LOCUSTS

Locusts in Queensland

PEST STATUS REVIEW SERIES – LAND PROTECTION

by
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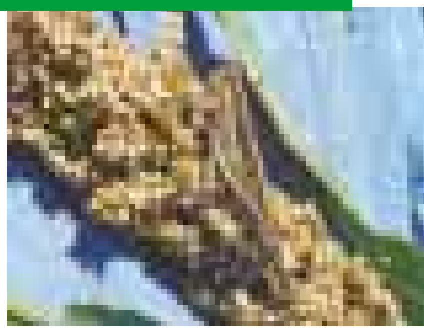

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Contents

1.0 Summary

Only three of the 712 species of grasshoppers and locusts in Australia are considered serious economic pests to Queensland. They are the spur-throated locust (*Austracris guttulosa*), migratory locust (*Locusta migratoria*) and Australian plague locust (*Chortoicetes terminifera*). These insects evoke considerable media and community interest due to the visible nature of the swarms and biblical tales of damage. The formation of dense aggregations (bands and/or swarms) makes locusts formidable eating machines that devastate crops. Their ability to migrate over large distances means that virtually all Queensland's agricultural areas are at some risk from locusts.

Locust outbreaks and plagues develop as a result of favourable seasonal—predominantly rainfall—conditions. If left unchecked, and given favourable weather conditions, locusts are capable of a sevenfold to tenfold population increase with each generation. Locust plagues are natural phenomena. Such outbreaks have become a common occurrence in Queensland over the last thirty years. Changes to climate and/or crops planted can give rise to an increase in locust species at any time. Although there have only been four major plagues in the past 50 years, many minor plagues and localised outbreaks have occurred in Queensland during that time.

Control is possible using a number of methods; although they have not proved equally successful with all species, with spur-throated locusts proving hardest to control. Management of locusts focuses on preventative treatment, targeting hoppers of each generation. Control of the first and second generations is essential in preventing plagues. Advances in technology, monitoring and increased action in early outbreak stages have allowed maximisation of avoidance of plagues in Queensland. An evaluation of strategic spraying undertaken to control the 1998–99 plague in central Queensland showed at least $18 in benefits for each dollar spent.

Locusts are declared under the *Rural Lands Protection Act 1985* and will remain declared as Class 2 pests under the *Land Protection (Pest and Stock Route Management) Act 2002*. Under this legislation landowners have an obligation to keep their lands free of locusts, but monitoring and, potentially, control need to be conducted over large areas because of the extremely mobile nature of locusts. Therefore, a spirit of partnership and cooperation between landholders and government agencies is essential for any meaningful control activities on these insects. Many of the costs of control have been borne by government; it is likely that the use of these funds and the associated total costs will change as locust response moves to earlier detection and preventative actions. In the future, greater understanding of locusts and their relationship to land use, combined with new control options such as *Metarhizium*, should improve management and reduce the impact of locusts on Queensland.

2.0 Taxonomy

Locusts are insects that belong to the order Orthoptera. This order also includes other insects which both jump and sing—grasshoppers, katydids and crickets (Rentz 1996). Locusts are identical in appearance to grasshoppers; they differ in that they can exist in two different behavioural states (i.e. solitary and gregarious). When populations are low, locusts behave as individuals, much like grasshoppers, but when the population density is high, locusts form highly mobile, gregariously behaving bands of nymphs or swarms of adults.

Locusts are in the superfamily Acridoidea, in the large family Acrididae, which has 712 species in 225 genera in Australia, most of which (93%) are endemic to this continent (Rentz 1996). Worldwide, this superfamily has 8000 species in 1500 genera (CSIRO 1991). The economically important species in Queensland are drawn from two subfamilies—the Australian plague locusts (*Chortoicetes terminifera*), migratory locusts (*Locusta migratoria migratorioides*), and the yellow-winged locust (*Gastrimargus musicus*) are members of the subfamily Acridinae; while spur-throated locusts (*Austracris guttulosa* synonym *Nomadacris guttulosa*) and wingless grasshoppers (*Phaulacridium vittatum*) come from a subfamily called Catantopinae, which has over 600 species.

Although extensive, the taxonomy of locusts and grasshoppers in Australia is not complete. A number of unclassified species have been known to cause localised environmental, if not economic, impacts. This is best illustrated by the effect of *Adreppus* 6, a species that was unclassified when it first caused an impact in Queensland, but is now named *Adreppus tuberculatus*, of the subfamily Catantopinae. From 1992–94 in the mulga belt near Quilpie, *Adreppus* 6 ravaged over two million hectares of native species, mostly mulga and gidgee (Nason 1994). This species of non-migratory, night-feeding grasshopper had previously only been identified from the coast; it has not caused problems since the early 1990s.

3.0 History

3.1 Outbreaks across Australia

Locust plagues can occur more or less anywhere in mainland Australia. Of the major locust species, the Australian plague locust has traditionally had the greatest impact in this country, with outbreaks having occurred since early settlement in south-eastern Australia. Problems with this locust are particularly frequent in inland areas of New South Wales and South Australia due to the proximity of these states to the usual source area for breeding—the Queensland Channel Country. In some years swarms of the Australian plague locust also reach cropping areas of Victoria and Queensland. The Great Dividing Range acts as a natural barrier to migrating locusts; however, from 1930–50, Australian plague locusts commonly invaded subcoastal areas of New South Wales, but preventive control by the APLC has made such invasions rare.

An unidentified species, believed to be the Australian plague locust, was first reported invading Adelaide in 1844 (Key, in Farrow & Baker 1989). Further outbreaks recorded in New South Wales and South Australia throughout the 1800s were a mixture of Australian plague locusts and the small plague grasshopper, *Austoicetes cruciata*. There have been thirteen plagues and six major outbreaks of the Australian plague locust in the eastern half of Australia since 1933. Although infrequent, outbreaks of locusts do occur in Western Australia.

The 2000 outbreak was unique in that it was the first time in living memory that a plague had occurred on both sides of the continent in the same year (APLC 2001a). Cyclone Steve, a late season cyclone that almost circumnavigated the country, brought the requisite rain across the whole country at the key time. This plague received widespread media coverage, with titles such as 'Day of the Locust' (Safe 2000) and 'Drought, flood—then locusts' (Konkes 2000). Over one million hectares were sprayed across the southern part of Australia, predominantly in South Australia and Western Australia. Queensland was not affected by this plague.

3.2 Outbreaks in Queensland

The first reported Queensland locust plague of importance was in 1934–35 (Elder, Sabine & Wicks 1979). Since then, severe locust outbreaks composed of spur-throated and migratory locusts (Elder, Sabine & Wicks 1979; Scanlan et al. 2000) have occurred in the 1970s and 1990s.

These outbreaks began in 1970, reaching a peak in 1974–75. The migratory locust outbreak area covered more than four million hectares by 1975, resulting in 73 000 hectares being sprayed in that year alone (Elder, Sabine & Wicks 1979). More than 230 000 hectares were treated for spur-throated locusts between 1973 and 1975 (Hunter & Elder 1999).

In the 1990s, outbreaks occurred between 1995 and 1999 (Scanlan et al. 2001). In contrast to the 1970s outbreaks, preventative treatment of 7000 to 12 000 hectares annually between 1996 and 1998 maintained control over migratory locust populations (Hunter, Strong & Spurgin 1998). (See the case study in section 6.) In the 1995 season, unsprayed inland populations of spur-throated locusts also formed large populations that invaded crops to the east in 1996, requiring treatment of 270 000 hectares by landholders. Preventative control of 23 000 hectares in 1996 resulted in only 3000 hectares needing treatment by landholders the next year (Hunter & Elder 1999).

Locust numbers built up again after good rains in late 1998, and the popular media claimed that the worst plague in 25 years was about to occur (Williams 1999). This outbreak was centred on the Clermont, Dysart, Emerald, Rolleston and Moura areas, and was met with significant on-ground misting by landholders and aerial spraying by the Department of Natural Resources. Over 70 000 hectares were treated before Christmas 1998, and about 65 000 hectares were subsequently sprayed in January–February, mainly in the Belyando, Peak Downs and Broadsound shires (Flynn 1999). The next generation was found to have fallen dramatically, and less than 1500 hectares were treated in the Belyando Shire, despite favourable conditions. The cost to the government of the program was $1.4 million over 4 months, while savings included protecting the potential $42 million sorghum crop in the Central Highlands and other winter crops (Anon 1999a).

4.0 Current and predicted distribution

Spur-throated, migratory and Australian plague locusts are all species native to Australia. The Australian plague locust is, however, the only one of the species *restricted* to Australia. Spur-throated locusts are also found in Indonesia, the Philippines, Papua New Guinea and offshore islands (APLC 1999b), while various subspecies of the migratory locust also occur throughout the warmers regions of Africa, Europe and Asia (Elder, Sabine & Wicks 1979). Major locust plagues occur across Africa, Europe and Asia, but the locusts responsible for these plagues—the Desert locust (*Schistocerca gregaria*), Moroccan locust (*Dociostaurus maroccanus*) and Senegalese locust (*Oedaleus senegalensis*)—are not found in Australia (FAO 1998).

4.1 Distribution of plague species

4.1.1 Australian plague locust (*Chortoicetes terminifera*)

The Australian plague locust can infest much of eastern Australia west of the Dividing Range; it does not breed on the coastal fringe and generally is not found north of 21°S. The species also occurs in Western Australia and is occasionally of major economic importance in the south-western cropping area (see figure 1). This species inhabits western Queensland, occasionally causing crop losses in Roma and the southern border areas (Elder, Sabine & Wicks 1979). Outbreaks are common in the Channel Country, especially in clay plains and stony downs that have long-lasting grasses like Mitchell grass (*Astrebla* spp.). In Mitchell grass areas, rain that allows adults to mature and lay, and eggs to develop, provides green vegetation that lasts until the hatching nymphs reach the adult stage (Hunter & Melville 1994). The migration of swarms is generally to the south and south-west, affecting New South Wales and South Australia (Symmons & Wright 1981). In 1990, however, a large swarm moved from the Darling Downs to the Bundaberg–Isis region, where it descended on cane fields, but did not cause significant damage (Jones 1991).

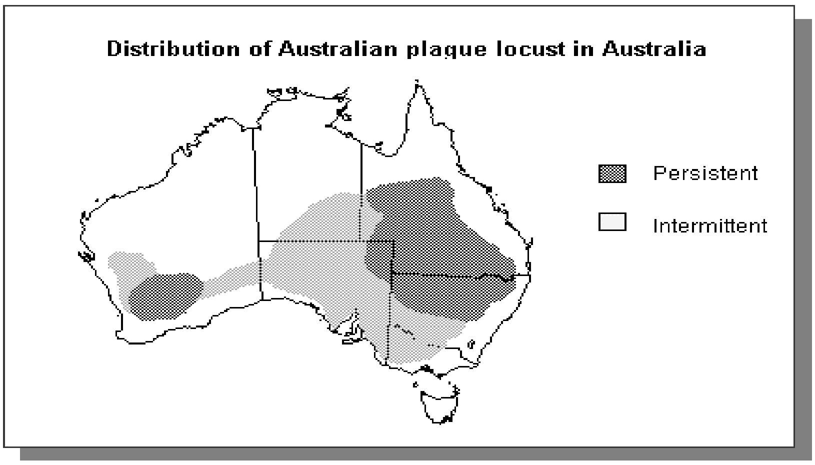

Figure 1: Distribution of Australian plague locusts in Australia (Source: APLC 2000)

4.1.2 Spur-throated locusts (*Austracris guttulosa*)

This species occurs naturally in western Queensland and the Northern Territory, in the tropical grasslands dominated by a monsoonal climate (see figure 2). These grasslands are characterised by a short, intense wet season and a long, severe dry season. Carried by cold fronts, this species migrates east, invading coastal districts. Spur-throated locusts can migrate south to New South Wales; they caused widespread damage there during the 1973–75 plague (Casimir & Edge 1979). A major outbreak of this species also occurred in the intensively irrigated Ord River Project in 1967–68, with significant impacts on the area's second most important crop, sorghum (Bullen 1968). In winter, swarms of immature adults may exist west of the Drummond Range in Central Queensland (White 1997). When dense swarms flew during the 1995–6 plague, they were described as resembling a dark smoke haze against the sky. The Central Highlands and Moura–Theodore–Bauhinia Downs areas have been substantially affected by recent plagues.

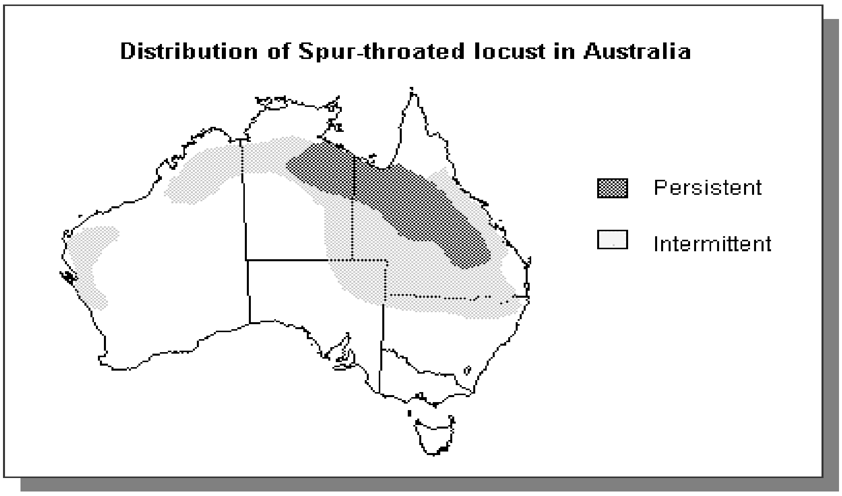

Figure 2: Distribution of spur-throated locust in Australia (Source: APLC 2000)

4.1.3 Migratory locusts (*Locusta migratoria*)

Migratory locusts are mainly located in Central Queensland, but occasionally populations extend south as far as northern New South Wales (see figure 3). The extended rainy season of the eastern coast provides permanent habitats. Migratory locusts in Queensland are historically coastal or subcoastal species, occurring east of the Drummond Range in Central Queensland. They live in natural grasslands on swamp margins; cane fields can also support large populations.

They are also present in the Central Highlands, restricted to black earth grasslands and crops on cracking clays. Plagues of migratory locusts first occurred in 1973–5 (Farrow 1979) and have reappeared frequently in the Central Highlands during the 1990s (APLC 1999b).

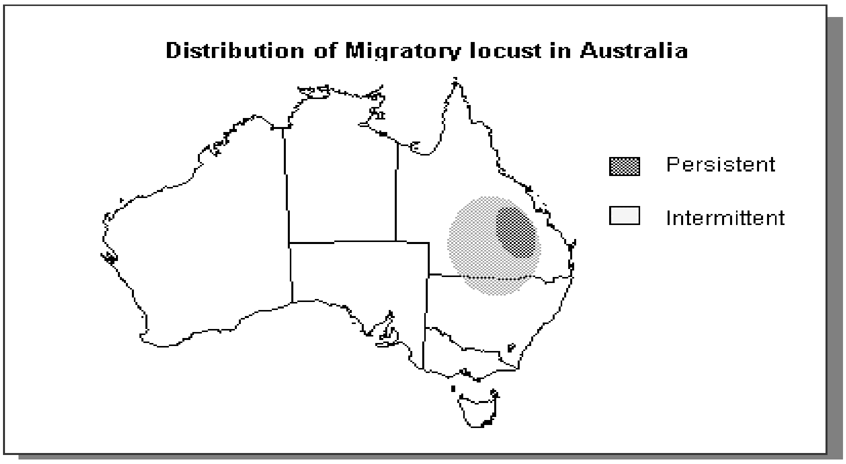

Figure 3: Distribution of migratory locust in Australia (Source: APLC 2000)

Migratory locusts have expanded their range from the coastal grasslands to inland habitats, particularly as a result of the expansion of favourable habitats—that is, cropping with broad acre crops (such as sorghum and other summer crops) and improved pastures on the black earth and the grey clays supporting brigalow scrub (Elder, Sabine & Wicks 1979; Farrow 1979). Further changes have included the use throughout Queensland of introduced grasses from Africa, which constitute the preferred habitat of migratory locusts in Africa. These grasses—buffel grass (*Cenchrus ciliaris*), panics (*Panicum* sp.), and windmill grass (*Chloris* sp.), among others—have extended growing seasons over the native grasses. It may be possible that these conditions allow for permanent populations in the Central Highlands, increasing the frequency of outbreaks. This upsurge in locust numbers, and incidence of outbreaks due to habitat changes, also has occurred in Africa in Middle Niger, the Sudan and Madagascar, and in Papua New Guinea (Farrow 1987).

4.1.4 Minor locust and grasshopper species

- **Wingless grasshoppers (*Phaulacridium vittatum*)**

  This species is restricted to moister coastal and elevated tableland areas of southern Queensland and the southern states. Outbreaks occur in localised areas of the southern borders, and in the Darling Downs and Beaudesert districts (Strong et al. 2001a).

- **Yellow-winged locust (*Gastrimargus musicus*)**

  Found throughout coastal and subcoastal eastern, western and northern Australia in districts with rainfall greater than 500 mm, swarms of this species were recorded between 1903 and 1908 in Herbert River, Charters Towers and Rockhampton, and again from 1911–16 (Common 1948). The last major outbreak of this locust in Queensland was in the period 1939–47 in Central Queensland. The Springsure–Clermont–Capella region was the critical build-up area, but the outbreak spread on the coast from Proserpine to Gladstone (Common 1948).

4.2 Monitoring methods

A swarm of Australian plague locusts covering 1 km^2 can contain from 4–50 million individuals and can be easily detected. Due to differences in swarming behaviour, other species of locusts, such as the migratory and desert locusts, can form much denser and easily seen swarms (APLC 2001b). If significant damage is to be avoided, it is important that plagues be detected long before they reach high numbers. Locusts persist in low numbers and are not noticed when conditions are dry; however, plagues arise from these background populations when there is a sequence of regular rains, which allow locust breeding and survival. It is important therefore to monitor population numbers constantly so that the small bands and swarms that form early in breeding sequences are located and treated before they can breed further and form large infestations.

4.2.1 Surveys

Methods for surveying and carrying out control operations on locusts in Queensland were compiled into an operational manual in 1999 (Willmott 1999), bringing together the experiences of a number of workers who had been involved in controlling various plagues. Best practice is to conduct surveys regularly in major locust breeding areas, previously occupied or controlled sites, and newly reported sites. The commonly used survey method involves stopping at 10 km intervals along a planned survey route and undertaking foot transects 250 m from the roadway. The number of locusts within a 250 m^2 area is recorded. If more than a 'concentration' of adults or a 'sub-band' of hoppers is detected (see table 1), a more intensive survey is begun. The presence of 'bands' or 'swarms' necessitates spraying. A minimum of 10 km^2 of targets is required for control to be feasible for adults and nymphs (APLC 1999a). Bands are defined by parameters, namely the:

- size of the band by length (<10 m (very small) to >500 m (very large))
- number of hopper bands in a specified area (3–10 (a few) to >50 (many)).

Table 1: Description of locust population density (no. of locusts/m^2)

Adults		Hoppers	
Concentration	0.5–3	Present	1–5
Low density swarm	4–10	Numerous	6–30
Medium density swarm	11–50	Sub-band	31–80
High density swarm	>50	Band	>80

Source: Anon 1996b

Dense locust swarms most suitable for spraying are usually very localised and often easiest to find by helicopter; however, the aerial visibility of locusts varies (Anon 1996a). During summer and autumn, both migratory locust and spur-throated locust adults are often in tall grass and, in some areas, are found repeatedly in forage sorghum. Usually, locusts can be disturbed easily by a helicopter hovering overhead, but even close hovering may not force locusts to fly in cold weather, making it difficult to locate swarm targets (APLC 1996). During autumn, spur-throated locusts are young and will flush only if helicopters are flown very slowly close to vegetation.

Because spur-throated locusts can remain in a crop for a month or more, populations greater than 1–2 per m^2 in grain sorghum warrant control. Infestations of this density require disturbance by walking because driving around the edges of a crop does not provide sufficient indication of population or density. Monitoring at various times of the day is also required. Activity is less in cool weather and during the early morning, when locusts may not be in the crop but basking on the tops of nearby trees.

During the winter, when spur-throated locusts roost in trees, there is often little sign of them from the ground, as often the only indication of the presence of high-density swarms roosting in trees (hundreds per m^2) is one or two locusts drifting across the road (APLC 1996). Swarms can, however, be detected by helicopter. During the warmth of the day they are easily disturbed and may be visible from some distance as a brownish stain on the tops of trees.

4.2.2 Light traps

The Australian Plague Locust Commission (APLC) assists states with the management of locust outbreaks (see section 8.1). As part of this program, the migration of locusts is monitored at eight light traps around Australia. Four of these are located in Queensland at Julia Creek, Longreach, Birdsville and, near Thargomindah, at Nooyeah Downs (APLC 2000). (See figure 4.) A 250 W lamp is used to attract night-flying locusts that subsequently fall into a water-filled base. The number of locusts trapped is recorded, as are the corresponding temperature and rainfall details. This information is used in predicting locust movements. When a large number is trapped, the occurrence of a local invasion is generally indicated (APLC 2000).

4.2.3 Models

Models are used to predict changes in locust populations and provide information on possible migrations. Rainfall, wind speed, and temperature are three critical factors determining migration (Symmons & Wright 1981). The APLC uses a computer-based decision support system to enhance current locust forecasting and operations. This system integrates weather data with survey information to make predictions of movements. The influence of weather patterns on locust populations is documented, and six-week forecasts are provided. This has enabled targeting of control actions, increasing the success of preventative controls in recent years.

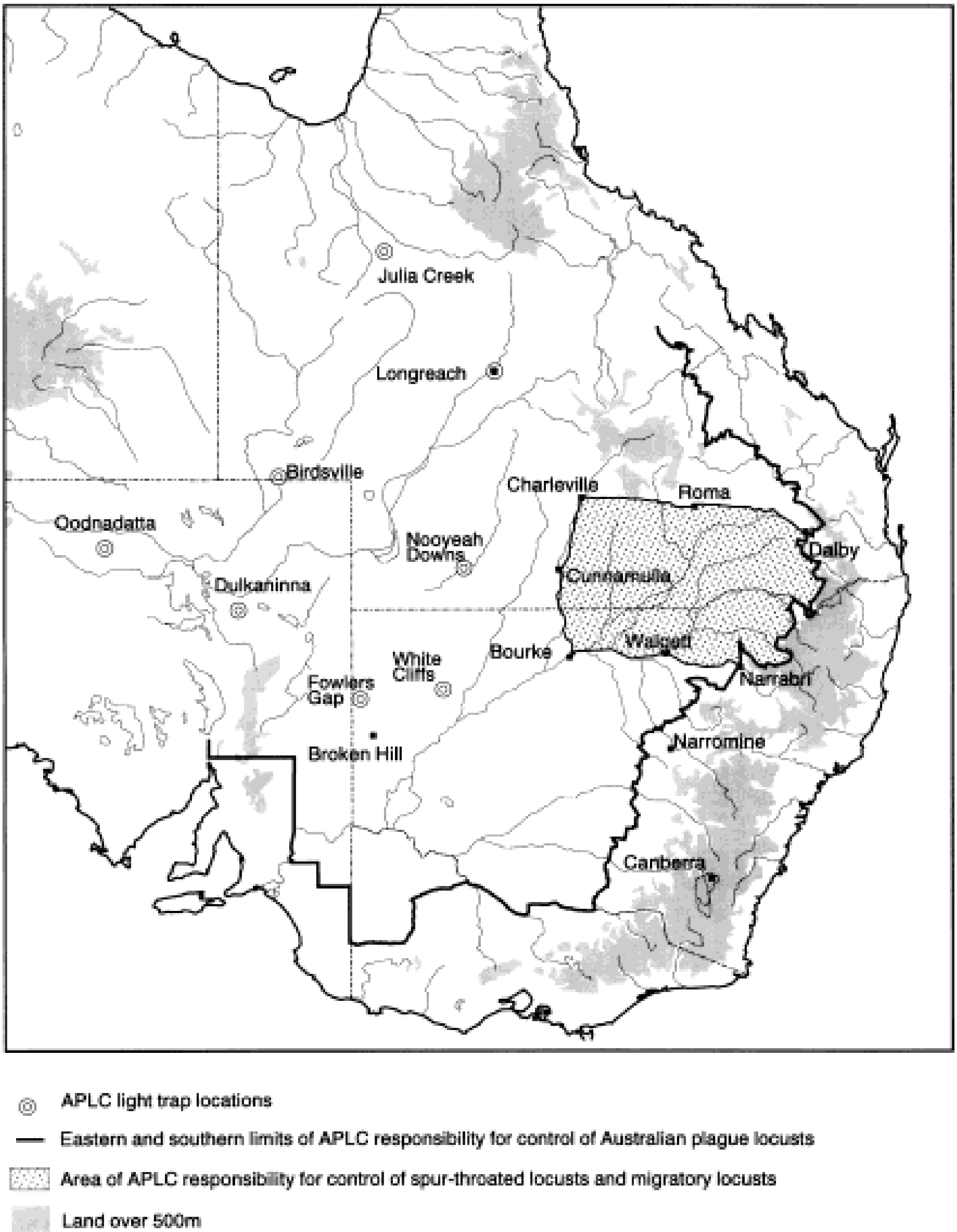

Figure 4: The area of responsibility of APLC in eastern Australia, and the location of light traps.

5.0 Estimates of current and potential impact

Locusts can have devastating impacts (Anon 1996b):

> *High density swarms of Australian plague locusts covering two square kilometres and averaging fifty individuals per square metre will contain about one hundred million insects and consume 20 tonnes of vegetation in one day.*

An Australian plague locust eats approximately one-third to half of its body weight per day throughout its life. This is approximately 0.2 g of vegetation per day (APLC 2001b). A plague of spur-throated locusts can cause ten times more damage (Bullen 1975). Migratory locusts cause the greatest loss per unit area due to their larger size, higher feeding rate, slow-moving swarms, and faster population growth (Bullen 1975). Therefore, the damage caused by locusts depends on a range of factors including the type, number and age of locusts, and their persistence in an area. A plague of Australian plague locusts that infested the New South Wales Riverina district in 1984 was estimated to cause $5.1 million in damages, and this was after early control action had accounted for 82% of the locust population (Wright 1986a).

5.1 Impact on primary production

Locusts rate as a high risk for primary producers in some parts of Queensland. Influenced by climate, locust plagues often occur in the good seasons when producers are trying to maximise returns to make up for poor production in dry years.

5.1.1 Impact on grain growers

Crops can suffer from defoliation, stem snapping, damage at head emergence/ flowering, and lost yield (Spackman 1996). Due to attack on stems of wheat plants resulting in the severing of the head of grain, Australian plague locusts have been shown to reduce grain production by 12–78% (Wright 1986b); although losses were insignificant if defoliation alone occurred more than 12 days after anthesis.

Elder, Sabine and Wicks (1979) collated the high cost to grain growers of the locust plagues between 1973 and 1975 (see table 2). Migratory locusts alone caused the destruction of 5730 hectares of sorghum crops and reduced grain production by 14 000 tonnes, presenting a loss of $1.4 million (Bullen 1975). Spur-throated locusts accounted for a total loss to crop production of $1.9 million, including $1.2 million for sorghum (Bullen 1975). Similar losses were experienced in New South Wales as the plagues spread south, with control costs of over $476 000, impacts estimated at over $1 million, and potential savings from control actions of $4.3 million (Casimir & Edge 1979).

Although cereal crops are the most affected by locusts, the 1970s spur-throated locust plague also resulted in damage to other crops. Bullen (1975) indicated that lost crop production, largely comprising sunflowers and soybeans, was valued at more than $0.5 million in Queensland. Canola is very susceptible to plague locusts when crops are emerging; while grain legumes, lupins and field peas are all at risk of defoliation in southern growing areas (Anon 1991).

Table 2: Cost–benefit summary of locust plague control in Queensland (1973–75)

Season	Total government expenditure ($)	Crop losses ($)	Crops saved ($)
1973–74	0.5 million	3.5 million	15 million
1974–75	0.9 million	5.9 million	30 million
Total	1.4 million	9.4 million	45 million

Source: Elder, Sabine & Wicks 1979

Locusts can seriously affect high-value crops such as grapes. In the Riverina region, vines of Cabernet Sauvignon and Black Shiraz were stripped by a plague locust outbreak in 1984, reducing the yield completely, with a loss of over $100 000 across two properties (Wright 1986a).

Plagues of spur-throated locusts spread over the northern half of Queensland during 1995. Due to the location and timing of outbreaks, sorghum was at greatest risk from these plagues (Bullen 1975). Mature grain crops tended to be favoured by the adult locusts, but damage was also recorded in the earlier grain-filling stages, resulting in severe yield losses in some crops, and a high proportion of cracked seed and locust carcases in grain samples. Sunflower crops were defoliated, and mungbean crops were severely damaged. Damage to wheat crops was light, and restricted to stem snapping due to roosting swarms. Dryland cotton crops were only lightly affected; although, spraying of adjacent grassed areas was required (Spackman 1996). Preventative control measures significantly reduced the potential damage level.

5.1.2 Impact on sheep and cattle graziers

Locust plagues usually have less significant impacts on grazing lands in Queensland, as hopper numbers tend to be at their highest when pastures have received plentiful rainfall (White 1997). In these conditions, the pasture carrying capacity is already higher and pastures are also quicker to recover from damage—for example, a severe migratory locust plague in the early 1970s had negligible effects, as pastures were thriving (Bullen 1975). The estimated reduction in pastures during plagues is equivalent to an increased stocking rate of no more than 10% (APLC 1999b); however, major effects are realised if drier conditions prevail and a shortage of feed exists, or if outbreaks are concentrated in a local area.

The control of locusts with chemicals is increasingly unwelcome by some graziers and presents another threat associated with locust invasions (see section 7.1.1). This is especially the case for organic producers, who may lose certification if chemicals are used.

5.2 Impact on the environment

Plagues of locusts can cause widespread environmental damage. Due to their varied diet, spur-throated locusts have a greater potential to cause damage to native plants; however, more research is needed, as the literature on these impacts is quite poor and fragmented.

Common environmental effects include defoliation of trees and branch breakage due to the weight of large numbers of the insect. Heavy defoliation of two species of native trees, *Casuarina lepidophloia* and *Eucalyptus microtheca*, occurred over thousands of hectares during the 1970s plagues (Casimir and Edge 1979). In 1995–96, swarms completely defoliated stands of *Casuarina cristata* in the Bollon–St George area; *Eucalyptus bloxsomei* was also eaten (Anon 1996a). The implications of these events included reduced resources for other animals, although such effects are only temporary. Moreover, increased locust numbers provide a plentiful resource for a range of predators such as crows, ibis, falcons and kites (Anon 1996a).

As locusts are native insects, they are protected under the *Nature Conservation Act 1992* (Qld) in protected areas. Controls on locusts in parks have occurred on two occasions: in 1995, spur-throated locusts were treated in Mazeppa National Park; and in 1999, approximately 75 ha of the Peak Range National Park near Clermont were sprayed after the discovery of dense hopper bands of migratory locusts—densities of over 1000 individuals/m^2 were recorded. These actions were taken to reduce the potential impact to pastoral and cropping areas, but it was also recognised that these plagues could have a significant impact on native vegetation in conserved areas and that active management of these reserves may require similar actions in the future. Subsequent to these actions, the Queensland Parks and Wildlife Service developed a policy allowing the treatment of locusts in protected areas in principle, provided that strict criteria, including off-target monitoring, are met. No action has been taken under the policy to date.

The environmental effects of plagues have increased in recent years as locusts have spread into new areas. Impacts on native vegetation are also increasing as outbreaks become more common. A further factor of greater significance is the use of chemicals to control plagues. *Fenitrothion* is the chemical most commonly used to control locusts, and has been reported to be of moderate toxicity to birds and fish. Toxicity is very high for aquatic and terrestrial arthropods but only slight for mammals (Anon, in

Walden et al. 1991). Phytotoxicity varies between plants; however, any environmental effects are minimised by the standard application of low volumes of insecticide and the short residual life of the insecticides used (APLC 2000). Chemical impacts on the environment will be reduced in the future, with greater use of biological sprays such as the *Metarhizium* products. These have been shown to attack acridid pests (grasshoppers and locusts) specifically, while other insects (even closely related crickets) can escape the effects (Milner, Staples & Prior 1996).

5.3 Off-farm impacts

Locust plagues can be very distressing for the general public—home gardeners and businesses can be affected by the destruction of household gardens and high-value crops respectively. During the 2000 plague, a plan to control locusts in the city of Adelaide was developed to counter the potential impacts on the city's parks (Haran 2000). Sporting events can also be affected, with bowling greens covered with swarms, or visibility limited during other outdoor events.

A range of other impacts can occur, some of which pose serious safety concerns (Bullen 1975). Plagues can present traffic hazards, and commonly block car radiators unless insect screens are fitted. The outbreaks in Victoria in 2000 resulted in warnings from the Royal Automobile Association (Austin 2000). Dense flying swarms constitute a hazard to low-flying aircraft. The closure of railway lines and airport runways can be required, due to lack of rail adhesion and lost air speed indication respectively. The sight of large flights of locusts can also scare the general public, evoking images from literature and movies of biblical plagues of locusts.

5.4 Cost of control

The cost of controlling locust outbreaks is significantly affected by the speed by which the plague is recognised and the coordination of actions to maximise returns. Piecemeal actions—with some landholders waiting until impacts are high or waiting until government agencies carry out controls—will increase overall costs and impacts, and reduce chances of success.

During the 1973–74 plague, $0.4 million was spent on reactive control of spur-throated locusts in Queensland, saving crops valued at $15 million. It was estimated that the value of crop losses resulting from spur-throated locust damage was $1.9 million. In 1974–75, the value of crop losses attributed to all locust species was $5.9 million, and $0.9 million was spent on control to save crops valued at $30 million. Although some labour costs were not included and no ongoing locust monitoring costs were included, it is clear that the benefits of locust control can be considerable (Elder, Sabine & Wicks 1979).

During 1995, 40 swarms of spur-throated locusts were controlled in an outbreak in Queensland (over 6,340 hectares), but many swarms were not found and treated. There were major infestations in crops the next year, with 270 000 ha treated during autumn 1996, mainly by landholders. Many of the sprayed crops had locusts of relatively low density, but because spur-throated locusts remain in crops for a month or more, these low densities had to be sprayed to limit damage. It was then decided to fund a large campaign against the dense, over-wintering swarms. Between May and October 1996, the Department of Natural Resources and the APLC treated several hundred dense swarms covering over 20 000 ha. Many of the swarms treated were in pastoral areas (Longreach to Bollon), the aim being to prevent major invasion of cropping areas the next year. The program was successful in that there were limited invasions of cropping areas the next year, with only 3000 ha sprayed to protect crops during 1997. Landholders contributed approximately $3.1 million (APLC 1996), and government expenditure was also more than $3 million (Anon 1996a).

Between October 1998 and March 1999 the Department of Natural Resources spent $1.4 million on migratory locust control in the Central Highlands, protecting crops in the area valued at $42 million and preventing locust migration to cropping areas further south, which would have resulted in substantially higher impact costs (Miller, Hunter & Strong 2002). Landholder rebates for ground spraying over this period were substantially lower, totalling only $25 000—a 50% rebate on funds expended. This decline in rebates related to the aerial control by the department of many bands during this plague, as they were highly visible and band control is more effective than waiting until treating swarms.

6.0 Biology and ecology

6.1 Life cycle

All locusts and grasshoppers have the same three-stage life cycle—egg, nymph (hopper) and winged adult. Important aspects of this life cycle are:

- There is, on average, a sevenfold increase in numbers with each generation.
- Locust survival depends on rainfall and temperature.
- Eggs are laid after rain, and need both moisture and warmth to develop.
- Most crop and pasture damage is caused by late hopper stages, young adults and egg-producing females.
- Summer crops are at greatest risk.

Table 3 summarises the key biological and ecological features of the three main locust pest species and their differences. Locust hoppers pass through at least five growth stages (instars) between hatching and fledging to adulthood. Spur-throated locust hoppers may undertake further instar stages, as their life cycle takes longer to complete. Cold or dry weather will increase the number of instars in all three locust species.

When population numbers are high, the hoppers of the Australian plague locust and the migratory locust congregate into bands. This usually occurs in the third instar. A typical band of Australian plague locusts will be 100 m wide, 5 m deep and contain more than 1 million insects (Bullen 1975).

Adult locusts undertake three life stages—body growth, fat accumulation, and egg maturation. During the body growth stage, wing muscles develop and the exoskeleton hardens (APLC 1999b). Sexual maturation usually occurs in the first two weeks of adulthood, but may be delayed over winter. Locusts accumulate lipids for flight, migrating to new areas to mature and lay eggs and continue the life cycle (Hunter, McCulloch & Wright 1981).

Spur-throat locusts differ from other locusts in a number of respects:

- They have only one generation per year. (It takes a longer period of time (3–4 years) for this species to develop into plague proportions.)
- Nymphs are the least tolerant of prolonged dry periods (limiting the persistence of populations outside tropical environments).
- The hoppers do not form bands and the young adults do not congregate in tight swarms.
- Adults can form dense swarms in trees during winter, and control of such dense swarms has proven to be a most effective time for preventive control.

6.2 Environmental requirements

Rainfall has both a direct and indirect influence on locust development. First, rainfall is necessary for eggs to hatch. Spur-throated and migratory locust eggs laid in summer will not survive more than 30 days without rainfall, and Australian plague locust eggs, no more than two months (APLC 1999b). Second, rainfall is critical in determining the condition of vegetation. Locusts bred on dry grass in hopper and early adult stages are unable to migrate and reproduction is reduced (Hunter 1982). A study of water stress on curly Mitchell grass confirmed that more than 20 mm of rainfall is required for the development of Australian plague locusts and that survival increased with increased tiller moisture (Phelps & Gregg 1991).

As locust outbreaks tend to occur in areas with unreliable rainfall, migration assists their survival. Long distance flights occur on weather fronts associated with rainfall. Adult swarms can contain more than 80 locusts per m^2, stretch from 1–25 km^2, and travel up to 1500 km in three or four days (Wright 1986b). Some locusts will usually find edible vegetation after flight. If rainfall is widespread, survival rates are improved to the point of plague proportions after three or four generations (Anon 1996b).

Australian plague locust mass movements only occur following the accumulation of body fat from rain-fed pastures (Symmons & McCulloch 1980; Hunter, McCulloch & Wright 1981), and are restricted to nights with warm strong winds and temperatures above 20^{o}C (Clark 1969).

Locusts inhabit environments where a combination of resources is provided. Bare ground is useful for basking and egg laying, while plants are used for shelter and feeding.

In winter, immature spur-throated locusts roost in trees; although some will descend to feed on crops or grasses during the daytime. In summer, the adults and hoppers exist in tall grasses or crops. Migratory and Australian plague locusts feed almost exclusively on monocotyledons (i.e. grasses), with the latter preferring plants 10–20 cm in height (Bullen 1975).

The broader diet of the adult spur-throated locust enhances its survival chances over the long winter dry season (Farrow 1977). Although spur-throated locusts prefer gramineous plants, they will feed on various crops and native *Eucalyptus* and *Casuarina* trees; however, this species has a greater dependence on rainfall in its lengthy nymphal stages.

Table 3: Biology and ecology of Queensland's three plague species

Species	Spur-throated locust	Australian plague locust	Migratory locust
Feature			
Generations per year (if conditions good)	Annual (1 generation per year)	2 generations per year, up to 4	4 generations per year, up to 6
Rate of increase/ generation	X5-10 (ave. 7-fold)	X5-10 (ave. 7-fold)	X5-10 (ave. 7-fold)
Hoppers present	Nov–April spring–autumn	Spring–autumn, few winter	All year
Adults present	Autumn–winter (immature); spring–summer (mature)	Spring–autumn, few winter	All year
Egg laying time	Mid Oct–Feb, sometimes until April	All year	All year
Number of egg pods per female	3–5	2–3	3–5
Number of eggs per egg pod	>100	40–50	40–50
Eggs (days to hatch)	18–30; no egg beds, pods scattered in soil	12–18; dormant over winter, egg beds	12–18; egg beds
Hopper stage	47–90 days	25–35 days	25–35days
Sexual maturity is reached (during winged adult stage)	14 days after rain during spring and summer	7 days after rain or migration to rain area	2 weeks after becoming adult, providing grass green to drying off
Adult life expectancy	10–12 months; can survive one summer to the next	2 months, or until they mature and lay	2 months, or until they mature and lay
Hopper food	Fresh green vegetation—grass feeders (mainly pasture, sometimes cereal crops)		
Adult food	Grass, broad-leaved plants (all crops, pastures); summer crops most at risk, including sorghum, sunflowers and soybeans	Mainly gramineous crops, pastures	Mainly grass family, including pastures and crops (esp. sugarcane and sorghum, also wheat, barley, oats, maize)
Season crop threat	Summer crops most at risk, extending into autumn		
Band formation	No hopper bands, swarm when sexually immature adults	Form hopper bands by third instar	
Swarming adults (Time of year)	Jan. to Sept.; immature over-winter, swarms disperse when sexually mature	Spring–autumn	
Long distance migration (Time ime of day)	Night	Night	Day, some night migration suspected

Source: (Anon 1996b, APLC 2000, Elder et al. 1979, D Hunter, pers comm., 17 April 1999)

A study found that, of seven outbreaks of spur-throated locusts from 1935 to 1968, five began in years of average or above average rainfall following drought (Bullen 1969 in Hunter & Elder 1999). Hunter and Elder (1999) calculated that for the spur-throated locust life cycle to be completed successfully, a minimum of 40 mm rainfall is required at egg-laying and again up to six weeks later. Another fall of 40 mm or more of rain six weeks later will enable development of a second batch of offspring.

Case study: Climate and migratory locust plagues in Queensland in the 1990s

During most seasons, any build-up in migratory locust numbers over the summer 'wet season' in central Queensland is generally offset by locust mortality in the winter 'dry season', and populations tend to remain low. This was the pattern during 1994.

When there is winter rain, there is good survival of laid eggs over winter, so populations do not decline. The population increase during the summer is followed by further increase in winter, so swarms form by the next season. Winter rain during 1995 allowed good survival, and swarms formed following summer rain during the late spring and summer of 1995–96, which were sprayed in February 1996 (10 500 ha treated) (Hunter, Strong & Spurgin 1998).

There was winter rain again during 1996, and swarms formed by early summer following further rain during spring. Preventive control programs against bands and swarms were undertaken during early summer 1996 (5200 ha); late summer 1996–97 (6900 ha); and again in the summer of 1997–98 (4200 ha), following patchy rains over winter. These small preventive control programs are generally sufficient to keep populations at moderate levels, provided there is only one generation between autumn and late spring. However, during 1998 there were rains both at the end of autumn (May) and at the end of winter (August). These two rain periods during the dry season led to two generations between autumn and mid-spring, leading to a very large population increase.

The rains at the end of autumn allowed adults surviving the summer control to lay and the moist soil allowed survival and development of the eggs. The winter was mild and the eggs hatched by mid-winter, reaching the adult stage by early September. The late August rains ensured that the adults laid, producing an extra generation. (Normally, adults do not lay until the spring rains of late October).

The result of this extra generation was a much higher than normal mid-spring locust population, with many bands and swarms by October and November, and about 70 000 ha requiring treatment. A second generation ensuing during January was also treated. Preventative control of these two generations was sufficient to reduce the population so that little further control was required, even though rains continued in late summer. Subsequently, a dry winter during 1999 effectively ended the outbreak (Miller, Hunter & Strong 2002).

6.3 Locust outbreaks and preventative control strategies

The clearer understanding of locust ecology developed over the last decade has allowed locust controls to be targeted to maximise the returns from control actions (see table 4).

Table 4: Preventative control strategies based on locust ecology

Species	Critical factors leading to outbreaks	Preventative control strategy
Australian plague locust	Winter and spring rain in Australian interior, leading to swarms in late spring/early summer. Plague levels by autumn or next spring. (Normally dry winters in interior.) OR Spring and summer rains in both interior and agricultural areas. Plague levels by summer of second year.	Begin intensive survey after winter and spring rain, and control swarms found. Control bands and swarms every generation thereafter.* Control any bands and swarms located.*
Migratory locust	Winter rain in Central Highlands allows eggs to survive over winter. Plague levels by late in second year. (Normally dry winters cause egg mortality)	Begin control of swarms that form late in the season after winter rain. Control bands and swarms every generation.*
Spur-throated locust	Rain for oviposition followed by further rain within 6 weeks allows for egg and nymphal survival. Plague levels after 3 - 4 years of widespread rain in Gulf Country & drier open plains to the south. (Normally only Gulf gets such rain; egg & nymphal mortality common in drier areas)	Control dense swarms that form in winter of 3rd year of such rain, and control every generation thereafter.*

Source: D Hunter, pers comm., April 1999

Note: Once control has begun, continue to control at least 30–50% of the total population every generation until dry conditions return and the population collapses.

7.0 Efficacy of current control methods

Similar types of control method are used on all locust species, but they have not been equally successful, as spur-throated locusts have proved harder to control. Management of locusts focuses on preventative treatment, with treatment of the Australian plague locust and migratory locust beginning with the small bands and swarms that form early in breeding sequences. With the spur-throated locust, preventive control begins when winter swarms form in pastoral areas of central western Queensland, as these can easily migrate to the cropping zone the next spring.

Traditionally, control methods have been based on aerial and ground spraying; however, a greater focus is being placed on alternative control methods as the reluctance to use chemicals grows. Although many methods are successful and practical, it is unlikely that the proposal (presented by a South Australian parliamentarian during the recent plague) for a chemical-free method using a large vacuum cleaner device will find wide usage (Leech 2000).

7.1 Spraying

Spraying of hoppers is undertaken to prevent the development of swarms and limit the number of egg-laying adults. Monitoring of hopper numbers identifies the scale of infestation and subsequent need for control by misting or aerial spraying. Spraying hoppers is most effective when they form bands, as do the migratory locust and Australian plague locust. Spur-throated locusts do not form bands, but sometimes occur in high numbers in headlands between crops. Control of these high numbers can be effective in preventing crop invasions. During hopper control operations, it is important that control actions are taken by as many affected landholders as possible. In many situations, landholders have not taken action until impacts were significant, leading to unsuccessful control programs. Landholder spraying of dense bands of the migratory locust is sufficient to limit populations so that only a few swarms need to be controlled at the adult swarm stage. The spur-throated locust does not form dense bands as hoppers or as young adults, so control of hoppers or young adults by landholders is useful in protecting crops, but will not reduce an infestation unless very large areas are treated. Preventive control has been most successful following intense campaigns against the dense adult swarms that form during winter. It is important to note that 50% control is sufficient during early preventive control, but >80% control is required to reduce populations that have reached high levels. Such high levels of control were achieved over the spur-throated locust in 1996, and over the migratory locust during 1998–99.

7.1.1 Chemical sprays

The various species of locusts have differing susceptibility to chemical treatments. The registered chemicals and application rates vary (see appendix 2). Hopper bands are sprayed using low-volume machines applying 50–100 litres per hectare, such as misting machines that produce a narrow droplet spectrum. Applying the correct dose of insecticide is important to achieving maximum economic control without exceeding the maximum residue levels (MRL).

Adult locusts are best sprayed when flying, but as this is often not possible, crosswinds assist in foliage coverage when spraying onground populations. Aerial spaying with micronair spray units, producing a droplet size of 80–120 microns at 5–10 m height, is most effective. Ultra-low volume application (210–400 ml/ha) allows large areas to be treated quickly and is ideal for strategic control and in pasture in 50–100 m swaths (Spackman 1996). Spraying in the early morning or late afternoon also assists control because hoppers are then basking to increase body temperature and are in the open, or on top of the grass, and directly exposed to the spray (Anon 1996c). A number of factors need to be considered before or when spraying, including conditions at the target, time of spray, and movement of locusts.

Chemical control methods are of increasing concern to a wide range of stakeholders. The issues raised about chemical control include:

- The control of locusts in and around national parks, protected areas, and waterways raises concerns for maintenance of biodiversity.
- Organic farmers may lose certification if synthetic chemical insecticides are used on their land for locust control.
- Some crops, particularly some varieties of sorghum, become photosensitive when sprayed with *fenitrothion* (Spackman 1996). *Fipronil* has been trialed as an alternative chemical; it is less hazardous to handle and is very effective,
- A 14-day withholding period is required for cattle in *fenitrothion*-treated areas.
- There are few chemicals registered for locust control that are commonly available for landholders. Landholders sometimes resort to the use of unregistered chemicals to avoid phytotoxic effects on sorghum crops.
- Off-target chemical drift is a threat to apiary and aquaculture industries, and is of concern because of human health issues. Off-target impacts threaten native wildlife, which ingest chemical residue in dead grasshoppers.
- Aerial application may cause problems with noise sensitive livestock, e.g. horses and ostriches.
- Spraying cannot occur close to watercourses and houses, and this can reduce the effectiveness of control campaigns.

7.1.2 Fungal sprays

In recent years, extensive research has been undertaken to determine the efficacy of fungal biocontrol for locust control, in part funded by a 5-year Queensland Treasury initiative. The hyphomycete fungi *Beauveria bassiana* and *Metarhizium anisopliae*, were initially chosen for further investigation because they can be mass-produced, stored, and sprayed through conventional equipment to control locusts. *Metarhizium anisopliae* var. *acridum* was chosen for further development due to its success in preliminary trials, its effect at high temperatures, and its host specificity (Milner 1997). Two strains have been collected in Australia—FI985 (from spur-throated locusts in Queensland) and FI1155 (from the Australian plague locust). The FI985 strain has been shown to be effective against Queensland's three significant locust pests (Milner, Staples and Prior 1996; Scanlan et al. 2001).

During 1998 and 1999, three moderate scale trials, each covering several hundred hectares, showed that *Metarhizium* at 3 x 10^{12} conidia in 1 L of oil/ha caused bands of migratory locust to decline in size by >90% between 7 and 15 days after treatment (Hunter et al. 1999). All bands and swarms treated were followed each day for the duration of the trial (up to 18 days). Modelling by Scanlan et al (2001) emphasised that locusts not only contacted the conidia during spraying, but also picked conidia up from the vegetation for several days afterwards. The models indicated that lower doses should be sufficient where vegetation was less dense. Subsequent trials against the Australian plague locust in the moderate to sparse vegetation of Windorah in western Queensland and Griffith in southern New South Wales showed that doses of 1 x 10^{12} conidia in 0.5 L of oil/ha were sufficient. Both treatments were successful, with death faster in the very hot conditions of western Queensland (Hunter 2001).

The success of these trials led to the first successful operational use of *Metarhizium* in the world, when over 23 000 ha of bands and swarms of the Australian plague locust were aerially treated during the 2000–01 locust season (Hunter 2001). Critically, the fungal treatments avoid the non-target impacts of chemicals, including organic production. A commercial *Metarhizium* product, Green Guard™, has been produced and undergone field trials, and its registration is currently being sought from the National Registration Authority (D. Hunter pers comm. April 2002). In 2002, about 750 kg of conidia were produced.

7.2 Biological control

Locusts are affected by a variety of predators and parasites. While predators such as birds and mammals consume locusts as part of a broad diet, they are unlikely to be effective at reducing numbers. A newspaper article described how an army of 700 000 specially trained ducks and chickens was used as part of a control program to control a plague in Xinjiang province in China in 2000 (Anon 2000b). This plague, the biggest in 25 years, had destroyed more than 4.1 million acres of crops across eleven provinces. The article did not comment on the eventual effectiveness of this control method.

In Thailand, locusts and other forms of grasshopper are eaten as a food source. Farmers can earn between 200 and 400 baht ($A8.67–$A17.34) per kilo for locusts, compared to 5 baht per kilo for corn (Stolley and Taphaneeyapan 2002). A farm research centre in Thailand estimates that crickets deliver more protein (20.6 gm per 100 gm) than most meat sources. These insects and others are canned for sale across Thailand. During lean times, these insects must be imported from Myanmar, Cambodia and Laos, creating a regional market in the sale of locusts.

Table 5: Locust mortality from native predators and parasites

Parasites	**Wasps**	**Flies**		**Nematodes**		**Protozoa**	**Fungi**
	(*Scelio* species)	Blaesoxipha spp. *(Parasitic Blowfly)*	Trichopsida oestracea *(Bee-fly)*	Amphimermis	Mermis		
Life cycle							
Eggs	✓						
Hoppers		✓	✓	✓	✓	✓*	✓
Adults		RF	✓RF	✓RF	✓	✓*	✓

Source: APLC 1999b

Key:

= usually kills host; RF = reduced fertility; * = large numbers required

A number of parasitic insects are dependent on locusts (see table 5) (APLC 1999b); however, parasites are unable to effectively control plagues without artificial breeding and multiplication, as population increase is generally slower than the locust increase. One exception is *Blaesoxipha* sp.*,* a parasitic blowfly that multiplies at a competitive rate to the annual life cycle of spur-throated locusts (White 1997). While this species is believed to have contributed significantly to the end of the 1970s outbreak (Baker & Pigott 1995), it tends to increase in number after locust outbreaks are established, and has not been shown to prevent plagues. Parasites such as nematodes (round worms) are important control agents in high rainfall districts (Milner 1997). Coastal invasion by swarms of spur-throated locusts is readily halted by these parasites (Elder, Sabine & Wicks 1979). Fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* tend to be present in the natural environment only at low rates (Milner 1997).

A biological agent used in China and the United States is the microsporidian protozoan, *Nosema locustae*. Locusts and grasshoppers near water have been treated with *Nosema* in China in recent years, but even at a high dose it usually only results in 50–60% mortality. Eggs laid by surviving locusts are infected with *Nosema*, ensuring carryover to the next year, which means there is potential for longer-term effects (Streett 2002). *Nosema* has a wide host range, which would be a concern in Australia with our large acridid flora. It was tested in Australia a number of years ago, but its high cost at the time and the low resulting mortality meant it has not been used here to date. This product is now sold commercially in a number of formulations in the United States and this may have resulted in a reduction in price. With new results from China showing greater effectiveness, it may be that this product has a small niche in Australia in environmentally sensitive sites.

7.3 Habitat modification

Habitat modification can influence locust outbreaks. Man-made changes to the environment can result in increases in locust numbers. Systematic burning, the clearing of brigalow scrub, grazing, cultivation and irrigation in Queensland appear to have benefited most locust species. For example, migratory locusts, which were originally a coastal to subcoastal species in natural grasslands and swamp margins, have extended their range into a large part of the Central Highlands and southern Queensland because of clearing of brigalow scrub and the introduction from Africa of the grasses (e.g. buffel grass) that they prefer (Farrow 1979; White 1997). On a microhabitat scale, migratory locusts prefer lightly grazed pastures to areas with heavy or no grazing. Better seasons and more conservative grazing practices have increased these conditions in Queensland. Likewise, migratory locusts favour open plantings in cropping areas, as they provide a combination of food, shelter and bare ground for egg-laying sites (Farrow 1979). Farrow (1987) speculated that, because these changes to land use are recent, the current rate of migratory plagues may decline as the new land usage and insects reach equilibrium, with the base population stabilising below a level required to initiate outbreaks.

Habitat modification that can reduce crop losses from locusts involves the growing of plants that are less susceptible to attack—including sunflower, soybeans, chickpea, safflower and cotton. Forecasts of impending locust outbreaks have led to some landholders planting less susceptible crops. Spur-throated locusts may attack any crop; however, different crop varieties (such as wheat with thicker stems) can be grown to withstand attacks (Bullen 1975). More intensive pasture management practices in coastal areas of Queensland limit grass tussock development and therefore restrict suitable locust habitat. These management practices are, however, unsuitable for inland regions. In the Philippines, cultivation and the use of improved pastures has replaced the natural grasslands that were home to migratory locusts, resulting in the declining incidence of plagues (Farrow 1987).

7.4 Economic returns from control actions

The funding of strategic control of locust outbreaks by government agencies has been a cornerstone of locust management over the last thirty years. If government is to maintain this funding, the returns from the investment must be significant and of benefit to a large proportion of the community (i.e. community funds should not be spent for the benefit of a few).

An economic model for strategic locust control assessment developed by the University of Queensland was used to assess the benefits and costs of the management of the 1998–99 migratory locust plague in Queensland (Miller, Hunter & Strong 2002). The cost–benefit model requires triangular distributions (minimum, expected, maximum) for key variables such as potential production impact and saved landholder control costs. Estimates of these variables are required per crop on a local government area basis. Triangular distributions are useful when relatively little is known about the precise nature of the distribution function of a particular variable. Cost–benefit analysis is a standard economic tool and may be defined as the appraisal of an investment project that includes all social and financial costs and benefits accruing to the project.

The output from the model shows that at least $18 of benefits accrued for every dollar spent by the Department of Natural Resources on the strategic control of the 1998–99 migratory locust plagues in Queensland (Miller, Hunter & Strong 2002). This benefit–cost ratio is broadly consistent with that for the strategic control of mouse plagues in Queensland in 1995 and 1997—29:1 and 12:1 respectively (Eldershaw 1996, Caughley 1998). The model further estimated total savings of approximately $25 million in affected areas. This was made up of funds that would have been spent by producers on control measures, and losses avoided because of crops saved from the plague. For example, the model estimated that strategic control saved potential sorghum losses of 10–30% in the Central Highlands.

A benefit of the strategic control program that could not be measured was the avoidance of adverse environmental effects due to the reduced use of insecticide. While strategic control required over 41 000 litres of *fenitrothion* and other insecticides, it was applied by trained individuals using best practice. Similarly, because of the strategic control undertaken, landholders used only about 600 litres of insecticides collectively, for which rebates were claimed. Without strategic control, the amount of insecticide applied by landholders and government could have been many times higher. (This is reflected in the higher estimates of expected control costs for landholders and costs incurred due to adverse environmental impacts from the application of additional insecticides.)

8.0 Management and control practices

8.1 Locust management at the national level

The Australian Plague Locust Commission (APLC) was established in 1974 and began operations in 1976. Its role is to reduce the threat posed to agricultural production in a member state by locusts breeding in another state. The Commission is jointly funded by a cost sharing arrangement between the Commonwealth (50%) and the state governments: New South Wales (32.5%), Victoria (10%), South Australia (5%) and Queensland (2.5%) (APLC 2001b). The APLC is responsible to the federal Minister for Agriculture, Forestry and Fisheries and to the state premiers. Six commissioners from various state and federal bodies oversee all APLC operations. Western Australia has elected not to become a member state. The APLC has 19 permanent staff located at its headquarters in Canberra and at three field bases—one each at Narromine, Broken Hill and Longreach. A director who is responsible to the commissioners heads the APLC.

In 1986, APLC responsibilities were extended to include the spur-throated and migratory locust species. As these species mostly inhabit tropical and subtropical regions, this is a major benefit to Queensland; they do not threaten Victoria and South Australia. The APLC was given a more limited area of responsibility for these species (see figure 4). In the Central Highlands of Queensland, for example, the APLC is responsible for Australian plague locusts, but the Department of Natural Resources and Mines is responsible for the other species.

The APLC monitors locust populations in an area over 2 million km^2 through ground and aerial surveys, the operation of light traps (see figure 4) and the investigation of locust reports. The APLC has a toll free number, and a web site at <http://www.affa.gov.au/aplc>. Locust activity between the months of August and May is reported in the *Locust Bulletin* and made available on the APLC web site, as is an online locust form for reporting new outbreaks. The organisation also carries out research and coordinates locust control programs (Commonwealth of Australia 2000).

8.2 Legislative status of locusts in Queensland

Locusts (Australian plague, migratory and spur-throated) are declared pests under Queensland's *Rural Lands Protection Act 1985* and will remain declared as Class 2 pests under the *Land Protection (Pest and Stock Route Management) Act 2002*. Under section 77 of this legislation, landowners have an obligation to keep their lands free of locusts. Because of the extremely mobile nature of locusts, monitoring and, potentially, control need to be conducted over large areas. Therefore, a spirit of partnership and cooperation is essential if any meaningful control activities are to be conducted.

It is important to note that a large number of other pieces of legislation are relevant to locust management practices in Queensland:

- *Agricultural Chemicals Distribution Control Act 1966*
- *Agricultural and Veterinary Chemicals (Queensland) Act 1994*
- Agricultural and Veterinary Chemicals Code Regulations 1998
- Civil Aviation (Carriers Liability) Regulation 1996
- *Environmental Protection Act 1994*
- *Health Regulations 1996*
- *Native Title (Queensland) Act 1993*
- *Nature Conservation Act 1992* (ss 15-21, s62, s137(1) and (2))
- Nature Conservation (Wildlife) Regulation 1994 (s51(2), s81(2))
- Transport Operations (Road Use Management—Dangerous Goods) Regulation 1998
- *Workplace Health and Safety Act 1995*

Unlike most other declared pests in Queensland, locusts are protected under the *Nature Conservation Act 1992* in protected areas, as they are native to Australia. Therefore, as with all other wildlife in protected areas, control actions must be undertaken with the cooperation of the Environmental Protection Agency and must take into account several pieces of legislation. The Queensland Parks and Wildlife Service policy *PA3.4.5* outlines the strict conditions for granting a permit to control locusts in a protected area.

8.3 Department of Natural Resources and Mines, Queensland—policy on locusts

The Department of Natural Resources and Mines undertakes strategic aerial control of locusts if there is a threat to agriculture from locust migration to, or within, the areas where local governments contribute to the Plague Pest Contingency Fund. Through the precept[1] system, these local governments provide funding for control responses to plague situations and assist in major control campaigns. The State Treasury matches expenditure from the fund on a dollar-for-dollar basis up to a limit of $250 000.

[1] The precept is an amount local governments contribute for various land protection activities.

When the Department of Natural Resources and Mines considers there is a significant local threat, it provides financial assistance, control equipment, technical advice and information to local government. Queensland also contributes 2.5% ($78 000 in 1999–2000) of the total funds required for the ongoing operations of the APLC.

The Department of Natural Resources and Mines *will*, to the extent of available funds:

(a) undertake strategic aerial control of locusts where there is any threat by migration to, or within, the area where local governments make contributions to the Contingency Fund (precepted area)

(b) provide financial assistance to locust committees or local governments for the cost of insecticides required for the control of locusts where the department considers them to be a significant local threat

(c) determine suitable control targets and coordinate major aerial spraying operations when funding is provided through the Contingency Fund

(d) provide locust committees and local governments with available misting machines and technical advice or information

(e) maintain a core of expertise (within NR&M) in locust control

(f) consult with locust committees and local governments in making decisions which impact on them under this policy

(g) continue to facilitate the activities of the Plague Pest Advisory Committee and provide advice to the committee on locust management.

The department *will not* accept responsibility for control where:

(a) control is within the charter and resources of the APLC

(b) control is not technically, operationally, or economically feasible

(c) effective control is within the resource capability of the landholder, locust committee or local government.

The department will maintain and access a Locust Contingency Fund based on:

(a) local government precepts collected from areas susceptible to significant locust damage

(b) precept collections of no more than $50 000 in any financial year (adjusted with the Consumer Price Index)

(c) no greater than $250 000 of local government precepts held in the fund (adjusted with the Consumer Price Index).

In 1999, a two-day workshop was held in Emerald to develop a strategy for the better management of locusts outside the areas of APLC control in Queensland. The vision of this strategy is 'coordinated, economically and ecologically sustainable, long-term management of locusts in Queensland'.

To achieve the vision, six interrelated, desired outcomes were identified:

- adoption of best practice management
- accurate and effective education and communication
- capacity to manage locusts and locust plagues
- full understanding of locust biology and ecology
- integrated locust management
- non-target impacts.

Strategies and actions to be undertaken by stakeholders were developed for each desired outcome. This strategy was released in November 2000.

The Plague Pest Advisory Committee is a stakeholder group responsible to the Minister for Natural Resources and Mines through the Rural Lands Protection Board for:

1. advice on policy direction for the management of mice and locusts in Queensland
2. the review of long term strategies and action plans that identify and address needs for improved:
    - research
    - education/awareness
    - control/management
    - resourcing
    - coordination
3. the review of performance of internal and external stakeholders in addressing needs for improved management of mice and locusts
4. improved communication of plague pest issues between industry, government and other stakeholders
5. the review of other plague pest issues as they arise.

The success of control actions undertaken on locust and mice plagues by NR&M staff was acknowledged in 1999 when the Plague Pest Management Team was awarded the Premier's Excellence Award for Service to Rural and Regional Communities (Anon 1999b).

8.4 Recommended management and control practices

Although the control of locust infestations is a landholder responsibility, locusts are recognised as being a community problem; once locusts start flying they are beyond the effective control capability of any individual landholder. The Australian Plague Locust Commission and the Department of Natural Resources and Mines undertake locust control to prevent plague development and migration, not to protect an individual's crop. The decision to launch a control program is based on many factors, including the:

- stage of development of the locusts
- density of the infestation

- size and location of the infested area
- presence of hazards (including non-target impacts) and sensitive areas
- economics and logistics of undertaking control
- vegetation and weather conditions.

Operational responsibilities are outlined in appendix 3. The Queensland Department of Natural Resources and Mines and the APLC promote preventative control of plagues through the monitoring, prediction and strategic control of locust populations. This approach succeeded in managing outbreaks during the late 1990s, when the control of hoppers and adults as soon as the first bands or swarms formed prevented plagues becoming as severe as those in the 1970s (Hunter et al. 1999; Scanlan et al. 2001).

Successful locust management requires landholders to monitor and report locust activity and control bands at a property level. This proactive action is essential to reducing total control costs and total crop damage. Control of hopper bands allows the largest number to be treated in the smallest area (Symmons 1984).

The continued successful management of locusts depends on continued efforts in monitoring, so problem locust populations can be detected, and action undertaken when necessary. This may require the use of non-chemical treatments (*Metarhizium* products). Currently, *Metarhizium* is only slightly more expensive than chemicals. Because *Metarhizium* acts more slowly than chemicals do, it is more suited to preventive control before locusts are in crops. For the foreseeable future, chemicals will need to be used to treat locusts near crops, but *Metarhizium* should become increasingly important in preventive control as part of a program of integrated pest management of locusts.

It is also important to look to international trends in locust management such as the use of *Nosema* as a biocontrol, or habitat modification, as both these activities can combine with current practices to reduce background population numbers and therefore decrease the occurrence of outbreaks.

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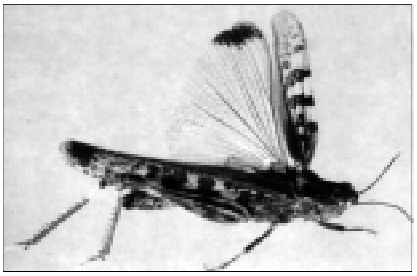
Appendix 1 Identification summary

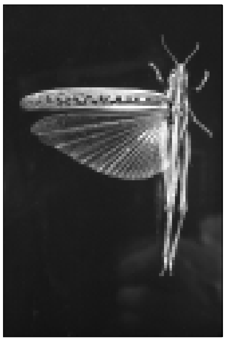
Common locusts

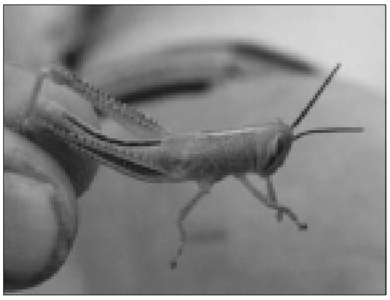
- **Australian plague locust** (*Chortoicetes terminifera*)



(Anon 1996b; Elder et al. 1979)
Adult: Size: 2.0–4.5cm. Females are larger than males.
Body Colour: Grey, brown or occasionally green with pale stripe down the middle of the back.
Features: Large black spot at tip of each back wing.
Hoppers: Difficult to identify but can be controlled in bands.

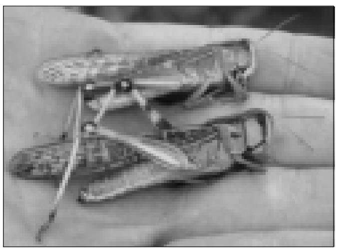
- **Spur-throated locust** (*Austracris guttulosa*)





Adult: Size: 5–8cm in length (from head to tip of closed wings).
Body Colour: pale brown–grey.
Features: Spur between front legs in adult and hopper stages, large size, white stripe on head.
Hoppers: Green on hatching with black stripe all the way down the middle of the back; colour may change to brown as adulthood approaches; rarely walk on 6 legs—usually hop with hind legs.

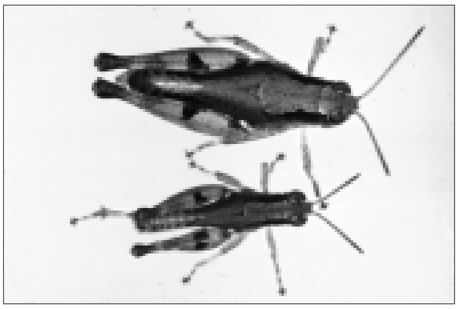
- **Migratory locust** *(Locusta migratoria)*



Adult: Size: 3.5–6.5cm. Females are larger than males
Body Colour: mandibles (jaws) are dark purple to black in colour and inside of hind legs is dark purple.
Features: A dark mouth and hairy 'chest' (downy layer on underside of thorax), clearwing.
Hoppers: Black and tan colour; usually hop only if disturbed—otherwise crawl or march on six legs. Eye stripe is characteristic.

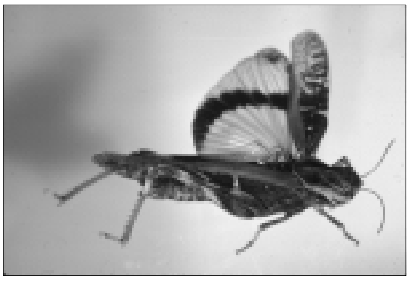
Other locust/grasshopper species

- **Wingless grasshoppers** *(Phaulacridium vittatum)*



(Strong et al*.* 2001a)
Adult: Size: 1.2–1.9 cm long.
Body colour: Brown, the low-density form has two white stripes along the back
Features: Generally wingless, only some adults have wings, when population densities increase.
Hoppers: Hoppers are similar in appearance to adults. They pass through a 5 hopper stages with a moult between each.
Biology: This species have only one generation per year with eggs hatching from October to November and eggs laid in February to April. This species has a strong preference for broad-leafed plants so market gardens can be affected as well as fruit trees and tobacco crops.

- **Yellow-winged locust** (*Gastrimargus musicus*)



(Strong et al*.* 2001b)
Adult: Size: 3.6–5.0 cm long
Body colour: Colour and body shape vary considerably with population density. Solitary individuals have predominantly green and dark brown colouration while gregarious individuals are predominantly dull brown colouration.
Features: This locust has bright yellow hind-wings and the males make a distinctive clicking sound in flight.
Hoppers: Hoppers are similar to adults in colour and shape but they lack fully formed wings. The tip of the mandibles in large hoppers is bright red.
Biology: This species appears to eat only grasses and gramineous crops.

Appendix 2 Insecticides registered in Queensland for locust control

(h) = Hoppers (a) = Adults

Insecticide	Trade name	Type	Formulation	Manufacturer	Rates (of product) per ha: Australian plague locust	Rates (of product) per ha: Migratory locust	Rates (of product) per ha: Spur-throated locust	Withholding period	Remarks
Fenitrothion	Fenitrogard	OP	EC 1kg/L	Aventis	-	270ml (h) 550ml (a)	270ml (h) 550ml (a)	7 days—pasture, sorghum,	Phytotoxicity may occur on many varieties of sorghum
	Fenitrothion 1000	OP	EC 1kg/L	Nufarm, Seajay	325ml (h&a)	400ml (h) 500ml (a)	400ml (h) 500ml (a)	Maize, cereals (grazing)	
	Fenitrothion 1000	OP	EC 1000g/L	Davison, Farmoz	270ml (h) 325 (a)	270ml (h) 500ml (a)	270ml (h) 500ml (a)	14 days—cereals, vegetables,	
	Sumithion ULV	OP	ULV 1.27kg/L	Sumitomo	300ml (h&a)	300ml (h) 400ml (a)	300ml (h) 400ml (a)	Fruit	
	Fenitrothion ULV	OP	ULV 1.28kg/L	Nufarm	200ml (h) 400ml (a)	200ml (h) 400ml (a)	200ml (h) 400ml (a)	Withhold stock from slaughter for 14 days	
	Sumithion 1000	OP	EC 1kg/L	Sumitomo	325ml (h) 420ml (a)	400ml (h) 550ml (a	400ml (h) 550ml (a		
Maldison	Maldison ULV	OP	ULV 1180g/L	Nufarm	550ml (h) 700ml (a)	550ml (h) 700ml (a)	550ml (h) 700ml (a)	1 day—pasture, sorghum, maize	Avoid applying close to uncovered beehives or to areas where bees may be working; apply when bee activity is at a minimum. AERIAL APPLICATION ONLY
	Fyfanon ULV	OP	ULV 1169g/L	Cheminova	700ml	-	-		
	There is no formulation of Maldison registered for ground control in Queensland								
Diazinon	Diazinon	OP	EC 800g/L	Barmac	700ml (h&a)	700ml (h) 850ml (a)	700ml (h) 850ml (a)	2 days—pasture	Harmful to bees—do not apply if bees are actively foraging in the area or in flowering lucerne.
	Diazinon 800	OP	EC 800g/L	Country	700ml (h&a)	700ml (h) 850ml (a)	700ml (h) 850ml (a)	14 days—maize, soybean, sorghum, oilseeds, cereals, sugar cane	
Chlorpyrifos	Bar 500 EC	OP	EC 500g/l	Sanonda	350ml (h) 560ml (a)	350ml (h&a)	1.25L (h) 1.5L (a)	2 days—pasture, sorghum	Phytotoxicity may occur on many varieties of sorghum
	Strike-Out	OP	EC 500g/L	Farmoz	350ml (h) 560ml (a)	350ml (h&a)	1.25L (h) 1.5L (a)	7 days—sugar cane	
	Pyrinex 500 EC	OP	EC 500g/L	Makhteshim	350ml (h) 560ml (a)	-	1.25L (h) 1.5L (a)	10 days—cereals	
	Cyren 500 EC	OP	EC 500g/L	Cheminova	350ml (h) 560ml (a)	350ml (h&a)	1.25L (h) 1.5L (a)		

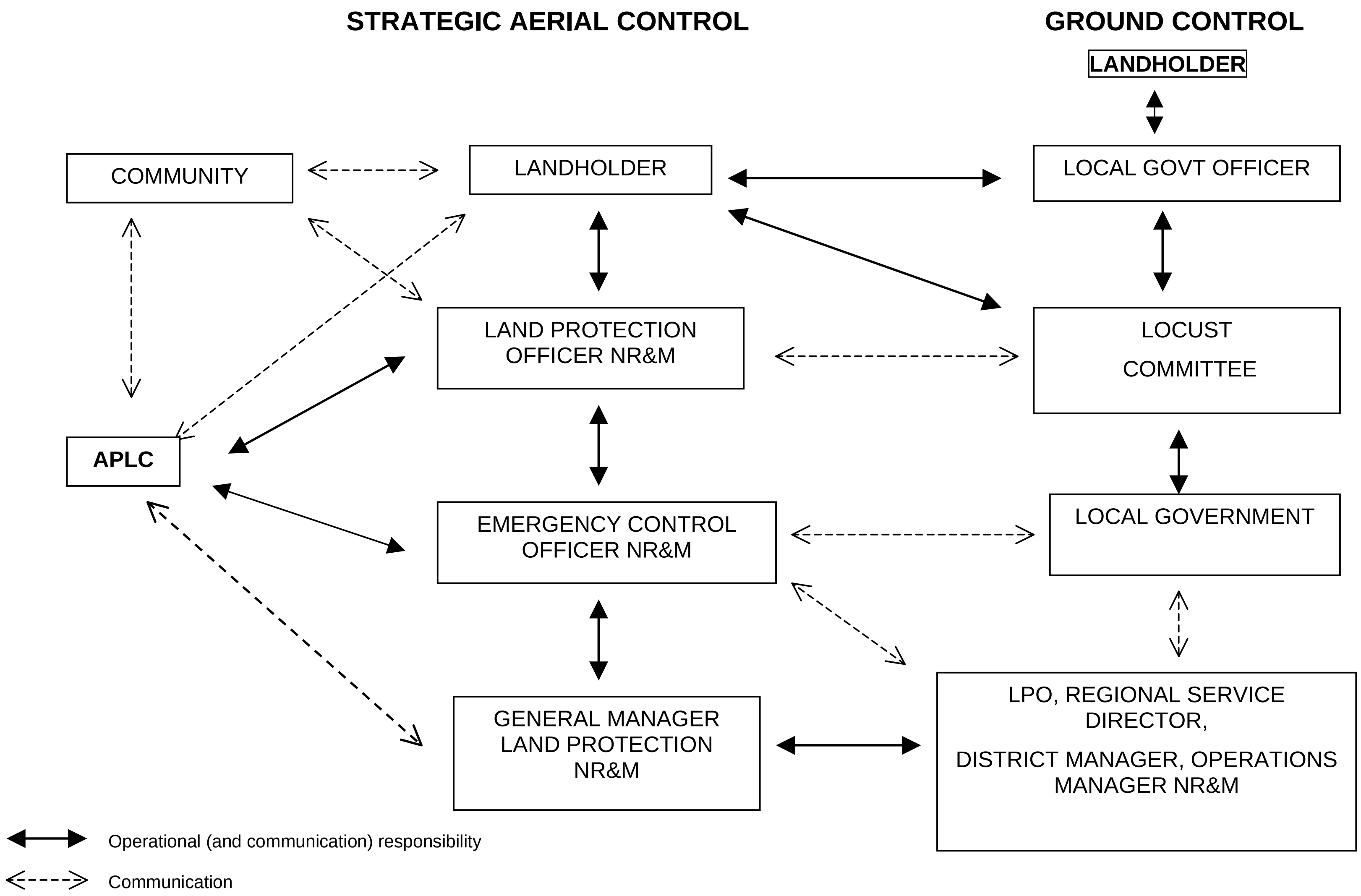
Insecticide	Trade name	Type	Formulation	Manufacturer	Australian plague locust	Migratory locust	Spur-throated locust	Withholding period	Remarks
Chlorpyrifos cont.	Lorsban 500 EC	OP	EC 500g/L	Dow Agrosciences	350ml (h) 560ml (a)	350ml (h&a)	1.25L (h) 1.5L (a)		
	Chlorpyrifos 500 EC	OP	EC 500g/L	Nurfarm, 4 Farmers, Agchem, Davison, Generex	350ml (h) 560ml (a)	350ml (h&a)	1.25L (h) 1.5L (a)		
	Chlorpyrifos 500	OP	EC 500g/L	Country, David Grays, Quadron, Chemag	350ml (h) 560ml (a)	350ml (h&a)	1.25L (h) 1.5L (a)		
	Chlorpyrifos ULV	OP	ULV 500g/L	Nufarm	350ml (h&a)	350ml (h&a)	1.25L (h) 1.5L (a)		
	Chlorpyrifos	OP	EC 500g/L	Lief, Barmac, Sumitomo	350ml (h) 560ml (a)	350ml (h&a)	1.25L (h) 1.5L (a)		
	Kensban 500EC	OP	EC 500g/L	Kenso	350ml (h) 560ml (a)	350ml (h&a)	1.25L (h) 1.5L (a)		
	Optem EC500	OP	EC 500g/L	Cropro/PCT	350ml (h) 560ml (a)	350ml (h&a)	1.25L (h) 1.5L (a)		
	Pest Controller 500	OP	EC 500g/L	Pidgeon	350ml (h) 560ml (a)	350ml (h&a)	1.25L (h) 1.5L (a)		
	Pest One	OP	EC 500g/L	Pest One	350ml (h) 560ml (a)	350ml (h&a)	1.25L (h) 1.5L (a)		
	Chlorpyrimax 500	OP	EC 500g/L	Artfern	350ml (h) 560ml (a)	350ml (h&a)	1.25L (h) 1.5L (a)		
	Iban 500 EC	OP	EC 500g/L	United Phosphorus	350ml (h) 560ml (a)	350ml (h&a)	1.25L (h) 1.5L (a)		
	Protector 500 EC	OP	EC 500g/L	Young	350ml (h) 560ml (a)	350ml (h&a)	1.25L (h) 1.5L (a)		
Carbaryl	Carbaryl 500	C	SC 500g/L	Nufarm, David Grays	1.2L (h) 1.4L (a)	1.2L (h) 1.4L (a)	-	1 day—pasture, forage, crops	Toxic to bees—do not apply during flowering/pollination period. Some damage may
	Bugmaster Flowable	C	SC 500g/L	Aventis	1.2L (h) 1.4L (a)	1.2L (h) 1.4L (a)	-	3 days—vegetables	occur on tender plant foliage following several days of rain or high humidity after spraying
Fipronil	Regent 200SC	PP	SC 200g/L	Aventis	6.25mL (h&a)	6.25mL (h&a)	6.25mL (h&a)	14 days— pasture, sorghum	Mortality will increase to a
	Regent 800WG	PP	WG 800g/kg	Aventis	1.5g (h&a)	1.5g (h&a)	1.5g (h&a)	21 days— withhold cattle from slaughter	maximum over a period of 3–5 days after spraying
	Adonis 8.5UL	PP	ULV 8.5g/L	Aventis	150mL (h&a)	150mL (h&a)	150mL (h&a)		

Key: OP = Organophosphate; PP = Phenyl Pyrazoles; C = Carbamate; ULV = Ultra Low Volume; SC = Suspension Concentrate; EC = Emulsifiable Concentrate

Notes: **Use as a guide only**
Consult your supplier if doubts arise
Always read the product label before use

Prepared by officers from the Animal and Plant Health Service, Department of Primary Industries, Queensland, and Land Protection, Department of Natural Resources and Mines—April 2000.

Appendix 3 The main operational responsibilities and lines of communication for the major stakeholders in locust management



Pest Status Reviews

Others in the series:

Prickly acacia in Queensland

Rubber vine in Queensland

Mesquite in Queensland

Urban Pests in Queensland

Sicklepod in Queensland

Feral pigs in Queensland

House mouse in Queensland

Cabomba in Queensland

Hymenachne in Queensland

Feral Goat in Queensland

Leucaena in Queensland

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