economic costs and benefits of

locust control

in eastern australia

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foreword

The Australian Plague Locust Commission is required to combat outbreaks or potential outbreaks of the Australian plague locust in the four mainland eastern states that could damage rural industries in more than one of these states. This report analyses the benefits and costs of the Commission's control activities from 1999-2000 to 2004-05, focusing on 2004-05. In that year the Commission undertook its largest control operation since commencing operations in 1976, treating 450 000 hectares for locusts.

To assist in planning for future outbreaks, the Commission is interested in assessing the net benefit of its recent activities — in particular, the benefits of controlling locust populations before they reach plague proportions. This report is aimed at assisting in that assessment.

Brian S. Fisher
Executive Director

November 2005

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contents

figures

tables

summary

Under its terms of reference, the Australian Plague Locust Commission (APLC) is required to combat outbreaks or potential outbreaks of the Australian plague locust that could damage rural industries in more than one of Australia's four mainland eastern states. In 2004-05 the Commission undertook its largest control operation since commencing operations in 1976, treating 450 000 hectares for locust bands and swarms. The APLC undertakes aerial operations against locusts, which complement the aerial and ground operations undertaken by state departments of primary industries and the ground operations undertaken by local authorities and landholders.

To assist in planning for future outbreaks, the Commission is interested in assessing the net benefit of its recent activities — particularly the benefits of controlling locust populations before they reach plague proportions. In August 2005 the Commission engaged ABARE to undertake a benefit–cost analysis of its locust control activities from 1999-2000 to 2004-05, focusing on 2004-05.

There are three main pest species of locusts in Australia, the Australian plague locust (*Chortoicetes terminifera*) being the most widespread and the main focus of the Commission's control activities. In some seasons the Commission may also undertake control operations against the spur-throated locust (*Austracris guttulosa*) and the migratory locust (*Locusta migratoria*).

The locust can be a devastating pest to agriculture through its ability to form into dense aggregations of locust nymphs (hoppers) and highly mobile aggregations of adults (swarms) that feed on various plants, often those of economic value to agriculture (crops and pastures). In years when seasonal conditions favor breeding, large populations of Australian plague locust can develop, typically in the rangelands of Queensland, New South Wales and South Australia. Swarms generated in the interior can migrate to cropping areas in New South Wales, Queensland, South Australia and Victoria.

Australian Plague Locust Commission

The Australian Plague Locust Commission was established in 1974 and began operations in late 1976. The Commission is financed by the governments of New South Wales, Victoria, South Australia and Queensland, with a matching contribution from the Australian Government. Large control operations were undertaken by the Commission in 1999-2000 and 2000-01. Locust activity was relatively low in the next two seasons, but in 2003-04 and 2004-05 large scale control operations were again required.

The Commission's expenditure on staffing, field operations and office and other expenses tends to be relatively constant from year to year. In real terms (2004-05 dollars) from 1999-2000 to 2004-05, these costs ranged between $2.6 and $3.1 million a year. However, expenditure directly related to the scale of control operations, such as pesticide expenses and aircraft hire, can vary greatly. In the period examined, these costs varied from zero in 2002-03 to $3.7 million in 2004-05. Total expenditure over the six year period amounted to $27.2 million, an average of around $4.5 million a year in real terms.

Previous studies

There have been relatively few benefit–cost assessments of locust control in Australia. In this study, six previous Australian studies (table 1)

1 Previous Australian studies on locust control

Study	Season(s) analysed	Type of study	Area covered	Locust species
Bullen (1975)	1973-74	Ex post	Eastern Australia	Australian plague locust, spur-throated locust, migratory locust
Wright (1986a,b)	1984-85	Ex post	Eastern Australia	Australian plague locust
McElwee and Walden (2000)	2000-01	Ex ante	Western Australia	Australian plague locust
Miller, Hunter and Strong (2002)	1998-99	Ex post	Queensland	Migratory locust
AECgroup (2002)	50 years beginning 2002	Ex ante	Queensland	Migratory locust
Smith (2005)	2004-05	Ex post	New South Wales	Australian plague locust

were investigated. A variety of methodologies were used in these studies. Some focused on assessing when it would be economic to undertake locust control in a particular season or area, based on experience with similar plagues in the past. Others focused on whether the control operations undertaken in a particular season were cost effective. A key problem investigated in all studies was how to estimate what might have occurred in the absence of control.

International literature on the benefits and costs of locust control was also examined. The bulk of this literature dealt with efforts to control locust plagues in Africa and the Middle East and tended to focus on the 'transboundary' problem — that is, that countries where locust populations develop may have little incentive to control these populations once the 'problem' takes wing and moves to another country. The United Nations plays a pivotal role in coordinating locust control activities in Africa and the Middle East. Australian governments are well aware of the 'transboundary' problem and the APLC was established in recognition of the fact that early response to the Australian plague locust when seasonal conditions favor the development of large populations in the inland can provide benefits to all four mainland eastern states.

After reviewing the Australian literature, the methodology considered most suitable for the current analysis (an ex post analysis of the APLC's activities from 1999-2000 to 2004-05) was assessed as being a variant of the methodology used by Smith (2005). A spreadsheet model was developed and used for the analysis.

Analysis and results

Estimating the composition and value of the green plant matter likely to be attacked by the Australian plague locust in seasons of high locust activity was a key requirement of the analysis. To provide some guidance in this respect, a statistical profile of cropping and grazing in seventeen statistical divisions in the inland areas of New South Wales, Victoria, Queensland and South Australia was developed. All statistics were drawn from Australian Bureau of Statistics' agricultural statistics for the years 2000-01 to 2002-03. These statistics provided detailed figures on crop and pasture area, production, and gross value of production at principal market (generally farm gate or silo delivery).

Individual state profiles were developed for New South Wales, Victoria, Queensland and South Australia (see chapter 4). Given the typical migration pattern within a season of high locust activity (from the interior, to the cropping belt), the seventeen statistical divisions were also aggregated into a 'grazing' group comprising six statistical divisions and a 'cropping' group of eleven statistical divisions.

The main benefits quantified in the analysis were the avoided losses to agriculture from locust control by the Commission. There is very little locust activity or damage to agriculture in winter. However, the potential for damage increases in spring as bands develop and then swarms appear. When seasonal conditions favor the development of large locust populations, there can be three locust generations, in spring, summer and autumn. In some years, the Commission may only need to control a spring generation. In other years it may need to control a spring and a summer generation. In exceptional years, it may need to control all three generations. Locusts will consume a certain quantity of green plant matter even with control. However, control will suppress population development and reduce the consumption peaks.

The value of the loss to agriculture from locust activity in 2004-05, with treatment, is estimated to have been $11.2 million (table 2). However, treatment is estimated to have avoided further potential losses of $55.5 million. The Commission's expenditure in 2004-05 was $6.8 million. The ratio of benefits to costs in 2004-05 from control is therefore estimated to have been around 8:1.

For the period 1999-2000 to 2004-05, which included four years of high locust activity and two years of low activity, the ratio of benefits to

2 Summary of key results
Values in 2004-05 dollars

	2004-05	Average 1999-2000 to 2004-05
	$m	$m
Estimated loss to agriculture with treatment	11.2	4.4
APLC expenditure	6.8	4.5
Estimated further loss to agriculture avoided by treatment	55.5	29.4
Benefit–cost ratio	8.1	6.5

costs from the Commission's activities is estimated to have been around 6.5:1. These benefit–cost ratios are lower than those estimated for locust control in some other studies; however, comparison between studies is not valid because of the different methodologies employed and/or the different seasons examined.

The two input variables possibly subject to the greatest degree of uncertainty in the analysis are the density of the locust bands and swarms, and the percentage loss in the value of crops and pastures because of locust attack. Sensitivity analysis of these two variables indicate that if the respective values assumed in the reference case were both halved, the ratio of benefits to costs for the APLC's operations would still have been greater than one.

Social, trade and environmental benefits and costs

Treatment of locusts can also have a number of social, trade and environmental benefits and costs, which are discussed qualitatively in chapter 6 of this report.

An estimated 1.7 million people reside in the seventeen statistical divisions in eastern Australia potentially subject to locust activity, mostly in the towns and cities of the cropping belt. Swarms of locusts can constitute a hazard to motorists, and in years of high locust activity, in the absence of control, many of the estimated one million vehicles in these locust prone areas would require insect screens to be fitted and to have their exteriors and engine bays thoroughly cleaned after being driven through locust swarms.

As the treatment of locusts involves the use of pesticide, pesticide residues in meat are also a potential issue. Studies undertaken have concluded that the slaughter withholding period of fourteen days currently approved by the National Registration Authority is sufficient to avoid this problem. The APLC also has the option of applying a biopesticide in place of conventional pesticides where required. The effects of pesticide use on nontarget species are also a potential issue. Again, studies undertaken to explore this issue have concluded that the effects on nontarget species tend to be transitory.

The benefits of locust control are largely nonexclusive and nonrival in nature. Therefore the only efficient way to provide these services is through direct public expenditure.

introduction

Objective

Under its terms of reference, the Australian Plague Locust Commission is required to combat outbreaks or potential outbreaks of the Australian plague locust in the four mainland eastern states that could damage rural industries in more than one of these states. In 2004-05 the Commission undertook its largest control operation since commencing operations in 1976, treating 450 000 hectares for locust bands and swarms.

To assist in planning for future outbreaks, the Commission is interested in assessing the net benefit of its recent activities, in particular, the benefits of controlling locust populations before they reach plague proportions. In August 2005 the Commission engaged ABARE to undertake a benefit–cost analysis of its locust control activities from 1999-2000 to 2004-05, focusing on 2004-05.

Locust control is also undertaken by state departments of primary industries, local government authorities, and landholders. In Queensland and northern New South Wales, the spur-throated locust and migratory locust can also reach plague numbers in some seasons. This report, however, concentrates specifically on examining the benefits and costs of the APLC's control activities for the Australian plague locust.

Some of Commission's activities may provide indirect benefits to other authorities by way of the development of new technologies and the provision of a centralised pool of expertise in locust control. These potential benefits are acknowledged here, but not quantified.

Locusts

There are three main pest species of locusts in Australia — the Australian plague locust (*Chortoicetes terminifera*), the spur-throated locust (*Austracris guttulosa*) and the migratory locust (*Locusta migratoria*). All are native to Australia. The Australian plague locust is confined in distribution to Australia, while the spur-throated locust is also found in Indonesia, the Philippines, Papua New Guinea and offshore islands. Various subspecies of the migratory locust are found throughout the warmer regions of the world (DAFF 2005).

The locust can be a devastating pest to agriculture owing to its ability to form into dense aggregations of locust nymphs (hoppers), which known as bands, and highly mobile swarms of adults. The highly mobile nature of swarms and their ability to migrate over large distances mean that virtually all agricultural areas in inland Australia are at risk from locust attack. Damage by locusts is often confined to pasture, although crops, particularly young winter cereals, are also susceptible. Damage can also occur to vegetable crops, particularly seedlings (DAFF 2005).

In any season, the area affected by locust bands and swarms will depend largely on where significant rain has fallen and which way the wind displaces migrating swarms. Outbreaks of the Australian plague locust are particularly frequent in inland New South Wales and South Australia because of the proximity of these areas to the usual source of breeding, the Channel Country of south west Queensland. In some years, swarms of Australian plague locust can also reach as far as the cropping areas of Victoria or eastern Queensland. Separate locust outbreaks can also occur in Western Australia (DAFF 2005).

The Great Dividing Range generally acts as a natural barrier to migrating locusts, protecting coastal areas of eastern Australia from invasion. Areas of regularly higher rainfall also have fewer locust problems because parasites and diseases keep locust numbers in check.

Geographic spread

Detailed maps of the areas affected in recent years by locusts can be found in the APLC's annual reports. The statistical divisions in which moderate to major locust activity (nymphal

3 Areas of moderate and major locust activity

	1999-2000		2000-01		2001-02		2002-03		2003-04		2004-05	
	B	S	B	S	B	S	B	S	B	S	B	S
New South Wales												
Northern						▲	●		●	▲	●	▲
North western	●	▲				▲	●			▲	●	▲
Far west	●	▲	●							▲	●	▲
Murray		▲	●	▲						▲	●	▲
Murrumbidgee	●	▲	●				●			▲	●	▲
Central west	●	▲								▲	●	▲
Queensland												
Central West									●		●	▲
South West	●	▲	●						●	▲	●	▲
Darling Downs												
Victoria												
Mallee		▲	●							▲		
Wimmera		▲										
Loddon										▲		
Goulburn										▲		
South Australia												
Northern	●	▲	●	▲								▲
Murray lands		▲	●	▲								
Yorke–Lower north		▲	●	▲								
Eyre		▲	●	▲								

● B = Nymphal band. ▲ S = Adult swarm.
Source: Based on locust distribution maps in the annual reports of the Australian Plague Locust Commission.

sub-bands and bands, and adult locusts in numerous or concentrated density, or swarms) has occurred are shown in table 3. In accordance with map conventions, circles are used to denote band activity, and triangles, swarm activity.

During the 1999-2000 and 2000-01 outbreaks, locusts reached the cropping belt areas of New South Wales, Victoria and South Australia. However, during the 2003-04 and 2004-05 outbreaks, the main areas attacked were in New South Wales.

The total area of agricultural holdings (2000-01 to 2002-03 average) in the seventeen statistical divisions in table 3 was 182.9 million hectares, which represented two thirds of the total area of holdings in the four mainland eastern states. The average area of crops was 14.1 million hectares (86 per cent of cropped area), and the average value was $10 billion (in 2004-05 dollars) (65 per cent of total value).

The seventeen divisions also contained 10.7 million hectares of sown pastures (52 per cent of sown pasture area) and 96.7 million hectares of native pastures (65 per cent of total area). In terms of individual crops, the divisions contained, on average, 6.7 million hectares of wheat (94 per cent of total area), 2.4 million hectares of barley (94 per cent), 122 000 hectares of rice (100 per cent) and 88 000 hectares of grapes (82 per cent).

An estimated 1.7 million people reside in the seventeen statistical divisions — 44 per cent in New South Wales, 29 per cent in Victoria, 14 per cent in Queensland and 13 per cent in South Australia. Around 370 000 (22 per cent) resided in the ‘grazing’ divisions and 1.33 million in the ‘cropping’ divisions (see chapter 4).

In years when weather conditions favor the development of large locust populations, therefore, a significant area of eastern Australia can potentially be affected.

Australian Plague Locust Commission

The Australian Plague Locust Commission was established in 1974 and began operations in late 1976. The Commission is financed by the governments of New South Wales, Victoria, South Australia and Queensland, with a matching contribution from the Australian Government (APLC 2000). Under its terms of reference, the Commission is required to combat outbreaks or potential outbreaks of the Australian plague locust in the four mainland eastern states that could damage rural industries in more than one of these states.

The Commission is also required to engage in operations against the spur-throat locust and/or the migratory locust in situations where there is the potential for damage in both Queensland and New South Wales. The Commission may also conduct operations against either of these species where the threat is confined to only one of these two states at the invitation of, and at cost to, that state.

The types of operations undertaken by the Commission include:

- collecting and collating data on the Australian plague locust, spur-throated locust and migratory locust
- forecasting significant changes and developments in locust populations
- undertaking control operations
- developing improved control measures and strategies
- monitoring all actions and the effects of control operations
- providing assistance to individual states through advice on local problems associated with the three locust species.

Activity in recent seasons

The level of locust activity and the required response to it varies from season to season.

1999-2000

In 1999-2000, exceptionally wet conditions over large areas of the semi-arid and arid zones, combined with repeated successful locust migrations to areas of high rainfall, caused the development of locust plagues on both sides of the continent. This was the first time on record that plagues had developed in both eastern and western Australia in the same season (APLC 2000).

The season began with moderate hatchings in agricultural districts of eastern New South Wales. Part of the residual spring generation apparently migrated into far western Queensland where heavy rainfall subsequently fell in late November 1999. Migrations from the agricultural zones of eastern Australia into the interior were thought to be rare but would explain the rapid buildup of populations in the interior in early summer.

More heavy rain fell over a large area of northern South Australia and New South Wales in February 2000, enabling adults from this summer generation to migrate and breed rapidly from White Cliffs to Lake Eyre, areas that are not normally suitable for breeding. Control efforts in Queensland in January were impeded by floodwaters, and the resulting adults migrated into agricultural districts of South Australia and New South Wales in early April. Extensive autumn swarm operations were undertaken to try to prevent a much larger plague from developing in the spring.

The separate outbreak that also developed in Western Australia after record spring and summer rainfall led to widespread breeding and the invasion of agricultural areas in the autumn.

2000-01

Following on from developments in autumn 2000, large scale control operations were undertaken through spring 2000 in western New South Wales and in South Australia. The locust campaign in South Australia was the largest on record for that state, requiring a substantial control effort by the South Australian Department of Primary Industries and Resources (PIRSA). The Victorian Department of Natural Resources and Environment (VNRE) also coordinated smaller scale ground and aerial control operations in the Mallee and Wimmera districts of western Victoria in spring.

The operations conducted in South Australia and New South Wales were effective in substantially containing and reducing a major locust population that had the potential to cause substantial crop damage if migration had occurred. By early summer 2000, however, the general onset of dry conditions throughout much of the southern part of eastern Australia prevented any substantial continuation of locust breeding during the late summer and autumn of 2001 (APLC 2001).

The extensive spring campaign (which involved the APLC, state governments, local authorities and landholders) also provided the opportunity to gain experience with two additional control agents that were introduced for operational use in 2000-01. These were the biopesticide Green Guard (*Metarhizium*), which was used operationally under permit from the National Registration Authority (NRA) against hopper bands in the Riverina area of New South Wales, and fipronil, which was used against hopper bands.

Agreement was also reached in the 2000-01 season between the Department of Agriculture, Fisheries and Forestry and the Commission member States to allow the APLC to carry over funds not utilised in any year to a reserve. Funds accumulated in the reserve in years of low locust activity were to be used in periods of major locust activity where expenses were likely to exceed the Commission's annual revenue. The ability to carry over funds was regarded as a means of reducing ad hoc requests for supplementary funding by the Commission to member states in years of high locust activity.

2001-02

Locust activity was comparatively low in 2001-02. A small but intense outbreak occurred between Quilpie and Windorah in western Queensland following heavy rainfall during January 2002. While the low numbers of locusts present during the year limited trials, advantage was taken of higher density populations in Western Australia to progress trials on the use of *Metarhizium*. Further *Metarhizium* trials were also undertaken against grass-hopper infestations in South Australia and Queensland (APLC 2002).

2002-03

In 2002-2003, locust numbers in eastern Australia were limited by persistent, severe drought. As a result, APLC survey operations were scaled back and no control activities were required. Expenditure was significantly lower than in the 1999-2000 and 2001-02 seasons, and the Commission posted an operational surplus of $1.2 million. The low level of locust activity in 2001-02 and 2002-03 allowed the APLC reserve to accumulate to over $3 million (APLC 2003).

2003-04

Locust activity increased in 2003-04. A major outbreak in the Channel Country of south west Queensland developed rapidly following heavy drought breaking rainfall. The scale and density of the band infestation in western Queensland in February and March 2004 was one of the largest ever encountered in the area. Treatment in the Windorah–Quilpie area resulted in substantial reductions in the locust population and helped to validate the APLC's integrated control strategy of combining barrier treatment with fipronil against hopper bands with the use of biopesticide. Despite this, however, other smaller scale locust infestations developed simultaneously in adjacent parts of Queensland and in northern New South Wales (APLC 2004).

The frequency of autumn migration and redistribution in 2003-04 was also exceptional, particularly in New South Wales. There appeared to be several migrations and substantial redistributions of locust populations during March and April. These were most likely a response not only to the generally dry unfavorable locust breeding conditions that prevailed during autumn in many areas but also to the unseasonally warm meteorological conditions in April 2004, which extended the potential for locust night migration.

In 2003-04, several years of collaborative research between the APLC, CSIRO and industry culminated with the *Metarhizium* biopesticide (Green Guard) being submitted for final registration in June 2004.

Another significant research activity completed in 2004 was the detailed study of locust migration. The results of this study suggested that frequent migratory exchange could occur between western Queensland and areas in New South Wales, South Australia and eastern

Queensland. The discovery that locusts in New South Wales and South Australia might migrate northwards into Queensland in late spring has important implications for future control strategies.

2004-05

The major plague that developed in New South Wales in 2004-05 was one of the largest in recent times. The large locust populations that developed in the spring were well beyond the level that had been expected given the size of the adult population in the autumn, the relatively poor autumn breeding conditions over much of the state, and the relatively few reports of egg laying that had been received (APLC 2005).

There was substantial summer breeding in southern New South Wales and central Queensland following significant redistribution of adults by both day and night migration in December 2004. The locust populations that developed in both these areas were eventually contained by substantial control activity in January through to March 2005, and a major swarm invasion of Victoria was prevented. The onset of dry conditions in the autumn meant that further locust breeding was limited, although some small, possibly moderate scale, breeding did occur in parts of southern New South Wales and northern Victoria.

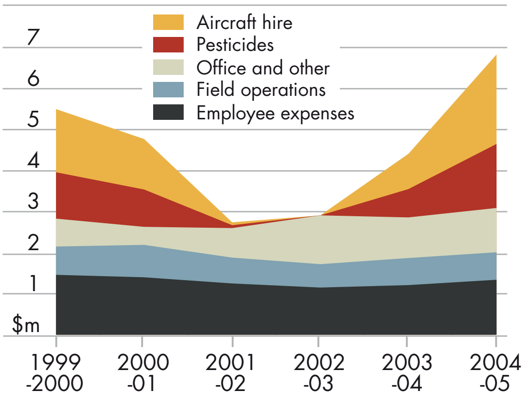
The scale of the control measures undertaken by the Commission in 2004-05 was unprecedented. Nearly 450 000 hectares was treated in the largest control effort undertaken by the Commission since it began operations in 1976. Fipronil was used as a barrier treatment against both hopper bands and swarms, with the extensive use of *Metarhizium* in environmentally sensitive areas.

Revenues and costs

An examination of the APLC's expenditure over the six years 1999-2000 to 2004-05 shows that in real terms (2004-05 dollars), expenditure on staffing, field operations and office and other expenses tended to be relatively constant from year to year. However, expenditure directly related to the scale of control operations, such as pesticide ex-penses and aircraft hire, varied greatly, in line with the scale of operations (figure A).

From 1999-2000 to 2004-05, the cost of staffing, field operations and office and other expenses varied between $2.6 and $3.1 million a year, while pesticide expenses and aircraft hire varied from zero in 2002-03 to $3.7 million in 2004-05. Total expenditure over the six year period was $27.2 million, an average of around $4.5 million a year in real terms. Total expenditure in 2004-05 was $6.8 million (table 4).

A **APLC expenses, by category**
In 2004-05 dollars



4 APLC expenditure

		1999-2000	2000-01	2001-02	2002-03	2003-04	2004-05
Nominal	$'000	4 671	4 285	2 535	2 777	4 296	6 835
Real	2004-05 $'000	5 502	4 766	2 741	2 911	4 402	6 835
CPI	2004-05 = 100	84.9	89.9	92.5	95.4	97.6	100.0

Source: Australian Plague Locust Commission annual activity reports.

The APLC's nominal dollar expenditure was converted to 2004-05 dollars using the Australian consumer price index series from Reserve Bank of Australia statistics.

Area treated

The area treated by the Commission for bands and swarms in recent years is shown in table 5. In three out of the six years, around 2000 square kilometres (200 000 hectares) were treated, while a record 4500 square kilometres were treated in 2004-05. In contrast, very little treatment was required in 2001-02 and 2002-03.

5 Summary of APLC control operations

		1999-2000	2000-01	2001-02	2002-03	2003-04	2004-05
Targets	no.	571	359	18	0	246	958
Quantity applied	L	54 735	44 627	2095	0	38 256	26 173
Area treated	km^2	2 616	1 908	133	0	2 005	4 493
Area treated, by type							
– band	km^2	1 310	1 177	133	0	1 476	1 878
– swarm	km^2	1 306	732	0	0	529	2 615
– band	%	50	62	100	0	74	42
– swarm	%	50	38	0	0	26	58
Area treated, by state							
– New South Wales	km^2	2 151	1 572	0	0	130	3 599
– Queensland	km^2	232	89	133	0	1 875	894
– South Australia	km^2	233	248	0	0	0	0
– New South Wales	%	82	82	0	0	6	80
– Queensland	%	9	5	100	0	94	20
– South Australia	%	9	13	0	0	0	0

Source: Australian Plague Locust Commission annual activity reports.

previous economic studies

There have been relatively few benefit–cost assessments of locust control in Australia. Six previous Australian studies are reviewed in this chapter. A variety of methodologies were used in these studies. Some focused on assessing when it would be economic to undertake locust control in a particular season or area, based on experience with similar plagues in the past. Others focused on whether the control operations undertaken in a particular season were cost effective. A key problem investigated in all studies was how to estimate what might have occurred in the absence of control.

Australia

Bullen (1975)

F.T. Bullen's detailed 1975 report to the Reserve Bank of Australia on the economic effects of locusts in eastern Australia (Bullen 1975) has been drawn on by most subsequent studies. The report covered the period January 1973 to July 1975, in which the author worked with the CSIRO Division of Entomology, Canberra. The study period coincided with the 1973-74 locust plague, which at that time was the worst plague experienced since 1934-35.

Bullen noted that locusts have always been recognised as one of the many hazards to agricultural production in Australia since such production first moved into inland areas well over a hundred years ago. Of the several locust species in Australia, the Australian plague locust had traditionally received the most attention because it frequently reached high levels of infestation in areas of high agricultural productivity in eastern Australia. The large plague of 1934-35 had prompted research into the plague locust's basic biology, life history, response to environmental factors, and movements in relation to meteorological features. However, little had been published to the early 1970s on the damage caused to agriculture by locusts and the economic effects.

While concentrating on the Australian plague locust, Bullen also examined two other species that had also increased to plague levels in 1973-74, the spur-throated locust and the migratory locust. Although plagues of these two species were relatively rare, during the 1973-74 plague they were believed to have caused as much damage as the Australian plague locust. Bullen examined the way in which the plagues of all three species had developed during 1973-74 and the geographic extent of the areas infested. This helped determine where and when crops and pasture were at risk from locust attack and, as a consequence, the geographic distribution of potential damage to crops and pasture.

Geographic extent of the 1973-74 plague

Bullen noted that the plague began to develop in the spring of 1972 as considerable populations of hoppers developed in south east Queensland, northern central and southern New South Wales, northern Victoria and South Australia from the over-wintering eggs laid by the last generation of the previous plague in the autumn of 1972. During the spring of 1972, most inland areas of south eastern Australia experienced below average rainfall, and most of these locusts had died out by summer. However, localised heavy rain in spring resulted in successful hatching and hopper band formation in a relatively small area in central Queensland, which produced adult swarms that had moved first into south west Queensland and then during January and February 1973 in a south easterly direction into north west and central New South Wales.

Successful breeding by these populations had resulted in the formation of young swarms that were displaced mainly at night in March and April 1973 to the south into southern New South Wales and northern Victoria, to the east into northern and central New South Wales, and to the south west into South Australia. This generation laid over-wintering eggs over a very large portion of south eastern Australia. In the following spring of 1973, hatching commenced in September and by October hopper bands were exceptionally widespread. Despite extensive control operations, many adult swarms formed in late October and early November. At this point the plague had reached its peak and was greater in geographic extent and estimated population size than any other plague since the 1934-35 plague. A map in Bullen's report summarising the locust situation in November 1973 shows infestation stretching across most inland agricultural and pastoral areas of south east Australia, particularly in western and central New South Wales, northern Victoria, and the south east of South Australia.

Extensive movement by young adult swarms continued into early summer. However, many swarms originating from the north west of New South Wales were apparently swept out to sea, as rafts of locusts were found at sea off the southern coast of South Australia and washed up on beaches in north western Tasmania.

The summer of 1973-74 was exceptionally wet in most inland areas of eastern Australia, resulting in rapid growth of pasture. While the rapid pasture growth was initially of advantage to the locusts its unusual abundance eventually created a habitat unfavorable for them. The swarms that laid over-wintering eggs during the spring of 1974 did so at the extreme southern edges of their potential range. This, together with the cooler conditions experienced across much of the inland during the spring of 1974, resulted in the plague locust population being at a very low recession level during 1974-75.

On the other two locust species, the spur-throated locust plague originated in substantially the same area and for the same reason as the Australian locust plague, but affected mainly the agricultural and pastoral areas of inland southern Queensland and northern New South Wales. In what was considered to be a very unusual occurrence, considerable number of locusts crossed the northern tablelands of New South Wales to breed on the New South Wales north coast. The development of the spur-throated locust plague was greatly assisted by the exceptionally heavy summer rainfall of 1973-74, and by the then-recent increases in the area of improved pasture grasses and summer grown cereal crops in northern areas.

Finally, the migratory locust plague began in Queensland's central highlands and remained largely confined to that area. Bullen noted that the recent clearance of large areas of Brigalow scrub and its replacement by introduced pasture grasses and summer grown sorghum crops had vastly increased the area of ideal habitat for the migratory locust in Queensland.

Frequency of plague occurrence

Based on an examination of past records of Australian plague locust activity back to 1844, Bullen concluded that the previous plague of similar extent to the 1934-35 and 1973-74 plagues had occurred in 1889–91. A moderately severe plague had also occurred in 1954-55. While the time series evidence was too short and incomplete for a valid statistical analysis, based on the historical record, Bullen concluded that severe plagues of the Australian plague locust appeared likely to occur once in about every forty years, while moderate to very extensive plagues appeared likely once in about every twenty years, and local population upsurges every two or three years. (It should be noted that these were Bullen's own conclusions based on information available up to 1974. Based on more recent experience some authorities consider that moderate to very extensive plagues have the potential to occur more frequently than this.)

Severe plagues of the spur-throated and migratory locust were regarded as unusual, although the expansion of agriculture and pastoralism in these species' traditional areas was believed to have increased the area of ideal habitat and to have created the potential for more frequent plagues in the future.

Biological factors affecting locust damage

Bullen noted that the main underlying cause of locust damage was the occurrence of the insect at times of very high densities, creating a much higher herbivorous biomass per unit area than was the case for most other insects. The amount of vegetation consumed per unit area could be large, constituting an economic problem if this vegetation had a high value to agriculture. Locusts were also highly mobile, particularly at high adult densities, which had the effect of distributing, and to some extent dispersing, the damage potential over a wide area. While the initial increases in locust populations were usually in areas of comparatively low agricultural productivity, by subsequent long range movement, the locusts were transported into areas of much greater productivity where their feeding potential had a much greater economic impact.

The damage caused by locusts was affected by a number of factors, including habitat preferences, feeding preferences, feeding rates, and density and movement. The suitability of the habitat provided by a particular area of crop or pasture could vary, affecting the probability of the area being heavily infested and damaged. The extent to which particular crops or pastures were preferred as food plants by locusts could also affect the vulnerability of particular plants to attack. The amount of vegetation lost per unit area could also vary depending on the time that the locust population was in contact with it. Finally, the vegetation's response to this loss could vary, depending on its stage in the plant cycle, and subsequent seasonal conditions.

Wright (1986a,b)

In two papers published in 1986, Wright assessed and reviewed the various ways that wheat crops can be damaged by locust attack, and estimated the damage to crops and resulting losses to agriculture that could have occurred in eastern Australia in the 1984-85 plague if no locust control had been undertaken. By comparing this estimate of potential damage with the actual cost of control operations, Wright calculated a benefit–cost ratio for control operations in 1984-85.

Wright (1986a) noted that locust outbreaks and plagues were frequent but short lived. Most plagues began with at least two generations of successful breeding in the south west arid interior of Queensland and adjacent areas in New South Wales and South Australia. A buildup of numbers in the interior could be followed by major night migration that could cover 1500 kilometres in three or four nights, leading to a sudden invasion of agricultural land in southern New South Wales, northern Victoria and central South Australia, usually in late summer (December–February) or in early autumn (March–May). The invaders laid eggs, which over-wintered. The subsequent spring hatching usually marked the peak of the plague, which then usually died out after failure to breed during the summer drought.

Wright noted that locusts have two phases: nymphal (hoppers) and adults (winged). Nymphs have five stages, or instars, in the four to five weeks before they reach the adult stage. When numbers are high, wingless nymphs form dense bands that march together, while adults mass together in flying swarms. Bands usually form in the third instar, and disperse late in the fifth. Bands vary in size, but can be up to 5 kilometres long and 100 metres wide, with a density of 2000 insects per square metre or more at the leading edge, or ‘front’. Hoppers in a band march as a unit and can travel up to 2 kilometres in a day (though typically less than this).

Adult swarms can vary in size from 1 to 25 square kilometres, with a density often exceeding 80 adults per square metre. Night migration can occur if adults accumulate fat from green pastures. Following night migration, adults mature and lay eggs in the invasion area, regardless of drought or dry conditions. Swarms usually form after night migration in the invasion area, but when conditions are dry, adults do not migrate and persist locally, flying during the daytime. Daytime flight tends to occur only if conditions are windy, or when the daytime temperature is greater than 20˚C but less than 35˚C. Flight is below 15 metres, and trees can inhibit flight. Locusts can form a highly mobile ‘dust cloud’ swarm that can travel as much as 20 kilometres a day (but more typically, around 5). In dry conditions, a swarm can last up to four weeks (and some up to ten weeks). Numbers then decrease rapidly and the swarm can disappear without laying.

Wright noted that the Australian locust is usually (though not always) a one-season pest, dying in the summer drought without laying. Therefore, there is usually no carryover effect from control, since new outbreaks will result from fresh invasions from interior. Control is aimed at reducing the scale of outbreaks and preventing migration. Both hopper bands and adult swarms cause damage, but a majority of damage is caused by swarms, which can also move much further and much faster than bands. Therefore, there can be a large benefit from controlling locusts at the hopper stage.

The economic analysis detailed in Wright (1986a) had four key elements. First, the actual damage caused by the 1984-85 locust plague (inclusive of both the band and swarm components) was assessed, based on crop surveys conducted in the affected areas. These surveys identified the different types of crops that had been attacked in each region and the extent of the damage caused to each crop.

Second, an assessment was made of the reduction in crop yield, and of the financial costs associated with yield downgrading. The amount of crop lost was estimated on the basis of the actual yield and the potential yield for each particular crop, while the financial costs for each particular crop were estimated using partial budgets. Combining the two gave an overall estimate of the total cost of damage. Wright noted that the relationship between initial apparent damage and final yield was complex because of regrowth, compensation or resowing. The overall cost of the damage could often be greater than the final reduction in yield, as additional costs were incurred, such as the costs of resowing or drying when harvested.

Third, an estimate was made of the effect of control on locust numbers based on samples taken of the plague before and after control, which also took account of mortality in the population.

Finally, an estimate was made of the potential damage that the plague could have caused in the absence of control. This required an estimation of values for six variables that took into account various factors such as the size of the plague, where and how far the plague might have spread in the absence of control, the types of crops in the areas assessed as potentially at risk, and the possible damage that locusts could have caused to these crops.

In a related paper, Wright (1986b) investigated the damage done by locusts specifically to wheat crops. The damage was of two types — damage to the wheat ear, and damage to the plant itself. Locusts usually damaged the wheat ear by severing it at its base as they fed. Both nymph and adult locusts could cause this type of damage. If the damage occurred at the milky ripe stage, the whole grain could be lost.

The second potential type of damage was defoliation of the wheat plant. In this type of damage, the timing of the attack was critical to the effect on yield. The most critical period was between anthesis and seven to ten days after. If an attack occurred during anthesis, it was possible that the number of grains would be reduced. An attack soon after anthesis could reduce the ability of the plant to fill the existing set grains. However, attacks after seven to ten days after anthesis, even if severe, were generally found to have no effect on yield.

The effect of a plague attack on the growth and yield of wheat therefore depended on the complex interaction between the pest's biology and behavior, its density and distribution within the crop, and the timing of the attack in relation to plant growth. The severity and area of defoliation by bands was found to increase progressively with nymphal size, and was not simply a direct function of the size and length of time of infestation. Band and swarm movement was determined by a number of biological and environmental factors, including the microclimate of crop — itself a function of vegetation density and height, local climate (locusts have an optimum development temperature that affects band width and density during the day, and attempt to reach this optimum), age, and the gregariousness of the population.

McElwee and Walden (2000)

McElwee and Walden calculated a benefit–cost ratio for ex ante locust control in Western Australia for 2000-01 using a method similar to Wright's. The two key variables in McElwee and Walden's analysis were the area susceptible to attack as a proportion of the total area of the crop, and the likely percentage loss in yield from attack.

McElwee and Walden first estimated the costs of running the locust control program, which comprised mainly pesticide, equipment and labor costs. All the different potentially affected shires were then categorised by a 'locust rating' from zero (lowest risk of attack) to five (highest risk of attack). The type and amount of area at risk in each shire was then assessed. The plants of agricultural importance considered were grain (pasture, wheat, barley, oats, triticale, lupins, chickpeas, peas and canola), pastures, horticultural crops (nurseries, vegetables, orchard fruit, nonorchard fruit and grapes) and trees.

The damage potentially caused to each of these plants was then calculated, based on an estimate of the percentage potentially lost, which was calculated as the product of the percentage of the crops that could be attacked and percentage yield loss that the locusts would cause to the area attacked. Potential damage was estimated for each plant type.

Because McElwee and Walden were assessing the potential value of damage to a much wider range of plants than Wright (who assessed the potential value of damage only to crops), these authors used a slightly different method to calculate the potential value of damage to pastures. The latter was estimated as the product of the replacement cost of feed, the percentage loss of pasture, and the number of cattle and sheep in the area. Crop and horticultural damage were calculated as the product of the percentage loss and the gross value of the crop or horticultural product. The gross value of crops was calculated based on area, production per hectare and the gross price, while tree damage was based on the percentage loss and replanting costs.

Summing the estimated value of the potential damage to each different plant type gave an estimate of the overall potential value of damage. The estimate was based on an assumption that the outbreak would be comparable in size with the 1990 plague, and that control would reduce the damage by 85 per cent. These numbers, combined with the costs of the program and the fraction of control that was attributable to the program, were used to calculate a benefit–cost ratio.

Three other scenarios were also considered, damage of a smaller magnitude (half the damage), and damage of a larger magnitude (twice and four times the damage). Each scenario was also given a different value for the percentage of damage controlled. McElwee and Walden calculated that if the 2000 outbreak turned out to be as severe as the 1990 outbreak, the ratio of benefits to costs from control could be 1.3:1. If the 2000 outbreak turned out to be four times the size of the 1990 outbreak, the ratio of benefits to cost could be 2.5:1.

AECgroup (2002) and Miller, Hunter and Strong (2002)

In 2002, the AECgroup examined the economic impact of state and local government expenditure on weed and pest management in Queensland. A wide range of weeds and pests were considered, including plague pests such as locusts and mice. The evaluation of the impact of plague locusts was based on an evaluation by Miller, Hunter and Strong (2002) of the impact of the 1998-99 migratory locust plague in Queensland. To fit with the other case studies, the AECgroup analysis adopted a fifty year time horizon when calculating benefit–cost ratios for control. The AECgroup analysis therefore became an ex ante analysis of locust control in the long term, with the costs and benefits amortised and applied over the length of the analysis on the assumption that a serious locust plague occurred approximately every five to ten years. The stream of net benefits was discounted to a present value and a benefit–cost ratio for locust control of 17.4:1 was calculated.

The main assumption in the analysis found to affect the outputs of the model was the length of time between plagues. In the model used, this was a linear relationship, so that if the expected time between plagues was halved, the net benefit from preventing or ameliorating plague pests was doubled, and vice versa.

Smith (2005)

In mid-2005 the New South Wales Department of Primary Industries undertook a benefit–cost analysis of the locust control operations in New South Wales initiated over the 2004-05 summer (Smith 2005). The analysis, which included control operations by the APLC, DPI and landholders, was provided to ABARE in draft form as a spreadsheet and is treated here as a personal communication. Smith's approach involved far less dependence on a detailed spatial assessment of areas at risk and the likely direction of locust spread than the approaches used by Wright, and McElwee and Walden.

Smith reported that in 2004-05 a total area of around 14 300 square kilometres had been treated for locusts in New South Wales — 3500 square kilometres by the APLC, 4000 square kilometres by the New South Wales Department of Primary Industries, and 6800 square kilometres by landholders (based on the total volume of pesticide issued, and assumed to be applied at the recommended rates). The area treated aerially by the APLC and DPI had been done so with each party supplying their own pesticides and labor. The area ground treated by landholders had been done using pesticides supplied by the DPI and labor supplied by the landholder. The total costs of treatment in 2004-05 by all three parties in New South Wales were estimated by the NSW DPI to be in the order of $50 million.

Smith noted that according to the 2001 ABS Agricultural Census, the total area of sown pasture in New South Wales in 2000-01 was 294 180 square kilometres. The actual area treated for locusts in 2004-05 was therefore equivalent to around 5 per cent of the state's sown pasture area. Of the total 14 300 square kilometres treated, 9150 square kilometres were treated for bands and 5150 square kilometres for swarms.

These bands and swarms would have eaten a certain amount of green plant matter per day, the total quantity of which would have depended on the density of the insects and the amount consumed per insect. Insect density can be highly variable, and the effect of assuming different densities was subsequently explored using sensitivity analysis.

The tonnage of green plant matter consumed per day by bands and swarms was estimated based on assumed insect density and daily green plant matter consumed per insect. The tonnage of green plant matter that could have been consumed by the new swarms that could have developed if the bands had not been treated (and had been allowed to develop into swarms) was also calculated. Allowance was made for the fact that the actual area occupied by bands in areas aerially treated using fixed wing aircraft is less than the total area treated for bands.

The total agricultural value of the green plant matter consumed by bands and swarms will depend on their duration, the type of green plant matter consumed, its value to agriculture, and the actual loss in value due to damage. The financial loss associated with the consumption of a particular tonnage of green plant matter being consumed per day by existing bands and swarms, and potential new swarms, was then calculated. The benefits in terms of avoiding further losses to agriculture by treatment of the existing bands and swarms were then compared with the estimated costs of treatment.

The results obtained from the calculations depend on a number of assumed values, some of which are more uncertain than others. The two most uncertain were believed to be the likely density of insects per square metre, and the likely type of plant matter consumed. Exploring these uncertainties through sensitivity analysis, Smith found that the estimated benefit–cost ratio was more or less directly proportional to assumed insect density. If the density was reduced by a factor of four, the benefit–cost ratio also fell by a factor of four, and vice versa. With respect to plant matter type Smith found, as might be expected, that assuming a higher proportion of (lower value) native vegetation in the mix reduced the benefit–cost ratio, while assuming a higher proportion of (higher value) crops in the mix increased it.

International

The importance of crop and locust lifecycle dynamics (discussed in Wright 1986a) is reinforced by Bullen (1961), who pointed to two further elements in the estimation of damage. The food intake of locust is dependent on the instar and stage of life. Growth, and food intake, is highest during the young or immature adult stage of the locust. Thus, the damage caused is highest for a swarm of this age. Indeed, Bullen reports that from surveys of the desert locust in Africa, 58 per cent of total damage was caused by immature adult swarms. Furthermore, Bullen noted that the mobility of the plague determines the intensity of damage caused. A highly mobile plague will distribute the damage caused over larger areas, which in turn could mean that lower losses in yield would result as some plants may be able to regenerate.

A study undertaken by the FAO (2001) discussed some general limitations with the use of benefit–cost analyses as applied to pest management. One point, which was also noted in other analyses such as Joffe (1998), is that in economic terms the damage inflicted, calculated through the value of crops multiplied by the estimated potential physical loss, may tend to overestimate the benefits of a control program, since the individual farmers may take action to mitigate the damage caused by a plague. The FAO (2001) study suggested that a better measure of the benefit of a program would be farm incomes, which would incorporate adjustment by farmers to the effects of the plague undertakes. However, this type of data were considered difficult to obtain, as were data on downstream effects, which could include price changes because of supply shocks or secondary shocks to livestock producers.

Another specific limitation of many studies noted in FAO (2001) was that these studies generally investigated the choice between running a control campaign and not running one. However, a more realistic question to investigate would be the choice of conducting a further *unit* of control, such as one more application of pesticide, which is usually the option open to a central control agency.

A more general observation made in FAO (2001) of pest management analysis is the difficulty in making the distinction between pest effects and other pressures on the farms and regions, which can include climate and environmental changes. The latter is further complicated by the fact that in many instances, pest outbreaks coincided with specific weather conditions.

Outside of benefit–cost investigations, many studies incorporated risk analysis into the framework. Joffe (1998), for instance, constructed an economic model of desert locusts involving case studies, historical analysis, simulations as well as risk analysis. This formed the basis for the ‘economics of desert locust simulator’ (ELS), which enabled the generation of population dynamic sequences, control measure intervention and the assessment of the likely levels of damage. The research and data were based on situations occurring in Africa and the Middle East.

Hardeweg and Waibel (2000) investigated the ways in which risk analysis could be incorporated into a benefit–cost framework. One of the main arguments was that the potential yield loss was irrelevant in choosing an intervention strategy. This was based instead on a decision matrix available to those conducting the control campaign that involved evaluating the likely outcomes of an action, assuming that insurance was available to farmers. The possible actions were to conduct a campaign or not, or to take out insurance, given some probability that an outbreak would occur. In this framework, the potential yield loss is unimportant, since a loss occurs if a choice is made that leads to a suboptimal outcome when compared with other actions.

Cheke and Tucker’s 1995 investigation of the control of African armyworm provided an example of employing a benefit–cost analysis framework in a predictive manner. Like many locust control analyses, Cheke and Tucker’s armyworm analysis compared the potential damage from not controlling the pest based on a comparison with a previous plague. A model that simulated the potential migration and spread of the armyworm was used to assess the costs and benefits of carrying out different control campaigns in different areas, as well as testing the results given different assumptions of control effectiveness.

cropping and grazing in inland eastern Australia

The main agricultural areas potentially at risk from attack by the Australian plague locust in years when weather conditions favor the development of large locust populations are the grazing and cropping areas of inland eastern Australia. Accordingly, in this chapter, a statistical profile of agriculture in these areas is developed. All statistics are drawn from Australian Bureau of Statistics agricultural statistics for the years 2000-01 to 2002-03, which provide detailed figures on crop and pasture area, production, and gross value of production at principal market (generally farm gate or silo delivery).

New South Wales

An examination of the history of past locust plagues indicates that virtually all of the pastures and crops in New South Wales west of the Great Dividing Range potentially could be attacked by locusts in plague years. The six statistical divisions that comprise most of this area are the Northern, North Western, Central West, Murrumbidgee, Murray, and Far West divisions. In the three years 2000-01 to 2002-03, these divisions contained 91 per cent the area of agricultural holdings, 79 per cent of sown pasture area, 93 per cent of native pasture area, and 95 per cent of cropped area in New South Wales. These six statistical divisions were also responsible for 86 per cent of the state's gross value of crop production ($4.25 billion out of $4.95 billion, in 2004-05 dollars).

Within these six statistical divisions, the average share of crops in total crop and pasture area in the cropping divisions (Northern, Central West and Murrumbidgee) was 16 per cent, compared with 9 per cent in the grazing divisions (North Western, Murray and Far West). The proportion of total crop and pasture area represented by sown pastures was also higher in the three cropping Divisions than in the three grazing divisions (table 6).

The total area of crops and pastures in the six New South Wales statistical divisions averaged 42.1 million hectares in the years 2000-01 to 2002-03, or 95 per cent of the state's crop and pasture area. Of this, 15.0 million hectares were in the cropping divisions, and 27.1 million hectares in the grazing divisions (table 7).

The average real gross unit values of production for wheat, barley, rice and pasture cut for hay averaged in the range $205–285 a tonne (in 2004-05 dollars) in the years 2000-01 to 2002-03. The differences in real unit values between the grazing and cropping divisions tended to be relatively minor (table 8).

6 Share of total crop and pasture area – New South Wales
2000-01 to 2002-03 average

	Three grazing divisions a	Three cropping divisions b	Six statistical divisions	New South Wales	Australia
	%	%	%	%	%
Wheat	5.1	12.6	7.8	7.3	4.0
Barley	0.8	2.7	1.5	1.4	1.3
Rice	0.2	0.4	0.3	0.3	–
Other crops	2.4	9.7	5.0	5.1	2.9
Sown pasture	6.4	23.5	13.0	15.0	9.0
Native pasture	85.0	51.0	72.4	71.0	82.8
Total	100.0	100.0	100.0	100.0	100.0

a North Western, Murray and Far West. **b** Northern, Central West and Murrumbidgee.
Source: ABS Agricultural Statistics.

7 Total crop and pasture area – New South Wales
2000-01 to 2002-03 average

	Three grazing divisions a	Three cropping divisions b	Six statistical divisions	New South Wales	Australia
	million ha	million ha	million ha	million ha	million ha
Wheat	1.39	1.89	3.3	3.4	11.6
Barley	0.22	0.41	0.6	0.6	3.7
Rice	0.06	0.06	0.1	0.1	0.1
Other crops	0.66	1.46	2.1	2.3	8.6
Sown pasture	1.73	3.53	5.5	6.9	26.3
Native pasture	23.01	7.65	30.4	32.8	243.3
Total	27.07	14.99	42.1	46.1	293.7

a North Western, Murray and Far West. **b** Northern, Central West and Murrumbidgee.
Source: ABS Agricultural Statistics.

8 Real unit gross value of production – New South Wales
2000-01 to 2002-03 average

	Three grazing divisions a	Three cropping divisions b	Six statistical divisions	New South Wales	Australia
	$/t	$/t	$/t	$/t	$/t
Pastures cut for hay	205	212	210	208	207
Wheat	246	248	247	247	272
Barley	212	212	212	212	232
Rice	266	284	276	276	276

a North Western, Murray and Far West. **b** Northern, Central West and Murrumbidgee.
Source: ABS Agricultural Statistics.

Victoria

The areas of Victoria most likely to be subject to locust attack in plague years, if locusts are allowed to reach Victoria, are the statistical divisions of Mallee and Wimmera, and the northern parts of the statistical divisions of Goulburn and Loddon. Between them, these four statistical divisions contain 58 per cent of the state's area of agricultural holdings, 46 per cent of its sown pasture area, 47 per cent of its native pasture area, and 88 per cent of its cropped area (2000-01 to 2002-03 average) and were responsible for around two thirds per cent of the state's gross value of crop production ($2.22 billion out of $3.31 billion, in 2004-05 dollars).

Agricultural production systems in the Mallee and Wimmera divisions tend to be oriented toward extensive cropping while in the Loddon and Goulburn divisions, fruit growing, irrigated agriculture and dairying are significant activities. These differences in production systems are reflected in the relatively high proportion of land devoted to cropping in the Mallee and Wimmera divisions, and the relatively high proportion of sown pastures in the Loddon and Goulburn divisions' total crop and pasture area (table 9).

In the years 2000-01 to 2002-03, the total area of crops and pastures in the four Victorian statistical divisions averaged 6.2 million hectares, comprising 3.9 million hectares in the Mallee and Wimmera divisions, and 2.1 million hectares in the Loddon and Goulburn divisions (table 10).

The average real gross unit values of production for wheat, barley, rice and pasture cut for hay in Victoria averaged in the range $190–285 a tonne in 2004-05 dollars in the three year period. There was little difference in real unit values between the Mallee and Wimmera divisions and the Loddon and Goulburn divisions (table 11).

9 Share of total crop and pasture area – Victoria
2000-01 to 2002-03 average

	Mallee and Wimmera	Loddon and Goulburn	Four statistical divisions	Victoria	Australia
	%	%	%	%	%
Wheat	23.3	7.9	17.8	11.5	4.0
Barley	15.6	3.1	11.2	7.1	1.3
Rice	0.0	0.0	0.0	0.0	–
Other crops	18.7	11.9	16.3	11.7	2.9
Sown pastures	28.0	48.5	35.4	45.6	9.0
Native pastures	14.3	28.5	19.2	24.1	82.8
Total	100.0	100.0	100.0	100.0	100.0

Source: ABS Agricultural Statistics.

10 Total crop and pasture area – Victoria
2000-01 to 2002-03 average

	Mallee and Wimmera	Loddon and Goulburn	Four statistical divisions	Victoria	Australia
	million ha	million ha	million ha	million ha	million ha
Wheat	0.90	0.17	1.07	1.17	11.6
Barley	0.60	0.07	0.67	0.72	3.7
Rice	–	–	–	–	0.1
Other crops	0.72	0.26	0.98	1.12	8.6
Sown pasture	1.09	1.04	2.13	4.65	26.3
Native pasture	1.13	0.45	1.58	2.94	243.3
Total	3.87	2.15	6.02	10.2	293.7

Source: ABS Agricultural Statistics.

11 Real unit gross value of production – Victoria
2000-01 to 2002-03 average

	Mallee and Wimmera	Loddon and Goulburn	Four statistical divisions	Victoria	Australia
	$/t	$/t	$/t	$/t	$/t
Pastures cut for hay	198	190	193	185	207
Wheat	285	285	285	285	272
Barley	240	241	240	241	232
Rice	237	244	243	237	276

Source: ABS Agricultural Statistics.

Queensland

The areas of Queensland most likely to be subject to attack by the Australian plague locust in plague years are the grazing and cropping areas west and south west of the Great Dividing Range. The three statistical divisions that comprise most of this area are the central west, south west and Darling Downs divisions. The first two of these divisions could be typified as grazing, and the latter as cropping.

Between them, these three statistical divisions contain 46 per cent of the state's area of agricultural holdings, 38 per cent of its sown pasture area, 46 per cent of its native pasture area, and 55 per cent of its cropped area (2000-01 to 2002-03 average), and were responsible for around a quarter of the state's gross value of crop production (just under $1.0 billion out of a total of $3.8 billion, in 2004-05 dollars).

The average share of crops in total crop and pasture area in the Darling Downs division of Queensland was 18 per cent compared with only 1 per cent in the two 'grazing' divisions. In the latter divisions, native pasture represented on average 96 per cent of total crop and pasture area (table 12).

The total area of crops and pastures in the three Queensland statistical divisions discussed above averaged 44.8 million hectares in the years 2000-01 to 2002-03, comprising 6.3 million hectares in the Darling Downs Division, and 38.5 million hectares in the Central West and South West Divisions (table 13).

12 Share of total crop and pasture area – Queensland
2000-01 to 2002-03 average

	Central West and South West	Darling Downs	Three statistical divisions	Queens-land	Australia
	%	%	%	%	%
Wheat	0.4	6.0	1.2	0.7	4.0
Barley	0.0	1.4	0.2	0.1	1.3
Rice	0.0	0.0	0.0	0.0	–
Other crops	0.4	11.0	1.9	1.9	2.9
Sown pasture	3.6	10.8	4.8	5.8	9.0
Native pasture	95.7	70.7	92.0	91.5	82.8
Total	100.0	100.0	100.0	100.0	100.0

Source: ABS Agricultural Statistics.

13 Total crop and pasture area – Queensland
2000-01 to 2002-03 average

	Central West and South West	Darling Downs	Three statistical divisions	Queens-land	Australia
	million ha	million ha	million ha	million ha	million ha
Wheat	0.14	0.38	0.52	0.67	11.6
Barley	–	0.01	.01	0.1	3.7
Rice	0	0	0	0	0.1
Other crops	0.15	0.69	0.84	1.86	8.6
Sown pasture	1.37	0.68	2.14	5.62	26.3
Native pasture	36.81	4.44	41.17	89.26	243.3
Total	38.45	6.29	44.76	97.51	293.7

Source: ABS Agricultural Statistics.

14 Real unit gross value of production – Queensland
2000-01 to 2002-03 average

	Central West and South West	Darling Downs	Three statistical divisions	Queens-land	Australia
	$/t	$/t	$/t	$/t	$/t
Pastures cut for hay	242	273	267	252	207
Wheat	271	275	274	272	272
Barley	215	234	234	234	232

Source: ABS Agricultural Statistics.

The average real gross unit values of production for wheat, barley, and pasture cut for hay averaged in the range $215–275 a tonne in 2004-05 dollars in the three year period. The differences in the real unit values for these crops between the Darling Downs division and the Central West and South West divisions were relatively minor (table 14).

South Australia

With locust numbers in plague years typically building up in the state's northern areas and in the adjacent areas in Queensland and New South Wales, the areas of South Australia potentially most likely to be subject to locust attack in plague years are the state's southern cropping areas. Most of this area is contained in the Eyre, Yorke and Lower North, and Riverlands Statistical divisions.

Between them, these four South Australian statistical divisions contain on average around 96 per cent of the state's area of agricultural holdings, 47 per cent of its sown pasture area,

15 Share of total crop and pasture area – South Australia
2000-01 to 2002-03 average

	Northern division	Three 'cropping' divisions	Four statistical divisions	South Australia	Australia
	%	%	%	%	%
Wheat	1.1	22.7	6.5	6.4	4.0
Barley	0.6	12.5	3.6	3.7	1.3
Rice	0	0	0	0	0.0
Other crops	0.5	10.4	2.9	3.4	2.9
Sown pasture	0.4	16.1	5.2	10.1	9.0
Native pasture	97.5	38.3	81.7	76.4	82.8
Total	100.0	100.0	100.0	100.0	100.0

Source: ABS Agricultural Statistics.

16 Total crop and pasture area – South Australia
2000-01 to 2002-03 average

	Northern division	Three 'cropping' divisions	Four statistical divisions	South Australia	Australia
	million ha	million ha	million ha	million ha	million ha
Wheat	0.23	1.64	1.87	1.97	11.6
Barley	0.14	0.90	1.03	1.13	3.7
Rice	0	0	0	0	0.1
Other crops	0.10	0.75	0.84	1.06	8.6
Sown pasture	0.08	1.16	1.48	3.14	26.3
Native pasture	20.83	2.76	23.35	23.59	243.3
Total	21.37	7.20	28.57	30.89	293.7

Source: ABS Agricultural Statistics.

17 Real unit gross value of production – South Australia
2000-01 to 2002-03 average

	Northern division	Three 'cropping' divisions	Four statistical divisions	South Australia	Australia
	$/t	$/t	$/t	$/t	$/t
Pastures cut for hay	231	243	241	256	207
Wheat	289	288	288	288	272
Barley	241	243	243	243	232

Source: ABS Agricultural Statistics.

99 per cent of its native pasture area, and 90 per cent of its cropped area (2000-01 to 2002-03 average), and were responsible for around three quarters of the state's gross value of crop production ($2.56 billion out of $3.40 billion, in 2004-05 dollars) (table 15).

The total area of crops and pastures in the four South Australian statistical divisions averaged 3.8 million hectares in the years 2000-01 to 2002-03, comprising 3.3 million hectares in the cropping divisions, and 0.5 million hectares in the grazing divisions (table 16).

The average real gross unit values of production for wheat, barley, and pasture cut for hay averaged in the range $230–290 a tonne in 2004-05 dollars in the three year period. The differences in real unit values between the Northern statistical division and the three cropping statistical divisions were relatively minor (table 17).

Inland eastern Australia

Based on the foregoing summary of agriculture in seventeen statistical divisions of the four eastern mainland states, an aggregate profile for grazing and cropping generally across the inland areas at risk from locust attack in plague years can be developed. The respective share of crops and pastures in these broadly defined areas is shown in table 18.

18 Share of total crops and pasture area – inland eastern Australia
2000-01 to 2002-03 average

	Six grazing divisions	Eleven cropping divisions	Seventeen statistical divisions	Four mainland eastern states	Australia
	%	%	%	%	%
Wheat	2.0	14.4	5.5	3.9	4.0
Barley	0.4	6.0	2.0	1.4	1.3
Rice	0.1	0.2	0.1	0.1	0.0
Other crops	1.0	11.2	3.9	3.5	2.9
Sown pasture	3.7	21.7	8.8	11.0	9.0
Native pasture	92.8	46.4	79.6	80.1	82.8
Total	100.0	100.0	100.0	100.0	100.0

Source: ABS Agricultural Statistics.

The total area of crops and pastures in these seventeen statistical divisions is shown in table 19. About two thirds of the crop and pasture area in the four mainland eastern states as a whole is potentially at risk from locust attack in plague years.

The average real gross unit values of production for wheat, barley, and pasture cut for hay averaged in the range $205–285 a tonne in 2004-05 dollars in the three year period. There were only minor differences in real unit values between the grazing and the cropping divisions (table 20).

19 Total crops and pasture area – inland eastern Australia
2000-01 to 2002-03 average

	Six grazing divisions	Eleven cropping divisions	Seventeen statistical divisions	Four mainland eastern states	Australia
	million ha	million ha	million ha	million ha	million ha
Wheat	1.76	4.97	6.73	7.18	11.6
Barley	0.36	2.07	2.43	2.60	3.7
Rice	0.06	0.06	0.12	0.12	0.1
Other crops	0.90	3.87	4.78	6.46	8.6
Sown pasture	3.18	7.50	10.68	20.35	26.3
Native pasture	80.65	16.0	96.66	148.09	243.3
Total	86.92	34.49	121.40	184.80	293.7

Source: ABS Agricultural Statistics.

20 Real unit gross value of production – Inland Eastern Australia
2000-01 to 2002-03 average

	Six grazing divisions	Eleven cropping divisions	Seventeen statistical divisions	Four mainland eastern states	Australia
	$/t	$/t	$/t	$/t	$/t
Pastures cut for hay	208	207	207	204	207
Wheat	255	270	267	267	272
Barley	226	236	234	235	232
Rice	266	283	276	275	276

Source: ABS Agricultural Statistics.

benefit–cost analysis

Previous studies

Previous studies by Wright (1986a), McElwee and Walden (2000), AECgroup (2002) (utilising the results of Miller, Hunter and Strong 2002) and Smith (2005) were reviewed in chapter 3. Essentially, all of these studies aimed to do the same thing — to identify the potential loss to agriculture in the absence of locust control, compared with the actual or prospective costs of control.

All of the analyses except AECgroup (2002) concentrated on the control operations required in a particular season — Wright for the 1985-86 season in eastern Australia, McElwee and Walden for the 2000-01 season in Western Australia, Miller, Hunter and Strong for the 1998-99 season in Queensland, and Smith for the 2004-05 season in New South Wales. Wright's and Smith's analyses were ex post analyses — that is, they examined the ratio of estimated benefits to costs of control after control operations had been conducted. In contrast, the McElwee and Walden, and AEGgroup analyses were ex ante, examining the likely ratio of benefits to costs from locust control for different degrees of severity of attack. In the McElwee and Walden analysis, the likely geographic spread of infestation was used as the indicator of severity of attack, while in the AEGgroup analysis, the indicator was taken to be the frequency of outbreak of serious plagues over a fifty year time period.

In the seasons examined by the various researchers, control operations took place, so it was not possible to directly observe what damage would have been done to crops and pastures in the absence of control. Wright, McElwee and Walden, and Miller, Hunter and Strong attempted to estimate the potential damage in the absence of control by referring to the actual damage done to crops and pastures during plagues of similar initial magnitude when locusts had not been controlled. The analyses were highly spatially dependent, requiring a detailed assessment of the crops present, their stages of development, and potential locust numbers for each statistical area. All benefits and costs were assumed to occur within the season being examined — a reasonable assumption in the case of a short lived, seasonal pest of agriculture such as the locust. The AEGgroup analysis was the only analysis that considered the benefits and costs of pest control over a long time period. All other studies examined the benefits and costs of control over only one season. Accordingly, the AEGgroup analysis was the only one of the studies in which a discounted stream of benefits and costs was calculated.

The Wright, McElwee and Walden, and Miller, Hunter and Strong analyses based their estimates of potential damage in the absence of control on the actual damage done by locusts in past seasons in which they had not been controlled. In contrast, Smith (2005) estimated potential damage in the absence of control on the area actually treated for locusts in 2004-05. The argument was that if the bands that were actually treated had not been treated, they could have developed into new swarms that could have caused further damage to crops and pastures. Neither the location of the bands, nor the potential migration paths of the swarms that could have developed from them needed to be specified.

The nonspatial nature of the analysis may be regarded as either an advantage or a disadvantage, depending on the objective of the analysis.

Although Smith's analysis was confined to ex post analysis of a single season (2004-05), there is no reason in principle why the method could not be applied to ex post analysis of multiple seasons. In the case of a highly seasonal pest such as the locust, a simplifying assumption would be that any carryover benefits or costs were negligible, or likely to cancel each other out over time.

As the main objective in the current analysis was to estimate the benefits and costs of the APLC's control operations over a number of recent years, it was decided to use a methodology similar to Smith's, rather than the more spatially oriented methods used in Wright, and McElwee and Walden. If more spatially oriented analysis are required in the future, some variant of the Wright, and McElwee and Walden methodologies could be explored.

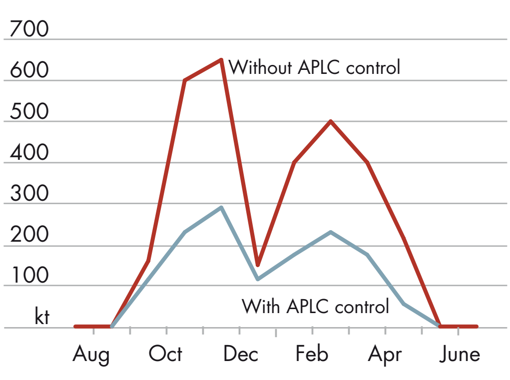
The analysis

Figure B shows a notional profile of the monthly consumption of green plant matter by locusts in a season when seasonal conditions favor the development of large locust populations. There is very little locust activity or damage to agriculture in winter. However, the potential for damage increases in spring as bands develop and then swarms appear. When seasonal conditions favor the development of large locust populations, there can be three locust generations, in spring, summer and autumn. In some years, the Commission may only need to control a spring generation. In other years it may need to control a spring and a summer generation. In exceptional years, it may need to control all three generations. Locusts will consume a certain quantity of green plant matter even with control. However, control will suppress population development and reduce the consumption peaks.

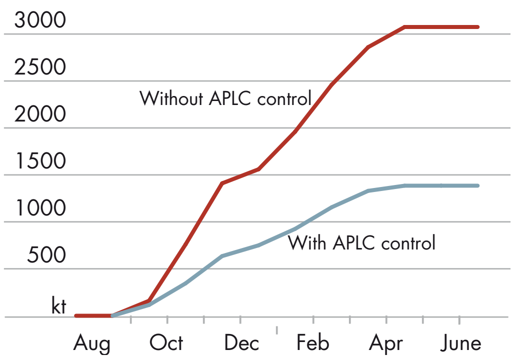
Over the season as a whole, the cumulative quantity of green matter loss avoided by control can be thought of as the difference between the heavy line and the lighter line in figure C.

Figure D shows the notional profile of the value of the loss in agricultural production resulting from the consumption of green

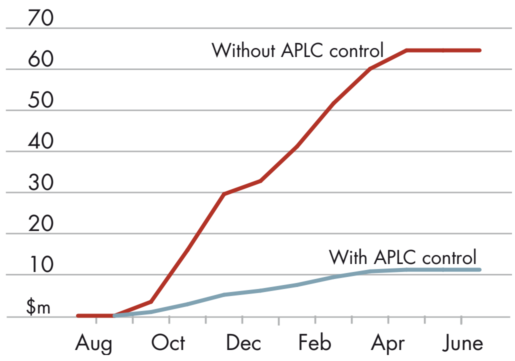
B **Notional profile of monthly green matter consumption by locusts in a season**



C Notional profile of cumulative green plant matter consumption by locusts in a season



D Notional profile of value of losses to agriculture in a season



plant matter by locusts. The profile is similar to figure C, but shows potentially larger losses without treatment, as the main damage caused by locusts without treatment would be in cropping areas where the average per tonne value of the green plant matter consumed is potentially higher.

A number of assumptions are made to estimate these physical and financial damage functions in the spreadsheet model.

With control

- Consumption of green plant matter by locusts prior to treatment is assumed to occur in grazing areas, where the average per tonne value of green matter consumed is relatively low.
- The number of insects eating per day is assumed to be related to the density of the insect populations in the areas treated by the APLC for bands and swarms.
- Based on the life cycle of the locust, the average number eating days for a juvenile in a band is assumed to be eighteen, and the average number of eating days for an adult in a swarm is assumed to be thirty.

Without control

- Green plant matter consumption that would have occurred without treatment is assumed to occur in cropping areas, where the average per tonne value of green matter consumed is relatively high.
- The number of insects eating per day is assumed to be related to the population of the swarms that could have developed if the bands actually treated by the APLC had not been treated.

Green plant matter consumption and losses to agriculture were calculated for the year as a whole. The ratio of benefits to costs was then calculated as the estimated value of the losses to agriculture that would have occurred without treatment by the APLC, divided by the total expenditure of the APLC in the season.

21 Areas treated by the APLC

	1999 -2000	2000 -01	2001 -02	2002 -03	2003 -04	2004 -05
	km^2	km^2	km^2	km^2	km^2	km^2
Treated area						
– band	1 310	1 177	133	0	1 476	1 878
– swarm	1 306	732	0	0	529	2 615
Total	2 616	1 908	133	0	2 005	4 493

Source: APLC annual activity reports.

The areas treated by the APLC for bands and swarms from 1999-2000 to 2004-05 are shown in table 21.

Relevant entomological assumptions are shown in table 22. The various parameter values were based on advice from the APLC, drawing on the scientific literature on locust population growth and behavior.

Both the quantity of green plant matter consumed by bands and swarms prior to treatment and the quantity potentially consumed by swarms were estimated from the above.

Past studies have shown that only around 15 per cent of the area treated for bands by fixed wing aircraft is actually occupied by juvenile locusts in a band. At this stage the band typically consists of Instar IV juveniles, at a typical Instar IV density of around 2000 insects per square metre. When moving to Instar V, the Instar IV juveniles approximately double in size, and the amount of green plant matter consumed per insect also doubles. However, the average density per insect approximately halves, so that the band as a whole maintains a relatively constant feeding density. In other words, as the juveniles in a band grow from Instar IV to Instar V, the band density will fall (typically from around 2000 juveniles per square metre to around 1000 per square metre), but the feeding density is likely to remain about the same.

The Instar V juveniles will become adults, and in sufficient densities, will form a swarm. The area that would be occupied by these new swarms is calculated as the product of the estimated area of band and the ‘band to swarm ratio’. For example, the density of the new swarm produced by a band of Instar V juveniles at a density of 1000 insects per square metre would be 63 adult insects per square metre.

Using this procedure, the quantity of green plant matter consumed with treatment and the quantity potentially consumed without

22 Entomological data

		Value
Insect density		
Band (Instar IV)	no./m^2	2 000
– Instar V equivalent	no./m^2	1 000
Swarm	no./m^2	63
Other		
Band to swarm ratio	ratio	16
Band occupancy rate	%	15
Daily green plant matter consumption		
Juvenile (Instar IV)	g/day	0.04
Adult (female)	g/day	0.2
Insect eating days		
Treated band	no.	18
Treated swarm	no.	30
Potential new swarm	no.	30

treatment can be calculated for each year from 1999-2000 to 2004-05. Taking 2004-05 as an example, it is estimated that around 400 000 tonnes of green plant matter of value to agriculture were consumed by the bands and nearly 1 million tonnes consumed by the swarms that were treated by the APLC. However, without treatment, these bands would have produced new swarms that could have consumed an estimated further 1.7 million tonnes of green plant matter (table 23).

23 Estimated quantity of green plant matter of value to agriculture consumed or potentially consumed by locusts in 2004-05

		Value
Area treated by the APLC		
For bands	km^2	1 878
For swarms	km^2	2 615
Area occupied by insects per day		
Bands	km^2	282
Original swarms	km^2	2 615
Potential new swarms	km^2	4 507
Green plant matter consumed per day		
Bands	$t/km^2/day$	80
Swarms	$t/km^2/day$	12.5
Green plant matter consumed per day		
Bands	t/day	22 534
Original swarms	t/day	32 688
Potential new swarms	t/day	56 334
Green plant matter consumed per year		
Bands	t/year	405 605
Original swarms	t/year	980 625
Potential new swarms	t/year	1 690 020

The estimated average weighted value of the green matter consumed by locusts is shown in table 24. The type of green matter consumed is assumed to follow the area share of that type of green matter in total crops and pastures area. The value of each type of green matter is taken to be either the harvested value per tonne (in the case of crops) or the cost of replacing the green matter consumed with purchased fodder (in the case of pastures). The real unit gross value of sown pastures was taken to be the real unit gross value of pastures cut for hay. The real unit gross value of native pasture was assumed to be a third of that for sown pasture, on the argument that average stocking rates on sown pasture in cropping areas are typically around three times higher than those on unimproved pasture. For the grazing areas this may underestimate the value of sown pasture relative to unimproved pasture. However, the average area of sown pasture in the grazing areas as a proportion of total crop and pastures area is relatively small. Similarly, to the extent that pasture may not be fully utilised by stock, the quantity of green matter lost to agriculture may be overestimated.

24 Estimated average value of the green plant matter of value to agriculture consumed by locusts

	Grazing divisions			Cropping divisions		
	Share	Unit value	Average weighted value	Share	Unit value	Average weighted value
	%	$/t	$/t	%	$/t	$/t
Wheat	2.0	255	5.10	14.4	270	38.88
Barley	0.4	226	0.90	6.0	236	14.16
Rice	0.1	266	0.27	0.2	283	0.57
Other crops	1.0	300	3.00	11.2	300	33.60
Sown pasture	3.7	208	7.70	21.7	207	44.92
Native pasture	92.8	69	64.03	46.5	69	32.09
Total/average	100.0	81.00	100.0			164.21

25 Results of the analysis
In 2004-05 dollars

		1999 -2000	2000 -01	2001 -02	2002 -03	2003 -04	2004 -05	Average
Loss to agriculture prior to treatment	$m	6.3	4.3	0.2	0.0	4.2	11.2	4.4
APLC expenditure	$m	5.5	4.8	2.7	2.9	4.4	6.8	4.5
Potential loss without treatment	$m	38.7	34.8	3.9	0.0	43.6	55.5	29.4
Benefit from treatment	ratio	7.0	7.3	1.4	0.0	9.9	8.1	6.5

The average percentage loss in yield or unit value after locust attack is assumed to be 10 per cent in the grazing divisions and 20 per cent in the cropping divisions, on the argument that plants of value to agriculture in the cropping areas occur in more geographically dense concentrations than in the grazing areas. This figure for percentage loss could be thought of variously as the total loss of part of the crop, the partial loss from all of the crop, or a downgrading in the price received for the crop because of the presence of insect debris. The average value of the financial loss to agriculture per tonne of green matter consumed by locusts is estimated to be $8.10 per tonne in grazing areas and $32.84 per tonne in cropping areas.

The results of the benefit–cost calculations are shown in table 25. The value of the loss to agriculture from locust activity in 2004-05 with treatment is estimated to have been $11.2 million. However, treatment is estimated to have avoided further potential losses of $55.5 million. The Commission's expenditure in 2004-05 was $6.8 million. The ratio of benefits to costs in 2004-05 from control is therefore estimated to have been around 8:1. For the period 1999-2000 to 2004-05, which included four years of high locust activity and two years of low activity, the ratio of benefits to costs from the Commission's activities is estimated to have been around 6.5:1.

Comparison of results with other studies

The results detailed above cannot be compared with the results from studies such as Wright (1986a) and others, for several reasons. First, the methodology, or the values chosen for key entomological and economic inputs, may be different. Choosing more conservative values for key inputs would obviously result in a lower estimated benefit–cost ratio for locust control operations.

Second, studies such as Wright (1986a) generally include only the variable costs of expenditure on control activities, and not the costs of maintaining the control organisation itself. However, this ABARE study includes both the variable costs of expenditure on control activities and the largely fixed costs of maintaining the APLC as an organisation. It would be expected that the estimated benefit–cost ratio for locust control operations would be lower when the largely fixed costs of maintaining the control organisation are included than if they were excluded.

Finally, the mixture of control operations undertaken by the control organisation would also be expected to influence the estimated benefit–cost ratio for locust control. By its nature, aerial control of bands and swarms tends to involve a higher cost per unit of control (and would therefore be expected to yield a lower estimated benefit–cost ratio) than ground based landholder control of hopper bands, which can target the pest more directly as well as appear particularly ‘cost effective’ if the cost of the landholder’s labor is not included.

It would be expected that the estimated weighted average benefit–cost ratio for a combined operation involving both aerial control of bands and swarms and ground based landholder control of hopper bands would be higher than the estimated benefit–cost ratio for an operation involving only aerial control. As noted in chapter 2, the remote nature of the areas for which the APLC is responsible for locust control operations effectively makes aerial control the only feasible control option in these areas.

Sensitivity analysis

Sensitivity analysis is conventionally used to investigate the effect of varying the parameter values of those inputs regarded as subject to the greatest degree of uncertainty, or with the greatest influence on the result. The two input variables possibly subject to the greatest degree of uncertainty in the analysis are the density of the locust bands and swarms, and the percentage loss in the value of crops and pastures because of locust attack. In the foregoing analysis, the density of Instar IV juveniles in bands is assumed to be 2000 per square metre. The likely percentage loss in the unit value of the green matter attacked in grazing areas is assumed to be 10 per cent, and the likely percentage loss in cropping areas, 20 per cent. With an estimated benefit–cost ratio for 2004-05 of around 8:1, at these assumed values, there is little need to undertake a sensitivity analysis assuming a higher insect density or a greater percentage of damage. Of interest, however, is the sensitivity of the result to reductions in insect density or in the degree of damage.

The results of a sensitivity analysis undertaken along these lines are shown in table 26. The response of the calculated benefit–cost ratio to changes in either of these variables is broadly linear. In other words, if both insect densities and percentage losses in unit values are halved, the calculated benefit–cost ratio declines by a factor of four. Nonetheless, even at these lower assumed insect densities and percentage loss rates, the benefit–cost ratio for APLC operations is still estimated to be greater than one.

26 Sensitivity analysis
In 2004-05 dollars

		2004-05	Average 1999-2000 to 2004-05
Insect density			
Band (Instar IV)	no./m^2	1 000	1 000
Swarm	no./m^2	31.5	31.5
Expected percentage loss in unit GVP			
Grazing areas	%	5	5
Cropping areas	%	10	10
Loss to agriculture			
– with treatment	$m	2.8	1.1
– avoided by treatment	$m	13.9	7.4
APLC costs of operation	$m	6.8	4.5
Benefit–cost ratio	ratio	2.0	1.6

social, trade and environmental costs and benefits

Social

The social effects of locust plagues are many and varied. For example, Bullen (1975) noted that the nonagricultural effects of locust plagues:

> '… cover a multiplicity of mainly nuisance effects which, in some cases, have constituted hazards to human safety and minor costs and inconvenience to individuals. Dense swarms on roads can cause blocked car radiators if insect screens are not fitted, and ultra-dense swarms settled on roads would constitute major traffic hazards if they occurred in denser traffic zones. Australian plague locust hopper bands crossing railway lines have occasionally halted trains due to the lack of rail adhesion caused by vast numbers of crushed insects, for example, the Menindee–Broken Hill line in October 1973. A locust swarm at Melbourne's Tullamarine Airport caused the temporary closure of one runway in March 1974 when a DC 9 aircraft lost all air-speed indication due to blockage by locusts of both air-speed indication inlets as it flew through the swarm just prior to touchdown. If this had occurred during take-off a serious accident could have resulted.'

An estimated 1.7 million people reside in the seventeen statistical divisions in eastern Australia potentially subject to locust activity, mostly in the towns and cities of the cropping belt. Around 370 000 residents live in the six grazing divisions. The low density of the human population in the grazing divisions may mean that few of these residents might actually be inconvenienced by locusts even in years of high locust activity. On the other hand, it could be argued that the estimated 1.33 million residents in the cropping divisions would be inconvenienced far more frequently by locusts were it not for the APLC's locust control operations.

Swarms of locusts can constitute a hazard to motorists. The number of motor vehicles in locust-prone areas in eastern Australia can be estimated from aggregate motor vehicle registration statistics. At 30 June 2001 the total population of the four mainland eastern states was 16.6 million and the total number of registered vehicles in these states, including heavy vehicles and motorcycles, was 10.5 million, or approximately 630 registered vehicles per thousand of population. If the same ratio were applied to the seventeen statistical divisions, there could be over a million registered motor vehicles in locust-prone areas. In the absence of control, in years of high locust activity, many of these vehicles would require insect screens to be fitted and to have their exteriors and engine bays thoroughly cleaned after being driven through locust swarms.

Trade and environmental

The control of locusts on a large scale requires the use of pesticide and therefore raises a number of trade and environmental issues. The profile of these issues will depend on which chemicals are used and how they are employed. Currently, the APLC uses three varieties of chemicals for locust control: fipronil (*Adonis*), *fenitrothion* and *metarhizium*. *Fenitrothion* is the most abundantly used insecticide because of its effectiveness and low cost. However, its use can affect nontarget species.

The impact of aerially applied *fenitrothion* on the epigeal invertebrate fauna (other insects that live on or close to the surface of the ground) of arid grasslands of inland Australia was investigated in a series of field trials from 1990 to 1993. *Collembola* (arthropods) constituted the most numerous and most sensitive group, but *Coleoptera* (beetles) and *Homoptera* (cicadas) also were present in numbers sufficient to permit meaningful conclusions. In the short term studies (up to a month post-treatment) the arthropod populations in the treated area were usually lower than in the untreated areas, but the degree to which they were was usually not statistically significant. Only occasionally was there a significant difference in populations more than a month after treatment (Hooper, Carruthers and Walker 2000).

Bunn et al. (1993) divided the toxicity effects of fenitrothion into two categories, direct and residual. The direct toxicity effects were further divided into those associated with terrestrial invertebrates (including locusts), terrestrial vertebrates and aquatic ecosystem. While no comprehensive study has been conducted for many vertebrates, it is generally understood that *fenitrothion* holds only moderate toxicity for mammals in low concentrations. Sanson (1998) notes that fenitrothion can be toxic for aquatic invertebrates and moderately so for fish, which could come in contact with the pesticide either directly or through spray drift.

While the direct toxicity effects are of concern, it is the residual effects of *fenitrothion* that possibly pose the most concern in terms of economic values. This is particularly so given the growing market for organic products, one of which is organic beef. This issue was explored by Sanson (1998), who noted that the goal of organic production is the encouragement of natural biological systems.

Current APLC policy is to avoid spraying those beef properties that produce or are hoping to be certified as organic. This complicates the planning and operation of a control program by limiting the areas in which the APLC can conduct treatment operations. While the number of properties currently certified or seeking such status is relatively small, Sanson (1998) notes that this number could rise and pose increasingly more difficult logistical problems for authorities responsible for locust control. On the other hand, the use of alternatives to *fenitrothion*, such as the biopesticide *Metarhizium*, has been field tested in recent years, and is now being used by the APLC.

A study conducted in February 1998 in central western New South Wales on the rate of depletion of *fenitrothion* in cattle, pasture and soil after *fenitrothion* spraying indicated that the half life of *fenitrothion* was 2–3 days in the soil and 1–2 days in the pasture (Gilmour, McDougall and Spurgin 1999). The study concluded that the 14 day slaughter withholding period currently approved by the National Registration Authority was appropriate.

conclusions

Based on the values assumed for various key variables (see chapter 5), it is estimated that the value of the loss to agriculture avoided by the Commission's control activities in 2004-05 was of the order of $55.5 million, compared with actual costs of operation in that year of $6.8 million, implying a benefit–cost ratio of around 8:1. Over the six years 1999-2000 to 2004-05 — which include years of both high and low locust activity and associated control operations — the benefit–cost ratio was calculated to be 6.5:1. It may be concluded from this that, in recent years, the benefits from the APLC's operations in terms of the avoided losses to agriculture from locust activity have exceeded the costs of obtaining these benefits, these costs being the expenditure required to maintain the APLC as an organisation and undertake control operations.

The social, trade and environmental benefits and costs were not able to be calculated in this report. However, it would appear that the general public also obtains net benefits from the avoidance of locust plagues.

While there are potential costs to the environment from controlling the numbers of one particular species of insect in particular years, it would appear that the effect on other insect species from locust treatment is transitory. The locust itself has shown an ability to breed up quickly when seasonal conditions favor the development of large locust populations, and the treatment of the locusts themselves in any one season does not appear to have a lasting long term effect in terms of reducing the potential size of plagues in successive years.

There could also be potential trade impacts from the presence of pesticide residues in agricultural products if the application of pesticides is not conducted carefully. However, the APLC conducts its control operations with a view to minimising any potential residue problems.

The benefits of locust control are largely nonexclusive and nonrival in nature. That is, it is difficult to exclude anyone from gaining the benefits of control, and one person obtaining the benefits does not preclude anyone else from obtaining them. Therefore the only efficient way to provide these services is through direct public expenditure.

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