
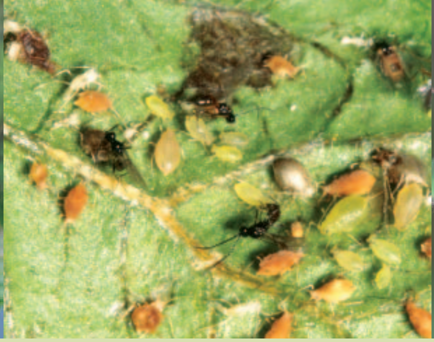


INTEGRATED PEST MANAGEMENT FOR CROPS AND PASTURES

PAUL HORNE AND JESSICA PAGE

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Front cover
Main photo: ladybird
Top, from left to right: hoverfly larva, parasitic wasps and aphids, *Netelia* spp.

Back cover
Clockwise, from top left: redlegged earth mite, European earwigs, predatory mite, heliothis, damsel bug

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Foreword

Integrated Pest Management is a relatively new concept for Australian broadacre crop and livestock producers, despite the fact it has been employed within the horticultural and intensive agricultural industries for many decades. I suggest that some of the reasons why broadacre cropping and livestock producers have not adopted an IPM approach in the past, have been the fear of catastrophic financial loss, limited understanding of the principles of IPM and a near total domination by the chemical companies as to how pest species should be controlled.

Meeting with Paul Horne and Jessica Page some seven years ago opened my mind to alternative approaches to controlling insect pests. At the time our farmers in the western districts of Victoria were losing the battle against slugs, with many canola crops being badly eaten at emergence resulting in depressed yields and a loss of faith in the crop. At the time we had tried alternative baiting strategies, principally relying on different products, rates and timings. We were making limited progress and needed a fresh approach. This was where Paul and Jessica came in, along with Dr Jim Fortune from the Grains Research and Development Corporation who showed real vision and was willing to fund an alternative approach to controlling the pest problem. This was the start of the Integrated Pest Management approach to controlling slugs and other insect species in crops in south-west Victoria.

The journey with Paul and Jessica in developing an IPM approach to pest control over the last few years has been an extremely exciting one, albeit somewhat nerve-racking at times. We were unsure just how effective an IPM approach was going to be, given the limited knowledge and un-chartered waters we were operating in. The pioneering farmers such as Rowan Peel and John Hamilton who committed significant areas of their farm to the new IPM system, showed extreme courage, however they knew that their total reliance on chemical control had to cease because of escalating costs and failure to adequately control the pests.

Paul and Jessica were very ably supported by Peter O'Loughlin from Agvise P/L who encouraged many of his clients to take on this new approach. Paul and Jessica worked closely with the cooperating farmers, building knowledge and confidence over time. Now there are many producers adopting an Integrated Pest Management approach across significant areas of their farm.

This publication is the result of significant effort of many people. For the publication to work, however, it needed the expertise of Paul and Jessica. This publication will certainly assist people who are investigating an IPM approach. Paul and Jessica have clearly outlined the principles of IPM, wonderfully presented the different pests and predators and their relationships, along with outlining some excellent farmer case studies.

We are no longer operating in the dark when it comes to implementing an Integrated Pest Management system on farms in southern Victoria. I am sure that the principles can be applied in many other regions. Well done Paul and Jessica for presenting such an excellent publication.

Colin Hacking
Retired CEO Southern Farming Systems

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We appreciate the help and support given to us by many people that have led to the production of this book. We thank, in particular, GRDC for their funding support of our IPM approach in cropping (Projects IPM 0001 and 0002), and also Col Hacking (Southern Farming Systems) and Peter O'Loughlin (AgVise Pty Ltd) who, along with Rowan Peel, were among the very first to help us attempt to implement IPM in cropping in Victoria. We also thank the many farmers that AgVise assist, and Cam Nicholson who has helped us move from awareness to adoption. Cam Nicholson also provided funding via Grain & Graze for the photographs of invertebrates used in this book, all of which were taken by Denis Crawford. (Grain & Graze is a collaboration between four leading research and development corporations – Land & Water Australia, Grains Research and Development Corporation, Meat & Livestock Australia, and Australian Wool Innovation Limited – and also farmer and landcare groups, research providers and regional management authorities. Southern Farming Systems (SFS) has been our key partner.) We thank Neil Hives for his dedicated work implementing our IPM approach in Victoria. We also thank Kate Lorey for her technical assistance and care of our insect colonies that are essential in our projects.

We acknowledge a great debt to Janet, James and Claire Horne and Ivy Page and Brian Pribble for their tolerance for time away from them while we wrote this book.

Finally we thank Ted Hamilton (CSIRO Publishing), who saw the potential of this book after hearing us present a paper on IPM at the Grasslands Conference in Ballarat.

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1
Introduction

The starting point of this book is that insecticides (and miticides and molluscicides) are the currently accepted best practice in dealing with pests in broadacre crops and pastures. Farmers have been asked simply to match up the pest and the pesticide, whether this involves a weed or disease, an insect or a mite. The standard practice does not require much knowledge of pest species as it merely entails the selection of a broad-spectrum pesticide that deals with a range of pests. That is, a farmer asking an adviser (government or private) how to control a pest is likely to receive a pesticide recommendation and – what is more important – is likely to *expect* such a recommendation. This is exactly the same situation facing medical doctors who deal with people expecting pharmaceutical prescriptions to be given following consultations.

Despite this being current standard practice, it is a relatively recent approach to pest management (in historical terms) and is not something that is likely to result in the sustainable control of pests. We can say this because, where reliance upon pesticides alone has been employed, pesticide resistance has led to control failures. There are many examples from horticultural experience to illustrate the problems associated with heavy reliance on pesticides, the same problem that broadacre farmers now face, but the horticultural experience also suggests the likely answers.

Integrated Pest Management or 'IPM' is not a new concept to entomologists (people who study insects) but it is also not a common tool used by most broadacre farmers. The development and implementation of IPM in broadacre cropping and pastures is in its infancy in Australia, and the situation is similar throughout most of the world. There is sufficient information to allow interested farmers to put IPM into practice but realistically this will occur where there is collaboration with entomologists who specialise in it. Certainly at this stage we are not able to give prescriptive recommendations for the control of all pests in all crops in all districts but we can use basic principles to guide implementation of IPM in Australia.

The range of pests is something that is likely to change as growers change practices and use less insecticide. In addition, the ranking of some pests as either serious or minor is also likely to change. At present the growers that have adopted an IPM approach are still attempting to define the full list of pests on their properties.

IPM involves integrating three different types of control options. The mainstays of IPM are biological and cultural controls. Chemical controls are used only as support tools, they are never the primary control option. Biological control may involve pathogens (viruses or bacteria), parasites (other insects or nematodes) or predators (primarily other insects and mites as well as larger mammals and birds). In most cases the biological control agents that are involved in the IPM described in this book are naturally occurring (usually native) species. They include generalist predators that will readily accept native and exotic species of pests as prey and also include specialist parasitic species that have a narrow host range. Insects that are parasitic upon other insect species are called 'parasitoids' and this type of insect can be extremely helpful to farmers; in IPM parasitoids can often be encountered. Cultural controls cover different farming methods and can be very effective; they can also include the use of GM (genetically modified) crops.

The generally accepted method of controlling insect and mite pests in agriculture since the 1950s has been the use of synthetic pesticides. That is, since the Second World War there has been a heavy reliance upon pesticides synthesised by chemists. The first of these pesticides were the organochlorines, which includes pesticides such as DDT, dieldrin, lindane, heptachlor and endosulfan. All of these except endosulfan have now been banned from agricultural use in Australia. Following on from the organochlorines were the organophosphates (e.g. 'Lorsban' – chlorpyrifos) and carbamates (e.g. 'Lannate' – methomyl and carbaryl), and later by synthetic pyrethroids (e.g. 'Talstar', 'Fastac'). Despite the fact that the synthetic pesticide era only began in the 1950s this approach has become accepted as the 'conventional' approach to pest management. Obviously control of agricultural pests was achieved by other methods for millennia without these tools, and so it is not really the conventional approach that people may think.

The 'conventional' approach has continued in recent years and, after the withdrawal of the organochlorines in the 1980s in Australia, the organophosphates and synthetic pyrethroids have formed the basis of pest control for much of broadacre agriculture. They are relatively cheap and broad-spectrum, which simply means that they kill a wide range of pest species. The pesticides' broad-spectrum effect means that it is often not necessary to know precisely the target species or their life cycles. The pesticides used in such an approach also kill the predatory and parasitic species that form the biological control agent component of an IPM strategy. Therefore, the ‘conventional’ approach that is totally based on pesticides is usually not compatible with an IPM approach that incorporates biological control agents.

Obviously the pesticide-based approach is simple, easy to understand and apply. There are methods to make a pesticide-based strategy more precise, by targeting particular life stages (see for example the CSIRO’s Timerite® Strategy for redlegged earth mite control), but it remains a pesticide-based strategy. Such an approach has been widely adopted for many years because of the advantages of simplicity and ease of incorporation into current practices.

However, there are also reasons why a broad-spectrum pesticide-based strategy is not ideal and there are significant disadvantages. The relative importance of the disadvantages will vary between farmers and farming situations, but they include the following factors:

1. insecticide resistance
2. residues in produce
3. worker safety
4. non-target mortality
5. induced secondary pests
6. environmental contamination (particularly waterway contamination)
7. drift into neighbouring properties.

Points 2 to 7 can be ignored by those determined to ignore them who wish to continue with the ‘conventional’ approach. However, Point 1 – *insecticide resistance* – cannot be ignored by farmers relying on pesticides. The options become: increase the dose; increase the frequency; change the active ingredient or do something altogether different. IPM was developed as an alternative to pesticide-based strategies.

It is important to recognise that chemical control is a part of IPM strategies. The discussion above highlights problems with reliance on chemical pesticides as the mainstay of pest management. The challenge is to develop the use of chemicals as a support tool rather than the main weapon.

IPM is more complicated in some regards (as it involves monitoring and identifying insects), but it can also be simple. When insecticide resistance sets in and spraying involves a Resistance Management Strategy using calendar-based options for rotations through different groups of insecticides (such as in brassica crops), then IPM is actually comparatively simple.

There are considerable advantages with an IPM strategy that involves (often) massively reduced insecticide and miticide use. Some of these, such as reduced costs and reduced exposure to anti-cholinesterase products, are readily observable. However, advantages such as improved pest control and healthier, more productive plants and avoidance of insecticide-resistant and secondary pests are less recognised but these are attributes that are regularly achieved and measurable.

There are examples from other crops in horticulture that illustrate these less obvious advantages, and in particular deal with the assertion that 'we have zero tolerance for pests'. It is often claimed that the reason for heavy use of pesticides is because it is the only way to achieve a high quality product. The inference is that IPM, allowing living things in the crop, cannot achieve such an outcome. Yet the opposite is true in very many cases and is easily observed. The example we will use here is glasshouse-grown roses. This crop is not a food crop and is sold on cosmetic value alone. The standards of pest management are very high and the growers had relied heavily on pesticides until insecticide and miticide resistance became a major problem. Growers using IPM found that they had better control of pests, far fewer insecticide and miticide applications, and the plants responded by being healthier and more robust. This also meant longer stems on the roses as well as more stems. Longer-stemmed roses are usually worth far more in the marketplace than short-stemmed roses, and so here there has been a measurable increase in quality as well as yield.

What we want to emphasise here is that the *only* reason growers turned to IPM was because they could not achieve adequate control relying on pesticides alone. Another important factor was that there were damage and pest problems in that so-called 'zero-tolerance' market.

The benefits that farmers should expect to see after adopting an IPM strategy include increases in quality and yield. This is simply because there should be improved pest control without the negatives of pesticide impact. There should also be economic benefits that go beyond decreased pesticide costs – such as sustainable control of many different pests and reduction in the use of hazardous chemicals that can affect workers. Sustainable control of pests can be expected because the populations of beneficial species that counter many pests will be given the required habitat and environmental conditions to survive and prosper.

Farmers who have been using a pesticide-based conventional approach for (perhaps) many years can expect to have fewer resident beneficial species than farmers who have not applied broad-spectrum insecticides. However, there are some beneficial species that all farmers can expect to find, irrespective of the previous years' approach. These are the transient species, and this is discussed in detail in Chapter 4. In brief, the transition from using a pesticide approach that eliminated beneficials to using a biological-based IPM strategy will vary in its difficulty on different farms, and will depend on the level of biological control agents existing on the property. *IPM is not simply an alternative spray program, and does require the presence of beneficial species.* This is a key point and one that is not universally understood. It is important that farmers understand that when they decide to adopt an IPM strategy they may have very different results to their neighbours in the short term, because of different pesticide histories. Some can expect immediate good results; others can expect a longer transition period until predator populations (for example) increase. Where there has been a history of sustained use of insecticides and a consequent loss of resident beneficial species then the transition to an IPM approach could be difficult and costly. Close monitoring will help farmers to know the situation at any time, so they can avoid unnecessary further insecticide applications, but monitoring does not control pests.

We hope this book will help farmers who would like to implement IPM on their properties. It outlines both the problems and the expected outcomes from the two strategies, but particularly indicates what farmers can expect when changing to an IPM strategy. The chapters in this book describe a range of pests to be dealt with, the key beneficial species known at present that would be useful, pesticide effects and the process of integrating all of these control options.

The conventional approach can be described as a 'pest by pest' approach, as the usual question that a farmer asks is 'What do I spray for pest X?' or 'How do I kill pest X?' Really the questions that need to be asked are 'How should I manage pest X along with all other pests?' and 'What has caused the problem with pest X?' IPM strategies attempt to deal with pests in a sustainable manner, by first determining why a pest problem has occurred and then what biological control agents can be employed and what cultural (management) tools can assist. Finally, if – and only if – these two control tools are not sufficient to achieve a satisfactory level of control to avoid economic losses, then IPM strategies look to support-chemicals that will assist.

One criticism that has been made of IPM (Pickett and Bugg 1998) is that too much reliance has been placed on pesticides within IPM. In our opinion there has been too much reliance on pesticides and true IPM has not been practised. Rather, in many cases an alternative spray strategy has been used and that has been called IPM (perhaps 'integrated pesticide management'). This is something to bear in mind when assessing the success or failure of so-called IPM strategies. The hardest task with IPM is to ask a farmer to try again when they failed when using it before. The problem usually is that they did not try IPM in the first case but whatever they tried was called IPM. Given the current interest in IPM approaches, there is massive potential for this problem to be repeated and a bad perception of IPM to be generated. We hope that this book provides information to growers and advisers that will help to minimise such problems with promotions of strategies falsely called IPM.

The main requirement for a farmer to begin to use IPM is the recognition of the role of biological and cultural controls, not just alternative pesticides, and that the pest spectrum may not be as thought or as seen under a pesticide-only approach. Therefore, watching what actually happens, not just what is expected to happen, is very important.

2

Pest management and IPM

In Chapter 1 we gave a brief definition of IPM. It involves integrating three different types of control options – the mainstays being biological and cultural controls with chemical controls used only as support tools, never the primary control option. Biological control may involve pathogens (viruses or bacteria), parasites (other insects or nematodes) or predators (primarily other insects and mites as well as larger mammals and birds). In most cases the biological control agents involved in the IPM described in this book are naturally occurring (usually native) species. They include generalist predators that will readily accept native and exotic species of pests as prey, specialist parasitic species that have a narrow host range and parasitoids.

It may seem surprising but often it is not initially possible to fill in the 'Pest' column for any particular farm. That is, the farmer or agronomist is not able to say what range of pests they are trying to combat on their farm. Usually the approach to pest control is to use broad-spectrum insecticides and therefore such specific information has not been required. This is a stumbling block to adoption of IPM and is the first task for those wanting to implement an IPM strategy. The full range of pests may not be known for many years after such a decision has been made and so completing such an apparently simple task is not as straightforward as it may seem.

The pest spectrum will often increase once broad-spectrum insecticides are taken out of the equation, but that does not mean that pest problems will necessarily increase. Whether pest problems become worse or not will depend upon many local factors and especially the relative numbers of pests to beneficials. For example, where there is a long-term crop (such as lucerne or pasture) that has been treated annually with broad-spectrum insecticides and there are resident pests and very low levels of necessary beneficial species, then biological control alone will be insufficient to prevent damage. At this stage there are some relatively compatible chemical treatments that can be used but there is not a ‘soft’ option for every pest.

In most locations it is likely that former minor and insignificant pests will become obvious and may require treatment, but control options for these minor pests can usually be developed. This means more thought has to go into the control options used.

In Table 2.1 below we present a very simple means of summarising an IPM strategy for any crop or pasture anywhere. Completing the table for your situation will allow you to identify what actions will be required and what information is lacking. Table 2.2a is blank except for the pests to be dealt with, and the subsequent tables contain further entries until Table 2.2e is completed for a hypothetical crop (we have used canola for our example) so that you can see how the approach can be used.

Table 2.1: Table describing a hypothetical IPM strategy for any crop or pasture

Column 1	Column 2	Column 3	Column 4	Column 5
Pest	Beneficial	Cultural	Chemical	Monitoring
Pest 1	Predator 1 Parasite 1	Weed control	BT	Direct search
Pest 2	Predator 2 Predator 3	Variety	Selective spray 1	Traps
Pest 3	Predator 4 Parasite 2	Irrigation	Selective spray 2	Sweep net
Pest 4	Predator 2 Predator 3	Tillage	Nil	Tiles/sacks

The first step is to identify the range of **pests** in any given situation. The full list will probably not be known until an IPM strategy is commenced and broad-spectrum insecticides are withdrawn from the farming operation, but there will be local knowledge on the likely range of pests to be faced. The status of each of these pests will not be equal as some will be more important or potentially cause more problems than others. Therefore, it is worthwhile categorising the pests as major or minor, and either regular or infrequent pests.

This approach allows us to see the most serious problems and where most effort must be directed. It also allows us to see the seriousness of applying harsh insecticides for minor pests. If we take the example given for canola below, applying a synthetic pyrethroid spray for aphids would have effects on the biological control of major pests such as slugs, earwigs and mites.

Table 2.2a: Hypothetical IPM strategy for canola, initial stage

Pest	Beneficial	Cultural	Chemical	Monitoring
Slugs				
Earwigs				
RLEM				
BOM				
Lucerne flea				
FWW				
Aphids				
Heliothis				
Armyworm				

The second part of completing the table is to identify the key beneficial species, the **biological controls**, that may prey on or parasitise each pest. Once again, there is not a great deal of information about many of these beneficial species in broadacre systems, or experience in utilising them, but there is enough information to identify likely beneficials. For example, carabid beetles (see Figure 2.1, page 51) are a group that contains many predatory species and we know that there are carabid beetles, but different species, across Australian agricultural districts. We know very little about most of these species, but if we know that they are generalist predators feeding on soft-bodied prey then they can be useful to keep.

There is highly detailed information on aspects of some beneficials and practically nothing known about others. For example, we have detailed information about the feeding rates of two species of hoverflies and the behaviour of parasitoids that attack heliothis but do not even have the names of carabid

Table 2.2b: Hypothetical IPM strategy for canola, identification of beneficials

Pest	Beneficial	Cultural	Chemical	Monitoring
Slugs	Carabid beetles			
Earwigs	Carabid beetles (different species)			
RLEM	Common brown earwig Predatory mites (Snout mites)			
BOM	Common brown earwig Predatory mites (Snout mites)			
Lucerne flea	Predatory mites			
FWW	Staphylinid beetles Carabid beetles			
Aphids	Brown lacewings Hoverflies Parasitic wasps Ladybird beetles			
Heliothis	Parasitic wasps Parasitic flies Damsel bugs Pentatomid bugs			
Armyworm	Parasitic wasps Parasitic flies Damsel bugs Pentatomid bugs			

beetles from different cropping and pasture systems. This means that for those wanting to implement an IPM strategy on their farms immediately then the range of information on beneficials is scattered and of variable detail. However, there is enough to see how the concept may apply on a local level.

As with the pests, there will be some beneficial species that are relatively more important than others, and so we need to identify what we believe to be the key species. The detail in the beneficial column is likely to change as more information becomes available, as farmers begin to adopt an IPM approach. It is also important to remember that very many more beneficial species will be found in an established IPM system, and that this table is only listing the major species at present.

The third column in the table deals with a large and diverse set of control options that we call **cultural**, and many of these are management practices that are carried out for other purposes. For example, time of planting will influence the

Table 2.2c: Hypothetical IPM strategy for canola, cultural strategies

Pest	Beneficial	Cultural	Chemical	Monitoring
Slugs	Carabid beetles	Rolling Burning Tillage		
Earwigs	Carabid beetles (different species)	Tillage		
RLEM	Common brown earwig Predatory mites (Snout mites)	Broadleaf weed control		
BOM	Common brown earwig Predatory mites (Snout mites)	Broadleaf weed control		
Lucerne flea	Predatory mites	Broadleaf weed control		
FWW	Staphylinid beetles Carabid beetles	Press-wheels		
Aphids	Brown lacewings Hoverflies Parasitic wasps Ladybird beetles	Late planting		
Heliothis	Parasitic wasps Parasitic flies Damsel bugs Pentatomid bugs	Nil (GM crops)		
Armyworm	Parasitic wasps Parasitic flies Damsel bugs Pentatomid bugs	Nil		

risk of aphid-vectored diseases in cereals, burning stubble will affect the number of pests (and beneficials) that are resident, and grazing intensity will affect the risk of damage by cockchafers.

This column deals with the management options that are available to the farmer, and obviously these may be different even on adjacent farms. Each farmer will have different thoughts on the suitability of any factor for their own situation. The important point here is that a range of options can be considered and some are highly effective in helping control pests. To ignore them or to forgo using a key cultural control option may critically weaken an IPM strategy by placing too much reliance on the biological or chemical components of the strategy.

One common cultural control is weed management. For example, redlegged earth mite (RLEM) (see Figure 3.1, page 51) flourishes on broadleaf weeds such as capeweed and so control of capeweed is a means to suppress the numbers of the pest. However, it needs to be done in the year before a susceptible crop is grown, before over-summering eggs are produced, and not just with a herbicide at planting. Weed control is a powerful tool to help control RLEM and can eliminate the need for insecticide applications. This has flow-on effects in helping to increase resident insect and mite predators, and so it is easy to see how important cultural options can be. These are discussed in more detail in Chapter 5.

In the cultural column we place any physical action or plant variety selection that the farm manager chooses. Once again, there will be some options that can have a major impact on pests, and others that have a minor impact. We need to list them in the table so that the farmer can decide which are worth the effort, and what will be the cost of not using them.

The final control option column is of course the use of **chemical pesticides**. The difference between the IPM approach and conventional practice is that here the chemicals are the support tools. They are selected to be effective on pests and not disruptive to any beneficials. This is not often possible, but there certainly are an ever-increasing number of products that are not lethal to all beneficial species. The types of pesticides available and their effects on beneficials is discussed in detail in Chapter 6.

To illustrate the difference between an IPM approach and a targeted pesticide approach we can look at the control of RLEM (redlegged earth mite – *Halotydeus destructor*). Australian entomologists have developed an approach to control it called the Timerite® strategy (refer to: www.timerite.com.au). This strategy is based upon the fact that *H. destructor* produces over-summering eggs that can survive desiccation. If the population can be killed before these eggs are produced then there will be no problem in the next season. To achieve this kill an insecticide is applied in spring, at a time known in any location to be just before such resistant eggs are produced. (The timing is different in different regions of Australia.) The insecticides usually used are either organophosphates or synthetic pyrethroids.

There are definite advantages in this approach compared to routinely spraying in autumn (perhaps several times) but there are also some disadvantages. The first is that the strategy is based upon the average life history of one species and does not take into account the effect on other pest species (such as blue oat mite and lucerne flea) or beneficial species (such as carabid beetles, lacewings and ladybird beetles). The pesticides used would kill most RLEM but would also kill the species that would help to control it and other species. So although Timerite® is one means of achieving control of an important pest, it is not an IPM approach.

In an IPM strategy, the aim is to use the best chemical product given the beneficial species identified in column 2. That is, to use a pesticide which, in

Table 2.2d: Hypothetical IPM strategy for canola, chemical pesticides

Pest	Beneficial	Cultural	Chemical	Monitoring
Slugs	Carabid beetles	Rolling Burning Tillage	Iron chelate Baits	
Earwigs	Carabid beetles (different species)	Tillage	Baits Seed dressing of fipronil	
RLEM	Common brown earwig Predatory mites (Snout mites)	Broadleaf weed control	Seed dressing of imidacloprid	
BOM	Common brown earwig Predatory mites (Snout mites)	Broadleaf weed control	Seed dressing of imidacloprid	
Lucerne flea	Predatory mites	Broadleaf weed control	Seed dressing of imidacloprid	
FWW	Staphylinid beetles Carabid beetles	Press-wheels	Seed dressings	
Aphids	Brown lacewings Hoverflies Parasitic wasps Ladybird beetles	Late planting	Seed dressing of imidacloprid	
Heliothis	Parasitic wasps Parasitic flies Damsel bugs Pentatomid bugs	Nil (GM crops)	GemStar/Vivus BT sprays 'Success'	
Armyworm	Parasitic wasps Parasitic flies Damsel bugs Pentatomid bugs	Nil	BT sprays Banded sprays targeting the 'front'	

conjunction with biological and cultural methods, will control the pest with minimal impact on the beneficial species that are present. The range of beneficials is almost certainly going to be different in different regions or at different times of year and so the selected pesticide could also be different.

The role of **monitoring** is to identify the pest and beneficial spectrum at any particular time to allow accurate decisions to be made for each and every site. Monitoring requires that the person monitoring knows what to look for and how to identify it! This may seem simple logic but finding advisers skilled in identifying beneficials as well as pests is not as straightforward as it may sound. The fundamental rule in monitoring is that the person monitoring knows how to identify pest and beneficial species, and further, how to make decisions based on

Table 2.2e: Completed hypothetical IPM strategy for canola crops

Pest	Beneficial	Cultural	Chemical	Monitoring
Slugs	Carabid beetles	Rolling Burning Tillage	Iron chelate Baits	Tiles in Spring and Autumn
Earwigs	Carabid beetles (different species)	Tillage	Baits Seed dressing of fipronil	Tiles in Spring and Autumn
RLEM	Common brown earwig Predatory mites (Snout mites)	Broadleaf weed control	Seed dressing of imidacloprid	After the Autumn break
BOM	Common brown earwig Predatory mites (Snout mites)	Broadleaf weed control	Seed dressing of imidacloprid	After the Autumn break
Lucerne flea	Predatory mites	Broadleaf weed control	Seed dressing of imidacloprid	Suction in Winter
FWW	Staphylinid beetles Carabid beetles	Press-wheels	Seed dressings	Shelter traps and germinating grain baits
Aphids	Brown lacewings Hoverflies Parasitic wasps Ladybird beetles	Late planting	Seed dressing of imidacloprid	Sticky traps and suction samples
Heliothis	Parasitic wasps Parasitic flies Damsel bugs Pentatomid bugs	Nil (GM crops)	GemStar/Vivus BT sprays 'Success'	Pheromone traps Direct search
Armyworm	Parasitic wasps Parasitic flies Damsel bugs Pentatomid bugs	Nil	BT sprays Banded sprays targeting the 'front'	Direct search

the results of the assessment. With this information added into the final column, the table is now complete.

The term Integrated Pest Management (IPM) was first suggested in the 1950s by Stern, Smith and Hagen (1959) and it simply meant that biological control agents, cultural methods and chemicals be integrated so that better control of pests would be achieved than by chemicals alone. We believe it is an approach that is never going to be static and will be different, even for the same crop, in different locations and on different farms.

3

Pests

The starting point for this chapter is that farms are agricultural ecosystems, not sterile laboratories. It is well known and accepted that soil biology and biodiversity (including earthworms and micro-organisms) are essential for productive farming systems. So it should not be a great step to accept that there are other macro-invertebrates (that is, invertebrates that you can see without a microscope) that contribute to ecosystem health, as determined by farmers. There are species that actively decompose plant material (such as stubble), species that prey on pests and others that are not pests or predators but which provide a link in the food chain.

Why do some insects and mites become pests?

Some things that farmers do can fundamentally change the agricultural ecosystems that they manage. A very recent example of this is the change from 'conventional' tillage to minimal tillage and stubble retention. The habitat for soil-dwelling invertebrates is changed in a substantial way when farmers decide to change from conventional to minimum tillage. The most immediate result seen by farmers is that increased pest problems (in terms of slugs, snails and earwigs) occur. The changed habitats have changed environmental conditions to favour certain pests because these conditions provide an increased food source and increased shelter. Habitat change is just one reason for increased pest problems that has occurred in the last few years. There are many other ways that insects and mites can become pests.

Most farmers grow monocultures of crops where the aim is to produce a single species that will be harvested. For example, a paddock of canola or wheat would normally be treated with selective herbicides to ensure that the crop has no plant competitors, and treated where necessary for pests so that it remains intact until harvest. So the emphasis is very much on the production of a single species per paddock. It is a similar situation in grazing, even where a mixed grass sward is present. The aim is to provide desirable species of grass in order to produce a single animal species (such as sheep or cattle).

The production of a single species means that there is a large amount of food present for potential pests, often without competitors or natural enemies. This situation occurs, for example, when reliance is placed on broad-spectrum insecticides where the pest becomes resistant to the insecticides. The pest can tolerate the rates and type of insecticides used but the predators and parasites that make up its natural enemies are killed. The result is a pest with an almost limitless food supply. In Australian agriculture we have pests such as diamondback moth (*Plutella xylostella*) and heliothis (*Helicoverpa armigera*) that are resistant to many insecticides and are of major concern to many farmers. Diamondback moth is of particular concern to those wanting to grow summer brassica forage crops.

A common method of *creating* pests is by the regular use of broad-spectrum insecticides (or even some fungicides). This often surprises people, because pesticides are applied *to reduce* pest problems. This can occur in a few different ways, as described below.

Secondary pests are created when pesticides targeting a primary pest (or disease) kill the natural enemies of a different species which is tolerant to that pesticide. For example, pesticides targeting cabbage white butterfly could kill the predators and parasites that control diamondback moth. The dose of insecticide may kill cabbage whites but not diamondback moth, and so a new – or secondary – pest is created.

1 We could expect a similar situation in cropping systems, where broad-spectrum pesticides targeting redlegged earth mite (RLEM) (see Figure 3.1, page 51) are used routinely, but where another species of mite (blue oat mite, BOM) (see Figure 3.2, page 51) is often present as well. Even if RLEM is controlled well by pesticides, if the result is a loss of predators that would otherwise have controlled BOM, then we can expect to see an increase in blue oat mite. Similarly, predators of lucerne flea (including predatory mites) (see Figure 3.3, page 52) exist in Australian crops and as these include several species of mites, the insecticide's targeting would be damaging to populations of these predators. Therefore, we could reasonably expect that in areas where routine sprays are applied for redlegged earth mite or blue oat mite we could find increasing problems with lucerne flea (see Figure 3.4, page 52).
2 It is entirely possible that in many cropping situations, foliar applications of pesticides (such as those targeting caterpillars or aphids) are killing the generalist predators (like carabid beetles and earwigs) that help to control

resident establishment pests such as slugs and mites. There has been research in Australia and overseas to indicate that this situation occurs often.

3 Insecticide resistance does not have to be involved for us to see increasing target pest numbers following pesticide application targeting that pest. Some pests, such as aphids, have very short life cycles and populations can increase rapidly. Pest aphid species have some unusual features to their life cycle, including having wingless adults, all-female populations and adults that give birth to live young (nymphs) rather than eggs. What this means in practice is that if not all aphids are killed by an insecticide application that kills most of their natural enemies, then the aphid population will grow very rapidly. This is called 'pest flare' and often occurs in many horticultural crops with two-spotted mite (*Tetranychus urticae*) being made to flare in crops such as apples and flowers. This same mite is now accepted as a routine pest in potato crops in the USA (*Potato Country* 2006) – a situation that would horrify Australian potato growers. It is almost certainly due to the pesticide regime used there and is a situation which is better avoided than treated! Pest flare with aphids is most likely to occur where the pest is in a sheltered position which makes it difficult to obtain good coverage with a pesticide. A dense canopy will obviously make it more difficult to place pesticide in contact with the pest.

4 Some insects may not cause any damage at all to a crop but still be considered a serious pest in some circumstances. Such a situation occurs for example when insects of any type are not accepted in export produce. They are contaminants rather than pests, but farmers may deal with them as they do other true pests. White snails in cereals are an example of contamination pests, as they move to the head of the plant just before harvest.

5 Not all pests are equal in terms of the damage that they do or the concern that they cause. There are often **major pests** (those that can cause serious damage) and **minor pests** (those that can cause damage at times but usually the damage is not serious). Examples of this include blackheaded pasture cockchafers as major pests and whitefringed weevils as minor pests in pasture. In the same paddock, the importance of a pest can change with the type of crop being grown. So in the example here, the minor pest (whitefringed weevil) in pasture can become a major pest if a susceptible crop such as potatoes is planted.

Factors that increase pest pressure

We know that any crop or pasture has its own set of potential pests, and these will vary from place to place. There are some factors, over which we have varying degrees of control, which can have great impact on the pest pressure. Managing these factors falls under the heading of 'Cultural controls' and is dealt with in Chapter 5. Here we simply want to emphasise that there are factors that may be peculiar to a locality, paddock or year that will make the pest pressure in any given pasture or crop different to that in another apparently identical crop in another locality, paddock or year.

Some of the factors that we think are important are listed here, with an example or two to illustrate the point.

1 The level of certain weeds (such as capeweed, *Arctotheca calendula*) over summer can increase populations of pests (such as RLEM). This winter broadleaf weed is a highly suitable host plant for RLEM, which will breed on it and lay summer dormant eggs. That means the mites will survive activities such as ploughing and spraying over the summer and early autumn, and hatch after rainfall in autumn. Therefore planting susceptible crops such as clover or canola in paddocks that had high levels of capeweed the previous winter can be expected to suffer RLEM damage.

2 Pasture paddocks with much bare ground and animal manure can be expected to have higher levels of blackheaded pasture cockchafers (*Acrossidius tasmaniae*). The adult female beetles prefer to lay their eggs in bare ground, and will lay more eggs if they have a dung meal than if they do not get such food. Therefore, you can expect more blackheaded pasture cockchafer problems in overgrazed paddocks or in drought years.

3 Timing of planting can have a far-reaching influence on the level of damage caused by both resident and invasive pests. For example, in south-eastern Australia, canola planted early in autumn (immediately after the break) will spend less time as vulnerable seedlings than later planted crops, simply because the weather gets colder as we move from April to May and then June. The crop that grows quickly is likely to have fewer damaged plants for any given level of pests (such as slugs or earwigs).

   Early-planted cereals on the other hand can be at much greater risk of barley yellow dwarf virus (BYDV) than later-planted crops. This is the exact opposite of the example given above for canola but the reason is very similar. Insects, including aphids, are active (and flying) when the weather is still relatively warm in early autumn, but they become less active and populations do not fly as the weather gets colder. Therefore, if BYDV is present and vectored by aphids then early-planted crops are likely to have more aphids and so be at higher risk of BYDV infection than later-planted crops.

4 The health of individual plants, and of course the whole crop, can affect the incidence and severity of pest (and disease) attack. Even very healthy plants can be attacked by pests, but stressed or unhealthy plants are more vulnerable. Pests such as aphids are often associated with less healthy plants. This can be seen on the edges of many crops, where fertiliser applications may have been missed or fungicide coverage may have been less than ideal and so the plants

are not as healthy as further into the crop. The same occurs on the edge of irrigated crops, where the outer plants may not receive the same amount of irrigation as the bulk of the crop.

Herbicides are often applied to germinating crops and sometimes the germinating crop suffers herbicide burn. When this happens the crop suffers a setback in growth compared to one that is not burnt, and so can remain in a more vulnerable stage to insect or other pest attack for a longer time.

5 Soil preparation is important, as every farmer knows, but once again it is not always possible to have perfectly prepared ground. When a crop is planted into very cloddy soil then there will be poorer germination rates and also relatively greater damage caused by pests such as slugs. The better protection provided to slugs by cloddy ground combined with the slower germination and growth means more damage for the same density of pests.

6 Two factors that can lead to increased pest pressure are performed deliberately by farmers because of agronomic advantages, and these are stubble retention and minimal tillage. Obviously pest management must change so that these desirable practices can be maintained, but they demonstrate the power of cultural methods in controlling pests. Slugs and wireworms are examples of pests that take advantage of the changed habitat and so become more important in crops grown using these methods.

7 The final example is the creation of secondary pests by pesticide application. This is discussed in detail later in the book, but is listed here as it is something that is within the farmer's control and is probably a regular occurrence in Australian agriculture. What happens is that pesticides applied to control one pest (such as RLEM or caterpillars) kill the biological control agents of another pest (like carabid beetles or brown lacewings). In these examples it would be expected that the pests that would have been eaten by carabid beetles and brown lacewings would then increase in number and become worse problems because the insecticide applied was not effective against these second pests. Therefore, in these examples we would expect slugs and aphids to become worse problems.

When all of these factors are considered it is fairly easy to see that there are many actions, over which farmers have control, that also have a great impact on pest pressure in any given location. To ignore these factors and rely on pesticides alone is not a good strategy.

Environmental factors beyond our control

Pest problems may be worse in some years compared to others for reasons that we cannot control, such as what is happening in neighbouring crops, or the weather conditions. Some pests such as heliothis can invade crops from long distances away as can other pests like the diamondback moth and the Rutherglen bug. In that sense there is really no typical year, as the range of pests and their intensity can vary markedly.

Thresholds

Thresholds have been developed and used for many years in Australian agriculture. The theory behind this is that no action is required until pests reach a level that will cause economic damage. Therefore, threshold numbers (the number of pests in a given sample) are the trigger for spraying an insecticide:

> *Example 1: Pea weevil*
> Spray if you find 2 or more beetles in 25 sweeps along an edge of a crop repeated 10 times.
>
> *Example 2: In canola crops*
> Spray if you find more than 5–10 caterpillars per m^2.

The thresholds that have been developed for the major pests in southern Australian crops are summarised in a GRDC Advice Sheet called *Insect Control Thresholds* (March 2000) which can be found on the GRDC website. Some of the thresholds from that document are included in Table 3.1 below. We include them for reference, not because we think they should be used on their own. The discussion below the table explains our thoughts on thresholds in more detail.

Table 3.1: Thresholds available for some pests in cereals and canola*

Pest	Threshold in cereals	Threshold in canola
Redlegged earth mite	50 mites/100 cm^2	10 mites/100 cm^2
Blue oat mite	50 mites/100 cm^2	10 mites/100 cm^2
Lucerne flea	–	10 holes per leaf
Common cutworm	2 large larvae/50 cm of row	2 large larvae/50 cm of row
Grey false wireworm (larvae)	–	50/m^2
Blackheaded pasture cockchafer	2–5 larvae/m^2	–
Slugs	–	None
Native budworm	–	5–10/m^2, larvae >1 cm
Armyworm	2 large caterpillars/m^2 barley	–
Common white snail	30/m^2	20/m^2

*Source: GRDC Advice Sheet: *Insect Control Thresholds* (March 2000) by Dennis Hopkins and Hemantha Rohitha.

The problem that we have with thresholds is that they do not take into account the many variables that can influence the ability of pests to cause actual economic damage. That is, given a number of pests (x) how much damage would they cause with (x, y or z) beneficial species present, at different planting dates (and so different growth rates), with different planting rates, different weather conditions, different value of crops at different times and in different years with the crop worth different amounts.

All of these variables make it impossible to say x pests means a set level of economic loss. In some situations (such as where no beneficial species are present) the threshold can be accurate but in the vast majority of situations we believe that there is no simple association between pest numbers and economic damage. For example, an early-planted crop of canola, sown into well-prepared ground with good germination, will tolerate a higher number of establishment pests than the same crop planted later, or into cloddy ground (see points 3 and 5 in the section above – 'Factors that increase pest pressure'). If the pest in question is a vector of viral disease then the use of thresholds is even more complicated to assess at this stage. We do know, however, that seemingly bad damage early on can often be tolerated and the plant grows normally. The problem for the farmer and adviser is to know with confidence that such will occur before the opportunity to apply an appropriate insecticide has passed.

A difficult item to address at this stage of IPM adoption in Australia is the true cost of pesticides. This is discussed further in Chapter 6 (Chemical controls) and Chapter 8 (Case studies) but is mentioned here because it makes the use of thresholds even more difficult. We need to know both the cost of lost beneficials in a paddock, and subsequent 'flare' of pests in both the current crop and future crops before we can decide on the economics of using a non-selective insecticide.

Descriptions of pest species

Information about some of the most commonly encountered pests is presented here. It is not an exhaustive list, but will cover the main concerns and requirements of anyone wanting to implement an IPM strategy on their farm.

We have given information about the biology of these pests, and included where known the most important natural enemies of each. Where possible we have used the species listed as examples of a wider group with similar traits. For example, information on mites in general can be found in the section on RLEM and information on weevils as a group is presented in the section on whitefringed weevil.

Resident pests

Black field cricket

Black field crickets (*Teleogryllus commodus*; see Figure 3.15, page 58) are abundant in southern Victoria while brown field crickets (*Teleogryllus* sp.) are pests in some areas of northern Australia (Queensland). They chew on leaves of plants and can leave large areas of pasture or young crops as bare ground when they are in high numbers. Females of these species have long ovipositors on the tip of their abdomens which insert their eggs into the soil. Eggs will sit dormant in the soil over winter and tiny nymphs hatch in spring. The nymphs gradually increase in size with many moults until they form wings as adults. These crickets benefit from dry conditions with cracking soils which provide them with shelter. Adults disperse on hot nights in summer, and are attracted to lights. In late summer and early autumn they will breed following rains, but when the weather becomes cold and wet they begin to get diseases and the population crashes.

Note that there are cricket species other than *Teleogryllus* that can be very abundant. In Victoria these include species of *Buangina* and the pygmy cricket *Yarrita pikiara*.

Cockchafers

Blackheaded pasture cockchafer (*Acrossidius tasmaniae* – formerly *Aphodius tasmaniae*)

The adult cockchafers are shiny, dark brown to black beetles about 10–12 mm long. The females prefer to lay eggs in bare ground, and will lay more if they can feed on animal dung. So areas where sheep or cattle camp are likely to be worst affected. Large flights of adult beetles occur on warm nights in summer. The larvae are stimulated to hatch following rains in autumn. Initially the tiny larvae feed on organic matter near the soil surface and later they eat living plants. The larvae form tunnels in the soil and emerge onto the soil surface at night to collect plant material. They take this material down into their burrows to eat. There is only one generation a year, with larvae ceasing to feed around September when they turn into pupae. Larvae are white-cream coloured, C-shaped grubs with a shiny black or brown head. They have three pairs of legs.

(See Figure 3.14, page 57.)

Redheaded pasture cockchafer *(Adoryphorus coulonii)*

This species of cockchafer is in many ways the opposite of the blackheaded pasture cockchafer as the adults are active at a different time (flying in winter and early spring). The redheaded pasture cockchafer prefers to lay eggs on dead, long grass or standing stubble, and it has a two-year life cycle so the immature (grub) stage stays underground for nearly two years. Also of great practical importance is the fact that the grub stage does not come up to the surface to feed, but instead eats the roots of plants from beneath. Without roots the grass can be peeled back by birds that are searching for grubs. It also means that applying conventional insecticides is not effective in most situations. These cockchafers are similar in shape to the blackheaded cockchafers except that they are larger and of course have red heads.

Cutworm

There are several species of moths that have caterpillars called cutworms (see Figure 3.12, page 57). The best-known of these moths is probably the Bogong moth (*Agrotis infusa*). Depending on the species and the time of year, cutworms can have a life cycle of a few weeks or many months. The caterpillars are plump and greasy-looking and when disturbed they curl up in a spiral. During the day the caterpillars shelter in the soil and come out to feed at night. They cut leaves or stems of seedlings (hence the name) and attempt to drag these underground. These caterpillars are very tough, and can even survive rotary hoeing in horticultural crops.

Earwigs

Earwigs are typically long, slender insects with a pair of forceps at the tip of their abdomen. The forceps of males are usually larger, and a different shape than those of females. Adults usually have wings folded in a complex manner under a short protective cover (elytra) but some species (such as *Euborellia*; see Figure 3.7a, page 54) do not have wings even as adults. The earwigs that are described here cover the range of ecological types as they include plant feeders, scavengers, predators, detritus feeders and a combination of all of these. Therefore, some of these species are beneficial and others are pests, and even more difficult to classify are those that are only pests when in high densities but could be beneficial at low densities.

Earwigs such as *Euborellia* are flightless, and they appear to form mating pairs that maintain a small territory. Therefore a male and female are often found together, and at certain times of year a brood of young earwigs may also be found. Parental care of egg masses and young earwigs is recorded in several species around the world and appears common here.

It is very important to correctly identify the species of earwigs found, simply because there are such variations in their roles as pests, beneficials or benign species. It is not sufficient to assume that the earwigs seen in a paddock are all pests. To identify a pest earwig as a beneficial, or a beneficial as a pest, would result in inappropriate action.

Pest earwigs damage young plants by chewing foliage at the establishment stage. They could also be a contaminant at harvest-time. Earwig damage to plant leaves is almost identical to that caused by slugs.

Adult European earwigs grow to 12 to 15 mm long and they have long slender bodies with a pair of forceps on the tail (see Figure 3.7b, page 54). Males and females have different shaped forceps (males more solid and curved than the females). The wings are folded under wing covers on their backs. Their bodies are dark red-brown and their legs are pale. Nymphs look like smaller versions of the adults.

There is one generation a year, with adults being inactive over summer, often forming aggregations in sheltered places. Nests of juveniles become active in winter and mature over spring. Sheltered positions such as cracked ground or under rocks, or paddocks with retained stubble, will favour European earwigs. Other earwigs can be beneficial (*Labidura truncata*) or minor pests (*Nala lividipes*; see Figure 3.7c, page 54) or benign (*Euborellia* spp.).

Lucerne flea

Lucerne flea (*Sminthurus viridis*) is a pest of broadleaf plants such as clover, canola and lucerne, although it also feeds on cereals (see Figure 3.4, page 52). Lucerne flea is not an insect, but belongs to a closely related group, the springtails (Collembola), and most members of this group are not pests. (Some of the non-pest species are often seen floating like a grey dust on puddles.) They prefer moist conditions and so they are typically winter pests. Their biology is extremely similar to that of RLEM as they produce over-summering eggs that are resistant to desiccation. The eggs are triggered to hatch after autumn rain and then there are several generations over winter (Wallace 1967).

Lucerne flea is not native to Australia; however, a range of native (and introduced) predatory mites are known to prey on it. This has been known for a long time (Swan 1940), as has the fact that insecticides can kill the predators and so exacerbate the problem (Wallace 1954). The effective control of lucerne flea, or more precisely avoiding lucerne flea problems, is linked to the careful use of insecticides. Even insecticides targeting aphids can induce a flare of lucerne flea by killing useful predators (Bree Walshe, La Trobe University, unpublished data, 2005). Problems with lucerne flea appear to have increased in the last few years, and we suspect that this is because insecticides targeting either lucerne flea or other pests have killed the predators that would otherwise have held them in check.

Redlegged earth mite (RLEM) and blue oat mite (BOM)

These mites look similar but have important differences in their biology and physiology that affect how they can be controlled. Both are mites which means they have only one body segment (spiders have two, insects have three) and eight legs. They have red legs and their bodies are velvety blue to black, but BOM has a red oval patch on its back (see Figures 3.1 and 3.2, page 51). Nymphs look like adults. Their feeding damage causes silvering of leaves, and so cotyledons can be severely affected.

RLEM usually has four generations per year, while BOM has two generations. Both become active in autumn following rain, and continue to be active over winter. Both RLEM and BOM produce summer diapausing (resting) eggs but they produce these at slightly different times, so the Timerite® strategy does not work for BOM. Also, BOM is far more tolerant of insecticides than RLEM. If an insecticide spray is required in autumn it is best applied within five weeks of the emergence of the mites, before they turn into adults and begin laying eggs.

Capeweed and other broadleaf weeds encourage a higher population of these mites.

To reduce RLEM and BOM populations we can:

- control broadleaf weeds in the years before vulnerable crops
- plant resistant varieties
- consider border sprays or border plantings of plants unfavourable to RLEM
- cease killing predators of these mites.

Slugs

All the slugs that are pests in Australian crops and pastures are not native Australian slugs (see Figure 3.6, page 53). They originate from a variety of countries across the northern hemisphere and some have adapted to Australian conditions. They are hermaphrodites, which means each individual has both male and female reproductive organs, and that each individual has the potential to produce offspring (not just 50 per cent of the slug population). Slugs require moist habitats, as they move on a slime layer and secrete a slime coating over their bodies. This means that they typically are inactive over summer or in dry conditions and become active only when there is sufficient moisture.

Some species such as *Arion intermedius* are only found in the coolest, wetter areas but others such as *Milax gagates* can tolerate relatively dry conditions such as found in South Australia and Western Australia cropping areas. However, as the conditions become dryer (such as in the Wimmera in Victoria) slugs cease to be a major concern and these mollusc pests are replaced by snails. Each species of slug has different biology to the others and this changes their relative pest status and optimal control measures.

Slugs can be serious establishment pests in broadleaf crops such as canola and clover. They eat cereals as well, and can be pests if they are present in enough numbers, but the canola and clover-type plants are more vulnerable than the grasses because of the cotyledon stage. If the emerging canola or clover plant is seriously damaged in the cotyledon stage then it will not recover and the plant will die. On the other hand, cereals can stand more harm to the plant and can even grow out of some damage.

We believe that rotations that consist of two tolerant crops (such as cereals) followed by a susceptible crop (such as canola) allow slug populations to increase in the cereals and cause serious damage in the canola. A better strategy would be to attempt to control the slugs in the cereals and not leave it all until the susceptible crop.

In pastures, a strategy that involves more than baiting is required, especially where seed is direct-drilled into existing pasture.

Deroceras reticulatum is the only species that produces a milky white mucus when disturbed (that is, poked). It will breed whenever moisture is present. It is a major pest in Australian crops and pastures.

Deroceras panormitanum is an almost uniform chestnut-brown colour with no distinctive markings. It may be more common in pastures than cropping habitats. It does less damage (per individual) than *D. reticulatum*.

Milax gagates is usually very dark with a sharp ridge, or keel, running along its back. It is very damaging (per individual) compared to the other slug species. It is a true burrowing species and can survive drier conditions than most, making it a relatively more serious pest in drier areas.

Lehmannia nyctelia has stripes down the length of the body, but these can sometimes be very pale and not immediately obvious. It tends to aggregate and so many can be found at one location with none nearby. Although a pest species, it is not particularly damaging per individual.

Lehmannia flava is a large slug that produces a yellow-orange mucus. It is not found in cropping situations, but it does occur in pastures. It is not known to be a serious pest in Australia.

Arion intermedius is a small slug with a yellow foot. Although it is an important pest of pastures in New Zealand (see Barker 1999) it is not a serious problem in Australia. In occurs in the wetter areas of SE Australia (Tasmania and Victoria).

For photographs of all these slugs refer to the *GRDC BackPocket Guide to Slugs* 2006.

Snails

There are a couple of snails that are serious crop pests, especially in South Australia, but there is also increasing concern in other states. The Italian white snail (*Theba pisana*) and common white snail (*Cernuella virgata*; see Figure 3.5, page 52) are the most serious pests at this stage, although conical snails are also increasing in pest status.

Snails have a shell, which means they can survive and inhabit drier areas than slugs. This requires calcium, which may be one reason introduced pest snail species prosper in high calcareous soils such as occur on the Eyre Peninsula. When conditions begin to dry out, these snails retract entirely into their shells and then produce special mucus that hardens and seals the opening. In this way they can survive the hot dry summer, and become active again only when moisture softens that seal.

Most work on snails as cropping pests has been performed in South Australia, including the release of a fly that parasitises snails.

Weevils

There are several different species of weevils (beetle Family Curculionidae) that can be found in crops and pastures, and their biology, pest status and control also differ. To illustrate this point, we give below just a few examples of weevils that are commonly found in Australian crops and pastures.

Adult weevils are identifiable by two features – the first is that the head is extended into a snout and the second is that their antennae (which are elbowed) are situated on the snout (see Figure 3.16, page 58).

Figure 3.17 (page 58) shows an adult weevil and it can be clearly seen from the photograph that it belongs to the weevil family.

The larvae are different to those of most other types of beetles as they have no legs and look like maggots, as can be seen in Figure 3.18, page 59.

Whitefringed weevil (*Naupactus leucoloma*) is an introduced pest of many crops (including both horticultural and broadacre) and pastures. No males are known, so the populations of pests are all females. Adult weevils do not fly and prefer legumes to other food types. If they eat legumes the weevils can lay more than 1000 eggs, but if they are restricted to cereals or grass then they will lay as few as 10 eggs or less. The juveniles are cream-coloured grubs that live below the soil surface and have no obvious head but simply a pair of black jaws (see Figure 3.18, page 59). The life cycle from egg to adult may take more than one year, depending on the location in Australia.

Vegetable weevil (*Listroderes difficilis*) is a smaller species but with a very different biology. The juvenile weevils (grubs) live above ground and feed on the foliage of plants rather than the roots. They particularly favour broadleaf weeds such as capeweed and marshmallow weed. The body shape of vegetable weevil larvae means that they could be mistaken for hoverfly larvae, but the weevils have a distinct dark head while hoverflies have no obvious head.

Small lucerne weevil (*Atrichonotus taeniaulus*) looks like a smaller version of whitefringed weevil, at least as an adult. The adults grow up to 10 mm long. The grubs are white and live below the soil surface feeding on roots, but they have a distinct dark head.

Desiantha weevil (spotted vegetable weevil) (*Desiantha diversipes*) is a common species in cropping systems in some areas of southern Australia. It is a tiny weevil (adults are about 5 mm long) and the body is spotted. It is a cereal crop pest due to its larvae living below the soil surface that attack germinating seedlings.

Sitona weevil (*Sitona discoideus*) is the smallest of the weevils mentioned here, and is a pest of lucerne and medic pastures. The adults are 3–5 mm long with three white stripes behind the head. The adults feed on leaves while the larvae feed on the roots of the plants.

Wireworms and false wireworms

Wireworms are so called because they have worm-shaped larvae. They are actually very tough-skinned insects – beetles, not soft worms. The two names refer to the larval stages of two different groups (families) of beetles. True wireworms are juvenile click-beetles (Elateridae) (see Figure 3.11b, page 56) while false wireworms are juvenile tenebrionid beetles (Tenebrionidae) (see Figure 3.11a and c, page 56). There are thousands of species in each of these families and only a very few are recorded as pests. Both wireworms and false wireworms are relatively long-lived native species with generation times ranging from one to seven or more years. That is, the juvenile stages live in the soil for slightly less than one year to more than seven years, depending on the species. The larvae can damage germinating seeds below the soil surface and the aggregating adults can also damage newly emerged seedlings. However, the natural food source for these insects is probably rotting plant material.

What is the difference between wireworms and false wireworms and why does it matter? Pest species of both wireworms and false wireworms appear to prefer poorly drained paddocks and they move vertically in the soil profile following a moisture gradient. That is, they move up when the soil profile is wet in winter and move down when the soil is dry in summer. That means of course that they are near the soil surface when seed is planted after rains in autumn. False wireworms are probably encountered as pests more than true wireworms. Adult beetles of these pest species can aggregate. Adult false wireworms such as *Gonocephalum* aggregate under shelter on the soil (such as under clods of earth, rocks or timber) and many true wireworms aggregate at times in the same places or under bark.

Pest species include several species of *Gonocephalum, Pterohelaeus, Adelium* and the smaller *Isopteron punctatissimus*. *Isopteron* has been regarded as a serious pest of canola but it is often difficult to find because of its small size.

Transient pests

Aphids

Aphids are sucking insects that feed on plant sap (see Figure 4.2, page 59). This is a protein-poor diet and so they ingest a lot of liquid and excrete a sugary waste called honey-dew. The deposits of honey-dew encourage sooty mould. Aphids can form large colonies of wingless individuals (often all females) and only develop wings when they detect that the season or the plant conditions require that they migrate away from the plant.

There are many different species of aphids that attack crops, but each species has its own preferences and seasonality. They can be pests because of the damage they do by feeding on crops but also because some are vectors of disease. For example, oat aphids *Rhopalosiphum padi* vector Barley Yellow Dwarf Virus.

Armyworm
There are three species common in southern Australia. These are:

- Common armyworm (*Mythimna convecta*)
- Southern armyworm (*Persectania ewingii*)
- Inland armyworm (*Persectania dyscrita*).

(See Figure 3.8, page 55.)

Adult moths fly on warm nights in autumn and again in September–October and lay their eggs in dried grass. The eggs take from one to three weeks to hatch and then the caterpillars begin feeding.

Armyworms can be distinguished from other caterpillars by the following set of features:

- they have three white stripes behind the head and on the tail
- they have three light stripes running the length of their bodies
- there are no obvious hairs.

They can occur in large numbers in cereals and pasture grasses and when they have locally depleted supplies of food, they march into adjacent areas (hence the name). Caterpillars range from 2 to 40 mm long. Armyworm caterpillars normally feed on leaves and in winter cereal crops can be affected. In spring seed-heads may be lopped (particularly barley).

Heliothis
Commonly known as heliothis, two species in the genus *Helicoverpa* (formerly called *Heliothis*) – *Helicoverpa armigera* and *Helicoverpa punctigera* – are important pests, especially in northern Australia where they can be more abundant (see Figure 3.9, page 55). Adult moths are up to 30 mm long, light brown with green eyes. Caterpillars can grow up to 35 mm long, have stripes and short black hairs along the length of the body. Their colour is extremely variable, from pale green to dark brown.

Heliothis chew holes in leaves, flowers and fruit, the damage becoming worse as the caterpillars grow. Damage is very similar to that caused by looper caterpillars (*Chrysodeixis* species), which are much easier to control.

The adult female moths lay round eggs on foliage, often singly on the underside of the leaf. Caterpillars tend to move continuously from leaf to leaf, probably to avoid predators and parasites. Adult moths are most active at night and are very strong fliers. They migrate long distances in Australia and are important pests in a range of crops (which includes cotton, corn and many vegetables). Insecticide resistance, especially in *Helicoverpa armigera*, has made this species a particularly difficult pest when insecticides are totally relied on for control (Horne *et al.* 2002).

Important beneficial species that help control these pests include wasp and tachinid fly parasites, damsel bugs and predatory shield bugs.

Pea weevil

The pea weevil (*Bruchus pisorum*) is actually not a weevil, but a beetle called a bruchid (Family Bruchidae rather than Family Curculionidae). If you look closely you will see that it does not have elbowed antennae as described above (see Figure 3.19, page 59). The fact that it lives inside pea seeds gives it the reputation of being a weevil.

It is extremely important to know the biology of this species to be able to achieve control. The beetles overwinter under the bark of trees or in fence posts. They emerge in spring to feed on the pollen of pea flowers and then shortly afterwards lay their eggs on the developing pea pods. As the crop and the beetles mature, the beetles move further into the crops laying successive batches of eggs.

Control is still based on insecticides, but the sprays can be limited to border sprays (plus around trees) if the timing is correct. Sprays should be applied at the first signs of flowering so that the beetles are killed before they lay that first batch of eggs.

***Plutella*: Diamondback moth**

Diamondback moth (*Plutella xylostella*) is possibly the most serious insect pest in the world, as it attacks brassicas, for which there are many different crops (see Figure 3.10, page 55). Asian vegetables such as bok choy and pak choy, European vegetables such as broccoli, cauliflower and cabbage, and also canola and fodder brassica crops are all affected by this insect.

Controlling this pest has been made much more difficult because of insecticide resistance. Until very recently, cabbage white butterfly (*Pieris rapae*) was the main caterpillar pest of concern to growers of brassica crops. Insecticides targeting this pest have been largely effective but the development of a new pest (*Plutella* – the cabbage moth or diamondback moth) has been a much greater problem.

The problems that Australian farmers have with *Plutella* are almost certainly the result of the insecticides initially applied to control *Pieris*. The same situation exists throughout the rest of the world. Insecticide resistance is the reason for the problem and also the difficulty in developing better control strategies. The cheap broad-spectrum insecticides applied at low rates simply do not work any longer.

Plutella can be easily controlled within an IPM strategy involving predators, parasites and BT sprays. 'BT' stands for *Bacillus thuringiensis* – a bacteria that produces a toxin that kills caterpillars (see Chapter 6 on pesticides).

Rutherglen bug

Rutherglen bug (*Nysius vinitor*) is a true bug; this means it is a sucking insect like an aphid (see Figure 3.13, page 57). The damage it does is also similar to that of aphids, but it can also be a contaminant as it often appears in extremely large numbers. Large flights occur on warm winds in November and December as the bush dries out.

Adult Rutherglen bugs are dark brown and 3–4 mm long. They have narrow, hard bodies and they are able to pass through flywire. Often mistaken for flies, they are often seen near windows once they get into houses. The juvenile stages are far more colourful than the adults, with dark red and orange on their backs, and they are also more rounded rather than straight sided.

The adult females can lay up to 400 eggs, and these are placed on grass, soil or weeds. Some of the favoured plants include capeweed, wireweed, fleabane, pigweed and thistles. It has been thought that there is usually only one generation per year, but when the adults move early in spring there may be more than one generation per year.

4

Biological controls

The most interesting component of IPM for many people is biological control. It is also the most complicated as there is a diverse range of species and types of predators and parasitoids. There are also many more species that are neither beneficial nor pests and it is important for growers to be able to recognise this.

Definitions

The term 'beneficial species' in this book is used to describe invertebrates that directly kill pest species. That is, we mean the biological control agents that exist in agricultural systems (wherever they originated). Obviously there are other types of beneficial invertebrates, such as those involved in breaking down organic matter so that nutrients are recycled. Earthworms and many types of beetles, mites and springtails, for example, fall into this category of 'beneficial' but not a biological control agent of pests.

There are many different ways to categorise the types of biological control agents in agricultural habitats – where it lives (resident or transient); the origin of the species (native or exotic); and the way it feeds (predator or parasite). Scientists can and do use many other divisions and definitions, but in this book these three categories are the most relevant to our theme.

Resident beneficials

The amount of living plant material in a crop or pasture changes dramatically during a season, from almost bare ground in many cases to a dense canopy of flowering plants. The change from a paddock that is herbicide treated and about to be planted with wheat, canola or beans in autumn to the crop before harvest in spring is massive and this change is reflected in the number of invertebrates (pest and beneficial) that can exploit the habitat. Similarly, in grazing paddocks (grass, lucerne or clover or other) there is a huge change in the amount of plant material at different times (such as just before and just after grazing) and it may be flowering or not. To invertebrates this represents a change in habitat structure and food sources, and so different species can live there at different times, just as they do in crops.

Over summer and in early autumn in southern Australia there is very little green plant material in paddocks and so the area cannot support the same invertebrate population that it does in spring. However, there is a resident population of invertebrates that lives in the soil or on and near the soil surface all through the year. This includes some pest species such as cockchafers, wireworms, European earwig, RLEM and lucerne flea but also beneficial species such as carabid beetles, predatory earwigs, spiders and predatory mites. These species live in the paddock all year round. In many cases they do not have wings as adults and so cannot fly which means that both juveniles and adults are permanent residents. The number of any particular species is determined by factors such as the history of pesticide use, habitat structure (such as stubble retention or not), and amount of food. These factors are interlinked of course, as the number of pests can influence the decision on pesticide use, which in turn will influence the number of pests and beneficials.

If the predators in the system are not disrupted by pesticide application, their numbers will be controlled by other factors such as shelter and food availability. General predators can feed on a range of prey and so populations can survive even when one type of food source is scarce. The numbers of individuals in species that are totally dependent upon a single other species as prey will oscillate as the numbers of its prey either increase or decrease (see Figure 4.1 below). This predator–prey cycle is known for many animals, not just invertebrates. When the prey is a pest species, the aim for us is to maintain the oscillations below levels where the pest can cause economic damage. That is, pest and beneficial species would both be present, but at levels where neither was particularly obvious – the system is in balance.

If the predator had more than one prey to feed on then the drop in predator numbers would not fall sharply when the first (preferred) prey was no longer available. This should be the situation where generalist predators are feeding on non-native pest species. Even if the pest is not the preferred prey, the predators should be maintained as they switch to alternative prey species.

Resident beneficials are the biological control agents that are relevant in controlling establishment pests in crops. The long-term maintenance of these beneficial species is what is required to obtain sustainable control of establishment pests and so disruption of these species in the previous crops is to be avoided.

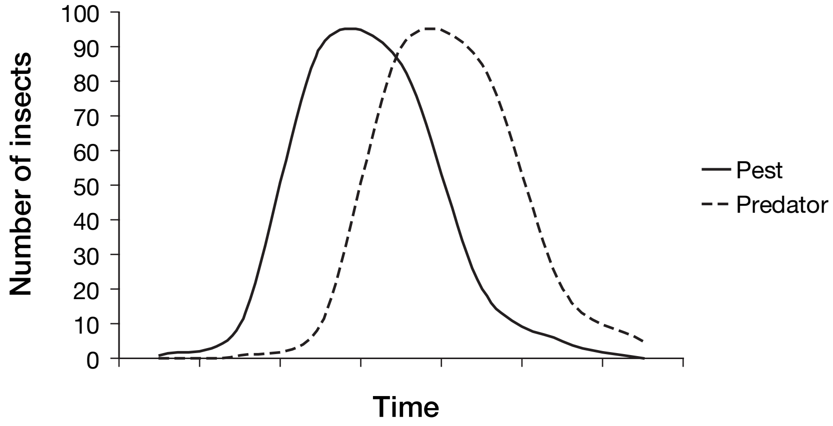

Figure 4.1 Predator–prey cycle.

Some, such as carabid beetles, have long life cycles and so populations will be slow to recover.

Transient species

There are populations of very important beneficial species that do not permanently reside in the same paddock. These are the mobile species with relatively short generation times (weeks rather than months or years) that follow the movements of their prey or hosts. For example, parasitic wasps, brown lacewings and ladybird beetles appear soon after the arrival of aphids (see Figures 4.2, 4.3 and 4.9a, pages 59, 60 and 62). This occurs in a whole range of crops where different species of aphids form colonies. Parasitic wasps would survive wherever their hosts occurred and would themselves colonise aphid colonies and begin to increase in number. Similarly, adult brown lacewings would fly to where aphids were beginning to form colonies and they would lay their eggs nearby. Typically ladybirds would respond to a higher level of aphids while brown lacewings can be found even with low numbers of aphids.

The transient species are neither more nor less important than the resident species – they simply feed on a different set of pests. They are also vulnerable to pesticide use, depending upon when such pesticides are applied. For example, if there is one major flight of lacewings a year lasting two weeks following an aphid flight, and an insecticide is applied that kills the lacewings in week 2, there will be no further large-scale replacement of that species in the current season.

Generalist predator

This term refers to a predator that is not restricted to one species of prey. Even though each will have limits to what it can and will eat, they will accept several different species of prey, and sometimes will also be scavengers. For example, many carabid beetles that are key beneficial species in our pasture and cropping systems will eat a range of pest species (slugs, caterpillars) and will also feed on dead invertebrates. This makes them fairly robust and able to survive well on what is available at the time, but the last attribute also makes them vulnerable to secondary poisoning (eating pesticide-affected invertebrates).

Specialist parasite

This term refers to insects that parasitise (usually) just one species of insect. They are more precisely termed parasitoids by entomologists, as this means an insect that parasitises another insect. They can only live where their one species of host occurs, and so they too follow the predator–prey cycle described in Figure 4.1.

Introduced/exotic

These terms simply mean that the species concerned is not native to Australia but originates overseas. It may have been introduced deliberately (as in the case of many beneficial species) or accidentally (pests). Pest species such as aphids, diamondback moth, slugs and RLEM all arrived from countries overseas as accidental introductions with plants or soil. That means that they have escaped the natural enemies that evolved with them. However, native generalist predators will also attack introduced pests when they are at an appropriate size or life stage. In addition, some of the specialist parasitoids of these pests have been deliberately introduced into Australia to help combat the pests.

Descriptions of beneficial species

Brief descriptions of several key beneficial species are given below.

Brown lacewings

Brown lacewings (*Micromus tasmaniae*) are a native species to Australia and are very abundant in low growing crops and native vegetation. The adults are easily identified by their delicate, lacy brown wings and they are between 8 and 10 mm long (see Figure 4.3, page 60).

Juvenile brown lacewings look completely different to the adults. The immature stages have long, thin bodies with prominent jaws at the front of their head. They are sometimes called 'insect crocodiles' because of their shape. They have cream-coloured eggs which they lay singly on the underside of leaves. The eggs are laid flat on the leaf.

Lacewings prefer aphids, but they will eat just about any insect that is an acceptable size. The larvae are the main predators but the adults also eat insects, especially insect eggs. Larvae eat their prey through curved, hollow jaws, and essentially suck out the body contents of their prey (see Figure 4.4, page 60). Larvae can eat between 100 and 200 aphids each in their short lives.

Adult brown lacewings fly at night, and move into crops soon after crop emergence. They may move into crops following aphids, but then stay to eat other pests. At temperatures of 25 to 30°C a generation takes about three weeks from egg to adult. Brown lacewings can usually be found in crops in spring and autumn when there are aphids present.

Carabid beetles

Carabids (also called ground beetles) are beetles (Coleoptera: Carabidae) in a group that includes many predatory species. The body shape of carabids with typical large jaws pointing to the front so that prey can be captured easily is recognisable throughout the world and the simple silhouette alone is enough for them to be recognised (New 1996) (see Figure 2.1, page 51). Juvenile carabids are also predatory and are likely to be important predators of pests such as cockchafers below the soil surface.

Carabids are generally considered to be beneficial in terms of bio-control of pests in agriculture (Thiele 1977; Kromp 1999), but detailed knowledge on key species in any agricultural ecosystem in Australia is poor. This situation is slowly changing with work, including ours, that involves the use of carabids in cropping and pastures systems.

Research in the UK, suggesting that refuges that foster carabids can be used by farmers to help with pest control in cereal crops, has been widely adopted here. These refuges were given the name 'beetle banks' (Wratten 1992). Research is currently under way in Australia and New Zealand to establish the impact of native carabid beetles on introduced slugs (Horne and Page 2004). In this case the native fauna is being assessed as to how it can deal with exotic pests.

There has also been research and commercial advice to growers in the UK to use pesticides that have least impact on carabids (for example www.mauk.co.uk – Care for carabids). While we have reservations as to the accuracy of the details in such advisories, the important point is that there is recognition that there is a role for beneficial species and the effect of insecticides on them is a factor to take into account.

Among the main pests that carabids are likely to attack are caterpillars, beetles and earwigs. However, detailed knowledge of Australian species and their ecology is so poor that at present they would be best regarded as 'beneficial' without knowing just what each species is best against each pest.

Many species are likely to have a one- or two-year life cycle. None so far are likely to have a shorter than one-year life cycle. This means that the impact of broad-spectrum insecticides applied to broadacre crops or pastures is likely to be far more disruptive to this group of beneficials than others with shorter life cycles (such as brown lacewings).

Damsel bugs

These insects are true bugs (*Nabis kinbergii*) and they kill their prey by stabbing them with their curved mouthparts, then sucking up the liquid contents of the victim. They are slender, pencil-shaped insects and the immature nymphs look like smaller versions of the adult. The adults have wings, which are not obvious as they are held lengthways along the body, and all stages are a grey-brown colour (see Figure 4.5, page 60).

Damsel bugs prefer to eat caterpillars and they can kill caterpillars up to the medium-sized *Helicoverpa*. However, they will also eat aphids and other soft-bodied insects. When damsel bugs are present in large numbers they will provide substantial control of caterpillar pests. Female damsel bugs lay eggs by inserting them into leaves or stems of plants, often in neat rows of 10 or more. The young nymphs emerge and will begin feeding almost immediately if a food source is present. It takes about four weeks for a generation to develop from egg to adult at an average temperature of 23°C.

Shield bugs

The shield bug (*Oechalia schellenbergii*) is similar to the damsel bug in that it is a predatory species of true bug that has sucking mouthparts. The adult shield bug is easily recognised by the large spikes behind the head (its 'shoulders') (see Figure 4.6, page 61). The immature nymphs have bright red marks on their backs that are not visible on the adult. They are larger and stouter than damsel bugs. Shield bugs are also known as stink bugs.

The eggs of this species are laid in closely packed batches and are a metallic, black colour with white spines around the rim of each egg. They are usually laid in multiples of 14. A closely related species is the glossy shield bug (*Cermatulus nasalis*). Adults are similar to the predatory shield bug without the spikes behind the head. The eggs of the glossy shield bug are also metallic coloured with white spines. However, they are usually laid in batches of 50 and have short white spines.

Predatory earwigs

There is one earwig species in Australian cropping and pasture systems that is important as a generalist predator, and that is the common brown earwig, *Labidura truncata* (see Figure 4.7, page 61). Males and females have different shaped forceps on the tip of their abdomen (those of the male are larger), but they are different to those of the main pest earwig, European earwig (*Forficula auricularia*) (see Figure 3.7b, page 54). The main identifying feature of the common brown earwig is the orange triangle behind its head, on its wing covers.

As a generalist predator *Labidura truncata* will accept a range of soft-bodied species as prey, including such different pests as RLEM and heliothis caterpillars. It can be very abundant in agricultural systems in Australia (Horne and Edward 1995) and is closely related to predatory earwigs in Europe such as *Labidura riparia*. Like the carabid beetles, it is relatively long lived with at least a one-year life cycle (Horne and Edward 1995).

Predatory mites

There are many different species of predatory mites that help control pests. They belong to a number of different families and genera and there is no single species that we can say is the most important. In Australia we have both a range of native species and a few deliberately introduced species.

Perhaps the easiest group to recognise is the Bdellidae, or snout mites (see section on lucerne flea, and Figure 3.3, page 52). The mites in this group are all predators (Krantz 1978) and have a characteristic pointed head. *Anystis* species are probably among the more important in our cropping and pasture systems. There are also many mite species that are not well known taxonomically in Australia and these have often been placed in the genus *Hypoaspis*.

Parasitic wasps

There are many species of wasps that attack pest aphids and caterpillars. Several species of *Aphidius* wasps that attack aphids are common. The adult wasps are tiny (2–3 mm long), very slender, winged insects that superficially look like midges (flies). If you look closer you will see the wasps have a very constricted waist and thin abdomen. Wasps have four wings, while flies have only two wings (see Figure 4.2, page 59).

The offspring of the wasps, the ‘mummies’, are more easily seen. These are the shells that were once aphids but have been transformed into cases containing the immature stages of the wasp. They are usually round, almost spherical, and a bronze-gold colour. If the adult wasp has emerged from its host, then a neat round hole can be seen in the mummy. The wasps only attack aphids. They are very efficient at finding and killing aphids and almost every colony of aphids will also have these parasites present if insecticides are not used. They are present wherever aphids are found, in crops, weeds and garden plants (especially seen on roses).

Winged adult wasps search for an aphid colony, or individual aphids. Female wasps sting the aphid and so lay their eggs inside the aphid’s body. The maggot-like immature stage develops inside the aphid, eventually killing it and turning it into a mummy. The wasp maggot pupates and then cuts its emergence hole in the mummy and the winged adult wasp emerges to begin the next cycle.

Initially, as an aphid colony becomes established, few mummies are present. The proportion of mummies to aphids becomes greater as immature wasps complete their development. It is only when the wasp has nearly completed its development that the mummy stage occurs, and only then is it clear that the aphid was parasitised. So, the level of parasitism is usually far higher than it seems.

The *Aphidius* wasps are present in crops where broad-spectrum insecticides are not used, and often keep the aphid population below a detectable level. If broad-spectrum insecticides are used (for other pests), a problem with aphids may be induced. This occurs when the parasites are killed but the aphids survive.

Many other species of wasps attack caterpillars, and each species of caterpillar will have several species that can kill it. These wasps can be relatively large and easily seen (see Figure 4.8, page 61) while others are tiny and more than one adult wasp may fit inside a moth egg. They can be endoparasites (living inside the body of the host) or ectoparasites (living outside the body), and different species will attack different life stages of the host (for example eggs, young caterpillars, large caterpillars). In addition to wasp parasites, there are also many flies that parasitise pests in exactly the same way.

Ladybird beetles

Four species which occur in Victorian crops are the common spotted ladybird (*Harmonia conformis*), the transverse ladybird (*Coccinella transversalis*), the minute two-spotted ladybird (*Diomus notescens*) and also the recently introduced species, *Hippodamia variegata*. Ladybird larvae look very unlike the adult insect they will grow into (see Figure 4.9, page 62).

The common spotted ladybird is larger than the others, and is orange with black spots. The transverse ladybird can be orange or red with black blotches rather than spots. The minute two-spotted ladybird is, as its name suggests, a very small black ladybird with two orange-red spots. *Hippodamia* has two small white patches just behind the head.

Aphids are the main prey of ladybirds. The ladybird catches the aphid and chews it up.

Hoverflies

The adult stage of hoverflies is recognisable to most people as the insects hover in one place in the air (often near flowers) (hence their name). They often have yellow markings on a black body and so are quite distinctive and visible. However, it is not the adults that are predators of aphids. In contrast to the adult insect, the juvenile stages of hoverflies are simply maggots that can climb around in the foliage of plants. These juveniles are usually pale yellow or green with a stripe down their sides. They are more difficult to see than the adults but this is the stage that preys on aphids (see Figure 4.11, page 63). The adults lay their eggs near aphid colonies so that there is food for the juveniles that hatch out.

Spiders

All spiders are predators and they prey on a wide range of invertebrates. There are many different types of spiders with varying methods of capturing their prey. For example some are ground-dwelling species that actively hunt their prey, others ambush prey from a burrow and many snare their prey in webs. Spiders vary enormously in body size and catch their prey according to relative size. It is likely that any control or suppression of pest populations by spiders is the result of the whole community of spider groups rather than just one or two common species (see Figure 4.10, page 62).

Although spiders do not have wings they can disperse by air. Young spiderlings spin a silk thread that is caught by the wind which potentially can carry it for great distances. It is therefore possible for spiders to become established even in areas where there is no nearby population of that species. Despite often being found in relatively high numbers, spiders have largely been neglected in agricultural systems. Overseas studies (Riechert 1998) have shown that spiders can have a major impact in stabilising pest numbers in crops, although the extent to which they actually control pest populations is unclear. Extremely little is known about the role of spiders in Australian agricultural systems, although there is increasing research being done in this area. We obviously need to know more about these potentially important predators in agricultural food webs.

5

Cultural controls

Definitions

Cultural controls are those management activities that the farmer can choose to carry out that make the environment unfavourable to one or more pests. These activities may not be primarily to control pests (for example planting trees). They may involve making the habitat better for natural enemies of pests, so that there is better biological control, or making the habitat worse for the pest (for example less food or shelter).

Cultural control options can be the most powerful tool that a farmer has to deal with some pests, and the section on 'Factors that increase pest pressure' (in Chapter 3) demonstrates how cultural factors can have significant effects. Pimental (1993) gives an example from the USA where changing rotation practices in corn production was responsible for an increase in losses to pests from 3.5 per cent to 12 per cent despite a 1000-fold increase in pesticide applications. The change from conventional tillage to stubble-retained, minimum tillage is also associated with increased problems with establishment pests such as slugs and wireworms (Stinner and House 1990). These examples illustrate how management methods can have major influences on pest populations, but in an undesirable way. Ideally, cultural controls use management methods such that pest populations are reduced.

The use of some cultural controls is not universally beneficial. For example providing nectar sources for beneficial insects may also provide nectar sources for pests. Rotations that include legumes can massively increase problems with whitefringed weevil (*Naupactus leucoloma*), but, conversely, taking the legume out of the rotation can effectively control this pest. Border plantings to increase diversity or provide habitat for predators has been found useful overseas but the scale of agriculture is different in Australia to Europe (where much of the research has been carried out) and edge effects on large Australian paddocks would mostly be very minor.

Examples of cultural control

Tillage

Tillage is one of the oldest methods of controlling some pests, although it was not the primary aim of the practice. The disturbance of the soil profile and the removal (by incorporation) of surface plant material results in a habitat that is less diverse in terms of many invertebrates, including some pests. This is done mainly through the removal of suitable shelter and food, and also physical damage to pests.

Burning

Burning crop stubble to reduce pest populations works in exactly the same way as tillage – it removes the shelter and food of the pests. It does not kill pests such as slugs and earwigs by heat, as these pests are usually protected in below-ground sites when burning is carried out.

Tillage and burning are not being promoted here as measures that should be taken in an IPM strategy, as they have other undesirable effects on paddock health and they also remove the habitat and shelter for beneficial species. These are mentioned because they have been used for a long time and are examples of cultural controls.

Rotation

Rotating the crops grown in the same paddock is a practice that has been used for centuries and it remains a key method of controlling pests and diseases of crops and pastures today. The principle is that the specific pests and diseases of certain plants will continue to increase when provided with a suitable host and so problems become worse as pests and diseases build up when the same type of plant species (or closely related species) are grown in the same ground in successive years. Therefore, to break the cycle of ever-increasing pest and disease populations, either a non-host crop or pasture is planted in the paddock, or it is left bare (fallow).

Variety selection

Careful selection of plant varieties is an extremely powerful cultural control. For centuries selecting plants resistant to pests and diseases has been one of the roles of the plant breeder. For example lucerne that is resistant to aphids and aphid-borne diseases has determined what varieties are grown in some locations. Just like conventional plant breeders, genetic engineers are attempting high-tech methods to exploit genetic diversity (but possibly from species that would normally not be able to interbreed).

Time of planting

The time of planting is another tool that farmers can use to help limit damage from pests and reduce disease or yield loss in many cases. However, there are many different reasons why this method works.

Location

The location of crops or particular paddocks can affect pest pressure. That can be on a district-wide scale (such as a district risk of BYDV carrying aphids) or local on-farm scale (such as a low-lying wet paddock with high risk of slugs or a newly planted clover crop surrounded by RLEM-infested crops). While such paddocks may have to be planted, the degree of risk should be recognised and appropriate strategies developed.

Weed management

One of the most important cultural controls available to farmers is weed management. This does not just mean applying herbicide after planting but getting on top of weed problems a year or two before susceptible crops are planted. If control of *Plutella* (diamondback moth) is an issue, then controlling brassica weeds, especially flowering weeds, is something that will have a major positive effect. Similarly, controlling capeweed is something that will have substantial effects on RLEM control.

What constitutes a weed or a weed problem varies considerably depending on the pests being considered. For example control of redheaded pasture cockchafer and blackheaded pasture cockchafer by cultural means are almost completely opposite. Redheaded pasture cockchafer beetles prefer long grass, rank pasture or standing stubble while adult blackheaded pasture cockchafer beetles prefer to lay eggs in bare ground where dung is plentiful (overgrazed areas). Grazing management is the key to control, but the approach taken will depend on what species is of most concern.

Intercropping: trap crops

Trap crops are sometimes used to attract pests, and once in place they can be treated with insecticides or managed within the trap crop. The aim is to provide pests with a suitable food or host plant that is not the main crop being grown. For example cotton farmers may plant lucerne strips to attract green mirids.

Provision of alternative food sources

An approach that concentrates on beneficial species rather than pests is providing alternative food sources for the predators. It aims to increase numbers of beneficial species by providing them with alternative food sources (that is, other than insect or mite prey) so that more beneficial individuals than would have otherwise occurred will be present in a crop or pasture. Examples of this include provision of flowering grasses in citrus orchards and vineyards to increase numbers of predatory mites.

Another approach is to provide a habitat (not just a nectar source) in strips through an area to encourage the establishment of beneficials. This could be planting grass to encourage lacewings in spring (this method is currently under investigation, see *Vegetables Australia* 2007).

Tree planting

Planting trees along the borders of paddocks is often raised as a possible method of increasing the numbers of beneficials that will help to control pests in crops. Our approach is to make the paddock habitat the ideal environment for resident beneficial species rather than rely on a population that is resident outside of the crop. One reason for this is the preferences of beneficial species. Basically the beneficial species found in trees usually prefer tree habitats (not grassland-type environments) while the species that prefer cropping/pasture/grassland situations do not prefer trees. Although the distinction is not absolute it should be remembered that the beneficial species that we want in crops and pastures would be more likely to come from similar habitats – low-growing plants rather than trees. What tree plantings can offer is a nectar source at certain times for resident or local beneficial species. However, the provision of nectar sources is likely to be short term and the benefit will depend on the timing of this nectar source compared to the occurrence of pests. The size of the paddock (basically the distance from the edge of the paddock) will also impact on the benefit of trees planted on paddock margins.

Tree plantings have value for reasons other than supporting insects that help control pest species. They are highly likely to have (at least) some transient benefits which will add to the overall degree of control provided by beneficial insects and mites. At this stage, we suggest that the decision about whether to plant tree borders or not should be based on reasons other than to provide habitat or food sources for beneficial species in crops and pastures.

Beetle banks

These are refuges for predatory beetles deliberately created in an agricultural environment that would otherwise destroy them. The idea is that the beetles will then re-invade the agricultural crop from their refuges. There are obviously limitations to this approach in Australia, even if it works in the UK.

Our preferred approach is to turn the entire paddock into a suitable habitat for beneficial species including predatory beetles. In that way there is no need for beetle banks as the entire paddock is a beetle bank. We have seen this work and know that it is achievable.

Physical barriers

Physical barriers are usually used in very small areas (such as copper strips to repel slugs, or mesh to prevent access by moths or other pests). However, it is possible for the same approach to be used on a larger scale. Think about the huge areas of pasture surrounded by roadside strips of remnant native grassland. These strips often have far lower pest numbers than the adjacent pasture and there is obviously an opportunity to exploit this fact. Native grasslands, even in narrow strips, could be used as physical barriers.

Integration of cultural controls

One aim of this book is to describe integration of pest control options – the integration of cultural methods with biological and chemical controls is critical. For example stubble retention will allow populations of some beneficial predatory species to prosper just as it provides improved shelter for pests. Therefore, the relative impact of pesticides on pest and beneficial species is what will decide whether the cultural option is good or bad in terms of pest management.

Applying knowledge of cultural controls

In the following section we give some examples of how cultural controls can be integrated into specific farm plans. It is worth noting that organic farmers are often more willing to use a range of cultural methods than conventional farmers because they have seen them to be effective and because they do not have the same chemical options.

Example 1: Pasture management for cockchafer control

Two types of cockchafers are common pests of pastures and some crops in south-eastern Australia, and they are described in Chapter 3. These are the blackheaded pasture cockchafer (BHPC) and the redheaded pasture cockchafer (RHPC). The larvae of each species are the pests, but it is the behaviour and preferences of the adult beetles that can determine the level of pest pressure and damage.

Blackheaded pasture cockchafer

The adult female BHPC beetles prefer to lay their eggs in bare ground and preferably where they can obtain a dung meal. If dung is present they can lay more eggs. Therefore, heavily stocked or heavily grazed paddocks could be expected to have worse problems than paddocks with good cover when the beetles fly in summer. There are no insecticides that can be used that will control this pest without detrimentally affecting populations of beneficial species (those that control other pests, not BHPC). So if you want to avoid problems with BHPC and do not want to use insecticides then managing grazing in the spring prior to planting the crop will be the key. Make sure that the paddock has as much grass cover as possible going into summer.

If there is a paddock with a bad BHPC problem it is too late to use the strategy described above. The available options are spraying with insecticide or ploughing up the paddock to expose or physically damage the grubs.

The cultural control options described here are not as quick and easy as the insecticide option, but they have advantages in terms of the long-term control of resident pests. They will not suppress populations of predatory mites and beetles as could be expected if some insecticides are used. There is also likely to be less capeweed where there is not a great deal of bare ground and so there will be more positive effects on the suppression of other pests such as RLEM and lucerne flea which prefer this weed host.

Redheaded pasture cockchafer

Adult beetles of the RHPC are almost the exact opposite of the BHPC beetles in terms of their behaviour and preferences. Female RHPC fly in winter and early spring and prefer to lay their eggs where there is long grass or standing stubble. The grub stage never comes to the surface and so treatment with conventional insecticides is not possible, although a fungal pathogen is commercially available (as 'Biogreen'). This pathogen will not give rapid control and so it is not a quick fix. Parasitic nematodes are also available for some situations.

Cultural controls are therefore relatively more important as there is not a chemical option as a last resort. Once again, grazing management is the key but in this case the results will be seen one and two years later, because of the long time the immature stages remain below the soil surface. In badly affected areas where there is a need for immediate action, ploughing or renovating the pasture remains a real option.

Example 2: Cultural controls in canola

There are several cultural controls that can be used to control established pests in canola crops. They are not all equal in the degree of control achieved but together they provide significant benefits. These controls are more about avoiding pest problems than killing pests, and the first three that we nominate here (*time of planting*, *good quality seed* and *soil preparation*) are all about getting the plants growing quickly so that they spend as little time as possible in the vulnerable cotyledon stage. Slugs and earwigs, for example, damage the plants by chewing off the cotyledons and so the plant may die. If the plant can survive until the true leaves emerge then the impact of these pests will be of little concern.

We suggest planting a canola crop early after the autumn break, before the temperature drops and slows the plants' rate of growth. This would give the crop the right conditions to grow strongly. Similarly, good quality seed and good contact between seed and soil will promote rapid germination and growth. There are other factors that help good germination and growth too, but the ones above have come up regularly in our discussions with farmers and agronomists.

Stubble retention is usually associated with pest problems, but – as explained earlier – it will also provide better habitat for beneficial species. The effect of retaining stubble will be seen over several years, not as an immediate benefit, in terms of predatory species.

Finally, weed management has a great effect on the numbers of certain pests. Controlling broadleaf weeds in winter the year before the canola crop will reduce the number of pests such as RLEM. Controlling flowering brassica weeds will reduce the nectar sources for diamondback moth and cabbage white butterfly and so reduce the numbers of eggs that they lay.

Example 3: Cultural controls in cereals

The methods described above for canola are also relevant to cereal crops but there are some interesting differences relating to different pests. First, time of planting is a highly valuable cultural control once again, but this time we suggest planting late in autumn rather than early. This would avoid the main aphid flight periods and so the crop would not be exposed to high aphid and possible BYDV pressure. This cultural technique may eliminate the need to apply any insecticide to a susceptible cereal crop.

Second, another factor that is related to aphid and virus control is the use of resistant varieties or those varieties that are suitable for planting late. There are varieties that are BYDV-resistant that could be planted even when the aphid flights are happening.

The other factors mentioned above for canola (*soil preparation*, *good quality seed* and *weed management*) are also important in cereals. If the crop can be established quickly and the plants are growing well, the problems with establishment pests will be significantly reduced.

Each of these cultural controls has an impact on the level of pest damage. The overall result is a reduced problem with pests achieved by management methods. These can be used in conjunction with biological and chemical methods. The impact of the cultural control measures can be greater than the biological and chemical methods for some pests (such as controlling BYDV in cereals) and should be given careful consideration. Choosing *not* to use such cultural controls means losing a powerful tool for pest management.

Figure 2.1 Carabid beetle.

Figure 3.1 Redlegged earth mite (RLEM).

Figure 3.2 Blue oat mite (BOM).

Figure 3.3 Predatory mite.

Figure 3.4 Lucerne flea.

Figure 3.5 Common white snail (*Cernuella virgata*).

Figure 3.6 (a) *Deroceras reticulatum*, (b) *Deroceras panormitanum*, (c) *Milax gagates* and (d) *Lehmannia nyctelia* – pest slug species in Australia.

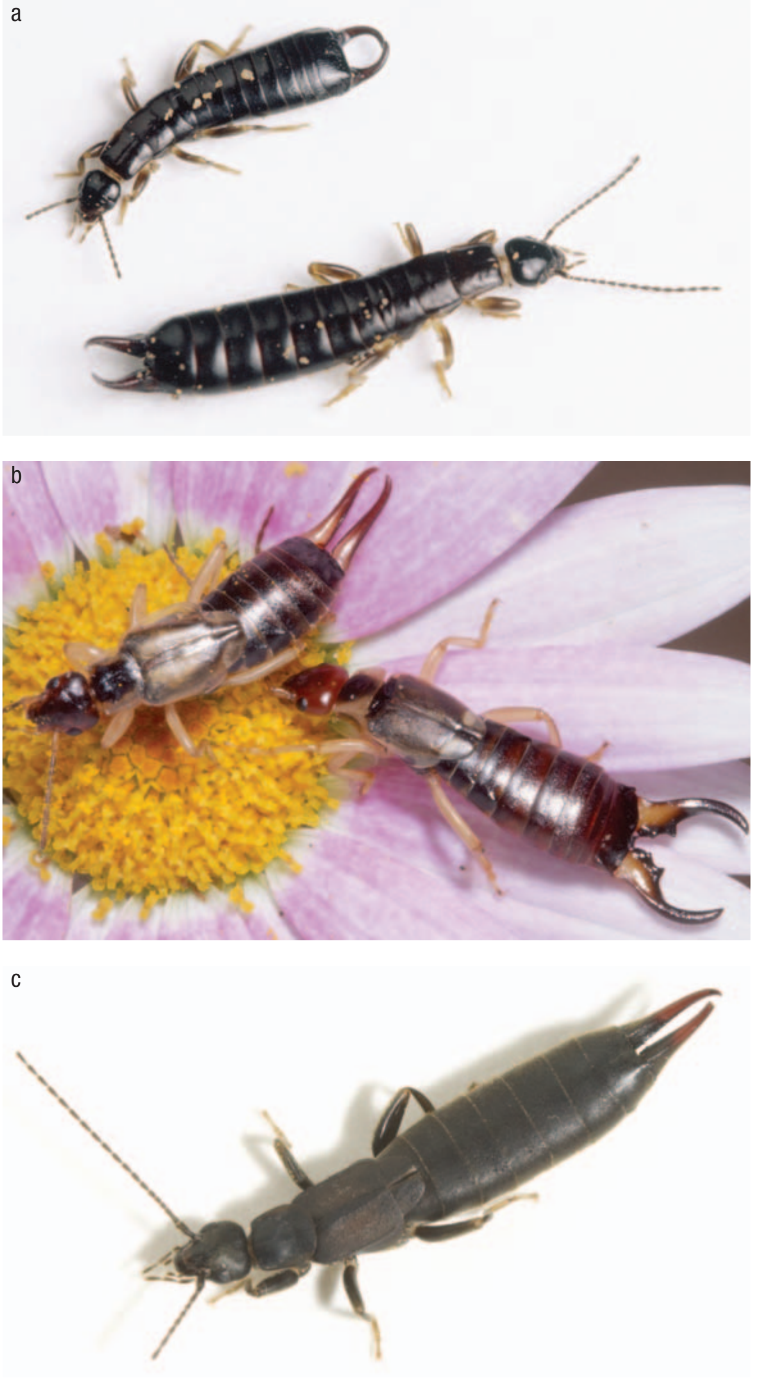

Figure 3.7 (a) *Euborellia* spp., generally benign; (b) European earwig (*Forficula auricularia*), a pest species; (c) *Nala lividipes*, a minor pest.

Figure 3.8 Armyworm.

Figure 3.9 Heliothis.

Figure 3.10 Diamondback moth (*Plutella xylostella*).

Figure 3.11 (a) False wireworm (Tenebrionid) larva; (b) True wireworms – juvenile click-beetles (Elateridae); (c) False wireworms (Tenebrionidae) (FWW).

Figure 3.12 Cutworm.

Figure 3.13 Rutherglen bug (*Nysius vinitor*).

Figure 3.14 Cockchafer.

Figure 3.15 Black field cricket (*Teleogryllus commodus*).

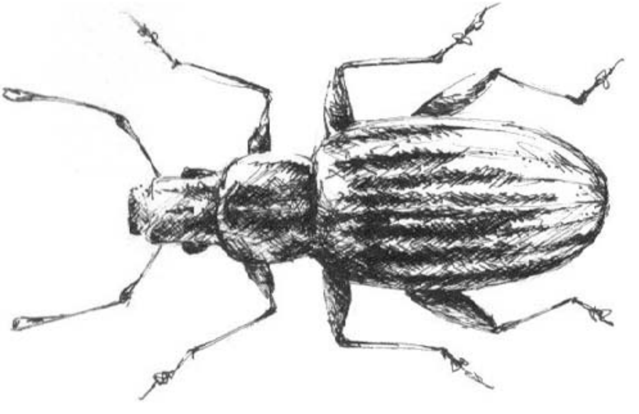

Figure 3.16 Weevil showing elbowed antennae.

Figure 3.17 Weevil adult (Curculionidae).

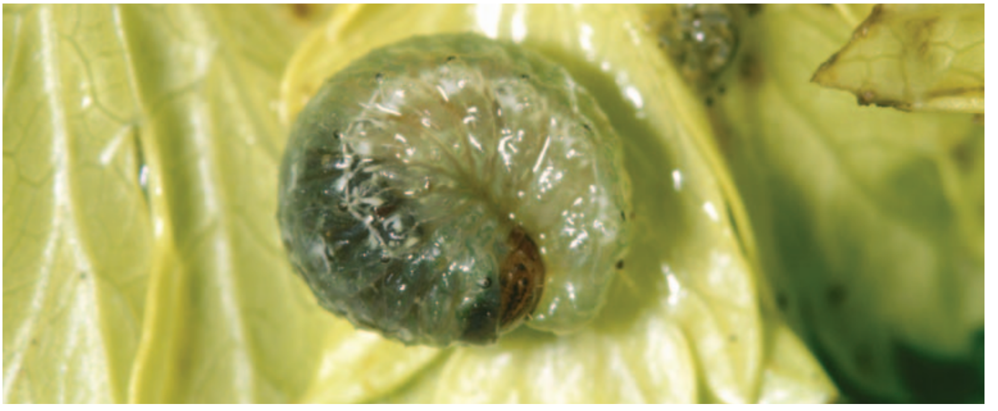

Figure 3.18 Vegetable weevil (*Listroderes difficilis*).

Figure 3.19 Pea weevil (*Bruchus pisorum*).

Figure 4.2 Parasitic wasps (*Aphidius* spp.) and aphids.

Figure 4.3 Brown lacewing (*Micromus tasmaniae*).

Figure 4.4 Brown lacewing larvae.

Figure 4.5 Damsel bug (*Nabis kinbergii*).

Figure 4.6 Shield bug (*Oechalia schellenbergii*).

Figure 4.7 Common brown earwig (*Labidura truncata*).

Figure 4.8 Parasitic wasp (*Netelia* spp.).

Figure 4.9 Ladybird adult (a) and larva (b).

Figure 4.10 Spider.

Figure 4.11 Hoverflies – adult (a) and larva (b).

Figure 7.1 Damage to canola and cereals caused by different pests.

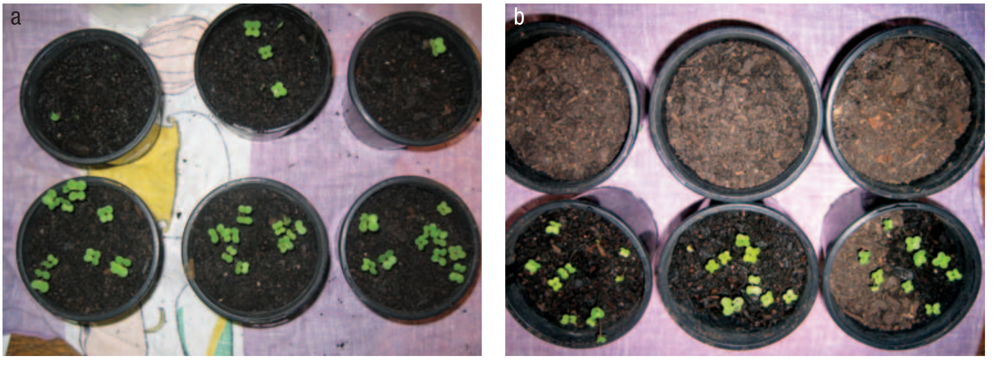

Figure 7.2 Damage to canola seedlings (a) and canola seed (b) by *Milax* slugs in 24 hours compared to controls.

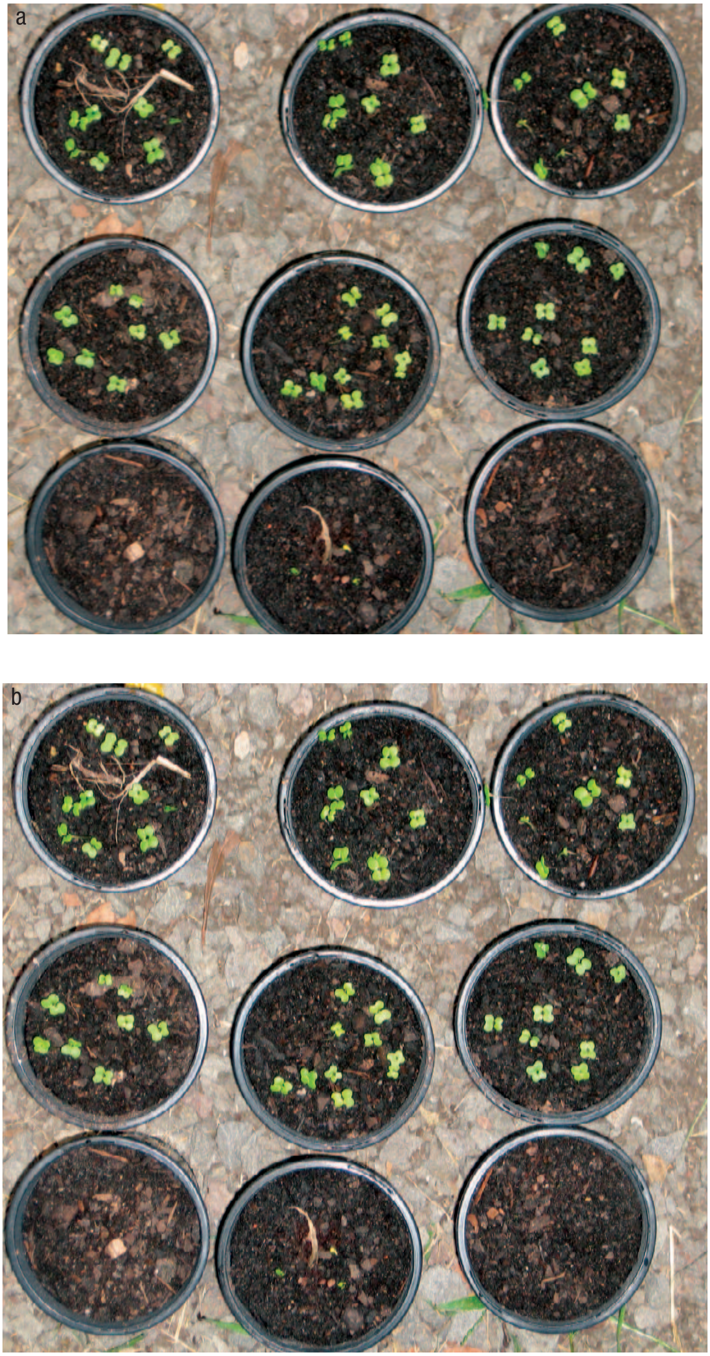

Figure 7.3 Damage to canola seedlings (a) and damage to canola seeds (b) by adult false wireworm beetles and European earwigs compared to control.

Figure 7.4 European earwig damage to canola seedlings after 72 hours compared with control seedlings (left).

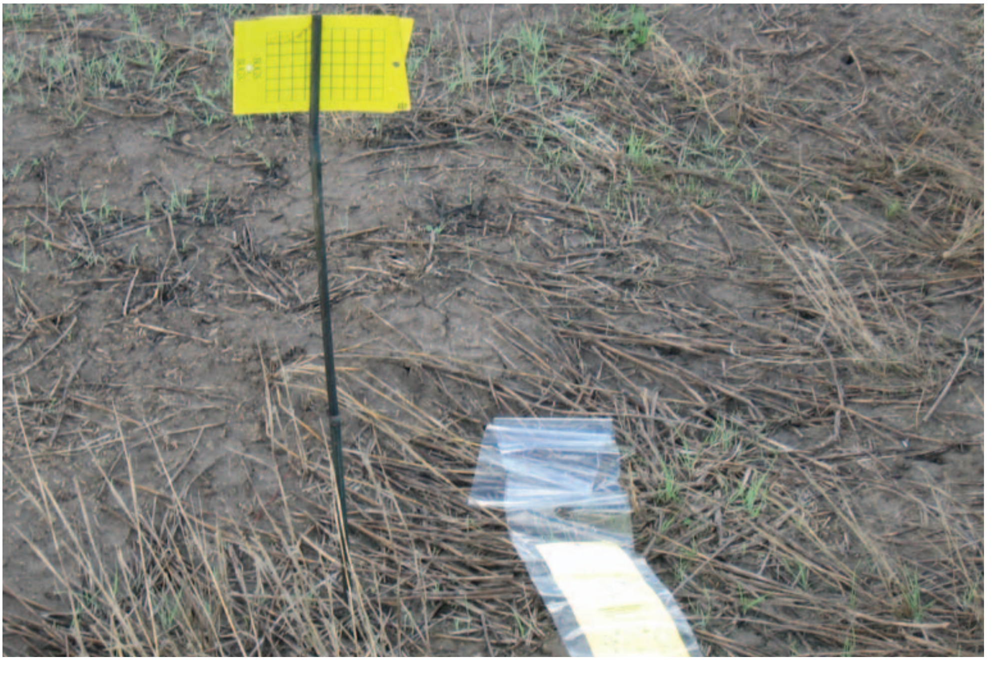

Figure 7.5 Yellow sticky trap.

6

Chemical (pesticide) controls

Introduction

We have briefly mentioned the history of pesticide use in agriculture in earlier chapters. The change in recent years has been the development of pesticides that are more selective in what they kill. By this we do not mean just that they are better on some pests than other pests (which they usually are), but that they do not kill at least some types of beneficial species of insects or mites. As described in Chapter 2, chemicals in an IPM strategy are the support tools, not the primary control tool. Pesticides are chosen not only for their effect on pests, or their cost, but because of the effect they have on beneficial species.

The legal registration of pesticides rests with the states, although there is a national registration authority. That means that in Victoria a farmer can decide to use an insecticide called ‘Success’ or ‘Entrust’ to kill caterpillars in canola or wheat but it would be illegal for a farmer in New South Wales to do the same unless there is a permit.

The pesticides are registered for certain pests in certain crops and in NSW that is all they are legally to be used for. However, in Victoria a farmer can use the pesticides in other situations at his own liability (that is, he cannot sue the chemical company if it does not work). ‘Entrust’ is a product that organic farmers can use and has very little effect on beneficial species, non-target species or humans, birds or fish. However, in NSW this product is not registered for use on broad-acre crops so it cannot be used by law.

Growers in NSW can use a range of synthetic pyrethroids or organophosphates that are non-selective, toxic to a wide range of animals (fish, birds or mammals) but which are legal chemicals. The argument on pesticide use here is not logical but is bound by law.

Those using a conventional pesticide approach rely mostly on information about the efficacy of pesticides on particular pests. That information is normally readily available, and efficacy data are required by the Australian Pesticides and Veterinary Medicines Authority (APVMA) before registration of pesticides can occur. At this stage, because there has been no real demand from farmers in Australia for the type of information discussed here, you cannot find any good source of comprehensive information about pesticides and beneficial species. However, for those wanting to begin an IPM approach, that should not stop you. There is information that can be found from horticultural sources, and there is much that can be extrapolated immediately to broadacre farming.

A starting point is to avoid what are known to be the most broad-spectrum insecticides leaving the highest amount of residue. These include the synthetic pyrethroids and organophosphates. Then, in the absence of readily available selective insecticides, insecticides that are broad-spectrum but not causing too high a level of residue would be a little less disruptive to some populations of beneficial species. Look for websites on the Internet that offer information on side-effects of pesticides on beneficials in horticulture for a rough guide to what to expect. Check with state authorities or the Australian Pesticides and Veterinary Medicines Authority (APVMA) website for the latest registrations and permits.

Effects of pesticides on beneficial species

Pesticides, particularly insecticides and miticides, can impact greatly on beneficial insects and mites. However, the impact is not equal on all species or groups, and may be short-lived or residual. The first category considered here is that of **acute** effects. Acute poisoning in this context usually means the individuals exposed either live or die, as measured in a short period of time. As far as pests go, this was usually the only information we required and if the pest was still alive after 48 hours then the pesticide would in most cases be considered a failure.

Beneficial species can be affected by pesticides and the effects not seen for days, weeks or months later. This is the category called **chronic** or **sub-lethal** effects. What is meant here is that the individuals exposed survive the pesticide application in the short term but the population is affected. Examples of this type of poisoning include reduction in the number of eggs produced and behavioural changes. Some pesticides cause a great, even total, reduction in the number of viable eggs produced (Bernard, Horne and Hoffmann 2004; Hattingh 1996). That means that although the individuals exposed to the pesticide survive, the population of that species can be locally severely disrupted or even destroyed.

Another way in which predators can pick up a lethal dose of insecticide even when they are apparently able to survive treatment is by eating treated prey (Cole and Horne 2006). Here the predators survive the pesticide application by being in a sheltered position or not being affected by walking on treated surfaces. However, they accumulate the poison by eating a number of treated prey, in much the same manner as dogs can be poisoned by eating poisoned rabbits. It is just happening on smaller animals.

Other pesticides may kill all individuals that they contact – pest or beneficial, and so these would all appear to be equal. However, there is a difference between a pesticide that kills 100 per cent of individuals contacted for two weeks and one that kills 100 per cent of individuals for an hour, or a day. That is, there are no residual effects of the pesticide after it is applied, and so there can be re-immigration by beneficial species a short time after the pesticide has been applied. This is obviously not the same as having no effect at all, but is much better than a long period of preventing beneficial species establishing.

The same chemical may be applied in different ways and the difference in effects on beneficial species is very great. For example a broad-spectrum pesticide sprayed onto a crop would kill a range of beneficial species but when used as a seed dressing or bait then the effects would be very much reduced and so could be part of an IPM strategy. Similarly, a border spray to deal with pests invading from an edge could be expected to kill both pests and beneficials in that area, but most of the beneficials in the paddock in total would survive while most of the pests would have been killed. Therefore we avoid giving out a list of 'safe' or 'unsafe' chemicals as even broad-spectrum pesticides can potentially have a place if used in particular ways. It would be much more convenient if this book contained a list of IPM safe products to use and a list to avoid but unfortunately the truth is more complicated. We really need to think about *every* pesticide application, *what* we are targeting and *how*, and *the consequences* of that application.

How do you decide if a product is safe for beneficial species in agriculture?

Claims that pesticides are 'safe' to beneficials or 'safe in IPM programmes' are abundant but, actually, how safe are these products? In reality, chemical companies are much more skilled in testing the effects on pests than beneficials. Only where there is a demand for information on beneficial insects and mites is there likely to be the relevant information. Australia has its own native beneficial species (as listed in Chapter 4) and information about pesticide effects on these species cannot be extrapolated from overseas studies.

What this means is that there is very little information available on the safety of pesticides to Australian beneficial species. Remember, the procedure to state 'safe' is very different to claiming 'kills pests'. To be safe, the pesticide should hopefully not kill as spray droplets (acute), not kill after exposure to dried residues, and also not reduce fertility or egg hatch after exposure to either the spray itself or to eating treated prey. These tests are not conducted as a routine measure (although we hope this will change) and so the short answer is: there is extremely little public information about the effects of pesticides on Australian beneficial species. This lack of information means that chemical companies will claim 'safe' until proven wrong. Farmers should be aware of this and seek information about the effects of pesticides on beneficials from other sources (such as private companies and universities).

The effect of chemicals on non-target species is a topic that is receiving more attention now, but information about the sub-lethal effects of pesticides on non-target invertebrate species is severely lacking in Australia. Are sub-lethal effects important and why should we need more information about pesticides? To give a human comparison: both nicotine and thalidomide would be passed as safe to humans if only 24-hour acute tests were conducted.

The three main types of pesticides used in agriculture are: (1) insecticides, miticides, nematicides and molluscicides; (2) fungicides; and (3) herbicides. The first group is the one we are mostly concerned about as they are designed to kill certain groups of animals. Pesticides in this group are more likely to have great effects on beneficial species of animals than fungicides or herbicides. The broad-spectrum insecticides are of most concern as they are designed to kill a wide range of animal species. However, some fungicides are known to have insecticidal or miticidal effects and, similarly, herbicides can have undesirable effects on animals. In situations where more toxic insecticides are being used, the effects of herbicides or fungicides will be masked. Therefore, it is only when the harsh insecticides and so on are removed that the effects of other pesticides become apparent.

Pesticides and organics

Some information is required to distinguish between IPM and organic agriculture. The two concepts are certainly not mutually exclusive, but some assume that all pesticides allowed for organics are automatically suitable for IPM. This is certainly not so as some pesticides allowed as organic inputs will kill beneficial species and do not automatically suit IPM strategies. Pesticides derived from natural sources are allowed within organic certification even if those pesticides kill a wide range of beneficial species. This includes such pesticides as pyrethrum and rotenone which are organic pesticides but which are not usually desired in IPM strategies.

IPM strategies are based on biological and cultural controls, with support from chemicals (whatever their origin). That is true for both organic and conventional agriculture. Therefore the only difference between organic and conventional IPM strategies is the list of support chemicals that are available. Organic farmers have decided that they will have a smaller list of chemical supports than conventional farmers. However, as the primary controls for IPM farmers are biological and cultural then there is actually very little difference.

The major point here is that pesticides allowed as organic are not necessarily suitable for IPM strategies. If the pesticide list of either organic or IPM growers were used in isolation then it would not work. It is the *integration* of biological, cultural and chemical controls that makes IPM work.

Pesticide options where no selective product is available

There is not always a selective chemical option available. At present, if there is no demand for a selective product then there will be no impetus for chemical companies to produce such special items. Furthermore, even if selective products do exist (such as in horticulture), then, unless specific registrations are made, the products are unavailable to farmers and growers. This is the situation in most states, except Victoria where more practical laws apply. For example a totally safe product such as one containing a *Bacillus thuringiensis* (BT) would formerly be illegal on the foliage of potatoes in New South Wales and Queensland even though the tubers (the crop) would never be exposed to the product. However, a broad-spectrum insecticide such as 'Lannate' (methomyl) is permissible for use on crops with a one-day withholding period, even if it kills beneficial species for 12 weeks. The registration of products and their withholding periods are therefore not a reliable guide to their usefulness in IPM strategies.

Given these restrictions, there are some alternatives for growers wanting to implement IPM, even when no selective pesticides are available. The first choice is to look for pesticides that have a very short residual activity. That is, the pesticide may kill all beneficial individuals present but will have no impact on newly arrived beneficials in a day or two. So although all suitable pesticides (for the pest) may be toxic to beneficials, there is also a gradation of effects. Some will be immediately toxic and have long residual effects, others will have general toxic effects but have only short-term effects on beneficials. Obviously these effects are not equal, and choosing pesticides with short-term effects will allow the adoption of IPM sooner than if residual pesticides are applied.

Pesticides and IPM

Pesticides within an IPM framework are the support tools used to assist control when biological and cultural methods are not sufficient. They are not expected to always give 100 per cent kill of the pest in question, but to suppress the population so that the biological and cultural methods will regain control.

Selective products will often be more expensive than broad-spectrum products when calculated per litre or per ha, but this is not the true cost of the pesticide. However, if the control is better, and secondary pests are not created and resistant pests are not maintained then the economics become much more favourable.

Then, if the costs of not losing beneficials are taken into account and the costing is worked out for a full rotation and not just one season, the advantages of avoiding the cheaper broad-spectrum products become clear. In this way the real cost of the pesticide in terms of pest management can be calculated by the farmer or grower.

As an example, consider the cost of spraying a paddock for RLEM with a cheap broad-spectrum insecticide versus using a more expensive seed dressing. The first option is less costly per ha, but what is the cost if predators that help to control slugs, lucerne flea, blue oat mite and Bryobia mite are killed? If that first spray then necessitated using pesticides against those additional pests, perhaps for several seasons, was the true cost of the insecticide taken into account? We suggest that farmers consider the implications of the pesticide application and what else that might incur, as discussed earlier in this book. In the USA, David Pimental and Anthony Greiner (1997) attempted to calculate the true cost of insecticides by factoring in many other issues than just secondary pests (such as loss of wildlife, fish kills and human poisonings). Their estimate (based on 1994 figures) for losses due to pesticides in the USA was US$8.3 billion per annum.

7

Monitoring and getting started

In previous chapters we have discussed the importance of correctly identifying pests as the starting point of any IPM strategy. We stress again that it is here that good control begins. We also want to highlight the fact that incorrect identification of pests can lead to massive mistakes and inappropriate control measures being applied.

What to look for

The first signs of pest problems are often symptoms of damage rather than observations of large numbers of pests. At this point it is important to recognise that several different causes may lead to almost identical damage and so it is necessary to work out at each site just what is causing the damage (see Figure 7.1, page 64). Remember, too, that more than one damaging cause could be present at the same time. For example, a canola crop could have slugs, earwigs, birds and tenebrionid beetles causing identical damage at the same time. We need to work out for each site which of these are the primary target (usually one or two), or whether all need treating (unusual but possible).

In the following section we look at the relative impact of several pests on the same crop. We planted canola seeds in pots and put different pests into those pots at different stages of the plants' growth (with the seed or five days later). The photos here show the different impact that the different species have on the same stage of plant growth. Essentially, this shows that the impact of one individual adult pest is not equal and that this needs to be considered when evaluating the pest status of different species. We are suggesting that the relative damage caused by different pest species needs to be considered when deciding on the appropriate response (especially when pesticides are an option). If a pest is present then we need to know how much damage that particular pest is going to cause compared to another and what actions should be considered. The impact of those control options is obviously of great relevance.

In the experiments that we conducted it is easy to see that one large *Milax gagates* slug will cause relatively more damage to germinating seedlings and five-day-old seedlings than five adult European earwigs in five days (see Figure 7.4, page 66); five false wireworm adults will cause even less damage in five days (see Figure 7.3, page 65).

It is not only pests that can cause damage that looks like insect or mite damage. Herbicide burn, seed dressings, hail and waterlogging can all cause responses in young plants that look like pest damage.

Who should monitor the crops?

The role of monitoring is to provide the farmer with information about pests and beneficial species in a paddock so that he or she can make an informed decision about what, if any, actions are necessary. Regular monitoring constantly updates that information and so decision making can be precise and timely. The farmer can decide to take no action or – if there is a need to apply pesticide – select the best option given the types of pests and beneficial species present. All of these decisions are absolutely dependent on the correct identification of the cause of the problem. It is crucial that the person conducting the monitoring is able to make the correct identifications.

One of the most important points to remember is that the presence of a pest does not necessarily mean there is a pest problem. Given the comments that we made above about the range of pests that can be found together, the monitoring should help to decide what pest pressure actually exists in a paddock. Finding one pest in a quick search does not mean that the species found is either a problem or the only pest present (see also the section on 'Thresholds' in Chapter 3).

Selecting your first IPM paddocks

If you have not used an IPM approach before, it may seem daunting. It is certainly a different methodology for many people. To gain some experience and confidence we suggest that you monitor a few paddocks and select one or two on which to trial the IPM approach for several years. That would give you a feel for the pest pressure, some experience with identifying beneficial and other invertebrates (not just pests), and paddock history in terms of pests and beneficials.

Choose a paddock that is not high risk at first and begin to apply a set of compatible control measures for all pests.

Monitoring more than one paddock has an added advantage in that it will give you some idea of the range of individual species abundance, such as a low, medium or high figure.

To assist you with decision making we suggest that you consult an experienced IPM adviser.

How to monitor a paddock

There is a range of monitoring methods available, depending on the type of invertebrates you are looking for. They can be permanent residents of a paddock (even when ploughing takes place) or they can be transient. Transient species may occur regularly each year at the same time or may be less common. Examples of permanent residents include mites, lucerne fleas and carabid beetles, while transient species include aphids, heliothis caterpillars and lacewings. Pests such as cockchafers are relatively long-lived and may inhabit a paddock for one or two years in the immature (grub) stage, but flights of adult beetles can re-invade and re-colonise each year.

Knowledge of the life cycle and habits of each species allows you to use trapping or other sampling methods to target each species. If you know the history of pest damage in a paddock it helps you to decide how many monitoring points are necessary and where they should be. It is impractical to try to attempt a detailed grid-like monitoring program over a large paddock, but it is possible to look in higher-risk areas. For example you can look in wetter areas of the paddock for slugs and check the borders of pasture paddocks for mites. In the absence of such information, just choose a convenient location in the paddock and move the monitoring point around over several weeks, especially if any signs of damage are noticed. If damage is seen, then you need to determine very quickly what pest is causing that damage and the extent of the pest problem.

Yellow sticky traps

You can use yellow sticky traps to monitor numbers of small flying insects such as aphids or brown lacewings. The insects are attracted to the colour yellow and become stuck in a waterproof glue. These traps can be useful if you want to watch for a sudden increase in a particular type of insect. Their drawbacks are that they attract a huge range of flying insects (including flies) and so looking for particular species is time consuming, and also the traps get covered with dust and dirt. Remember that they only catch the flying stage of any particular species. A yellow sticky trap could also be placed alongside tiles (shelter trap) to check for different types of pests. Several different types are available, made of plastic or cardboard coated with waterproof glue. We prefer the cardboard traps as the plastic ones can become brittle and break in cold, windy weather. To place the trap, make a slit about 15 cm long in one end of a bamboo stake. Into this slit place the sticky trap (see Figure 7.5, page 66) and leave for a week or two before replacing. Note that the aphids caught on a yellow sticky trap in a cereal crop may not be the type of aphids that will colonise a cereal crop. It may be covered in flies at times, or by aphids and brown lacewings at others. These traps can also be covered in dust which renders them ineffective.

Direct searching

Searching for pests directly is an important way of obtaining useful information that cannot be supplied by trapping methods. Direct searching can give an estimate of damage caused by pests as well as reveal what shelter materials are present in the paddock (such as rocks, stubble and even the top layer of soil). Mites of all types can be found on the surface of puddles. Direct searching is useful for monitoring invertebrates such as earwigs (in the stubble), slugs, carabid beetles and earwigs (under rocks) and cutworms and weevils (in the soil). Following establishment of the crop or pasture, direct searching for colonies of aphids, moth eggs or leaf damage, for example, is simple and quick. It is also an important way to monitor the unforeseen pests for which there are no specific traps placed. Results can vary markedly between different people, as it depends on the person's eyesight, skill, patience and experience and sometimes also on the time of day and the weather. However, if the same person conducts the direct search then the results are more consistent.

This procedure should be repeated from before the crop is planted until the crop is established.

Pheromone traps

Pheromone traps are particularly useful for monitoring the activity of some species of moths. Pheromones are chemicals produced by female moths to attract males. These chemicals are highly specific, as the females only want to attract males of their own species. Baits containing synthetically produced pheromones are commercially available for some species of pests, including *Helicoverpa* (heliothis) species and *Plutella xylostella* (diamondback moth), but at this stage not for some other important pests such as armyworms. These can be placed at a convenient point, such as next to the tiles or yellow sticky traps. Empty these once a week and record the number of moths in each trap.

Sweep nets

For many years sweep nets have been used to sample the upper part of some crops. The net is simply brushed through the vegetation and any insects present will be caught in the bag of the net. An estimate of pest or beneficial numbers can be made so the risk of damage to a crop or pasture can be calculated. This is one of the standard tools of crop monitoring and is particularly useful for checking on pests such as pea weevil and caterpillars. It can be standardised by sweeping a set distance (for example 25 m) or by taking the same number (such as 25) of sweeps.

Suction samples

Suction samplers are like motorised sweep nets. A mesh bag placed on the inlet side of a vacuum cleaner (such as a blower-vac) will collect insects from the vegetation it passes through.

Pitfall traps

Entomologists have used pitfall traps for many years to collect insects and other invertebrates that are active on the soil surface. They can be left in place for a set period of time and the accumulated catch can be examined. Pitfall traps are useful to check the presence of nocturnal species that shelter in the soil but they are not essential if you want to monitor a paddock and can use the other techniques described here. They need a lot of maintenance to work properly, as they are easily disturbed (by sheep or cattle for example) and have the disadvantage of capturing animals such as frogs and lizards.

Shelter traps

Shelter traps are refuges under which some invertebrates (such as slugs, beetles, earwigs) will retreat during the day. Examples of shelter traps are tiles or sacks placed in a paddock during spring and autumn. These function as artificial rocks that can be placed and checked as desired. Note that these traps will only work when the invertebrates are active and are looking to retreat under such a shelter during the day. At times of year when it is very cold they are not efficient, because the invertebrates are either not active or do not need the shelter.

When to monitor

As emphasised earlier, monitoring should begin a year or two ahead of any vulnerable crop or pasture being planted or converted to an IPM approach. In that way a paddock can be assessed for establishment pests that can then be treated in another non-susceptible crop before the vulnerable crop is planted.

In the current crop or pasture, monitoring should be conducted weekly during critical periods of pest activity – such as after the autumn break, spring flights of aphids, spring and summer flights of moths (heliothis, armyworm).

Recording information

It is useful to keep records of observations on pest and beneficial species found during monitoring, as information can be referred to in future years. For example the timing of flights of pests may be seasonal and able to be predicted, as can the movement of some beneficial species. Records should also show how populations of beneficials are developing. If records are available, the current season's information can be compared to previous years to assess whether pest pressure is higher or lower, earlier or later. Most importantly, the outcomes of previous actions can be assessed (Was a pesticide needed? If applied, did it work?) and so pest management can be constantly improved and refined.

The type of records kept will vary between individuals, but some sort of paddock diary with information about pest and beneficial species with dates and seasons, and itemising actions taken will be of use when looking at seasonal events over years. A spreadsheet with columns for the range of pests and beneficials found, action taken and rows for dates is also a useful way of seeing trends in a range of data for a paddock over a season.

When assessing whether an IPM approach has worked or not, be consistent and compare the results to what had been achieved with the older approach. Remember that the decision to try using an IPM approach was (most likely) because there was a problem with a conventional approach.

Decision making

If a paddock is found to have a significant resident pest population before it is cultivated for a vulnerable crop then what options are available? What can be done to reduce pest damage without reducing resident beneficial populations? The options could be seed dressings, time of planting and variety selection, among others (see Chapter 5). It may be that a slug problem is detected just prior to next season's vulnerable crop being planted, so knowing which species (one or more) are present will allow better timing of baits.

There are three possible outcomes from the monitoring:

1. no pests and so no economic damage
2. many pests and likely serious economic damage
3. some pests, some beneficials and possible economic damage.

The first two outcomes are relatively easy to deal with and an appropriate action is relatively easy to decide on. The third option is more difficult to assess.

The first possible outcome is surprisingly common and it is very likely that many farmers will be able to reduce pesticide use by monitoring and avoiding the sprays put on 'just in case' or because another spray is being applied.

The second outcome listed is also fairly straightforward, even if not desired. Action must be taken and the action that is effective with least impact on beneficial species is chosen.

The third outcome listed here is the most difficult to deal with and make a decision on. Mainly this is due to lack of specific information about how many individuals of each of the many beneficial species that occur in different locations are required at different times to deal with the range of pests found. It is only by repeated experience of different levels and combinations of pests and beneficials that we will be able to improve decision making. However, to start on a paddock, we have found that trying to answer the following questions helps.

- *There are pests present, but is there immediate danger of economic damage?*
- *What is the level of damage to plants and will they grow out of this risk stage soon or not?*
- *Although there is damage to plants, is it going to cause economic loss?*

You may find not much at all but it is not safe to conclude that there are no pests or beneficials in the paddock. It could simply be too dry or too early in the season. For example if it is dry under the tiles then these traps are not going to catch slugs even if they are present in the paddock. Leave them in the same place for another week or two before moving to another point.

When to use a pesticide and what to use

By this stage in the book any reader should have concluded that pesticides are the support tool only, and planning for control of pests begins at least one or two years ahead. (If you have scanned the index and jumped straight to this section then we suggest you go back and read some of the preceding chapters (at least Chapter 6) before going further.)

If the crop or pasture is present and there are no cultural control options, we have found that answering the following sequence of questions helps to decide what to do:

1. *What is the pest that is present?* (Make sure it is present and that it is correctly identified.)
2. *Are there beneficial species to help control it?*
3. *What other pests are present?*
4. *What other beneficials are present for control of other pests?*
5. *Are there sufficient pests to cause economic loss?* That is a different question to ‘Are they causing damage to the plants?’
6. *Are the beneficial species likely to control the pest in the short term or the long term?*

Then, if after answering these questions you think that the pest needs to be controlled or there will be an economic loss, continue with the following:

7. *Are there selective pesticides available to spray?*

    If the answer is ‘Yes’, then it would be safe to spray. However, if the answer is ‘No’ or ‘Yes, but it is too expensive’ then continue with the following:

8. *Is a seed dressing or bait or border treatment possible?*

If so, this will not be too disruptive to beneficials and so could be used rather than a spray over the entire paddock.

9 *What will the non-selective pesticide kill in terms of beneficials, and what pest problems are going to occur as a result of their loss?*
10 *What is the cost going to be to control these pests in the near future or in the next crop?*

It may well be that the more expensive insecticide could be less costly than trying to treat ongoing pest problems, especially if insecticide resistant pests are involved. If not, and a broad-spectrum insecticide must be used, ask:

11 *What residual toxicities do the pesticides that are available have?*

Choosing the pesticide with the least residual activity will allow re-invasion of beneficials before it would otherwise occur with longer residual chemicals.

The reason for going through this process and trying to avoid some chemicals is only to help develop a population of beneficials in the paddock or crop. It is not of any value to those relying on a pesticide-based strategy. Those relying on pesticides would and should rely on the opposite set of decisions in some cases (such as question 11). If no beneficials are present or not to be considered, then the cheapest, longest residual chemical would probably be the best choice.

Finally, the last item is very important:

12 *Did the pesticide perform as hoped against the pest, and what effect was there on beneficial species?*

This process of decision making will help with information for future years as well as the current year.

The real decisions that farmers have to make are as follows:

1 *Do we continue to use a conventional pesticide approach?*

'Yes' – no change.
'No' – what do we do?

2 *If 'No':*
Assess an IPM approach.
3 Then – *How do we implement an IPM approach?*
4 And – *How do we get the information required?*

If a farmer answers 'No' to continuing with conventional use of broad-spectrum insecticides then the theory and examples in this book should provide a starting point. The section below provides some hypothetical scenarios and decision-making examples.

Specific examples of monitoring with some selected scenarios

Scenario 1: Canola

Paddock history is very useful in helping you know what to look for in terms of particular problems or problem areas. For example do you know that parts of the paddock always seem to have slug problems or RLEM damage? If so, you need to monitor for these pests and their associated predators or parasites in particular. In this instance, you could initially place tiles to sample for slugs and predatory carabid beetles in the places you suspect there is a problem. However, if you do not have this type of information, especially for beneficial species, then a start must be made somewhere.

Let us assume that the crop is about to be planted, and some farms will have paddock histories while others will not. In our experience in Victoria, farmers and growers can place tiles to monitor for establishment pests and beneficials from March onwards.

Select a monitoring point or points where you can set the tiles. This could be near a gate because it is convenient, or in an area that you consider high risk (such as low-lying areas or near rock piles). After placing the tiles, come back after one week and check underneath for any pests or beneficials. Remember that the tiles will also be used by species that are not pests or beneficial. You are likely to find a range of invertebrates including millipedes, centipedes, slaters, slugs, spiders, earwigs, beetles and assassin bugs (and sometimes snakes and mice). Obviously you will need to be able to identify these groups. The tiles are simply refuges for invertebrates that are active on the soil surface and so they attract a wide range of species.

Let us imagine that one week after planting you find five large slugs, three earwigs and two carabids under five tiles. What does this mean and what should you do?

You then need to know which species each insect belongs to; this will help you determine what risk they will pose to your crop.

This then may be three *Milax gagates*, two *Deroceras reticulatum*, three *Forficula auricularia* (European earwigs) and two small carabids. That could be equated to five major pest slugs, three major pest earwigs and two predators that are unlikely to have any impact in the short term on these particular pests. If there are signs of damage increasing; the crop was planted late; the weather is cold; and the plants are not growing rapidly – action could be required. However, if the plants are growing well and there aren't any signs of increasing damage then it is possible that no action would be necessary.

This is a very different scenario to five *Lehmannia nyctelia*, three *Labidura truncata* and two carabids. In this case we have minor pest slugs and predatory earwigs, not pest earwigs. Damage is unlikely to be serious, and if this is confirmed by regular monitoring then no action may be necessary.

Let us now consider another possibility with similar numbers. Assume that under our tiles we find five large slugs and two large carabid beetles and there are signs of damage to plants. The slugs turn out to be *Milax gagates* and the carabid beetles are those that eat slugs. You may assume that because the specific biological control agent that we want to be present for slugs is actually there then there will be no problem. However, the carabids eat smaller stages and the large slugs are causing damage now. So the biological control agents in this situation cannot be relied on to prevent damage in this current crop and baiting may be required.

The aim in this paddock now will be to suppress the pest slugs so that damage in this crop is avoided, without reducing the predatory carabid beetle population. In this way you would hope that the next crops to be planted in this paddock, including the next canola crop, would face less pressure from slugs as the biological control delivered by the resident carabid population takes place over years.

Scenario 2: Summer brassicas

Let us now imagine that we have a newly emerged fodder crop of brassicas in spring or summer. There are pests present eating the plants and these are small caterpillars. What should you do?

Closer inspection reveals that two types of caterpillars are present together with a number of other insects and eggs. The eggs are orange and are present as single eggs, not clusters. Then there are also dense clusters of smaller yellow eggs and clusters of orange eggs very similar to those laid singly. Many other insects are present including brown lacewing larvae and parasitoids of diamondback moth.

This type of observation is typical of a situation where there are both pest and beneficial species present. There are eggs of both pests and beneficials (such as diamondback moth, cabbage white butterfly and ladybird beetles) and also larvae and pupae of predatory lacewings and parasitoid wasps. The mix of beneficial species of different types and different ages is likely to differ greatly from paddock to paddock even within a local area.

You will see this kind of situation in most paddocks where broad-spectrum insecticides have not been applied. That is, there will be the obvious presence of pest caterpillars but on closer inspection there will be also signs that beneficial species are present. The lag between the arrival of pests and then beneficial species will always mean that there will be signs of pest damage before there are signs of beneficial presence.

What is required is some means of determining whether or not there will be economic damage before the beneficial species catch up with the pest population in the crop. If pesticide needs to be applied – what should be used?

In the example given above we will assume that there are eggs of diamondback moth, cabbage white butterfly and ladybirds. There are also parasitoids of diamondback moth and predators such as brown lacewings. Therefore the decision to be made depends on an assessment of whether there are enough beneficials to deal with the level of pests before economic damage occurs. How can you do this? It is the relative numbers of pests and beneficials and the trend in this relationship that will determine the effectiveness of biological control alone, and the impact of any other measure such as chemical control.

Consider for example, there are very many caterpillars of both species and a few beneficials on week 1, and more caterpillars but more beneficials on week 2 and significant damage to the plants. This would be a typical scenario. There is an obvious presence of pests but not such an impressive presence of biological control agents.

The lack of obvious biological control needs to be considered in the following context. Even if there was 100 per cent parasitism of caterpillar pests then it would not be apparent until the parasitoids had taken control of the caterpillars in the pupal stage. Adult wasps sting small caterpillars and the resulting death of the caterpillar will not be seen for several weeks. So there could potentially be massive biological control taking place but it could not be seen until the caterpillars progressed to the pupal stage. This is obviously a difficult situation to assess as there are both pests and beneficials present, but how do you gauge how the trend is progressing? It is only by regular monitoring that the change in pest–beneficial relative abundance can be measured and the risk of damage determined.

There are not always going to be enough beneficial species present at a critical time to avoid economic loss. In that situation there will be a requirement to reduce pest numbers quickly and ideally to avoid impact on beneficial species. In the scenario given above, an application of an insecticide containing *Bacillus thuringiensis* (BT) would reduce the caterpillar population without harming the populations of beneficial species present. This would not kill all the pests. The intention here would be to lower the number of pests so that the beneficial species would be able to control the remaining pest population without there being significant damage.

It is important that after applying such a pesticide that monitoring is conducted to determine whether or not it achieved the desired outcome. In this case the BT does not work as a rapid 'knock-down' but takes a few days to be effective. We suggest you leave the assessment for at least three or four days after spray application. When calculating the effectiveness of the pesticide, remember too that large caterpillars are harder to kill and may take longer to die than small caterpillars, although they should cease feeding after ingesting BT.

Whether or not a second application of insecticide is needed will depend on a variety of factors such as the success or otherwise of the initial spray, the age and value of the crop, the proximity of other sources of the same pest and so on. What you will be looking for is a change in the relative numbers of pests and beneficials and whether this is sustained.

Scenario 3: Cereals

We will consider here two stages of the crop, an establishing crop and one nearing harvest. First, in the newly established crop we may find signs of damage (small holes in leaves), and ragged chewing damage on the leaf margins. Under the five tiles that you have placed there are 20 European earwigs and two large slugs (*Deroceras reticulatum*). You have placed yellow sticky traps to monitor for flights of aphids and so far none have been found. What does this mean and how does the direct observation of damage fit with the counts of pests under the shelter traps?

The level of European earwigs is significant and is highly likely to cause damage to emerging crops. It is consistent with the observation of feeding damage to the margins of plants. The level of slugs present is also consistent with this set of observations. However, the small holes in leaves are not likely to be caused by either of these pests. It is an example of where there is visible damage and known pests present but the two things are not associated. That is, there is not cause and effect in this case to say that one pest is causing significant damage to plants.

What is also likely is that there is a population of lucerne flea present which is causing minor damage to the plants and there are also other pests which are causing more obvious damage, but still perhaps not economic damage, to the plants.

So what can be done at this stage? If it was known that European earwigs were present in high numbers before planting, a seed dressing would have been the preferred option. If it is too late for that to be done, selective baits could still be applied as a preferred option to a broad-spectrum spray. Both options are preferable to a spray of a broad-spectrum insecticide over the crop after planting, but the least disruptive option in the face of high pest pressure is the seed dressing.

Depending on the time of planting, you may detect an aphid flight by counting aphids on the yellow sticky traps. For example counts per week may be: Week 1 – 10 aphids, Week 2 – 10 aphids, Week 3 – 150 aphids, Week 4 – 1000 aphids, Week 5 – 50 aphids, Week 6 – two aphids. We would expect that predators and parasites of aphids (such as brown lacewings and wasps) would also show up in weeks 4 and 5 in this hypothetical example. Decisions on what to do about the aphids will depend on factors such as whether or not a seed dressing to control aphids was used and what the district risk of barley yellow dwarf virus (BYDV) has been in previous years.

Note that in Week 6 in the example above it seems from the sticky trap count that the aphids have gone. However, the traps do not catch the wingless forms and there could well be large colonies on the plants. So it is necessary to follow up these observations by inspecting the base of the plants for colonies of wingless aphids.

Later in the life of the crop direct observation and sweep netting reveal that there are heliothis and armyworm in the crop. These could be sprayed, when small, with a BT depending on factors such as time to harvest. Spraying a bacterial-based insecticide (BT) allows a highly selective insecticide to be used against caterpillars. Caterpillars must eat the insecticide for it to be effective, and it is rapidly degraded by UV. Therefore, timing of sprays is important.

Scenario 4: New lucerne

A lucerne crop has just been planted and has begun to emerge. Let us assume that monitoring detects mites and lucerne fleas. The most important items to determine immediately are:

1 *What sort of mites are they?*

and

2 *How many of each type are there?*

It may be that there are say 10 RLEM, two blue oat mites, four bdellid mites and three lucerne fleas in a sample area of 10 × 10 cm. There is also some visible sign of feeding damage. In this situation there is the presence of important pests and also signs of damage. The harder questions to answer in this situation now that we have identified the pests are:

1 *Will the pests cause significant economic loss?*
2 *Is the relative abundance of beneficial bdellid mites to pest species sufficient to control the pests?*

and

3 *What are the longer-term consequences of applying an insecticide that will kill predatory mites and other beneficial species?*

More than the immediate damage needs to be considered in a situation where the lucerne pasture will be present in the paddock for several years and resident predators are required to control resident pests. Furthermore, removing one pest with insecticide may favour other pests that are more tolerant of insecticides, thus making a pest problem that is harder to deal with than the original. So in this scenario, regular monitoring should be carried out to keep a good check on the level of damage that is occurring, as well as the numbers of pest and beneficial species. Only apply an insecticide if the requirement to protect the immediate crop outweighs the longer-term considerations.

Another possibility is that there are more than 50 RLEM and 20 lucerne fleas per 100 cm^2 and no sign of predatory mites. Feeding damage is obvious, no seed dressing has been used and so a loss is likely. In this situation an insecticide is required to prevent immediate damage, but there is a high likelihood that further spraying would be required. This is the type of situation that is encountered in lucerne that has a history of insecticide applications for mites and lucerne fleas.

8

Case studies and examples

In this chapter we provide some examples from farmers with whom we have worked, outlining their experiences with adopting IPM. They are from both broad-acre cropping and intensive horticulture and all except the first example (Rowan Peel's) are extracts from various existing sources. The 'Six broadacre crops' are from notes prepared for two workshops in Victoria by Cam Nicholson as part of the Grain and Graze Project. Peter O'Sullivan presented a paper on his experiences with IPM at the Potatoes 2000 Conference in Adelaide. The experiences of three different vineyard owners and/or managers were published in the magazine *Australian Grapegrower and Winemaker*. The final example is from the website of Peter Schreurs and Sons (www.leeks.com.au) who grow a range of vegetable crops near Cranbourne in Victoria.

ROWAN PEEL, CROPPING, INVERLEIGH

We run a cropping and grazing property near Inverleigh. The main farm is 1350 ha and there is an additional 400 ha run as a share farm. Our crops are a rotation of wheat, barley, canola and lucerne.

Before using IPM we had a fairly standard, calendar-based pesticide strategy (using broad-spectrum insecticides). That consisted of applying insecticide with the herbicides before planting and just after sowing, then spraying for aphids at pre-determined times and possibly for grubs such as heliothis late in the season. Baiting for slugs was also standard for us in canola crops.

Our approach to pests and pesticide use has now changed totally. We now only use insecticides if absolutely necessary, and then we try to use selective products. For pests such as lucerne flea in lucerne we now treat only problem spots rather than the whole paddock. We began by trialling IPM on three paddocks four years ago, but quickly decided that this was the way to go and three years ago decided to apply IPM on the whole farm.

We see several advantages in using IPM. The main advantages to us are being better off financially, not having to handle so much pesticide, it is better for the environment and also that we know exactly what pest we are dealing with and so are getting better control.

Farmers like to see other farmers in their area having success with any new technique, and so on-farm demonstrations are a good way for growers and agronomists to become confident in IPM. It also needs skilled people to help get it started. The decision making became much easier when we began to understand about beneficials in our crops. That meant having a really good look in our crops and being aware of what was going on at that level on our farm.

Six broadacre crops

In 2005, six growers and/or Agvise P/L agronomists near Inverleigh in Victoria using an IPM approach were asked to describe their reasons for getting involved in this type of pest management; what IPM involves; and the benefits they have obtained so far. Minimal editing has occurred to each paper to ensure each story reflects the perspective of the growers involved. These stories were collected and presented by Cam Nicholson in a workshop for the Grain and Graze Project.

JAMES RICHARDSON, TERRINALLUM, DARLINGTON

Terrinallum

The property is 2700 ha with 360 ha cropped to canola, red and white wheat and barley. Soils range from free draining lunettes to heavy black clays with basalt clay loams. There is a 75 ha centre pivot irrigation system to grow feed for lamb finishing. The property has 800 cows and 5500 crossbred ewes. Rainfall should be 650 mm but last year was 475 mm.

Why get involved in IPM?

I have been concerned for some time about the amount of chemicals we use in our cropping program. So when Agvise approached me with a proposal to start using IPM, and having the outline of the methods used in IPM explained to me, I thought that this was a very positive step in the right direction and we should be involved.

The main reasons for implementing the IPM program have been:

1 Insects becoming resistant to chemicals.
2 The damage insecticides do to the environment.
3 The financial benefit of not having to spray insects, by encouraging natural predators to deal with the problem pests.
4 To improve the farm environment.

The paddocks

We started with three paddocks being inspected once a week by Neil Hives, IPM Technologies Pty Ltd, for the duration of the crop. One paddock was canola, one was barley and one was of red wheat. All have had a history of slugs, aphids and redlegged earth mite (RLEM).

Canola and redlegged earth mite

The paddock of most interest was the canola paddock, 'First Quarry'. On the 19th of July Neil rang me reporting that a high level of RLEM was present around the edge of the canola. He suggested that a border spray in about 12 metres would be advisable as the RLEM would do some damage to the crop. He did suggest that we leave a strip so we could actually see what would happen if we did nothing.

Due to bad weather, high winds and misty rain, I did not get around to doing the boundary spray with the recommended insecticide. The following week when Neil looked at the paddock he reported that the predatory mites, present in greater numbers, were getting on top of the RLEM and the population was at least being held if not declining. At this point we took the decision not to proceed with the boundary spray.

Conclusions

In this paddock we saved at least $11/ha by not including routine insecticides in our spray brew; this equates to about $500 but more importantly we have been able to maintain the beneficial insect population which will give ongoing benefits in subsequent years.

It was a great exercise and an extremely valuable lesson that if we continue to monitor the levels of beneficial species in our crops we may be able to significantly reduce the amount of insecticides we all use.

The future

In 2005 we applied the same strategies mentioned above across the entire cropping operation. We also are applying an IPM approach to our pasture management.

In 2006 we intend to undertake the application again across the entire property and expect, as knowledge and experience increase, so will application of the IPM approach.

Inspection notes, Neil Hives, IPM Technologies P/L

We give below the inspection notes by Neil Hives which track the monitoring and assessment process and background to the decisions taken and paddock history.

Re: RLEM in First Quarry canola crop
21/6/05
Crop just coming through.
No RLEM present and no predatory mites, beetles or spider present (all predators of RLEM but we do focus on predatory mites as the main control beneficial).

28/6/05
Nil RLEM.
Nil predatory mites.

5/7/05
Nil RLEM.
Nil predatory mites.

12/7/05
Low numbers of RLEM present in the crop and moderate numbers at the crop edge. Predatory mites present among the RLEM population at the crop edge but not many predatory mites when compared to RLEM.

19/7/05
Low numbers of RLEM present at the edge of the crop – coming perhaps 1.5 m into the crop here and there only. Not a consistent invasion into the crop along the entire edge. Some plants near the edge showing damage from RLEM.

Predatory mites present in greater numbers this week than last at the crop edge – an indication that the key predator was showing a classical numerical response, i.e. increasing in number in response to the increasing prey number. The big question being 'Was this predator response going to be big enough to suppress the RLEM numbers before RLEM could inflict **economic damage** on the crop?'

James – this is the week I first suggested a border spray if you were concerned about seedling loss which may increase significantly if RLEM numbers continued to increase. I thought at the time ideally this border spray, if applied, would only be up to 2 m into the crop (but often this is not practical).

You chose not to spray, which was fantastic so we were able to see the real impact of a patchy edge invasion of RLEM but also how the predatory mites responded to increasing RLEM numbers and more importantly whether or not RLEM numbers would be held by predators.

25/7/05
This week some really important things were observed:

- RLEM numbers had not increased around the crop edge on last week which suggested predatory mites had significantly slowed the RLEM population growth.
- RLEM numbers had not increased into the crop.
- RLEM numbers were still low on the beds.
- Canola plants were growing strongly on the edge of the crop – a few had been retarded a little, a few also had been lost here and there along the edge but the plants remaining were growing really well.
- There were plenty of predatory mites among the RLEM population and also more predatory mites were now moving deeper into the crop even though RLEM numbers were still low further into the crop.

Economic damage had not been sustained by this crop. If only RLEM numbers were used to determine risk of damage, then many would have sprayed. If one considers the presence of predators, the risk of damage changes. We do not use thresholds for this reason. 20 mites per 100 cm^2 are often cited in literature. A given number of RLEM per plant or area is less relevant if there are predators also present in good numbers at the right time. Most often no attention is given to beneficials. Situations do need monitoring more closely.

1/8/05
RLEM numbers were observed to have decreased on last week but still numerous at the crop edge. Predatory mites had continued to increase as a proportion of the mite population. Plants growing strongly.

8/8/05
RLEM more difficult to find this week. Predatory mites still common. Plants well past risk of damage.

STEPHEN MENZE, CROPPING MANAGER FOR CHARLES IFE PIGGERIES NEAR BALLARAT

A short background on the property

Charles Integrated Farming Enterprises (IFE) Pty Ltd was formed in 1967 with the main enterprise being an 1800 sow piggery, supported by a garden products company, a stockfeed business and 1127 ha of farm land. 826 ha are owned and the balance either leased or share farmed. It is situated 15 to 20 km north-west of Ballarat where the average rainfall is 600 mm (24 inches). Of this land about 95 per cent is cropped. Winter wheat is grown for the pigs and canola is grown in the rotation mainly for a disease and weed break.

Typical pest problems faced and past approaches

The main pest problems that we have faced in the last five years are slugs, earwigs, rabbits, mice, armyworm and aphids. The slugs are controlled with a baiting program at the emergence of the canola seedlings or preferably over summer if rainfall events allow. Mice have been controlled by burning the wheat stubble and armyworm have been controlled by natural predators. Both rabbits and earwigs have been controlled with in-crop baiting, though this year some control of the European earwigs was achieved by predation by the fatbottom earwigs. Aphids in the past were controlled by a broad-spectrum insecticide whenever we thought they needed to be controlled on agronomist advice.

The graph below gives an indication of control costs of pests on our property (Figure 8.1). Our aim is to reduce these costs by using a carefully implemented IPM approach and by managing the beneficial populations. We expect this to reduce our insecticide costs but more importantly reduce the number of times we have to spray. This could result in a saving to the property of around $20/ha or $20 000; a very significant amount.

Why we have become interested in an IPM approach

We became interested in an IPM approach due to our ongoing effort to continually become more environmentally friendly. We were worried that over time ‘Spraying The Shit Out Of Everything’ probably wasn’t the best thing to do. We were concerned about a pest, in this case aphids, building up a resistance to the chemical and the chemical residue levels that may be passed onto the consumer of the grain, in this case the pigs. We didn’t think that we could continue farming using these practices and also liked the idea of less work, and letting Mother Nature do some of the work for me so that I could have the weekends off.

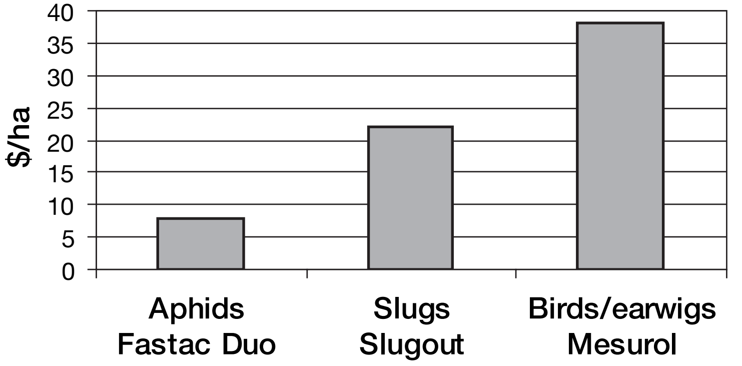

Figure 8.1 Pest control costs of various insects.

Our experiences with IPM

Aphids and barley yellow dwarf virus (BYDV)

In January 2005 we had 91.5 mm of rain which shot a lot of volunteer canola. This created a perfect environment for aphids to breed and then infect the emerging autumn-sown wheat crop with barley yellow dwarf virus (BYDV). After discussion with our agronomist, Steve Dickson of Agvise, we decided that action had to be taken. There were basically two choices: spray with a broad-spectrum insecticide such as 'Fastac', which was cheap and would kill all insects including the beneficials, or, option two: use a product such as 'Pirimor' which was a lot dearer but would only kill the aphids and leave the beneficials. Hopefully the use of 'Pirimor' would control the aphids for the rest of the cropping season.

The other decision we had to make was whether to trial this idea or use it across all of our farm. After discussion with my boss, the property owner Melville Charles, independent insect expert Neil Hives and agronomist Steve Dickson, we went with the option of using 'Pirimor' and the results were excellent, with no BYDV in any of the crops.

Where to with IPM in the future?

I believe that in the future more pressure will be put on farmers by consumers and 'do-gooders' to use an IPM approach to the way they farm. I think that farmers will see more and more benefits as the idea is further researched and developed. I believe that IPM is all about opportunities. In some situations an IPM approach is the best answer but be warned that one year is only a trial – not a conclusion!

PETER O'LOUGHLIN, LEASING LAND ON BOOBOOK AT INVERLEIGH

I am a director of Agvise Services Pty Ltd, a company which, among other things, provides advice on IPM to farmers. I am also involved in growing crops. It's one thing to recommend an IPM approach to someone else, but what about when you are spending your own money?

Background

About five years ago through a meeting of industry people gathered together by the GRDC to discuss action to combat the newly emerging slug issues, I met Paul Horne. This proved to be the start of my IPM journey.

Through focusing on the slug issues it became very apparent that to focus only on the one pest/one crop approach was not the answer when it came to insect pest problems. The one-dimensional approach of matching an insecticide to a pest in any given crop was, in my opinion, starting to emerge as a limiting factor to the sustainability of our exciting new farming system. We needed to look at the issues with a bigger picture in mind. The bigger picture included understanding the downside of non-specific insecticide use, what other bugs were present, both good and bad, and finally thinking about this in a longer-term crop rotation.

Through the skills of Paul Horne and Jessica Page we were able to set up a trial/demonstration at Rowan Peel's property at Inverleigh, to look at not only slugs but what other pests, both good and bad, were present. This quickly showed us that slugs were not our main problem and baiting them doesn't work that well if they are not present! It also showed that the previously held belief that earwigs didn't cause any significant damage to seedling canola was totally false. That's a lot to learn in a couple of paddocks in one year!

Since that original trial it became very apparent to all involved that we needed to learn a lot about IPM – and fast! So we broadened the 'Rowan trial' to numerous other Agvise clients who were happy to pay in order to develop an IPM approach. Before long we were using 'soft' bacterial products to control grubs in summer crops with excellent results and cutting out 'harsh' insecticide use on many cereal and canola crops. These products protected the beneficial insect populations allowing them to be the principal long-term control measure.

The challenge always for me as a commercial agronomist was to work the commercial line between managing the production risks that come with broadacre cropping and an IPM technique that was evolving rapidly but was in essence still young and untested. Paul's experience in horticulture gave us the confidence to proceed in most cases but there were times when more conventional approaches were used as the risks were deemed too great. We have come a long way in our knowledge in this time.

Agvise and our clients, through our commercial relationship with Paul, are continually learning more about IPM and changing our methods to include this new approach in our farming system. It would be reasonable to say we are all collectively sold on the concept and it's all about getting more knowledge to ensure all our decisions are good ones.

The 'real world experience'

Boobook, Inverleigh, is a property leased by Agventure for the past three years, with 210 ha cropped.

A trial was conducted at Boobook in 2005 by Bree Walshe from LaTrobe University in conjunction with Paul Horne and Agvise Services. The trial was set up to look at the practice of programmed insecticide use to combat aphids, which carry the barley yellow dwarf virus (BYDV) in cereal crops compared with an IPM approach.

There was a treated and untreated area and both were monitored weekly to gather information on both pests and beneficials. The treated area had an insecticide treatment at both 4 and 8 weeks post sowing in line with district practice.

Key findings

Beneficials

- High numbers of lacewings present
- Lacewing population was **reduced in treated plots**
- Lacewing population **increased in untreated plots**
- Low numbers of beneficials other than lacewings.

Pests

- High numbers of lucerne flea on site
- Lucerne flea **outbreak** occurred at week 8 in **treated plots** (see Figure 8.2 below)
- **Untreated** plots showed a lot **lower lucerne flea numbers**
- Very low numbers of aphids
- No need to spray for aphids in 2005
- Spraying **does** reduce beneficial species
- Pitfall traps best method to monitor bug numbers.

The balance of the farm had no insecticide used, in line with this IPM approach, thus saving $10 per ha, or about $10 000. The approach will also make us better placed for 2006 with a growing population of beneficials.

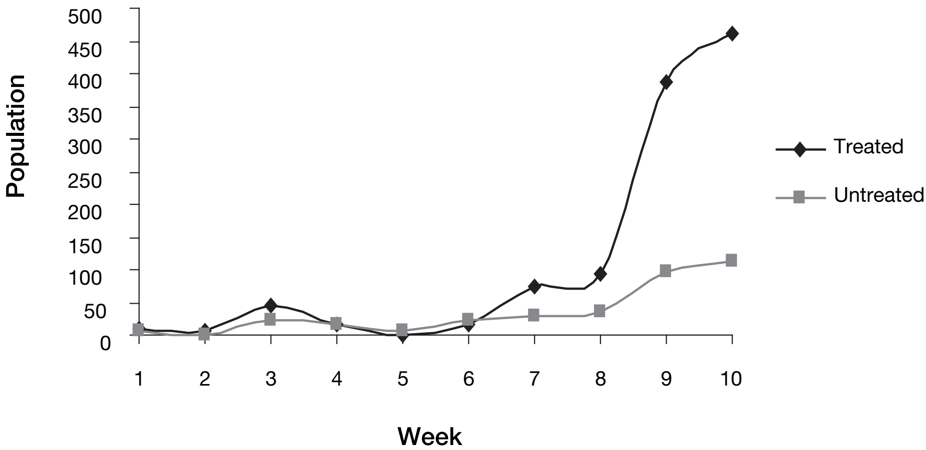

Figure 8.2 Lucerne flea outbreak.

In summary

The programmed spray for aphids was not necessary because incoming flights did not occur with spraying times.

By using the programmed spray, beneficial lacewing populations were reduced leading to a large build-up of lucerne flea later on, so creating a further requirement for more spraying.

Key components to succeed with IPM

1 Technical knowledge and support
2 Beneficial bugs
3 Captive audience of growers
4 Time and patience
5 Product choices at competitive prices
6 Monitoring, monitoring and more monitoring.

Challenges that lie ahead for IPM

1 Better detection methods
2 Quality technical support
3 Skilled people in the paddocks doing regular monitoring
4 Invest in R & D from GRDC and so on
5 Industry support.

Thanks for this work must go to Bree Walshe and Peter Sale from LaTrobe University and also to Paul Horne for his assistance in this trial and the general development of the IPM concept in our farming system.

JOHN HAMILTON, LEIGHVIEW, INVERLEIGH

The Leighview farming operation

Our operation comprises about 2000 ha of crop and about 1500 merino wethers. Cropping consists of about 500 ha of canola, 700 ha barley, 400 ha milling wheat, 300 ha of red wheat and a few peas and linseed. Approximately half the area is owned and the rest is leased and share farmed. Our own country is continually cropped with some paddocks now up to 28 crops in a row. Sheep are run on non-arable areas and are used as stubble crunches after harvest.

I am not a Greenie. My previous approach has been the only good bug is a dead bug. We have done much preventive insecticide work in the past which may or may not have been necessary. Our normal approach has been to add an insecticide to any application of 'Round-up' and 'Endosulfan' with any 'Simazine' or 'Atrazine'. Slug baiting post sowing of any canola crop had become routine. These chemicals cost about $25/ha.

Developing resistance

After observing the amount of herbicide resistance happening in farming I decided a new approach was necessary. Frequent applications of insecticides would lead to a similar situation in our pests. Weeds don't have predators but insects do, so it seemed a natural progression to try and harness these wherever possible. We have ceased much preventive spraying and now prefer to see insects before spraying. Many times as pest populations build up so do beneficial populations, so by not spraying we are increasing these beneficial populations. This is sometimes very hard on the nerves as there is a delay of several days for the predator to build up to controlling levels. If you go in and spray immediately you will also kill the beneficials – creating problems perhaps later in the season requiring another insecticide application.

We have been monitoring a wheat, a barley and a canola paddock each year for the last three years with Dr Paul Horne building our knowledge each year. Paddock monitoring is carried out every fortnight by Steve Dickson of Agvise and when a problem is suspected I inspect it every other week. If a problem actually arises it is monitored as required which is probably every day or second day.

Earwigs and aphids

Last year we had problems with earwigs in canola, which we may have been blaming on slugs. This gets very involved because the native earwig is not a problem but the European earwig is, and believe me – one earwig looks just like another earwig, even with my glasses on! To combat this we had to bait for earwigs. There is not a recommended bait for earwigs but IPM Technologies found some information from Western Australia, so we tried it. The bait consisted of an insecticide, vegetable oil and attractant mixed with wheat and was very successful.

In late October we had a rapid build-up of aphids in canola. We normally would have sprayed immediately. However, it was recommended that we wait a few days to see if we had a build-up of beneficials, because there were a few in the paddock. Within a week the predators had control of the aphids. We monitored the paddock daily to see what was happening. This is very difficult for someone who wants to act on a problem immediately.

IPM requires a lot more time to see exactly what is happening in the paddock or even just on one side. It is a slow process and requires getting on your hands and knees.

Dollars and beneficials

At this point in time IPM has actually led to a saving in costs for us but has required more time. It does require more planning even from year to year regarding what crop is going into the paddock the following year and what pests and beneficials are there now. It has surprised me at this point to see how good a job the beneficial insects have done.

An IPM approach is not always possible. You must be prepared to use insecticides if necessary, although the choice of insecticide becomes very important. Often insecticides can be selected that are soft on beneficials and hard on the pest. Concern for the beneficial population is a priority and may require a more expensive option of chemical to use.

Where to next?

IPM has become a fundamental part of our farming practice and it is our intention to expand its application across our entire cropping operation as our knowledge and confidence grows.

STEVE DICKSON, CONSULTING AGRONOMIST AT THE FALLS, INVERLEIGH

The Falls is located on the Inverleigh–Winchelsea Rd. Historically a traditional grazing property, it was transformed to raised beds and cropping in 2003. Total area to crop is 246 ha with some area still grazing country. It is in a 520 mm rainfall area that tends to become waterlogged in a wet winter. The Falls is a leased property and I am engaged to provide agronomic inspections and recommendation to the lessee.

The pests

In the cropping phase pests such as slugs, lucerne flea, redlegged earth mite (RLEM), ground larks, aphids and armyworm have had to be combated in the canola–wheat–barley rotation.

The traditional approach for control of these pests has been:

- Canola. A ‘Dimethoate’ spray with the knockdown herbicide for RLEM, aphids and lucerne flea, ‘Endosulfan’ sprayed once the crop has been sown for protection from RLEM, lucerne flea and ‘Mesurol’ applied to the canola seed to protect against ground larks, with possibly one or two slug baitings.
- Cereal phase. ‘Dimethoate’ with the knockdown, two ‘Fastac’ sprays to prevent infection with barley yellow dwarf virus (BYDV), then a possible further ‘Fastac’ with the fungicide treatment to clean any other pests that may be about.

The advent of the IPM approach

My introduction to Paul Horne and IPM Technologies happened about two years ago. Paul had been working successfully in horticulture and there was interest to try the methods in broadacre cropping in our current cropping systems. The realisation that natural predators existed and that they could combat the ‘nasty’ bugs without having to throw an insecticide at them naturally sounded fantastic.

Paul and Jessica Page started monitoring an area of the barley paddock prior to sowing the crop to establish what predators and enemies were there. Tiles were placed down for slugs pre-sowing and after sowing, and sticky plates to catch aphids were also put out. Inspections were conducted fortnightly up until harvest with regular email and phone conversations to talk about what was there and how to handle the pests that were found. The pests that were there included three species of slugs, wireworm, lucerne flea and blue oat mite. No action was needed throughout the year in the IPM-monitored part of the paddock, while the rest of the farm followed the traditional spraying program for cereals.

In November a flight of armyworm flew in, which was one of the largest for some years. We decided to treat all but 18 ha of the property by including the insecticide ‘Fastac’ with a fungicide application in November. The untreated IPM area (18 ha) was sprayed with fungicide only and no ‘Fastac’ was included. Paul later discovered that the treated area had no beneficial insects, the chemical had destroyed them, whereas the untreated IPM area had ample numbers of brown lacewings, predatory wasps and mites. These natural predators were able to build in numbers to fight off the armyworm invasion, which I found amazing. The armyworm numbers built up again in the treated area but it was not able to be resprayed with insecticide as it was close to harvest by the time the adults had started doing damage and the insecticide withholding period prevented it. IPM had certainly hit home as to its worth and the understanding of how habitats and creatures live in the bug world.

Future application

This had been such an interesting exercise that the methods we have learnt in the last two years from Paul, Jessica and IPM will continue to be expanded on the farm. The understanding of natural predators and that there exists more options than just mixing up an insecticide and killing the first pest that we see has now been replaced by a better understanding and the need to think about sustainability in our agricultural system. It is not only the money spent on insecticides, ranging from $27–$36/ha that we could save, but also the thought in the back of the mind regarding development of resistance to insecticides. This has occurred in the horticulture world through overuse of insecticides, but overall the thought of what we are harming in the process is a concern to me.

We will continue to look at options such as bacterial sprays, seed dressing for targeted insect control and the adoption of a number of cultural controls that will help overcome our pest problems. I am confident this will evolve into a new and complete management system that is cheaper, more productive and environmentally sustainable.

I certainly will look forward to continue learning from Paul and the IPM team.

ROBERT MEEK, STRATHLEIGH, SHELFORD

Barbara and I farm 1000 ha, 10 km north-west of Shelford. The country varies from rocky basalt plains, volcanic gullies and slopes to river flats on the Leigh River used for lucerne production.

Land use

500 ha are cropped with 50 per cent being bedded. The crops grown are canola, white and red wheat, barley, oats, linseed and broad beans. 500 ha are grazed along with the stubbles in the summer. Like most sheep farmers the shift is toward meat sheep. Border Leicester, White Suffolk and SAMM rams are used over 1000 of the 1800 merino ewes.

Pest problems

When we started growing larger areas of canola, we saw damage in the emerging canola and always blamed slugs. On joining the Agvise IPM programme, Paul Horne informed us, after monitoring our paddocks, that earwigs were most of the problem. A big saving appeared when we stopped baiting for slugs (often twice). We successfully controlled the earwigs in last year's canola using a seed dressed with 'Cosmos'.

Again, with advice from Paul Horne, we stopped the routine spraying of insecticides for the control of aphids in our cereal crops. A lot of insecticide is wasted spraying before aphid flights occur. All this kills are the predators and parasites so when the aphids move in they have a free rein.

Why I became interested in IPM

I have slowly come to realise that, in the main, killing bugs with a boom spray doesn't work. Heavy infestations of armyworm in barley could be one exception I can think of. Sure you can get a very quick reduction in numbers, but if you also kill all the insects that are eating your pests you are only compounding the problem.

When you start to think that some insects are eating other insects and not your crop you have a whole different outlook! Balance is the key and you will not achieve it with a boom spray.

Monitor your paddocks: that means getting down on your hands and knees. Put bags or tiles out and see what moves in under them.

Redlegged earth mite and pastures

My interest in pests started over 10 years ago. We have a lot of native volcanic country that in some years needs spraying with herbicides by plane to control variegated thistles, capeweed and so on. I was encouraged to add insecticide to control RLEM but I resisted because I could not see a problem. However, on our arable country sowing down we would use insecticides to protect the clover. I slowly realised that I wasn't controlling the RLEM with insecticides so about 10 years ago I stopped spraying sown down pastures for them, except for a border spray in the year of sowing. It took three or four years for the sown down country to follow the path of the native country and have minimal damage from RLEM. I didn't know it at the time but it took that long for the predators to build up.

When we are looking at pests in cropping the same principle applied – **protect your predators!**

Some costs

The following are my insecticide costs per ha compared with the benchmark results from Agvise clients for 2004 (see Table 8.1 below). Since most Agvise clients undertake a level of IPM their figures are probably lower than the average.

Table 8.1: Direct cost savings from IPM compared to Agvise clients

	Meek	Agvise
Crop	**$/ha**	**$/ha**
Amarok wheat	1	5
Mitre wheat	1	5
Gairdner barley	2	5
Canola	6	21
Total	10	36
Ave (all crops)	2.50	9.00
Total over 500 ha	1250	4500
Total Saving	$3250	

IPM – the future

I see seed dressings becoming more popular in the future because these only harm the pests that eat the crop. One of the drawbacks I see with IPM is the lack of experienced consultants such as Paul Horne and Jessica Page of IPM Technologies. I think more agronomists have to gain more knowledge. Steve Dickson, Agvise, is great and a good back-up to Paul and Jessica.

PETER O'SULLIVAN, POTATO GROWER

Following is the text prepared for a paper presented by Peter O'Sullivan at the Potatoes 2000 Conference in Adelaide.

Introduction

I have grown potatoes at Cora Lynn (near KooWeeRup) for many years, and until five years ago I relied on regular use of insecticides to get control of insect pests. I was keen to reduce the cost of production in an area that I could control. The contract or market prices were out of my control, as were most other factors of production (seed, fertiliser, water, transport and so on). Looking at reducing the cost of pest control was something that was of interest but there was no way that I could compromise on quality or yield.

Before using IPM, it was routine for me to add an insecticide with every blight spray, and if aphids or moths were around then I would use an extra spray. The cost of insecticide was not a major issue, but I would rather not have to spend money on chemicals if there was another way to get good control of pests.

Five years ago, the opportunity arose for me to be involved in a trial to use IPM to control potato pests. At that stage, I was unaware that beneficial insects existed in potato crops, and I believed that there was some possible advantage in changing from my routine spraying, but also a very big risk of damage.

Initial use of IPM

It seemed to me at the time that IPM was very risky, and I was not prepared to try it out on my whole farm. The trial was conducted on a paddock with a history of very little damage by insects (potato moth in particular). I kept a close interest in the results as they were gathered week by week, and I began to be more aware of beneficial insects and how they influenced pest numbers.

There was an immediate saving in reduced use of insecticide, and the results from that paddock were good. Because of that, I tried IPM out on a second paddock planted later. Results were also good from that paddock and I decided to try it out on a larger scale in the next year. I was not yet prepared to use IPM on my whole farm but I tried it on a few more paddocks that were low risk. The emphasis at that stage was still on potato moth, and I was still treating the use of IPM as a trial.

Full IPM

In the third year I took the decision to use IPM on my whole farm, including high-risk paddocks. I had the crops monitored weekly for all pests and beneficial insects, not just potato moth. It was a very nervous time! In addition to using no insecticides, I began to change the management of the crops. In particular I changed the way I formed hills, how and when I irrigated and even the timing of harvest in particular paddocks.

The results from using IPM were very good. I had controlled all pests, including potato moth and aphids, without any insecticide at all. I was then convinced that I could use IPM in any year, as it had been a season when pests would normally cause damage. However, I was also convinced that weekly monitoring was very important which was a fact that I had not appreciated before. If I had not had close monitoring and advice from IPM specialists at that time, I think I would have gone back to regular spraying when I saw large numbers of moths flying. Since then IPM has become easier for me (less risky). I am still prepared to spray with insecticides if necessary, but now I am more likely to choose not to spray when the risk is borderline.

Changes made with IPM

The easiest change to measure was the savings on chemicals. I estimate that I have saved $55 000 since using IPM. I have not sprayed any insecticide now for five years. I now place a much greater emphasis on soil cover and hilling. I have seen how important this is, as I have seen the consequences of not providing good cover. The change in irrigation includes watering at the end of the season, more or less using water instead of insecticide. This had no effect on specific gravity, which is a major factor to consider when growing crisping varieties.

I am now in the crops more often, as I need to check on insects and soil condition more than when I relied on sprays. This has the benefit that I know much more precisely just how my crop is going in areas other than pest management.

Something harder to measure, but a real bonus, is that my family and neighbours are much happier now that I am not spraying so much.

Initially, 'doing nothing', as it seemed, was not easy, but the worry about not spraying gets less as each year goes by. I now realise that I was actually building up populations of beneficial insects by not spraying, and not just 'doing nothing'.

The cost of monitoring is an expense, but one that pays for itself. I find it more efficient to get it done by IPM specialists as I do not always have time to do the regular crop checks. My time is better used on other aspects of production but I need to know the monitoring will be done. The information that is gathered by the crop monitors must be available either at the time the monitoring is done or on the next day. If I need to do something to control pests or assess the risk myself, then I need to know quickly.

I have been very surprised at how pests such as aphids and potato moth can be controlled so well by beneficial insects. In early-planted crops I often see aphids, and they just disappear when brown lacewings arrive. I now rely on these predators, clean seed and good rotations to control aphids and viruses, and similarly, I use parasitic wasps, damsel bugs, hilling and irrigation to control potato moth and not routine use of insecticides.

I know that insecticides remain an option for me to back up the other methods of pest control. My preference has been to choose not to use insecticides but I may decide to use insecticides at times in the future when there is high pest pressure. If so, the choice of insecticide is likely to be very different than when relying on pesticides alone. It is important to know what the effects of sprays are going to be on beneficial insects, and to make a balanced decision. I have seen first-hand now how inappropriate use of insecticide can actually cause pest and disease problems, not solve them. In particular, I have seen aphids and leaf-roll virus get worse on farms sprayed with insecticides that have killed beneficial species.

Using IPM has been a major change in production methods for me, and one that I intend to keep.

Three vineyards

The following is the slightly abbreviated text of an article prepared for the industry magazine, *Australian Grapegrower and Winemaker*, by Danielle Hibbert and Paul Horne. It was published in 2001.

IPM in practice: case studies

We chose to investigate three growers who have implemented IPM within their vineyard management. The three were chosen because, between them, they represent new and also established vineyards, and small to very large plantings. These are:

Ross Baldwin, Director Whitsend Estate
Whitsend Estate, Coldstream, Yarra Valley

- Vineyard size: 12.2 ha.
- Varieties grown, wines produced or future plans: Cabernet Sauvignon, Merlot, Shiraz and Pinot Noir.
  50 tonnes of fruit produced this vintage. Sold to commercial winery in Yarra Valley. 3000 litres of CS and Merlot made for Whitsend. CS in new French oak, Merlot in new American oak.

Dr David Lance, Director Diamond Valley Vineyards
Diamond Valley Vineyards, St Andrews, Yarra Valley

- Vineyard size: 3.5 ha.
- Varieties grown and wines produced: Chardonnay, Pinot Noir and Cabernet Sauvignon, Cabernet Franc, Merlot and Malbec.

Phillip Island Vineyard & Winery, Phillip Island, Gippsland

- Vineyard size: 2 ha.
- Varieties grown and wines produced: Sauvignon Blanc, Chardonnay, Pinot Noir, Merlot and Cabernet Sauvignon.

Ray Guerin, Regional Viticulturist Victoria / Tasmania BRL Hardy Ltd.
Hoddles Creek Vineyard

- Two locations: Gladysdale, Vic, 24 ha and Hoddles Creek, Vic, 58 ha. Both vineyards within the Yarra Valley region.
- Varieties grown and wines produced: Chardonnay, Sauvignon Blanc, Pinot Noir and Pinot Meunier.

Current wines produced are under the Yarra Burn label. These include a Sparkling Chardonnay/Pinot Noir/Pinot Meunier blend. Table wines are comprised of Chardonnay, a Sauvignon Blanc/Semillon blend and Pinot Noir. Our premium brand is the Yarra Burn 'Bastard Hill' label of which there is a Chardonnay and Pinot Noir wine.

Both David Lance and Ray Guerin changed their management to include IPM whereas Ross Baldwin has been using IPM since establishment two years ago.

By looking at IPM in practice, you can begin to understand how management theories and practical strategies can work within a vineyard situation. There are many reasons for implementing IPM, namely to achieve a superior product, using fewer chemicals which reduces costs and improves monitoring effectiveness. IPM is not a rigid set of rules, but rather is an approach to deal with pests. IPM is adaptable to any agricultural situation and has enormous outcomes for the future of modern viticulture.

These three case studies show how IPM can be used in viticulture by those just starting out or those with great experience in the industry. We thank Ray, David and Ross for their time in responding to our questions (see Table 8.2).

Table 8.2 IPM experiences of three vineyards in Victoria

	Whitsend Estate	Diamond Valley Vineyard	BRL Hardy LTD
How long have you been using IPM and why did you choose IPM?	Since the first year. I studied IPM and attended a lecture by Paul Horne. Generally agree with philosophy that spraying with chemicals is the last form of defence.	Five years. We wanted to create a balanced ecosystem within the vineyard that would limit problem pests and give lasting results.	We have practised IPM for the past six years with the assistance of Dr Paul Horne – IPM Technologies Pty Ltd. We were using Dipel for two or three seasons prior to this with poor results.
How is IPM used within the vineyard?	Specialist monitoring service, vineyard staff awareness and records kept each season. Weekly monitoring of block with most prolific broad leaf weeds. Graphs kept of LBAM. Vineyard staff meet to discuss findings with Monitors. Regular reports to management. Discussions on seriousness of pests. Debate on possible solutions.	IPM Technologies monitoring services plus vineyard staff awareness and in-house record keeping.	We were not happy with the control of insect pests within the vineyard and knew that we had damaged the ecological balance in prior years with the use of hard insecticides. We could see the need to change our ways and with the assistance of Dr Horne coming on site to assist and guide us into a sustainable IPM method. Craig Callec, vineyard supervisor, was also fortunate to do a course with DeAnne Glenn on the monitoring of insects within the vineyard. This helped in our ability to find LBAM egg masses, spot various stages of lacewing insects, find predatory mite and know other beneficial insects. Also know when to spray, if needed at all.

	Whitsend Estate	**Diamond Valley Vineyard**	**BRL Hardy LTD**
Outcomes of IPM so far? (Advantages/ disadvantages) *How important do you think monitoring is in helping with pest management?*	Our preference is to minimise use of all broad-based insecticides. Monitoring is critical. If a philosophy of minimisation of chemical use is adopted, then a fundamental requirement exists to adopt a planning strategy to minimise and manage the subsequent risks. In this case, professional and independent (from chemical suppliers and from vineyard staff) monitoring serves to mitigate this risk.	So far IPM has proven to be a great success, creating not only the balance we were looking for but also the demise of non-selective insecticides such as Lorsban which must be healthier for everyone. The monitoring process for IPM is essential to gain a real understanding of the current situation and assists also in keeping an eye on general vineyard health. The only real disadvantage would be a little extra time and cost but that seems quite insignificant when compared with the results. Also it's great for vineyard staff to interact on a regular basis with vineyard canopy in great detail.	Advantages • Good control of insect and bug issues with an ecological balance. • High predator numbers within the vineyards. • No harmful sprays used to affect wildlife environment or ourselves. • Savings in spray application costs. • With a high export potential product we need to be practising clean and green to match or better our competitors. • (New insecticide products on the market certainly are helping the cause.) Disadvantages – none, just a change of mind-set. Monitoring is the answer to the whole issue, actually having a look regularly and being aware of what you are seeing. This allows a soft insecticide option to be use at optimum timing for best effect.
Any changes since began using IPM?	IPM has been adopted since vineyard establishment.	A great decline in problem pests and a much greater awareness of the hidden population within our vineyard both unwanted and beneficial.	We have moved away from the Mancozeb, Dithane group. We are using pheromone traps in the vineyard to give an indication of LBAM. We are doing a visual monitoring of the vineyards weekly with own staff. Also using IPM Technologies to do monitoring which includes garden weevil monitoring of larvae in the soil prior to emergence.

	Whitsend Estate	Diamond Valley Vineyard	BRL Hardy LTD
		Phillip Island: As per D.V.V. but a lot more labour hours with staff monitoring, also a greater emphasis on broadleaf weed eradication as we had a very high infection rate of LBAM.	We use Mimic as a control for LBAM without harm to predators. Through monitoring we have found that the most likely time for LBAM pressure was at flowering and could be controlled by two applications of Mimic 14 days apart. Our experience over the past three years has been – two Mimic sprays at flowering in 1998–99 season was all that was required; no requirement for any sprays in 1999–2000; one Mimic spray 2000–01, due to predator numbers being in abundance and in balance. We have also released predatory mite (persimilis) in some Pinot Noir blocks on the Prices Road property due to rust mite being a problem late in the season of 1999 and 2000. We bought these from the Beneficial Bug Company and released 200 000 each year when weather warmed enough to allow survival. This was very effective. We have also been applying winter oil and wettable sulphur the past three seasons as our first spray to control bud mite which is very effective. This is applied at the bud swell to woolly bud growth stage prior to any foliage appearing. We also manage two adjoining properties that have a garden weevil problem. With Paul's assistance in monitoring and advice it was found that good control was achieved by waiting until November when the weevil larvae was within 1 cm of the soil surface and about to emerge, then rotary hoeing the colony areas gave a 95 to 97 per cent kill. This was only necessary again some four years later to maintain low numbers. It was necessary to keep weeds out from under the vines so that the majority of weevils were in the central grass area for rotary hoeing to work. Records are kept of moth counts and heat summations to predict important times for monitoring. Also Paul has graphed all monitoring work that he has done.

	Whitsend Estate	**Diamond Valley Vineyard**	**BRL Hardy LTD**
What pests are important in your vineyard?	Occasionally snails, but seem to be related to the use of vineguards. LBAM, most serious problem. European wasps are a problem near harvest. IPM techniques are not used to combat wasps. But a similar monitoring approach is used to seek out sources of nests and subsequently eradicate.	D.V.V.: Mites, weevils and LBAM. Phillip Island: LBAM and rust mites.	Insects that are a concern in our vineyards are LBAM, garden weevil and European wasp. The first two we have good control measures in place but European wasps have been a concern the past four years and will be more so if numbers increase. We have been searching out nests where possible and destroy them but you can only find a percentage with forest nearby.
Has IPM changed your management practices?	Essentially no. But IPM is an integral part of the philosophy to produce a better product.	IPM has altered our vineyard management practices as we are gaining a clearer understanding of how to deal with pests by monitoring their life cycles which do not always follow the same cycles as the vines and challenges us to think a little more laterally.	IPM has certainly changed our approach to pest management. It was obvious we were going in the wrong direction for many years. When we look back now and see the ecological balance can come back very quickly if given half a chance and do exactly what we require, we can control pests with just a little help at times.

PETER SCHREURS AND SONS, VEGETABLE GROWERS, DEVON MEADOWS

Integrated Pest Management – Why do we use IPM?

Before we moved into using IPM we had a set insecticide spray program for control of insect pests. We used broad-spectrum insecticides, which killed all insects so in theory we should have had clean crops with no insects.

In the 1990s we had a problem with two-spotted mite in our leek and parsnip crops. We had been rotating our chemicals making sure that we were using different chemical groups so as to not cause resistance to one chemical, but this was not working. The two-spotted mite had built up resistance to whatever we hit them with and were building in numbers.

Not liking the idea of continuous use of dangerous chemicals (for health reasons) and having no success in controlling our pests, we needed an alternative. A fellow grower (Tom Schreurs of J. & J.M. Schreurs & Sons) advised us to talk to Dr Paul Horne of IPM Technologies. Dr Paul Horne came out to have a look at the problems we were having with the two-spotted mite and immediately advised us to stop spraying. This was unprecedented advice when for decades we had relied on spraying chemicals to control pests to then not spray at all. Paul then went on to explain how a predator mite called persimilis actually fed on two-spotted mite and by allowing the persimilis to live in the crop they would then control the two-spotted mite.

Being a bit sceptical we tried a small-scale experiment (in a fish tank) to see what would happen. By 18 days the persimilis had eaten all the two-spotted mite. This then brought us on to try this out in the field on our leek crop. We closely monitored the crop, a little nervously, but after four weeks there was not one two-spotted mite to be found in the leek crop. This made us realise that there was more to pest management than just spraying chemicals. If we can understand more about what is happening in the insect world we may then possibly understand how to control them naturally.

With this first experience with our leek crop we then built up enough courage and experience to then use IPM in all our crops. By 2001 we had all of our crops' pests being controlled using IPM.

What are the benefits of using IPM?

We feel there are many benefits to using IPM. As we are no longer using broad-spectrum insecticides it is much safer for the people involved with pest management. It is also safer for the environment, protecting birds, waterways and other insect species from dangerous chemicals. For the consumer this has the added benefit of knowing that there will be no insecticide residues on produce that may be harmful.

Using IPM means that we spend more time in the crop monitoring insects rather than sitting in the spray tractor, which then allows us to be in more contact with the crop and able to detect other problems such as disease or weeds before they become serious problems.

IPM is a long-term sustainable way of controlling pests. Since using IPM, we have been led to have a greater understanding of how nature works and of how our actions on the farm impact on the environment around. We have a much broader view on what our farm was and this has led us to start our own sustainability initiatives.

Challenges and the future

To encourage more beneficial insects onto our farm we are planting more native trees and shrubs that flower during different times of the year so that some insect species can use these as a food source between crops. We have also started growing crops such as rye corn in the ground side by side with lettuce. The rye corn attracts grass feeding aphids that provide food for a large number of predator insects, which then breed up, and move into the lettuce crop controlling aphids such as currant-lettuce aphid.

One of the problems that we have had in using IPM is that we cannot guarantee that our entire product is insect-free. Using beneficial insects to control insects means of course that we will have insects present throughout crop production. Despite having very thorough washing systems in place before any produce is packed and dispatched there may still be some insects present in some produce.

It has been a challenge dealing with some of our customers, in particular with product being exported, to be able to meet the criteria of no presence of insects. We feel that with more awareness of what IPM is, people will then understand that finding a ladybird or a brown lacewing in your lettuce is not a bad thing and in fact people may become more comfortable in finding this in their produce knowing that there are no chemical residues that inhibit any insect activity.

(Peter Schreurs and Sons website: http://www.leeks.com.au/pestcontrol.html)

Further sources

This book provides information on some of the most common pests and beneficials, but there are also other guides that are worth having and other sources of information. It is not necessary to restrict your library to books dealing with only crops or pastures as many of the pests and beneficials are found in a range of crops, including horticultural crops. A few are listed here:

> *Ute Guide to Insects*, published by GRDC (Grains Research & Development Corporation).
>
> Horticultural guides (for example *Pests, Beneficials, Diseases and Disorders in Lettuce: Field Identification Guide*, by Sandra McDougall, NSW Department of Agriculture, 2003).
>
> *A Field Guide to Insects and Diseases of Australian Potato Crops*, by Paul Horne, Rudolf de Boer and Denis Crawford, Melbourne University Press, 2002.

There are also CD-ROMs such as *Prime Notes* available, which contain information sheets from State Agriculture Departments. However, these are also usually accessible on the Internet. If using the Internet to search for a particular pest or beneficial species, just be cautious about the use of common names. The reason for using scientific names is to be sure we are talking about the same thing. For example, different countries have insects they call 'green lacewings' but they are a different species to the Australian lacewings. So you may find masses of information if you use the common name, but possibly none of it is relevant.

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