are often overlooked, or unrecognised in the crop (Annetts *et al.* 1998). The impact of parasitoids can be relatively easily assessed because their activity results in a parasitised egg or larvae. Annetts *et al.* (1998) trialed a number of methods for assessing parasitoid population levels and found direct observation and percent parasitism the most practical for use in the field.

A survey of grain growers in southeast Queensland and northern New South Wales showed that three quarters (87%) of respondents scouted for predators in their crops (see Appendix 1). Predator abundance from scouting data was used by growers when making spray decisions but primarily in an *ad hoc* manner in combination with other factors. In cotton the calculation of predator to pest ratios and pest thresholds are included in decision-making protocols (Murray & Mensah 1996, Mensah 1999b). However, the use of these protocols by farmers may be limited. A criticism of the predator to pest ratio is that it does not take into account non-predaceous stages of individual species. All predators observed in the cotton crop are included in the calculation regardless of the level of impact imposed on the pest. Despite this criticism, Johnson (1999) notes that this work has demonstrated to farmers how predator counts may potentially be incorporated into IPM programs.

Farmers and consultants have access to a large amount of extension material that provides photographs and information on the predators of common pests such as *Helicoverpa* spp. (see Pyke & Brown 1996, Wood *et al.* 2000). Through this type of readily available extension material farmers are gradually becoming more aware of which insects within their crops are “good” and should be conserved. However grain growers are not very confident in identifying predators in their crops (only 15% said they could identify them very well, compared to 43% for pests, see Appendix 1). For farmers to expend time and resources on regular sampling of predators and parasitoids the benefits, in terms of pest reduction must be clear. The potential usefulness of regular sampling of predator abundance as well as pest abundance is limited by our inability to quantify impact. We are currently unable to determine what predator abundance levels equate to in terms of pest mortality, and therefore we are unable to incorporate predator counts into spray thresholds.

Quantifying predator impact

Prey consumption by predators is difficult to quantitatively measure in the field because completely consumed prey cannot be counted, and partially consumed prey are often unrecognizable (Knutson & Gilstrap 1989, Mills 1997). Furthermore, the interaction between a predator and its prey is brief and hard to observe (Mills 1997). Despite these difficulties a number of techniques have been utilised to evaluate natural enemy impact with varying degrees of success. These include laboratory based feeding tests, direct observation in the field, exclusion experiments using cages or insecticides, lifetable analysis and post-mortem gut analysis using antibody or molecular based techniques. Luck *et al.* (1988), Sunderland (1988), Seymour and Jones (1991) and Mills (1997) provide extensive descriptions of these techniques.

Problems with predators

A complex of natural control factors operate on pest populations within a crop. It is hard to isolate the action of predators within this complex, and so the significance of predators is difficult to demonstrate in a field situation. Impact studies usually examine correlation between the abundance of predators and prey population changes. The impacts of pathogens and parasites are often included in the estimates of predator impact. Consideration of an individual species in an assemblage of generalist predators can lead to the erroneous conclusion that they are relatively ineffective (Luff 1983, Richman *et al.* 1980). This is because, according to Shepard *et al.* (1983), the significance of an individual predacious species lies in their role as part of the overall beneficial complex. The predator complex of grain legumes in Northern Australia consists of a diverse range of many arthropod groups. Shepard *et al.* (1983) notes that fewer then a dozen species were abundant enough to make a significant impact by themselves. However, collectively the predacious species may substantially reduced pest populations in soybeans.

Fitt (1989) notes that in Australian cotton predators of *Helicoverpa* spp. cannot be relied upon for control, since they never approach densities of 0.5 to 1.0 predators per egg or larva suggested as necessary for control. Other authors have suggested that predator densities are not sufficient to exert economic control over the crop pest being studied. However, few studies seek to actively enhance predator numbers in a field situation in order to determine if this will reduce crop damage. A small number of authors (Lopez *et al.* 1976, Thead *et al.* 1987, Lang *et al.* 1999) have artificially enhanced the numbers of predators within field cages. A study by Lang *et al.* (1999) included experimental enclosures with natural predator densities, predator-reduced enclosures and predator-enriched enclosures in maize crops. The effect of predators on the prey populations within these enclosures was assessed, however the relevance of these results to the field situation is limited. The cages restrict movement of both the predator and prey and in some cases environmental conditions within a cage are different to those outside the cage (Hand & Keaster 1967). Habitat manipulation techniques have been shown to be useful in increasing predator abundance in a field situation (Riechert & Bishop 1990). A clear link between the increase in predator abundance and a reduction in crop damage due to pest mortality still needs to be established.

The majority of studies of aspects of biological control concentrate on the effects of variation in natural enemy populations on pest mortality. Hence, little work has been conducted on what factors contribute to this variation and practical methods to reduce it in the field. Biological control science may benefit from studies that concentrate more on the ecology of the predator complex, rather than the pest. In any one location, at any given time, the pest represents only one part of the community of insects and other organisms that are present and interact.

Arthropods of grain crops in Australia

Of all the agricultural crops, the grain crops, such as wheat, maize, rice, sorghum and the grain legumes, directly and indirectly furnish the basic food supply of the world's population (Huffaker & Messenger 1976). More than 550,000 hectares of grain crops are planted for harvest each summer and winter in Queensland alone. Sorghum is the major summer grain in Queensland, with harvests of about 1.2 million tonnes, and wheat is the major winter grain. Cereal grains in Queensland had a gross value of about $284 million in 1994-1995 (DPI web site).

The invertebrate fauna in grain crops has had scattered attention. Evans (1985) collected arthropods from soybean crops in Southeast Queensland and classed the species as phytophagous (42%), predatory (28%), parasitic (24%) and non-pest (6%). The predator complex in grain legumes in Northern Australia was found, by Shepard *et al.* (1983), to include a diverse range of groups such as beetles, ants, wasps, spiders, assassin bugs and others. The pest complex of grain crops consists of pod feeding insects (*Helicoverpa* spp.), podsucking bugs (Green vegetable bug, *Nezara viridula* (Linnaeus)), leaf feeders (loopers, cluster caterpillar *Spodoptera litura* (Fabricius)), leaf minners and webbers (soybean moth *Stomopteryx simplexella* (Walker)), stem borers (*Zygrita diva* Thomson), bud feeders (mirids, Miridae), mites, some soil insects and many other occasional pests. *Helicoverpa* spp. are considered the key insect pests of the Australian grain industry as they attack a wide range of crops causing significant economic losses (GRDC annual report 1998-99).

Most of the research into IPM of grain pests has involved the development and marketing of resistant cultivars, optimising chemical control measures, and developing selective biopesticides. Biological control programs have mainly been aimed at identifying exotic agents for introduction and control of helicid snail species, redlegged earth mite and green vegetable bug (GRDC annual report 1998-99). The use of naturally occurring predator populations for the control of *Helicoverpa* spp. has not been investigated in a concerted fashion.

The majority of work on predators within Australia has been carried out in cotton crops. The high value of cotton, low economic thresholds, easily damaged structures, coupled with the widespread use of pesticides make this crop particularly susceptible to *Helicoverpa spp.* damage (Annetts 2000). Grain crops, which are often grown in the same regions as cotton, are relatively less susceptible to damage and have higher economic thresholds. Predators may potentially play a more significant role in pest reduction in these crops (Michael 1973). Investigations into the impact of predators on *Helicoverpa* spp. in grain crops are warranted.

Impact of predators on *Helicoverpa* spp. in Australia

Helicoverpa armigera (Hübner) and *Helicoverpa punctigera* (Wallengren) are significant pests of field crops in Australia (Adamson *et al.* 1997, Zalucki *et al.* 1986). The *Helicoverpa* spp. larvae cause economic damage to crops by feeding on the reproductive structures and growing points of their hosts (e.g. cotton buds and bolls, corn ears, grain flowers and pods, and sorghum heads) (Titmarsh 1992, Fitt 1989). The average cost of *Helicoverpa spp.* damage to mung bean crops alone in the Darling Downs was estimated at $1.7 million in 1989 (McGahan *et al.* 1991). More recent figures estimate that in Queensland *Helicoverpa* spp. damage to grain legumes (of 40%) costs $26.2 million (Adamson *et al.* 1997). As increasing levels of insecticide resistance are demonstrated in *H. armigera* investigations into biological control must be considered a priority.

The extent to which naturally occurring populations of predators control *Helicoverpa* spp. in Australian crops is uncertain. Research to date shows that the both predation rates and predator abundance are highly variable at a number of spatial scales. Johnson (1999) states that under conventional cotton management practices it is unlikely that the predators alone can maintain populations of *Helicoverpa* spp. eggs below economic thresholds. However, she encourages the incorporation of predators into IPM programs. Stanley (1997) concluded that the impact of predators on *Helicoverpa* spp. in commercially produced cotton is generally low. Laboratory prey consumption trials showed that predators had considerable potential for control of *Helicoverpa* spp.; however field cage studies resulted in significantly lower estimates of prey consumption. Furthermore, highly variable rates of predation where recorded between experiments. This variability may be due to a number of factors including environmental conditions, the presence and absence of alternative prey, and differences in the developmental stages of predators (Annetts 2000, Stanley 1997). The unpredictability of predator mortality limits their use in pest management programs (Stanley 1997). A greater understanding of the factors that cause this variability is required in order to improve the reliability of predator mortality.

Research aims

Many authors argue the importance of polyphagous predators for controlling insect pests in crops. However, a review of the literature suggests that this presumption is not supported by adequate experimental evidence (Luck *et al.* 1988). There are very few instances that demonstrate unambiguously that predators are agents of significant irreplaceable mortality (Riechert & Bishop 1990). The same can be said for studies that conclude that predators are relatively ineffective in suppressing pest populations (Titmarsh 1992). Many of these inconclusive results are due to the experimental problems associated with assessing predator impact discussed previously. In view of the importance placed on predators as biological control agents in IPM programs it is pertinent to try and resolve this issue.

This study aims to firstly determine if the naturally occurring predators within grain crops are of use for the control of *Helicoverpa* spp. Secondly, does an increase in abundance of predators within a grain crop result in a reduction in crop damage due to insect pests? Finally, what factors contribute to the variability in abundance of predators, both spatially and temporally within the grain crop and between crops? Practices that may reduce this variability in abundance and so lead to more effective predators are discussed.

Thesis structure

The title of this thesis is necessarily broad because I cover many aspects of predator ecology and pest control in grain crops. This does not mean I have covered all aspects of this broad area of research, but rather filled in some of the gaps in the past research. Most of the ecological questions investigated have an applied aspect that relates to integrated pest management. Where possible I have highlighted what the conclusions mean for pest management in grain crops. I have focussed mainly on spiders throughout the thesis.

References are located at the end of each experimental chapter (Chapters two to 10) along with a single page summary of the major results and conclusions. Statistical analyses for the majority of the thesis (with the exception of the SADIE analysis in Chapter eight) were performed in the program S-Plus (Mathsoft 1999). Robust linear regression was frequently used to test linear relationships between variables. These models are useful for fitting linear relationships when the random variation in the data is not normal or when the data contains significant outliers. Standard error is used to show variation around a mean value throughout the course of the thesis.

For the first half of the thesis I broadly investigate spatial dynamics of predators in agricultural landscapes. Wratten and Thomas (1990) outlined a number of classes of movement that they used (and I also have used) as a framework for studying predator movement and dispersal within the agricultural landscape (table 2). The remainder of the thesis focuses on the problem of measuring prey consumption by predators in the field.

The colonisation of fields within the agricultural landscape by spiders is primarily via aerial movement known as ballooning. Water traps (Chapter three) placed in various crops and non-crop areas were used to assess ballooning rate and the composition of the ballooning fauna. The relationship between ballooning activity and within-field abundance was discussed. Directional traps (pitfalls and sticky traps) were used to assess patterns in immigration and emigration of spiders across the edge of a soybean field (Chapter three). Focussing on the influence of an adjacent lucerne crop on predator abundance in the soybean field. Lucerne has been suggested as an ideal refuge crop for beneficials and may provide a source of beneficials to surrounding crops. Multiple chapters within this thesis investigate the impact of lucerne on predator abundance within an adjacent crop (Chapter four and eight). Ground movement of Lycosidae spiders within fields was investigated using a mark-recapture-recapture experiment (Chapter five). Again the influence of an adjacent lucerne crop was investigated. Management decisions such as the use of insecticides on predator abundance and recovery times was briefly investigated in a field experiment (Chapter six). The recolonization pattern of the sprayed plots by predators and pests in relation to the surrounding lucerne fields is discussed.

Table 2. Classes of movement suggested by Wratten and Thomas (1990, see fig. 11.1) as a framework for the study of spatial dynamics of beneficials in agricultural landscapes. How each class of movement has been investigated in this thesis is shown.

Class of movement	Experiments conducted in thesis	Chapter
1. Colonisation of crops from non-crop habitats in the spring.	Spider ballooning in crop and non-crop areas.	3.A & B
	Spider movement across field edge (ballooning and cursorial).	3.C
2. Movement between crop types during the season.	Influence of adjacent lucerne crop on abundance and movement.	4.
	Lycosidae mark-recapture.	5.
3. Colonisation of new habitats as the area under cultivation expands.	Not assessed in thesis.	NA
4. Recolonisation of land as the effects of pesticides decline with time.	Predators and insecticide use.	6.
5. Reproductive and aggregative numerical responses to areas of high prey density in the crop.	Within-field spatial patterns (predator aggregation in response to pest density).	7. & 8.
6. Large-scale migration of beneficial arthropods into cropped areas.	Spider ballooning ? (not always considered a migratory behaviour).	3.

Variability in the within-field patterns in predator abundance and activity was investigated and related to the spatial patterns in pest abundance. *H. armigera* eggs on cards attached to plants in the field were used as sentinel prey. Preliminary experiments (Chapter seven) were necessary to design an effective protocol for their use. The egg cards were then used to estimate within-field spatial patterns of predation (Chapter eight). Egg predation was related to spatial patterns in predator abundance, pest abundance and plant damage in an intensive grid sampling scheme.

In an effort to gain a greater understanding of the relationship between predator abundance and predation rate in the field further investigations were conducted on techniques for quantifying predation rate. Exclusion cage experiments were used to get an estimate of first instar larval and egg survival in the field (Chapter nine). Molecular techniques were used to detect *H. armigera* in the guts of Clubionidae spiders (Chapter ten). Laboratory based no-choice feeding tests were used to determine which spider families should be targeted for further study (Chapter ten).

Finally grain growers' attitudes towards the use of predators for pest control were canvassed (Appendix 1) to get a better understanding of the current use of naturally occurring predators in decision-making. This data was used in multiple chapters of the thesis. By the end of the thesis the reader should have a greater understanding of predator movement within and between fields and across the greater agricultural landscape; the consequences of movement in terms of predator abundance patterns within fields; and finally, some measurement of the impact of predators in terms of pest mortality.

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