A MARK-RECAPTURE STUDY OF *HELIOTHIS* MOVEMENT FROM A SOURCE CROP IN THE NAMOI VALLEY.

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Introduction

The potential for extensive adult movements is one of the key factors contributing to the success of *Heliothis* spp. as pests (Farrow & Daly 1987, Fitt 1989). Adult movements may occur on several spatial scales; from one field to another, between areas within a valley or between regions (see Gregg et al 1990). Quantitative information about adult behaviour, and movement in particular, is required for the *Heliothis* population models currently being developed to provide forecasts of infestations on cotton crops (Dillon & Fitt 1990). There are a number of questions to be answered and these are being tackled using a range of techniques (Drake & Fitt 1990) to provide a comprehensive picture of *Heliothis* movement. In particular we are interested in the behaviour of newly emerged moths produced from crops within the cotton areas. How far do these moths fly before colonising a crop in which to lay eggs? When do they leave? How do they move in relation to the wind? What characteristics of crops cause moths to leave or stay within them to mate and lay eggs? To answer some of these questions we are conducting a series of mark-recapture studies at Myall Vale.

Mark-recapture techniques

Mark-recapture is a technique widely used in studies of insect movement, and has been used elsewhere with *Heliothis* (King et al 1990). It involves marking a large number of insects with a specific identifying mark, releasing them at a known location and later recapturing them, usually by a network of traps. By analysing where the marked insects are recaptured it is possible to calculate the average distance moved in different directions and relate this to various environmental parameters (wind directions, crop attractiveness etc.). In addition an analysis of the proportion of captured moths which are marked can provide estimates of the total population of moths within the study area. Most mark-recapture studies have involved the release of laboratory reared insects marked with a coloured dye or fluorescent dust. This approach has several disadvantages; first the released insects, being from laboratory colonies, may not behave in the same way as the natural population. Laboratory insects may not fly as stongly or may not respond normally to environmental cues. Second, the application of the marking agent (dust, dye etc) may alter the survivorship or behaviour of the insect. Third, the insects may be so disturbed by the marking and release procedure that their initial dispersal flight from the point of release is more akin to an escape reaction than to natural emigration behaviour. An alternative approach, which we have used, is to mark a naturally occuring population of insects and then allow them to emigrate from the site without disturbance.

Methods

Producing a population and marking techniques

Large populations of *Heliothis* were produced on specially grown crops at Myall Vale. In the 1989/90 season these were chickpea (spring), maize (summer) and pigeonpea (autumn). This paper deals only with the spring population produced on chickpea (6.2 hectares). The crops were exposed to oviposition by the natural *Heliothis* population and insects were not controlled in any way so as to build high densities of larvae.

To mark the population we used Strontium, a naturally occurring, but rare heavy metal. *Heliothis* moths in the Namoi Valley normally contain strontium at very low concentrations (3-4 parts per million (ppm)). We produced moths with elevated levels of strontium (10-50ppm) by spraying the crop with an aqueous solution of strontium chloride (SrCl) when the larvae were small to medium (3rd-5th instar). The SrCl forms a deposit on the plant surfaces and some is absorbed and transported around the plant. Larvae ingest the SrCl during feeding and a proportion of the resultant adults carry increased levels of strontium. The crop was sprayed 3 times (Oct.31, Nov.3 and Nov.8) with SrCl at a rate of 9-10kg/ha (plus 0.1% Monsoon surfactant/ sticker) at high volume (approx. 560 l/ha). Three applications were applied since the first two were followed immediately by rain (11.2 and 23.2mm respectively) which may have removed much of the strontium from the foliage. One area of the crop (8m x 100m) was left unsprayed to provide estimates of natural levels of strontium in moths.

Emergence and Recapture

Estimates of pupal density were obtained on six occasions (9/11, 15/11, 22/11, 29/11, 6/12, 13/12) by sampling ten to twenty $1m^2$ areas of soil uniformly distributed over the field. Emergence of the population was monitored by means of 20 cages, each 1m x 1m, distributed throughout the field. Moths were collected from these each day to provide a measure of the numbers and species composition of adults which had emerged the previous night. All moths from the pupal samples and from the emergence cages were analysed for strontium content so that numbers of marked and unmarked moths could be determined. Moths from the control (unsprayed) area were collected on 3 nights as they emerged from the soil.

A network of pheromone traps was established to recapture male moths from the marked population. A total of 50 pairs of traps (1 *H. armigera* and 1 *H.punctigera*) were distributed within a circle of approximately 10 km radius centred on the chickpea crop (a recapture area of 314 square kilometres). One set of traps was in the chickpea crop where moths were emerging while the remainder were mostly positioned near attractive crops (44 pairs in cotton, 3 in safflower, 1 in sorghum, 1 in maize and 1 in fallow). The traps were cleared about every 2 days from November 29-December 20 covering the period of adult emergence from the chickpea. All the trapped moths were counted and stored for strontium analysis.

Strontium Analysis

All moths from the pupal samples, from the emergence cages and from the recapture traps were individually analysed for strontium content using wavelength-dispersive X-ray spectroscopy (at CSIRO Plant Industry, Canberra). Each moth was first oven dried at 80^{o}. It was then weighed and an equal weight of a 1:1 mixture of boric acid and glucose powders was added. The moth and diluent were then ground in an agate pestle and mortar, and pressed into a small, thin pellet from which the concentration of strontium was determined automatically using the X-ray spectrometer.

Results and Discussion

Emergence

The chickpea crop commenced flowering in mid-September and substantial numbers of eggs were laid from September 29 to October 12 (Julian date 272-285, Fig.1). Larval densities of up to 60/m^2 were recorded and a final population of 20 pupae/m^2 was produced (1.21 million pupae in total). From these a total of 1,063,300 adults emerged successfully; 43% *H. armigera* and 57% *H. punctigera*. Adult emergence began in late November (Jday 328). As Figure 1 shows the HEAPS model quite accurately predicted the phenology of emergence (see also Dillon and Fitt 1990), though the natural emergence peak was more extended than that predicted.

Analyses of the chickpea plants after each application of strontium chloride showed that most of the deposit was on the surfaces of leaves and pods (2200ppm and 300ppm respectively compared to 200ppm and 90ppm in the leaves and pods of untreated plants). Concentrations in the seeds were almost doubled (18 to 31ppm), indicating that some strontium was absorbed and translocated around the plant. Medium and large larvae feed mostly on the developing seeds of chickpea but they would also have ingested some of the marker when chewing through the pod walls to gain access to seeds.

The mean strontium content of moths produced on the chickpea were significantly elevated (Table 1). Moths were deemed to be unequivocally marked if they contained 10ppm or more (dry weight) of strontium. This is a conservative figure since the upper 95% confidence limit around the mean strontium content of males from the unsprayed control area was 3.61 ppm strontium (Table 1). Using the 10ppm criterion about 30% of all males which emerged were unequivocally marked (*H. armigera* -32%, *H. punctigera* - 29%). Thus a total of approximately 150,000 marked males moved out of the crop. By contrast 41% of the females were marked. The reason for this difference is not clear, but has been observed in other studies (King et al 1990). This level of marking is somewhat disappointing but may have been due to our inability to apply sufficiently high volumes of spray. Other studies have achieved levels of around 50% marked (King et al 1990), and in preliminary experiments here we achieved 90% successful marking when Sr Cl was applied by knapsack to pigeon pea.

Figure 1. Numbers of eggs laid and moths emerged from chickpea crop. For moths the figure shows actual emergence and the predicted emergence from the HEAPS *Heliothis* model (simulating from Oct. 26, Jday 299) (note different axes for eggs and moths)

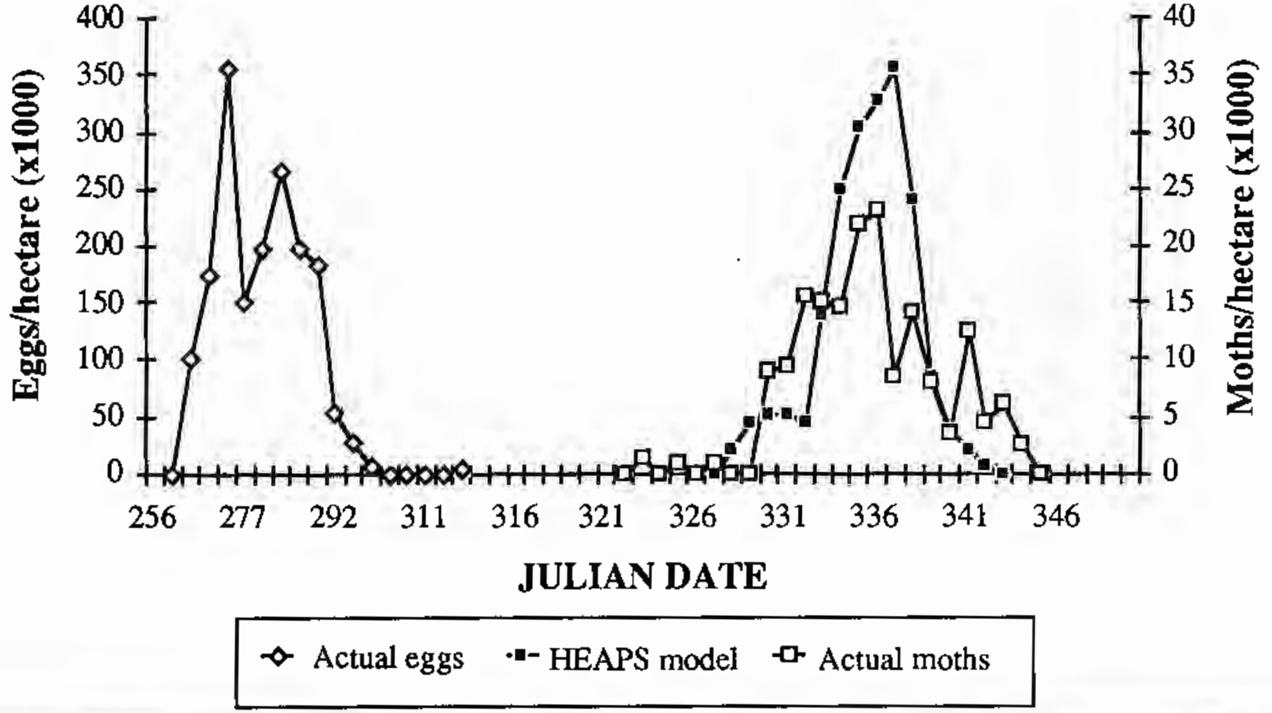
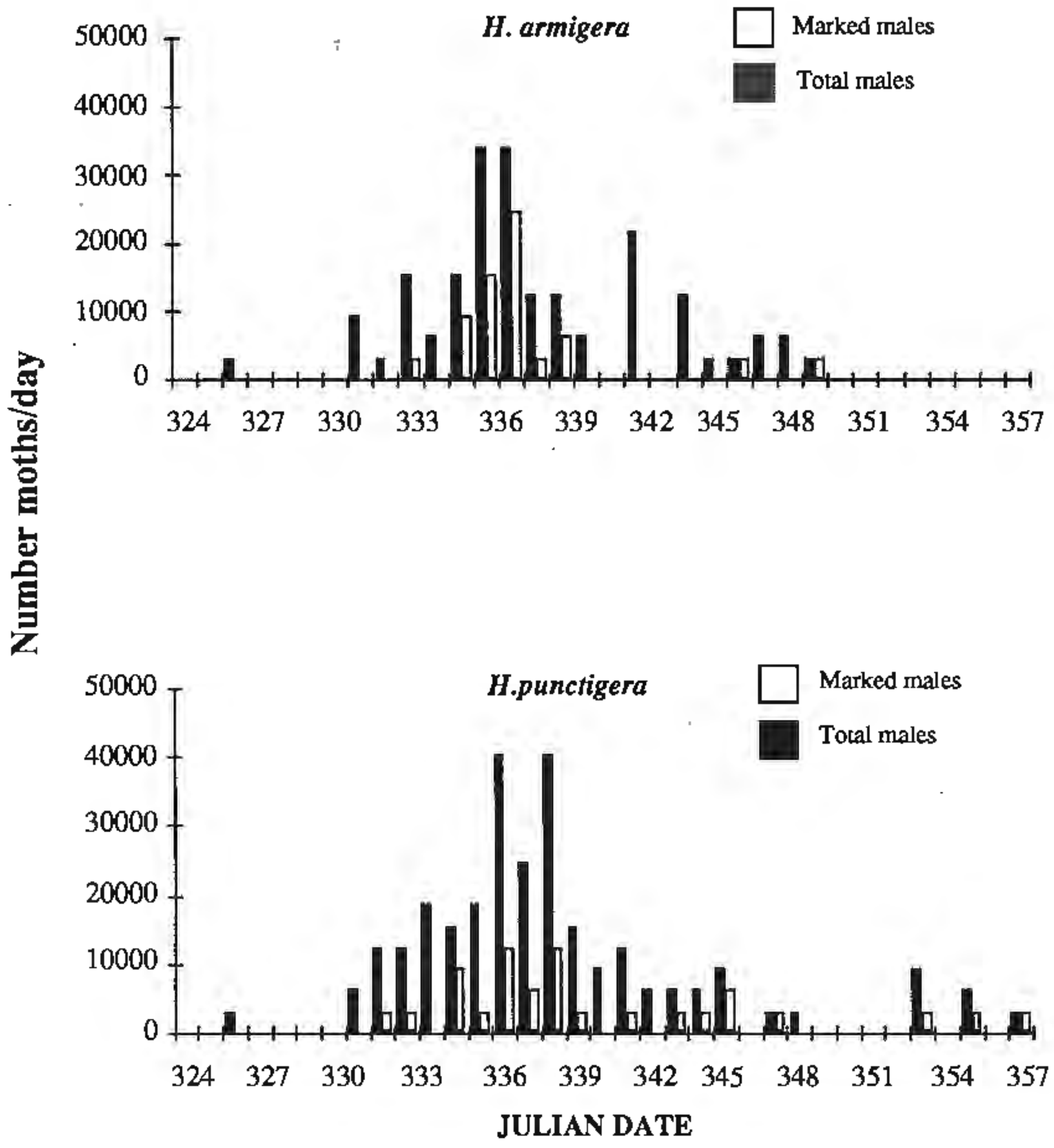


Figure 2. Emergence of total and labelled (>10 ppm strontium) male *H. armigera* and *H.punctigera*



Since only male moths were recaptured in the pheromone trap network the remainder of this paper refers only to the male portion of the population. Figure 2 shows the period of emergence of marked and total males of both species. The earliest moths to emerge were not marked, probably having pupated before the marker was applied. The bulk of the marked males emerged during the period from November 30 - December 7 (Figure 2).

Table 1. Mean strontium content (ppm) of *Heliothis* moths which (i) emerged from the unsprayed chickpeas (controls) (ii) those collected as pupae and (iii) those collected as they emerged from the areas sprayed with strontium chloride.

Group	Sex	Mean Sr (ppm)	Range	95% confidence limits lower	95% confidence limits upper
(i) Controls (unmarked)	Male	3.07	0.5-11	2.52	3.61
	Female	3.66	0.5-10	2.72	4.60
(ii) Collected as pupae	Male	7.42	0.5-77	6.34	8.50
	Female	11.58	0.5-156	9.85	13.31
(iii) Collected in emergence cages	Male	8.43	0.5-69	6.97	9.88
	Female	12.25	0.5-78	10.29	14.21

Recaptured moths

A total of 12,000 moths were trapped during the total emergence period from November 28-December 25. These preliminary results are based on analyses of 3964 moths completed to date (June 1990) and focuses on the main emergence period (Nov.30-Dec. 12). During this period a total of 5250 *H. armigera* males were trapped of which 8.8% were marked, while 3172 *H. punctigera* males were trapped of which only 2.3% were marked. These high levels of capture of marked moths relative to the unmarked population arise because we were lucky enough to conduct the study in a season when the natural *Heliothis* population was not abundant. When the level of unequivocal marking (30%) is taken into account the data suggests that about 27% of the total *H. armigera* population in the recapture area was produced on the source crop, while about 7% of the *H. punctigera* population was from the chickpea source.

There are a number of ways we might analyse the recapture data, and these analyses are far from complete. Nevertheless some striking patterns are apparent. Firstly we can crudely analyse recaptures by distance from the source by aggregating trap sites into annuli of 500 metres (ie. all traps between 0 and 500 metres, 500-1000, 1000-1500 and so on). We can then ask what proportion of moths captured within each distance were marked and how many marked moths were captured at each distance (proportion marked multiplied by the total number of moths captured). Figure 3 shows these two results for the two species. For *H. armigera* a high proportion of moths captured close to the source were marked (most of these were in an adjacent silking maize crop), with a general decline in % marked with distance ($y = -0.411\ x + 12.35$, $R^2=0.36$). Even so 11 marked *H. armigera* were recaptured at 9800 metres (in a safflower crop, see below) and 5 were recaptured as far as 13 km away (in a couple of traps outside the main recapture network).

For *H. punctigera* the proportion of marked moths was clearly much lower, but there was no decline in this proportion with distance ($y = -0.067\ x + 2.40$, NS). Since more marked *H. punctigera* left the chickpea than *H. armigera* (85,500 vs 64,500 (males only)) the results suggest the majority of the *H. punctigera* left the trapping area altogether whereas many of the *H. armigera* colonised crops within 10 km of their emergence site.

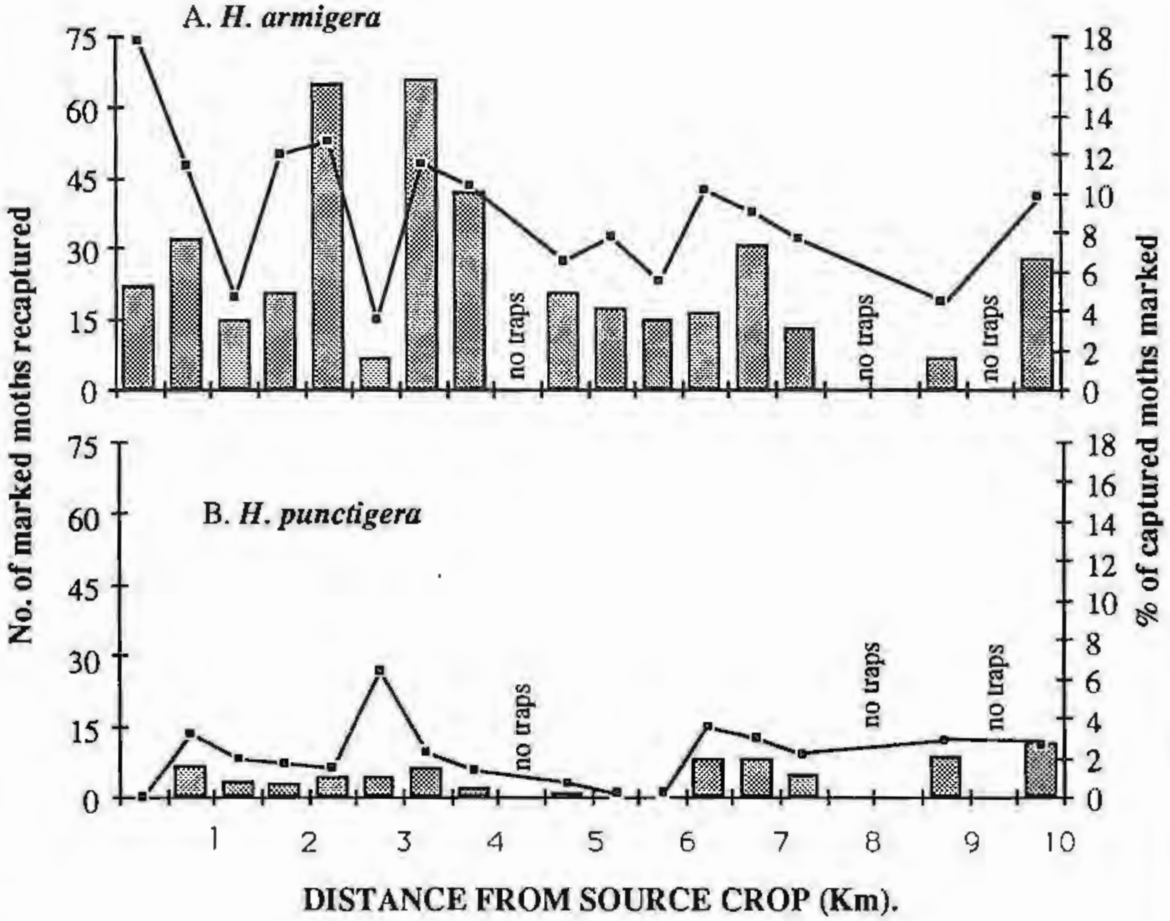
Closer analysis of the recaptures shows just where the moths ended up. Of the marked *H. armigera* which were recaptured, 27% (73 of 240 marked *H.armigera*) were in 4 traps in safflower crops which were flowering at the time. These were at 2200 and 3380m to the south-east, 3820 to the NNW and 9850m to the NNW from the chickpea. A further 17% were caught in a group of 4 adjacent traps in cotton crops at distances of 4800-6200 metres to the south of the crop. A further 10% were caught in traps in the source crop or within 100m of it. Thus over half the marked *H. armigera* moths were caught in just 11 of the 50 traps.

Of the marked *H.punctigera* captured none were within 500 m, while 25% were caught in the four safflower traps (7 of 28 marked *H.punctigera*).

Conclusions.

A major advantage of this study was that we were able to quantify the movement of a natural population of both species from the one source and were able to do so at a time when *Heliothis* were generally not abundant, thus maximising our chances of

Figure 3. The percentage of trapped males which were marked (▪——▪)
and the number of marked males captured (% marked * total moths captured)
(histogram) at different distances from the source crop.



recapturing marked moths. It may well be that these conditions will not pertain in the future, though we plan a repeat study next season.

The results appear to confirm that *H. punctigera* is more mobile than *H. armigera* (Farrow & Daly 1987) and is a obligate migrant (ie. much of the population leaves an emergence area irrespective of local conditions), whereas *H. armigera* is more a facultative migrant which colonises nearby crops if these are suitable for reproduction. The majority of the *H.punctigera* which emerged from our crop appear to have left the study area altogether and thus flew at least 10 km (and probably much further) even though suitable host crops were present nearby. This interpretation is supported by observations of emigration behaviour using other techniques (Drake & Fitt 1990). It is important to realise nonetheless that this was only one study conducted under one set of environmental parameters. Newly emerged moths may move differently when conditions are different. For example, how would *H. armigera* moths behave if they emerged from a chickpea crop set in the midst of large areas of pasture where few hosts were present nearby ?

A major disadvantage of this type of recapture study is that we monitor only the movement of males and must infer that females move similarly. This is unfortunate since half the moths leaving the source crop were females and a higher proportion of these were marked. Nevertheless it is not practical to operate the large numbers of light traps (and sort the catches!) which would be required to recapture both sexes. In the coming season, when this study will be repeated, we plan to operate up to 10 light traps in strategic locations, in addition to the pheromone trap network.

The results indicate that squaring cotton was much less attractive to both species than was flowering safflower. The emergence site was surrounded in all directions by cotton crops over which the moths would have flown to locate the safflower crops. Although safflower made up only a small proportion of the cropped area many of the *H. armigera* were captured there. This demonstrates that *Heliothis* adults are able to locate small areas of highly attractive crops and highlights the potential for using trap crops in combination with repellants applied to cotton in *Heliothis* management (as suggested in the push/pull strategy by Pyke et al 1986).

What do these results mean for the further development of the HEAPS population model? In HEAPS we explicitly model the movement of adults using a set of simple rules which summarise our understanding of how moths behave. The aim is to predict how a population of moths emerging from one point will be re-distributed throughout a region. Low level wind speed and direction are major factors influencing this movement. Further analysis of these results and those from complimentary radar studies (Drake & Fitt 1990) will allow us to better quantify parameters relating the influence of wind, which we monitor continuously, and crop distributions on the re-distribution of moths.

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