HEAPS: A REGIONAL MODEL OF HELIOTHIS POPULATION DYNAMICS.

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Heliothis spp. are very successful as pests for a number of reasons (Fitt 1989): adult moths are highly mobile and have a high reproductive rate, larvae can utilize a wide range of host plants including most crops, and successive generations can develop resistance to pesticides. Management of such pests in commercial crops relies on regular scouting to provide information on egg and larval densities within each crop, and their likely resistance levels. We believe that the local management of *Heliothis* could be improved if predictions of the densities and the origin of *Heliothis* eggs on each crop could be made several days in advance. Regional management strategies (see Murray, these proceedings) and insecticide resistance management (see Forrester, these proceedings) would also benefit if overall seasonal predictions of likely densities for each species of *Heliothis* could be made with confidence. Such information would be available if we understood the population dynamics of *Heliothis* on a regional scale.

To this end we are developing a series of simulation models under the name "HEAPS" (HEliothis Armigera and Punctigera Simulation) (Hamilton and Fitt 1988). HEAPS currently consists of 5 main modules: (i) Adult movement, (ii) Oviposition, (iii) Development, (iv) Survival, and (v) Host phenology. Further planned modules include (vi) Diapause and (vii) Resistance genetics. HEAPS works by dividing a region into a grid of simulation units (SU's) each $16km^2$, (4x4 km) and then simulating the subpopulation of each species of *Heliothis* within each unit. The number of *Heliothis* within an SU is a function of the rates at which individuals enter (as eggs or immigrants) and leave (by dying or emigrating). These rates are modified by two main factors: (a) daily weather, and (b) the host type and stage within each SU. The length of time it takes individuals to develop from eggs through larvae and pupae until emergence as moths is also governed by daily temperatures and host quality. Each day the SU subpopulations are linked into a dynamic regional population by simulating the movement of adult moths in response to weather patterns, and alighting moths for oviposition in response to the attractiveness of hosts they may fly over.

The modules:

To define the all important "rates" mentioned above for immigration, oviposition, development, survival, and emigration, and to define the degree to which these rates are modified in response to variations in weather and hosts, each of the HEAPS modules uses mathematical parameters that have been derived from a wide range of research findings. Each module is tested by comparing its predicted results with actual results measured in the field, and the parameters are revised if necessary as further results come to light. The concepts underlying the modules and their current state of development is described below.

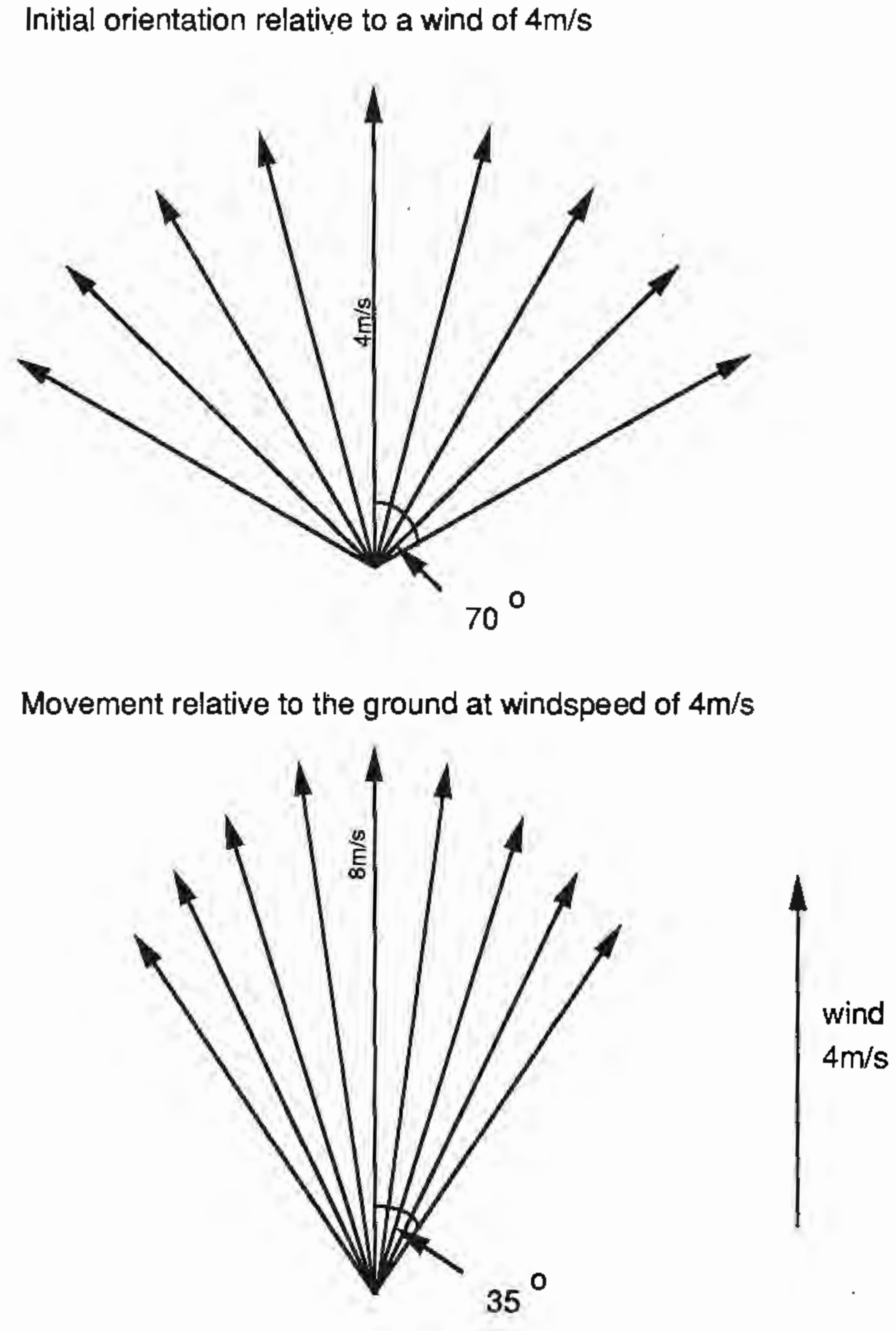
(i) *Moth Movement.*

Heliothis flight behaviour and ecology is the key to understanding the population dynamics of *Heliothis* on a regional basis. A number of research programs are currently focused on examining *Heliothis* moth behaviour and movement patterns. A wide range of techniques are being employed, including radar, direct observations of movement using night vision goggles and sampling of moths in flight (Drake and Fitt 1990), flight mill experiments (Coombs these proceedings), mark and recapture studies (Fitt and Pinkerton 1990), elemental analysis of host chemical signatures (Fitt 1986), electron microscopic examination of pollen particles carried by moths (Gregg et al 1990) and the correlation of long range moth movement with synoptic weather patterns (Fitt et al 1990, Gregg et al 1990). All the results indicate that moth behaviour is a complex phenomenon that is governed by a vast array of variables. In terms of simulating movement then, we have synthesized our *current* knowledge into a set of rules and assumptions summarized below:

- Adult moths move on their second night after emergence.
- Moths only take-off at temperatures higher than 12 C.
- Moths only take-off at windspeeds lower than 10 metres/second.
- Unassisted flight speed = 4 m/s (14.4 km/hr).
- Maximum flight duration = 5 hours.
- Windspeeds over 1 m/s cause moths to orientate in a general downwind direction with a standard deviation about this that decreases linearly as windspeed increases (see figure 1).
- Moths alight in response to host crop attractiveness.

A network of wind recorders is being installed throughout the lower Namoi valley

Figure 1. Effect of windspeed and direction on *Heliothis* movement relative to the ground.



to improve the quality of the input data upon which HEAPS will be basing its predictions. The movement module has not yet been tested in the field, and the rules listed above are still very much in the prototype stage.

(ii) *Oviposition.*

The oviposition module estimates the number of eggs laid in each simulation unit each day. The sheer number of eggs that an individual female *Heliothis* of either species can lay (on average about 1000 but up to 3000 are possible) has important implications for predicting regional population dynamics. A relatively small number of moths (a few hundred) can move into a host patch and potentially leave over a million eggs and larvae in their place. The number of eggs that a female lays may vary depending on weather conditions, the moths age, her mated status, and possibly the quality of the host she fed on as a larvae. The proportion of infertile eggs also varies. These factors have recently been investigated in the field and laboratory (A.Spessa and G.Fitt unpublished) and the results are currently being analysed. In the meantime the oviposition module currently uses a simple function of moth age to estimate the number of eggs females lay each day, with each female laying a maximum of 1000 eggs over her breeding life.

(iii) *Development.*

This module simulates the development of cohorts of *Heliothis* from "birth" as eggs through a number of larval stages, and a pupal stage before emerging as adult moths that eventually senesce and die. The most important parameter governing development is the temperature individuals are exposed to on the host plant. A problem with predicting the rate of development on a particular host is that the microclimate under the vegetative canopy, and in the structures which *Heliothis* inhabit, differs from the outside air temperatures measured by a meteorological station. For the past 3 seasons we have been measuring temperatures on a range of hosts with the aid of electronic dataloggers, and correlating these with local met station data in order to derive our conversion equations. These then allow us to predict microclimatic data under the different hosts, and subsequently predict the mean rates of egg, larvae and pupal development. Our simulation also takes into account the range of individual variation about the mean development times. All individuals do not develop at the same rate. The fact that some *Heliothis* develop quickly and others more slowly leads to considerable overlap of generations by the end of a season. At present our knowledge of *Heliothis* development is reasonable for a number of important crops (Cotton, Maize, Chickpeas, and to a lesser extent Sunflowers and Sorghum). Given the number of *Heliothis* eggs and larvae on a particular crop, and long term temperature data for the area, we can estimate the number of moths that will eventually emerge and the timing of emergence with a fair degree of confidence (Figures 2 and 3).

(iv) *Survival.*

The survival of an individual *Heliothis* from when it is first laid as an egg, through a range of larval and pupal stages, until its final emergence as a mature moth is an unlikely event. This is fortunate, as populations would otherwise increase exponentially. The natural factors responsible for *Heliothis* mortality are many and varied, with the most important being predation, parasitism, diseases, host plant defence mechanisms and of course, weather. Natural mortality rates for eggs and larvae on different hosts typically range from 97.5 to 100% (Titmarsh and Murray 1990) although we have recorded mortality rates of 90% on cotton. The HEAPS survival module utilizes separate mortality parameters for each *Heliothis* stage, and these vary depending on the type and stage of the host. These values are derived from life-table studies in which repeated measurements of *Heliothis* densities are taken within a field, allowing the calculation of stage specific mortality rates. At present the only *Heliothis* mortality values of which we are entirely confident are those defined for cotton which have been fine tuned through their use in the SIRATAC cotton management program.

(v) *Host Phenology.*

Host plants govern most aspects of *Heliothis* life, and therefore are an important component of any attempt to simulate *Heliothis* population dynamics. This module computes the rate and timing of host development in response to daily temperatures. The resulting predictions of the current host stage in each simulation unit for each day are then used by each of the other modules. For example, the attractiveness indices used by the movement module vary depending on the type and stage of host (flowering hosts are generally more attractive, and the attractiveness indices are also different for the two species of *Heliothis*, reflecting their different utilization of host plants). Likewise rates of *Heliothis* development and mortality vary with host type and stage because the availability of resources such as nutrition and shelter change. HEAPS splits the development of each host into 4 stages, typically as follows: (1) planting to first flower bud, (2) first flower bud to 50% flowering, (3) 50% flowering to fruit maturity,

Figure 2. 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 indicated by arrow). (note different axes for eggs and moths)

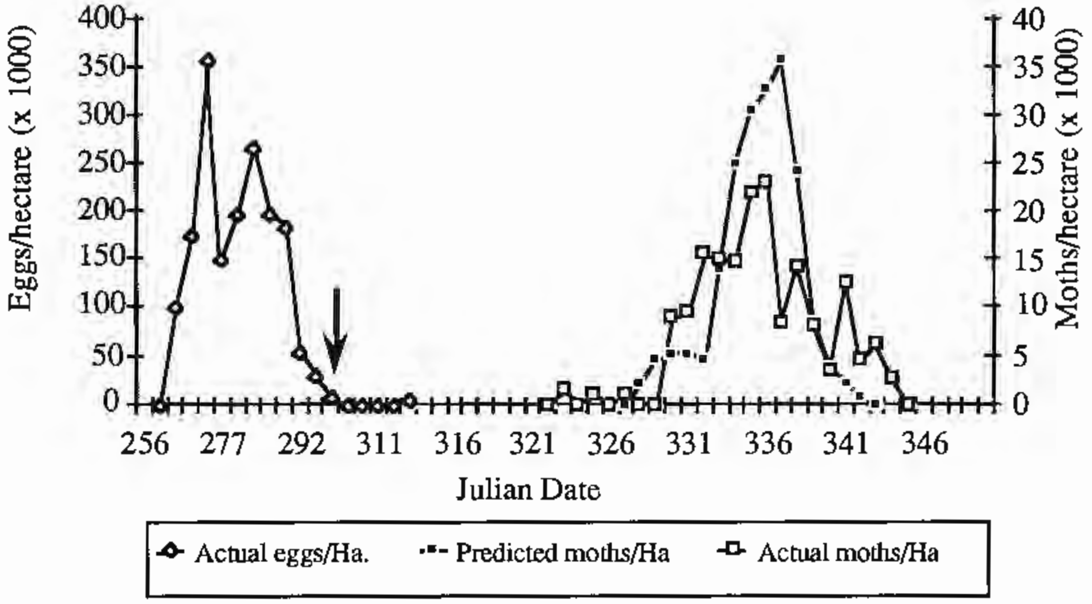
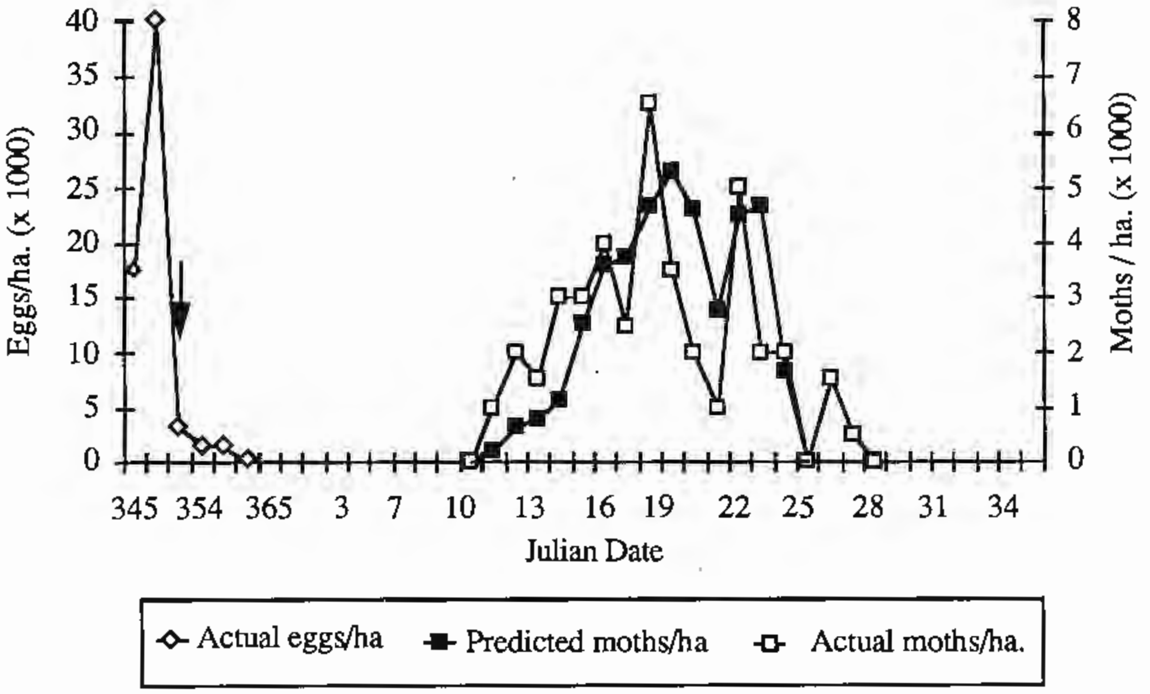


Figure 3. Numbers of eggs laid and moths emerged from maize crop. For moths the figure shows actual emergence and the predicted emergence from the HEAPS *Heliothis* model (simulating from Dec. 18, Jday 352 indicated by arrow). Note different axes for eggs and moths.



and (4) maturity to harvest. At present we feel we have good models for the development of cotton, maize, and chickpea, and for some varieties of sunflower and sorghum.

Putting it all together:

The development of HEAPS is far from simple. We still do not understand enough about *Heliothis* to make some parts of HEAPS biologically accurate. However, rather than waiting for all the holes in our understanding to be filled before embarking upon such a model, we feel that developing HEAPS while doing related research is the best way to pin-point gaps in our knowledge and to fill them with sound research. HEAPS will serve 4 main functions:

1. To predict *Heliothis* recruitment and egg laying on cotton crops and thus strengthen management decision-making processes.
2. To evaluate the effects of various agronomic practices on the regional abundance of *Heliothis* .
3. To evaluate the impact of patterns of pesticide usage on resistance levels in *H. armigera* populations.
4. To pinpoint areas for research that are critical for an understanding of *Heliothis* dynamics and about which we know little.

In addition to its practical applications HEAPS is also a valuable research tool. It has been designed and coded in a way that allows the user to experiment with different scenarios, or to run repeated simulations with slight variations to the underlying mathematical parameters. The effects of different distributions of pests and/or hosts for example, quickly make themselves apparent in the resulting distribution and abundance of *Heliothis* over the simulated region. In this way we can test hypothesis relating to the first 3 functions listed above at the touch of a keyboard, rather than the slow and costly process of carrying out field trials. At present HEAPS is about 80% complete, with the remaining 20% involving the gathering and fine-tuning of host related parameters from a range of hosts. When complete the individual modules and the overall model will need to be validated by comparing the predicted results with actual results measured in the field. It is after this has been completed that HEAPS will begin to be used to aid commercial management decisions.

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References

Drake, V.A. and Fitt, G.P. 1990. Studies of *Heliothis* mobility at Narrabri, summer 1989/90 *(these proceedings).*

Fitt G.P. 1986. The use of elemental analysis as a tool in the study of intercrop movement by adult *Heliothis*. pp. 207-213 in in *Proceedings of the Australian Cotton Conference,* Surfers Paradise, 1986.

Fitt, G.P. 1989. The ecology of *Heliothis* species in relation to agro-ecosystems. *Annual Review of Entomology* 34: 17-52.

Fitt, G.P., Gregg, P., Zalucki, M. and Twine, P. 1990. Studies of the ecology of *Heliothis* spp. in inland australia: what relevance to the cotton industry? *(these proceedings).*

Fitt.G.P. and Pinkerton, A. 1990. A mark-recapture study of *Heliothis* movement from a source crop in the namoi valley. *(these proceedings).*

Gregg, P., Fitt, G.P., Zalucki, M.P and Twine P. 1990. Evidence for spring migration of *Heliothis* spp. from inland Australia to cotton areas. *(these proceedings).*

Hamilton G. and Fitt G.P. 1988. HEAPS, *Heliothis armigera* and *punctigera* simulation model. pp. 139-145. in *Proceedings of the Australian Cotton Conference,* Surfers Paradise, 1988.