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Studies of *Heliothis* mobility at Narrabri, summer 1989/90.

V. A. Drake[1] & G. P. Fitt[2]
Division of Entomology, CSIRO, [1]GPO Box 1700, Canberra, ACT 2601 & [2]PO Box 59, Narrabri, NSW 2390.

Introduction

The importance of population movement in the development of *Heliothis* infestations, and in the maintenance of pesticide resistance within these populations, is increasingly being recognised (Fitt 1989). Egglaying in a susceptible crop may arise from moths that have emerged elsewhere, perhaps in a neighbouring field where an alternative host plant is starting to senesce, or perhaps at greater distances in dryland crops, pastures, weeds, and native vegetation. With wind assistance, movements of a few hundred kilometres overnight are possible, and have in fact been recorded for *H. punctigera* (Drake *et al.* 1981, Drake & Farrow 1985).

Information about the frequency and intensity of immigration and emigration movements is essential for forecasting *Heliothis* infestation levels in crops, and thus for developing more efficient strategies for managing this pest. In particular, there is a specific need for this information for incorporation into computer models of *Heliothis* population processes that are being developed as aids to pest managers (Dillon & Fitt 1990). To meet this need, a comprehensive study of *Heliothis* movement is being undertaken at Narrabri Agricultural Research Station by researchers from CSIRO's Division of Entomology. In this paper, we outline the research methods being used and present some preliminary results for the first full season of observations, 1989/90.

Methods

Because *Heliothis* movements occur over a range of scales, and with the moths flying at heights from just above the canopy up to about 2 km, a variety of methods is required to determine the frequency and extent of movement. Some of these methods are aimed at particular distances of displacement (or, and almost equivalently, at particular heights of flight), while others provide complementary information about the same type of movement. For example, direct observation of movement will often provide quantitative measures of migration intensity and direction, and the variation of these quantities with time, but it will usually need to be complemented by sampling in order to establish the identity of the migrants and to enable their sex and physiological state to be established.

A strength of the present study is that a wide variety of methods are being used simultaneously, so that the relative frequency of different types of movement can be assessed.

In order to provide sufficient moths for observations and sampling to be effective, special crops were grown specifically as sources of *Heliothis*. The crops were selected because of their ability to carry large numbers of *Heliothis* through to maturation, and were unsprayed. Three crops were grown in 1989/90 (6 ha of chickpeas in spring, 2 ha of maize in summer, and 2 ha of pigeonpeas in autumn), but only the first two produced a suitable study population. The field program was timed to cover the period of emergence of moths from the source crops, and the observations were made within them or in their immediate vicinity. The emergence sites were almost surrounded by cotton crops, which were attractive to *Heliothis* during both study periods.

Emergence timing and intensity. Oviposition within the source crops and the subsequent development of larval populations was monitored by regular surveys which also provided estimates of the density of the infestation. Pupal densities and development were similarly monitored by sampling the soil. The timing of emergence was forecast using the development submodel of the "HEAPS" *Heliothis* population-simulation model (Dillon & Fitt 1990), using conversions for soil and canopy temperatures appropriate for each crop. These results were used to determine whether the moth emergence was likely to be sufficiently intense for detailed observations to be effective, and when these observations should begin. On the basis of this monitoring, intensive observations were made during the two periods 29 November–12 December 1989 (emergence from chickpea) and 16–30 January 1990 (emergence from maize).

Emergence was monitored by means of 20 traps each of area 1-m^2 which were distributed throughout the source crop. These were checked daily and the number and sex of each species, and the number of parasites, were recorded. Regular searches for newly emergent adults were also made along transects through the crop on most nights, so that the timing of emergence, and of the subsequent first flight, could be established.

Cotton crops around the source crop were monitored for eggs and larvae every few days. The egg counts provide an additional indication of moth population levels resulting from local emergence or immigration.

Short-range movements. Short-range movements (those into adjacent fields and out to distances of a few kilometres) usually occur at low altitudes, and are therefore relatively easy to observe directly and to sample. In addition, mark-and-capture type studies are much more practicable if the distance of dispersal from the source region, and hence the reduction in density of the marked population, is relatively small.

At Narrabri, short-range movements were studied by direct observation, sampling of moths in flight, and a mark-and-capture study. The direct observations were made with night vision goggles (using an infra-red spotlight to illuminate areas of the field), a stereoscopic video system (January 1990 only), and the CSIRO Entomological Radar. The first two provided information on flights at particular localities in the source crops and adjacent cotton fields, both immediately above the canopy and at heights around 10 m, while the radar showed movements at heights of 5–20 m over an area of about 5 km^2 around the source crop. During the summer observation period, the radar was also used to monitor flight activity at heights of 2–10 m over a fallow field adjacent to the source crop. Sampling was undertaken at heights of 2–4 m with an 8-m^2-aperture vehicle-mounted net and at 8–12 m with a 12-m^2-aperture windsock-type net on a tower. The vehicle was driven around a 4-km circuit, mainly between cotton crops and with the source crop near the centre, while the tower was located about 500 m from the source crop. In the mark-and-capture study (Fitt & Pinkerton 1990), moths raised on the chickpea crop were marked with strontium (a rare heavy metal) sprayed on the plants when larval feeding was at its peak. Adults were then captured in a network of pheromone traps extending in all directions out to 10 km.

Long-range movements. Long-range movements, which typically cover distances of 50–300 km and would carry moths to or from the farthest regions of the Namoi valley cotton-growing area, and perhaps beyond it, occur at altitudes of 100–2000 m. Quantitative observations of migration at these heights were made with the CSIRO Entomological Radar, and sampling was undertaken at 100–200 m with a 1-m^2 aperture kite-borne net. Sampling at higher altitudes with an aircraft-borne net had been planned but did not occur because the radar indicated that insect numbers at these heights were so low that it was unlikely that even one individual would be caught. Some indication of the identity of these high-flying migrants can be obtained from radar measurements of target size and wing-beat frequency.

Observations of the initiation of long-distance movement were made by visual observations of emigration flights at dusk. Ascending moths were observed through binoculars against the light of a clear western sky. This take-off flight was also studied with the radar, by measuring the increase in the number of insect targets that occurs at dusk, and by observing plumes of moths ascending and dispersing away from localised source regions such as the experimental crops.

Preliminary results

Emergence. Pupal densities and the number of each species emerging are shown for each source crop in Table 1. *H. punctigera* (57%) was more numerous than *H. armigera* (43%) on the first (chickpea) crop, but only *H. armigera* was produced on the maize. Losses during pupation were small and due mainly to parasitization by tachinids and the

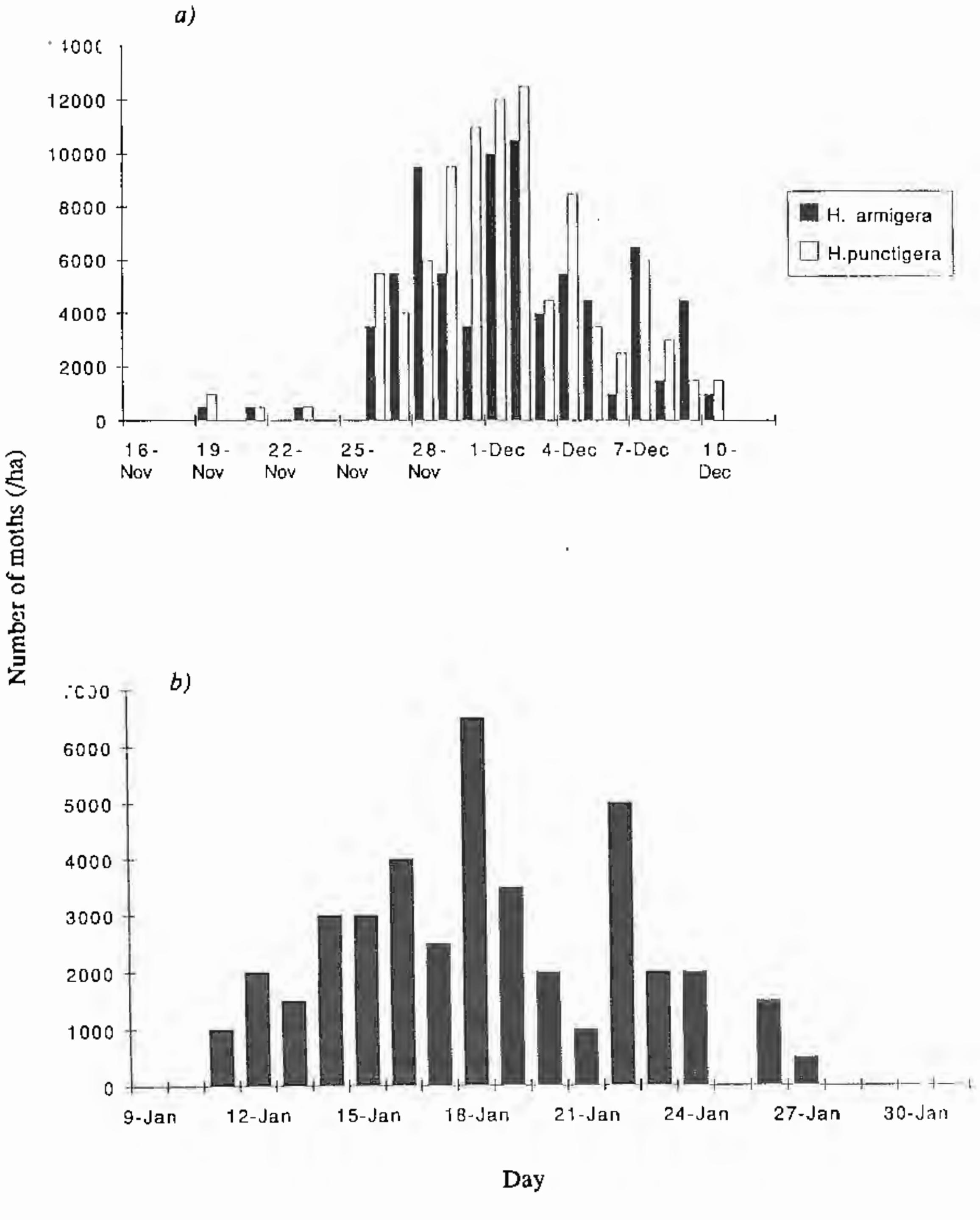

Fig. 1. Emergence of *H. armigera* and *H. punctigera* from source crops at Narrabri Agricultural Research Station, summer 1989/90. *a)* From chickpea (8 ha), November-December 1989. *b)* From maize (2 ha), January 1990 (*H. armigera* only). [Note: The indicated date is that of the morning on which the traps were checked; emergence would have occurred during the previous night.]

ichneumonid, *Ichneumon (=Pterocormus) promissorius*. Each emergence extended over a period of about 15 days (Fig. 1), peaking around 1 December for chickpea and 17 January for maize. The two species emerged almost synchronously in November-December, but peak emergence of females was 2–3 days earlier than that of males. Emergence occurred between 20:30 and 23:00 h each night. The moths took off on their first short flight about 2 h after emergence (22:30–01:00 h), but did not travel far. Most emigration from the source crops occurred on the night after emergence.

Table 1. Numbers of pupae and moths produced, and proportion of successful emergence, from two source crops at Narrabri Agricultural Research Station, summer 1989/90.

Crop	Area (ha)	Total Number of *Heliothis* pupae	Total adults emerged *H.a*	Total adults emerged *H.p*	% successful emergence
Chickpea	6.2	1,211,460	457,219	606,081	87.8
Maize	2.0	87,150	82,000	-	94.1

Short-range movements. In November-December, when approximately 1 million moths emerged from the chickpea crop (Table 1), the observations with night-vision goggles showed higher densities of moths active above the highly attractive maize crop than over adjacent, less attractive, crops (Fig. 2). At the edges of the maize crop a high proportion of the moths, mainly *H. armigera*, which flew out past the edge were seen to turn back into the crop. This behaviour effectively constrained the population to the small attractive block of maize.

In January, the general level of flight activity was lower (Fig. 2b). The maize was senescent and densities of moths flying over the maize and cotton crops (then in flower) were similar. Flight activity between 21:00 and 23:00 h varied between nights, partly reflecting changes in numbers of moths emerging the previous night (Fig. 3), but many other factors (temperature, wind conditions, etc.) would also have influenced activity.

These findings were essentially confirmed by the stereoscopic video system during the summer observation period. The number of moths flying immediately above the maize crop was much greater than at 10 m, and the number over an adjacent fallow field was low at both heights. All methods of observing low-altitude flight (radar, video, and night-vision goggle observations over crops and with a vertical beam) showed flight intensity to be high from dusk until about 23:00 h, and then to fall rapidly. Insect densities estimated from simultaneous radar and stereoscopic-video observations over a fallow

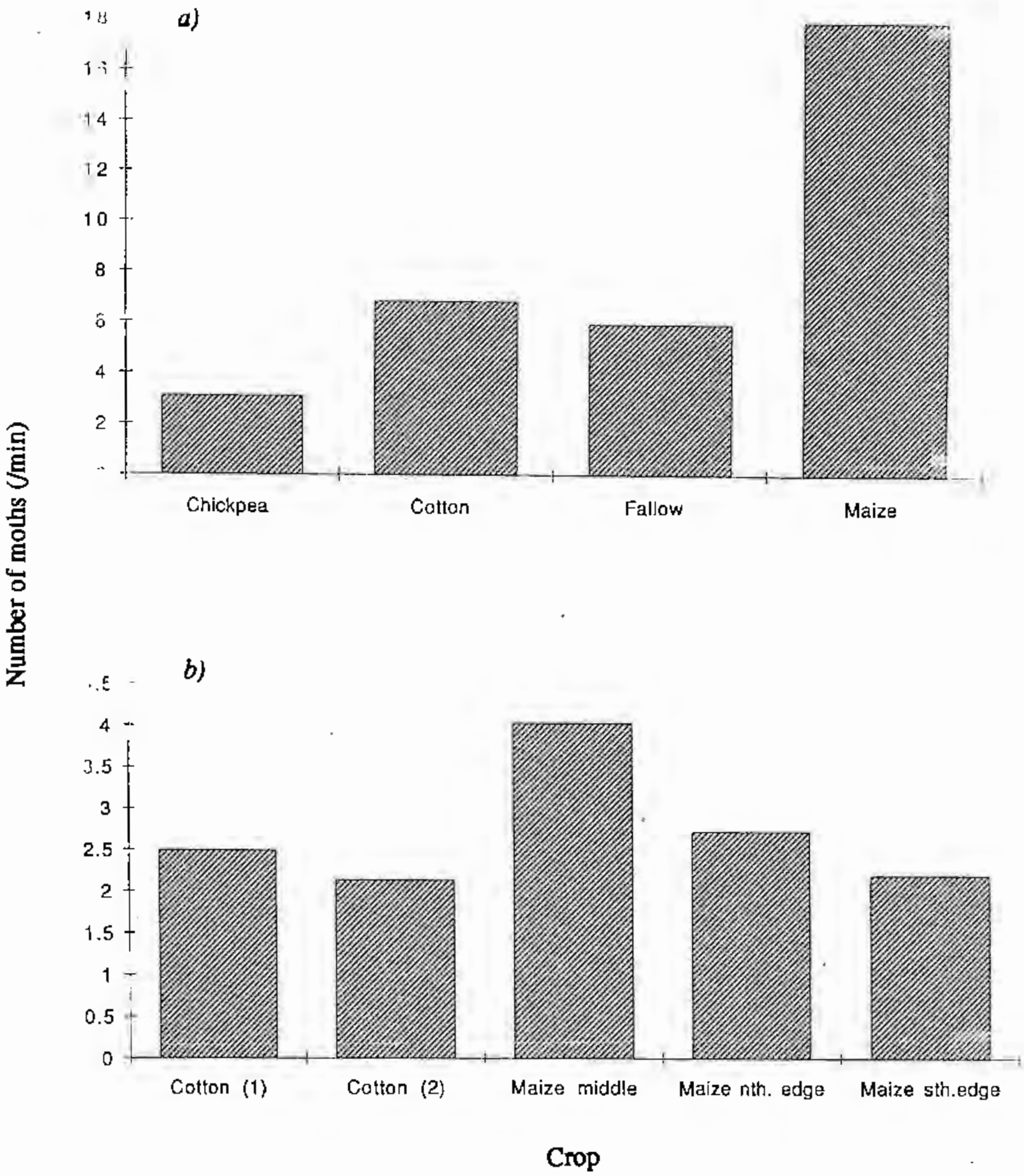

Fig. 2. Relative abundance of *Heliothis* moth flight activity over crops at N.A.R.S., summer 1989/90. The measure of abundance is the average rate at which flying moths appeared within a defined observation volume above eacb crop between 21:00 and 23:00 b each evening. ***a)*** Activity over senescent chickpea, squaring cotton, a fallow field, and silking maize, December 1989. ***b)*** Activity over flowering cotton and senescent maize, January 1990.

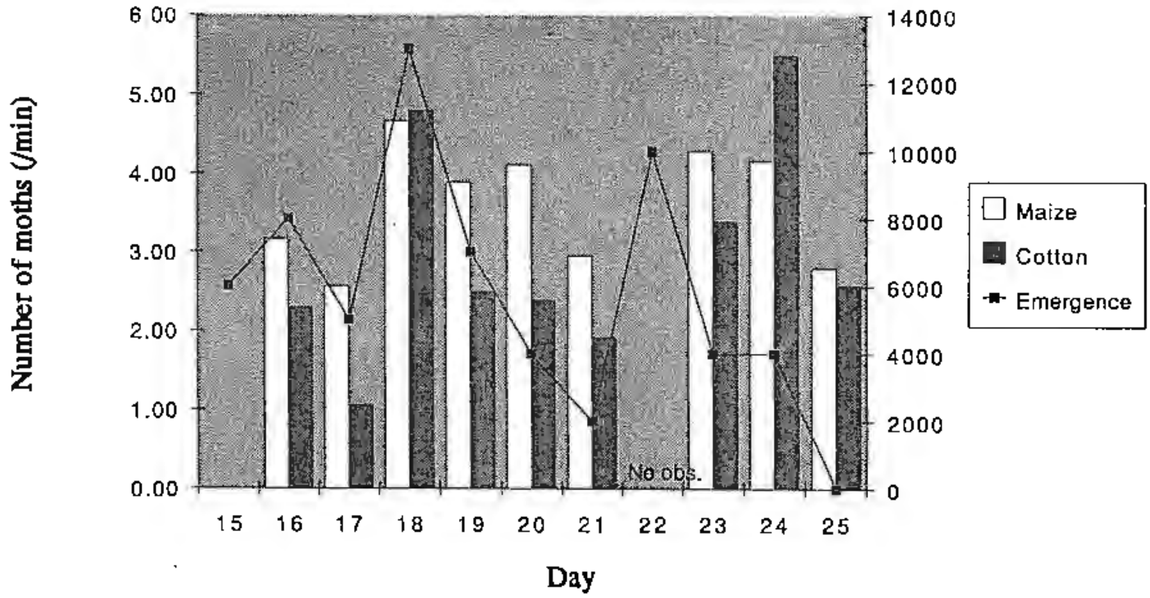

Fig. 3. Night-to-night variation in *Heliothis* moth flight activity over maize and cotton crops, and in emergence from the maize crop, at N.A.R.S. during January 1990. Details as in Figs 1 and 2.

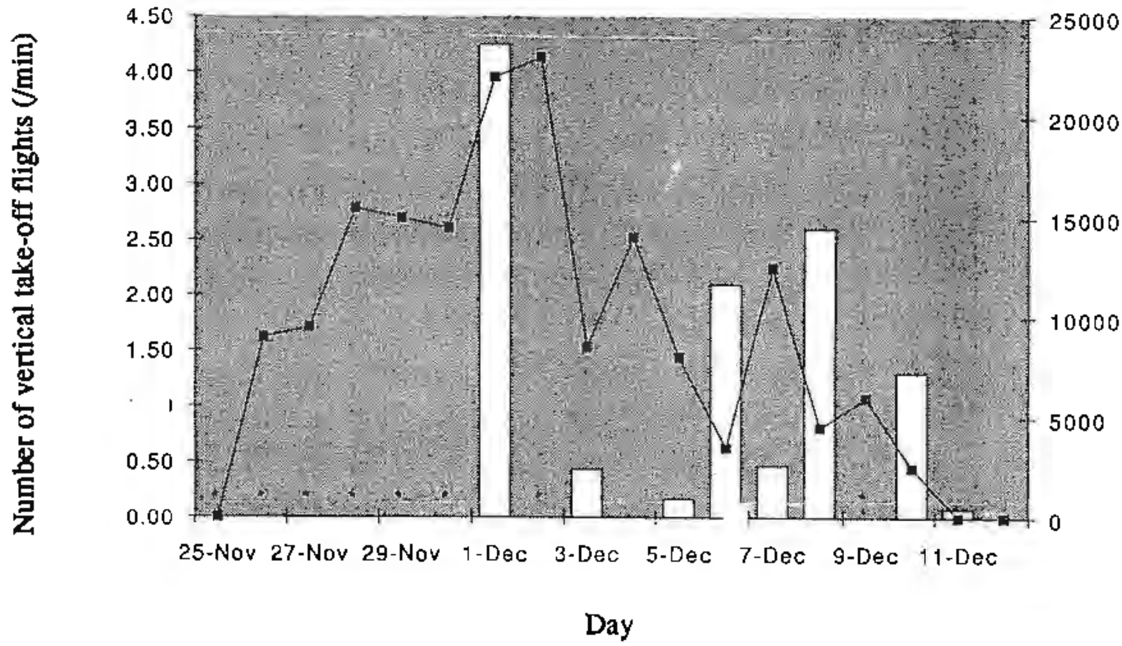

Fig. 4. Night-to-night variation in the number of moths making vertical take-off flights from the chickpea crop between 20:00 and 20:30 h, and of moth emergence the previous night, at N.A.R.S. during December 1989.

field were in broad agreement, suggesting these two techniques were detecting the same class of insect. The relatively large counts obtained during the vertical-beam observations suggest that this technique is sensitive also to smaller insects which are usually more numerous.

Totals of 57 and 6 *Heliothis* moths were caught in the vehicle-mounted trap in December and January respectively. Other similar-sized moths (catches 48 and 8) and orthopteran species (85 and 33) were present. These make interpretation of the radar observations difficult, as the insect echoes clearly cannot all be attributed to *Heliothis*. The tower net caught very few moths positively identifiable as *Heliothis* during the entire observation period. While this may have been partly a result of operational difficulties experienced with this equipment, it does support the video and radar observations that moth numbers at 10 m were very low.

The mark-and-capture study showed that a high proportion of the marked *H. armigera* moths which emerged from the chickpea crop colonised crops within a few kilometres, whereas the bulk of the *H. punctigera* population dispersed further, apparently moving beyond the 10 km radius of the trapping network (Fitt & Pinkerton 1990). This is the first documentation of greater dispersive behaviour in *H. punctigera* compared with *H. armigera* and is consistent with the direct and radar observations of vertical take-off flights described below.

Long-range movements. Insect migration at altitudes from 30–2000 m was monitored from dusk until about midnight throughout the two periods of intensive observations, and the intensity and direction of migration at each altitude was measured regularly. From the strength of the echoes and their behaviour (especially their flight altitude of only a few hundred metres), it is thought likely that these migrants were mainly grasshoppers and crickets. This is partly confirmed by the sampling with the kite-borne net at altitudes of 50–150 m, during which 2 grasshoppers but no moths were caught. Further analysis, especially of radar-target wing-beat frequencies, should provide additional information on the migrants' identity. The conclusion from these observations is therefore that there was no intensive long-distance migration of *Heliothis* over the Namoi valley during the summer of 1989/90.

Moths were seen making rapid, steeply ascending emigration flights during dusk binocular observations over the source crops in December but not in January. The number of emigrants observed varied considerably from night to night (Fig. 4), but did not reflect changes in emergence from day to day. Moths were also seen to be making near-horizontal flights at dusk during both observation periods. On two nights during December, the rapid ascent flight was just detectable on the radar as a steeply rising plume which could be followed up to a height of about 100 m. Generally, however, emigration from the source crop was difficult to distinguish from the widespread take-off flight of other species (probably mainly grasshoppers and crickets) which occurred every evening.

Discussion

The primary findings of this study are:–

— Apart from the moths emerging from the source crops, *Heliothis* activity was low during the observation periods and indeed for much of the cotton-growing season.

— The moths emerging in December consisted of *H. armigera* and *H. punctigera* in approximately equal numbers. In January, only *H. armigera* was present.

— Local movement occurred very low down, at heights of only 1–4 m above the crop canopy.

— *H. armigera* dispersal was concentrated within about 5 km of the source crop, while *H. punctigera* dispersed more extensively, with much of the population probably emigrating beyond the 10-km radius of the trapping network.

— There was no intensive long-range migration of *Heliothis* over the Namoi valley during the summer.

— A proportion of the moths from the source crops initiated a long-distance migration, and hence emigrated from the local region, in December but not in January.

The mark-and-capture study and the observations and sampling at low altitude all indicate that moths of both *Heliothis* species frequently move distances of at least a few kilometres between emergence and oviposition sites. Once a highly attractive host is located, however, they appear to avoid departing from it. Many *H. punctigera* moths probably move considerably further, and effectively depart from the region in which they emerged.

The most likely interpretation of the observations of take-off flights is that the moths initiating long-distance flight in December were *H. punctigera*. This is consistent with earlier evidence that *H. punctigera* is an obligate migrant while *H. armigera* emigrates only when local conditions are poor. When combined with the insignificant level of long-distance *Heliothis* migration over the Namoi valley (and hence immigration into it) during the summer, the obligate emigratory behaviour of *H. punctigera* accounts for the decrease in the proportion of this species from December to January. This decrease occurs regularly each season, and follows an initial heavy infestation in spring. It therefore appears likely that *H. punctigera* migrates into the Namoi valley in spring, probably from native pastures in the inland, and emigrates in early summer, probably to more coastal habitats from which it may reinfest the far inland in autumn.

The low-intensity of long-range migration and of flight at altitudes around 10 m at Narrabri contrasts with observations made at the same season in earlier years in the Darling Downs and Emerald cotton-growing areas of Queensland. In both localities, strong migrations were regularly present at both altitudes. The migrants at 10 m, and probably also those at 100–2000 m, were moths, although whether or not *Heliothis* was present in significant numbers could not be established. It is not yet clear whether these differences arise from the geographic location, especially the more tropical climate, of the two Queensland localities, or whether they are simply variations between seasons. It should be emphasised, however, that there are strong indications that *H. armigera* does move long distances in some circumstances (Fitt 1989), but apparently the conditions at Narrabri during summer 1989/90 were not such as to induce this type of behaviour.

Acknowledgments

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