Chapter 6

Monitoring *M. demolitor* in the field

Abstract

This trial aimed to develop methods of estimating *M. demolitor* populations in the field. These methods will be used to draw conclusions about the extent of control *M. demolitor* exerts on *Helicoverpa* spp. populations in the field. Techniques evaluated included traps baited with virgin female wasps, direct observations, suction machines, traps based on attractive colors, traps based on host insects and estimations of percent parasitism of the host. It was determined that direct observations, percent parasitism of host larvae and traps based on virgin female wasps provided the most useful data for the effort involved. It was also determined that *M. demolitor* is the dominant larval parasitoid in southeast Queensland. They appear in the crop from early November to early December, and become significant in the crop from early to mid December onwards. Parasitism of *Helicoverpa* spp. by *M. demolitor* occurred from early December, became prevalent mid to late December and continued at varying levels throughout the season. Parasitism attributable to *M. demolitor* peaked at between 50% and 90% of second to third instar *Helicoverpa* spp. larvae. *M. demolitor* are present in the cotton crop at the critical stage of crop development. This study shows that conservation of *M. demolitor* is critical for IPM in Australian cotton. The implications for IPM in Australian cotton are discussed.

Introduction

Extensive work has investigated methods of monitoring populations of pest species such as *Helicoverpa* spp. in the field, including egg and larval counts and pheromone traps for monitoring adults (Gregg and Wilson, 1991; Titmarsh *et al.*, 1991; Wilson and Morton, 1989; Fitt *et al.*, 1984). However, little work has investigated techniques for monitoring beneficial insects. Predator numbers are relatively easy to assess, and techniques for this, as well as accepted predator: prey ratios have been published (Anon, 1997). However, parasitoids are often small and inconspicuous and their activity is difficult to assess. Parasite eggs and larvae are not easily recognised in the field and adult stages are usually small and inherently highly mobile. Monitoring parasitoid populations is crucial as it is the first step in their conservation.

Methods of monitoring parasitoids in the field

Methods examined for sampling parasitoid populations in the field include traps based on sex pheromones (Keller and Chang, 1995; Powell and King, 1984; Lewis *et al.*, 1971), traps based on host insects (Harris and Okamoto, 1983), traps based on host plants (Messing and Wong, 1992; Nishida and Napompeth, 1974), traps based on semiochemicals (Pivnick, 1993), suction machine samples (D. Murray, *pers. com.*), sweep netting (Hopper *et al.*, 1991; Powell and King, 1984), traps based on attractive colours (Vargas *et al.*, 1991; Adams and Los, 1989; González *et al.*, 1970) and parasitism rates of the host (Murray *et al.*, 1996; King *et al.*, 1985d; Powell and King, 1984). This is by necessity a very brief review of some of the methods used for studying parasitoid populations in the field. Methods which have potential for use with *M. demolitor* will be highlighted. A reliable, easy to use method for monitoring *M. demolitor* in the field would be a useful tool for IPM in Australia.

Attractive colours

Parasitoids are attracted to certain colours. Vargas *et al.* (1991) demonstrated that *Biosteres arisanus* (Sonan) (Hymenoptera: Braconidae) were attracted to the colour yellow. Attractive colours have been incorporated in traps and have been used to monitor parasitoid populations. Messing and Wong (1992) showed that *Diachasmimorpha longicaudata* (Ashmead) (Hymenoptera: Braconidae), a parasitoid of tephritid fruit flies, were attracted to yellow coloured balls. González *et al.* (1970) found that *T. prestiosum* Riley (Hymenoptera: Trichogrammatidae) were significantly more attracted to *H. zea* eggs glued on white cards compared to green or black cards. The use of colours as bait in traps for parasitoids is a very cheap, easily replicated and convenient method, and is certainly worth testing for *M. demolitor*.

Suction machines

Insect populations are commonly sampled with suction samplers or D-Vac® machines (Dietrick, 1961). This method is recommended for estimating predator populations in a cotton IPM system incorporating food sprays (Anon, 1997). It is relatively untested for parasitoids. However, parasitoids such as *M. demolitor* have been caught in suction machines sampling beneficial populations in cotton in southeastern Queensland (D. Murray, *pers. com.*). The efficiency of these machines in sampling parasitoid populations is unclear and needs further investigation.

Percent parasitism of the host

Estimation of the proportion of pest larvae parasitised by parasitoids is termed percent parasitism and is perhaps the most common method of evaluating parasitoid populations. This technique involves collecting host larvae and evaluating them for parasitism, either by rearing or by dissection. The measure of percent parasitism can be used to identify species of parasitoids at a particular locality, compare treatments, such as insecticide regimes or release rates, or to assess the impact of parasitoids on a pest species (Van Driesche, 1983). Levels of parasitism by indigenous populations of *M. crociepes* and *M. demolitor* have been published (see p. 23) and show that this may be a useful tool for the study of *M. demolitor*.

Pheromones

Traps based on pheromones have been used to estimate parasitoid populations. Unfortunately, unlike pest species, commercial preparations of pheromones for parasitoids are usually not available, therefore live females are generally used as bait. Lewis *et al.* (1971) successfully used traps baited with field collected males and females to catch *C. nigriceps*, a parasitoid of *H. virescens* in tobacco. They found that males attracted other males, while females attracted both males and females They also found that the height of traps in the plant canopy determined which sex was caught. Lewis *et al.* (1971) suggested that using virgin females as bait would most likely increase trapping efficiency. Powell and King (1984) demonstrated that male *M. croceipes* could be trapped in sticky traps baited with virgin females in the field. They found that only males were captured and only virgin females were attractive. Keller and Chang (1995) used traps baited with virgin females to capture male *Cotesia rubecula* (Marshall) (Hymenoptera: Braconidae) a parasitoid of *Pieris rapae* L. in kale. They used capture-recapture methods to assess the population of these wasps by marking males with a dot of enamel paint. They suggest that environmental factors had a major impact on rates of capture. They found that trap catches were weakly correlated with estimates of the released population and when the intensity of trapping was sufficiently high, this method could be used to provide an index of wasp activity. Pheromone traps may have potential as a monitoring tool and may even be used to determine parasitoid populations. This technique warrants further investigation with *M. demolitor*.

Direct observations

The simplest of methods used in sampling parasitoid populations is direct observation or simply observing parasitoid behavior. Wasps may be trapped and sexed in sweep nets to provide additional useful information. Powell and King (1984) have made direct observations of diurnal behavior of *M. crociepes*. They found that males were most active during the morning, starting at 0630 with peak numbers occurring between 0800 and 1100. Females were also more active in the morning compared to the afternoon, but females were active throughout the day. Females became active one hour later than males. Hopper *et al.* (1991) used sweep netting to estimate populations of *M. croceipes* in a cotton field. This technique has potential for monitoring *M. demolitor*.

The aim of this study was to develop reliable, repeatable, easy to use, time-efficient and accurate methods of sampling *M. demolitor* in the field. Sampling methods examined included suction samples, coloured water traps, sticky traps baited with virgin females, direct observation (sweep-netting) and parasitism rates of the host. As *M. demolitor* is the dominant parasitoid in many cotton growing areas, a rapid method that provides an accurate assessment of wasp numbers in the field would be a integral component of IPM. Additional data collected included plant measurements, *Helicoverpa* spp. numbers and insecticide application histories from each site. From these data, the impact of *M. demolitor* on *Helicoverpa* spp. populations throughout the season will be discussed.

Materials and Methods

Field sites

Trials were conducted over 3 seasons starting in the 1994/1995 season. Field trials described were carried out at 6 sites on the Darling Downs, southeastern Queensland. These included 2 sites at Warra, 1 site each at Nandi, Witu and Dalby. See Appendix 4 for trial site information, including trial location, configuration and yields. Finding unsprayed cotton fields on the Darling Downs posed somewhat of a challenge. As a result, trial sites were often incorporated into a large scale IPM trial being carried out by Dr. D. Murray (Farming Systems Institute, QDPI) or were unsprayed refuges for Ingard® crops.

Farming Systems Institute, QDPI, IPM trial site (Appendix 4)

The large scale IPM trial consisted of four treatments in each year. A biological treatment, based predominantly on NPV treatments, a "soft" treatment, based predominantly on non-disruptive insecticides, and a conventional treatment, based on a conventional control regime recommended by the crop scouts. Often the layout and size of plots were a compromise between experimental needs and the interests of the farmers. The IPM trial was conducted in each of the three seasons.

Biological data

Plant measurements were recorded in the 1994/95 season. *Helicoverpa* spp. egg and larval densities were determined at all sites in all years and the insecticide application histories were recorded for all sites in all years.

Plant measurements

Plant measurements were recorded in the unsprayed treatment at the Warra site over the 1994/95 season. The number of squares and bolls were counted weekly in 4 x 1 m lengths of row. These data were courtesy of Dr D. Murray (QDPI).

Helicoverpa spp. egg and larval counts

Helicoverpa spp. egg and larval densities were determined at all sites in all years. They were estimated at least twice a week by counting eggs, small (>3, <7 mm) and medium (>7, <20 mm) larvae on four groups of five plants per treatment. Counts were transformed to numbers per metre using the entomoLOGIC® program (Anon, 1999). These data were courtesy of QDPI and Total Agriculture Services (TAGS).

Spray histories

The insecticide application histories were recorded for all sites during all years and are displayed in Appendix 5.

Sampling methods

Field sampling began in 1994/95 season and continued until the end of 1996/97 season. Some of the methods described were found to be useful while others were discontinued, because they were unsatisfactory or unreliable at catching *M. demolitor*. In 1995/96 suction sampling, yellow coloured water traps, sticky traps baited with virgin females and parasitism rates were evaluated at the Warra IPM site. At Nandi, sticky traps and parasitism rates were trialed. In the second season (1995/96), sticky traps baited with virgin females, sticky traps baited with host insects and parasitism rates were studied at the Warra IPM site. In 1996/97, sticky traps baited with virgin females, parasitism rates and direct-observations were trialed at the Warra IPM site, Warra Ingard® refuge site and Witu Ingard® refuge site.

Suction samples

Five 100 m long vacuum samples were taken at weekly intervals (from 16 November 1994 to 23 February 1995) using a suction sampler (McCulloch Blower Vacuum, see Appendix 3) in each of the four treatments (unsprayed, conventional, soft and biological) of the QDPI IPM trial site (see Appendix 4). Samples where taken running the suction sampler over the entire plant, at a fairly brisk walking speed (1 m/s). Insect samples were collected into fine muslin bags and transferred immediately to 70% alcohol (see Appendix 3) after removal of any large plant material. Samples were transferred to the laboratory and examined under a stereo microscope (see Appendix 3). Any *M. demolitor* were sexed (see p. 31) and recorded. Results are shown as the total number of *M. demolitor* collected in each of the IPM treatments.

Yellow coloured traps

12 yellow ice-cream containers (1 Litre) filled with water were placed in the skip rows weekly from 22 December 1994 to 12 January 1995. Traps were placed in a 3 x 4 grid, 30 m apart. Trapping was carried out in the unsprayed block only of the IPM trial. A few drops of detergent were added to each trap in order to break the surface tension of the water and allow any caught insects to drown in the water. Traps had a small hole drilled near the rim to prevent rain overflow. Trap catches were collected weekly, bulked, transferred to the laboratory and examined under a stereo microscope. Any *M. demolitor* were sexed and recorded.

Traps based on host insects

Sampling with traps baited with *H. armigera* larvae was carried out from 30 October 1995 to 11 January 1996. Traps were set up at Warra and two traps were set up at Dalby in a lucerne crop. Sampling was carried out using the same design of trap used with virgin females as bait, however, small *H. armigera* larvae (see Appendix 1) were used as bait, by bending a cotton leaf into the Solo® (see Appendix 3) and placing a small larva on it. The trap was then set up as usual around this cage.

Sticky traps baited with virgin female *M. demolitor*

Sampling with sticky traps baited with virgin female *M. demolitor* was started on 22 December 1994 and continued till the end of the trial in 1997. Virgin female *M. demolitor* used as bait were from a laboratory culture. Methods for insect rearing are described in Appendix 1. *M. demolitor* adults and pupae were stored normally until needed; this did not affect calling behaviour in females (see p. 32). *M. demolitor* pupae were collected from the laboratory culture on brown paper. Individual pupae were placed in plastic capsules (see Appendix 3). After emergence adults were sexed, males were returned to the colony for maintenance while females were transferred to trap cages.

Sampling started with fairly crude traps made from used 1 litre milk containers. After very promising results, traps were refined and standardised. Traps were made of unused 1 litre, 28 x 7 x 7 cm open ended, cardboard milk containers (Tetrapac, see Appendix 3). The floor of the trap was coated with a sticky material (Birdoff®, see Appendix 3). Virgin female *M. demolitor* were placed in cages and attached to the roof of the milk container with a rubber band. Cages used in the traps were Solo® cups with the bottom and top cut out and replaced with fine metal mesh. Honey was smeared on the lid and water was supplied on a cotton dental wick, placed in a small hole drilled in the side of the cup. This arrangement facilitated "topping up" of water and honey the morning before the traps were used. Traps were re-used a few times until the sticky coating became contaminated with insects or rubbish or occasionally traps were ruined in the field by rain.

A standard 3 x 4 grid of traps was set up in each treatment of the IPM trial. Traps were spaced approximately 40 m by 14 m (7 skip rows) apart. Traps were placed on conduit poles (see

Appendix 3) at a height just below the cotton canopy. If there were insufficient poles, traps were attached to cotton plants by rubber bands just below the canopy (Lewis *et al.*, 1971, showed that the height of sex pheromone traps within the crop canopy did not affect catches of male *C. nigriceps*). Often there were insufficient female wasps to supply demand. When this occurred, the available wasps were spread evenly amongst the treatments. Results are displayed as the number of wasps caught per trap.

Percent parasitism

The first collection of *Helicoverpa* spp. larvae was taken on 15 December 1994 and collections were taken periodically throughout each season until the end of the trial, whenever larvae were present in sufficient numbers to justify the time spent searching. Thirty larvae was considered a minimum while approximately 100 larvae where collected when infestations were sufficient. Larvae were collected only from unsprayed block of the IPM trial sites, and the Ingard® refuges at Warra and Witu. Percent parasitism was determined by collecting larvae from the field and recording their fate 10 days after collection. Small (>3 mm) to medium (≈15 mm) *Helicoverpa* spp. larvae were collected. This size allowed for parasitisation by *M. demolitor*. Larvae were collected into Solo® cups partly filled with standard *Heliothis* diet (Appendix 1). Larvae were transferred to the laboratory, where they were placed in controlled temperature conditions (25°C, 60-70% relative humidity and a 14:10 light: dark photoperiod).

The fate of larvae was recorded every few days. Larvae were scored in six categories: parasitised by *M. demolitor*, infected with ascovirus, healthy larvae, dead from unknown causes, parasitised by a parasitoid other than *M. demolitor* (most often tachinids), or infected with NPV.

Infection with ascovirus was determined by visual means. A test of visual identification compared with molecular testing by PCR (Polymerase Chain Reaction) methods showed that the visual assessment method was over 90% accurate (I. Newton, *pers. com.*). Larvae infected with ascovirus were considered to have been parasitised by *M. demolitor* (see p. 35-56). Results of ascovirus and *M. demolitor* combined represented the total percentage of larvae parasitised by *M. demolitor*.

Direct observations

Direct observations by sampling using sweep-netting for adult *M. demolitor* were started on 11 December 1996 and were carried out weekly until the end of the trial. The majority of work was carried out in the unsprayed block of the IPM site and Ingard® refuge blocks at Warra and Witu. Sweep netting involved the operator walking continuously up and down the cotton rows, concentrating on one row of cotton, searching for adult wasps. Walking pace was slow but deliberate (about 0.5 m/s). *M. demolitor* adults fly in a very characteristic manner, and after a short amount of practice, wasps were easily spotted and captured in a sweep-net. Captured wasps were sexed, recorded and released. Sampling was abandoned if no wasps were caught in the first 30 minutes of searching. Results are shown as the number of *M. demolitor* caught in 30 minutes of searching.

Results

Biological data

Plant data

Plant data for a typical season in a dryland (non-irrigated) cotton crop on the Darling Downs, southeast Queensland is shown in Figure 6-1. This crop was sown on 31 October 1994. The first squares (fruit) appeared on 27 December, with peak square formation on 24 March. The first bolls were found on 21 January, with peak boll production occurring from 24 March. Bolls started opening on 7 April with peak boll opening occurring on 22 May. This graph shows the crucial phase (boxed area) of the cotton season, from early square production (early January) until boll opening (mid April). During this period it is especially important that pests are controlled adequately. For growers to get the most out of key beneficials, it is important that they are active throughout the cotton season, but particularly though this crucial stage.

Helicoverpa spp. egg and larvae counts

Helicoverpa spp. eggs and larvae numbers were low to moderate at both sites throughout the 1994/1995 season (Figure 6-2 and Figure 6-3). Larvae numbers rarely reached 5 per metre,

which is considered quite low for the region. Throughout the 1995/96 season larvae numbers were moderate to high, reaching extreme numbers (ca. 25 larvae per metre) towards the end of the season (Figure 6-4). During the 1996/97 season larvae numbers were moderate at the Warra site (Figure 6-5), however, numbers were moderate to high at the Warra refuge (Figure 6-6) and Witu refuge (Figure 6-7) sites. The high numbers of larvae were often due to the lack of control measures in these plots. The significance of egg and larvae numbers in relation to monitoring of *M. demolitor* will be discussed later.

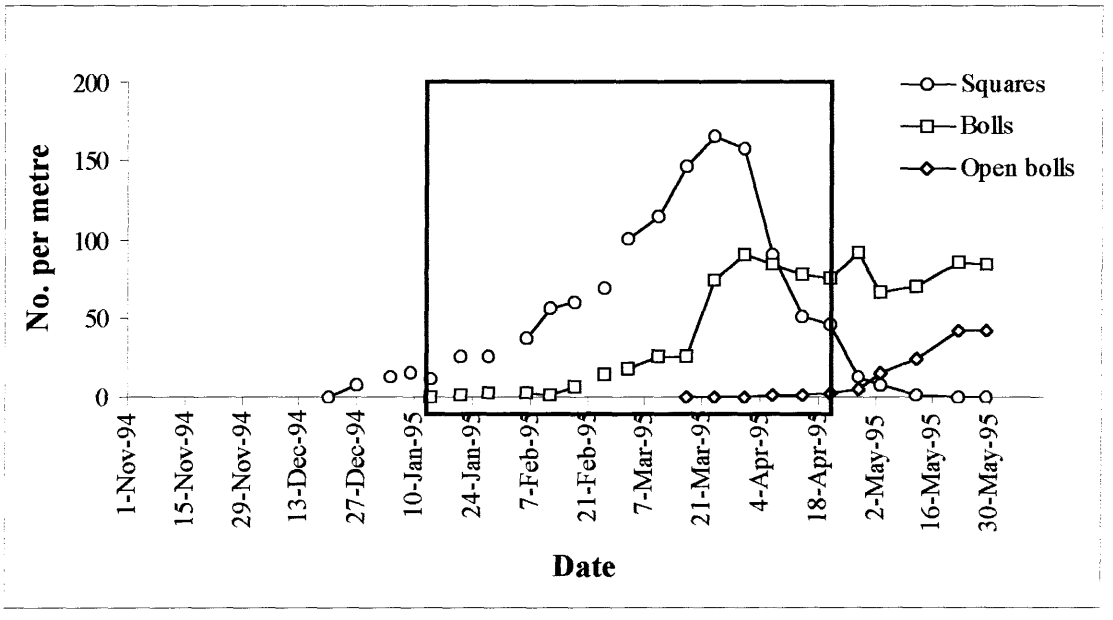

Figure 6-1. Cotton development calendar from a dryland crop at Warra, southeast Queensland during 1994/95 (Data courtesy of Dr. D. Murray, Farming Systems Institute, QDPI). Boxed area is the critical period for insect control.

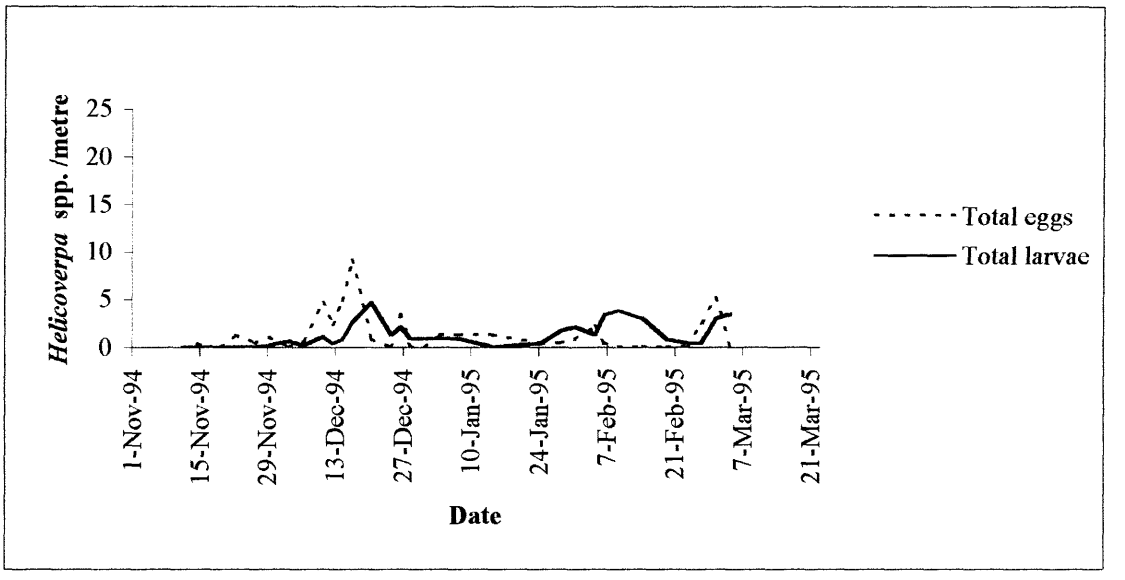

Figure 6-2. Number of *Helicoverpa* spp. per metre in the unsprayed block at Warra during 1994/95 (data courtesy of M. Boshammer, Total AGricultural Services (TAGS).

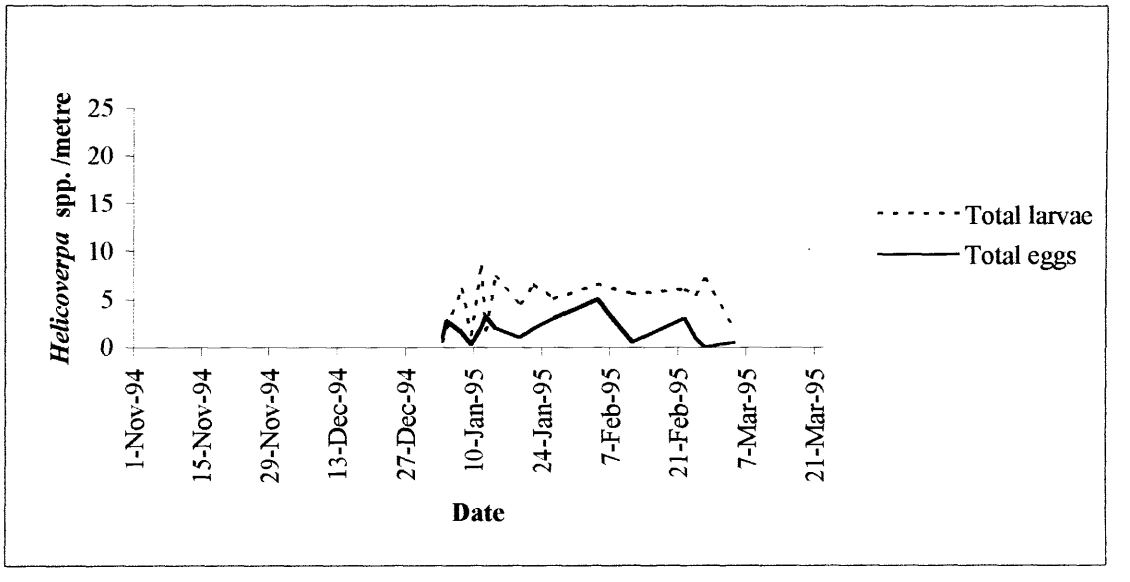

Figure 6-3. Number of *Helicoverpa* spp. per metre at the unsprayed block at Nandi during1994/95 (data courtesy of QDPI, Farming Systems Institute and John Marshall, QDPI, Dalby).

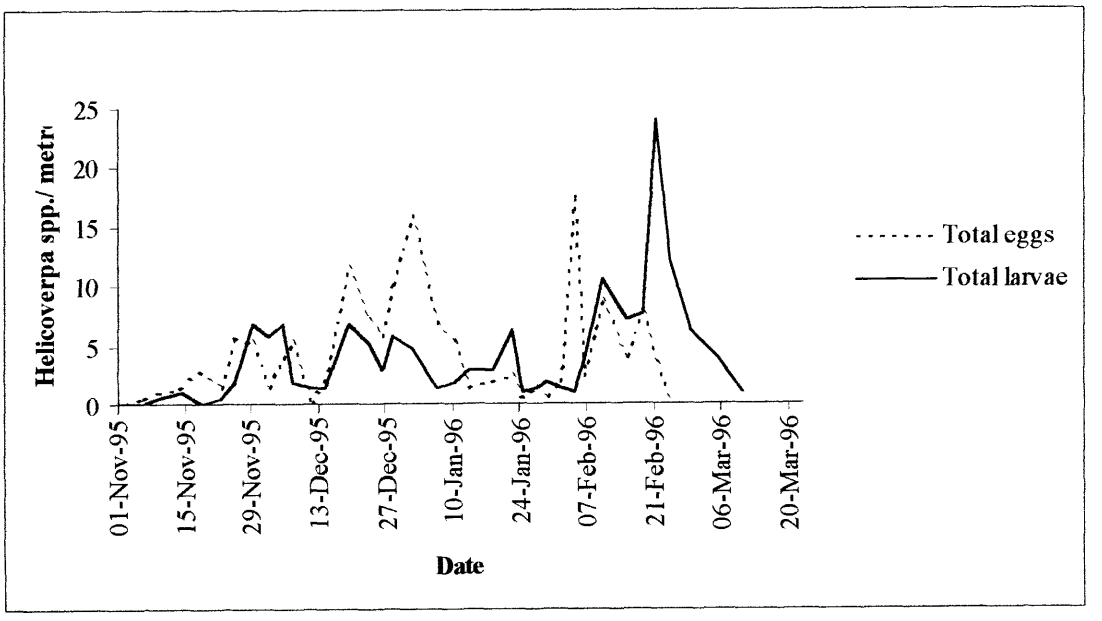

Figure 6-4. Number of *Helicoverpa* spp. per metre at the unsprayed block at Warra during 1995/96 (data courtesy of TAGS).

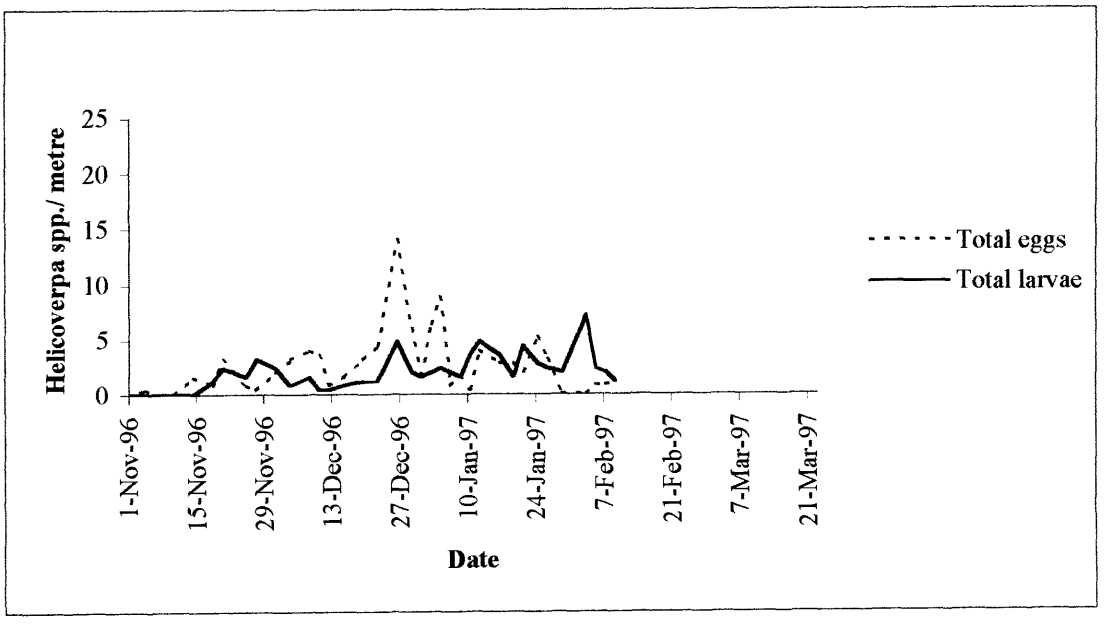

Figure 6-5. Number of *Helicoverpa* spp. per metre at the unsprayed block at Warra during 1996/97 (data courtesy of TAGS).

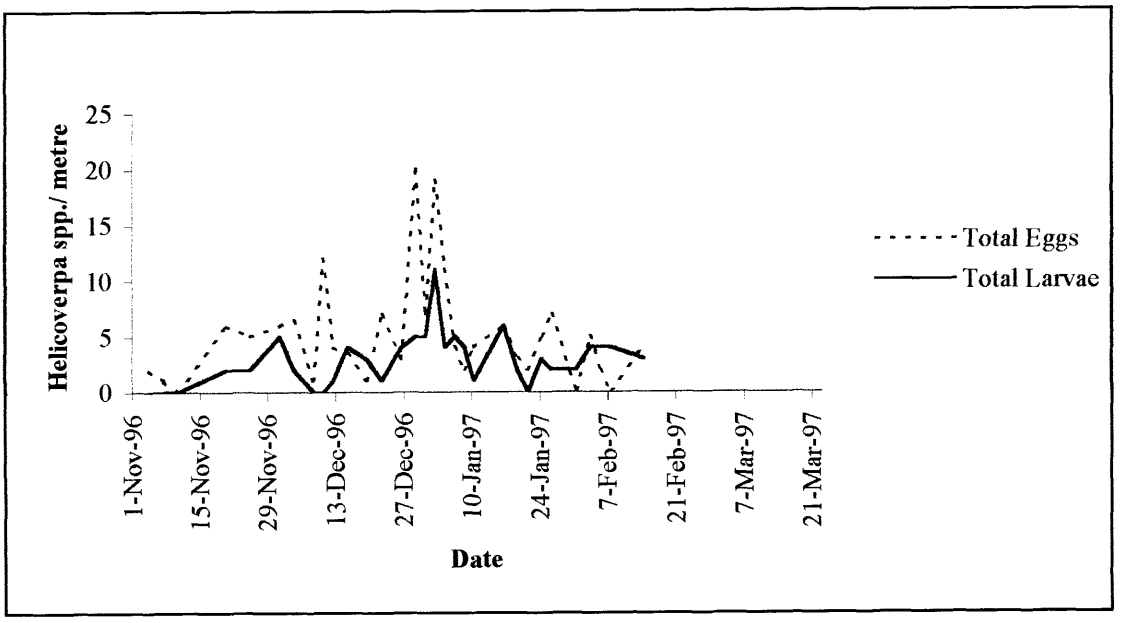

Figure 6-6. Number of *Helicoverpa* spp. per metre at the refuge block at Warra during 1996/97 (data courtesy of TAGS).

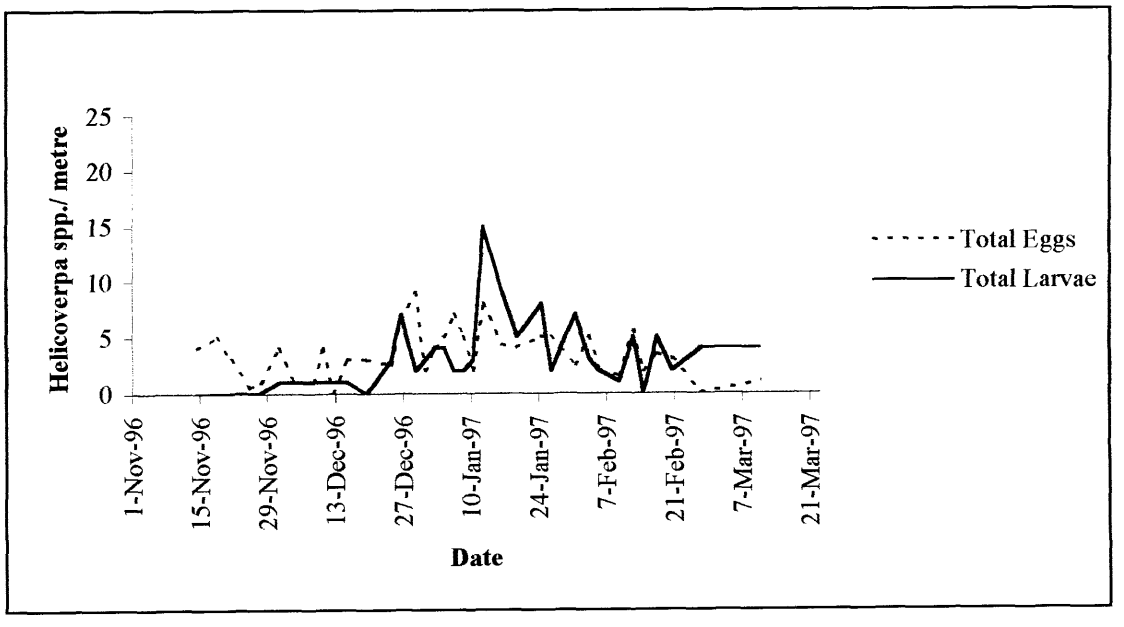

Figure 6-7. Number of *Helicoverpa* spp. per metre at the refuge block at Witu during 1996/97 (data courtesy of TAGS).

Spray history

Insecticide applications were recorded for each site in all years and are displayed in Appendix 5. Records are in trade names with active ingredients. Trade names, active ingredients, and suppliers of these insecticides are shown in Appendix 2. The spray history of the IPM site at Warra during 1994/95 is shown in Table Appendix 5-1. The Soft insecticide control regime in all blocks, including the commercial block, reflected the low *Helicoverpa* spp. numbers which occurred through the season.

Table Appendix 5-2 shows the spray history for Nandi during the 1994/95 season. This plot received large amounts of insecticides which was not reflected in the *Helicoverpa* spp. numbers, however, larval counts were from a relatively small unsprayed plot at the side of the commercially sprayed field. The Biological block received 2 conventional insecticides before the Gemstar® program began. Five Gemstar® applications (Table Appendix 5-3) were made. During 1995/96 at Warra the commercial block received 13 insecticide applications. This was in response to heavy and sustained *Helicoverpa* spp. pressure throughout the season. During 1996/97 at Warra there were 8 insecticide applications in the conventional block for control of *Helicoverpa* spp. (Table Appendix 5-4). These applications were in response to moderate to high *Helicoverpa* spp. pressure. The refuge blocks did not receive any insecticide applications for control of *Helicoverpa* spp. The implications of the spray histories of each trial block in each year in relation to effects on *M. demolitor* will be discussed in detail later.

Sampling methods

Suction samples, yellow coloured water traps and sticky traps baited with *H. armigera* larvae

Suction techniques, yellow coloured traps and traps based on host insects proved to be unsatisfactory in sampling field populations of *M. demolitor*. A total of 8 wasps were caught over approximately 5 months of regular sampling using a suction sampler (Table 6-1). Only one wasp was caught using the yellow water traps after 1 month of sampling (Table 6-2). The use of sticky traps baited with live *H. armigera* was unsatisfactory at trapping *M. demolitor*. On one occasion 1 *Cotesia* sp. wasp was caught, however, this was perhaps just a chance capture as no other

parasitoids were caught on any other occasion. This trap was placed in a lucerne paddock at Dalby (Table 6-3).

Table 6-1. Number of *M. demolitor* caught in suction samples (500 metres), at Warra IPM trial site, during the 1994/95 season.

Date	Treatments				Total
	Commercial	"Soft"	Biological	Unsprayed	
15-November-94	0	0	0	0	**0**
23-November-94	0	0	0	0	**0**
30-November-94	0	0	0	0	**0**
07-December-90	0	0	0	0	**0**
14-December-94	0	0	0	0	**0**
21-December-94	0	0	0	0	**0**
29-December-94	1	0	0	1	**2**
04-January-95	0	0	3	0	**3**
11-January-95	0	0	0	0	**0**
22-January-95	0	0	0	0	**0**
08-February-95	2	0	1	0	**3**
22-February-95	0	0	0	0	**0**
Total	3	0	4	1	**8**

Table 6-2. Number of *M. demolitor* caught in yellow coloured water traps in the unsprayed block at Warra IPM trial site, during the 1994/95 season.

Week ending...	No. traps	Male	Female	Total
22-December-1994	12	1	0	1
26-December-1994	12	0	0	0
30-December-1994	12	0	0	0
5-January-1995	12	0	0	0
12-January-1995	12	0	0	0
Total	**60**	**1**	**0**	**1**

Table 6-3. Number of *M. demolitor* caught in traps baited with live *H. armigera* larvae in unsprayed Ingard® refuge blocks, during the 1995/96 season.

Date	No. traps	Male	Female	Other
30-October-95*	2*	0*	0*	1 *Cotesia* spp.*
31-October-95	2	0	0	0
6-November-95	12	0	0	0
7-November-95	12	0	0	0
13-November-95	12	0	0	0
14-November-95	24	0	0	0
21-November-95	12	0	0	0
28-November-95	12	0	0	0
10-Decmber-95	24	0	0	0
19-Decmber-95	12	0	0	0
9-January-96	12	0	0	0
11-January-96	11	0	0	0
Total	**149**	**0**	**0**	**1**

* 2 traps were placed in a lucerne paddock at Dalby Agricultural College (see Appendix 4).

Sticky traps baited with virgin females

Throughout the trial, sticky traps baited with virgin females caught only male wasps. Trap catches varied considerably over the trial period. Observations throughout the studies indicated that males attracted to traps were not always caught. Often they would bounce off the side of the trap and fly away, but once caught in the Bird-off®, they were never observed to escape. Data from the sticky traps is incomplete, especially in the 1995/96 season. This was due to insufficient

production of female wasps in the laboratory culture. These problems were ongoing and need to be considered as a disadvantage of this technique.

Figure 6-8 shows the number of males caught in sticky traps baited with virgin females from Warra during 1994/95. Trap catches represent the total catch over 1 week, which was generally the longevity of the female. Catch numbers in the conventional block peaked at approximately 60 wasps. Figure 6-8 shows the evenness of catches across the IPM trial treatment blocks and the relatively large number of wasps caught in the conventional block, suggesting that wasps were readily moving between treatments (p. 105). The decline in catch numbers in the conventional block and across the whole trial after 12 January and 9 February coincided with applications of endosulfan and dimethoate on 13 January and 3 February in the conventional block. The drop in other treatments may be in response to a decline in the number of hosts present or due to wasps moving into the conventional block and being killed by insecticide residues. These data show the usefulness at catching *M. demolitor* of the sticky traps baited with virgin female wasps, as these large catches coincided with unsuccessful catches with other methods, such as suction samples and coloured traps.

Figure 6-9 shows the number of males caught in the sticky traps baited with virgin females from Nandi during 1994/95. Trapping at this site did not start until mid-season. This site had repeated applications of deltamethrin plus parathion-methyl, profenofos and thiodicarb after trapping had started. The dramatic fall in the number of males in the conventional block and continued suppression may be a direct response to insecticide applications and residues, through mortality or repellency of adult wasps, as well as a decline in host larvae in the block. This site had the disadvantage that the unsprayed block was very small in relation to the large conventional block.

Figure 6-10 shows the number of males caught in sticky traps from the Warra IPM block in 1995/96. These results are slightly different to the preceding year's results, as traps were left in the field for only one day rather than one week. As a result, trap numbers are not comparable to the previous year. These data show that *M. demolitor* did not appear in great numbers in the crop until quite late in the season, (mid-January) even though host larvae were present in large numbers from

mid November onwards. This is probably due to the heavy and sustained used of insecticides throughout the season. Unfortunately these data are not as complete as would be desired, with only one sample from mid January until early March, due to a shortage in female wasps in the laboratory culture at this critical time.

Table 6-6 shows the average number of males caught from the trial site at Dalby on 3 sampling occasions. Treatments were unsprayed, conventional block and an Ingard® block. Although the numbers of males caught and the number of traps was very low, these data show that wasps were present in the Ingard® block. The traps in the Ingard® block trapped fewer males than the conventional block and untreated on one occasion. This may be in response to a lack of hosts. However, the Ingard® block had more wasps than the other blocks on one occasion.

Figure 6-11 shows the number of male wasps caught in sticky traps during the 1996/97 season at the Warra IPM site. This year's data are the most complete. Catches are from traps placed out in the field for one day. Early season insecticide applications of 4 endosulfan (Thiodan®), and 2 pyrethroids (Scud® and Bulldock®) seemed to suppress wasp numbers from late January until mid-February. Wasp numbers rose during mid February and mid March, especially in the Ingard® block, possibly due to a reduction in insecticide use (2 applications during this period). However, wasp numbers were reduced mid-March, possibly due to late applications of dimethoate. Figure 6-11 shows the trap catches from the unsprayed Ingard® refuge block at Warra. The trap catches in the refuge block at Warra were higher than at the IPM block only several hundred meters away, possibly in response to no applications of insecticides to control *Helicoverpa* spp. in this field or in the adjacent field.

Figure 6-12 shows the number of males caught in sticky traps in the refuge block at the Witu site. This site had higher catches than the IPM site, probably in response to the relative isolation and low insecticide use at this site.

Table 6-4. Number of sticky traps at Warra and Nandi during 1994/95. 1 female/trap unless noted, checked after 7 days.

Date	Nandi		Warra			
	Unsprayed	Conventional	Conventional	Unsprayed	Biological	Soft
22-January-95	3	2	6*	6*	6*	6*
29-January-95	5	5	6	6	6	6
05-February-95	6	5	6	6	6	6
12-February-95	3	6	6	6	6	6
22-February-95	2	2	6	6	6	6
01-March-95	4	8	6	6	6	6
07-March-95	4	8	6	6	6	5
15-March-95	4	8	6	6	6	6
20-April-95	4	8	6	6	6	6
23-March-95	4	8	6	6	6	6

* 2 females/trap

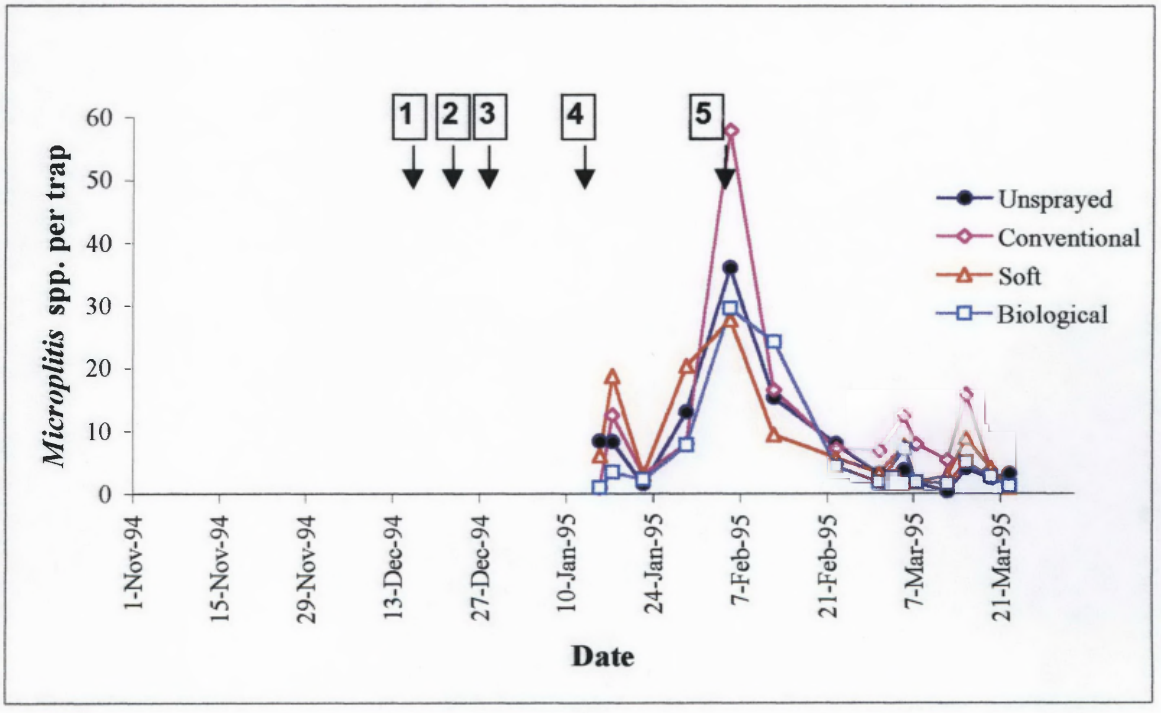

Figure 6-8. Number of male *M. demolitor* caught in sticky traps, baited with virgin females. Warra 1994/95, results from Warra IPM trial. See Table 6-8.

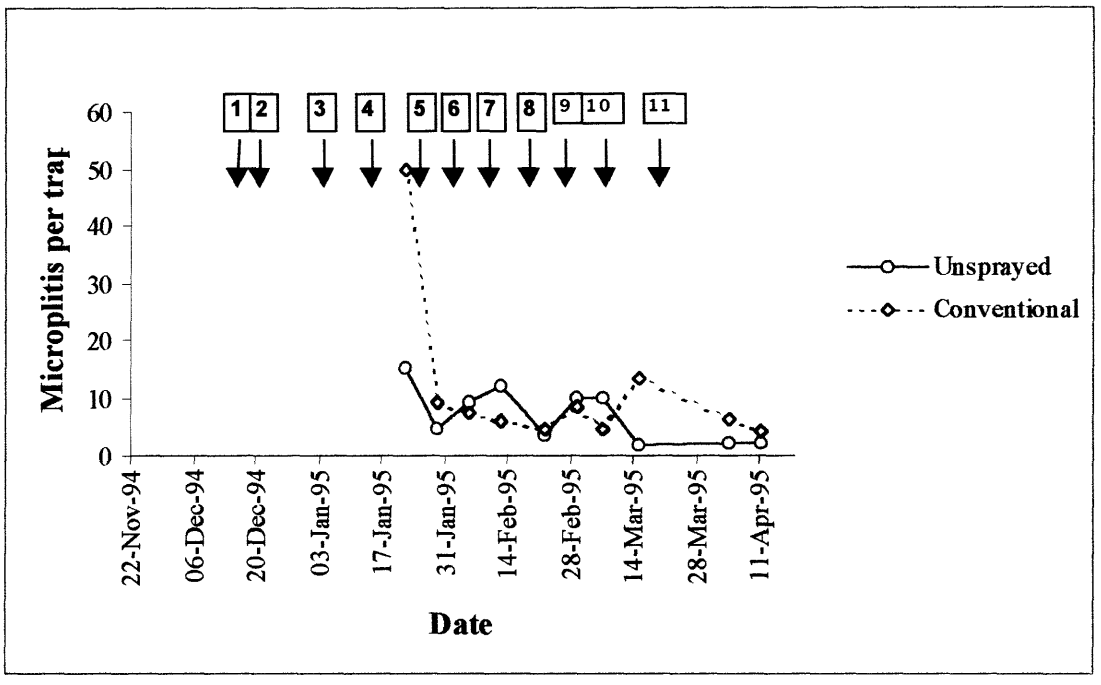

Figure 6-9. Number of male *M. demolitor* caught in sticky traps, baited with virgin females, at Nandi during 1994/95. See Table 6-8 for number of traps on each sampling occasion. Numbers refer to application of possible disruptive insecticides, see Table 6-2.

Table 6-5. Number of sticky traps at the IPM site at Warra during 1995/96. 1 female/trap, checked after a day.

Date	Unsprayed	Biological	Spinosad	Soft	Commercial
23-October-95	12				
30-October-95	12				
06-November-95	12				
13-November-95	12			10	
21-November-95	12			12	
28-November-95	12	12	12	12	12
10-December-95	12	12	12	12	12
19-December-95	12	11		11	11
27-December-95	12	12	12	12	12
10-January-96	12	12			
11-January-96	12	12		12	12
12-January-96	12	12		12	12
13-January-96	7	10		8	9
14-January-96	4	7		7	6
15-January-96	4	7		7	6
07-February-96	12	12	11	12	12
08-February-96	12	12	11	12	12
09-February-96	12	12	11	12	12
10-February-96	7	7	8	5	8
11-February-96	6	5	7	5	7
06-March-96	12	12	12	12	12
07-March-96	11	11	12	11	11
08-March-96	11	11	12	9	11
09-March-96	10	11	9	5	10
10-March-96	7	9	7	3	8
17-March-96	11	12		9	12
18-March-96	11	12		9	12
19-March-96	8	10		3	8
20-March-96	3	6		1	5

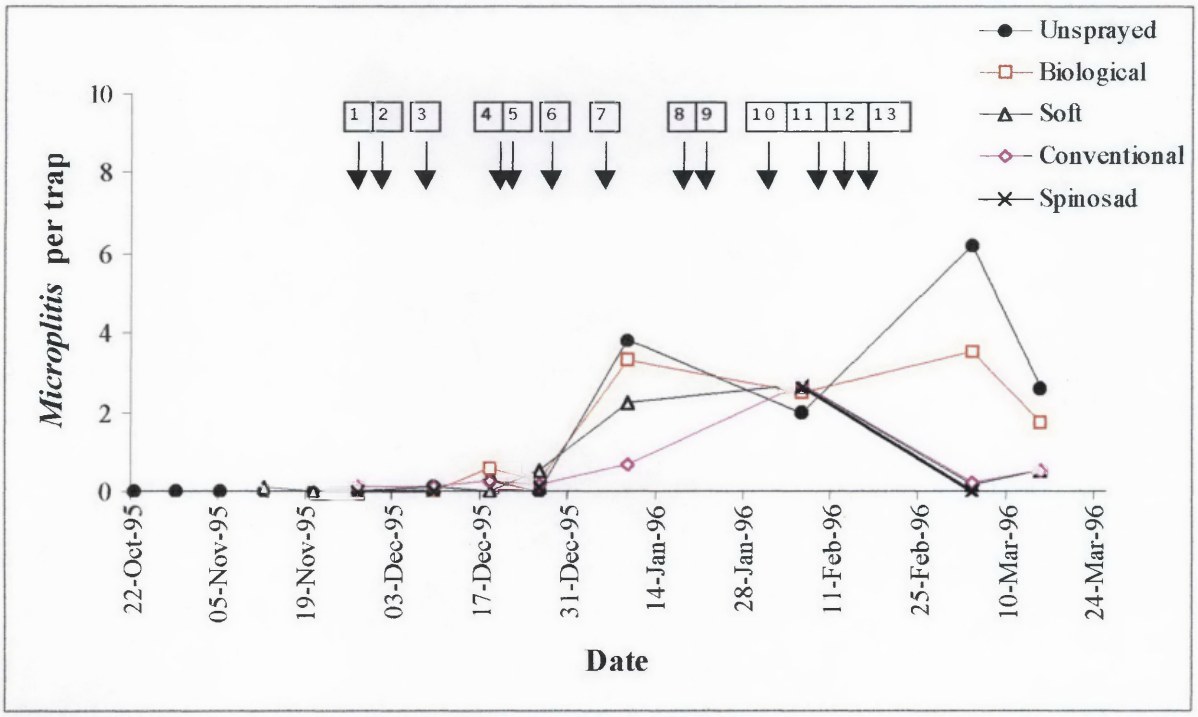

Figure 6-10. Number of male *M. demolitor* caught in sticky traps baited with virgin females from Warra IPM trial site during 1995/96. See Table 6-5 for number of traps on each sampling occasion. Numbers refer to application of possible disruptive insecticides, see Table 6-3.

Table 6-6. Average number of *M. demolitor* caught in sticky traps baited with virgin females at Dalby during 1995/96.

Date	Average *M. demolitor* / trap (no. of traps)		
	Conventional	Ingard	Untreated
09-February-96	0 **(7)**	1 **(7)**	0.3 **(6)**
06 March-96	8.4 **(5)**	4 **(5)**	6.2 **(5)**
19-March-96			5.4 **(25)**

Table 6-7. Number of sticky traps baited with virgin females at the Warra IPM site, Warra refuge site and Witu refuge site during the 1996/97. 1 female per trap, checked after 1 day.

Date	Unsprayed	Commercial	Ingard®	Refuge	Witu
02-November-96	12				
10-November-96	12				
17-November-96	12				
25-November-96	12				
02-December-96	12	12	12	12	
09-December-96	12	12	6	5	
29-December-96	10	10		8	
02-January-97	12	12	12	12	
05-January-97	12	12	24	12	
09-January-97	12	24	24	24	
12-January-97	12	12	24	12	
16-January-97	12	12	24	12	
19-January-97	12	12	24	12	
22-January-97	12	12	24	12	
10-February-97	12	12	12	12	
13-February-97	12	12	12	12	12
06-February-97	12	12	24	12	
18-February-97	12	12	12	12	12
23-February-97	12	12	12	12	12
04-March-97	12	11	12	12	12
10-March-97	12	12		12	12
17-March-97	12	12		12	12
25-March-97	12			12	12
01-April-97	12			12	12
07-April-97					12

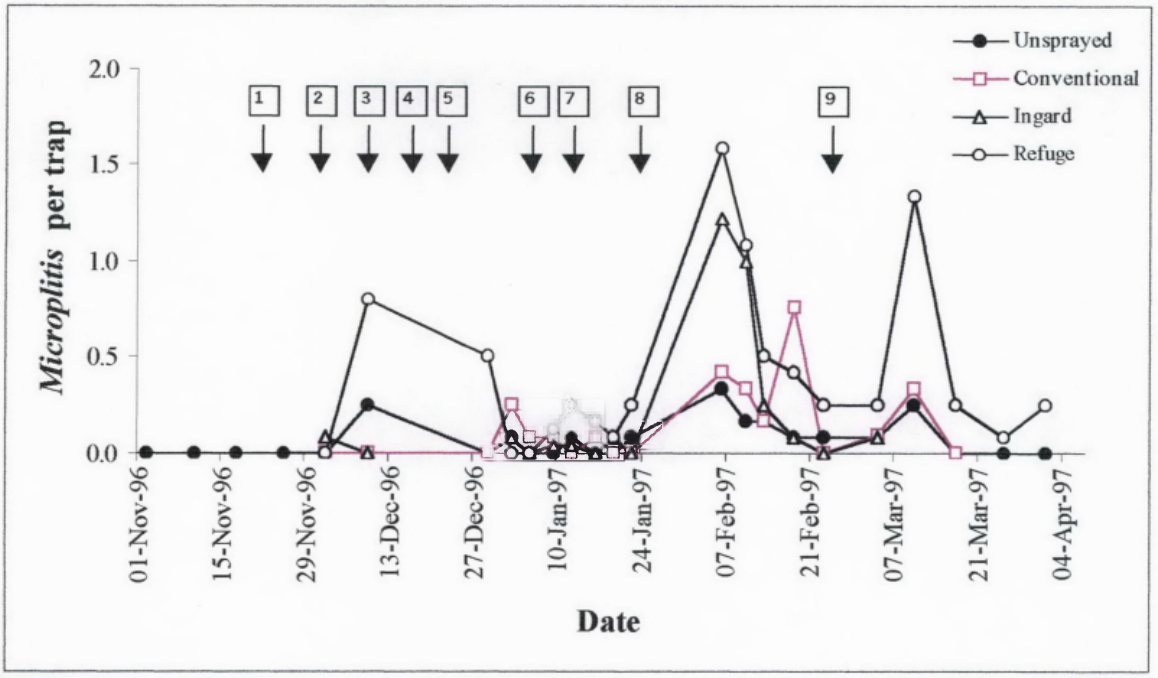

Figure 6-11. Number of male *M. demolitor* caught in sticky traps baited with virgin females at the Warra IPM site and Warra refuge site during 1996/97. See Table 6-7 for number of traps on each sampling occasion. Numbers refer to application of possible disruptive insecticides, see Table 6-4.

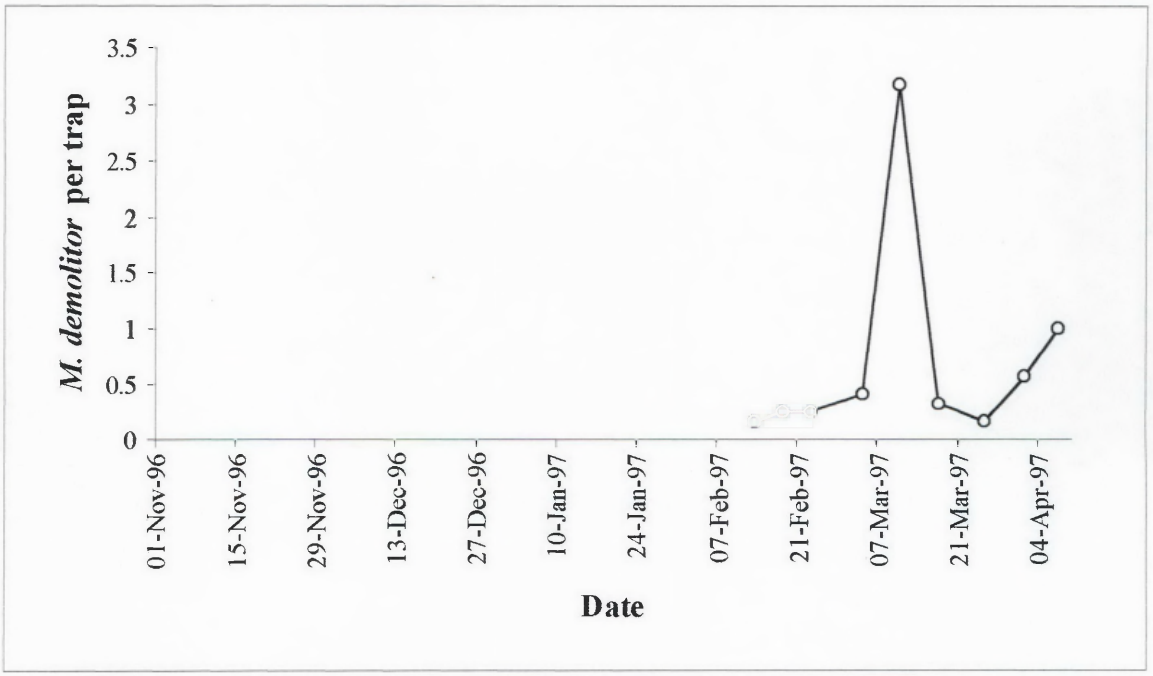

Figure 6-12. Number of male *M. demolitor* caught in sticky traps baited with virgin female at the Witu refuge site during 1996/97. See Table 6-7 for number of traps on each sampling occasion.

Fate of collected larvae and percent parasitism

Helicoverpa spp. larvae were collected whenever there were sufficient numbers to justify the effort required. This means that data are patchy and incomplete. Larvae were collected only from unsprayed blocks. Table 6-8 shows the number of larvae collected on each sampling occasion at the Nandi and Warra sites during 1994/95. The fate of collected larvae from Warra and Nandi are shown in Figure 6-13 and Figure 6-14 respectively. The peak of *M. demolitor* parasitism in larvae collected from Warra was approximately 30%, larvae infected with ascovirus peaked at approximately 60%, mortality from "other" causes at approximately 10%, while NPV accounted for approximately 10% of larvae. However, if the number of larvae infected with ascovirus is added to the number parasitised, giving a more accurate account of the effects of *M. demolitor*, then the total parasitism of *Helicoverpa* spp. larvae was between 10% and approximately 60%. There was a low incidence of larvae parasitised by *M. demolitor* ($\leq$ 20%) from the larvae collected from Nandi, however, the incidence of ascovirus peaked at approximately 90%. This indicates that the influence of *M. demolitor* on *Helicoverpa* spp. larvae was between 20% and 90%. The high incidence (up to approximately 25%) of NPV infection in mid January to mid February was most likely due to spraying with Gemstar® in the biological block (see Table Appendix 5-1).

Table 6-8. Number of larvae collected on each sampling occasion at Warra and Nandi during 1994/95.

Date	Warra	Nandi	Date	Warra	Nandi
8-December-94	25		**11-February-95**		35
15-December-94	98		**13-February-95**	30	35
22-December-94	50		**16-February-95**		36
26-December-94	47		**20-February-95**	51	36
30-December-94	26		**23-February-95**		29
19-January-95		46	**27-February-95**		34
23-January-95		37	**2-March-95**		44
26-January-95		31	**6-March-95**		26
30-January-95		33	**8-March-95**		35
2-February-95		48	**10-March-95**		30
6-February-95	42	29	**13-March-95**		29
9-February-95	39	27			

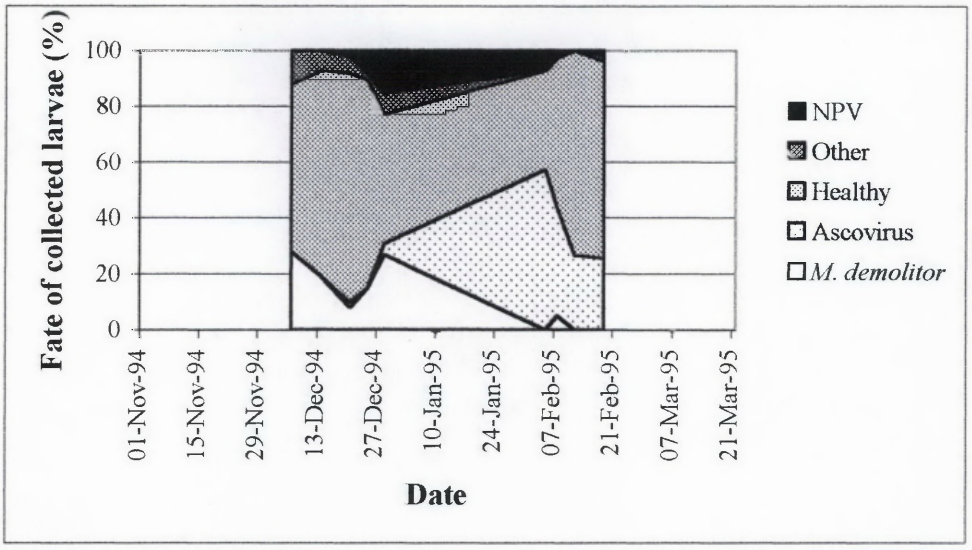

Figure 6-13. Fate of *Helicoverpa* spp. larvae collected from the unsprayed block at Warra during 1994/95.

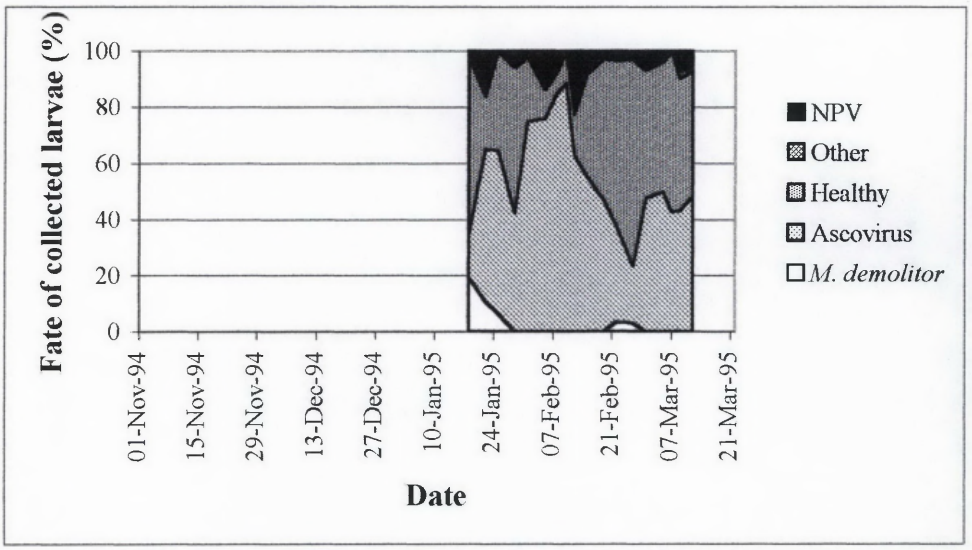

Figure 6-14. Fate of collected *Helicoverpa* spp. larvae collected at Nandi during 1994/95.

The numbers of *Helicoverpa* spp. larvae collected at Warra and Nandi during the 1995/96 season are shown in Table 6-9. The fate of these larvae from Warra and Nandi is shown in Figure 6-15 and Figure 6-16 respectively. At Warra, parasitism by *M. demolitor* was variable, peaking at 20% but generally around 10% throughout the season. Two distinct peaks of infection by ascovirus occurred, the first at approximately 80% and the second at approximately 55%. NPV and "other" causes of mortality accounted for a small number of collected larvae, approximately 10%. Figure 6-15 shows the total percent parasitism attributable to *M. demolitor* at the Warra site. These data

indicate a gradual build up to a peak at approximately 80% during early February. Then there was a steep decline in parasitism and then a gradual recovery late in the season to a second peak at approximately 55%. Data from Nandi (Figure 6-16) follows a similar trend to the data at Warra, however, the trends were not as pronounced. Parasitism by *M. demolitor* and infection with ascovirus accounted for ≤ 20% of collected larvae throughout the season, while infection with NPV and "other" mortality accounted for between 0-15% of collected larvae. Parasitism by *M. demolitor* at Nandi during the 1995/96 season accounted for between 10% and approximately 50% of collected larvae. These data also showed a "two peak" trend, with a gradual build up, sharp drop-off and gradual increase at the end of the season.

Table 6-9. Number of *Helicoverpa* spp. larvae collected at the Warra IPM trial site and Nandi during 1995/96.

Date	Warra	Nandi	Date	Warra	Nandi
29-November-95	20		**18-January-96**		20
1-December-95	41		**22-January-96**	31	
4-December-95	42		**25-January-96**	27	
7-December-95	40		**29-January-96**	26	
11-December-95	29		**1-February-96**	19	21
18-December-95	31		**5-February-96**	14	
21-December-95		48	**8-February-96**	31	29
24-December-95	26		**12-February-96**	30	28
27-December-95	36		**15-February-96**	40	30
28-December-95		14	**19-February-96**	34	29
2-January-96	51		**22-February-96**	56	47
5-January-96	33		**26-February-96**	38	48
8-January-96	27		**29-February-96**	33	35
11-January-96		20	**4-March-96**	27	26
15-January-96	30		**16-March-96**	26	

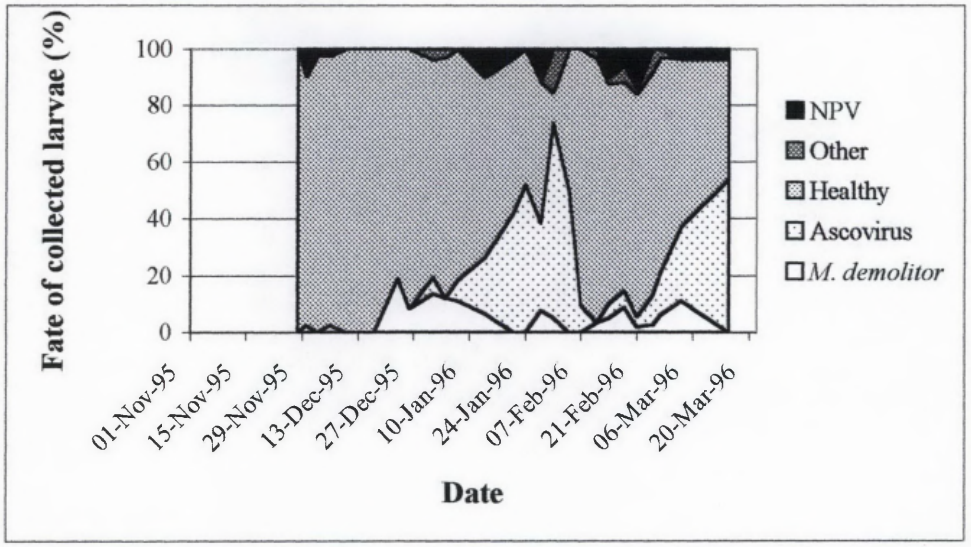

Figure 6-15. Fate of collected *Helicoverpa* spp. larvae at the unsprayed block at the Warra IPM trial site, during 1995/96.

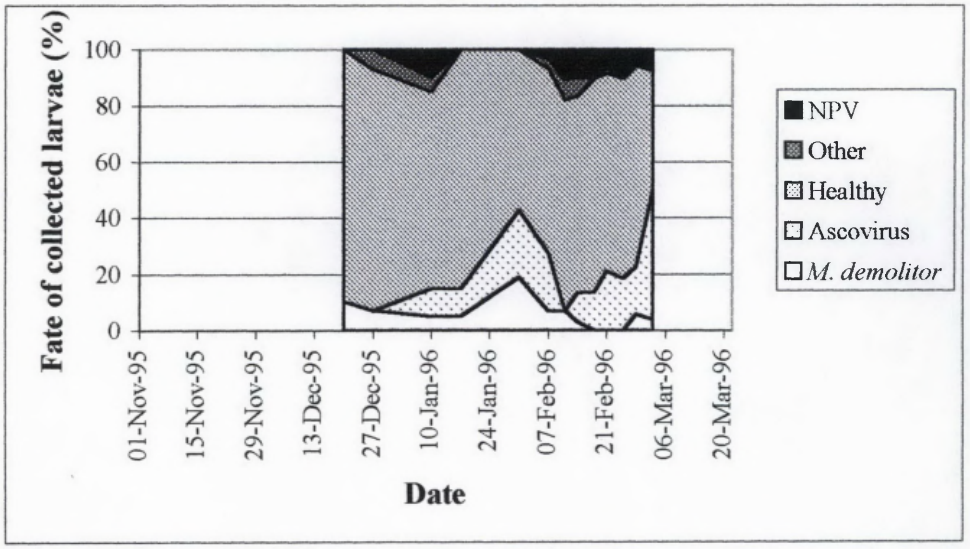

Figure 6-16. Fate of *Helicoverpa* spp. larvae collected at unsprayed block at Nandi during 1995/96.

Table 6-10 shows the number of *Helicoverpa* spp. larvae collected on each sampling occasion during 1996/97 at Warra and Witu. Despite a concerted effort, these data were not as complete as would have been liked. The fate of collected larvae from 1996/97 is shown in Figure 6-17 (unsprayed), Figure 6-18 (Warra refuge) and Figure 6-19 (Witu refuge). Data from the unsprayed block at Warra shows that parasitism by *M. demolitor* gradually rose from late December to a peak of approximately 20%, where ascovirus seemed to take over and rise to a

peak of approximately 55%. NPV infection and other parasitoids were insignificant at < 10% total. The data from the refuge block shows a "snapshot" from the middle of the season. Parasitism peaked at 30% and fell to approximately 5%, while infection with ascovirus peaked at approximately 70% late January, before falling. NPV infection and other parasitoids were insignificant, accounting for < 10% of collected larvae. Data from Witu show parasitism by *M. demolitor* peaked at approximately 40% before falling to < 10%. Infection with ascovirus showed 3 distinct peaks of 60%, 40% and 60% through the season. Infections with NPV and other parasitoids were insignificant at < 5%.

Percent parasitism at the three sites is shown in Figure 6-17 to Figure 6-19. Percent parasitism peaked at 80% in the unsprayed block, 60% in the refuge block and 60% three times in the Witu block. The Witu site showed 3 peaks in parasitism by *M. demolitor*.

Table 6-10. Number of *Helicoverpa* spp. larvae collected from the unsprayed block at the Warra IPM trial site, Warra refuge and Witu refuge during 1996/97.

Date	Warra Unsprayed	Warra refuge	Witu refuge	Date	Warra Unsprayed	Warra refuge	Witu refuge
2-December-96	13			**3-February-97**	68		
27-December-96	20			**6-February-97**		62	
30-December-96	41			**7-February-97**			78
6-January-97	63			**11-February-97**			42
9-January-97	24			**18-February-97**			95
10-January-97		101		**26-February-97**			114
13-January-97	107			**5-March-97**			32
17-January-97		100		**19-March-97**			96
23-January-97	48	48		**26-March-97**			96
24-January-97		47		**2-April-97**			96
28-January-97	106	104		**8-April-97**			107

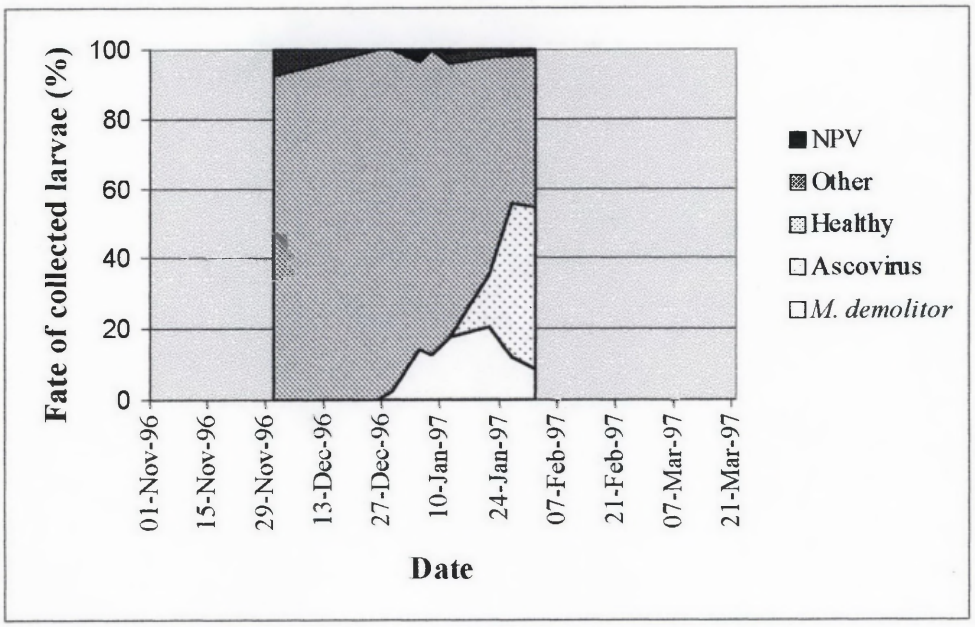

Figure 6-17. Fate of *Helicoverpa* spp. larvae collected from the unsprayed block at the Warra IPM trial site, during 1996/97.

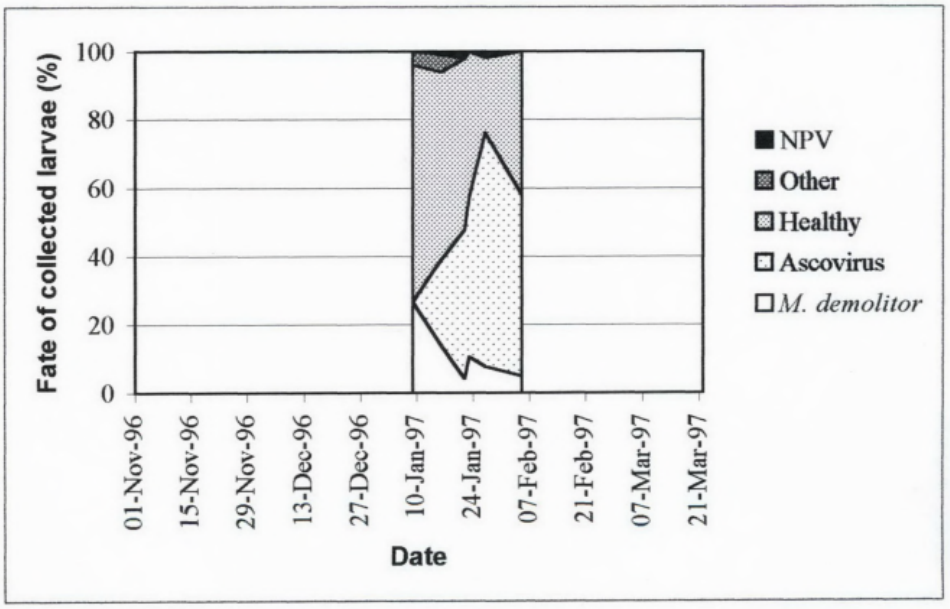

Figure 6-18. Fate of *Helicoverpa* spp. larvae collected at the Warra refuge block during 1996/97.

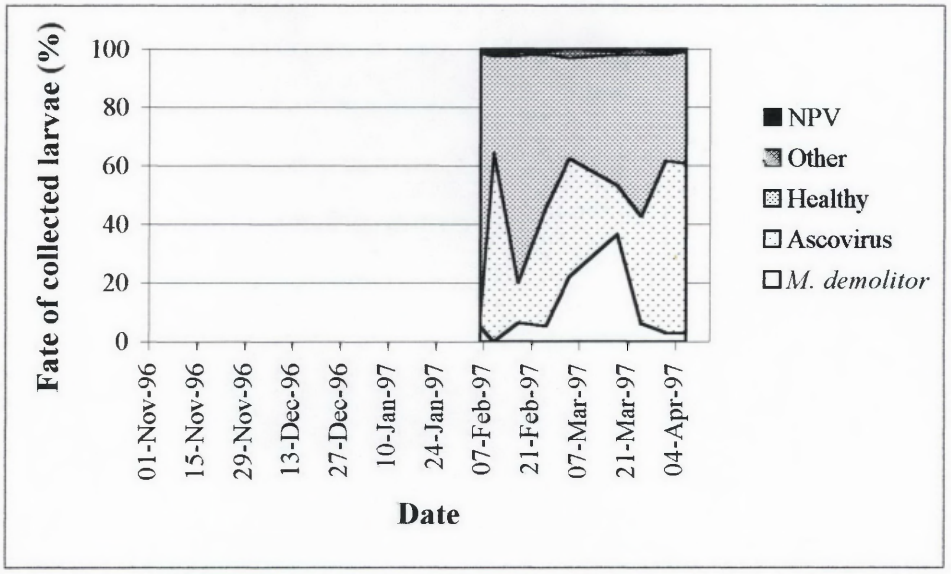

Figure 6-19. Fate of *Helicoverpa* spp. larvae collected at the Witu refuge site during 1996/97.

Direct observations

Direct observations were carried out in the unsprayed blocks, Warra refuge and Witu refuge blocks during 1996/97. Figure 6-20, Figure 6-21, and Figure 6-22 show the number of *M. demolitor* adults caught in a sweep net per 30 minutes of searching. These data show that this technique was a very successful method of monitoring *M. demolitor*, with catches peaking at approximately 5, 10, and 12 adults per 30 minutes at each site respectively. On all but a few occasions more males were caught than females. Data from the unsprayed block and refuge block show a peak in male activity with a small increase in female numbers. At these two sites, peak wasp activity coincided with the crucial period of the crop where protection from pests is especially warranted (Figure 6-1). Data from the Witu site was unfortunately not complete; however, this crop was late compared to the other crops so the late season data are still relevant. These data show both sexes increasing in numbers late in the season.

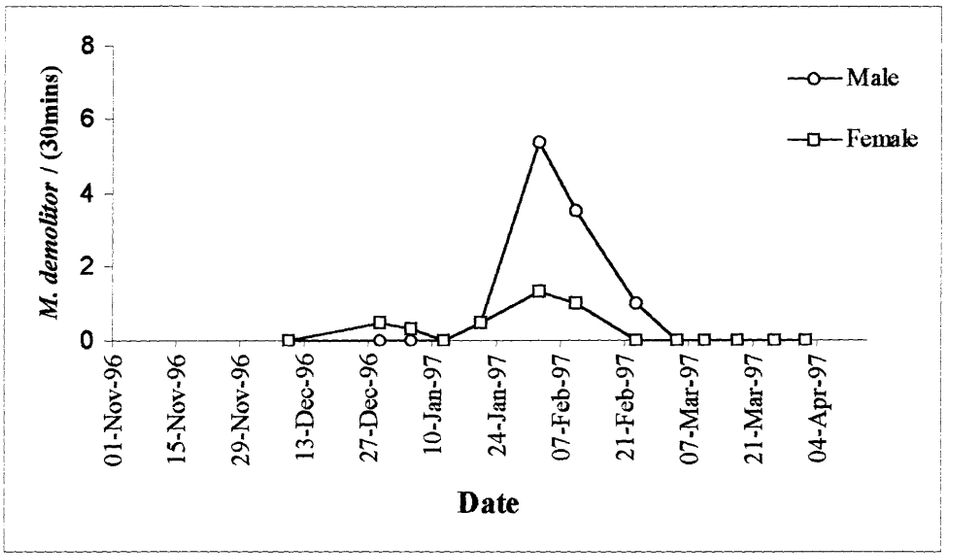

Figure 6-20. Number of *M. demolitor* caught in sweep net per 30 minutes (100m) searching at the unsprayed block at the Warra IPM trial site during 1996/97.

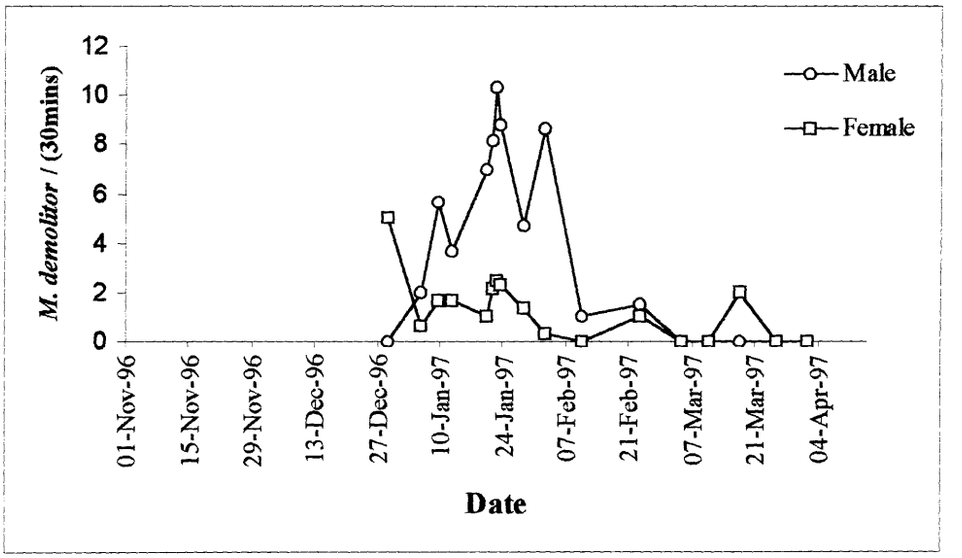

Figure 6-21. Number of *M. demolitor* caught in sweep net per 30 minutes (100m) searching at the Warra refuge site during 1996/97.

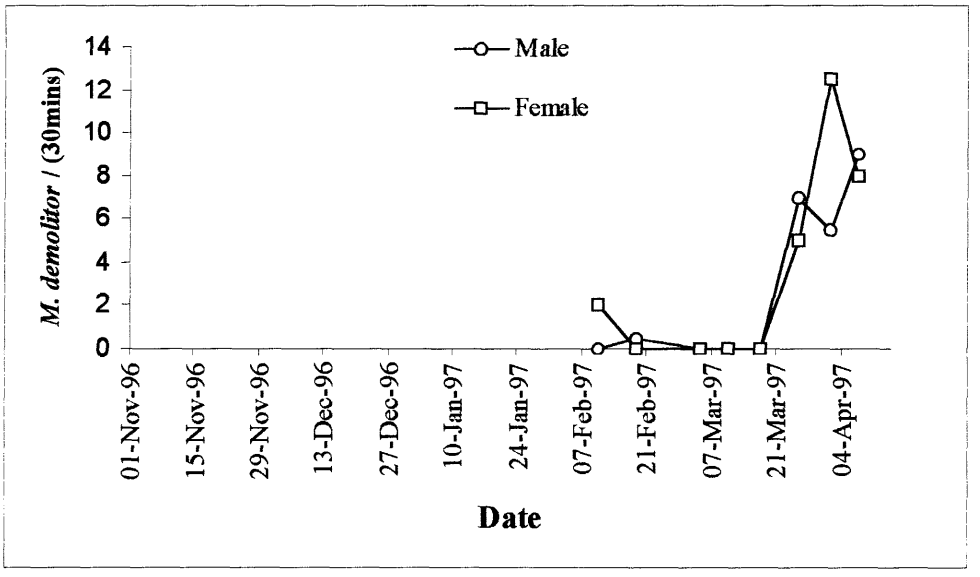

Figure 6-22. Number of *M. demolitor* caught in sweep net per 30 minutes (100m) of searching at the Witu refuge site during 1996/97.

Discussion

Sampling of insect populations is a compromise between the amount of time available and the accuracy required. It is therefore necessary to make an estimation with an accuracy that justifies the amount of time expended. Of the methods tested, suction sampling, coloured traps and traps based on host insects proved to be unsatisfactory at sampling *M. demolitor* in the field. Successful techniques included sticky traps baited with virgin females, estimates of percent parasitism of the host and direct observations through sweep netting.

Suction machines have been previously shown to be unsatisfactory at sampling parasitoids. Stanley (1997) found that Trichogrammatidae were poorly sampled by suction machines. Suction machines are noisy which may disturb parasitoids. Coloured traps are perhaps the most convenient and time efficient methods trialed. Unfortunately they were unsatisfactory at catching *M. demolitor*. Only yellow water traps were trialed, as yellow has been previously identified as an attractive colour. There is potential for further investigation with other colours and catching agents. Traps baited with live *Helicoverpa* spp. larvae feeding on cotton foliage were unsatisfactory at catching *M. demolitor* adults. It is well documented that female *M. demolitor* and *M. crociepes* are attracted to kairomones, such as 13-meylhentriacontane (Nordlund and Lewis,

1985), and plant volatiles (Whitman and Eller, 1992), which are released when a larvae feeds on the plant. Wasps are known to learn both chemical and visual characteristic of hosts (Wäckers and Lewis, 1994). It is therefore very difficult to design a trap which effectively imitates host behavior in the field. It was hoped that this technique would catch female wasps as well as males. Several trap designs were trialed including a trap designed to catch live adults and a trap which was similar to the sticky virgin female trap. Although this method proved unsuccessful further investigation, perhaps with traps baited with semiochemicals, may be profitable. These techniques were abandoned, perhaps prematurely, due to the success of the sticky traps baited with virgin females.

Sticky traps baited with virgin females

Sticky traps baited with virgin females provided data when other techniques failed. These data indicate when *M. demolitor* first appear in the crop, *M. demolitor* response to insecticide applications, population estimates, and calling behaviour. These data posed more questions than they answered, and are discussed below. However, this technique was identified as a useful technique for monitoring adult male *M. demolitor* in the field.

During 1995/96 at Warra, the first male *M. demolitor* adult was caught on 13 November, and the first significant catch was on 19 December, indicating that wasps numbers may have been building up in the crop. During 1996/97 at the Warra unsprayed and Warra refuge sites the first *M. demolitor* were caught on 2 December and significant numbers on 9 December. This indicates that *M. demolitor* were present in the crop early in the season and before control measures for *Helicoverpa* spp. are normally warranted (see p. 17 of this thesis). Any insecticide applications before these dates will not directly disrupt *M. demolitor*. Trap data showed that *M. demolitor* are common throughout the identified crucial stage of the cotton crop's development (see Figure 6-1).

Trap data showed that *M. demolitor* adults were active in heavily sprayed fields. Whether adults were moving into the sprayed fields in response to females calling, or whether they were already present is unclear. A study was undertaken to identify how far males were moving in response to calling females, see Chapter 9. Data showed on occasion a decline in wasps numbers or suppression of wasps numbers in direct response to insecticide applications. Insecticides observed detrimentally affecting adult *M. demolitor* numbers over the trial period were endosulfan,

dimethoate, parathion-methyl, profenofos, thiodicarb, and pyrethroids. The effects of commonly used insecticides on adult wasps is discussed further in Chapter 11.

As with all traps based on pheromones, only males were trapped. However, it is the female that exerts control on the pest, making female numbers of direct concern. Extrapolation from male wasp numbers to female wasp numbers poses many questions. These include whether sex ratios are 1:1, whether sex ratios vary in relation to factors such as migration and emigration, differential mortality, and differences in sex ratio of progeny from mated and unmated females. It is also necessary to consider whether large numbers of wild females "dilute" the calling of trap females causing the traps to underestimate the population, and whether low numbers of wild females cause the traps to overestimate the population. Natural variability in the calling ability of trap females, trap catching efficiency, environmental effects and distances males are moving to each trap must also be considered.

One of the biggest problems of using sticky-traps in the field to monitor insect populations is that they become fouled with other insects and debris which interferes with the stickiness of the trap surface. The design of the closed cardboard container definitely reduced the amount of fouling, although catch potential was probably reduced. It was observed on several occasions that male wasps were attracted to the traps but were not caught, colliding with the side of the trap and escaping. Messing and Wong (1992) found that catches of Braconid parasitoids increased when permethrin was mixed with the Birdoff®. Their data seemed to indicate that wasps could escape the Birdoff® alone, but this was not observed in this study.

It is doubtful that sticky traps baited with virgin females would become a regular monitoring tool for farmers and cotton consultants due to the intensive labour involved in setting up traps and maintaining laboratory cultures. However, these traps are certainly a research tool. They could be used as an indicator of presence/absence after the introduction of a new parasitoid species to a new area or for basic population studies, monitoring of augmentative releases, dispersal studies and behavioral studies on host-habitat finding. At the very least, these traps indicate the presence of adult male wasps. If an artificial *M. demolitor* pheromone can be isolated and synthesised, for use in conjunction with these traps, their use may become more widespread.

An attempt was made in collaboration with Dr C. Moore (Queensland Department of Primary Industries, Yeerongpilly) to isolate and synthesise an artificial pheromone. Compounds isolated and synthesised were methyl laurate (methyl dodecanoate) and methyl myristate (methyl tetradecanoate). Initial testing at approximately 1 mg/mL applied at approximately 1 μL, did on occasion induce excitation in males at close range (extract on filter paper in petri dishes), and once a male orientated to the source in a wind tunnel. However, it was quickly realised that a systematic attempt to isolate and formulate the pheromone was well beyond the scope of this thesis and work on these lines was abandoned. There is however potential for further studies in this area.

Percent parasitism

Percent parasitism is often the only practical technique providing information on the controlling impact of *M. demolitor* on *Helicoverpa* spp. *M. demolitor* was the most abundant larval parasitoid in southeast Queensland. Parasitism by *M. demolitor* occurred in early December, and became prevalent by mid to late December. As has already been discussed, infection with ascovirus can be directly attributed to *M. demolitor* as ascovirus can only be transmitted effectively by injection into the haemolymph of the host. Infection can occur through digestion. However in the field, larvae do not readily consume enough virus for successful transmission (Govindarajan and Federici, 1990) (see p. 35). *M. demolitor* was the only larval parasitoid present in significant numbers. Other parasitoids capable of transmitting ascovirus, shown as the "other" category, were in most cases insignificant. An interesting study would be to relate the incidence of ascovirus transmission with parasitoids which do not superparasitise their hosts.

Parasitism directly attributable to *M. demolitor* peaked at between 50% and 90% during the season over the 3 years of study. This is a significant level, which must be considered in any IPM system. Previous estimates of parasitism by *M. croceipes* and *M. demolitor* are presented on p. 23. These data obtained from this trial are comparable to the previously published studies and may even indicate that parasitism by *M. demolitor* in Australian cotton may be higher than previously found.

Distinct patterns in seasonality of *M. demolitor* were identified in this study. Seasonal patterns in parasitism have been previously identified (see p. 23).

The characteristic pattern of parasitisation by *M. demolitor* and infection with ascovirus is further proof that there is an interaction between the two. As *M. demolitor* numbers increase the prevalence of ascovirus infection increases in the population of larvae and as infected hosts do not produce *M. demolitor* progeny, the *M. demolitor* population collapses. The fact that super parasitism in *M. demolitor* is common indicates that infection would spread rapidly. It can be seen that the peaks in parasitism are particularly apparent and are approximately one *M. demolitor* generation apart. These results show that initial levels of ascovirus are extremely low and the disease tends to become significant from late December to early January. It is unclear where the initial inoculum of ascovirus originates. This is discussed on page 35. This origin of the initial ascovirus inoculum requires future study.

The use of percent parasitism to assess the impact on a pest species has many problems. Parasitism may be over-estimated if sampling methods preferentially collect either parasitised or unparasitised hosts, if unparasitised hosts develop to a stage which is not susceptible to parasitism, or if hosts are not initially present, but enter the susceptible stage gradually concurrent with parasitoid oviposition. Percent parasitism may be underestimated if parasitoid emergence begins before generational oviposition is complete. If hosts and parasitoids are gradually entering and leaving the system and these processes overlap to varying degrees, percent parasitism values will bear little relation to generation intervals (Van Driesche, 1983). One of the major limitations of collecting host insects for estimation of percent parasitism is that the host is removed from future exposure to other agents of mortality when it is collected, so that generational mortality will be underestimated. In the case of *Helicoverpa* spp. larvae parasitised by *M. demolitor*, larvae tend to become motionless on the leaves towards the top of the canopy, especially when ascovirus is involved. *M. demolitor* also slows the rate of development of its host, thereby causing an accumulation of parasitised individuals in any given population. This is especially evident if, as in the case of *M. demolitor,* the host is parasitised at an early stage but continues to develop as the parasitoid larvae develops. *H. zea* and *H. virescens* larvae parasitised by *M. croceipes* were observed more frequently resting and less frequently crawling and feeding than unparasitised larvae (Hopper and King, 1984a; 1984b). However, Powell and King (1984) found that there was no difference in the rates of parasitism by *M. croceipes* in larvae collected from different areas of the cotton plant, or where feeding on squares, flowers or bolls. They suggest that parasitised larvae

become uniformly distributed on the plant after parasitisation. According to Van Driesche (1983), steps can be taken to improve the estimation of percent parasitism. These include defining the susceptible stage, assessing the behavior of parasitised and unparasitised hosts, avoiding premature removal of hosts before the completion of parasitism, not summing percent parasitism across a series of seasonal samples and not equating peak percent parasitism and generational parasitism. If the problems discussed are recognised, then percent parasitism levels can be very useful.

Dissection of parasitoids from the host generally results in more accurate identifications (Cate, 1985). The percent parasitism method can be refined by consultants and farmers who, with a little practice, can identify parasitised larvae by squashing larvae of the suitable size with their fingers. The developing parasitoid larvae are readily identified most usually at the rear of the host. This technique can be done routinely in normal crop checks giving a rating of percent parasitism.

Direct observations

Results from sweep-netting revealed that *M. demolitor* appear in the crop in significant numbers mid to late December. Data from the Warra site during 1996/97 indicated that males were present in greater numbers than females, although it must be acknowledged that males could be more active than females. There was also a peak in the number of wasps of both sexes in the middle of the season. The high number of males relative to females could be due to several factors, such as temperature (Bryan *et al.*, 1969), arrhenotokous parthenogenicity, (virgin females producing male progeny, see p. 29) (Shepard *et al.*, 1983b; Hafez, 1951), differential emigration rates or differential rates of mortality. The cause of differential sex ratios in the field needs to be investigated.

Direct monitoring gave the most useful data of wasps present in the crop at a particular time. Other methods, such as percent parasitism and pheromone traps, may have a significant time lag in results. It is important that the correct sex is determined because males are often present in up to five times the numbers of females. Relying on total numbers would overestimate the number of wasps which would actually attack *Helicoverpa* spp. Direct monitoring provides the best method for monitoring adult *M. demolitor* in the field by farmers and researchers. Adult *M. demolitor* fly in a characteristic manner and, with a little practice, are easily identified. This method

could be modified by consultants so as to be less time consuming or rigorous but still provide data on the presence/absence or density of wasps.

Environmental conditions affected the efficiency of direct observations. Overcast or windy conditions seemed to reduce *M. demolitor* activity and windy conditions reduced the catching efficiency by making the wasps harder to see and catch.

Conclusions

This study shows that *M. demolitor* is the dominant parasitoid of *Helicoverpa* spp. in southeast Queensland cotton. *M. demolitor* appear in the crop early November to early December, and occur in significant numbers in the crop from early to mid December to the end of the season. Parasitism by *M. demolitor* starts early in December, becoming prevalent in mid to late December, and continuing at varying levels throughout the season. Parasitism attributable to *M. demolitor* peaked at between 50% and 90% of second to third instar *Helicoverpa* spp. larvae during the season over the 3 years of study.

This study showed that using an estimate of percent parasitism of host larvae is a useful tool in monitoring *M. demolitor* impact of the pest larvae, while sticky traps baited with virgin females and direct observations were successful tools for monitoring *M. demolitor* adults in the field. Suction sampling, yellow coloured water traps, and traps baited with *H. armigera* larvae proved unsuccessful at monitoring *M. demolitor*.

There were relatively large numbers of *M. demolitor* adults found in unsprayed fields, *M. demolitor* were present in the cotton crop at the critical stage of the crop's development; and relatively high parasitism rates of *Helicoverpa* spp. were recorded at a critical stage in the pests life cycle.