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Cotton *Research & Development Corporation*

FINAL REPORT

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Population dynamics and migration of *Heliothis* spp. in inland Australia: Towards the development of an early warning system (forecasting) of *Heliothis* migration into eastern Australia.

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Queensland Department of Primary Industries

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A final report prepared for the Cotton R&D Corporation

CRC for Tropical Pest Management

- The University of Queensland
- CSIRO Division of Entomology
- Queensland Dept of Primary Industries
- Queensland Dept of Lands

Report of a workshop on developing a heliothis forecasting service in Australia

7-8 December 1992

Narrabri Agricultural Research Station, New South Wales

AUSTRALIA

M. Dale, P.C. Gregg and V.A. Drake

Sponsored by ICI Agricultural Chemicals, Shell Chemical (Australia), the Cotton Research and Development Corporation, and the Rural Industries Research and Development Corporation

Workshop on developing a heliothis forecasting service in Australia

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Workshop organisation and report

The workshop was organised by Gary Fitt (CSIRO Division of Entomology) and Myron Zalucki (Department of Entomology, University of Queensland), and facilitated by Michele Dale (CRC for Tropical Pest Management). This report was prepared by Michele Dale (CTPM), Peter Gregg (University of New England) and Alistair Drake (University of New South Wales).

CONTENTS

1. Executive Summary

1. A workshop convened by the Cooperative Research Centre for Tropical Pest Management at Narrabri on 7-8 December 1992 examined the feasibility, benefits, and funding implications of providing an operational forecasting service for heliothis. The workshop participants represented grower organisations, insecticide suppliers, pest-control services, and rural-industry research funding bodies, along with state-government, CSIRO, and university scientists.

2. The workshop focussed especially on the question of forecasting spring infestations of the native budworm *Helicoverpa punctigera*, a serious pest of various legume crops (especially lupins in Western Australia and field peas in Victoria), and the main early-season pest of cotton. It is now known that these infestations are initiated by immigrants from the far inland, where a research programme now approaching completion has located very large numbers of caterpillars on native vegetation during 3 of the last 4 winters. These inland populations emerge as moths in August-September, and are carried into cropping regions by the wind; damage is caused either by the offspring of these moths (in legume crops), or by the subsequent (second) generation (in cotton).

3. The magnitude of the early-spring influx of *H. punctigera*, and the consequent potential of this pest to cause economic damage, varies significantly from year to year. Now that the source regions are known, surveys can be undertaken to estimate the size of inland populations in winter, and a forecast of the damage potential issued several weeks/months before control action needs to be taken in legume crops and cotton respectively.

4. Tentative forecasts of *H. punctigera* damage potential, based on observations made during the course of the current research programme, have been issued by the researchers for the last 3 years. These forecasts have both proved reasonably accurate, and been received with considerable interest by growers, insecticide suppliers, and pest controllers. The workshop was convened primarily to determine the utility of continuing (and improving on) these forecasts, and, if continuation is merited, to recommend how the provision of forecasts should be funded.

5. Following extensive discussions, the workshop participants reached a general consensus on the following points:-

- Although the prospects for routine forecasting of early-season heliothis infestations were good, it would be premature to attempt this now without some additional research. This should include further trials with the methods currently in use, some assessment of new and potentially less expensive remote sensing methods, and an economic evaluation of forecasting.

- Forecasts of the magnitude of early-season heliothis infestations were potentially valuable to growers, insecticide suppliers, and pest controllers. All of these users considered the forecasts had some utility for them.

- There are four major user groups for heliothis forecasts: cotton growers, grain-legume growers, insecticide suppliers, and agricultural pest-control services. Until better information becomes available, the benefit to each of these groups should probably be considered to be equal. Grain-legume growers, estimated at about 6000 across Australia, are by far the most numerous potential beneficiaries.

- The size of the benefit to potential users is uncertain. A careful cost-benefit analysis is required before the utility of a service can be properly assessed.

- The cost of providing operational forecasting of the magnitude of the early-spring *H. punctigera* influx for both eastern and western Australia would be of the order of $0.6M p.a. Additional costs might be incurred in providing local, crop-specific, interpretions of this information: these could most appropriately be met by local user organisations or state governments.

- An operational forecasting service would require its own staff and facilities. The scientists currently working on heliothis forecasting would have no more than an advisory role. Some may undertake further research or development projects related to heliothis forecasting, but others will probably move on to new topics.

- The spring influx of *H. punctigera* frequently extends across state boundaries. A national approach to forecasting it is required.

- The Australian Plague Locust Commission provides one possible model for the type of organisation required for an operational *H. punctigera* forecasting service. However, despite considerable commonality of mission, infrastructure, and expertise, it would not be straightforward for the APLC to take on this task: there are both administrative and logistical/resource constraints on the Commission assuming additional functions. Surveys could be undertaken on a contract basis, but they could not be given priority over locust work and therefore might have to be abandoned during locust outbreaks.

- Once a forecasting service becomes operational, funding other than that provided by Rural Industry Research and Development Corporations is needed. These bodies can, of course, continue to support research and development projects aimed at improving forecast accuracy, reducing costs, etc.

- Costs cannot be recouped by selling the forecast product to individual users, because the information cannot be kept confidential. SIRATAC provides an unfavourable example in this respect. Participants identified a levy (e.g. on crop yield, or on sales or applications of insecticide), and provision from government (federal and/or state) consolidated funding, as the only practicable means of paying for an operational forecasting service. Forecasts would then be broadcast freely.

6. There was a consensus on the following:-

- The heliothis-forecasting research program should be renewed for another 2 years. Funding from rural industry research and development corporations is appropriate for this, and supported. In the new program, the hitherto separate research efforts in eastern and western Australia should be integrated.

- The objectives of the new program should be a) to continue developing methods for routine forecasting, including the use of remote sensing technology, b) to carry out a full cost/benefit analysis to determine the economic value of forecasts to users, and c) to issue tentative forecasts like those provided in the past, and to evaluate the accuracy of those forecasts.

- Consideration of setting up an operational forecasting service should be deferred until the results of this research programme, and especially of the cost-benefit analysis, are available.

2. Introduction

The two "heliothis" species (the native budworm *Helicoverpa punctigera* and the cotton bollworm *H. armigera*) are together the most important agricultural pests in Australia. More insecticide is applied against heliothis than against any other Australian insect. Both species infest a number of different crops, but economic losses are particularly significant in cotton, various legume crops (especially lupins and field peas), and tomatoes. Losses to heliothis have been estimated as $73 million p.a. in Queensland alone (McGahan *et al.* 1991).

There have been indications for many years that *H. punctigera* is migratory, and that the large adult populations that appear in cropping regions in September each year are immigrants from regions with warmer winters. In the last 3 years, winter surveys and trap networks in inland Australia have located very large populations of this species developing on ephemeral native vegetation following heavy rain. Adults emerging from these source regions fly upwards at dusk and are carried by the wind into the cropping regions, which they reach after 1-3 nights. *H. armigera* has also been found in the inland, but in relatively small numbers; there is other evidence that it migrates in some circumstances, but immigration does not seem to have the key role in bringing infestations to economically significant levels that it does for *H. punctigera.*
The magnitude of the early-spring *H. punctigera* immigration varies significantly from year to year, and this in turn determines, at least to some extent, the potential of this species to cause economic damage if not controlled. The identification of the source regions of these immigrants introduces the possibility that this damage potential, and thus the amount of control effort required, could be forecast. Tentative forecasts have in fact been issued by the scientists carrying out the inland survey and trapping programme. These have so far proved reasonably accurate, and have been received with considerable interest by growers and the pest-control industry.

The current research programs on inland heliothis populations terminate in 1993 and 1995 for the eastern and Western Australian programs respectively. This raises the question of whether any steps should be taken to provide forecasts of *H. punctigera* immigration intensity after that date. The work so far has been funded by a number of rural industry research and development corporations, but an ongoing forecasting service would be an operational rather than a research programme, and not eligible for support from these sources; in addition, an operational service would probably require a relatively secure source of funding to be viable. In order to determine whether the provision of forecasts would have significant utility to potential users, and how the costs might be recouped, a workshop was convened at Narrabri Agricultural Research Station on 7 and 8 December 1992. Representatives from grower organisations, insecticide suppliers, pest-control services, and funding bodies participated, along with state-government, CSIRO, and university scientists with heliothis research experience.

The aims of the workshop were to:-

- bring together researchers and potential users of a forecasting system for heliothis;
- review what research has been done and what this has told us;
- establish whether there is a need for a heliothis forecasting system;
- discuss how forecasts may be used and by whom;
- begin to specify the research and development requirements;
- establish a mechanism for funding the provision of a service and the required research.

This report presents a digest of the discussions that took place during the workshop, and presents the participants' conclusions. Some short talks that were presented to provide background information are reproduced in section 3. The workshop discussions on the questions of the potential utility of forecasts, the most useful form for the forecasts, and the options for funding an operational service, are summarised in sections 4, 5, and 6 respectively. The participants' key conclusions are presented in section 7. Some additional information about the workshop and the participants is provided in the Appendices.

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3. Formal presentations

3.1 Can we forecast early season abundance?

3.1.1 Spring abundance of heliothis - summary of research by *Helicoverpa* Inland Research Group to date

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Summary

For the first time, we now have a general grasp of the ecology of *Helicoverpa* spp. over broad areas of Australia, including the inland. While there is still much we do not understand (such as the source of winter breeding populations in the inland) we know enough to begin forecasting outbreaks. Our initial attempts at forecasting will be described in the following paper.

Introduction

Helicoverpa spp. are the major pests of Australian crops, causing losses which amount to hundreds of millions of dollars (McGahan *et al.* 1990). They are difficult to manage because of their wide host range, high mobility and fecundity and propensity for diapause (Fitt 1989). With such pests, crop or region based studies are of limited value. A wider approach, including many crop and non-crop hosts over a large area, is needed. For these reasons an informal research group was formed in 1987. The *Helicoverpa* Inland Research Group (HIRG) consisted of G. Fitt (CSIRO Division of Entomology), M. Zalucki (University of Queensland), P. Twine (later replaced by D. Murray, both of Queensland Department of Primary Industries), and this author. We set ourselves the task of understanding the general ecology of *Helicoverpa* spp. over wide regions of eastern Australia, concentrating on the possible role of inland areas as sources of potentially damaging populations. The work of the HIRG was funded by 3 Rural R.& D. Corporations and CSIRO (Fig. 1). Aspects of the project have been published in industry journals (Gregg *et al.* 1987, Fitt *et al.* 1990, 1991) and conference proceedings (Gregg *et al.* 1990, Fitt *et al.* 1990, Zalucki *et al.* 1991, Fitt *et al.* 1992), and are currently in press in the scientific literature.The purposes of this workshop include reviewing this work and determining what practical application it may have.

Research methods

We established a network of about 60 pheromone and light trap sites throughout NSW, Qld, Vic, SA and NT. In remote inland areas the traps are serviced by paid collaborators (local residents including police, graziers, oilfield workers etc.). In more populated areas they are serviced by schools, working through the CSIRO school science club, the Double Helix Club. Catches are sent weekly to UNE, where they are sorted and dissected for identification and determination of mated status.

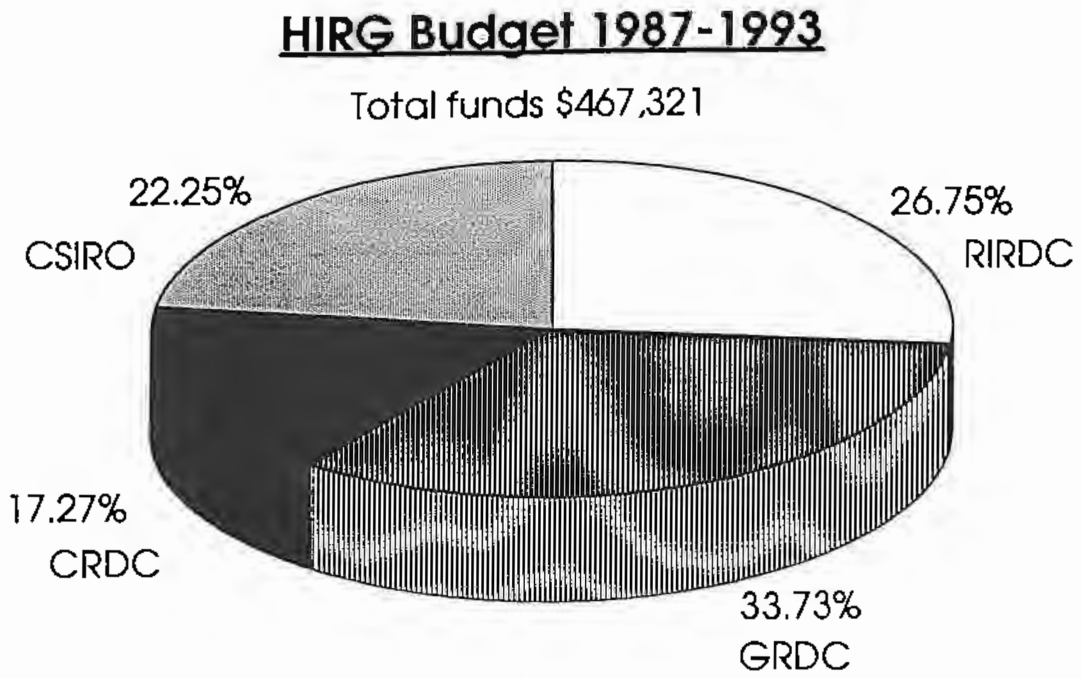

Fig. 1. Sources of funding for the *Helicoverpa* Inland Research Group, 1987-1993. RIRDC = Rural Industries R. & D. Corp. and predecessors), GRDC = Grains R.& D. Corp. (and predecessors), CRDC = Cotton R. & D. Corp., CSIRO = CSIRO core funding. Salaries of the principal investigators and overhead support from their institutions are not included in the total.

The suitability of inland regions for *Helicoverpa* breeding is assessed by rainfall records, reports from collaborators and satellite images from the NOAA AVHRR system. The images are obtained from CSIRO Division of Oceanography and processed by QDPI. Rain in autumn and winter can produce abundant growth of *Helicoverpa* hosts, including plants in the Fabaceae, Malvaceae and Asteraceae. We have identified over 60 host species. In contrast, summer rain mostly produces growth of grasses and perennials which are not *Helicoverpa* hosts, so the inland is not a major source region at this time.

The extent of winter breeding is assessed by strategic surveys. A quantitative sweep netting method is used to estimate larval densities, and larvae recovered are reared to enable species identification. Large populations, which can exceed those overwintering in cropping regions by several orders of magnitude, have been located in all years of the study. The larvae are predominantly *H. punctigera*. In more northerly regions, especially in autumn and early winter, *H. armigera* can account for up to 30% of the larvae. However, in the southern inland during late winter, only about 1% of the larvae are *H. armigera*.

Moths from the overwintering generation emerge in August-September, when temperatures are rising and the vegetation is drying off. The timing of emergence can be estimated by simulation modelling (eg with HEAPS). Mass emigration, usually to the east or south, follows emergence. The spring peak of moth catches, particularly *H. punctigera*, in cropping regions from southern Queensland to the grain legume areas of Victoria and South Australia usually coincides with these events, rather than with local emergence.

Migration is studied by backtracking. When suitable migration systems (usually cold fronts) coincide with sudden increases in trap catches synoptic working charts are obtained from the Bureau of Meteorology, Brisbane. Upper wind data recorded on these charts are used to calculate trajectories of potential migrants and thus define possible source areas. This has shown that in 2-3 nights moths could have travelled from the Great Victoria Desert to the grain legume areas of Victoria, or from western Queensland to the cotton growing regions. That some moths did undertake the latter migration is indicated by the finding of pollen from characteristic inland plants on the probosces of moths trapped at Narrabri, Armidale and on the Darling Downs in early September of 1989 and 1990.

Patterns of winter breeding and spring migration, 1989-1992.

Figure 2 summarises the information we have obtained in these seasons. In both 1989 and 1990, heavy autumn rain fell in western Queensland. Large populations of *H. punctigera*, and a few *H. armigera*, bred in the Channel Country of Queensland, and possibly further west. Extensive early spring migration to the east and south led to major invasions of northern NSW and south-eastern Queensland, especially in 1990.

In 1991, western Queensland and adjacent parts of South Australia, NSW and the Northern Territory had a very dry autumn and winter. No significant breeding of *Helicoverpa* spp. occurred in these areas. However, extensive breeding occurred following good rains in the Great Victoria Desert of western South Australia, and parts of Western Australia. In early September, these moths migrated to the cropping regions of South Australia and Victoria. Some immigration occurred in the northern cropping areas, probably as a result of north-eastern movement on post-frontal winds.

Analysis of the events of winter and spring 1992 is incomplete, but the season was dry in the eastern inland, with the exception of parts of the southern Simpson Desert and regions around Innamincka and Oodnadatta. An unusually early immigration to both southern and northern cropping areas occurred in mid August, probably from this source. However, moth numbers in spring were lower than usual.

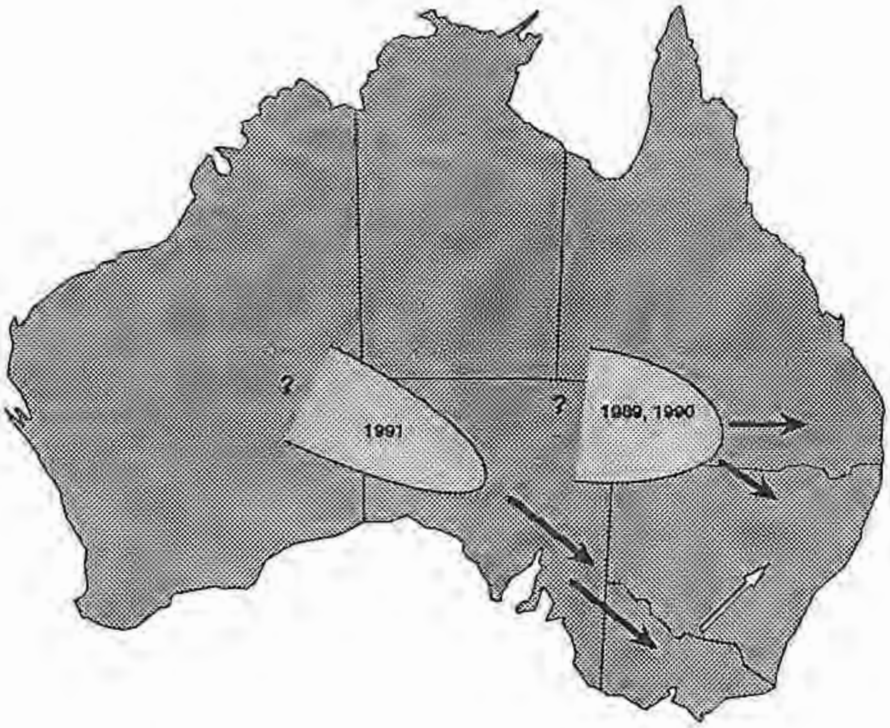

Fig. 2. Winter breeding areas and spring migration routes of *Helicoverpa* spp., 1989-1991.

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3.1.2 Forecasts of spring *Helicoverpa* abundance in eastern Australia

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Introduction

The *Helicoverpa* Inland Research Group (HIRG) was established initially to determine the origin of major flights of *Helicoverpa* moths which appear in many parts of eastern Australia in early spring. These flights of predominantly *H. punctigera* initiate the first generation in the cropping areas which may directly, or in subsequent generations, cause problems on a number of crops. Much of the research of the group has been summarised by P. Gregg at this Workshop.

For the past three years the HIRG has made forecasts for the cotton industry in northern N.S.W. and southern Qld of the likely magnitude of pest problems for the coming season. These forecasts have been highly qualitative to date and based on our understanding of the dynamics and movements of *Helicoverpa* populations in the inland.

The Forecasts

The forecasts have been provided under considerable pressure and interest from various parts of the cotton industry; the first being in the form of a letter to the N.S.W. Consultants Association via one of its members. Since then forecasts have been published in the Australian Cotton Grower magazine. While focussed for the cotton industry, we are aware than many other groups including chemical companies operating in other crop markets have been interested in these forecasts.

1990. The first forecast was made in June 1990. In summary it said:
"...conditions in the inland are again ideal for the production of large populations of moths. If we could predict the weather in October this year we might be able to predict the abundance of *Helicoverpa* in the next cotton season, but of course we can't. All we can say is that given average spring weather the current situation suggests there could be substantial numbers of *Helicoverpa* next season. It all depends on the weather!".

This forecast was followed by large migratory flights of *Helicoverpa* in early September (Fig. 3) which established a significant first generation. Continuing immigrations through October/November combined with the successive emergence of locally produced moths from the first generation resulted in extremely high abundance of eggs and larvae on cotton crops. Heavy pesticide use resulted and stocks of the commonly used chemical endosulfan were exhausted by late December. Special shipments were flown into Australia by Hoechst to cover the shortfall, but at high cost which was borne subsequently by growers.

1991. this year a forecast was made in August and published in September/October edition of the Australian Cotton Grower (12:7 - 10). In summary it said:

"Overall, these observations suggest that *H. punctigera* should not be particularly abundant on cotton this year for two reasons:

♦ there should not be large numbers of immigrant moths this year from the inland
♦ [weather] conditions in the cropping areas may not remain favourable for development of a large first generation".

this forecast carried a caveat in that we had recently discovered a new breeding habitat in far western S.A. (Great Victoria Desert) where extensive populations of *H. punctigera* were confirmed in early September. This area produced large migrations which moved through southern Australia severely damaging crops of field peas, canola and chickpeas in Victoria, southern N.S.W. and South Australia. However, the cotton areas received only small numbers and in all areas but the Macquarie and Bourke, the abundance of *H. punctigera* was markedly lower than the previous year (Fig. 3). The Macquarie Valley, the most southerly cotton growing valley suffered heavy pressure through December, with waves of moths appearing with each southerly change. It is conceivable that these were moths generated in the south as populations of moths emerged from earlier breeding.

1992. Again this year a forecast was published in the Australian Cotton Grower (13:7 - 9). In summary it said:

"the abundance of *H. punctigera* in the spring should be similar to or even less than last year"

"...the major migrations which establish the first generation of *H. punctigera* in cotton cropping areas have arrived in mid-late September. We predict that if these migrations occur this year they will be small and that *H. punctigera* is not likely to be any more abundant than last year in most areas".

To date this forecast has been broadly correct in most areas. *H. punctigera* has been present, but at levels below average. The season was characterised by an unusual peak of *H. punctigera* during August, but subsequent populations were relatively small (Fig. 3). Cool weather which delayed the growth of cotton crops has also favoured higher than normal survival of eggs on seedling cotton leading to several sprays in some areas, but egg densities have been generally low through November/December.

While it is difficult to obtain quantitative measures of the success of these forecasts in the form of numbers of sprays on cotton or overall chemical use, the information we have from trap catches, sampling of spring populations and estimates of early season egg densities on cotton indicate that in broad terms the forecasts have been accurate. Clearly it has not been possible to date to provide sufficiently quantitative forecasts to expect major changes in management strategies.

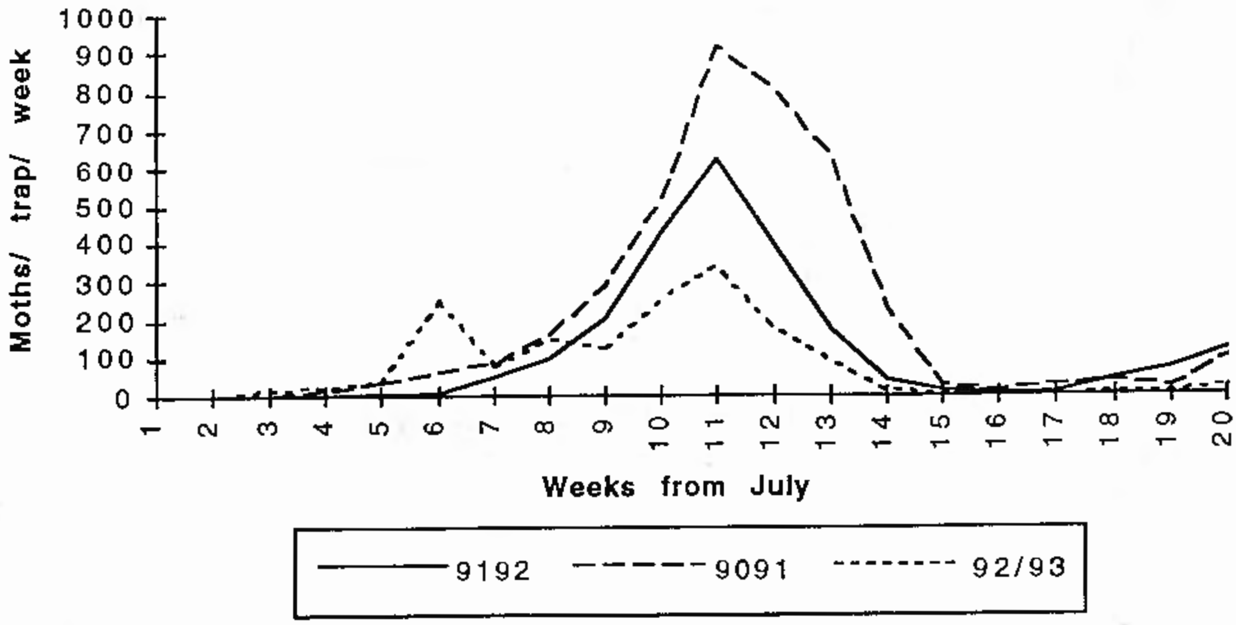

Figure 3 Early season pheromone trap catches of *H. punctigera* in the Namoi Valley over the three years since forecasts have been made.

Nevertheless it is clear that our understanding of *Helicoverpa* ecology has reached a level where forecasts are possible. More comprehensive data input could result in more accurate forecasts.

The Role of Weather

The expanded versions of these forecasts all emphasise the role of the weather in determining likely *Helicoverpa* abundance in any season. This influence has tow components. Firstly rainfall in inland areas during autumn and early winter providing suitable winter breeding habitat and secondly 'local' weather in the various cropping regions which determines the suitability of those environments for survival of the first generation each spring. This latter point reflects the difficulty in making forecasts specifically for the cotton industry since the first local generation (October) established by the inland immigrants is not the one which damages cotton. This damage is caused by subsequent generations during December/January. Our forecasts are more directly applicable to spring grain legume crops (chickpeas, faba beans, field peas) throughout eastern Australia, which are attacked by this first generation.

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3.1.3 Forecasts of abundance in summer based on light trap data

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[1] University of Adelaide; [2] University of Queensland

Light-trap data from Narrabri for the years 1973/74 to 1986/87 have been analysed in an attempt to forecast the summer abundance of heliothis sp. from mid-December to the end of January, when the species - and especially *H. punctigera* - are the main insect pests of cotton in N.S.W. The trap data were expressed either as (a) bimonthly totals, as given by Wilson (1983), starting with totals in Sept+Oct, or as (b) weekly accumulative totals from 1 July for the years 1973/74 to 1977/78 and 1981/82 to 1986/87. Weather data were also expressed as weekly means or as totals of various combinations of months. The data were analysed by:

* simple regression, with the equation :

$$Y = a0 + a1.X1$$

and:

* multiple regression, with:

$$Y = a0 + a1\ X1 + a2.X2$$

where Y = the predicted trap-catch up to the end of some time
X1 = the trap-catch up to some earlier time
X2 = rainfall or some other weather variable.

The significance of each regression will be expressed in terms of r^2 and its probability value. For the bimonthly catches of *H. punctigera*, the simple regression of Nov+Dec on Sept+Oct was significant ($r^2 = 52.7\%$; $p < 0.01$); and the only X2 variable which improved the regression was rain in Sept+Oct. The r^2 value for the multiple regression was 71.9% ($p = 0.0007$); and the coefficient for rain in Sept+Oct was negative. No relation was found between Jan+Feb and Nov+Dec. The bimonthly catches of *H. armigera* were much smaller than those of *H. punctigera*, and no relation was found between the bi-monthly catches of *H. armigera*. The weekly catches of *H. punctigera* show great promise as predictors of abundance. Four main variables were tried as predictors (i.e X1 variables), namely :

(i) the total catch in generation 1, denoted as G1. This total was accumulated up to some week, denoted as G1week, when there was a natural trough in the numbers about mid-November. The average G1week was 20 weeks from 1 July.
(ii) the catch up to weeks 18, 19, 20 or 21 from 1 July; denoted as 18w, 19w, etc.
(iii) and (iv) the number of day-degrees (in 2 forms) from 1 July to the end of G1week. The predicted (y) catches were similarly expressed as :

(i) G1week + weeks 4,5,6 or 7; denoted as G1+4w, G1+5w etc.
(ii) 24w to 29w from 1 July.
(iii) 1000 to 1500 day-degrees from 1 July.

The simple regressions of all the combinations of Ys and X1s were significant at $p < 0.05$ or less, and most of them were improved by 35-40 % by the addition of rain in Sept+Oct to the multiple regression. Again, rain in Sept+Oct was always the only significant X2 variable; and it always had a negative coefficient. The predictors, 19w and 20w, as well as day-degrees at about 20 weeks from 1 July, gave multiple regressions (with rain in Sept-Oct) with r^2 values greater than 90%.($p < 0.0001$) for predicted (Y) values of 25w to 29w.

A comparison of pheromone-trap and light-trap catches of *H. punctigera* at Narrabri suggest that light-traps catch many more moths from December onwards. If weekly counts of eggs of H. punctigera in the field can now be shown to be correlated with weekly light-trap catches of moths, counts of eggs could be reasonably predicted 4-6 weeks in advance.

3.1.4 Other pests in inland areas (armyworms, plague locusts, mirids)

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Apart from *Helicoverpa* spp., army worms (particularly *Mythimna convecta*), cutworms (*Agrotis infusa* and *A. munda*), loopers (*Chrysodeixis argentifera*)m bugs (particularly Rutherglen bug, *Nysius vinitor*, mirids and various plant hoppers) and locusts are among the most significant migrant pests with potential origins in inland Australia. Predicting their occurrence in agricultural or pastoral situations depends on an understanding of their population dynamics. Typical examples follow.

Armyworms

M. convecta is a grass feeding caterpillar pest occurring throughout Australia. The species is opportunist, and may appear in high densities in any grassland area when grass growth is dense and luxuriant, after sufficient rain occurs over a sustained period. Hence, the major constraints to population growth are rainfall and temperature, so breeding during winter may occur in the higher rainfall areas or the arid inland at latitudes north of 33^{0}S. Outbreaks in cereals in late winter or spring mostly appear to occur after population build-up in grasslands to the north or west of the outbreak regions.

An early warning system for outbreaks will depend on both long and short term forecasts. Long term forecasts require a method to forewarn of autumn and winter conditions which are conducive to above-average population growth and the locations in which they occur. A condition which frequently predisposes outbreaks is drought, although only on a large scale. As rainfall is the principal variable regulating population growth, a rainfall index is needed that accounts for quantity, temporal spread and spatial spread, in addition to the relative measure (decile) which is currently used. The major constraint in using rainfall data is the lack of weather stations available within the major grassland areas; a constrain which will continue for the foreseeable future. In contrast, remote sensing technology using course grain images provides an alternative and probably more realistic technique, but requires sophistication in analytical and interpretative software. The desirable outcome from both techniques (rain index and NOAA) is an estimate of the likelihood that pre-spring populations have reached 'outbreak' potential. Short term forecasts require a means of monitoring moth populations in the crop environment. Fermentation traps provide a useful research tool, but pheromone traps, yet to be developed, holds the only commercial prospect.

Rutherglen bug

During winter, *N. vinitor* are predominantly found breeding on *Portula oleracea* (pigweed) in the higher rainfall areas of N.S.W. and Queensland, and in arid areas, on the flowering ephemerals such as *Brachychome* spp., often *B. multifida*, *Myriocephalus stuartii* (poached egg daisy), *Craspedia uniflora* (Billybuttons) and

Erodium spp. (storksbill). These are also typical hosts of *H. punctigera* and hence, population growth of both species will be influenced by similar conditions, i.e. widespread sustained rainfall. During winter, a generation is completed in about 4 - 6 weeks, about the time that these plants remain viable, indicating the importance of migration into new habitats. Major migratory flights occur from September to November, predominantly on prefrontal (northerly or north-westerly) wind systems.

3.2 Making use of forecasts in insect pest management

3.2.1 Forecasting in the Australian Plague Locust Commission

Gordon Hooper

Australian Plague Locust Commission, Department of Primary Industries and Energy.

The role of the Australian Plague Locust Commission is to minimise/prevent damage to the rural industries of a member State resulting from the interstate movement of plague locusts, and to accomplish this goal we need to be able to forecast the distribution and development of locusts.

The basic components for a locust forecasting service are knowledge of
- the distribution and state of favourable vegetation
- The distribution and state of development of locusts
- the distribution of rainfall
- locust biology and ecology,

a robust model of locust development, and dedicated highly competent staff.

The first two components are met by ground survey but, given the limited number of field staff and the size of the area to be surveyed (2 million square kilometres), generalised survey would not necessarily yield sufficient or sufficiently timely information. With a good knowledge of the distribution of rainfall the value of ground survey could be optimised, but traditional meteorological data were inadequate. The APLC developed a remote sensing capability which now permits us to detect, with acceptable accuracy, areas where rain has fallen. This is based on cloud top temperature data derived from a Geostationary Meteorological Satellite.

Hence ground surveys can now be directed to areas where there is a high probability of locusts being present and the survey data thus obtained enhances the accuracy of forecasts.

Our forecasts then are used to
- define areas to be surveyed
- advise State departments of agriculture and rural organisations of further developments via a monthly Locust Bulletin
- define where control may be required and so permit planning for the dispositions of staff, insecticide, aircraft, aviation fuel etc.
- issue warnings of the likelihood and direction of migrations.

To further enhance our forecasting capability we have acquired a geographical information system to integrate a range of data sets, with the ultimate aim of developing a decision support system.

3.2.2 Early warning system for native budworm in Western Australia

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Department of Agriculture
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The native budworm, *Helicoverpa punctigera*, is a major pest throughout Australia and is the primary pest of lupins. Lupin growing for seed production is a relatively new industry that is undergoing a major expansion in Western Australia and is beginning to expand Australia wide. In Western Australia, the area sown each year has grown from 3,000 hectares in 1968 to around 800,000 hectares, with further increases expected.

Major outbreaks of the native budworm in lupin crops have been recorded in Western Australia in 1986, 1989 and 1991. The native budworm distributes itself over large regions during the adult moth stage and during the larval stage damages lupin seed immediately prior to harvest. Over 400,000 hectares were sprayed by aerial and ground contractors alone in 1991, yet significant yield losses were still recorded.

One factor that contributes to the continuing yield losses is the extreme fluctuations in the size of outbreaks each season and the lack of time to prepare for major outbreaks. Sufficient stocks of insecticide are kept in Western Australia to treat only infestations arising during a non-outbreak year when as little as two to five percent of the total crop is treated. During major outbreaks, when around half the total crop is treated and much more requires treatment, extra insecticide must be obtained from interstate, if it is available. Distributors must buy and transport the insecticide to infested regions and insecticide application contractors must have their equipment ready and personal available. It takes only a few days for a large infestation to destroy a lupin crop. The likelihood that an infestation will destroy a particular lupin crop is determined only days before damage begins, however, whether the total extent of damage throughout the lupin growing regions is to be light, moderate or heavy can be estimated several weeks in advance. A reliable forecast will enable agricultural support industries to estimate grower's requirements throughout Western Australia each season. Chemical and equipment could then be deployed to outbreak areas before crop damage begins and growers could budget for and prepare their own on-farm control programs.

Research to develop a means of predicting the size of native budworm outbreaks begun in 1987. It is aimed at discovering the origins of the spring moth flights that bring the native budworm into lupins and the factors that determine the size of the flights. Forty light-traps have been constructed and placed throughout the State. The contents of these traps are collected by volunteers either every day or twice a week and daily on specified occasions throughout the year. The samples are sent to the Geraldton office of The Department of Agriculture where the moths are sorted, identified, counted, and dissected. Field surveys are conducted to locations where major flights have occurred and the continued development of native budworm populations is observed.

This work reveals the distribution and abundance of the native budworm each season. At various times of the year it can be found at locations throughout Western Australia but of considerable interest are populations that develop during winter in areas directly north and north-east of lupin growing regions. These populations can be very large and the production of moths coincides with spring moth flights into lupin crops. Radar studies (Drake and Farrow 1985), have shown that native budworm moths are capable of long distance, high altitude night migrations. Flight paths estimated using data on upper air currents supplied by the Bureau of Meteorology demonstrate that moths produced in pastoral regions of Western Australia during the beginning of spring are capable of migrating on warm tropical winds to lupin growing regions in the south-west of the State and on strong winds ahead of cold fronts to the eastern states of Australia.

Information arising from the research work that may assist in preparing for outbreaks is passed on to the farming community. Each season, predictions of the size and location of native budworm outbreaks are immediately and directly extended to lupin growers via television and radio broadcasts, newspaper articles, Department publications, field days and solicited advice. The first prediction is made in July, almost three months before any major lupin damage can be expected, and updated regularly as further information is collected from the light-traps and field surveys. If a major outbreak is expected, the extension effort is increased. Department staff and farming support industries are alerted so information, expertise, equipment and chemical can be available to growers.

Forecasting outbreaks on limited historical data, which has not been completely analysed, is a high-risk past-time. Continued trapping, surveying and analysis will decrease the chances of embarrassment and increase the chances of glory when indulging in this past-time. The work will also help determine the frequency and importance of interstate migrations.

This research is supported by the Grain Research and Development Corporation and the Grain Research Council of Western Australia.

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3.2.3 The use of forecasts in pest management

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Forecasts form an integral part of many aspect of human society. From the less than convincing tarot cards, astrology etc. to the somewhat more useful forecasts of the weather (thought these may be unconvincing also), we often believe that some indication of future events is better than none.

In insect pest management forecasts are used extensively. Economic thresholds developed for key insect pests are a forecast that the current abundance of a non-damaging stage will result in an abundance of a later stage that causes economic damage (see Fig. 4). These are essentially short term fore casts, based on intensive time consuming monitoring, and form the basis of most spray decisions.

To reduce the costs associated with monitoring of eggs etc. within crops many attempts have been made to develop traps for the mobile adult stage that often lays the eggs, as in lepidoptera, and/or damage the crop directly (say in coleoptera).

Such traps can give early warning of pest densities. For migratory pests, whose abundance can vary greatly among years, among seasons and among locations, forecasts needs be based on more than just traps (see Fig. 5). A knowledge of extent and quality of breeding habitats via remote sensing, ground counts defining the (abundance and) age distribution of breeding populations, and information on weather are needed to forecast potential outbreaks of population size of the pest on a regional basis, as well as the timing of damaging flights (Fig. 5).

How can such information be used in pest management? Obviously reliable knowledge of pest levels months in advance can greatly enhance the ordering and deployment of our most commonly used pest management tools - pesticides. This might ensure not running out when the need is greatest (as has happened on occasions), and reduce the costs of keeping stocks when they are not needed.

Other uses of advance warning include reduced monitoring costs. If pest numbers are predictably low then less time can be spent sampling for these pests, and low counts can be considered reliable.

On the other hand if numbers are predicted to be high, or on the increase, then additional scouts may be required, or more time spent searching so as to increase confidence in decision making.

Of course with the advent of management techniques that more precisely target early non-damaging stages of an insect pests such as *Helicoverpa* then more reliance will be placed on accurate forecasts of pest abundance and timing. For instance it is useless to put out egg parasitoids and for anti-ovipositants to be applied well after the main 'wave' of egg laying has occurred.

Perhaps one of the main uses of forecasts is an intangible benefit: being forewarned decreases the uncertainty surrounding future events, and improves our ability to forward plans and cope with those events.

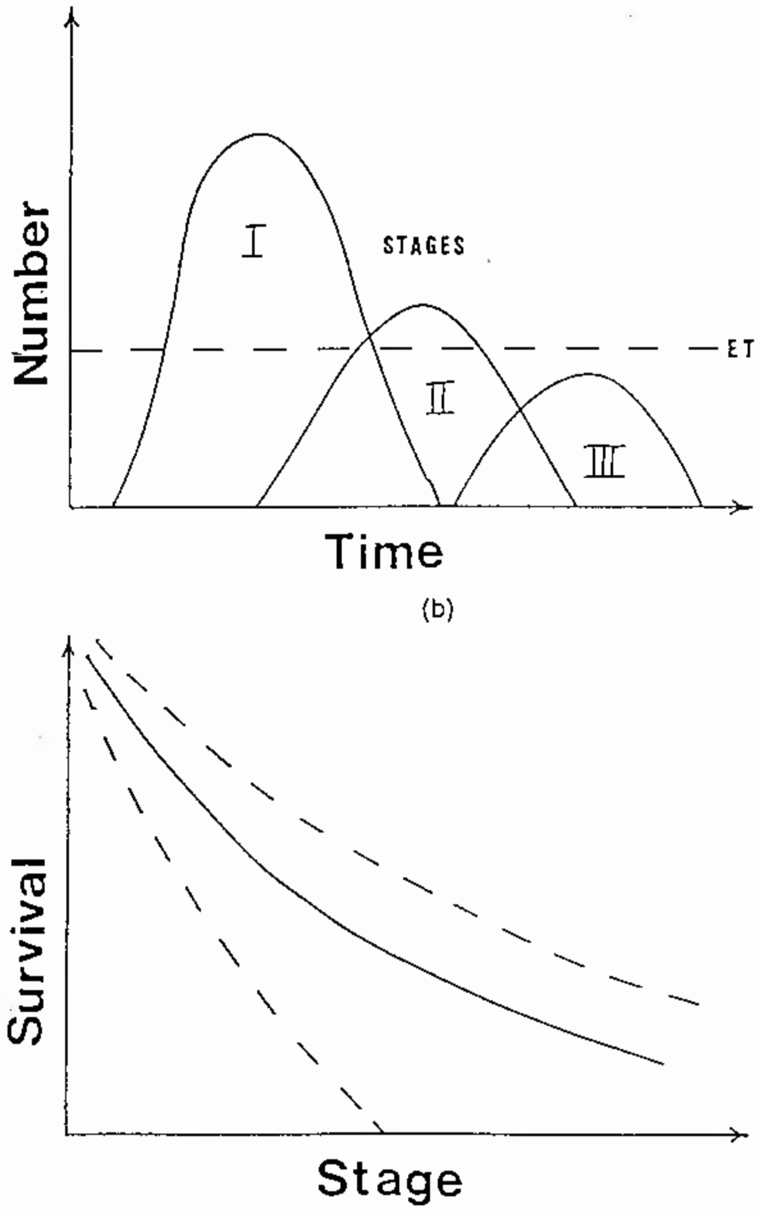

Figure 4 Relationship between pest abundance in a breeding habitat, abundance in a cropping region and in a farmer's field and the major process (arrows) that link these. The data requirements for forecasting these are also indicated.

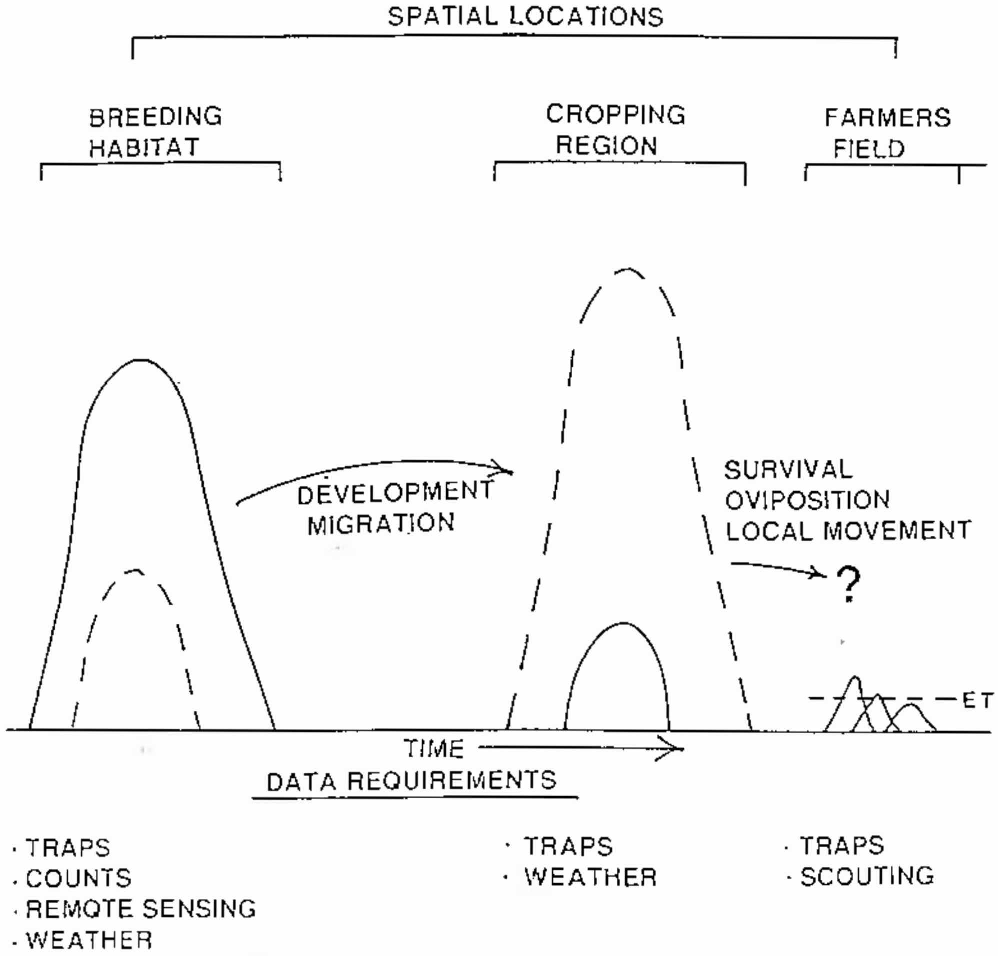

Figure 5 (a) Relationship between changing abundance and stage distribution of an insect over time and some predetermined economic thresholds and (b) the mean survival of an insect with stage. The latter of course can vary over time. If the damaging stage is III for example, it would be best to estimate its future abundance based on counts of stage I and some average survival value (as shown in Fig. 4b).

3.2.4 The Chinese operational pest-forecasting system

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China has operated a national system for forecasting agricultural pests, especially the oriental armyworm *Mythimna* (=*Pseudaletia*) *separata* since 1978 (Lewis 1983; McDonald *et al.* 1984). The system has a hierarchical organisation with a Central Forecasting Station (CFS) in Beijing and a network of regional and local stations at provincial, prefectural, and county levels. In 1984 there were 1600 stations nationwide, employing 8000 people. Eggs, larvae, and adults are monitored at local agricultural stations and by individual cooperating farmers, and observations are collated by the stations and forwarded up the network, with forecasts being received back down the network in return.

Armyworm is considered the most damaging pest of grain crops in China. In central and northern China, where the climate is highly seasonal, it is a migrant, arriving from the south or southwest at the start of the growing season. The number of generations ranges from 5-6 in the humid subtropical south to 2 in northeastern China, where it is nevertheless a severe pest. The migratory habits of the armyworm were established and related to meteorological conditions in a pioneering research programme in the 1960s; in the last decade, further advances have been made with the aid of an entomological radar (Chen *et al.* 1988). Timing of migration into the northeast appears to be highly predictable, flights occurring in the same 10-15-day period each year, with the great majority of the immigrants arriving on only a very small number (2-4) nights (Chen Rui-lu, pers. comm.)

In Jilin province (northeastern China), the provincial station issues forecasts for armyworm, corn borer, meadow moth, sorghum aphid, soybean aphid, soybean moth, rice leafminer, and soil pests as well as plant diseases (mainly of rice). Armyworm forecasts are based mainly on catches at lure traps at 73 sites distributed across the province. Each site has two traps (usually located in different crops) which are checked daily between 10 May and 30 June (for the first generation) and from 15 July to 5 August (for the second). Results are forwarded to the provincial station every 3 days. Forecasts are issued for each of the six prefectures making up the province and are distributed to local stations in bulletins. They are based mainly on trap catches from sites within each region. Other factors taken into account in forecasts are regional differences in susceptibility (based on long-term averages and the area of crops at risk) and, for the first generation forecast, temperature and rainfall data for late May. The latter factor probably predicts the growth stage, and hence the susceptibility, of the hosts. There appears to be no formal validation of forecasts, which it was claimed were "generally correct".

The key armyworm forecast in Jilin province is the first of the season, which has to be issued by 10 June at the latest. Immigration occurs in late May and early June, and in some years cool conditions in the source regions delay development so that not all the moths have arrived by 10 June; in these circumstances the forecast is based mainly on information on infestation levels in the source regions provided by the CFS. The forecasts are used mainly by local-government pest-control departments, apparently mainly to allow them to get in adequate stocks of insecticide. Control itself is decided upon by the individual farmer (with advice available from the local pest-control office) on the basis of infestation levels within the particular crop.

Current developments in armyworm forecasting in Jilin province include computerisation of the records database and (non-operational) analysis (in collaboration with the CFS), and a project with the Jilin Academy of Agricultural Sciences on the use of entomological-radar observations for forecasting. The latter appears to be in part a response to the increasing cost of operating the lure-trap network (which was cut back in size to the present 73 sites in 1983), and to growing concern about the reliability of some of the trap data: both factors probably result from the decentralisation of Chinese agriculture that has occurred over the last decade. The CFS has also expressed interest in using radar operationally, and is observing the Jilin project. Concern about reliability is the only explanation offered for the extreme reluctance of the CFS and regional forecasting organisations to make their observation database available to other researchers (including Chinese).

The Chinese operational pest-forecasting system has been implemented in a social, political, economic, agricultural, and natural environment very different from that in Australia. We do not have the high population density, intensive agriculture, low employment costs, and centralised economic and manpower management that China experienced when its system was set up. Insect migration in Australia is an adaptation to an erratically arid climate rather than a regularly frigid one. On the other hand, migration, over distances of several hundred kilometres between generations, is of key significance in both countries. The early spring immigration may be as important for *Helicoverpa punctigera* forecasting in Australia as it is for *M. separata* in China, and this at least appears to occur within a predictable and quite narrow time interval each year. The only operational pest forecasting system in Australia (that for Australian plague locusts *Chortoicetes terminifera*) differs in many respects from its Chinese counterpart, but is similar in one perhaps significant respect: its forecasts are issued to, and acted upon by, government organisations (in Australia the Plague Locust Commission itself and the State Departments of Agriculture) rather than farmers or commercial organisations.

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4. Current and potential uses for forecasting services

Participants considered the following questions in two separate group discussions:

(i) How do you currently use forecasts?
This question related to forecasts in general, not just heliothis forecasts.

(ii) What do you see as potential uses for forecasts?
This question focussed specifically on heliothis forecasts.

Participants were divided into 4 groups, with each group having representatives from research groups and industry organisations (Table 1).

Table 1. Composition of discussion groups.

Group 1	Group 2	Group 3	Group 4
Peter Bailey	Joanne Daly	Martin Dillon	Alistair Drake
Roger Farrow	Gary Fitt	Neil Forrester	Peter Gregg
Gordon Hooper	Derek Maelzer	Garry McDonald	Dave Murray
Ian Titmarsh	Kevin Walden	Myron Zalucki	Wayne Rochester
Geoff Brown	Stefan Henggeler	Hugh Holland	Wayne Tildon
Phil Tuck	Phil Glover	Richard Bull	Ian Anderson
Geoff Hokin	David Carey	Lindsay O'Brien	Hans Woldring
Phil Firth	David Walker	Ralph Shulze	Mark Harris

Each question was considered separately and each was shown on an overhead transparency while the participants wrote their ideas on butcher's paper. Each group reported back to the workshop.

In response to the first question (how do you currently use forecasts), forecasts in general were seen as useful in budgeting for chemical usage (both for chemical manufacturers and growers) and monitoring costs, and in crop management decisions such as choice of crop and varietal selection. Two groups mentioned using the weather forecast in combination with scouting in the short term to assist with spray decisions. The importance of historical data in predicting trends in chemical usage was noted as being important for chemical manufacturers.

Forecasts are currently issued for plague locusts by the APLC, and for heliothis by Kevin Walden in Western Australia. In both cases they are of value in planning the logistics of control campaigns. Forecasts by the *Helicoverpa* Inland Research Group are more general and have so far been targeted at the cotton industry. Anecdotal evidence suggests that growers are interested in the forecasts and bear them in mind when making decisions, but are not yet sufficiently confident to base major decisions on the forecasts alone.

After reporting back on the first question, participants considered the second question (potential uses for heliothis forecasts). There was a consensus that one of the most valuable uses of a forecasting service would be the ability to predict chemical usage for the coming season, along with the purchase of equipment such as planes and ground rigs.

Forecasting could also be useful at or prior to planting time. The choice of crop might be affected by its susceptibility to heliothis damage, depending on the likelihood of a light or heavy heliothis season. In cotton, the advent of transgenic BT varieties, which are resistant to heliothis but more expensive, may increase demand for a forecasting service. In the event of a forecast for a light year, growers might tend towards conventional varieties thereby saving money and reducing the selection pressure for resistance to BT.

The area of crops planted might also be influenced by heliothis forecasts. If a severe outbreak was forecast, growers might be less inclined to plant marginal areas such as compacted land, or areas for which the water supply was not guaranteed. They would wish to avoid the risks of expensive chemical use on such areas. Of course, other factors (such as the crop price) would have a strong influence on such decisions, but a heliothis forecast would be one more piece of information to aid decision making.

Some groups mentioned the potential for improving the insecticide resistance management strategy for *Helicoverpa armigera*. If forecasts could include the species composition, as well as the level of pressure, then the pyrethroid window might be changed from season to season. This could help restrict resistance while optimising the use of the pyrethroids.

In the short term, forecasts might minimize the number of spray applications. Growers were thought unlikely to spray, or refrain from spraying, solely on the basis of a forecast. However, they might increase the intensity of scouting at critical times if a forecast indicated a likely outbreak. This might be of particular value in those industries where the concepts of heliothis management are not well known, such as grain legumes in south-eastern Australia. Adequate scouting can avoid unnecessary sprays, and timely spraying can reduce the need for re-sprays. In addition, growers and the chemical industry would benefit in terms of public perception of environmental responsibility through being seen to support the rational use of insecticide.

A final benefit of forecasting mentioned by the researchers was the focus it brought to research. Hypotheses must be expressed in precise terms, and are then specifically tested by the success or otherwise of the forecast.

5. Specification of a useful heliothis forecasting service

Participants were asked to consider, in their groups, what characteristics a useful heliothis forecasting service would have, with respect to:
(i) Level of precision (how specific/detailed does the forecast have to be)
(ii) Format (two aspects: what is the best medium for getting the information across and how should the information be presented e.g. graphs, statistics, tables?)
(iii) Timeliness (how soon before the event does the prediction need to be?)
and
(iv) Accuracy (what level of error is acceptable?).

Each group discussed the question separately, writing their ideas on butcher's paper, and then reported back to all participants, after providing a summary of their discussions in a matrix on a whiteboard (Appendix II). At this point, all participants took part in a mediated discussion to arrive at a consensus view of what sort of heliothis forecasting service would be most useful.

It was agreed that there was an inverse relationship between the level of precision and the level of accuracy. The more general a forecast is, the more likely it is to be correct, while detailed forecasts offer more potential for error. Participants stressed that it was important for early season forecasts to be accurate, even if somewhat general, because many decisions were made at the beginning of the season. Early season/long-term forecasts could generalize over large areas but as the season progressed, forecasts would need to be more region-specific. Long-term forecasts could be qualitative, whereas short term forecasts needed to be more quantitative.

Although participants recognised that timeliness requirements would vary according to who required the information and for different crops, it was decided that April each year was a practical and useful starting point for forecasting information. Initially, forecasts should be made on a monthly basis (pre-planting), changing to weekly and becoming more region-specific after planting.

Information about forecasts should be available on a continual basis and accessed using a 0055 or 008 recorded telephone service, along with radio updates. Long-term forecasting information could be distributed via personal faxes or mail-outs. During severe outbreaks, participants favoured using as many media as possible. The group agreed that whilst qualitative statements, such as descriptions of possible scenarios, were suitable for long-term forecasts, quantitative information was required for short-term forecasts. The possibility of providing information regarding factors such as separate data for *H. armigera* and *H. punctigera* was also mentioned.

6. Cost of providing a heliothis forecasting service

Once the specifics of a heliothis forecasting service were established, researchers from the *Heliocoverpa* Inland Research Group met and discussed the resources required to provide such a service. A report was presented to all of the participants the following day by Peter Gregg.

6.1 Current costs of heliothis forecasts

The researchers tabulated the cost currently incurred in research directed towards providing heliothis forecasts:

(i) Industry funds	$K			
HIRG	90			
Kevin Walden	30			
	120	-------->	Salaries	78
			Collaborators	15
			Operating	15
			Travel	12
(ii) Institutional support				
Salaries (PI's)	140			
Travel	30			
Operating	20			
Sub Total	190			
TOTAL COSTS	310			

6.2 Resources required for an improved heliothis forecasting service

Based on the feedback from the workshop on the previous day, the researchers provided a list of what needed to be done to provide a useful heliothis forecasting service and what this would involve (Table 2).

A budget specifically detailing the resources required to provide the improved heliothis forecasting service was presented:

(i) Industry funds		$K
Salaries:		
	1 Forecaster	60
	2 Field Officers	80
	2 Laboratory Assistants	80
	0.5 Administrative Assistant	20

Operating:	Vehicles	60
	Remote sensing	10
	Travel allowance	10
	Other	20
Capital:	(5 yr replacement)	10
TOTAL (Industry funds)		380

(ii) Institutional support

Salaries (PI's)	70
Travel and operating	30
Modelling (CTPM)	70
Cotton CRC (?)	40
TOTAL (Institutional support)	210
TOTAL COSTS	590

Table 2. Requirements outlined by researchers to meet needs for an improved heliothis forecasting service.

Need	Required action
Early forecasts April - September	Inland trap network (60 pheromone, 15 light) Remote sensing (Australia wide) Strategic winter surveys inland
Improved precision with reasonable accuracy and frequent updates	Better data processing - more support staff, full time support staff, better east-west communication
Region-specific forecasts Precise post-immigration forecasts	Local overwintering surveys. Spring generation surveys. Local modelling e.g. HEAPS (partly industry-specific)
Industry-specific forecasts (*H. armigera* resistance)	Require further research. Industry should pay. Not included in budget
Efficient communication of forecasts via different media	Administrative assistance e.g. a half-time secretary

The researchers also made several general comments:

1. Continuity of funding

Once the service moved out of the research phase, it would require funding beyond the 3 year terms of normal rural industry R & D Corporation grants. Such funding would of course be subject to periodic reviews.

2. Continuation of funding for related research

There are still major research questions about the basic ecology of heliothis. These include:

- where do moths come from to originate the autumn/winter breeding in the inland? Are they return migrants from cropping areas, or do they spend summer in the inland? Is there a summer diapause?

- what is the level of pyrethroid resistance in inland *H. armigera*? Is the inland a significant source of susceptible moths which dilute resistance in cropping areas?

- are eastern and western Australian populations linked by migration? Can the west be a significant source of spring moths for the east, and vice versa?

- are there new techniques which might assist forecasting, such as the use of vertical beam radar?

These questions would be appropriately addressed by competitive grant applications. The applications would be framed in the light of the infrastructure provided by the forecasting service, so that there was no duplication. However, this basic research would be the responsibility of individual researchers, not the forecasting service.

A general discussion followed the researchers' presentation. There was concern that the budget presented did not include money for research, and that funding bodies may think there was no need for further research. Some participants maintained that if the service saved just one spray on 11 000 ha of cotton, it would offset the cost. Another suggestion was that a levy of only 2 - 3 cents per litre on the major heliothis insecticides e.g. endosulfan and the pyrethroids would cover the cost.

It was suggested that support from industry depended on a marketable product being offered. Researchers indicated that the level of accuracy currently possible was not quite acceptable for a marketable product but that it could be improved. There was a general consensus that a cost benefit analysis was required, not just costs, and that industry consultation was required for this to be achieved. The service needed to fit high priority needs across a range of crops to appeal to industry. There was some discussion as to whether or not the research was at a stage where a marketable product was possible. Industry groups agreed that they would probably be willing to provide research funding but not operational funding. There was some debate about the benefit from such a service in terms of cost savings from reduced spraying - some felt that spray schedules of growers would not change much with the advent of a forecasting service. Concern was expressed about the actual provision of the service - staff would only be required for 6 months of the year and then would have to be redeployed. It was noted that a national approach to forecasting was necessary, and that it would be difficult to coordinate such a service across many different cropping industries. A study of the impact of heliothis on a national level was required to highlight the relative contribution of each crop to the pest problem.

To initiate discussion, Alistair Drake provided a working hypothesis on how a heliothis forecasting service might be funded, assuming the total cost of the service was about $500K per annum. He assumed that the two main beneficiary groups, chemical/industry suppliers and growers, would share the cost equally ($250K each per year). Assuming there are 10 major suppliers in Australia, this equals $25K per supplier. Dividing the grower group into cotton growers and others, each of the 700 cotton growers in Australia would pay $180 per year. The remaining growers, approximated at just over 6000 in number, would pay about $20 each per year. A discussion then ensued as to whether or not the users of the forecasting service would benefit financially.

Representatives from the chemical suppliers agreed that at this stage, there was insufficient evidence of sufficient economic benefit to warrant such an outlay for the service on the part of the suppliers. It was also noted that the chemical suppliers had already addressed problems of supply through research into chemical formulation, thereby improving storage and availability of chemicals at short notice. It was suggested that other potential user groups may include seed suppliers of transgenic plants, and aerial applicators, who have to make decisions on the purchase of capital equipment, the employment of pilots and locations for deployment.

Gordon Hooper discussed the administration of the Australian Plague Locust Commission (APLC), noting that it took about 20 years for the Commission to become operational. The Commission was financed through Commonwealth (50%) and State (Qld 3%, N.S.W. 32%, Vic. 10%, S.A. 5%, proportions allocated on basis of perceived "risk") Government funding. There were administrative difficulties associated with the APLC performing heliothis monitoring because no such risk allocation had been agreed on for heliothis. However, the Commission could undertake contract work. Dr Hooper provided an approximate costing for field surveys of $2000/week for one field officer with a vehicle. Although staff training for the heliothis work was not a problem, monitoring for heliothis was necessary during the winter months, and this coincided with the only time that APLC staff were able to take annual leave. This implied that extra staff would have to be appointed to APLC.

7. Conclusions

Following extensive discussions, the workshop participants reached a general consensus on the following points:-

- Although the prospects for routine forecasting of early-season heliothis infestations were good, it would be premature to attempt this now without some additional research. This should include further trials with the methods currently in use, some assessment of new and potentially less expensive remote sensing methods, and an economic evaluation of forecasting.

- Forecasts of the magnitude of early-season heliothis infestations were potentially valuable to growers, insecticide suppliers, and pest controllers. All of these users considered the forecasts had some utility for them.

- There are four major user groups for heliothis forecasts: cotton growers, grain-legume growers, insecticide suppliers, and agricultural pest-control services. Until better information becomes available, the benefit to each of these groups should probably be considered to be equal. Grain-legume growers, estimated at about 6000 across Australia, are by far the most numerous potential beneficiaries.

- The size of the benefit to potential users is uncertain. A careful cost-benefit analysis is required before the utility of a service can be properly assessed.

- The cost of providing operational forecasting of the magnitude of the early-spring *H. punctigera* influx for both eastern and western Australia would be of the order of $0.6M p.a. Additional costs might be incurred in providing local, crop-specific, interpretions of this information: these could most appropriately be met by local user organisations or state governments.

- An operational forecasting service would require its own staff and facilities. The scientists currently working on heliothis forecasting would have no more than an advisory role. Some may undertake further research or development projects related to heliothis forecasting, but others will probably move on to new topics.

- The spring influx of *H. punctigera* frequently extends across state boundaries. A national approach to forecasting it is required.

- The Australian Plague Locust Commission provides one possible model for the type of organisation required for an operational *H. punctigera* forecasting service. However, despite considerable commonality of mission, infrastructure, and expertise, it would not be straightforward for the APLC to take on this task: there are both administrative and logistical/resource constraints on the Commission assuming additional functions. Surveys could be undertaken on a contract basis, but they could not be given priority over locust work and therefore might have to be abandoned during locust outbreaks.

- Once a forecasting service becomes operational, it is no longer eligible for funding by rural industry research and development corporations. These bodies can, of course, continue to support research and development projects aimed at improving forecast accuracy, reducing costs, etc.

- Costs cannot be recouped by selling the forecast product to individual users, because the information cannot be kept confidential. SIRATAC provides an unfavourable example in this respect. Participants identified a levy (e.g. on crop yield, or on sales or applications of insecticide), and provision from government (federal and/or state) consolidated funding, as the only practicable means of paying for an operational forecasting service. Forecasts would then be broadcast freely.

There was a consensus on the following:-

- The heliothis-forecasting research programme should be renewed for another 2 years. Funding from rural industry research and development corporations is appropriate for this, and supported. In the new programme, the hitherto separate research efforts in eastern and western Australia should be integrated.

- The objectives of the new programme should be a) to continue developing methods for routine forecasting, including the use of remote sensing technology, b) to carry out a full costs/benefit analysis to determine the economic value of forecasts to users, and c) to issue tentative forecasts like those provided in the past, and to evaluate the accuracy of those forecasts.

- Consideration of setting up an operational forecasting service should be deferred until the results of this research programme, and especially of the cost-benefit analysis, are available.

Appendix I

TIMETABLE

Day 1 December 7

10:30 Morning Session: Presentations

Can we forecast early season abundance?

1. Spring abundance of heliothis - summary of research by heliothis Inland Research Group to date - Peter Gregg

2. Predictions to date - Gary Fitt

3. Forecasts of abundance in summer based on light trap data - Derek Maelzer

4. Other pests in inland areas (armyworms, plague locusts, mirids) - Garry McDonald

Making use of forecasts in insect pest management

1. Forecasts of Australian Plague Locusts and their uses - Gordon Hooper

2. Heliothis forecasts in W.A. - Kevin Walden

3. Potential uses of short-term and long-term forecasts - Myron Zalucki

12:30 - 13:30 Lunch

13:30 Afternoon session - small group participatory discussions focussed around the following questions:

How do you currently use forecasts?
What additional uses might you have for forecasts?
What types of forecasts would you require?

16:30 Close

Day 2 December 8

9:00 Research and operational requirements

Presentation of research and operational requirements, and budgets to meet the expectations of a forecasting service specified on Day 1.

10:00 Morning tea

10:30 Specifics of a forecasting service

Group discussion on specifics of establishing a forecasting service centred around the following questions:
How is it going to be done?
Who does it?
Who would pay?

12:00 Future plans

12:30 Close and lunch

Appendix II

Characteristics of a useful heliothis forecasting service identified through group discussion.

Factor: Group No.	Level of precision	Format	Timeliness	Level of accuracy
1	Supplier: national, by region, by species and when. Retailer: regional, whole season, indication of abundance by species. Grower: indication of abundance on specific days. Indication of potential egg lay, and species (timing and number).	Cotton grower: By radio for medium term forecasts, regional information, broad base /updates By fax for short term forecasts, local information, ensures accurate receipt of information.	Important for chemical supplier, retailer, grower. As early, regular and accurate as possible Budgeting begins May revised until October (for endosulfan).	Reliability is important.
2	Grower: precision important Manufacturer: precision not important	Fax or phone 008, 0055 If major, outbreak conditions on news / newspaper	Monthly then weekly as outbreak occurs. Access at all times	Grower: high level of accuracy Manufacturer: accuracy not important provided bias known
3	Need specific regional forecasts, less specific for major areas - (this would require better monitoring)	Long term forecasts: Journals and newspapers Short term forecasts: Electric media and paper Poll fax Computer database Direct mailing	Long term: Manufacturer: 6 - 9 months in advance (ideal 3 months) Growers (e.g. grain legume): 4 - 5 months in advance (planting) Short term: - cotton: 1 month prior to planting - legumes: 2 - 4 weeks to allow for scouting and purchase of chemicals	Long term forecast: Accuracy not as critical Short term forecast: Need to know what probability - within about 20% of required values
4	Precision required increases from May through to September and then high for rest of season. Region specific for the planning of the planting period.	Newsletter, fax, telephone (0055), radio, newspaper. Quantify: number of sprays needed; Pressure Index for pest density.	Timeliness has a tradeoff for precision. Pre-plant: monthly Post-plant: weekly updates as required.	High accuracy required early in season (80%) reducing to lower accuracy later (60%)

Appendix III

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APPENDIX I. LIST OF PUBLICATIONS

1. Gregg, P.C., Fitt, G.P., Zalucki, M.P. and Murray, D.A.H. Insect migration in an arid continent. II. *Helicoverpa* spp. in eastern Australia. In Drake, V.A. and Gatehouse, A.G. (Eds.) *Insect Migration: physical factors and physiological mechanisms*. Cambridge University Press. in press.

2. Zalucki, M.P., Murray, D.A.H., Gregg, P.C., Twine, P.H. and Jones, C. Ecology of *Helicoverpa armigera* (Hübner) and *H. punctigera* in inland areas of eastern Australia: Larval sampling and host plant relationships during winter/spring. Submitted to *Australian Journal of Zoology*.

3. Fitt, G.P., Gregg, P.C., Zalucki, M.P. and Murray, D.A.H. New records of *Helicoverpa armigera* (Hübner) from South Australia and Western Australia. Accepted by *Journal of the Australian Entomological Society*.

4. Gregg, P.C., Fitt, G.P., Coombs, M. and Henderson, G.S. Migrating moths collected in tower mounted light traps in northern New South Wales, Australia: species composition and seasonal abundance. *Bulletin of Entomological Research*. in press.

5. Coombs, M., Del Socorro, A.P., Fitt, G.P. and Gregg, P.C. Reproductive maturity and mating status of *Helicoverpa armigera*, *H. punctigera* and *Mythimna convecta* moths collected in tower mounted light traps in northern New South Wales, Australia. *Bulletin of Entomological Research*. in press.

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9. Gregg, P.C., Coombs, M., Fitt, G.P. and Henderson, G.S. (1993) Migratory patterns of noctuid moths indicated by tower-mounted light traps. *24th Annual Conference of the Australian Entomological Society, Cairns, July*.

10. Dale, M., Gregg, P.C. and Drake, V.A. (Eds.) (1992) *Report of a workshop on developing a heliothis forecasting service in Australia*. CRC for Tropical Pest Management, Brisbane. 42 pp.

11. Fitt, G.P., Dillon, M.L., Gregg, P.C., Zalucki, M.P. and Murray, D.A.H. (1992) The dynamics of *Heliothis* populations: Can we predict? *Sixth Australian Cotton Conference, Broadbeach, August*. Australian Cotton Growers Research Association, Brisbane. pp. 197-207.

12. Fitt, G.P., Gregg, P.C., Zalucki, M.P. and Murray, D.A.H. (1992) Migration of *Helicoverpa* spp. from semi-arid inland regions to southeastern Australia. *Proceedings of XIX International Congress of Entomology, Beijing, June 28 - July 4.* A151.

13. Fitt, G.P., Gregg, P.C., Zalucki, M.P. and Murray, D.A.H. (1992) Forecasting heliothis levels for the cming season. *Australian Cotton Grower* 13: 7-9.

14. Fitt, G.P., Gregg, P.C., Zalucki, M.P. and Murray, D.A.H. (1991) Forecasting early season dynamics of *Heliothis* species in agricultural areas: the role of climate. *National Conference on Agricultural Meteorology, Melbourne, July.* National Committee on Agrometeorology, Melbourne. pp. 220-222.

15. Gregg, P.C. (1991) Ecology of *Heliothis* spp. in non-cropping areas. In Twine, P.H. and Zalucki, M.P. (Eds.) *A review of Heliothis Research in Australia.* Conference and Workshop Series, No. QC91006, Queensland Department of Primary Industries, Brisbane. pp 63-73.

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20. Gregg, P.C. (1990) *Heliothis* spp. in inland Australia: implications for pest management. *Twenty-first Annual Conference of the Australian Entomological Society, Canberra, July*.

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APPENDIX II. STATEMENT OF CONTRIBUTIONS TO THE PROJECT

Year	Source of Funds			
	RIRDC	Industry[1]	Research Organisations[2]	TOTAL
1990/91	15000	31020	142250	188270
1991/92	15000	26325	142250	183575
1992/93	15000	26325	142250	183575
TOTALs	45000	83670	426750	555420

1 - Cotton Research and Development Corporation
2 - Queensland Department of Primary Industries, University of New England, CSIRO Division of Entomology and University of Queensland.