

Thirty years of Helicoverpa research in inland Australia

PART 1 – THE INSECTS AND THEIR HOSTS

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AROUND the world, semi-arid regions with unpredictable rainfall are outbreak areas for certain insect pests. The locusts and armyworms of Africa are classic examples, as are our own Australian Plague Locusts. These insects are highly polyphagous (they can utilise many plant species) and highly migratory. They have short life cycles and lay many eggs, meaning they can reproduce very quickly. Ecologists call this set of characteristics the *r*-strategy, and it works by enabling insects to colonise areas that have recently become favourable – where their population growth is largely free of constraints from natural enemies.

Many agricultural pests are *r*-strategists, and in the 1980s a group of entomologists realised that *Helicoverpa* (then the number one enemy of conventional cotton) fitted the model. The *Helicoverpa* Inland Research Group (HIRG) was formed by researchers from the University of New England, CSIRO, Queensland DPI and the University of Queensland, and for seven years we studied the distribution and abundance of *Helicoverpa* in a broad region of inland Australia, with funding from CRDC, GRDC and RIRDC.

When that work ended, a project funded by the Australian Research Council involving researchers from UNE and the Australian Defence Force Academy in Canberra investigated the potential of radar for monitoring insect migration from the inland. Then in 2000, CRDC funded a project to test our capacity for forecasting migration.

From 2001 to 2008 there was no work in the inland. Two important things happened during this break. One was the Millennium Drought – the worst recorded drought in southeast

Australia – which drastically reduced production. The other was the introduction of Bollgard II GM cotton crop varieties, which basically removed *Helicoverpa* from the pest management equation – so long as they remained susceptible to Bt toxins.

In 2009 another CRDC-funded project investigated whether alleles (segments of DNA that code for protein) for Bt resistance existed in inland *H. punctigera* populations, far from the summer cropping region.

They do, but at much lower frequencies than in the summer crop region.

This made *Helicoverpa* migration from the inland an opportunity rather than a threat, because it might bring in susceptible insects to genetically dilute Bt resistance.

But there was evidence from other research – notably from a CSIRO pheromone trap network in the lower Namoi – that we were seeing less immigration from the inland. So we examined the ecology of *Helicoverpa* in the inland.

In all, we have made 79 field trips to the inland. While the researchers and the objectives of the projects have varied, certain techniques (pheromone trapping, sweep netting for larvae, and host plant assessments) have remained constant, and this has allowed us to build up a picture of the long-term ecology of *Helicoverpa* which is almost unique in world entomology.

In this article we will focus on the larval sampling, and what we have learned about the native host plants.

Host plants

We made a total of 2053 sweep net samples on 233 hosts (mostly natives) from 32 plant families. For *H. punctigera* we

FIGURE 1: Densities of *H. punctigera* larvae on inland hosts, 1987–2017

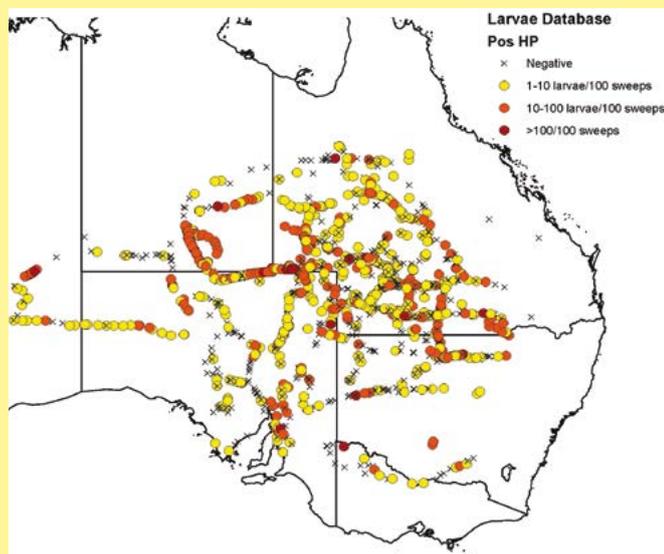
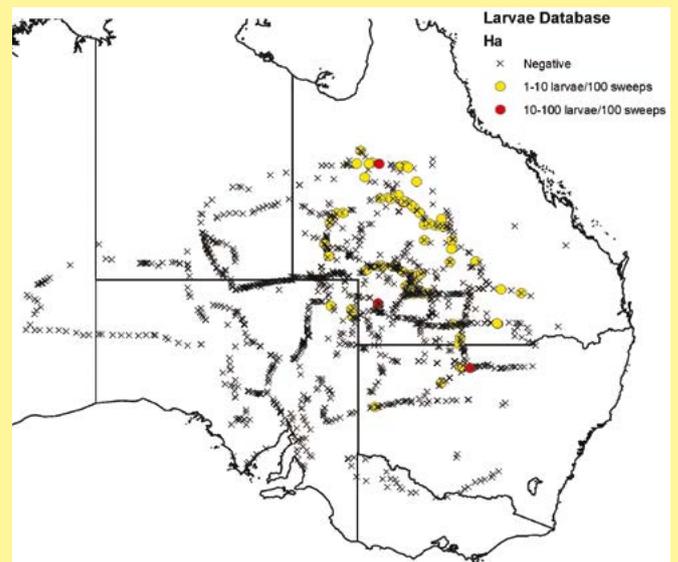


FIGURE 2: Densities of *H. armigera* larvae on inland hosts, 1987–2017



recorded larvae on 120 host plants, of which 107 were new host records. When added to the list of previously known species, the host range of *H. punctigera* includes 232 species, from 40 families.

This makes it a good candidate for the most polyphagous insect in the world.

Larvae of *H. punctigera* were present on about 50 per cent of the samples, throughout the inland (Figure 1). By contrast, *H. armigera* larvae were found on only about 4 per cent of sample sites, from 38 plant species, mostly in the northeast inland (Figure 2), and in generally lower numbers.

We assessed the suitability of host plants based on the relative incidence of larvae (percentage of sites infested) and the relative abundance (average numbers of larvae per 100 sweeps). The best hosts were annual daisies such as *Rhodanthe floribunda* (Photo 1) and *Polycalymma stuartii* (Photo 2), and annual legumes such as *Cullen cinereum* (Photo 3) and *Cullen pallidum*.

On these hosts we sometimes found more than 100 larvae per 100 sweeps, which is many more than we saw on crops such as chickpeas, faba beans, canola and lucerne around the margins of our inland study area. Given that there are millions of hectares of these native daisies in a good season, it is likely that in many years there are far more *H. punctigera* in the inland than in the cropping areas.

Rainfall is the key to the abundance of all these hosts. The most important daisy hosts have seed dormancy mechanisms which prevent them from germinating in spring or summer. Rain at these times mostly produces grasses and perennial shrubs, which are not hosts for *H. punctigera*. It is rain from April through to August which germinates the daisy hosts.

But in inland areas south of about the Queensland border, frosts usually curtail the development of larvae in mid-winter. The areas that produce the most larvae in mid-winter are therefore daisy habitats in the Channel Country of western Queensland and the Simpson Desert.

In contrast, the legume hosts can germinate in response to rain at any time. One species, annual verbine (*Cullen cinereum*) can dominate the floodplains of western Queensland – the Cooper, Diamantina and Eyre Creek/Georgina systems. These systems have been described as the world's largest natural irrigation area, and examination of Photo 3 will show you why.

The rain that feeds these systems falls far to the north and east, usually in summer. The land is flat, so water takes months to move down the floodplains, which are dissected by thousands of channels that spread the water. It is often late autumn or winter before the water is off the floodplains, and the host plants can grow.



Photo 1: An expanse of the large white sunray, *Rhodanthe floribunda* (inset), on the Darling floodplain near Wilcannia, August 2016. *R. floribunda* is a good host for *H. punctigera*.

Migration to the cropping areas

The daisy hosts senesce rapidly in early spring, leaving an environment which is unfavourable for further breeding. Moths emerging at this time migrate to the south and east, flying at night, at altitudes of up to 1000 metres where wind speeds can easily reach 60–100 km per hour. We believe the moths do not control their direction of flight but on nights when the temperature is high enough for nocturnal flight, the winds will generally be from the north or north-west, and they carry the moths towards the cropping regions in the east.

Floodplain hosts also usually senesce in spring, and are another source of emigrating moths. We believe though that a few moths remain behind, where they may survive the summer on patches of legumes which are germinated by local rain.

Cullen pallidum (Bullamon lucerne) may be a key host in this respect, because unlike most native legumes it grows in sandy country where moisture from small falls of rain is readily available to plants.

The fate of emigrating moths depends entirely on the direction and strength of the wind. Their flight speed is usually much less than the wind speed, so they have very limited control over where they end up. Wayne Rochester from the University of Queensland modelled migration in relation to the wind, and Alistair Drake and colleagues from the Australian Defence Force Academy have used radar to track their movement.



Photo 2: *H. punctigera* larvae on the daisies *Polycalymma stuartii* (poached egg daisy) and *Senecio gregorii* (fleshy groundsel) in the Simpson Desert, August 2016.

These studies suggest that while it is occasionally possible for moths to move from inland breeding areas to cropping regions in one flight, it is more likely that they will reach areas such as the mulga lands of western Queensland, or the Darling floodplain, or western Riverina. If there has been good winter and spring rain in these areas, native hosts will be abundant and larvae can survive when the weather has warmed.

Such 'bridging' areas may be the source of moths which infest cropping areas in mid to late spring.

Return migration and the Pied Piper?

One of the unsolved mysteries of the *H. punctigera* story is whether the descendants of immigrant moths ever return to the inland. While there are winds that blow from the southeast towards the inland in summer and autumn, they are generally much weaker than those which bring moths. Perhaps the discovery by Sharon Downes of CSIRO that resistant alleles for Bt toxins exist in inland populations (albeit at lower frequencies than in summer crop areas) is evidence of return migration, but there are other explanations.

Geneticists pose an interesting conundrum about return migration, known as the "Pied Piper hypothesis", after the legend from Hamelin.

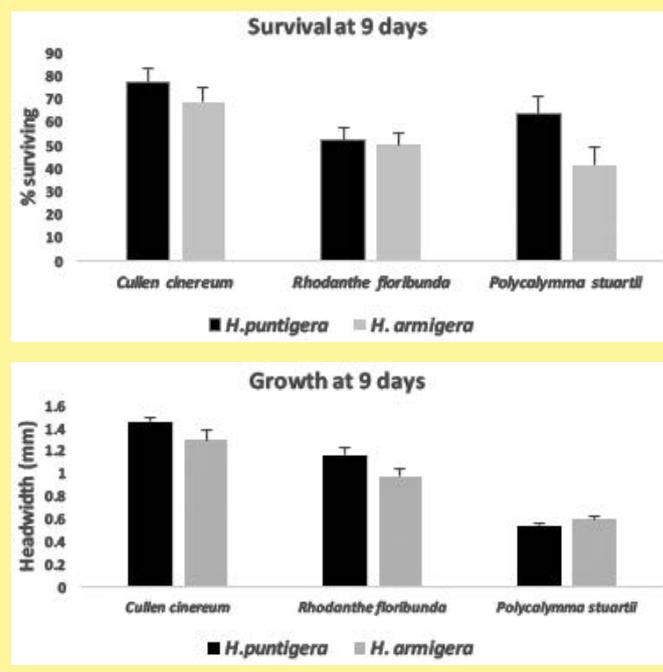
The argument goes like this – Migration, like most characteristics, is strongly influenced by genes. If individuals that have genes that favour migration leave, and they or their descendants do not return, the genes for migration will eventually die out in the source population and it will become sedentary. In an environment as uncertain as inland Australia, that would be fatal. So the continued existence of *H. punctigera* suggests that return migration must occur.

Some ecologists question the Pied Piper hypothesis though. In any case, the existence or not of return migration is perhaps the biggest question we cannot yet answer.

Why so few *H. armigera*?

Comparison of Figures 1 and 2 suggests that the outback is a fairly hostile environment for *H. armigera*. It becomes markedly less common going southwest from Queensland, and in central Australia it is almost non-existent. To determine whether this

FIGURE 3: Comparisons of survival and growth rate of *H. punctigera* and *H. armigera* larvae on three key inland hosts



is because it does not handle the native hosts, we grew three plants, *Cullen cinereum*, *Rhodanthe floribunda* and *Polycalymma stuartii* in the lab and compared the growth and survival of the two *Helicoverpa* species (Figure 3).

There were clear differences between the host plants, but only minor differences between the two *Helicoverpa* species (with the exception of survival on *P. stuartii*). While these are only three of up to 120 possible hosts in the inland, they are three of the most widespread and abundant and it is likely that any insect that could handle them as well as *H. armigera* can, should do well in the inland. We need to look elsewhere for a full explanation of the rarity of *H. armigera* there.

Perhaps the migratory strategies of the two species are different. We used to consider that *H. punctigera* was an obligatory migrant that moved every generation, while *H. armigera* was a facultative migrant that moved only when the environment deteriorated. Observations following the wet springs of 2010 and 2011 suggest it is not quite that clear-cut.

At least some *H. punctigera* remain behind if the host plants are still there. But there may still be a difference – while both species are capable of long distance migration, perhaps *H. punctigera* does it more often and that may make the difference in adaptation to such a patchy and unpredictable environment.

Implications for management

A clear implication of the capacity for polyphagy and migration that *Helicoverpa* spp. exhibit is that, very often, farmers are not responsible for their own pest problems. Moths can arrive, with little warning, from outside their farms or even outside their districts, and past pesticide use is largely irrelevant.

This is in contrast to less mobile pests like aphids, mites and whiteflies. Poorly chosen pesticide application can flare these pests, so ecologists call them secondary pests – meaning secondary in origin, not necessarily in importance!

So what can we do with migratory, *r*-selected, primary pests such as *Helicoverpa* spp.?



Photo 3: The floodplain of Eyre Creek, near Bedourie, Queensland in May 2009. The many channels serve as a natural irrigation system, growing extensive areas of annual veld (Cullen cinereum, inset), a good host for *H. punctigera*.

One option is to be ready with selective pesticides, which can be applied quickly when immigration occurs. This requires good forecasting and monitoring techniques. While these may have become less important in the transgenic era for cotton, in other crops such as grain legumes and canola, they remain crucial.

An alternative is to have built-in protection in the crop, ready for any immigration. This of course is what Bollgard II and III varieties have provided for cotton. It opens the way to fewer and more selective pesticide applications for other pests, too.

This is why entomologists see Bt cotton as a platform for IPM, not a magic bullet. But this strategy only works as long as *Helicoverpa* spp. remain susceptible to Bt toxins.

Resistance management strategies are critical, and in this respect our research suggests that they are particularly critical for *H. armigera* because it does not have the large natural refuges in inland Australia that *H. punctigera* does.

Unlike *H. armigera*, *H. punctigera* did not develop sustained resistance to insecticides during the era of conventional cotton, and we believe this was largely due to regular immigration of unselected insects from the inland.

It was therefore a shock to find that, during and after the Millenium Drought, the frequency of resistance alleles for Cry2Ab seemed to be increasing in *H. punctigera*. At the same time, research by Geoff Baker and Colin Tann of CSIRO suggested that we were seeing less spring immigration to cotton areas than before the drought.

In the next article we will discuss the impacts of the Millenium Drought on *Helicoverpa* ecology in the inland, and their implications for pest management.

Acknowledgments: I have written this article as a sole author because there are simply too many people to include them all as authors. Among the many who have contributed to this work are Alice Del Socorro, Kris Le Mottee, Holly Ainslie, Chris Jones and Rob Duthie (UNE), Gary Fitt, Colin Tann, Cheryl Mares and Tracey Parker (CSIRO), Meron Zalucki and Wayne Rochester (UQ), Peter Twine and Dave Murray (QDPI), Alistair Drake (ADFA) and Haikou Wang and David Hunter (APLC). We have also had invaluable help from many residents of the outback, who ran pheromone and light traps and assisted in many other ways. Funding has come, at various times, from CRDC and the Cotton CRC, GRDC, RIRDC and ARC. ■



Tracey Parker and Sharon Thomas (CSIRO) sorting sweep net catches from *Cullen cinereum* on the Eyre Creek floodplain near Birdsville, Queensland, May 2009. Note the area of host plants in the left middle distance, which has been extensively eaten out by *H. punctigera* larvae.



Peter Gregg with students and teachers from Birdsville State School. Several outback schools operated pheromone traps for the project, and in return we conducted insect collecting sessions with the children.



Gary Fitt and Matt Cahill (CSIRO) installing a pheromone trap and data logger on the edge of the Cooper floodplain during a dry winter (July 1987).



Rob Duthie (UNE) sampling sweep netting for *Helicoverpa* larvae on daisies (*Lawrencella davenportii*) in the Great Victoria Desert, South Australia, September 1991.