HEPTACHLOR USE FOR THE CONTROL OF ARGENTINE ANTS

A Public Discussion Paper

Environmental Protection Authority
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CONTENTS

SUMMARY

This review paper was prepared by the Environmental Protection Authority at the request of the Ministers for Agriculture, Health and Environment, after community concern was expressed over the use of heptachlor for the control of argentine ants.

The Environmental Protection Authority sought input from the Agriculture Protection Board on the spraying programme, and commissioned two papers, one on the environmental impact of heptachlor use, and the other on the effects of heptachlor use on human health.

The aim of the review paper is to elicit informed community response on the following issues associated with the argentine ant control programme.

1. Should a specific programme for the control of argentine ants continue, and if so, should the objective of this programme be containment (ie, prevention of spread) or eradication of argentine ants?

2. Is the use of heptachlor for the control of argentine ants acceptable? If so, under what circumstances and in which areas should heptachlor be replaced with other control means? Alternatively, should heptachlor be seen as not acceptable, what programmes for control are seen as being acceptable? What constitutes an environmentally sensitive area in the context of argentine ant control?

3. What control options should be available to residents whose homes and properties are infested with argentine ants, and what information should be provided to them? Should residents be compelled to control ants on their properties?

GLOSSARY OF TERMS

bioaccumulate	- the ability of a substance to build up within the fatty tissue of an organism.
biomagnification	- the process of a substance increasing in concentration in an organism through the consumption of other organisms containing smaller amounts of the substance.
blood dyscrasias	- blood disorders (for example leukaemia, haemophilia)
cyclodiene insecticide	- insecticides having a particular chemical structure known as a cyclodiene. The group includes heptachlor, chlordane, aldrin and dieldrin.
ecotoxicology	- the study of poisons in the environment.
efficacy	- the extent to which a substance produces the desired effect.
endemic	- confined to a given region and having originated there.
epidemiological	- the distribution of diseases.
non-neoplastic	- not giving rise to neoplasms (abnormal growths).
organochlorine insecticides	- a group of insecticides, containing common chemical elements (for example heptachlor, dieldrin)
organophosphate insecticides	- a group of insecticides containing a common chemical structure (for example chlorpyrifos, isophenphos).
synthetic pyrethroid insecticides	- a group of insecticides, artificially manufactured, but designed to mimic naturally occurring compounds.
teratogenic	- causes congenital abnormalities (birth abnormalities).
termiticide	- a substance that kills termites
trophic level	- the particular level occupied by an organism in the food chain.

GUIDELINES ON MAKING A SUBMISSION TO THE ENVIRONMENTAL PROTECTION AUTHORITY

The Environmental Protection Authority invites people to make a submission on the issues raised in this Review Paper. The Review paper will be available for comment for a period of 10 weeks, finishing on 2 June 1988.

Comments received will assist the EPA to prepare an Assessment Report which will contain recommendations to Government.

Why Write a Submission?

A submission is a way to provide information, express your opinion and put forward your suggested course of action including any alternative approach. All submissions received will be acknowledged.

Developing a Submission

You may agree, disagree or comment on, the general issues discussed in the review paper. It helps if you give reasons for your conclusions, supported by relevant data.

When making comment on specific issues raised in the Review Paper:

- clearly state your point of view;
- indicate the source of your information or argument if this is aplicable; and
- suggest recommendations, safeguards or alternatives.

Points to Keep in Mind

By keeping the following points in mind, you will make it easier for your submission to be analysed:

- attempt to list points so that the issues raised are clear. A summary of your submission is helpful;
- refer each point to the appropriate section in the Review Paper;
- attach any factual information you wish to provide and give details of the source. Make sure your information is accurate; and
- please indicate whether your submission can be quoted, in part of in full, by the EPA in its Assessment Report.

Remember to include: - your name, address, and the date.

The closing date for submissions is: 2 June 1988.

Submissions should be addressed to: The Chairman
Environmental Protection Authority
1 Mount Street
Perth WA 6000

Attention: Ms N Arrowsmith

1. INTRODUCTION

This review is the result of an Environmental Protection Authority (EPA) investigation of the use of Heptachlor for the control of argentine ants in Western Australia. The review was initiated by the Ministers for Agriculture, Health and the Environment who requested the Authority to advise Government on the environmental effects of the current argentine ant control programme. This programme is conducted by the Agriculture Protection Board (APB) and relies on the use of insecticide sprays, the most common of which is heptachlor.

Residents of Denmark separately referred the proposed spraying programme in that area to the Authority, and this review also addresses that referral. In addition, Coolbinia residents have expressed concerns over the spraying programme in that area. Therefore, whilst this review considers argentine ant control throughout Western Australia, the proposed programmes in Denmark and Coolbinia have been specifically addressed.

In order to have the most up-to-date information on the current status of the argentine ant control programme, the Authority called for the preparation of a position paper by the Agriculture Protection Board detailing the extent of infestation in WA, the history of control, the proposed control programme for 1988, and alternatives to the use of heptachlor. The APB Position Paper forms Appendix 1 of this review and contains material which is not repeated in the body the this report. Therefore this review should be read in conjunction with the APB Position Paper.

The current Agriculture Protection Board spraying programme has been suspended, pending the outcome of this investigation and subsequent advice to and decisions by Government.

The EPA believes that the consideration of the best available information is crucial to any reasoned discussion of this issue, and to the formulation of its own recommendations. Therefore, the Authority considered it necessary to commission two further review papers from independent authors not directly involved in the current debate. Dr Barbara Porter, Lecturer, WACAE Joondalup Campus , has prepared a paper on the ecotoxicological effects of heptachlor use on the environment, and Dr Roger Drew, Flinders Medical Centre, Flinders University of South Australia, has prepared a paper on the risks to human health associated with heptachlor use. These papers form Appendices 2 and 3 respectively of this report.

The specific purpose of this review paper is to provide sufficient information to elicit informed community response on the issues associated with the argentine ant control programme, prior to the Authority making recommendations to Government. Therefore this Review is released for public analysis and comment for a period of 10 weeks. Guidelines on how to make a submission are given at the beginning of this Review Paper.

2. THE ARGENTINE ANT

2.1 BIOLOGY

The argentine ant (Iridomyrmex humilus) is native to South America and was first collected in Argentina in the mid 19th Century. Worker argentine ants are light-brown to dark-brown, 2.2 to 2.6 mm long and wingless. The queens are approximately 6 mm long and the males 5 mm long. Usually only the males have wings and they are slightly darker in colour. These characteristics, particularly those of the worker, make them very similar in appearance to several small species of native ant, but they are easily distinguished by their behaviour, such as travelling in narrow, well defined trails, and their lack of a distinctive formic acid odour ("crushed ant smell") when crushed. Argentine ants live primarily on sugar. Sometimes they form an association with aphids whereby they protect the aphids in return for harvesting the sugar collected by the aphids from sap on new growth. Agentine ants will also live on dead insects and other proteinaceous foods. Readily available food sources attract argentine ants to areas intensively used by humans.

2.2 INFESTATION AND SPREAD IN AUSTRALIA

The argentine ant is now found in many parts of the world, especially in warmer, temperate climates. It was first recorded in Australia in Victoria in 1939, and was first recorded in Western Australia in 1941. Since that time it has been found in all other Australian states except the Northern Territory and Queensland.

The Agriculture Protection Board Position Paper describes the present extent of infestation in WA. Major infestations now occur in central Perth, Scarborough, and Coolbinia as well as country centres such as Denmark.

Argentine ant spread occurs through two means: their natural behaviour to progressively establish new nests; and by inadvertent transport by humans. The ants themselves can spread at a rate of up to 100 m per year through the establishment of new nests. However, the spread of ants from locality to locality generally arises from the movement of pot plants, vegetable produce and soil by humans. Therefore there is enormous potential for argentine ants to spread throughout the agricultural areas of Western Australia. The capability of these ants to extend their distribution is indicated by their world wide occurrence.

3. ARGENTINE ANT ERADICATION

3.1 THE NEED FOR ERADICATION

According to the APB (Appendix 1), argentine ant infestations have the potential to damage community interests in three ways: as a domestic nuisance; by causing environmental damage, and by posing a threat to agricultural crops and their export.

As discussed by the APB, many Western Australians will remember the nuisance of argentine ant infestations in the 1950s, and there are many tales describing the extent of the ants' impact on human health and happiness. The ants were known to invade houses in search for food, and found their way into refrigerators and screw top jars. In extreme cases they have caused the deaths of chickens, caged birds and other small domestic pets. It was common practice to stand the legs of beds and tables in tins of oil or water to prevent the ants from gaining access.

The negative impacts of argentine ants on the environment, as suggested by the APB, include their tendency to drive native ant species from areas where they have established, as well as the destruction of other native insects. Large argentine ant numbers are thought to prey on nestling native birds and other small fauna, such as lizards.

According to the APB, the argentine ant has the potential to affect agriculture in two ways: by direct damage to crops, nurseries, market gardens and poultry farms, and by their contamination of exported goods. Many countries will not permit the entry of produce containing argentine ants. This has not yet occurred in Western Australia or in other Australian states.

It is these potential impacts that make the eradication or containment of argentine ants a desirable course of action in the eyes of many in the community, and which has led to the control programme which has been conducted in Western Australia for over the last 30 years.

3.2 HISTORY OF ARGENTINE ANT ERADICATION IN WESTERN AUSTRALIA

The argentine ant control programme began in WA in 1954. The position paper prepared by the Agriculture Protection Board (Appendix 1) gives the history of the programme since its commencement, including the extent of infestation, approximate areas sprayed for argentine ant and the quantities of pesticides used.

Initially, chlordane and dieldrin were the insecticides used in the programme. These were later replaced with heptachlor, as this insecticide was considered to be less residual whilst still achieving control with a single application. Since 1985, chlorpyrifos has also been used in the programme.

The initial objective of the spraying programme was to achieve eradication of argentine ants in Western Australia and in this context the programme has not been successful. However, information provided by the Agriculture Protection Board indicates that the spraying programme has led to a large reduction in the area infested with the ants and in the density of infestations. The spraying programme has therefore been one of containment rather than eradication.

In the past, there has been no systematic investigation of the environmental impact of the spraying programme, with the exception of two studies carried out in recent years, which are discussed below. Only anecdotal observations on the decline of non-target organisms exist. In addition, little or no studies have been done in Western Australia of alternative argentine ant control techniques, including integrated past management (a combination of biological, physical and occasionally chemical techniques) which has shown some success overseas.

3.3 THE CURRENT ARGENTINE ANT CONTROL PROGRAMME

The current Argentine ant control programme utilises two pesticides, heptachlor and chlorpyrifos. Heptachlor is the pesticide most favoured by the Agriculture Protection Board, and is used in all residential areas. Chlorpyrifos is used on pasture infestations (since heptachlor was banned in agricultural areas), around aviaries, fishponds and other sensitive areas, and on residential blocks when objections to the use of heptachlor are raised.

Until heptachlor spraying was suspended in February 1988, the APB had plans to treat a number of areas in that year, both within the metropolitan area and at country centres. The areas included 32 hectares at Scarborough, 60 hectares within the City of Perth, 20 hectares at Coolbinia and 60 hectares at Denmark. Resumption of the programme will be dependent in part on the the outcome of this review.

The intentions of the current argentine ant spraying programme are to eradicate local infestations and to contain larger ones such as that at Herdsman Lake. The eradication of small infestations prevents connection between adjoining infestations and slows the potential speed of spread. One of the major problems associated with the programme at present is that more than 70% of the currently infested area poses difficulties for treatment, either for environmental reasons or because of a risk of contamination of animals. In addition, the total area of infestation is increasing at a rate greater than the area being treated annually by the Agriculture Protection Board. This means that the successful control of argentine ants is becoming more and more difficult.

The current objectives of the argentine ant control programme and the procedures followed by the Agriculture Protection Board, including notifying residents of intention to spray, are detailed in the Agriculture Protection Board's Position Paper in Appendix 1.

3.4 THE PROPOSED CONTROL PROGRAMME FOR DENMARK

Argentine ants were first reported in Denmark in 1986 and at present there are 80 ha infested, 60 ha of residential area and 20 ha of pasture. The final survey for determining the spread of the ant was carried out in January 1988, with spraying planned for February 1988; however spraying has not been undertaken as a result of the suspension. The intention was to treat all residential properties with heptachlor and chlorpyrifos, and for pasture to be treated with chlorpyrifos.

3.5 THE PROPOSED CONTROL PROGRAMME FOR COOLBINIA

The Coolbinia ant infestation was discovered in 1987 and covers 200 residential blocks in an area of 20 hectares. The objective of the programme was to spray most properties with heptachlor, and to use chlorpyrifos in sensitive areas. However, at a public meeting attended by representatives of the Minister for Agriculture's Office, an undertaking was given to residents that properties would be sprayed with chlorpyrifos if they objected to the use of heptachlor. No spraying has yet been undertaken as a result of the suspension. The argentine ant infestation is considered heavy in the central areas.

3.6 CURRENT CONTROL OF ARGENTINE ANTS IN THE UNITED STATES OF AMERICA

Argentine ants have been present in California since the turn of the century and are now considered to be endemic, that is as an established part of the "natural" ant fauna. A similar situation exists in South Africa.

Chemical control of argentine ants in California occurs only at the point of export. Produce is examined and, if necessary, fumigated to ensure that export produce is free of the ants. All agricultural control of the ant is the responsibility of the farmer. The ant is known to have caused damage to citrus crops by preying upon the biological control agent (ladybird beetles) introduced to control citrus scale insects. Citrus growers prevent the ant from gaining access to the foliage of trees by physical means and by spraying tree butts with diazanon or chlorpyrifos. In San Francisco, argentine ants have been successfully controlled on street trees and citrus trees through water spraying to control aphids, on which argentine ants depend.

Broadscale chemical control of argentine ants does not occur in any other country or other Australian State.

4. HEPTACHLOR

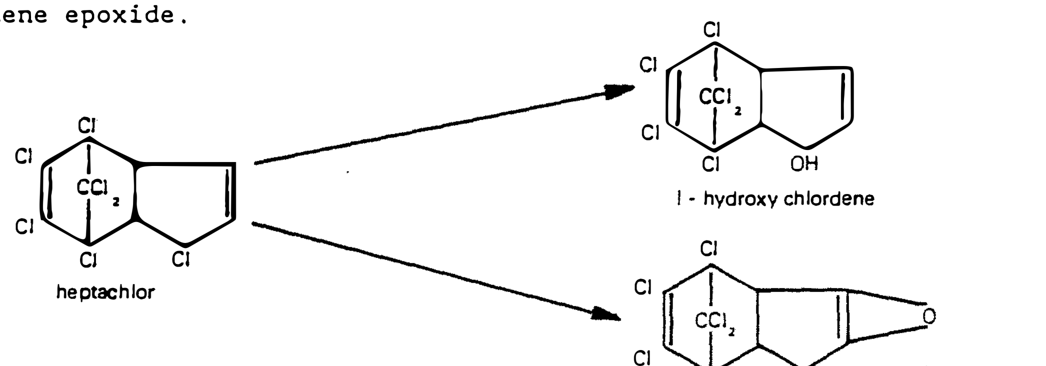
4.1 PHYSICAL/CHEMICAL PROPERTIES

Heptachlor is commonly referred to as an organochlorine or chlorinated hydrocarbon insecticide and has been used as a stomach and contact insecticide for over 30 years, mainly for the control of termites and soil insects. It is a white crystalline solid having the chemical structure:

The structure of heptachlor is closely related to the other cyclodiene insecticides chlordane, aldrin and dieldrin. Technical grade chlordane contains a certain percentage of heptachlor and vice-versa, so in effect both compounds are applied wherever either is used.

Heptachlor is considered by the APB to be effective for use in the control of argentine ants because of its persistence in the environment and its low solubility in water. The APB suggests that its efficacy as a pesticide is maintained for a longer period than other less persistent insecticides. The half-life of heptachlor in soil in temperate regions ranges from 9 months to 2 years, depending on soil type (World Health Organisation, 1984). However, heptachlor residues have been detected in lower levels of soil for up to 14 years after its application (WHO, 1984). The control of argentine ants by heptachlor has not been studied in detail to show how important is the question of persistence in the lower soil regions. Argentine ants have been shown to return to sprayed areas after a few years, hence persistence on the soil surface may be the major criterion rather than persistence in the lower levels of soil.

In the environment, heptachlor degrades through two major pathways to form 1-hydroxy-chlordene and heptachlor epoxide (WHO, 1984). There is also evidence to suggest that soil microorganisms have the ability to dechlorinate heptachlor to give chlordene which is then oxidised to give chlordene epoxide.



4.2 REGULATORY STATUS OF HEPTACHLOR

In Western Australia, heptachlor is registered for use in the control of argentine ants, and the control of termites in buildings in accordance with the Australian Standards 2057 and 2178. It is also registered for certain wood preservation treatments, the treatment of termites along fencelines and around poles, and the control of singapore ants under Government and local government direction.

Chlordane is registered for use for the same purposes as heptachlor, but is currently also available to the general public in a 500 ml bottle for ant control. However, the Environmental Protection Authority understands that this availability will shortly be removed, and chlordane will only be available to licensed pest control operators in the same manner as heptachlor.

Figures made available to the Environmental Protection Authority indicate that sales of heptachlor in Western Australia in 1987 for argentine ant control were approximately 17% of total heptachlor sales. This implies that most heptachlor used in WA is for the control of termites.

The regulatory status of heptachlor in other Australian States is similar to that in WA. In NSW, it is registered for the control of argentine ants, termites and borers, and the control of numerous insects on turf, including domestic and public lawns (State Pollution Control Commission NSW, 1986).

In the USA, heptachlor was first registered for use as an insecticide in 1952. For a time, it was widely used for insect control on numerous crops, including corn and citrus. Its major non-agricultural use was for termite control and home and garden insect control. During the 1970s, the United States Environmental Protection Agency (US EPA) took regulatory action resulting in the cancellation of virtually all uses of heptachlor and chlordane. Cancellation was a phased process between 1978 and 1 July 1983. From 1983, heptachlor/chlordane use was only permitted for subterranean termite control, and for fire ant control as a minor use.

In late 1987, the US EPA announced that the Velsicol Chemical Corporation, the only world manufacturer of heptachlor/chlordane had voluntarily agreed to cease the sale of pesticides containing heptachlor/chlordane intended for subterranean termite control. The agreement came about through increasing evidence that heptachlor/chlordane treatment of buildings was giving rise to measurable airborne concentrations of heptachlor/chlordane inside dwellings, resulting in widespread and long-term human exposure (US EPA, 1987). This exposure was estimated to lead to tangible risks of cancer for people living in treated houses, with the risk of cancers ranging from one cancer case in every one thousand people per annum to one cancer case in every ten thousand people per annum (US EPA, 1987). The Executive Summary from the US EPA document is provided as Appendix 4 of this Position Paper.

Under the agreement, Velsicol will not be permitted to sell termicides containing heptachlor/chlordane unless it can be demonstrated that new application methods can be used which do not give rise to detectable airborne residue levels inside homes. In effect, existing heptachlor/-chlordane stocks may be sold, distributed and used until 15 April 1988, but use during this time is severely restricted by certain conditions. All use of currently existing heptachlor/chlordane stocks for subterranean termite control, except for special trials, is prohibited after 15 April 1988 (US EPA, 1987). The US Environmental Protection Agency-Velsicol agreement has no effect on the manufacture and export of heptachlor/chlordane products by Velsicol from the United States.

4.3 ENVIRONMENTAL IMPACTS OF HEPTACHLOR USE

As previously mentioned, the Environmental Protection Authority commissioned an independent literature review of the ecotoxicological effects of heptachlor use in the environment. This work was undertaken by Dr Barbara Porter and is published as Appendix 2 to this report. Dr Porter's review also considers the impact of use of two possible alternatives to heptachlor for the control of argentine ants, chlorpyrifos and isofenphos.

The characteristics of heptachlor that have led to its use as a control agent for argentine ants are its low solubility in water, and its chemical stability, which lead to a relatively long life in the environment. However, it is this persistence, along with its ability to bioaccumulate in animal tissues as heptachlor epoxide, and its toxicity to many species, which led to concern about its use.

In Western Australia, the focus of the argentine ant control programme has been at Herdsman lake. Dr Porter's paper discusses the toxicity of heptachlor to a variety of animal species, and the incidence of heptachlor residues in other parts of the world. However, very little specific water, sediment or animal tissue residue monitoring has been undertaken in WA. Some anecdotal evidence exists on the impact of the argentine ant spraying programme undertaken in Perth in the 1950s, but this programme initially used chlordane and dieldrin and only later began to use heptachlor. Such evidence includes the large decline in the insectivorous bird population in Perth following the 1950s spraying programme.

In summary, the conclusions on heptachlor drawn by Dr Porter in her review paper are:

- there is ample evidence that organochlorines persist in the environment and that there is widespread contamination of non-target wildlife;
- bioaccumulation and biomagnification of residues of organochlorines occur, particularly amongst aquatic organisms;
- at high exposure levels, heptachlor and its epoxide cause death across a broad spectrum of animal life by disrupting the function of the nervous system;
- at lower exposure levels, numerous sublethal effects on organisms have been recorded such as hepatotoxicity, behavioural anomalies, reproductive failures and neoplasms;
- there has been very little research on the biological and physicochemical behaviour of heptachlor and its epoxide under Australian conditions; and
- there is a possibility that argentine ants may develop a resistance to heptachlor, as argentine ant resistance to cyclodienes has been previously recorded and heptachlor may be creating favourable conditions for the ants through the damage to predators and competitors.

Davis and Garland (1986) undertook an investigation of the environmental effects of spraying to control argentine ants at Herdsman Lake in March/April 1986. Sampling of water, sediments and two species of aquatic fauna (the mosquitofish, *Gambusia affinis* and the water boatman, *Micronecta robusta*) were undertaken pre-spraying and post-spraying of the lake with heptachlor, as well as after the first heavy rains following spraying. The conclusions drawn by the authors are that:

- The 1986 spraying programme at Herdsman Lake was responsible for the presence of heptachlor in the water at levels considered to be detrimental to the maintenance of aquatic ecosystems;

- There is evidence of bioaccumulation of heptachlor within the tissues of common and abundant members of the lake's aquatic fauna, and a suggestion that levels may be elevated in higher tropic levels, in particular the predatory species of waterfowl that feed on the fish;

- Surface run-off or leaching of pesticides through adjoining sandy soils plays an important part in the transport of pesticides into the lake.

Further sampling of water, sediments, aquatic fauna and waterbirds at the lake was undertaken by Davis and co-workers approximately seven months after the spraying programme (Davis et al, 1987). The results indicate that heptachlor levels in water remained above the recommended criterion for freshwater life (0.001 micrograms per litre) although there was an overall decrease in levels. Sediment levels of heptachlor increased markedly, whilst those in fish decreased, but were still above those measured prior to spraying. Levels in waterbirds, whilst appearing high, were difficult to interpret as waterbirds were not sampled previously.

Majer and Flugge (1984) have undertaken work to investigate the immediate effect of heptachlor spraying on argentine and native ant fauna, and the subsequent recovery of ants over a one year period. The study found that jet spraying with 0.05% heptachlor totally eradicated argentine ants from an infested area, as well as two other ant species in one plot. About one year later, argentine ants had not returned but had been replaced with the meat ant, Iridomyrmex purpureus. Flugge (1985) followed up this study two years after spraying to determine what changes had occurred in ant species richness. This study found that argentine ants had returned to the site approximately two years after spraying, and had effectively displaced the meat ant.

4.4 EFFECTS OF HEPTACHLOR USE ON HUMAN HEALTH

In simplified terms, insecticides (and all chemicals) can affect human health in two ways, and these are distinguished in the medical literature. The first is the acute effects of the chemical, which are essentially the immediate effects the body experiences after taking in the particular substance. Acute effects of insecticides on the human body include vomiting, headache, and dizziness but these depend on the particular insecticide to which the person has been exposed.

The second is the chronic effect, which is the effect experienced after many exposures and a relatively long period of time. Chronic effects of insecticide exposure could include liver damage, tumor development, and cancers, as well as effects on the future children of the person exposed.

Chronic effects of insecticides on humans can come about when there is some way in which the insecticide (or its derivative) can be stored in the body. Many insecticides are not water soluble but are soluble in fats, including body fat. They can therefore be stored in human body and thereby give rise to chronic effects at a later date. Release of the chemicals from the fatty tissue can occur when the body is stressed or when body fat is lost through weight loss. The chemicals can also be excreted in the fat of breast milk. Heptachlor can be stored in the body fat as heptachlor epoxide, and therefore has the potential to give rise to chronic effects.

Dr Roger Drew from the School of Clinical Pharmacology, Flinders Medical Centre, has prepared an independent discussion paper titled Human Health Aspects of Heptachlor. This discussion paper is reproduced as Appendix 3 of this report.

In summary, Dr Drew found that:

- heptachlor has a moderate acute toxicity and is easily absorbed by the skin, lungs, and gastrointestinal tract, although little study has been done on its sublethal effects;

- heptachlor is potentially hazardous to humans if incorrectly or carelessly handled;

- heptachlor is clearly carcinogenic in the mouse at very low exposure levels and there is limited evidence for carcinogenicity in the rat;

- although epidemiological studies do not show an association between heptachlor exposure and increased cancer risk to humans, heptachlor is regarded as a potential human carcinogen;

- heptachlor is avidly stored in human fat as heptachlor epoxide and human breast milk is a major source of exposure of infants to heptachlor; and

- there is a growing number of case reports linking chlordane and heptachlor exposure to a variety of blood dyscrasias (eg leukaemia) in humans, although a cause-effect relationship has not been established.

In his paper, Dr Drew concludes that it is unlikely that acute toxic reactions to heptachlor will occur during, or as a result of spraying heptachlor if standard precautions are observed. These precautions would include wearing protective clothing during application and avoiding direct contact with areas immediately after spraying. On the chronic effects of heptachlor exposure, Dr Drew states that:

"The long term storage of heptachlor epoxide in human body fat, its mobilisation and excretion in breast milk, and subsequent exposure of infants, indicates that exposure of women to heptachlor should be minimised. This conclusion is reinforced by a lack of knowledge of heptachlor effects on infants and their development." and "Our present state of knowledge dictates that heptachlor should be regarded as a potential human carcinogen. This coupled with limited evidence of an association between cyclodienes and blood dyscrasias in man should be enough to limit exposure of the general population to heptachlor."

The possible carcinogenicity of heptachlor and its general impact on human health have been reviewed in the literature by several bodies and authors (US Environmental Protection Agency, 1987; World Health Organisation, 1984; International Agency for Research into Cancer, 1979; US Environmental Protection Agency, 1986; Reuber, 1987). Copies of these papers are available on display in the library of the Environmental Protection Authority. The US EPA Executive Summary (1987) is included as Appendix 4.

5. ALTERNATIVES TO HEPTACHLOR FOR THE CONTROL OF ARGENTINE ANTS

In the past, several of the cyclodiene group of insecticides have been used to control argentine ants in Western Australia, including chlordane and dieldrin. This section would be more appropriately titled "Alternatives to Cyclodiene Insecticides for the control of Argentine Ants" as it is not proposed to examine the use of other cyclodienes to replace heptachlor, but rather other classes of insecticides and other control measures.

There are two classes of insecticides which are often mentioned as two alternatives to cyclodienes for the control of argentine ants, the organophosphate insecticides, and the synthetic pyrethroids. Chlorpyrifos, an organophosphate insecticide, is used by the Agriculture Protection Board in the argentine ant programme for treatment of pasture and environmentally sensitive areas. Isofenphos, another organophosphate, has been used in the past but is not currently registered for argentine ant control in WA.

In general, the organophosphate insecticides have a slightly higher acute toxicity to mammals than heptachlor and therefore extra care needs to be taken to avoid exposure during and post application. However, they are not considered a probable carcinogen, are metabolised to non-toxic compounds, and pose minimal risks to human health a short period after spraying. Despite this high acute toxicity, organophosphorus insecticides do not accumulate in body fat and are generally less persistent in the environment than heptachlor.

Synthetic pyrethroids have very low acute and chronic toxicity to mammals and do not accumulate in body fat. Their inability to be stored in body fat and their shorter persistence in the environment, means that they do not undergo biomagnification. However, their lower persistence, according to the APB, means that they are unlikely to be as effective as heptachlor for long term control. This assumes that residual persistence is an important property of a successful insecticide for argentine ant control. As argentine ants have been found to return after a few years, long term control obviously depends on such factors as the concentration of the chemical on the surface of the soil traversed by the ants, and how effectively the ants were killed in the first spraying.

Several synthetic pyrethroids are available and have been put foward as possible alternatives to heptachlor. These include cypermethrin, deltamethrin and permethrin. The US EPA has investigated the efficacy of permethrin for the control of termites under house pads and has concluded that permethrin would have to be applied 2 to 3 times more frequently than a cyclodiene insecticide to achieve the same degree of protection. Permethrin under house pads has been found to provide protection against termites for a period of 5 to 6 years (US EPA, 1987). However, there is much variability regarding the efficacy of a pesticide, and this is directly related to the method of application, the climatic and soil conditions, and the target organism. Caution needs to be taken in applying results achieved elsewhere under different conditions and for a different pest.

In the review paper prepared by the Agriculture Protection Board, it is stated that long term containment of argentine ants could only be considered a viable option if the use of heptachlor continued. The APB also states that chlorpyrifos, other organophosphate insecticides, and synthetic pyrethroids could not be relied on to give local eradication of argentine ant populations. If the use of heptachlor was discontinued, the APB believes that only short term containment would be feasible, and this would be likely to require far greater chemical and labour inputs.

No discussion has been provided by the APB on the use of physical techniques for controlling the ants, options such as baiting, or on the importance of household hygiene in controlling the preferred food source (sugar) of argentine ants.

6. DISCUSSION

The current debate over the control of argentine ants appears to be centred on three issues: the need for, and feasibility of, eradication of the ant, the use of chemical sprays to control the ants, and the choice of chemical if chemical sprays are to be used. This section discusses these three issues and identifies particular questions on which the EPA requests specific public comment.

The premise on which insecticides such as heptachlor have been used to control argentine ants in the past is that argentine ants need to be controlled, if not eradicated. The perceived need for control has been based primarily on the potential of the ants to affect agricultural crops and their export, and the nuisance they create in domestic situations. The impact of the ants on the environment was also considered as reason for control of the ants, though this is questioned by Dr Porter's evidence that significant environmental impact occurs when heptachlor is used for control and that it may be favouring argentine ants over native ants and other insects.

As previously mentioned, argentine ants are distributed widely throughout the world, and temperate climates such as that of the south west of Western Australia appear to be most favourable to the ants' existence and spread. The argentine ant is also found in California, which has a similar climate to the south west of WA and a similar reliance on the export of primary produce. However, it is understood that, unlike WA, in California the argentine ant is not the subject of specific chemical control programmes, although trials to control the ant with a range of experimental insecticides (not heptachlor or other cyclodiene insecticides) are being conducted by the US Department of Agriculture and physical control methods are being used.

The spraying which has been conducted since the commencement of the programme in Western Australia has been unsuccessful in totally eradicating the ant, but appears to have resulted in restricting its spread. Considering only the currently available control options, eradication of the ant, if feasible, would likely require a large increase in the area to be treated and a consequent increase in the quantities of spray used. Alternatively, there could be a change in techniques and ideas for pest control which are more akin to the Californian approach of containment, by use of a range of techniques.

The Authority therefore requests specific public comment on:

> **Should a specific programme for the control of argentine ants continue, and if so, should the objective of this programme be containment (ie. prevention of spread) or eradication of argentine ants?**

The Authority believes that any controls should be effected through the most environmentally acceptable means. As previously discussed, whilst the ant itself spreads radially through the establishment of new nests, by far the greatest rate of spread comes about through human activities. Therefore the most effective and environmentally acceptable way of achieving control (ie, restricting the spread of the ant) appears to be through community education on the method of spread and ways of minimising it through human activities, accurate and rapid identification of the ant, and notification procedures. Such community education would appear to form an integral part of any future control programme for argentine ants.

Whilst community awareness of the method of spread of argentine ants will help to minimise that spread, the need for some other specific control means cannot be doubted. There are techniques which can be used to control argentine ants utilising several different insecticides, and other methods. However, in its limited investigations, the Authority has not found any conclusive evidence of techniques which are fully successful in the control of argentine ants. The APB considers that the most successful technique is the spraying of cyclodiene insecticides (eg, heptachlor, chlordane, dieldrin and aldrin). For this reason, chlordane and dieldrin were initially used, and heptachlor has been used until the commencement of this review.

Insecticides, by definition, are designed to kill insects and related organisms, and insecticides which act only on the target insect species are very rare. There are a few new generation insecticides which achieve specific control, for example, bacterial agents for mosquito and midge larvae. However, the unavoidable consequence of most insecticide use is that other non-target invertebrate species will be effected.

Heptachlor is preferred by the Agriculture Protection Board because of its efficacy and residual activity. The APB believes that the use of heptachlor rather than other insecticides requires less manpower and lower quantities of chemical. The APB also believes that existing alternatives to heptachlor, whilst effective, may not be able to achieve the same control as heptachlor under the same spraying regime. However, given the findings of Flugge (1985), it may be possible to design a spraying regime, using less persistent insecticides, which is as effective as heptachlor use. If heptachlor use was to be replaced with an alternative such as permethrin or chlorpyrifos, repeated applications as suggested by APB, may need to occur. If this does occur, this would require an extra commitment of resources to the Agriculture Protection Board and greater control efforts by the community.

The method of application of heptachlor by the APB, and the precautions taken, are detailed in Appendix 1 of this report. In his paper, Drew states that acute toxic reactions to heptachlor are unlikely to occur in humans if adequate precautions are taken during and after spraying. However, Drew points to a number of possible chronic effects of heptachlor exposure and it is these which appear to give rise to most community concern.

The US EPA cancellation of heptachlor use for subterranean termite control was based on evidence that heptachlor use under house pads is giving rise to long term human exposure of heptachlor through exposure to gaseous heptachlor concentrations, and that such exposure poses risks of adverse health effects including those of cancer and chronic liver damage.

Given the outdoor use of heptachlor for argentine ant control, public exposure from airborne concentrations of heptachlor from argentine ant control spraying, is likely to be minimal. The method of grid spraying of heptachlor by the APB, and advice issued to the community on avoiding newly sprayed areas, helps to minimise direct contact of the community to heptachlor and resulting risk of skin absorption. These factors indicate that the outdoor use of heptachlor for the control of argentine ants, in accordance with the procedures established by the Agriculture Protection Board, is such that exposure to the general community is likely to be low. Some questions could be raised over areas that have been sprayed several years previously where residual levels in soil could be mobilised if soil is tilled or in which children play. Linkages between heptachlor sprayed in the general environment and agricultural production are also quite possible from dust and groundwater movement. Exposure to the community could be further minimised through the addition of dyes to the heptachlor formulation so that sprayed areas could be identified. However given the US evidence of heptachlor exposure from subterranean termite control (the US EPA have found that under-slab spraying of heptachlor/chlordane gives rise to measurable airborne concentrations within homes, and that no decay curve could be established) (US EPA, 1987), and the wide usage of hetachlor for this purpose in WA (approximately 80% of heptachlor usage in WA is for the control of termites in homes), the health impacts of heptachlor use for termite control are likely to be greater than those associated with the argentine ant spraying programme. In areas where both occur, the effects would be cumulative.

In her review paper, Dr Porter has discussed the impact of heptachlor use on the environment. Although little specific work has been undertaken in the Western Australian environment, the Authority believes that sufficient general information exists to suggest that in the WA environment, heptachlor is highly toxic to many species, is persistent in the environment, and is stored in the fatty tissues of organisms, leading to bioaccumulation and biomagnification. Heptachlor and associated compounds are believed to be responsible for the decline in populations of insect species and the death of insectivorous birds. However, insect populations may recover after reduction from heptachlor application (Davis et al, 1987) and therefore the question needs to be asked whether some localised decline of insect populations is an acceptable consequence of argentine ant control efforts, or whether the cumulative impact of heptachlor in the environment makes its continued use unacceptable.

The APB already has a policy of using chlorpyrifos in environmentally sensitive areas. This raises the question of the definition of environmentally sensitive areas.

The EPA therefore requests specific public response on:

> **Is the use of heptachlor for the control of argentine ants acceptable? If so, under what circumstances and in which areas should heptachlor be replaced with other control means? Alternatively, should heptachlor be seen as not acceptable, what programmes for control are acceptable? What constitutes an environmentally sensitive area in the context of argentine ant control?**

In the past, the APB has used chlorpyrifos on residential properties only when strenuous objections to the use of heptachlor have been voiced by the residents. The Authority recognises that if the heptachlor spraying programme is to continue on residential properties, the likely low level of exposure to heptachlor from that spraying is not likely to be of comfort to those in the community whose homes have been treated, although they may consider this to be an acceptable trade-off in removing ants. This raises the question of how involved the community should be in deciding how to manage argentine ants on their own property, and what options are presented to them. For example, the possible options could include use of a less residual chemical spray, other control means such as baiting, or no control.

Therefore, the EPA requests specific public response on:

> **What control options should be available to residents whose homes and properties are infested with argentine ants and what information should**

be provided to them? Should residents be compelled to control ants on their properties?

A final note of caution needs to be made with regard to turning to the use of any chemical without prior consideration of the environmental and human health impacts associated with that use. Any proposal to introduce insecticides for the control of argentine ants should be accompanied with a thorough examination of the impacts experienced elsewhere, and the likely impact in the context of our own environment, method of use, and target species.

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APPENDIX 1

Agricultural Protection Board Review Paper on the Argentine Ant Control Programme

A REVIEW OF
ARGENTINE ANT CONTROL IN
WESTERN AUSTRALIA

This review has been compiled in response to a request from the Environmental Protection Authority (E.P.A).

Argentine ants, Iridomyrmex humilis (Mayr), have been the subject of an eradication programme in Western Australia for more than three decades. Under the provisions of the Argentine Ant Act, 1968 and the earlier legislation, the relevant Minister is charged with the "treatment and eradication of [Argentine] ants" Sec. 6(1)(a).

As part of this programme, spraying was planned for Coolbinia and Denmark. Public concern over the potential effects on the environment and community health resulted in a deferral of spraying plans and a Government decision to review the control programme. The E.P.A. were asked to consider the whole issue of Argentine ant control including the use of the insecticide heptachlor, and possible alternative control techniques.

Prepared for
The Agriculture Protection Board
By Simon Whitehouse

February 1988

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1. BIOLOGY

The Argentine ant was first collected in 1866 near Buenos Aires, Argentina and described in 1868. It was later found in Brazil and Uruguay and general evidence sugests it is indigenous to those areas (Forte & Greaves, in prep). There has been very little fundamental biological study of the Argentine ant in Australia and most of the work was done in United States in the early part of this century (e.g. Newell, 1909). However there has been a considerable amount of incidental observations by entomologists in Australia and these all tend to support earlier ecological studies.

1.1 Description

Workers (sterile females) of the Argentine ant are light to dark-brown, 2.2 to 2.6mm long, monomorphic and wingless. They are not readily distinguished from many other species of small ant. However, behavioural habits such as travelling in well-defined narrow trails, combined with the musty or greasy odour given off when they are crushed, rather than the sharp formic acid smell of other small ants, are usually sufficient evidence to identify Argentine ants (Madge & Caon, 1987; Smith, 1965).

Queens (females) are up to 6mm long, are brown, with a silky pubescence, and are usually wingless. Males are up to 5mm long and are shiny brownish black, with wings.

Under a microscope, Argentine ants can be separated from all other Iridomyrmex by the combination of: (1) eyes situated low on the head capsule close to the mandibular insertions; (2) trunk glabrous without setae or pilosity; (3) propodeum short, rounded and a dull brown colour; and (4) petiole with a single node (Greenslade 1979). Mandibles of Argentine ants have several small teeth between the rear incisors and the two front incisors and are quite characteristic.

1.2 Life cycle and habits

The ants are social insects with their colonies containing queens, males and workers. The brood consists of eggs, larvae and pupae. The pearly-white, elliptical eggs are about 0.3mm long and take from 12 days to nearly 60 days to hatch, depending upon temperature. The larval stage takes from 11 to 60 days and the pupal period may last 10 to 25 days. The minimum period required from egg to adult is about 30 days, but it may be as long as 4 to 6 months in winter (Newell, 1909).

Large numbers of eggs are produced in late winter and early spring and mostly sexual forms develop from them. The queens and males mature in late spring and mate. After mating, the queens shed their wings and start ovipositing. Workers are produced from early spring onwards, with a peak in abundance in midspring.

The number of ants in a colony may vary from a dozen to many thousands and, unlike other ant species, there may be many reproductive queens in one colony. Nuptial flights are not common; the queens are usually fertilised in the nest, after which the males are eliminated. Queens are incapable of successfully rearing young without the aid of worker ants.

When climatic conditions are suitable, often in spring and summer, the queens will travel in trails with small groups of workers to search for new nesting sites. Argentine ants spread laterally by 'budding' (sociotomy). Queens plus workers establish new nests outside the existing colonized area. This spread can be up to 100m per year. However most of the spread of Argentine ants both between and within countries appears to be the result of human activities. Ant colonies are frequently spread by pot plants, vegetable produce and other items distributed by people.

Argentine ants cannot sting, but may bite if their movement is restricted.

At any one time approximately only 1- 2% of workers are away from the nest (Newell & Barker, 1913). However individuals probably have the capacity to remain underground for long periods (many weeks) without emerging to forage for food (J. Majer, pers.comm.). For this reason control techniques need to be long lasting to be effective in killing the whole ant colony.

Ecological studies and incidental observations show that Argentine ants are dependent on an adequate supply of moisture. For this reason in areas of low rainfall they tend to be confined to urban areas where domestic water is available, to irrigated agricultural areas or to bushland within about 100 metres of water (P. Ward, pers. comm.). Many Argentine ant infestations seem to be confined to disturbed soil (J. Majer, pers.comm.) although this does not seem to be the case in South Africa or California.

2. DISTRIBUTION

Since first being described in Argentina in 1868, the Argentine ant has spread to many other parts of the world.

In 1891 it was first recorded as a small infestation in New Orleans, U.S.A around wharves where coffee ships from Brazil docked. By 1907 it was discovered in California and in 1936, more than 10,000 km^2 were infested. The ant was variously referred to as "the housewife's nemesis", "the gardener's grief" and "the orchardist's plague" (Mallis, 1938). It now also occurs in the north-eastern states (Madge & Caon, 1987).

Argentine ants now occur in most of the warmer regions of the world such as southern Africa, Indonesia, Hawaii, Bermuda and south-western Europe (Commonwealth Institute of Entomology, 1958, Crowell, 1968). It is also found in colder regions (Belgium, Ireland, Poland) but restricted to greenhouses and heated buildings (Madge and Caon, 1987). The current world distribution of Argentine ants is shown in Figure 1.

Despite their wide distribution Argentine ants appear to be most successful between latitudes 30° and 36° N or S (Fluker & Beardsley, 1970; Lieberburg et al, 1975).

2.1 Australia

The Argentine ant was first recorded in Victoria in 1939 (Jenkins, 1948),in Western Australia in 1941 (Jenkins, 1949), New South Wales in 1950 (N.S.W. Dept. Agric, 1977), Tasmania in 1951 (Jenkins, 1973), South Australia in 1979 (Madge, 1979) and the Australian Capital Territory (A.C.T.) in 1982 (C. Nazer, pers.comm.).

2.1.1 Northern Territory & Queensland

Argentine ants have not been recorded from either the Northern Territory or Queensland.

2.1.2 A.C.T.

The infestation in the A.C.T. was small (about 50 residential blocks) and was eradicated by a chemical control programme. Subsequent resurveys of the area as late as 1986 show no reinfestation.

2.1.3 South Australia

In South Australia, Argentine ants are confined to metropolitan Adelaide. Populations are generally considered to be "slight" (Madge & Caon, 1987) and not a nuisance (G. Baker, pers. comm). No co-ordinated central control programmes have been carried out by State or Local Government authorities.

FIGURE 1 DISTRIBUTION OF ARGENTINE ANTS

COMMONWEALTH INSTITUTE OF ENTOMOLOGY

DISTRIBUTION MAPS OF INSECT PESTS

Series A, Map No. 94. Issued December, 1958.
Published at:- 56 Queen's Gate, London, S.W.7.

Pest: *Iridomyrmex humilis* (Mayr)
(Hymenopt., Formicidae) (Argentine Ant)

Hosts: Polyphagous; scavenger, invading houses; fosters Aphids and Coccids, notably on *Citrus*; aggressive.

▲ Occurrences recorded in literature
(See text)

2.1.4 Tasmania

Argentine ants are confined to the metropolitan area of Hobart and Launceston. In Hobart they are confined to the immediate area around the wharves although occasional infestations have been found up to 5 kms away and eradicated.

In Launceston, the original infestations were in a nursery and rubbish tip. Currently the infestation covers several city blocks.

The ants thrive inside buildings, especially those which are heated. In summer they may be seen trailing outside.

The State Department of Agriculture has been co-ordinating an eradication campaign which is currently being reviewed.

2.1.5 Victoria

In Victoria, Argentine ants are widely distributed throughout metropolitan Melbourne in a radius of about 30 kms. In 1980 the metropolitan infestation was surveyed at more than 70,000 hectares. They are also present in more than 20 regional towns including Mildura on which the Sunraysia citrus growing area is centered. In Melbourne, most infestations are in the well-established suburbs. While Argentine ant populations were considered to be very high in the 1950's, current populations are light (R. East, pers.comm). Early population densities were sufficiently high that people were unable to carry out activities such as gardening due to being "mobbed" by ants. While co-ordinated State and Local Government ant control programmes were carried out in some areas, the current light population densities do not seem to be the result of these activities as virtually no Government co-ordinated programmes were carried out in metropolitan Melbourne except around freight exporting areas. The Government control programme ceased in 1985.

2.1.6. New South Wales

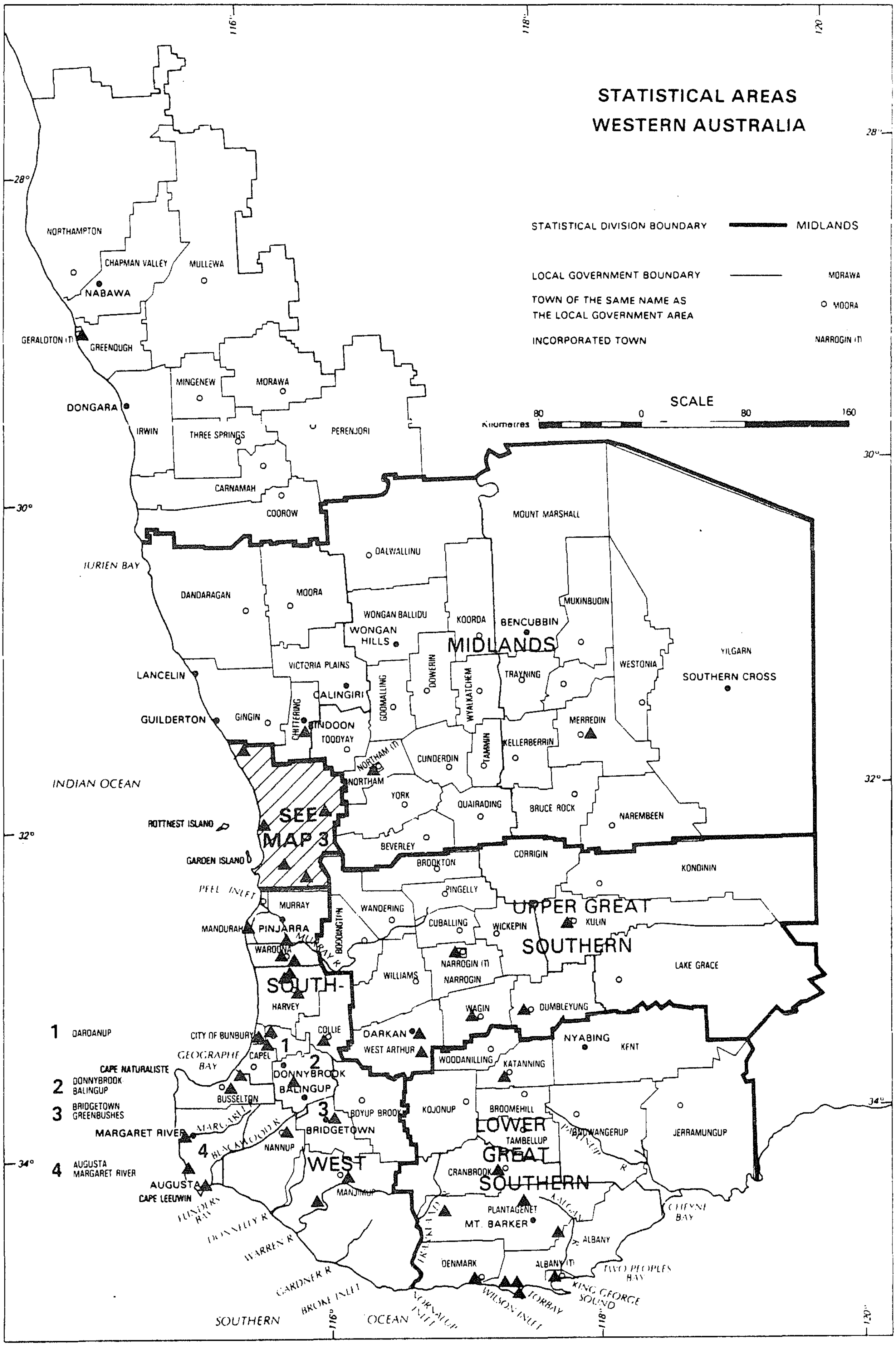
In New South Wales, Argentine ant populations were initially widespread across Sydney. Ant populations in the 1950's were very high to the extent that some residents were forced to leave their homes (R. Tofflin, pers.comm). Currently the Argentine ant infestations cover approximately 80 hectares and this reduction is attributed to the State and Local Government ant control programmes. These programmes were stopped in late 1983 at which time Argentine ant infestations had been reduced to less than 40 hectares.

2.1.7. Western Australia

The Western Australian distribution of Argentine ants is discussed below and shown in Figure 2.

FIGURE 2

Locations in W.A. where Argentine ants have been discovered since 1941



▲ Denotes Argentine Ant infestation
Note : Also found in Esperance

3. ARGENTINE ANTS AS A PEST

The significance of Argentine ants as a pest can be considered under three categories:

domestic/commercial nuisance
environmental damage
agricultural damage

3.1 Domestic Nuisance

Argentine ants are "one of the most persistent and troublesome of all our house-infesting ants...... Argentine ants ...... will infest every house persistently, continuously, and in large numbers, once they are established in a given area" (Smith, 1965, P54).

In heavily infested areas the ants infest street trees and gardens, and when these sources of food are insufficient, usually in late summer, they invade household blocks and the interior of houses. Chicken pens, pet's living areas and aviaries are infested, often resulting in the death of chickens, cage birds and other animals (Forte & Greaves, in prep).

In dwellings the ants search for food and moisture in kitchens, and also infest pantries and dining rooms. They are capable of invading refrigerators and food containers. They trail around the thread of screw top jars and will reach the contents (such as honey or jam) through any small space between the top of the jar and the lid. The ants have been known to trail through as many as three rooms in a house to reach a packet of sweets in a bedroom (Forte & Greaves, in prep).

In severely infested areas, the legs of beds must be placed on plates of glass smeared with vaseline, or in tins of water with a film of kerosene to prevent the ants climbing onto the beds (W.A. Dept. of Agric, undated).

Argentine ants have been recorded in households, hospitals and nursing homes attacking babies in cots and incapacitated adults. These people have been found swarming with ants, attacking sores, penetrating nostrils and causing great discomfort. As recently as March 1987, Argentine ants were found feeding on an open wound of a patient on the 7th floor of the Queen Elizabeth Medical Centre in Perth. Ipinza-Regla et al (1981) identified the Argentine ant as a vector of bacteriological infection within hospitals. Bodies laid out in mortuaries and private homes have also been infested with Argentine ants (Forte & Greaves, in prep).

Argentine ants are also a serious problem to commercial enterprises involved in the production and sale of food.

Similar observations have been widely recorded in the literature which is reviewed by Forte and Greaves (in prep).

All these forms of domestic nuisance have been observed and recorded in Western Australia.

3.2 Environmental Damage

Argentine ants live in well organised communities in which individual nests remain in contact with the rest of the community. Markin (1968) discovered there was greater than a 50% exchange of workers between adjoining nests over a 5 day period. Colony dispersal occurs from spring to autumn by sociotomy where a queen/s and workers move closer to a food source. These new nests remain in contact with the rest of the population. In winter, and at other times of stress, smaller nests coalesce into large nests which may contain hundreds or even thousands of queens and associated workers.

In effect this almost perfect social system means there is little or no intra-specific competition and hence little self regulation. As a result large populations develop.

These large populations, combined with the cohesive social structure, give Argentine ants a competitive edge against other ant species. In direct conflict with other ants, Argentine ants can draw on the reserves of the whole community while most other species of ants are limited by the reserves available from a single nest. "Once these ants become established in a locality they will not tolerate the existence of any other species of ants, and as the populations of each colony build up in density, they emigrate in all directions, consolidating as they go and driving other species before them. Not only does I.humilis displace native ant species, but it has been shown to displace other introduced tramp species" (Erickson, 1972, P257).

As a result, one of the characteristic features of an Argentine ant infestation is the lack of other ant species in the area. The literature records that in most areas of the world where Argentine ants have established, the species diversity of native ants has been reduced and in some areas eliminated. (e.g. Bond & Slingsby, 1984; Erickson, 1972; Fluker and Slingsby, 1970; Lieberburg et al, 1975; Ward, 1987).

Argentine ants have caused local extinction of some species of native ants (P.C. Ward, pers.comm.).

It appears that in some areas after a period of time the localised eradication by Argentine ants slows, and an equilibrium is established between the Argentine ant and other species. This has been suggested in Bermuda (Lieberburg, et al, 1975) and Hawaii (Fluker & Beardsley, 1970). However more recent studies (Loope et al, 1986) have shown that Argentine ants have exerted a serious impact on a wide range of native, ground-dwelling arthropods including spiders, bees and earwigs.

Recent studies of Argentine ants in South Africa have found that they have replaced native ants and severely disrupted seed dispersal in native shrub land ecosystems (Bond & Slingsby, 1984). As a result these authors predict that many rare, endemic Cape Proteaceae species will become extinct by slow and subtle attrition of seed resources. Bond and Slingsby recommend stopping the spread of Argentine ants in South Africa for this reason.

Severe infestations of Argentine ants can also disrupt native fauna by predation of nestling birds and other small fauna such as lizards. Even large fauna with wounds may fall prey to severe infestations of Argentine ants.

While there have been numerous incidental observations of environmental damage by Argentine ants in Australia and Western Australia, the only systematic observations reported have been the result of native ant population suppression by Argentine ants (Majer & Brown, 1986; Majer and Flugge, 1984). Entomologists from the N.S.W. Department of Agriculture are reported to be currently studying this aspect.

3.3 Agricultural Damage

Agricultural industries can suffer from Argentine ant infestations in two ways. Firstly as a result of production losses caused by ant populations. Secondly as a result of foreign markets rejecting produce either infested with or affected by Argentine ants.

The most frequently recorded agricultural damage attributed to Argentine ants is in citrus crops (Madge & Caon, 1987; Quayle, 1938). They have also been reported as destroying buds, blooms and fruit by direct attack (Newell, 1909).

One of the major food sources of Argentine ants is the sweet exudates (honeydew) of hemipteran insects on plants (Forte & Greaves, in prep). Scale insects, mealy bugs and other sap sucking insects on plants have their population naturally maintained at a relatively low level by parasites and predators.

When ants are present they swarm over the plants in search of the honeydew and effectively protect the insects from their natural enemies by aggressively warding off most predators and parasites of the honeydew producing insects (Phillips, 1986). This results in a rapid build up of insects to the detriment of the plant. Many species of ants feed on honeydew and in turn protect the hemipteran insects, but Argentine ants appear to be much more effective in the protection they afford.

Where biological control programmes have been established to control scale insects and other pests, Argentine ants can cause heavy economic losses to crops such as citrus, figs and grapes by disrupting the biological control. Insect attack may be severe enough to cause tree deaths.

Similarly, Argentine ants can cause damage in nurseries and market gardens. Argentine ants have also been a pest in the apiculture industry, and have disrupted high density animal rearing programmes, especially poultry.

Argentine ants are a major agricultural pest in California where biological control has been a cornerstone of integrated pest management (I.P.M.) (Baker <u>et al</u>, 1985, Moreno <u>et al</u>, 1987).

There are no records of Argentine ants causing significant agricultural production losses in Australia although C.F.H. Jenkins (pers.comm.) reports that some market garden produce was contaminated in the 1950s and hence made unsaleable. Most infestations are in urban areas or pasture used for grazing on the fringes of urban areas. In Western Australia, the organised control programmes have been effective in limiting the spread of Argentine ants to agricultural areas.

However the ant has been recorded in Mildura, the centre of the Sunraysia fruit growing region on the Victorian/New South Wales border. No reports of agricultural damage have been received (M. Mekhamer, pers.comm., R. East, pers.comm.).

Most countries in the world prohibit the importation of insects particularly if associated with vegetable matter. To this end they require certification from the exporting country - a Phytosanitary Certificate - that the exported goods are free of any injurious organism. In addition, under the Export Control Act (1982), fresh fruit and vegetables exported from Australia are inspected for quality. Inspection for both of these purposes is carried out by staff of the Department of Agriculture on behalf of the Commonwealth Government.

Argentine ants are considered an injurious organism and likely to impair the quality of exported produce. Because of their biology they are most likely to cause a problem if an infestation occurs around export facilities such as wharves, airports or packing sheds.

4. HISTORY IN AUSTRALIA

4.1 Western Australian Legislation

Argentine ants were first recorded in Western Australia in April 1941 at Albany in the South West. Following a survey by the Government Entomologist, regulations were gazetted under the Plant Diseases Act restricting the movement of nursery stock and plants carrying soil from infested to clean areas of the State (Jenkins, 1951).

However, in May 1941, specimens were recorded from Perth (Hansard, 1943) and the sending of plants in pots or packed in soil from within an eight kilometre radius of the Perth Town Hall was banned unless a permit was issued from the Department of Agriculture (Jenkins, 1948).

In 1948 the Argentine ant was added to the Third schedule of the Vermin Act. In that year an infestation of Argentine ants was recorded in Bunbury. At that time the total area appeared to be about 0.05 hectare. In 1951, less than three years later, a survey showed the area of infestation to be approximately 12 hectares (Jenkins, 1951).

In 1949 the Health Act was amended to include Argentine ant control. This was done because it was felt that the Health Department had more staff in urban areas where most infestations had been found. Control programmes however, were carried out in close consultation with the Department of Agriculture (Hansard, 1954).

In 1954 the Argentine Ant Act was enacted (Appendix 1). This legislation was passed as a result of the widespread community concern over Argentine ants and the decision to allow the Department of Agriculture to control the campaign. The Argentine Ant Control Unit remained within the Department of Agriculture until 1987.

It is important to note that concern within the Western Australian community over Argentine ants was so great that at a meeting of local authority representatives on February 10, 1954, a unanimous request was made for the Government to pass legislation to collect a special rate from ratepayers within the South-West Land Division.

The legislation also established the Argentine Ant Control Committee as being responsible for employing staff and carrying out the programme. From the Minister's Second Reading Speech it is clear that the objective was to eradicate Argentine ants from Western Australia within five years. Finance for the campaign came from ratepayers and the State Treasury.

New legislation was passed in 1959 which changed some of the administrative arrangements of the 1954 Act. The Argentine Ant

Control Committee was continued but the financial arrangements changed so that State Treasury contributed most of the funding.

In 1968 new legislation was passed which abolished the Argentine Ant Control Committee and made the Minister for Agriculture through the Department of Agriculture, responsible for Argentine ant control (Appendix 2).

Hansard at the time (Hansard, 1968) shows that the community concern had abated to some extent but there was recognised a need to ensure no repeat of the problem of the magnitude of the 1950's. It is stated in the debate that the programme had been very successful and that [local] eradication had been achieved. The 1968 legislation states that the "functions of the Minister include the control and direction of the treatment and eradication of [Argentine] ants" Sec.6(1)(a).

From December 1, 1987, the Agriculture Protection Board of Western Australia (A.P.B.) assumed responsibility for Argentine ant control. On that date, the Argentine Ant Control Unit previously located within the Department of Agriculture was transferred to the A.P.B. This was a result of a review of the functions of the A.P.B. and the Department of Agriculture by the Functional Review Committee.

4.2 Legislation in other parts of Australia

In the A.C.T. the Parks and Wildlife Service of the A.C.T. Administration carried out an eradication campaign under the Plant Diseases Ordinance (1934).

In N.S.W. the eradication campaign was carried out under the provisions of the Argentine Ant Eradication Act (1962). However in 1983 the campaign was challenged by the Lane Cove Bushland Conservation Group through the Environmental Planning and Assessment Act. The N.S.W. Argentine Ant Eradication Committee was advised that they would be required to carry out an Environmental Impact Statement on each occasion they wished to spray insecticide. This effectively prevented the eradication campaign from proceeding and the Argentine Ant Act was repealed in 1985.

In Tasmania, Argentine ants were declared a noxious insect under the Noxious Insects Act. The Act requires landholders to eradicate declared noxious insects but the government effectively assumed responsibility by carrying out a campaign. This is currently being reviewed and it appears likely that the Tasmanian government may advise landholders how to carry out their own control without government assistance.

4.3 Control methods

4.3.1 Western Australia

A variety of control methods have been applied to Argentine ants in W.A. in line with the technology available at the time.

In 1948 carbon bisulphide and calcium cyanide were being recommended as fumigants, and sodium fluoride, Paris green, arsenical sheep dip and sodium fluoro-silicate as poison dusts (Jenkins, 1948). Baiting was also recommended using sodium benzoate and/or sodium arsenite as the toxin and honey as the attractant. The insecticidal properties of DDT were discovered in 1939. This was the first of the synthesised organic insecticides to become available. Spraying with D.D.T. in either oil, kerosene or water solution was recommended as being both cheap and effective.

Large scale spraying with D.D.T., the only insecticide considered suitable at the time, was carried out in metropolitan Perth between 1949 and 1951 but eradication was not achieved although it afforded some relief to householders (Hansard, 1954).

Following the discovery of Argentine ants in N.S.W. in 1950 a collaborative programme was developed between C.S.I.R.O. and the N.S.W. and W.A. Departments of Agriculture aimed at evaluating the possibility of eradicating Argentine ants. Trials commenced immediately with the organochlorine insecticides chlordane and dieldrin which had recently become available.

It soon became evident that eradication of individual infestations, even large ones, was possible. Even though only 1-2% of Argentine ants are out of the nest foraging at any one time, these insecticides persisted in the environment sufficiently long for the whole colony to be killed.

The techniques involved the spraying around the perimeter of an infestation (to prevent emigration during the spray operation) and then the spraying within the infestation in a grid pattern with grid lines spread 3 metres apart. This allowed for a minimum use of insecticide while at the same time leaving sufficient residue for Argentine ants to contact while foraging and travelling from one nest to another.

Chlordane and dieldrin were then used by the Government authorities in their control campaigns with chlordane being used as the insecticide of choice around difficult sites such as aviaries and fish ponds. The programme in W.A. commenced in 1954. Subsequently the programme switched to using heptachlor as it was considered safer and was the least residual pesticide capable of achieving eradication with a single application. Heptachlor is applied in a grid pattern with grid lines 1 metre apart.

Since 1985, while heptachlor has remained the pesticide of choice, chlorpyrifos has been used on pasture infestations; around aviaries, fishponds and other environmentally sensitive areas; and on a few occasions when householders raised strenuous objections to the use of heptachlor.

A detailed description of the procedures followed is contained in Appendix 3.

4.3.2. Other parts of Australia

Similar control programmes have been used in other parts of Australia. In the A.C.T. chlorpyrifos was used by government authorities to eradicate a small infestation.

In New South Wales, dieldrin was used before substituting chlordane in the 1960's. This continued to be used in government eradication programmes until they were stopped in late 1983.

In Victoria, local government authorities used clordane and dieldrin in the 1970's before switching to chlorpyrifos. It is now the insecticide recommended to householders to control Argentine ant infestations.

In Tasmania, chlordane is the insecticide used by government authorities in their eradication campaign. However its use will be deregistered in Tasmania from June 30th 1988 and it is likely that householders will be advised to use chlorpyrifos against Argentine ants.

In South Australia where no government sponsored control programme has existed, householders are advised to use general pressure-pack surface sprays inside houses and chlorpyrifos or diazinon outside.

4.4 Insecticides in use

Use of insecticides in Western Australia is controlled by the State Health Department.

Chemicals with insecticidal activity are first considered by the Technical Committee on Agricultural Chemicals (T.C.A.C.) - a national committee within the Commonwealth Department of Primary Industry and Energy. Each state has one representative - the State Registrar of Pesticides - on the Committee plus other specialist members. The National Health and Medical Research Council (N.H. & M.R.C.) provide the T.C.A.C. with recommendations for the Maximum Residue Levels, with-holding periods, poison schedule and first aid treatment. At this stage the bulk of the toxicological data on the insecticide are examined. Input is received from a wide range of non-government and government sources.

A clearance from the T.C.A.C. is only necessary for

1) new active ingredients used for the first time in Australia,
2) major departures from existing registered use patterns, and/or
3) major formulation changes.

If the insecticide is considered acceptable, a clearance is granted and the applicant then seeks registration in particular states, the uses and formulations for which clearance was obtained. In Western Australia, application for registration is made to the Pesticides Advisory Committee (P.A.C.), a statutory committee established under the Health Act. The P.A.C. has one represent- ative from the Health Department (who chairs the Committee), the Department of Agriculture and the Government Chemical Laboratories. At this stage most of the consideration concerns the efficacy of the product as toxicological data have been considered at the previous clearance level. Detailed labelling requirements are imposed, particularly relating to safety precautions.

Registration of a chemical involves the applicant being advised that the product is acceptable for sale as specified and the product label, including directions for use, is approved and four final printed copies of the label are supplied.

Heptachlor and chlorpyrifos are registered for use in Western Australia against Argentine ants. The Argentine Ant Control Unit has at all times complied with all directions for use. Heptachlor will not be available for use in the United States from April 15, 1988 but chlorpyrifos will (U.S. E.P.A., 1987).

It can be seen from the Procedures described in Appendix 3 that the Unit has adopted very conservative and safe spraying practices. Spray operators are under close supervision at all times by experienced supervisors, all of whom have successfully completed Pest Control Operators' courses run by the W.A. Technical & Further Education Division as well as in-house training.

There have been some reports of accidental damage caused by the sprays used in the Argentine ant control programme. Official records are shown in Appendix 4. There are subjective impressions of large scale losses of avifauna from metropolitan Perth as a result of the campaign in the 1960s. Cases of loss and damage have declined markedly in recent years apparently as a result of the introduction of heptachlor.

There appears to be only two documented systematic observations of the effects of Argentine ant spraying on fauna. The first resulted from the spraying of Yanchep National Park for Argentine ants in 1982 (Muir, 1982).

The infestation was sprayed using heptachlor in areas away from public picnic lawns, and isophenfos (an organophosphorus insecticide) in areas where public contact was likely. A limited series of transects was carried out both before and after the spraying counting fish, mammals, reptile and terrestial invertebrates. Vertebrate fauna showed almost no response to the programme even in the short term. Invertebrates, particularly ground fauna, were virtually eliminated in the spray area but showed excellent recovery in a few weeks. No trace of insecticide transport into the lake could be detected.

The second study (Davis & Garland, 1986) examined the environmental effects of Argentine ant spraying at Herdsman Lake. Sampling of water, sediments and some aquatic fauna showed residues of DDT, dieldrin, chlordane, heptachlor and chlorpyrifos. Fish populations were not affected but corixids were.

The study did not continue long enough to ascertain whether insect populations recovered as at Yanchep. However there were indications that insecticide levels in the Lake were being supplemented by inflow from drains from the surrounding catchments.

Subsequent studies have confirmed that residues of heptachlor, chlordane and dieldrin following Argentine ant spraying increase immediately after spraying then decline. However each winter there is a significant pulse of these pesticides entering the Lake from the surrounding catchment (J. Davis, pers.comm.; S. Halse, pers.comm.). This may be attributed to their use in termite control around buildings, and in market gardens. The amount of heptachlor used in Argentine ant control is a small percentage of the total use in W.A. These figures have been supplied in commercial confidence to the E.P.A.

4.5 Control Programme for 1987/88

Table 1 shows details of the Argentine ant infestations which were sprayed in the 1987/88 control programme and Table 2 the areas planned for treatment prior to suspension of the programme. These Tables along with examination of Figures 3(i) and 3(j) demonstrate the number of isolated, but small and manageable, infestations.

TABLE 1

Areas Sprayed in 1987/88 Prior to Suspension of Operations

	Ha.
Canning Vale	3
Osborne Park	4
Leederville	12.5
Wembley	9
Trigg	3
Osborne Park	1.5
Noranda	5
Noranda	6
Applecross	1.5
Osborne Park	1
Gwelup	2
Waneroo	1
Cannington	9
Maddington	1
Pinjar	4.5
Ascot	6

The programme operates by local eradication of infestations, and containment of larger, difficult areas such as Herdsman Lake. This is to prevent the numerous isolated infestations acting as multiple force and connecting adjoining ant infestations and therefore increasing the speed of spread.

TABLE 2

Treatments Planned for 1987/88

	Ha.
Kewdale	10
Perth	60
Scarborough	25
Scarborough	7
Leeming	12
Duncraig	8
Coolbinia	20
Mullaloo	1
Kardinya	3
Kelmscott	2
Karrawarra	3
Denmark	60

4.6 Control Programme in Denmark

After initially discovering Argentine ants in the area in 1986 there are currently 80 hectares infested - 60 hectares of residential area and 20 hectares of pasture. Following the discovery the Argentine Ant Control Unit received numerous calls requesting assistance. The local Member of Parliament also received calls requesting assistance and these were passed on to the Argentine Act Control Unit.

In January 1988 a final survey was carried out and residents were informed of the spray programme which was scheduled for February. The programme was for heptachlor and chlorpyrifos to be used in all residential blocks according to standard procedure (see Appendix 3). All grazing areas were to be treated with chlorpyrifos.

Subsequently a meeting was held to oppose the spraying to which the A.P.B. was not invited. It was reported that the meeting opposed the use of both organochlorine and organophosphorous insecticides.

4.7 Control Programme in Coolbinia

The Coolbinia infestation was first discovered in 1987. It currently covers approximately 20 hectares involving 200 residential blocks. The infestation is considered heavy in the central 100-120 houses but light in the outer areas. Complaints were received from some residents by the Argentine Ant Control Unit.

Residents were notified that spraying was about to commence in the area and at least one week before their property was scheduled to be sprayed. Subsequently a residents' group meeting was held which representatives of the A.P.B. and the Minister for Agriculture's office attended along with some politicians. An undertaking was given to the residents that people who objected to the use of heptachlor could have their property sprayed with chlorpyrifos.

The current review has meant that no survey has been carried out of the number of residents wishing to take up the chlorpyrifos option.

5. REVIEW OF THE PROGRAMME

Initial survey results of the extent of the infestations existing in the 1950s were not located but details of area sprayed are available for every year since the commencement of the programme in 1954. Detailed estimates of the areas infested by Argentine ants in Western Australia are available from the early 1970s. However in the first six years of the programme some 17,000 hectares were sprayed and this probably gives a reasonable indication of the extent of the problem infestation at that time.

While the original 1954 legislation does not mention eradication as the objective of the campaign, the Minister's Second Reading speech makes it clear that this was intended. The 1968 legislation does refer to eradication. In this context, that is, total removal of all individuals, the campaign did not achieve its objective.

Nevertheless the campaign must be considered highly successful - when compared with other situations. In the U.S.A., following discovery in California in 1907, the area infested had increased to more than 10,000 kilometres^2 in less than thirty years.

In Victoria, in forty years from discovery to 1980, the infestation covered more than 70,000 hectares in metropolitan Melbourne as well as more than 20 regional towns.

In Western Australia, the infestation of Argentine ants has been reduced from an initial figure of approximately 17,000 hectares to 1,260 hectares at June 30, 1987. This is a significant reduction in the total area infested, and the infestations are isolated thereby making eradication of many local ant populations a realistic objective.

In addition to the total area infested being greatly reduced, the density of the remaining infestations have also been greatly reduced. As described earlier, infestations in the 1950s and 1960s were extremely heavy and the damage done, especially public nuisance, was severe.

Since the late 1960s Argentine ant infestations in Western Australia have not been sufficiently severe to cause major problems similar to those of the 1950s. Argentine ants have been eradicated from many country towns and localities within Perth. While numerous householders have had ant infestations, the majority of those infestations have been treated before the ants have become well established and demonstrated their full pest potential. Distributions of Argentine ant infestations at 10 year intervals are shown in Figures 3a-j.

To some extent it is the success of the control programme in reducing the extent and density of Argentine ant infestations

FIGURE 3(a) DISTRIBUTION OF ARGENTINE ANTS IN ALBANY, 1941 - 1951

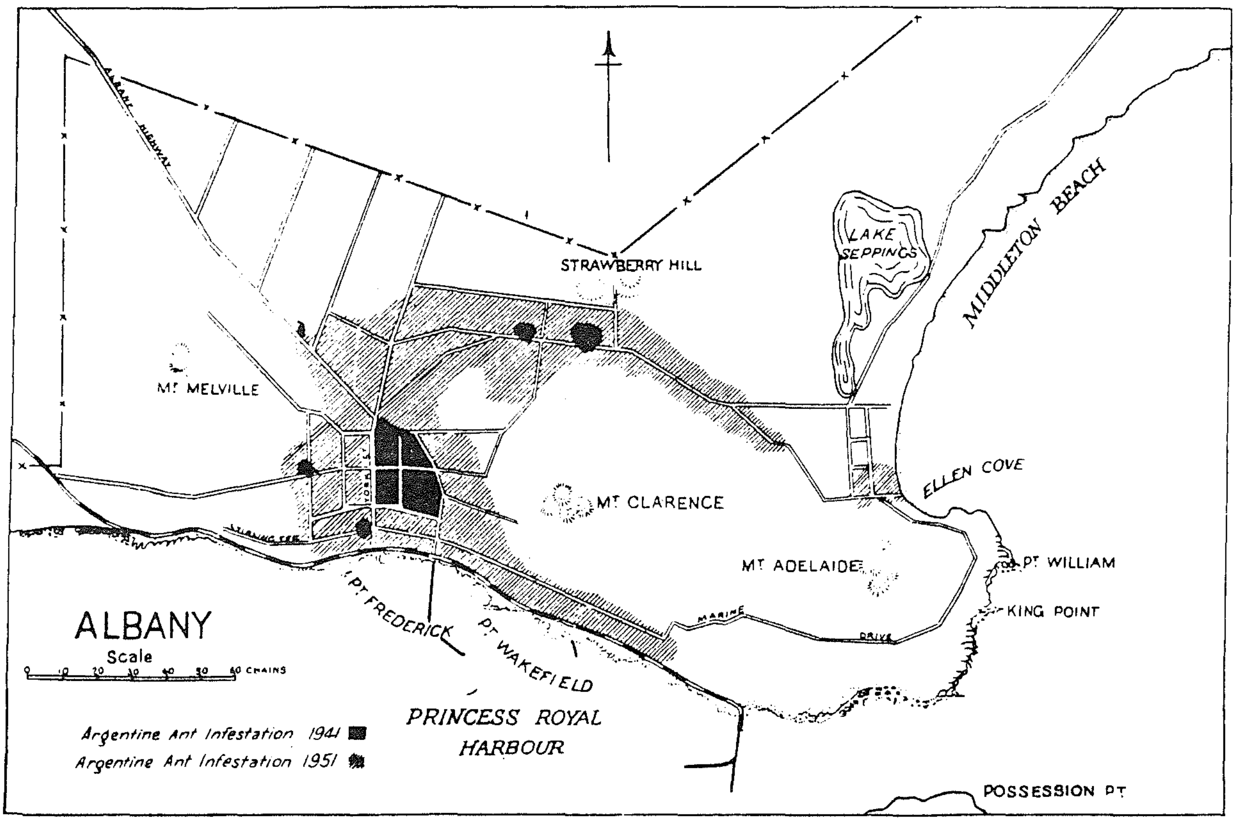


FIGURE 3(b) DISTRIBUTION OF ARGENTINE ANTS IN PERTH, 1941 - 1951

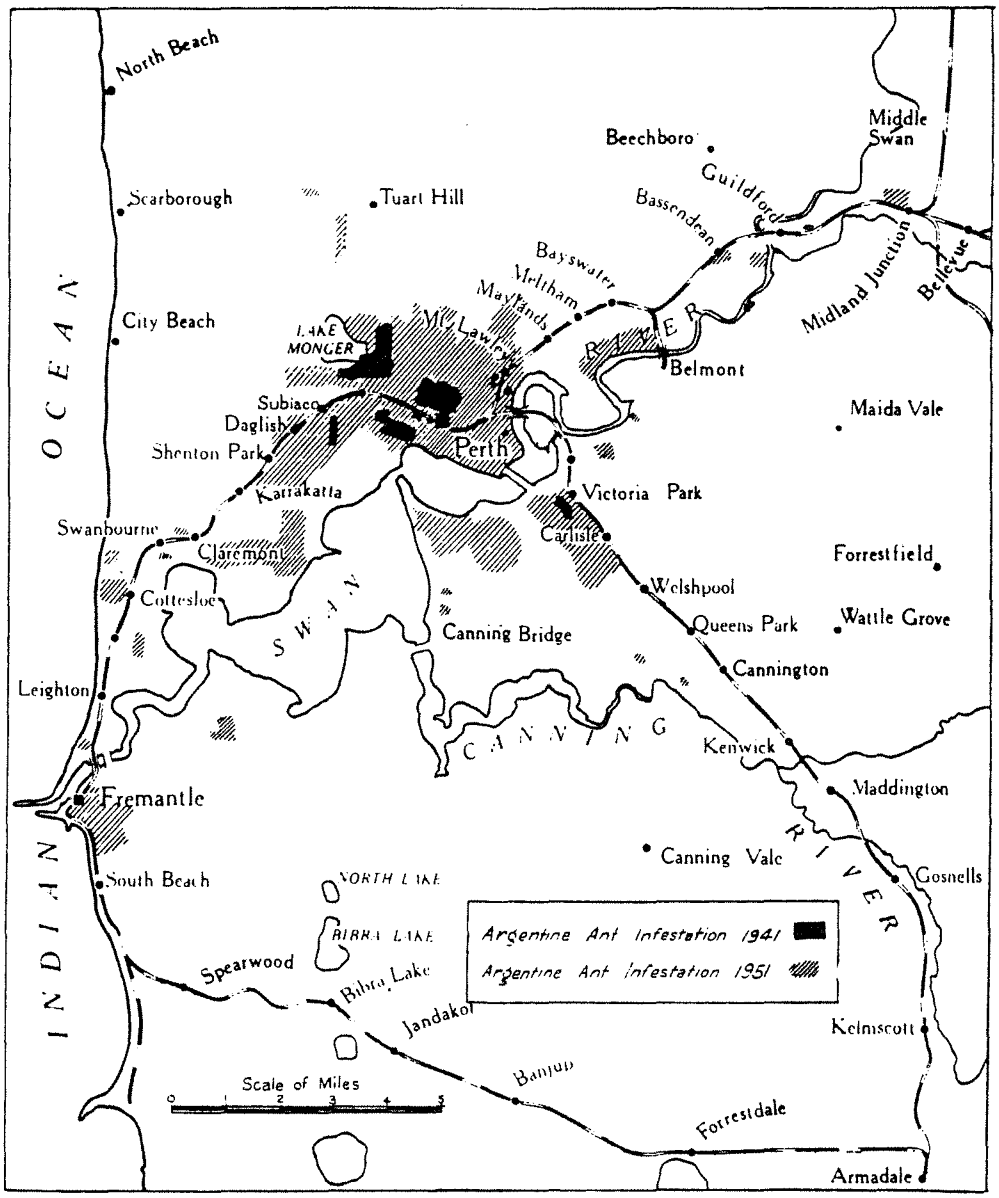
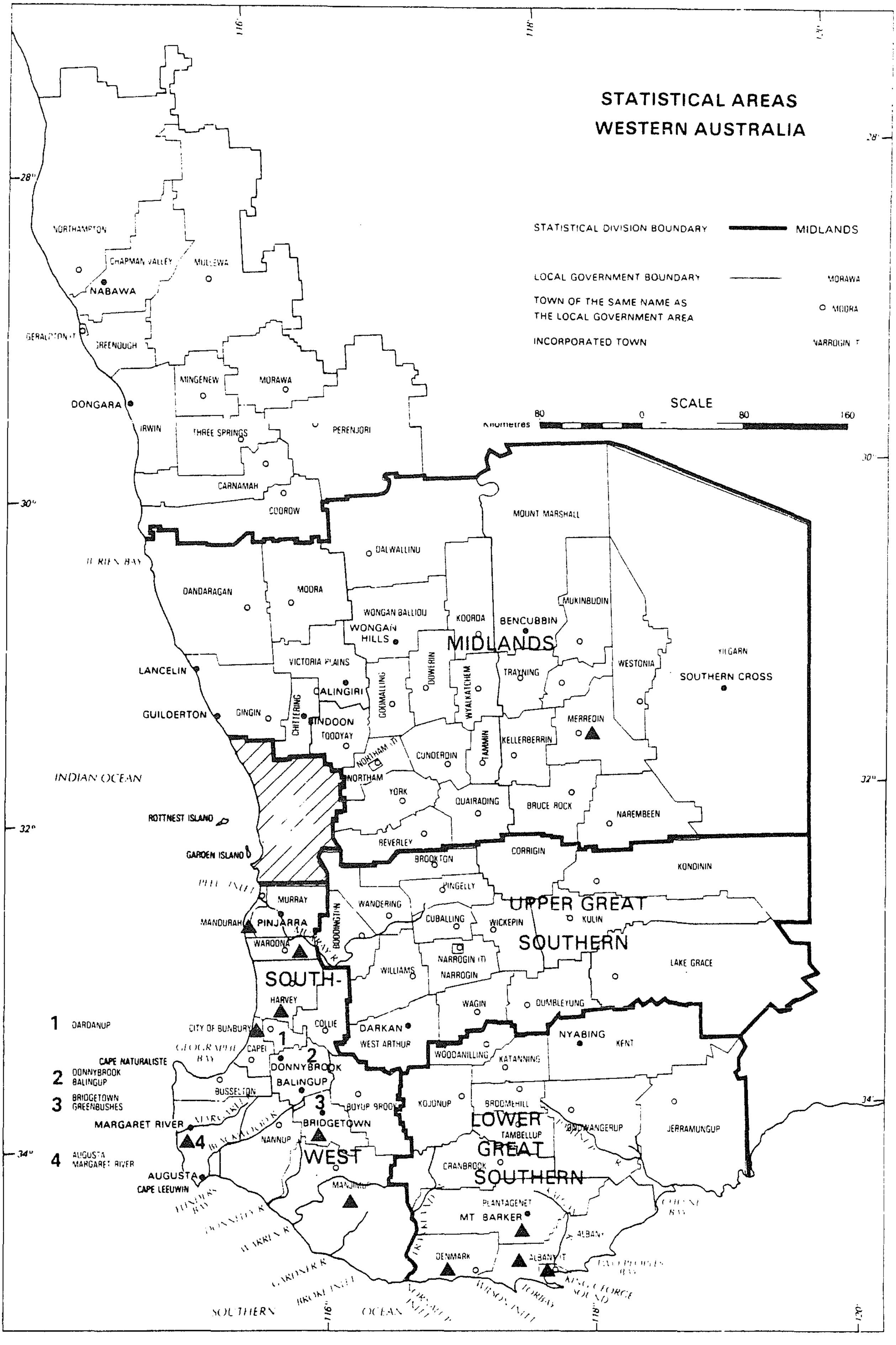
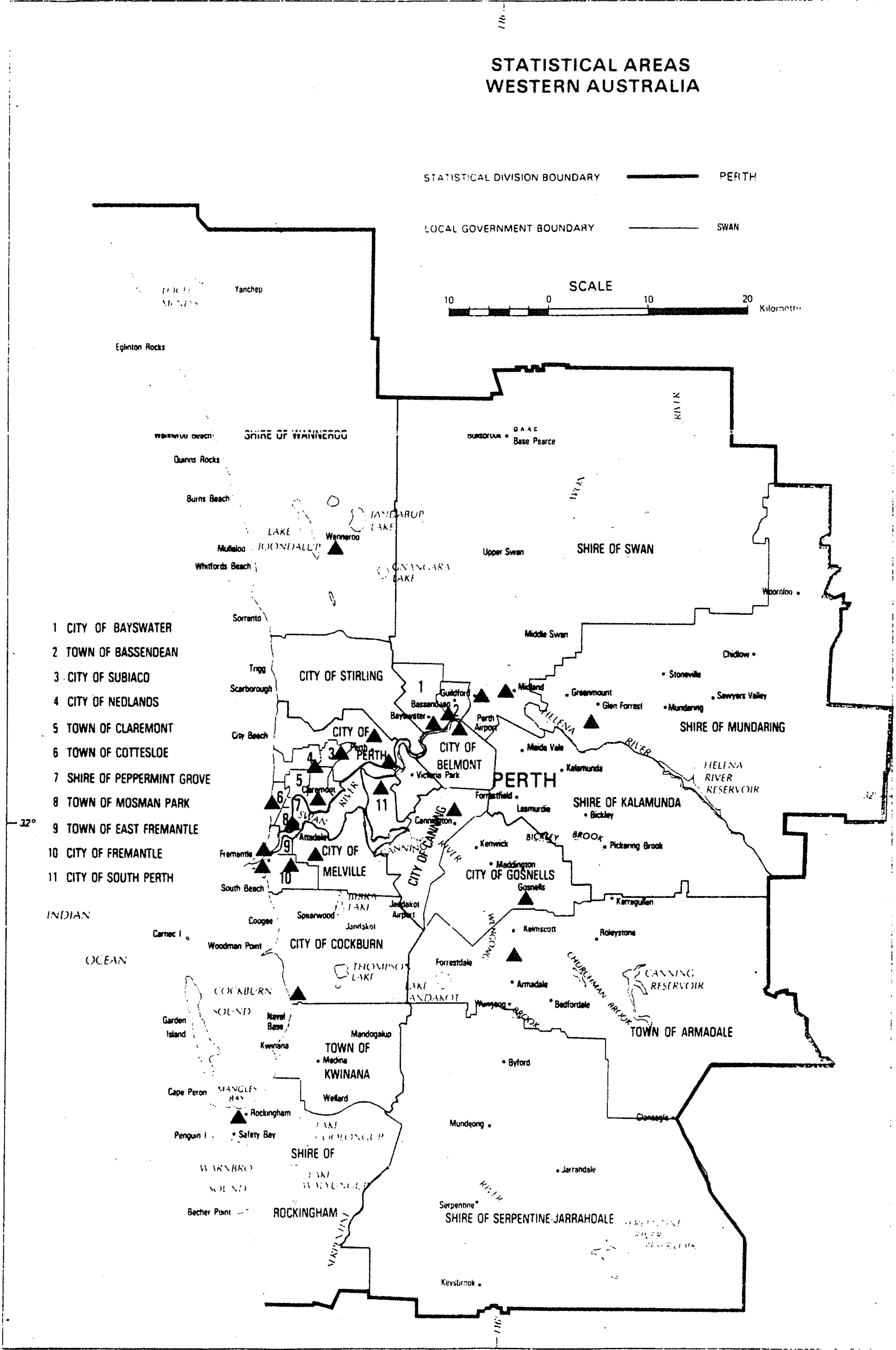


FIGURE 3(c) DISTRIBUTION OF ARGENTINE ANTS **1961**



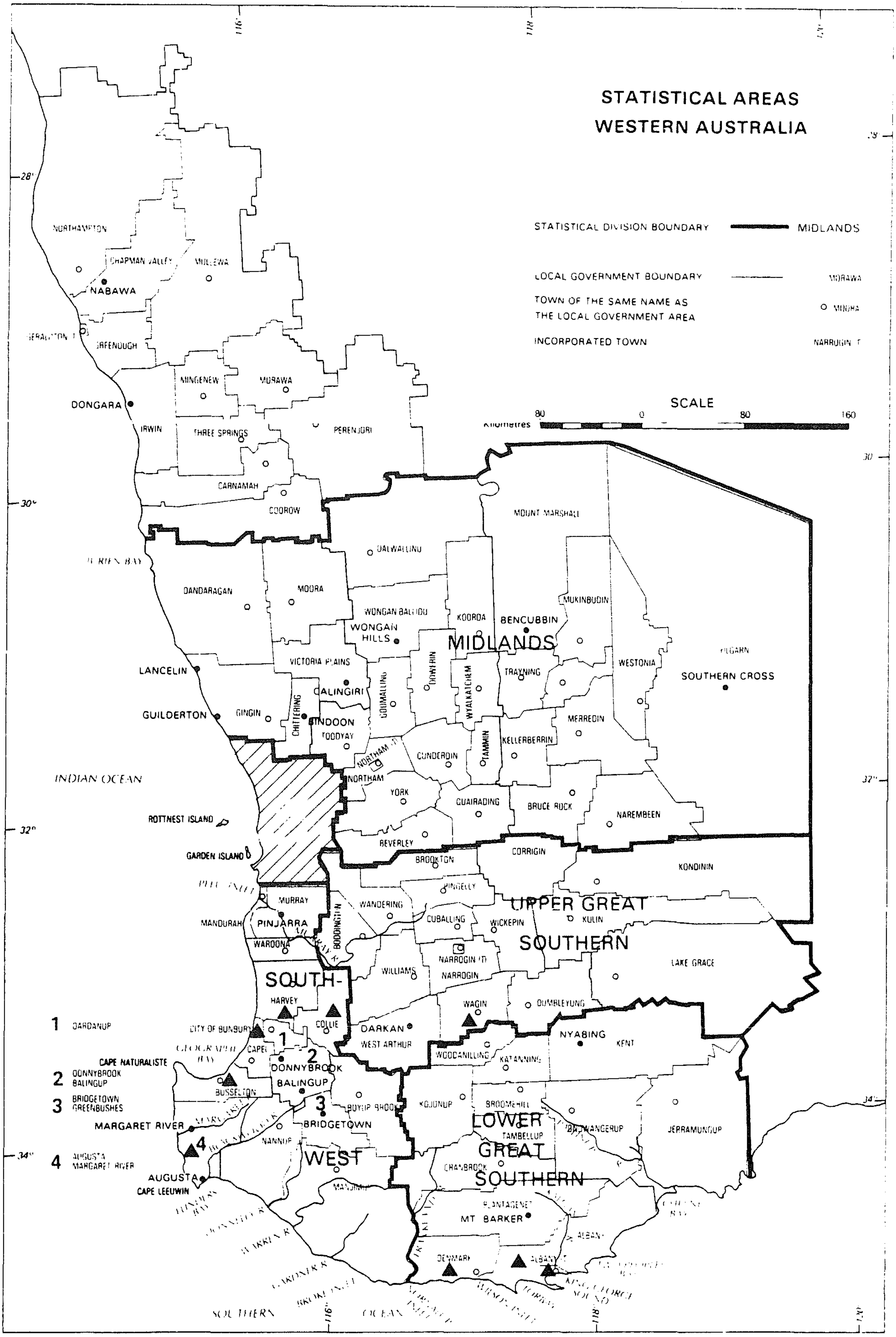
▲ Denotes Argentine Ant infestation

FIGURE 3(d) DISTRIBUTION OF ARGENTINE ANTS **1961**



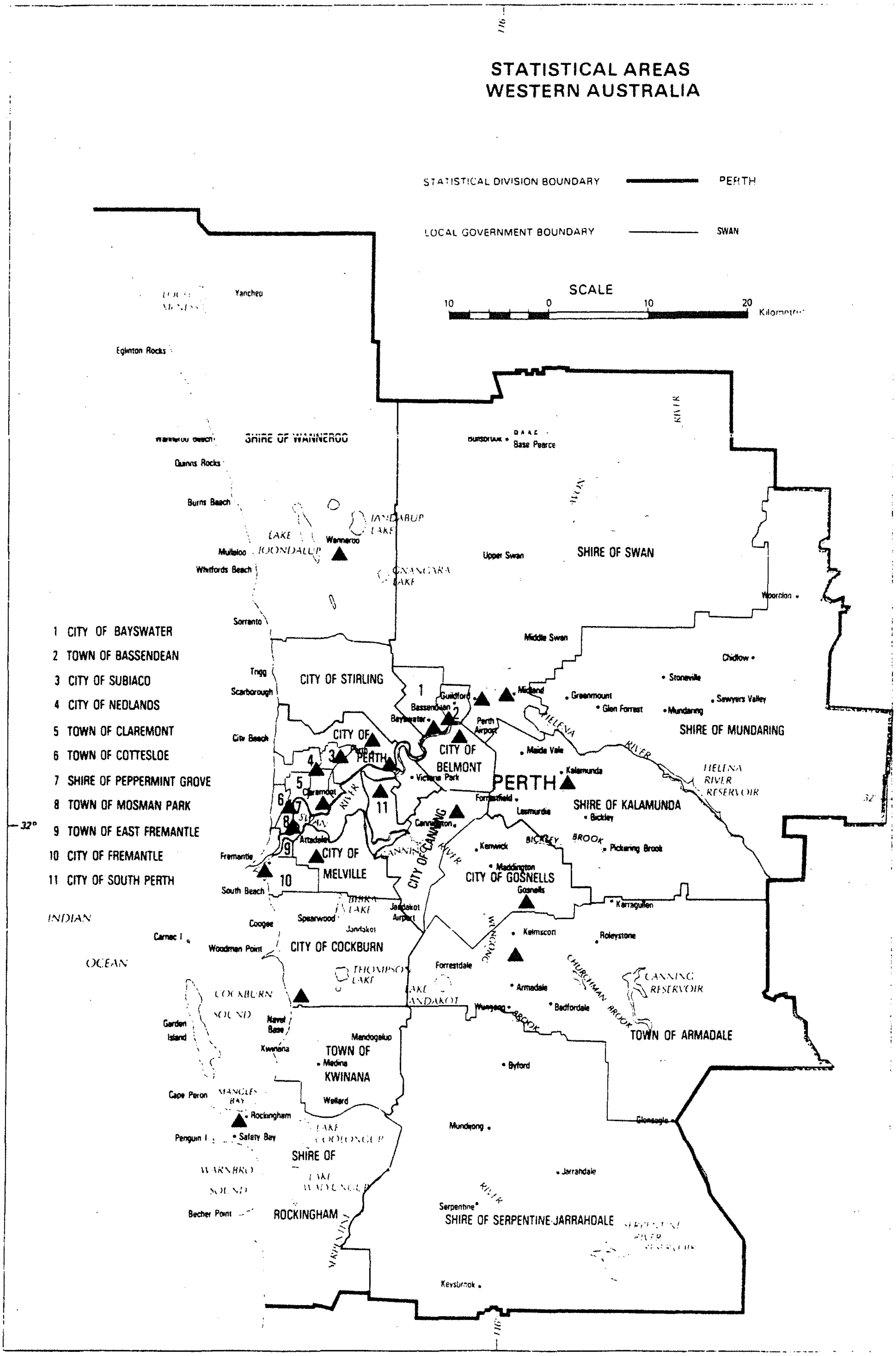
▲ Denotes Argentine Ant infestation

FIGURE 3(e) DISTRIBUTION OF ARGENTINE ANTS **1971**



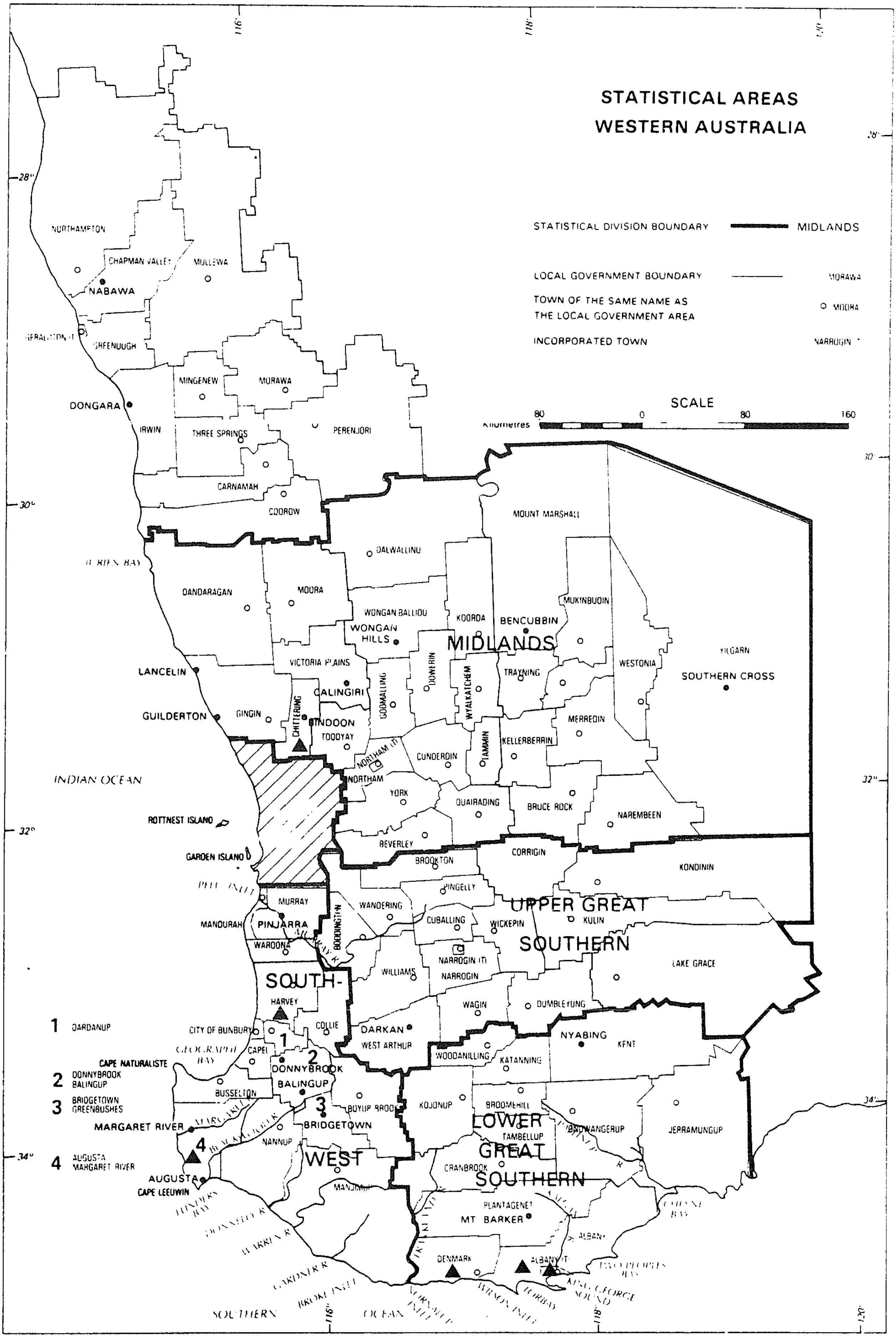
▲ Denotes Argentine Ant infestation

FIGURE 3(f) DISTRIBUTION OF ARGENTINE ANTS **1971**



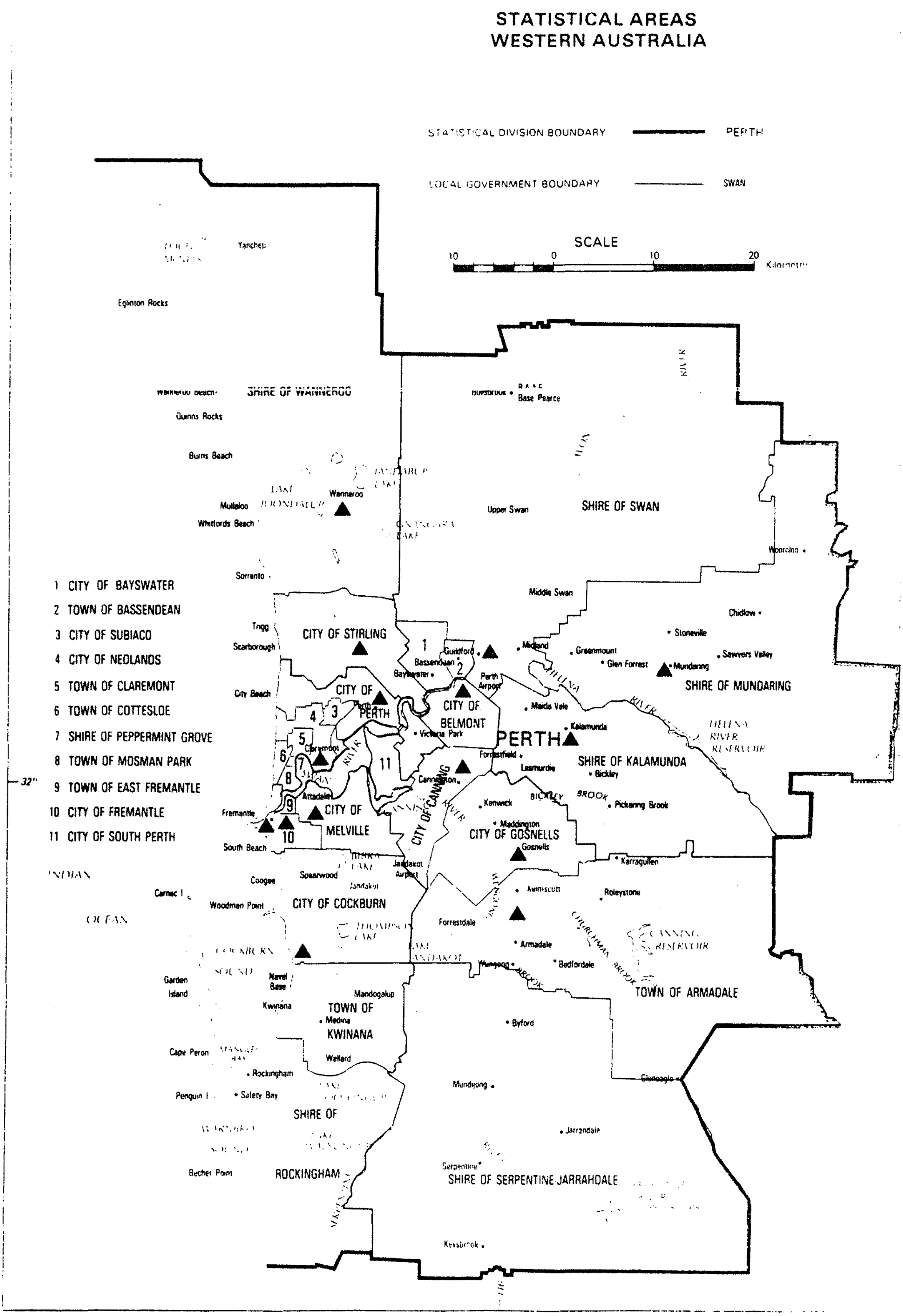
▲ Denotes Argentine Ant infestation

FIGURE 3(g) DISTRIBUTION OF ARGENTINE ANTS **1981**



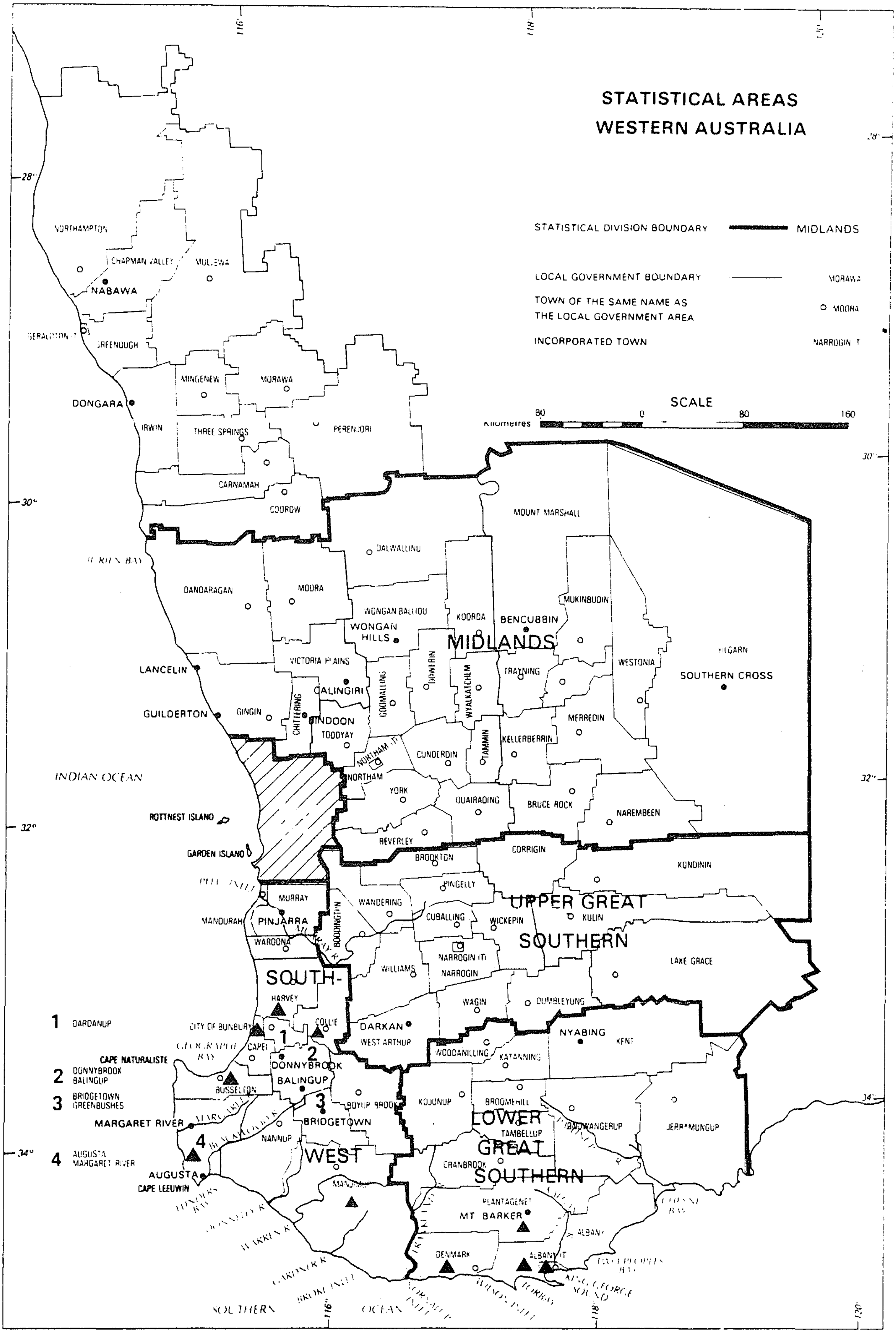
▲ Denotes Argentine Ant infestation

FIGURE 3(b) DISTRIBUTION OF ARGENTINE ANTS **1981**



▲ Denotes Argentine Ant infestation

FIGURE 3(1) CURRENT DISTRIBUTION OF ARGENTINE ANTS **1988**



▲ Denotes Argentine Ant infestation

that is the origin of the current review. It has meant that a high proportion of Western Australian people are not familiar with the extent and severity of Argentine ant damage from first hand knowledge.

This lack of familiarity with the problem leads to a changed perspective on the review that people carry out when they examine the costs and benefits of a programme such as the Argentine ant control programme, i.e. whether the spraying programme should be continued or not.

5.1 Results

Statistics for the Argentine ant control programme vary in both what was collected and the way they were collected since the inception in 1954. The earliest record for the total area of the state infested with Argentine ants is 1970/71 but continuous records date from 1973/74 (Figure 4). Records of the area sprayed for Argentine ant control data from 1954/55 to the present Figures 5 and 6. (Note changes of vertical scale.)

Apart from the dramatic reduction in total area infested which was apparently achieved in the 1960's, it has remained roughly constant since 1973/74. Since 1979/80 the area sprayed for Argentine ant control has shown a general downward trend in line with reduced Government resources available to the programme (Table 3).

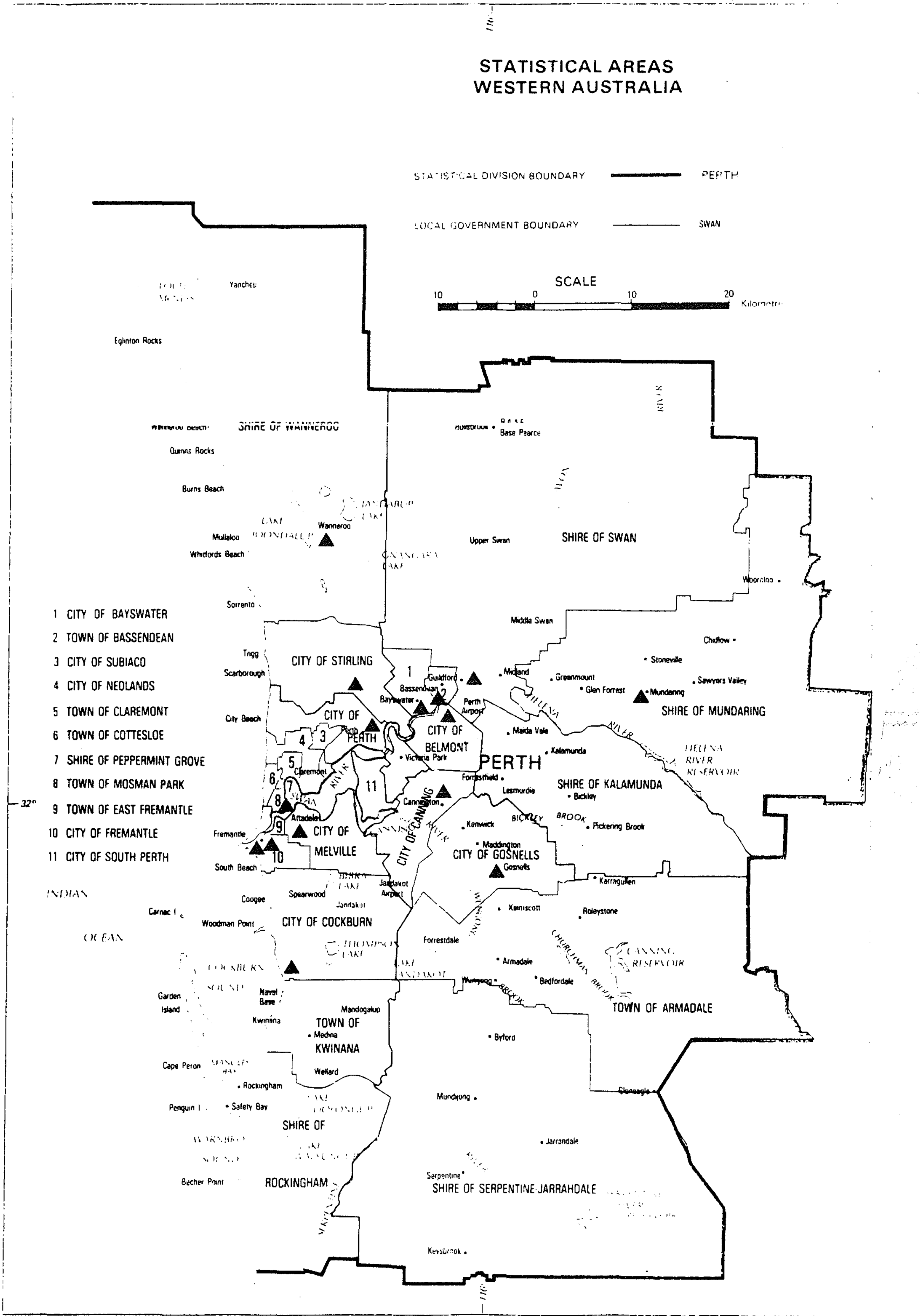
Of particular significance are the trends since 1983/84. In that year containment perimeter spraying of the large infestation at Herdsman Lake was suspended. Since then the total area infested has increased each year while the proportion of that area that has been sprayed has declined.

The programme cannot be termed an eradication programme because there are areas such as Herdsman Lake for which there are no treatment plans. In excess of 70% of the current known area of infestation poses difficulty in treatment for environmental or animal residue reasons. This situation has existed for years making overall eradication unrealistic but containment a viable alternative programme objective.

However the increasing gap between area treated and area infested can only compound the problem and without the available resources being significantly increased, the range and density of Argentine ants in Western Australia would seem likely to increase.

These data suggest that, at least since 1978/79, the programme has acted as a containment programme. Local infestations of Argentine ants have been treated and eradicated while other new areas have been found. At the same time some areas, e.g. Herdsman Lake, have been given an encircling treatment to delimit the problem and prevent it getting any larger.

FIGURE 3(.) CURRENT DISTRIBUTION OF ARGENTINE ANTS **1988**



▲ Denotes Argentine Ant infestation

FIGURE 4

AREA INFESTED AND AREA TREATED FOR ARGENTINE ANTS IN W.A.

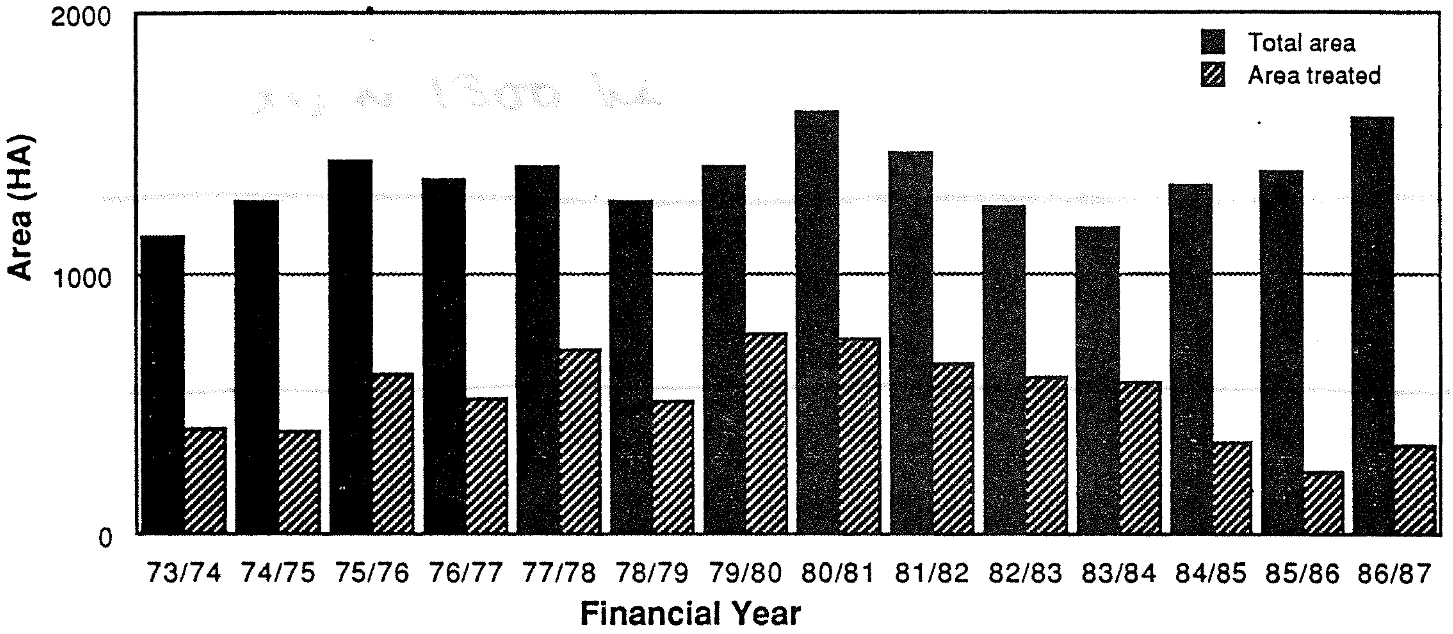


FIGURE 5

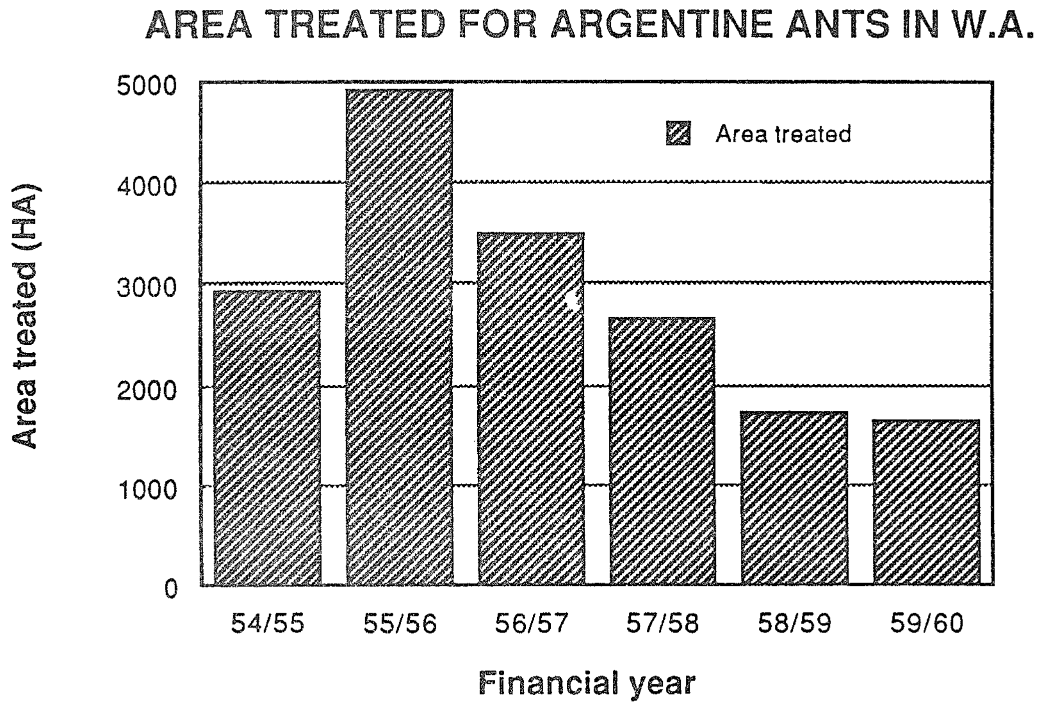
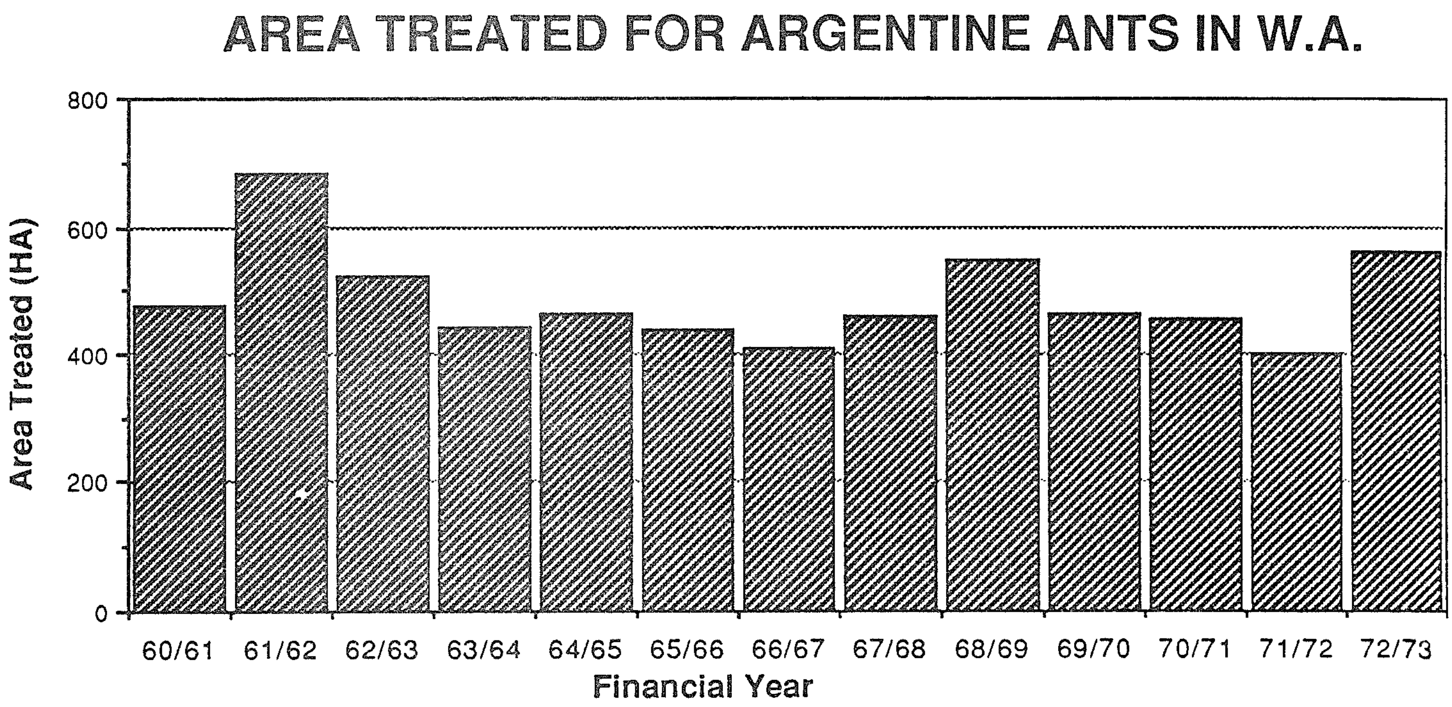


FIGURE 6



Note change in scale between Figures 4,5 & 6.

TABLE 3

ARGENTINE ANT CONTROL - SUMMARY OF CAMPAIGN JULY 1, 1954 TO JUNE 30, 1987

Year	Hectares Sprayed	Man Hours Worked	Spray Laid Litres	Cost (est) per hectare	Spray Laid Litres per hectare	Man Hours per hectare	Expenditure $
				$			
1954-55	2,898.6	78,351	2,168,496	55.00	748.12	27.03	268,368
1955-56	4,857.0	112,512	3,347,842.5	50.00	689.28	23.16	226,204
1956-57	3,502.0	80,504	2,565,238.5	55.00	732.51	22.99	188,380
1957-58	2,672.4	96,652.5	3,011,566.5	75.00	1,126.91	36.17	256,194
1958-59	1,728.25	89,951	2,747,655	105.00	1,589.85	52.05	188,054
1959-60	1,647.75	60,234	2,642,670	103.75	1,603.80	36.36	144,624
1960-61	474.8	13,633	677,160	115.00	1,426.20	28.71	47,376
1961-62	683.3	20,382.5	1,064,070	107.50	1,557.25	29.83	73,666
1962-63	522.6	14,407	841,347	115.00	1,609.92	27.57	60,228
1963-64	441.3	12,779.5	726,655.5	121.25	1,646.62	28.96	55,284
1964-65	464.7	11,594	642,240	118.75	1,382.05	24.95	55,426
1965-66	439.7	12,185	699,075	125.62	1,589.89	27.71	57,929
1966-67	409.5	8,119	525,532.5	119.55	1,283.35	19.83	54,413
1967-68	457.8	9,483	685,395	116.72	1,497.15	20.71	53,977
1968-69	548.3	8,742	725,130	105.10	1,322.15	15.94	57,664
1969-70	465.1	8,134	531,706.5	120.22	1,143.21	15.34	56,778
1970-71	453.8	7,180	592,807.5	121.18	1,306.32	15.82	60,687
1971-72	400.6	5,764	521,730	138.72	1,302.32	14.39	59,078
1972-73	561.1	8,621	725,220	108.55	1,292.50	15.36	63,785
1973-74	443.1	5,864	544,965	139.60	1,229.89	13.23	63,848
1974-75	395.0	5,183	399,060	185.60	1,010.28	13.12	74,371
1975-76	600.7	7,191	644,970	155.42	1,073.69	11.97	93,362
1976-77	520.7	6,322	639,900	212.88	1,228.92	12.4	112,050
1977-78	707.1	8,440	779,960	227.57	1,103.04	11.94	157,836
1978-79	505.5	7,677	566,884	313.47	1,121.4	15.18	172,773
1979-80	768.0	10,901	1,065,015	309.59	1,386.74	14.19	232,392
1980-81	748.3	12,449	1,222,885	350.79	1,634.22	16.64	262,498
1981-82	649.5	11,388	1,183,625	415.19	1,822.36	18.53	269,669
1982-83	620.8	11,027	944,086	543.27	1,520.75	17.76	337,267
1983-84	578.8	9,146	800,688	615.91	1,383.35	15.80	356,490
1984-85	353.4	6,134	420,800	926.55	1,190.71	17.35	327,443
1985-86	234.6	4,670	219,741	941.92	936.66	19.90	220,976
1986-87	339.3	4,524	314,730	748.95	927.58	13.33	254.120
TOTAL	31,093.4	769,144.5	35,188,846.5	159.6	1,131.71	24.73	4,963,230

The *de facto* current objective of the programme is containment of the current problem to manageable proportions with eradication as a possible long term goal.

It is aimed to hold the infestations to current or reduced levels (in both area and density) as the alternative of allowing the unrestricted spread of Argentine ants is believed to be of greater cost to the community and more injurious to the environment. In the light of the current technology and resources available - insecticides, spray technology, money and staff - eradication does not appear to be a realistic objective in the short to medium term.

5.2 Control Techniques

5.2.1 Sprays

Heptachlor - Heptachlor is the current insecticide of choice for most areas (see Procedures in Appendix). It can eradicate Argentine ants in a single treatment and is the least persistent of the currently available insecticides which can achieve this. Chemical costs are approximately $105 per hectare sprayed.

Because eradication of individual infestations is achieved, there is little likelihood of genetic resistance to the insecticide evolving in Western Australia. Surveys done by the Department of Agriculture show no evidence of resistance.

Heptachlor's insecticidal and chemical properties make it the only chemical currently available which allows the current containment and local eradication objectives to be retained for the Argentine ant control programme.

Chlorpyrifos - Chlorpyrifos is an organophosphorous insecticide with oral toxicities to mammals comparable to heptachlor.

However it is far less persistent in the environment - approximately 6 weeks. It can be effective in killing Argentine ants as either a 2% single spray or two sprays of 1% spaced 6 weeks apart. Chemical cost is approximately $640 per hectare sprayed but the double application at least doubles the labour costs involved. Additionally the use of chlorpyrifos with its less reliable toxicity to Argentine ants incurs significantly higher administrative costs in scheduling re-inspections and re-spraying of properties. At current estimates if more than approximately 5% of households require chlorpyrifos treatment within an otherwise heptachlor treated zone, local eradication becomes impractical because of the additional strain on resources. Beyond this level the maintenance component of the programme would increase until it became the major activity of the Argentine Ant Control Unit.

The use of chlorpyrifos alone as an Argentine ant control agent without heptachlor would only allow containment to be maintained for a short period of time - perhaps as short as two to three years. The unpredictable and unreliable kill would be likely to allow the ant population to persist in some areas and slowly but surely expand its range and population density.

In addition, the use of chlorpyrifos raises the likelihood of genetic resistance to the insecticide evolving in Argentine ants in Western Australia. This possibility only exists when insecticides are used which do not give total kill of a population. Genetic resistance due to repetitive spraying treatments is therefore a possible disadvantage of any of the chemicals discussed below. Insect resistance to a number of organophosphorous insecticides is well documented.

Isophenfos - This is an organophosphorus insecticide which is currently not registered for use against Argentine ants in Western Australia. Initial experimental trials show the chemical to have reasonable toxicity to Argentine ants and low environmental persistence. It could be suitable for use on pastures. However registration would require trials for maximum residue limits for pasture and grazing animals to be set, as well as toxicity to other fauna. Current indications suggest that chemical costs could be in the approximate range of $335 - $670 per hectare sprayed.

Synthetic pyrethroids - This group of insecticides is rapidly expanding as new products are being discovered and released. None are registered for use against Argentine ants in Western Australia. Initial screenings have suggested permethrin and fenvalerate have no significant residual life in the field. Deltamethrin has middle range mammalian toxicity and residual characteristics while cypermethrin and alphamethrin showed initial promising results in the field but proved less effective than chlorpyrifos. Chemical costs for treatment would be approximately $135 per hectare for cypermethrin and $215 per hectare for alphamethrin.

Table 4 compares some of the relevant data for the insecticide spray alternatives which have been considered in Western Australia.

5.2.2 Baiting

Baiting has been widely used in Australia and other parts of the world as a method of control. Commonly borax is the active ingredient. However baiting generally gives local reduction of populations. In some instances, baiting can spread infestations as Argentine ants move out from areas where they are being poisoned and re-locate in non-baited areas. ?

Recent reports suggest that hydramethylnon and avermectin have produced good results in baits in California (P. Ward, pers.comm.; M. Rust, pers.comm.). Initial trials have achieved Argentine ant reductions greater than diazinon baiting - the standard commercial Pest Control Operator treatment in U.S.A.. Argentine ant population levels have been extremely depressed for more than 3 months in the hydramethylnon treated areas.

Hydramethylnon is registered in U.S.A. as the active ingredient in baits for several species of ants and cockroaches. A clearance application for its use in Australia in a cockroach bait has recently been made. It is believed that hydromethylnon reformulated into an Argentine ant bait will be registered in U.S.A. this year. There is likely to be a significant time lag before hydromethylnon can be fully trialled in W.A.

5.2.3 Biological control

This is a mechanism whereby one organism is predated or parasitised by another. As a result the population of the prey organism is reduced. The relationship may be the classical predator-prey as in lady-bird beetles eating aphids or in transmission of disease (e.g. myxomatosis affecting rabbits).

It is important to note two principles of biological control. Firstly, the end result may be a reduced prey population, i.e. control, but not eradication. A successful programme

TABLE 4 PARTICULARS OF INSECTICIDES WITH POSSIBLE USE FOR ARGENTINE ANT CONTROL

INSECTICIDE	ACUTE TOXICITY (RAT) LD 50 mg/kg Oral	Dermal	APPLICATION RATE g ai/ha	APPLICATION METHOD	TOTAL COST/Ha $
Heptachlor	147 - 220	119 - 250	5000	1 metre grid, single	105
Chlordane	365 - 590	217	10000	1 metre grid, single	150
Chlorpyrifos	135 - 163		10000	Cover spray, double	
Isofenphos	28 - 39		5000-10000	Cover spray, single	335 - 670
Cypermethrin	200 - 800	1,600	500	Cover spray, repetitive	135
Alphamethrin	79 - 400	500	500	Cover spray, repetitive	215
Deltamethrin	128	2,000		Interior buildings	
Borax	Lethal dose infants 5-6g**			2% bait.	

* Hartley, D.& Kidd, H.(Eds.), 1987
** Worthing, C.R. (Ed.), 1979

relies on both predator and prey populations persisting but at a reduced level.

Secondly, the predator organism must be target specific - it must affect the target species and no other. If other non-target species were to be affected, a new pest species would simply have been introduced.

Argentine ants are a member of the genus Iridomyrmex - a large genus containing many closely related species. The genus is centred on Australia and is third behind Melophorus and Camponotus in number of species contained within the genus. Because of this it is especially important for the predator organism to be target specific and hence the difficulty in obtaining specificity is increased. The costs of identifying, researching, breeding up and releasing a viable biological control agent are very high - at least several millions of dollars - and with a lead time of several years.

Despite this, it has been reported that several United States authorities have closely examined biological control for Argentine ants. Several researchers have looked and still are looking for a possible biological control agent, but so far without success.

6. ALTERNATIVES FOR THE FUTURE

6.1 Long Term Containment Objective

This option involves the Argentine ant control programme continuing its current operations with eradication of local infestations and containment of others (e.g. Herdsman Lake and agricultural land) where there are no adequate control techniques. The programme would require the continued use of heptachlor as it is the only insecticide currently available which can reliably give eradication with a single application.

Long term containment could not be considered a viable option without heptachlor. Chlorpyrifos or other organophosphorous insecticidal sprays as well as currently available synthetic pyrethroids could not be relied upon to give local eradication of Argentine ant populations.

6.1.1 Benefits

The continuation of this programme would produce significant community benefits in that local Argentine ant infestations could be reliably eradicated. This would mean that householders would be unlikely to suffer significant or prolonged annoyance from Argentine ants and that commercial operations within urban areas, e.g. food producers, would be protected.

The programme would also produce continued benefits to agricultural production especially citrus, vegetable and cut flower enterprises which would otherwise be significantly adversely affected by Argentine ants. Additionally export markets would be protected by minimising the risk of Argentine ants being found in exported goods.

Environmental benefits would also result by reducing the damage done by Argentine ants to native ant species. Argentine ant populations can reduce native ant numbers and species diversity. Argentine ant populations could also disrupt native plant-ant mutualisms as has occurred in South Africa leading to disappearance of some native plant species. Damage to other species of native fauna and flora by predation and other activities would also be avoided.

6.1.2 Costs

The continued use of heptachlor would involve environmental and possibly some human health costs. The health cost due to use of heptachlor must be balanced with the health cost of alternative strategies. However the A.P.B. does not consider itself the appropriate body to comment on these health issues. Any insecticide use depletes non-target insect species although the evidence suggests that populations of these species recover quickly.

The current annual cost of the programme is approximately $250,000. This level of funding would at least need to be maintained but probably increased.

Additional resources would be needed to fund future research by the A.P.B. into alternative insecticides and/or technologies.

6.1.3 Likelihood of Achieving Objective

The continuation of the programme under the current guidelines would be likely to achieve its objectives. Data suggests that the total area infested is being contained, the density of the infestations is generally light and local eradication is being achieved.

However should the proportion of properties where heptachlor cannot be used increase, without there being an adequate replacement insecticide, the objective is unlikely to be sustainable for more than two or three years. Hence, in practice, increased opposition to the use of heptachlor may prevent this objective being achieved.

6.2 Short Term Containment Objective

Should heptachlor no longer be available for use in Argentine ant control programmes, the long-term containment objective will no longer be achievable. Because of the reduced efficacy against Argentine ants in Western Australia of chlorpyrifos and other insecticides and/or techniques, far greater chemical and labour inputs will be required to attempt containment. Likely limitations on additional inputs will quickly change the programme focus from local eradication of new infestations to maintenance treatment of existing sprayed areas.

6.2.1 Benefits

This objective is mostly likely to occur as a result of it no longer being possible to use heptachlor. Some possible benefits to human health would be claimed by those who oppose its continued use.

6.2.2 Costs

Given the cost and effectiveness of alternative control techniques, this objective would inevitably lead to an increase in the total area of infestation and the density of those infestations. Perth is within the latitude range favourable to Argentine ants and apparently presents environmental conditions most suitable for ant population to proliferate. This is similar to Sydney and contrasts with Adelaide, Melbourne, Hobart and Launceston.

Under this scenario within several years the resources of the Argentine Ant Control Unit are likely to be insufficient and the number and volume of public complaints to quickly increase. This is likely to lead to demands for additional public funding of Argentine ant control. A complete switch to chlorpyrifos in the current programme would increase chemical costs alone from $30,000 to $150,000.

There is also likely to be increased demands placed on private Pest Control Operators to carry out Argentine ant control. Currently this service costs, mostly using chlorpyrifos, between $100 and $130 and gives protection for approximately 6 weeks.

Private individuals are likely to increase their use of insecticides in attempts to deal with their Argentine ant problem. As a result the total volume of insecticides being applied to the environment and the frequency of misuse of those insecticides is likely to increase significantly. The possibility of health benefits resulting from not using heptachlor must be balanced against the possible health costs of increased use and misuse of other insecticides.

Agricultural effects in both production losses and increased risk to export markets are also likely.

Environmental effects are likely to be two-fold. Firstly the increased quantity and misuse of insecticides. Secondly the fauna and flora are likely to suffer increased damage from these insecticides as well as the increased range and density of Argentine ant populations.

6.2.3 Likelihood of Achieving Objective

Short term containment of Argentine ants is possible with current technology. However within several years the Argentine ant population is likely to have increased so that nearby infestations may become linked, and return to present levels of control not possible. Under this scenario, containment will no longer be possible without alternative technologies.

6.3 Stop Government Argentine Ant Control

Under this option the State Government could generally no longer be involved in controlling Argentine ant infestations. Under some circumstances small scale sprayings of specific infestations at sensitive areas, such as wharves, may be carried out, but generally control would be the responsibility of the individual landholders. This is similar to the situations in South Australia and Victoria.

It is likely that this would lead to an increase in the spread and density of Argentine ant infestations due to the favourable environmental conditions encountered in much of the South West of Western Australia. In those areas with an annual rainfall exceeding 625mm, Argentine ants are likely to become a serious domestic pest, and cause agricultural and ecological damage. In regions with an annual rainfall below 500mm Argentine ants are only likely to be a significant pest in areas where water is readily available, e.g. valleys with water courses and urban areas. Results would be similar to the previous Short Term Containment Objective (Section 6.2) but in a shorter time frame.

6.3.1 Benefits

Savings to Consolidated Revenue in excess of $250,000 per year would be achieved. Heptachlor would no longer be used in Argentine ant control and the quantity of insecticides distributed by Government officers would be reduced.

6.3.2 Costs

With the responsibility for Argentine ant control passing to the private individual, overall use of insecticides by the community is likely to increase higher than in scenario 6.2. This will be due both to spread of the Argentine ant affecting more and more residences, plus unco-ordinated use of less residual insecticides leading to frequent repetitive treatments.

There is also likely to be increased demands placed on private Pest Control Operators to carry out Argentine ant control. This option is likely to have a greater effect on those segments of the community unable to apply treatments themselves, e.g. aged and invalids.

The increased use and misuse of insecticides by the community may further affect the health of the community.

Repetitive use of insecticides will also increase the chance of Argentine ants developing genetic resistance to one or more chemicals.

In the short term, when only a portion of the metropolitan area is infested, real estate values in infested areas may be depressed.

Agricultural effects in both production losses and increased risk to export markets are also likely. Integrated Pest Management programmes will also be disrupted leading to an increased use of insecticides.

Environmental effects are likely to be two-fold. Firstly, the increased quantity, number and misuse of insecticides are likely to have a direct effect upon fauna and flora. Secondly, and more importantly, will be the direct effect of Argentine ants on the environment.

Over time Argentine ants can be expected to significantly reduce native ant species richness in parts of the South West of W.A. This is likely to lead to similar effects to those described in South Africa. Besides the adverse effect on birds, lizards and invertebrates there are likely to be other adverse effects associated with the spread of this exotic pest which will become evident with time.

7. CONCLUSIONS

The total effect which Argentine ants will have on W.A. ecosystems cannot accurately be predicted as there are insufficient data. As with most exotic pests, many effects will only become evident in retrospect and may be quite unexpected. The overall effect of Argentine ants on the W.A. environment is likely to be detrimental and permanent.

The possibility that a 'founder effect' was responsible for the initial severe Argentine ant infestations in Perth is countered by the presence of Argentine ants in Herdsman Lake for over 30 years. There seems little evidence from recent observations that the populations have declined. Also, South Africa has had Argentine ants for approximately 80 years and it is from there that adverse environmental effects are now being reported.

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PROCEDURES

ADMINISTRATION

Step 1. Reporting. Most reports of Argentine ants are received by telephone at the Argentine Ant Control Unit at the Agriculture Protection Board at South Perth.

In many instances the telephone calls come from householders who are being troubled by ants in their homes and are seeking assistance in control techniques. In some instances reports are received from Shire Health Inspectors who have been called to assist householders with ant problems.

In either instance the reporter is asked to describe the ant and the general situation. If the officer receiving the call, usually the Technical Officer in charge of the unit or one of the foremen, suspects that the ant described may be an Argentine ant, a report form is completed - AD 349 (Attachment 1). This gives all relevant details of the contact and the necessary follow-up action.

Step 2. Programming Inspection. The technical officer in charge then programmes one of his foremen to inspect the property. If possible this is done with the land-holder present.

At this stage the ant is identified as being an Argentine ant or not. This is relayed verbally to the land-holder if he/she is present as well as the person reporting the infestation if this is different.

If the land-holder and/or the person reporting the infestation is not present, they are advised in writing by means of Circular 1 (when Argentine ants are not found), or Circular 2 (when Argentine ants are found). Examples of these circulars are in the Attachments to this Appendix.

Step 3. Survey. If the sighting is positive, the area is surveyed to find the extent of the infestation. Surveying mostly involves a simple inspection of the front verge area. As Argentine ants remain in contact with other nests, the infestations are continuous. Hence, once the outer limits have been defined, all the area within can be taken as infested.

Step 4. Informing Householders. Once the infestation has been defined, all householders in the area are informed that the infestation has been found and that the area will be sprayed. If possible all householders are contacted personally.

All householders are given a circular (Circular 3) at least seven (7) days before it is intended to spray their property. This circular also informs them of the find and that it is intended to spray the area. This circular contains detailed information on safety precautions to be followed by the householder.

The circular also contains a contact telephone number where the householder can obtain further information. This section is highlighted in all circulars.

At this stage there have been at least two surveys of the area and in many instances two personal contacts with the householders. Specific problems such as days when the householders do or do not want treatment have been discussed and recorded, as well as the occurrence of sensitive situations such as fishponds, aviaries, children's sand-pits, etc.

Absent householders are given formal written notification of the day when their property will be sprayed (Circular 5).

Step 5. Spraying. On the day of the treatment, all households are informed approximately half a day in advance of the time of the treatment. However due to variables such as weather which are outside the control of the team, the spraying time may be varied.

Step 6. After Spraying. After the treatment all householders are given written notification that their property has been sprayed (Circular 6).

Step 7. Resurvey. Once the area has been sprayed, it is resurveyed approximately 12 to 24 months afterwards.

SPRAYING PROCEDURES

Heptachlor is the chemical of choice for most sprayed areas, and in general the steps described above apply to that chemical. The spray mix is 0.5% heptachlor EC in water. It is delivered at approximately 750-1000 litres to the hectare. The average residential block receives approximately 75 litres of mix, which corresponds to 375 gms of active ingredient.

Since 1984 chlorpyrifos has been used in all areas where stock may graze, such as pasture used for cattle and sheep. It is also used in and around chicken runs if spraying there is necessary.

If possible vegetable patches are left unsprayed except for the perimeter. However if this is not possible, chlorpyrifos is used on the ground in between some rows of vegetables.

However in some instances when householders object strenuously to the use of heptachlor, chlorpyrifos is used as a substitute over the entire property. In these instances the properties are inspected within 8 weeks and resprayed with chlorpyrifos where necessary. This is despite the legislative power given in the Argentine Ant Act (1968) to enforce a spraying programme. As a matter of policy it has been decided by the Department of Agriculture and its successor the Agriculture Protection Board that enforcement is not an option.

Residents are given at least half an hour warning before spraying commences. All aviaries, fishponds and children's sandpits are covered with taurpaulins by the spraying staff.

Lawns are treated in a grid pattern at approximately 1 metre centres with a swathe width of approximately 8 - 10 cms. A similar pattern is used on bitumen driveways.

Border gardens are cover sprayed as are shrubs.

Concrete driveways are sprayed around the edges and along the expansion joints. A similar pattern is used for unenclosed patios.

The base and up to 15 cms from the ground of fences and building foundations are sprayed.

Trees are sprayed around the trunks and up to the first fork or 2 metres from the ground whichever is lower.

No spraying is done within houses or enclosed patios as Argentine ants do not nest indoors.

ATTACHMENT 1

A.D. 349

DEPARTMENT OF AGRICULTURE

ARGENTINE ANT REPORT

№ 32772

Date..

Name..

....

Address..

....

Remarks..

....

Action taken..

Date first inspected.................... Finding..

Surveyed.................... Hectares.................... Mapped.................... Reference....................

Sprayed.................... Hectares.................... Mapped.................... Reference....................

Report on Survey..

....

....

....

45889/2/86—50 BKS

CIRCULAR 1

Western Australian
Department of Agriculture

BARON-HAY COURT.
South Perth 6151.
Western Australia.
Telephone (09) 368 3333 Telegrams AGDEP Perth Telex AA 93304

Your Ref
Our Ref
Enquiries
Date

Please address all letters to the Director of Agriculture, quoting our reference number to your correspondence

Dear Sir/Madam

Your property has been inspected for Argentine ants during your absence.

Only native ants were found to be present.

Should suspected Argentine ants be found in the future please forward specimens, clearly marked with your name and address, to the Chief Entomologist, Department of Agriculture, Baron-Hay Court, South Perth WA 6151.

Ants can be forwarded attached to a piece of paper by clear adhesive tape. Ant specimens do not need to be living for identification.

Yours faithfully

(G.D. Rimes)
CHIEF ENTOMOLOGIST

CIRCULAR 2

Western Australian Department of Agriculture

3 Jarrah Rd. (West).
South Perth 6151.
Western Australia.
Telephone (09) 367 0111 Telegrams AGDEP Perth Telex AA 93304

Your Ref
Our Ref
Enquiries Mr
Date

Please address all letters to the Director of Agriculture, quoting our reference number to your correspondence

Dear Sir/Madam

Your property has been inspected for Argentine ants during your absence.

Argentine ants were found to be present, and your property will be sprayed during the current season.

Yours faithfully

(G.D. Rimes)
PRINCIPAL ENTOMOLOGIST

CIRCULAR 3
PAGE 1

AGRICULTURE PROTECTION BOARD OF WESTERN AUSTRALIA

Baron-Hay Court
South Perth WA 6151
Ph (09) 368 3333
Telex AA93304

Your ref:
Our ref:
Enquiries:
Date:

Dear Sir/Madam

A recent inspection of the area has shown your property to be infested with Argentine ants. Argentine ants are a pest of world standing. They have the ability to severely affect some forms of agriculture, and their presence in export cargoes is a barrier to international trade. They adversely affect the natural ecology and can become a serious domestic pest.

In response to its pest status the Agriculture Protection Board is engaged in an eradication campaign. Already more than 300 square kilometers - mostly in the metropolitan area - has been successfully treated. To continue the eradication campaign, and to prevent the further spread of Argentine ants via the transport of pot plants, soil, refuse etc, it is necessary that your property is sprayed in the near future to eliminate the infestation in your area.

Heavy vegetation, tall grass and ground debris, especially around the boundary line of a property, can reduce the effectiveness of the treatment. The cleaning up of such areas will ensure the maximum effect of the treatment and allow a reduction in the amount of chemical applied. Infested material should not be removed from the property prior to treatment as this may spread the infestation.

Following treatment, sprayed areas should not be watered for at least 24 hours and lawns not mowed for at least a week as this reduces the effectiveness of the treatment and may allow survival of the Argentine ants. The ploughing or disturbance of soil has a similar effect and should not be attempted for at least a fortnight after treatment.

General Precautions

Children's toys should be picked up and brought inside prior to spraying. During spraying, and while the spray remains damp, children should be kept inside.

Washing should be removed from external clothes lines prior to spraying.

Pets - food bowls, old food and water containers should be removed or covered.

It is estimated that your property will be treated on or about

the ________________________.

If you have not had an opportunity to discuss problems associated with poultry, bird aviaries, fish ponds, animals or shade houses, or if you need further information you are requested to contact the Officer in Charge, Argentine Ant Control, Baron-Hay Court, South Perth, phone 368 3336.

You are reminded that Regulations under the Argentine Ant Act allow entry to properties by employees of the Agriculture Protection Board for the purpose of treating Argentine ants. Your co-operation and compliance in this matter will greatly assist this campaign.

Your attention is drawn particularly to the safety precautions detailed on the accompanying circular.

Yours faithfully

(A.W. Hogstrom)
CHIEF EXECUTIVE OFFICER
AGRICULTURE PROTECTION BOARD

PLEASE READ CAREFULLY

ARGENTINE ANT CONTROL

SAFETY PRECAUTIONS

The insecticides used for Argentine ant control leave residues effective against the ants for long periods. These residues, however, may be dangerous to grazing animals and poultry unless special care is taken.

Spray operators have been trained to take all the necessary precautions when using insecticides for Argentine ant control; the co-operation of householders is requested in assisting spray personnel in the performance of their duties.

CHILDREN

Children should not run bare-foot over sprayed areas before the liquid has dried. All children's toys must be removed from the area before spraying commences.

CLOTHES ON LINES

Clothes on clothes lines and in other external areas should be moved indoors before the property is treated.

POULTRY, PETS AND OTHER ANIMALS

Before spraying starts remove food scraps, bones and seeds, which may be eaten by pets or poultry. Food and drink containers must be emptied and removed to avoid contamination. Grazing animals should be excluded from the area during spraying and after spraying for the period specified at the time of spraying. Grass, straw or hay from treated areas should not be cut and fed to animals before this time. Long grass needs to be heavily sprayed to get effective ant control and therefore presents an increased risk to grazing animals. Removing long grass before spraying will improve the effectiveness of the spray and reduce residues.

FRUIT AND VEGETABLES

Care will be taken to avoid contaminating produce. However, to further minimize chances of contamination, all ripe and nearly ripe produce should be picked before your property is treated. Fruit and vegetables picked after treatment should be carefully washed before eating.

FISH PONDS

Because insecticides are toxic to fish, ponds will be covered with tarpaulins and sprayed carefully and sparingly around the perimeters by members of the spray team.

BEEHIVES

Beehives should be placed on stands away from fences and they should be closed up during the spraying operation. Fresh water should be placed near the hives after spraying has finished.

Every care will be taken by the spray teams, but the responsibility of seeing that the above precautions are taken rests with you.

58226/12/87—5M—2572

CIRCULAR 4

Western Australian Department of Agriculture
3 Jarrah Rd. (West).
South Perth 6151.
Western Australia.
Telephone (09) 367 0111. Telegrams AGDEP Perth Telex AA 93304
Please address all letters to the Director of Agriculture, quoting our reference number to your correspondence

Your Ref
Our Ref
Enquiries Mr
Date

ARGENTINE ANT CONTROL NOTICE

To the Occupier

Dear Sir/Madam

You are advised that your property will be sprayed on

....

Please refer to householder's leaflet previously supplied as to precautions and restrictions after spraying has been completed.

(Signed) ....

CIRCULAR 5.

Western Australian Department of Agriculture

BARON-HAY COURT
South Perth 6151
Western Australia.
Telephone (09) 368 3333 Telegrams AGDEP Perth Telex AA 93304

Your Ref
Our Ref
Enquiries
Date

Please address all letters to the Director of Agriculture, quoting our reference number to your correspondence

ARGENTINE ANT CONTROL NOTICE

To the Occupier

Dear Sir/Madam

You are advised that in your absence your property was sprayed at

....

Please refer to householder's leaflet previously supplied as to precautions and restrictions after spraying has been completed.

(Signed) ....

ARGENTINE ANT CONTROL

Record of inspections, survey, interviews and negotiations relating to Report No.............. dated................ in order of date.

e	Details	Signature

APPENDIX 2

Review Paper on Ecotoxicological Effects of Heptachlor Use on the Environment

ECOTOXICOLOGY OF BIOCIDES, WITH PARTICULAR REFERENCE TO HEPTACHLOR, CHLORPYRIFOS, AND ISOFENPHOS

Prepared by : Dr. Barbara Porter
Environmental Consultant

For : The Environmental Protection Authority
Western Australia

February 1988

CONTENTS

TABLES

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FOREWORD

The fate and impact of biocides introduced into the environment are often the subject of community concern. The objective of the current review is to describe the ecological impact of biocides, with primary reference to heptachlor (and secondary reference to chlorpyrifos and isofenphos), in the context of Argentine ant control.

THE ECOTOXICOLOGY OF BIOCIDES

LITERATURE REVIEW

A. GENERAL ECOTOXICOLOGY

Analysis of the environmental behaviour of biocides reveals that both abiotic and biotic processes determine the fate of these chemicals.

Physical parameters such as wind, rainfall and air temperature influence abiotic dispersal of chemical substances through drift, leaching, runoff, erosion, evaporation (volatilisation), and sedimentation. Chemical changes may also occur by processes which include the formation of complexes, hydrolysis (through which many pesticides lose their toxic properties), oxidation, and various photochemically induced processes.

The differential uptake of biocides by different species of organisms, and the subsequent distribution, accumulation, metabolism, remobilisation and excretion of these chemicals and their derivatives, result from the interaction of biological processes and the chemical structure of the biocide. At the ecosystem level, plant-soil interactions and aquatic communities have significant involvement in the transformation and degradation of environmental chemicals. In both terrestrial and aquatic ecosystems, the processes of bioconcentration and bioaccumulation are important ecotoxicological considerations. Although bioconcentration of nutrients is a general and essential activity of living cells and organisms, that same process may also generate damaging concentrations of xenobiotics in living tissue; the bioconcentration factor will depend on the partition coefficient (between the tissue and the releasing medium, usually water), and on species-specific characteristics (such as metabolic parameters). The organochlorine insecticides in particular may be concentrated many thousand-fold by aquatic organisms (Edwards, 1977).

Exposure of living organisms to pesticides may result in acute effects, often as a result of the disruption of an identifiable biochemical or physiological system. Such acute toxic responses are often readily quantifiable, the standard measure being the LD_{50} (50% lethal dose) : a statistical estimate of the dosage required to kill half of the organisms in an exposed population under given experimental conditions. Such values can be considered only as guides since toxicity varies with species, sex, age, nutritional state, and with formulation and administration technique of the insecticide. These same factors will also influence values for the LC_{50} (lethal concentration).

By contrast, chronic effects may occur when organisms are exposed to single or repeated non-lethal doses of harmful substances. Sub-lethal effects may include alterations in behaviour, metabolism or reproductive capacity which may not be quantifiable or even apparent (especially in short-term studies). Those less-susceptible organisms that survive exposure may be the foundation of successive generations of organisms whose genotype confers resistance to that specific insecticide (and sometimes to related compounds : 'cross-resistance'). Thus 'resistance' is a genetic change in the population in response to the selective pressure of pesticide exposure. The development of insecticide resistance has important ramifications for pest control, since the consequent compulsion to use higher doses and more frequent applications for effective control may lead to severe disruption of ecological processes and systems. According to Georghiou and Mellon (1983) there was a 2.65-fold increase (from 313 to 829) in documented cases of pesticide resistance between 1970 and 1980. This list included 269 cases of resistance to the cyclodiene group of organochlorines, and 200 cases of resistance to the organophosphates.

B. CHARACTERISATION OF THE ORGANOCHLORINES AND ORGANOPHOSPHATES

1. THE ORGANOCHLORINES: DDT, Chlordane, BHC, Aldrin, Endrin, Dieldrin, Toxaphene, Heptachlor etc.

The insecticidal potential of organochlorines (chlorinated hydrocarbons) was discovered during World War II, and these pesticides have since been accredited with the saving of many human lives through the control of diseases such as malaria and yellow fever (Hassall, 1982). However, their persistence in the environment, their lack of specificity with respect to target organisms, and the development of resistance to members of this group, have curtailed the use of organochlorines as general all-purpose insecticides.

Most organochlorines are chemically stable and have low solubility in water. The latter property, together with a strongly lipophilic character, results in partition coefficients which strongly favour bioaccumulation (Hassall, 1982). Although the organochlorines are generally non phytotoxic, they are toxic to members of the cucumber family, and are very toxic to bees and fish. For mammals, acute oral toxicities of organochlorines are variable but intermediate.

The organochlorines' mode of action is destabilisation of neural activity ie neurotoxicity.

Chambers and Yarbrough (1982) detail the physiological and biochemical effects of chronic exposure of vertebrates to organochlorine insecticides. These authors propose that the observed responses (including changes in hepatic structure and function) are typical of those that occur when animals respond to stress and that, therefore, they may be mediated through the hypothalamic - pituitary - adrenal cortex axis.

1.1 HEPTACHLOR: C10 H5 C17

: 1,4,5,6,7,8,8-heptachlor-3a,4,7,7a -tetrahydro-4,7-methanoindene

(Drinox, H-34, Heptamul, Termide, Aahepta, Agroceres, Heptachlorane, Heptagran, Rhodiachlor, Velsicol 104).

1.1.1 CHEMISTRY

Heptachlor is a non-systemic stomach and contact biocide with some fumigant action. Chemically it is one of the cyclodienes, an important group of chlorinated cyclic hydrocarbons containing an endomethylene bridge. Heptachlor is a white crystalline solid with a mild camphor odour. It was isolated from technical chlordane and introduced for agricultural use by the Velsicol Corporation in 1948. Its solubility in water is very low (0.056 mg/l at 25^{o}C) but it shares with chlordane ready solubility in organic solvents (Metcalf, 1955). A typical analysis of the product is 73% heptachlor, 22% trans-chlordane, 5% nonachlor (Brooks, 1974). Technical heptachlor has been formulated as emulsifiable concentrates, oil solutions, dust concentrates, granules and wettable powders. It is not readily dechlorinated and is stable on exposure to air, light and moisture, but susceptible to epoxidation (amongst other reactions) under environmental conditions.

Heptachlor is more active biocidally than chlordane and is applied at 0.5-0.25 times the dosage of the latter. It is also has a higher toxicity to mammals with an acute oral LD_{50} to the rat of 100-162 mg/kg (Worthing, 1979). When applied to soil a large proportion of heptachlor volatilizes, while the remainder degrades to the insoluble epoxide over a period of time. Heptachlor is metabolised by birds, insects, microorganisms, plants and mammals to form the epoxide (Brooks, 1969), a product as toxic as the parent compound and with the undesirable characteristic of bioaccumulation in animal tissues. However, there is now evidence to show that chemical degradation may convert the epoxide to less toxic forms; also that soil microorganisms in culture have the capacity to deoxygenate heptachlor epoxide. (Miles et al., 1969, 1971; Bonderman and Slach, 1972).

1.1.2 USE OF HEPTACHLOR

Although heptachlor is most commonly used for cost-effective control of ants and termites, it has also been used as a seed dressing. In Britain its use for this purpose ceased in the early 1960's following incidents of bird poisoning linked with high residues in bird tissues of dieldrin and heptachlor epoxide - it has been used little there since (Brooks, 1972).

In Canada where the progress of cyclodiene-resistance has been closely followed for some years, heptachlor use began to decline on this account around the middle 1960's. In 1969, the use of heptachlor (as well as dieldrin and aldrin) was banned in Ontario Province, and its use is still discouraged despite registration in 1970 of heptachlor for specific uses (eg wireworm and cutworm).

In some countries, the organochlorines are proscribed for all uses as a result of toxicological (and oncological) studies. A survey in 1974 by EPPO (European and Mediterranean Plant Protection Organisation) showed that heptachlor was totally banned in 17 member countries (DDT in 10, aldrin 15, chlordane 18, dieldrin 21) (McFarlane, 1977). The eventual outcome of administrative hearings called by the USEPA (1974-1978) to examine a proposition for cancellation of virtually all uses of heptachlor and chlordane (except for subterranean termites), was agreement permitting continued use of heptachlor on termites and on certain specified crops and insects on a phase-out basis over a number of years.

The uses of heptachlor in Australia are summarised in Table 1.

In Western Australia heptachlor is a Schedule 6 poison (State Poisons Act) which includes "substances that are required to be readily available to the public for agricultural, pastoral, horticultural or veterinary purposes or for the control or destruction of pests and vermin or for industrial purposes".

2. THE ORGANOPHOSPHATES

The organophosphorus compounds are esters or organic salts of phosphoric acid or it derivatives. They have a wide spectrum of physiochemical and biological properties, and a correspondingly broad range of uses as fumigants, contact poisons and systemic compounds. The structural variability of organophosphorus compounds confers the possibility of species selectivity and minimises the risk of development of cross-resistance amongst the organophosphate group of insecticides (Hassall, 1982). For these reasons, and because of the generally lower environmental persistence of organophosphates, the latter have to a significant degree replaced the

Table 1. The agricultural uses of heptachlor in Australia.

CROP	STATE	TARGET
Potatoes	WA	African black beetle
Apples	WA	Apple weevil
Apples	WA	Fuller's rose weevil
Apricots	WA	Apple weevil
Apricots	WA	Fuller's rose weevil
Bananas	NSW	Banana weevil borer
Citrus	WA	Fuller's rose weevil
Peaches & Nectarines	WA	Fuller's rose weevil
Plums and Prunes	WA	Fuller's rose weevil
Sugar	Qld	Funnel ant
Lucerne	SA	White-fringed weevil

Source: Uses of Insecticides in Australia 1979 (Dept. Primary Industry AGPS, 1979)

organochlorines for insect pest control, although some of the organophosphates now available for the control of refractory pests are highly persistent, highly toxic to vertebrates and costly (Hassall, 1982).

The organophosphorus insecticides are neurotoxins ie they disrupt the function of the nervous system, by inhibition of the enzyme cholinesterase. In addition, there are suggestions of teratogenic (embryo-deforming) effects in birds and mice and mutagenic effects (chromosomal abnormalities) in humans (Hassall, 1982). Some organophosphate pesticides pose a serious threat of delayed neuropathy following single or chronic exposures : the minimum effective dose by chronic exposure to some compounds is apparently up to 1000 times lower than the minimum effective single dose (see Chambers and Yarbrough, 1982).

2.1 <u>CHLORPYRIFOS</u>: C9 H11 C13 NO3 P5
: O, O-diethyl O-(3,5,6-trichloro-2-pyridyl phosphorothioate

(Dursban, Killmaster, Lorsban)

Chlorpyrifos, introduced to the pesticide market in the mid 1960's, is a thionphosphate (phosphorothionate). This group also includes Diazinon, Parathion, Temephos and Fenitrothion.

The thionphosphates are compounds of moderate to high chemical stability, usually with low solubility in water but soluble in lipids. They have been classified as persistent contact or quasi-systemic compounds (Hassall, 1982). Chlorpyrifos is a colourless crystalline solid with low water solubility (2mg/l) but ready solubility in most organic solvents. It is stable at room temperature. Generally, when metabolised, it is excreted via the urine, the degradation product appearing mainly due to dealkylation.

Chlorpyrifos has a broad range of insecticidal action and has been used for the control of mosquitoes, flies, bovine ectoparasites and various soil, plant and household pests (Blair, 1979); it has been used extensively for the control of Culex pipiens fatigans, the main vector of Bancroftian filariasis, a widespread disease in urban and rural Asia and Africa (WHO,1978). Although possible interactions between chlorpyrifos and other biocides have received little scientific attention, a recent study (Atwood et al., 1987) indicated that chlorpyrifos may be antagonistic to the fungicidal activity of captan.

2.2 ISOFENPHOS (ethyl 2 - [isopropoxycarbonyl] phenyl isopropylphosphoramidothionate

(Oftanol, Amaze)

Isofenphos, an aryl phosphoramidate, is a contact and stomach insecticide effective against soil-dwelling insects. Like other organophosphates, it has a neurotoxic mode of action. However, Heppner et al. (1987) provide evidence that, unlike the activity of other organophosphates, the neurotoxic action of isofenphos involves oxidative bioactivation and subsequent cholinesterase inhibition by its metabolites, as well as disruption of interneuron function.

Failure of isofenphos to control damage caused by larval corn rootworms (the purpose for which it was initially registered) resulted in its withdrawal from that market in the USA in 1983. This poor performance has since been explained (Racke & Coats, 1987) by "enhanced degradation", a not uncommon phenomenon wherein a soil-applied pesticide is rapidly degraded by a population of microorganisms that has adapted as a result of previous exposure to the pesticide. Evidence presented in several studies (Racke & Coats, 1987; Chapman et al., 1986; Abou-assaf et al., 1986; and Felsot et al., 1982) indicates that in soils with a previous history of isofenphos use, the (enhanced) degradation of isofenphos can be sufficiently rapid to compromise its effectiveness. This induced phenomenon appears to be pesticide-specific, in that previous use of other organophosphorus insecticides does not affect soil degradation of isofenphos (Racke & Coats, 1987).

C. ECOLOGICAL IMPACT

1. AQUATIC SYSTEMS

(a) Introduction

Persistent pesticides are potentially damaging to aquatic systems because the aquatic organisms may be exposed to residues for some time after only a single contamination. If the contamination is repeated, the potential exists for accumulation of the pesticide in biotic or abiotic components of the aquatic ecosystem. Residue levels in water tend to vary considerably with turbulence, season, content of organic matter etc, so fish are generally considered to be more reliable indicators of pesticide pollution in aquatic systems. (Edwards, 1977).

Although the water solubilities of organochlorines are generally lower than those of the organophosphates, the potential for uptake and bioconcentration of the former group coupled with their documented persistence (see Table 3) indicate that they must be considered highly toxic to aquatic fauna, whereas the organophophates are generally considered moderately toxic.

(b) Invertebrates

Phytoplankton and zooplankton, a major food resource in most aquatic systems, are extremely susceptible to organochlorine insecticides, and to a lesser extent, organophosphate insecticides (Edwards, 1977) - although some species of Cladocera seem to be particularly susceptible to organophosphate insecticides such as chlorpyrifos (Mulla and Khasawinah, 1969). The cyclodiene insecticides are considerably more toxic than DDT, and a little less toxic than chlorpyrifos, to the insectan fish-food species, as demonstrated by the work of Sanders and Cape (1968) on stonefly nymphs. Tiny ostracod crustaceans living in surface mud where insecticide residues accumulate, are also susceptible to cyclodienes (Kawatski and Schmulbach, 1971). In mud (sediments), as in soil, organochlorine insecticides tend to persist longer than most others. Brown (1978) details toxic responses of, and development of resistance by, other groups of aquatic invertebrates to organochlorine pesticides.

Similarly, chlorpyrifos has been found to be destructive to mayfly nymph and dytiscid diving beetles (Washino et al., 1972) and, to a lesser extent to corixid water boatmen whose populations soon recovered (Hurlbert et al., 1970). Significantly, chlorpyrifos (applied at 0.025 lb/a) also temporarily reduced populations of (non-target) predaceous species (Hurlbert, 1975). Brown (1978) cites further studies indicating that marine invertebrates also are susceptible to organochlorines, and to a lesser extent, to organophosphates.

It is generally accepted that many aquatic invertebrates build up concentrations of persistent pesticides, such as the organochlorines, in their tissues to levels much higher than those in the surrounding water. Wilson (1965) demonstrated that oysters can concentrate heptachlor almost 18 000 times (wet weight basis); data relating to crustaceans and fish (Schimmel et al., 1976) suggest that the involvement of several trophic levels might increase the degree of accumulation. Table 2 shows the acute toxicity of selected pesticides to aquatic organisms. Organochlorine residues accumulate in the aquatic biota because of their low water solubility and a high fat solubility.

Most organophosphates, however, are detectable only during, or immediately after, treatment (McEwen and Stephenson, 1979). As a result, the application of organophosphates is often followed by rapid re-establishment of aquatic invertebrate populations whereas the organochlorines usually cause more severe long-term effects.

(c) Fish

Pesticides taken in by fish via the gills or through food consumption are generally concentrated in the fatty tissues (Edwards, 1970). Khan (1977) points to the qualitative negative correlation between the water solubility of pesticides and their bioaccumulation by fish, hence the high levels of bioaccumulation of substances such as heptachlor. Since heptachlor is a highly persistent chemical which bioaccumulates in aquatic organisms used for human food and is also potentially carcinogenic (Train, 1974), levels of heptachlor in waterways should be kept as low as feasible. Table 3 compares the persistence of biocides in natural waters and Table 5 indicates the permissible levels of biocides in potable and surface waters. Water quality criteria for marine and estuarine waters in WA (EPA Bulletin 103, 1981) specify heptachlor levels not exceeding 0.001 μg/L for all uses of water other than industrial water supply (< 0.005 μg/L).

Table 2. Acute toxicity of selected pesticides (ppb) to aquatic organisms (McEwen & Stephenson 1979).

PESTICIDE	EFFECT ON PHYTO-PLANKTON (a)	DAPHNIA "WATER FLEA" LC_{50}	GAMMARUS "SAND-HOPPER" LC_{50}	PTERONARCYS LC_{50}	CULEX MOSQUITO LARVA LC_{50}	CRANGON "SHRIMP" LC_{50}	BUFO TOAD TAD-POLE LC_{50}	RANA FROG TAD-POLE LC_{50}
Aldrin	-85	28	28	8	5	30	2000	
Chlordane	-94	29	160	170				
DDT	-77	.36	4.7	41	70	3	2400	>2000
Dieldrin	-85	250	1400	6	8	68	1100	
Endosulfan	-87	240	9.2	24				
Endrin	-46	20	47	4	15	2.8	570	
Heptachlor	-94	42	150	8	54	110		
Methoxychlor	-81	.78	4.7	30	67	9		
Toxaphene	-91	15	70	7			600	
Abate			960	100	16			>2000
Azinphosmethyl		3.2		8			680	
Chlorpyrifos			.76	50	3			>400
Diazinon		.9	800	60	830			>2000
Dimethoate		2500		140				
Ethion	-69	.01	56	24				
Fenitrothion		.4	12	28	6			
Malathion		1.8	3.8	35	80	246	1900	
Parathion		0.6		8	3	11	1600	
Phosphamidon		8.8	8.4	1400				
Carbaryl	-17	6.4	40	30			7600	>4000
Carbofuran							2700	
Propoxur			25	110				595
Allethrin		21	20	28				

Table 2. Acute toxicity of selected pesticides (ppb) to aquatic organisms (McEwen & Stephenson 1979) (cont'd).

PESTICIDE	EFFECT ON PHYTO-PLANKTON (a)	DAPHNIA "WATER FLEA" LC50	GAMMARUS "SAND-HOPPER" LC50	PTERONARCYS LC50	CULEX MOSQUITO LARVA LC50	CRANGON "SHRIMP" LC50	BUFO TOAD TAD-POLE LC50	RANA FROG TAD-POLE LC50
Rotenone		100	6000	2900				
Amitrol		23						
Atrazine		3600						
Dalapon	0	11000		>100000				
Dicamba			1000					
Dichlorbenil		3700	1500	4400				
Diquat	-45					>10000	54000	
Endothall		46000	2000					
MCPA	0	100000						
Monuron	-94	106000						
Paraquat	-53	3700	18000	>100000				
Picloram	0	>380000	48000	120000				
Prometone								
Simazine			21000	50000				
Trifluralin		240	8800	13000				
2,4-D		320000	1800000					
2,4,5-T (acid)		>1500						
Copper sulfate								
Dichlone		26	3200					
Nabam								
Benomyl		640						
TFM-2B		7350	26000	15400				

(a) percentage reduction in carbon fixation during 4 hours in a mixed natural culture of phytoplankton from a marine estuary when exposed to 1 ppm pesticide.

SUMMARY

1. Heptachlor has moderate acute toxicity. It is well absorbed by skin, lungs and gastrointestinal tract. Acute cyclodiene poisoning is characterised by convulsions, sometimes preceded by nausea, vomiting, malaise, headache and dizziness. There are no reports of acute poisoning in man by heptachlor. It is unlikely that acute toxic reactions to heptachlor spray residues will occur in adult humans.

2. Heptachlor is toxic and is potentially hazardous to humans if incorrectly or carelessly handled. It is therefore essential that adequate precautions be observed.

3. Non-neoplastic liver toxicity in man resulting from exposure to chronic low levels of heptachlor is unlikely to be of clinical significance.

4. Heptachlor is clearly carcinogenic in the mouse at very low exposure levels, there is limited evidence for carcinogenicity in the rat. Epidemiological studies do not show an association between heptachlor exposure and increased cancer risk in man. Nevertheless heptachlor is regarded as a potential human carcinogen.

5. Heptachlor is avidly stored in human fat as heptachlor epoxide. The toxicological consequence of this is unknown. Human breast milk is a major route of elimination of heptachlor epoxide and the most significant source of exposure of infants to heptachlor. Although the toxicological effects of such infant exposure is unknown, limited animal studies suggest marked adverse effects during suckling.

6. There are gaps in the teratogenic animal data for heptachlor and it is not possible to assess the possible human teratogenic aspects. Multigeneration animal studies indicate high exposure may interfere with reproduction and viability of progeny.

7. Although a cause-effect relationship has not been established, there is a growing number of case reports linking chlordane and heptachlor to a variety of blood dyscrasias in humans.

8. It is concluded that the potential human health effects of heptachlor warrant minimising exposure of the general population, and of women in particular.

1. INTRODUCTION

Heptachlor is a member of the cyclodiene group within the general class of organochlorine insecticides.

The toxicity data on heptachlor has been reviewed by several international bodies [1-4], the U.S. EPA [5] and the Australian NH & MRC [6]. It is not the intention of this paper to re-review the toxicity of heptachlor, but rather to present some of the human health aspects of heptachlor. Animal toxicity data is only presented where it will help the discussion of human aspects.

2. ACUTE TOXICITY

In laboratory animals heptachlor causes the same kind of illness as that produced by other cyclodiene insecticides. Heptachlor is readily absorbed by the skin, lungs and gastrointestinal tract. Avid dermal absorption is demonstrated by the fact that heptachlor is only twice as toxic when given orally as dermally to animals[7].

There is no information on the dermal absorption of heptachlor in man, hence it must be assumed that it will penetrate human skin as easily as animal skin. Heptachlor is rapidly metabolised and its acute toxicity is partly due to its major metabolite, heptachlor epoxide, which is at least, if not more toxic than the parent compound [4,5,8].

There are no reports of acute human poisoning (accidental or suicidal) by heptachlor [4,8]. However, heptachlor is toxic and is potentially acutely hazardous to humans if incorrectly or carelessly handled. It is therefore essential that during handling and use correct precautions are observed. Since the acute toxicity of heptachlor in animals is the same as other cyclodienes (e.g. chlordane, aldrin, dieldrin) it might be expected that symptoms of acute heptachlor poisoning in man may also be similar. Convulsions are usually the first clear indication of cyclodiene poisoning in man, however nausea, vomiting, malaise, headache and dizziness may atypically occur before signs of central nervous system overactivity. There are usually no prodromal symptoms prior to the initial fit. Convulsions can be very severe and violent, they are usually accompanied by confusion, incoordination, excitability, or, in some instances coma. Treatment of poisoning is primarily directed towards control of convulsions and removal of unabsorbed compound via lavage, cathartics or adsorbants. Although barbiturates (pentobarbital and phenobarbital) have been used most often to combat the convulsions it may be prudent to use adequate doses of diazepam (iv or im) since this has demonstrably less effect on respiration than the barbiturates. Paralysis, combined with artificial respiration has been effective when anticonvulsants have failed [9,10].

It should be appreciated that in documented cases of acute toxicity to cyclodienes the toxicity occurred within 0.5-3 hours as a result of over-exposure, either orally or dermally, to relatively high concentrations of chemical, i.e., during manufacture, handling or use. With the exception of hypersensitivity to heptachlor, it is unlikely that acute toxic reactions resulting from exposure to heptachlor residues following spraying programmes will occur in adult humans.

On the other hand, it is not known if there is greater absorption of the cyclodienes through the skin of infants and young children compared with adults, or if this group is more susceptible to the effects of cyclodienes. It is not possible, therefore, to reach a conclusion regarding exposure of infants or young children to heptachlor spray residues and the likelihood of an acute toxic reaction. Heptachlor is approximately seven times less toxic in newborn rats than in adult rats primarily because of a decreased ability of newborn animals to metabolise heptachlor to heptachlor epoxide [11,12].

3. CHRONIC TOXICITY

Animal, residue and clinical studies raise a number of areas of concern regarding the potential chronic effects of heptachlor on humans. The areas of concern are non-neoplastic liver toxicity following low heptachlor doses, potential carcinogenic effects, residue levels in human tissue and breast milk, potential teratogenic effects and the possibility that heptachlor may be linked with blood dyscrasias in man.

3.1 Non-Neoplastic Liver Toxicity

In subchronic and chronic feeding studies in animals heptachlor and heptachlor epoxide cause histopathological and degenerative changes in the liver. These are characterised as increased liver weight, endoplasmic reticulum hypertrophy, enlarged central lobule cells and necrosis at higher doses. The changes are slowly reversible on cessation of heptachlor exposure and are typical of liver effects of chlorinated hydrocarbon insecticides [4,8]. The slow regression of liver changes is probably related to continued slow release of heptachlor epoxide from fat tissue. Recent studies [5,6] indicate that these changes can occur at very low exposure levels. No effect levels could not be established in the mouse (lowest dose tested 1 ppm) and were established in rat and dog at 5 ppm (0.5mg/kg/d) and 1 ppm (0.015 mg/kg/d) respectively.

The implications of these findings for human exposure are unclear. Although they raise some concern about the potential for liver toxicity following low level exposure of heptachlor, such changes are considered to represent adaptive changes of the liver to chemical exposure and not to be of toxicological consequence. The reversibility of the minor liver changes and the fact that many therapeutic agents are known to have similar effects supports this idea. To date, liver changes observed in animals have not been demonstrated in man (4,5,8,13).

3.2 Carcinogenicity

The carcinogenic potential of the organochlorine insecticides has been intensely studied over the last decade. It has been known for some time that the organochlorines, including heptachlor, can induce hepatic tumours in mice. Although heptachlor may act as a promoter of liver neoplasms [14] there is no clear evidence to indicate that it is gentotoxic. In 1982 IARC concluded there was limited evidence for the carcinogenicity of heptachlor in experimental animals[2]. In 1984 the IPCS concluded there was limited evidence for both heptachlor and heptachlor epoxide carcinogenicity in mice[4]. The US EPA, in 1986, classified heptachlor and heptachlor epoxide as group B-2 carcinogens[15], i.e. probable human carcinogens based on the weight of evidence of available animal studies. Similarly, after reviewing all of the available carcinogenic studies for heptachlor and heptachlor epoxide, Reuber [16] concluded in 1987 that both chemicals were unequivocally carcinogenic in rats and mice.

Despite the latter evaluations, the evidence of carcinogenicity in rats is still somewhat equivocal. There is strong evidence that heptachlor and heptachlor epoxide are carcinogenic in mice producing benign and malignant liver tumours. The relevance of hepatocellular tumours in mice for assessing the risk to humans has been, and still is controversial and questionable [8,17,18]. Nevertheless the very low level at which heptachlor is tumourigenic in the mouse is a source of great concern (5 ppm, 0.75 mg/kg/d). Therefore in the absence of clear evidence that the mouse is unique, a potential carcinogenic risk to man from heptachlor and heptachlor epoxide must be assumed.

Epidemiological studies of workers manufacturing or applying chlordane or heptachlor suggest there is not an increased risk of cancer associated with relatively high, chronic exposure to these chemicals. Unfortunately these studies are regarded as being insufficient to judge the carcinogenic hazard of heptachlor to man[2,4].

3.3 Residues in Human Tissue and Breast Milk

Heptachlor, once absorbed, is rapidly metabolised by the liver to heptachlor epoxide. There is a substantial body of evidence to indicate that heptachlor epoxide is stored for considerable time in human adipose tissue [4,8]. In fact the vast majority of humans have organochlorine pesticide residues in their body fat. The health hazards, if any, resulting from the presence of cyclodiene insecticides in fat are unknown.

Excretion via milk is a major route of elimination and means of decreasing the body burden of heptachlor epoxide[5]. Many studies have shown the presence of heptachlor/heptachlor epoxide in human milk, the residues in which can be tenfold higher than those in dairy milk and dairy products[4]. The most significant source of exposure to heptachlor for infants is via human breast milk. The health effects of such exposure are unknown. Studies in rats and dogs, however, indicate that heptachlor and heptachlor epoxide treatment of dams results in increased mortality of pups during suckling [4,5]. This is probably due to increased sensitivity of the neonates to the hepatotoxic effects of heptachlor epoxide excreted in the maternal milk supply. The acute toxicity of heptachlor in newborn rats is enhanced by pretreating them with agents that increase the hepatic conversion of heptachlor to heptachlor epoxide[11].

Neonatal exposure to relatively large amounts of heptachlor epoxide through maternal milk is a matter of concern and is undesirable. It would therefore be prudent to minimise exposure of pregnant and nursing women, and probably all women of child bearing age, to heptachlor.

3.4 Teratogenic Effects

A teratogenic study in the rabbit at doses of 5mg/kg was negative for gross defects, behavioural abnormalities in the offspring and standard teratogenic test parameters. High exposure levels in 3-generation reproduction studies in rats and dogs indicated that heptachlor can interfere with reproduction and viability of offspring[4]. In rats cataracts were observed in both parents and progeny. There is a suggestion that chlorinated cyclodienes have an affinity for the highly lipid ocular neural tissue[5]. The animal data for teratogenic effects of heptachlor and heptachlor epoxide is incomplete and it is not possible to judge the human health aspects of heptachlor in relation to potential teratogenicity.

In 1980-1982 the milk supply of the island of Oahu, Hawaii was contaminated by heptachlor (0.12-5.00ppm). A case controlled study for birth defects during 1981-1983 failed to show an association with the heptachlor exposure[19]. The authors noted however, that misclassification of exposure status may have obscured a moderate effect in increased cardiovascular malformations and hip dislocation. Heptachlor and the epoxide readily cross the placenta[4].

3.5 Blood Effects

There are clinical reports linking cyclodiene exposure to increased incidence of blood dyscrasias. Thus, Infante et al[20] have reported a circumstantial link between chlordane or heptachlor exposure with aplastic anemia and acute leukemia. A single case of self-limited refractory megablastic anemia reputedly associated with chlordane was described by Furie and Trubowitz[21]. More recently Epstein and Ozonoff [22] described 25 new cases of blood dyscrasias linked with chlordane/heptachlor exposure. According to these authors the number of reported cases of leukemia or other blood dyscrasias following chlordane/heptachlor exposure is 59. In a company commissioned study, Wang and Grufferman[23] found no statistical association between 60 cases of aplastic anemia and occupational exposure to chlorinated hydrocarbon pesticides. They suggest that cases of aplastic anemia following pesticide exposure may be the result of idiosyncratic bone-marrow reactions in rare individuals. Although chronic animal studies have not shown blood dyscrasias to be caused by heptachlor, the Russian literature on heptachlor mutagenicity (reviewed in [4]) suggests that heptachlor can produce chromosomal aberrations in bone-marrow cells of treated rats and mice.

The low incidence of blood dyscrasias limits the association of such diseases with specific agents to case reports, epidemiological studies are not feasible. The cases described to date do not prove chlordane or heptachlor cause blood dyscrasias in man, however a cause and effect relationship cannot be discounted and there is need for further study.

4. CONCLUSIONS

It is unlikely acute toxic reactions to heptachlor will occur during, or as a result of spraying if standard precautions are observed.

The long term storage of heptachlor epoxide in human body fat, its mobilisation and excretion in breast milk and subsequent exposure of infants indicates that exposure of women to heptachlor should be minimised. This conclusion is reinforced by a lack of knowledge of heptachlor effects on infants and their development.

Our present state of knowledge dictates that heptachlor should be regarded as a potential human carcinogen. This coupled with limited evidence of an association between cyclodienes and blood dyscrasias in man should be enough to limit exposure of the general population to heptachlor.

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APPENDIX 4

Executive Summary from United States Environmental Protection Agency Technical Support Document on Chlordane, Heptachlor, Aldrin and Dieldrin

EXECUTIVE SUMMARY

Chlordane, heptachlor, aldrin and dieldrin are related compounds called cyclodienes that are used principally to control subterranean termites. This draft Technical Support Document presents EPA's evaluation of the risks and benefits of these four chemicals for use on subterranean termites.

These chemicals once were used extensively in agriculture and around the home for controlling a variety of pests. In the mid-1970's EPA cancelled most of their uses based on evidence that these pesticides caused tumors in laboratory animals. The Agency did not cancel the subterranean termite use because there were no effective alternatives available and because it was believed that when these pesticides were correctly applied, occupants of treated structures would not be exposed.

Air monitoring data submitted in early 1987 by Velsicol Chemical Corporation for chlordane and heptachlor, and by Scallop Corporation for aldrin, show the presence of cyclodiene residues one year after treatment. In general these air concentrations were relatively constant over the one year period and no decay curve could be derived from the data. These studies also represented "best case" data; the registrants chose the test houses and applicators and application was made strictly according to label directions.

In addition to concern about the finding of air concentrations following careful application, the Agency has also been concerned for some time about exposure and property contamination from misuse/misapplication of these chemicals. The Agency believes exposure from misuse/misapplication is a significant problem.

Chronic effects of exposure to these chemicals are primarily to the liver. These effects include increases in organ weight, various tissue changes including necrosis and increased incidence of benign and malignant tumors. The Agency's Carcinogen Assessment Group has classified all four of these chemicals as probable human carcinogens. Other health effects associated with exposure to the cyclodienes include reports of increased incidence of blood dyscrasias and effects on central nervous system activity.

EPA was not able to establish No Observable Effect Levels (NOELs) for non-oncogenic effects because these effects often occurred at the lowest dose levels tested. Without NOELs, the Agency believed it appropriate to establish conservative acceptable daily limits of exposure for these effects. The exposures posed to occupants of treated houses exceed these prudent limits for the large majority of applications.

Applying the cancer potency values calculated by EPA for the cyclodienes to the recent exposure data provided by the registrants shows estimated cancer risks in the range of 10^{-3} or 10^{-4} for occupants of treated homes. Using exposure values reported in other studies results in risk estimates as high as 10^{-2} for some exposure situations. These estimates, which represent the upper bounds of risk, are higher than usually accepted even with substantial benefits.

The population exposed to cyclodiene residues from subterranean termite control is estimated to be very large. An estimated 1.3 million to 1.8 million people per year are exposed to these chemicals as occupants of newly treated structures. A cumulative total of approximately 30 million structures have been treated with these chemicals for termite control, which means over 80 million people altogether may be exposed.

The Agency's two essential findings regarding exposure and risk are (1) that the use of cyclodiene termiticides results in widespread and long-term human exposure, and (2) such exposure poses risks of adverse health effects, including (but not limited to) risks of cancer and chronic liver effects.

This document also evaluates the efficacy of chemical alternatives to the cyclodienes and the economic impact of cancellation. The Agency found that two commercially available alternatives, chlorpyrifos and permethrin, can provide effective termite control for up to 12 or more years. These alternatives do not pose the serious health effects associated with the cyclodienes. EPA concluded that the loss of the cyclodienes for termiticide use would not eliminate effective means for protecting structures from termite attack. However, the loss of the cyclodienes could be expected to require more frequent applications of the remaining registered termiticides and subsequently greater costs to homeowners. The individual homeowner may need 2 or 3 treatments in a twenty year period which would have required only one cyclodiene treatment. The probable need for more frequent termiticide treatments is seen as the primary long-term economic impact of cancellation of the cyclodienes.

The total cost difference due to the higher price of chlorpyrifos and permethrin is estimated to be about $37 million annually for several years. Costs to the individual home owner are estimated to increase by $60-$100 per treatment. Average charge per treatment is currently estimated to be between $500-$650. Aggregate long-term costs of more frequent treatment may amount to several hundred millions or even billions of dollars over 20 to 30 years. However, these costs would be distributed over millions of individuals. In addition, the current termiticide market is in a state of flux since some commercial users appear to be switching to non-cyclodiene products. Thus, impact projections are somewhat speculative.

EPA evaluated several options for reducing exposure to the cyclodienes in order to permit their continued use. At the time of this draft of the Technical Support Document, a final regulatory position has not been announced by the Agency, and consequently, a discussion of regulatory options is not included in this draft.

In summary, the Agency has evaluated the risks and benefits of the cyclodiene termiticides and concluded that their use results in exposure to occupants of treated structures. There is substantial toxicological test data demonstrating the potential of these compounds to cause liver tumors in laboratory animals. Nononcogenic liver effects have also been shown to occur in test animals, as well as other disorders such as blood dyscrasias and central nervous system effects from one or more of these chemicals. Large numbers of people are exposed to these chemicals.

Effective alternatives are available that do not pose hazards of the magnitude associated with exposure to cyclodienes. The cost to the public of replacing the cyclodienes with available alternatives may be large, but it is distributed among millions of individuals.

Table 3. Relative persistence of some pesticides in natural waters (McEwen & Stephenson, 1979).

NON PERSISTENT [a]	SLIGHTLY PERSISTENT[b]	MODERATELY PERSISTENT[c]	PERSISTENT[d]
azinphosmethyl	aldrin	aldicarb	benomyl
captan	amitrole	atrazine	dieldrin
carbaryl	CDAA	ametryne	endrin
chlorpyrifos	CDEC	bromacil	hexachlorobenzene
demeton	chloramben	carbofuran	heptachlor
dichlorvos	chlorpropham	carboxin	isodrin
dicrotophos	CIPC	chlordane	monocrotophos
diquat	dalapon	chlorfenvinpho	
DNOC	diazinon	chloroxuron	
endosulfan	dicamba	dichlorbenil	
endothal	disulfoton	dimethoate	
fenitrothion	DNBP	diphenamid	
IPC	EPTC	diuron	
malathion	fenuron	ethion	
methiocarb	MCPA	fensulfothion	
methoprene	methoxychlor	fonofos	
methyl parathio	monuron	lindane	
mevinphos	phorate	linuron	
parathion	propham	prometone	
naled	Swep	propazine	
phosphamidon	TCA	quintozene	
propoxur	thionazin	simazine	
pyrethrum	vernolate	TBA	
rotenone		terbacil	
temephos		toxaphene	
TFM		trifluralin	
2,4-D			

[a]Half-life less than 2 weeks.

[b]Half-life less than 2 weeks.

[c]Half-life 6 weeks to 6 months.

[d]Half-life more than 6 months.

Although heptachlor is among the least toxic to fish of the organochlorines, treatment of ponds with heptachlor to a concentration of 0.05 ppm resulted in the death of 90% of their resident bluegills (Andrews et al., 1966). In the US, heptachlor and heptachlor epoxide residues are widespread in fish. Residues of 8.33 ppm in white perch (Morone americanus) and 6.93 ppm heptachlor epoxide in large mouth bass (Micropterus salmoides) have been found during the National Pesticide Monitoring Program. Heptachlor and/or heptachlor epoxide were found in 32% of the samples while chlordane was reported 22% of the time (Henderson et al., 1969). Heptachlor and chlordane residues have been reported in excess of 0.01 ppm in fish from Canadian rivers (Miles and Harris, 1973). The ability of chlordane and heptachlor epoxide to pass from gravid female fish to their eggs has also been documented by Johnson and Morris (1974). This accumulation of lipid soluble organochlorines in eggs can lead to death of fry as the yolk sac is absorbed at a critical state of growth (Holden, 1973). The persistence of pesticides in rainbow trout is described in Table 4.

Table 4. Persistence of pesticides in Rainbow Trout (Macek, 1970).

PERSISTENCE	PESTICIDE
< 1 day	Malathion
< 2 days	Lindane
< 3 days	Simazine
< 1 week	Diazinon, Dursban, Azinphosmethyl Parathion, Methoxychlor, 2,4-D
< 2 weeks	Dichlorobenil
< 3 weeks	Diquat, Endothal
1 month	Heptachlor, Dieldrin
4 months	Sodium arsenate
> 5 months	DDT
> 6 months	DDT, Campheclor

Table 5. Levels of some pesticides permissible in potable water and maximum recommended levels for the maintenance of fish and aquatic life.* (McEwen & Stephenson 1979.)

PESTICIDE	PERMISSIBLE LEVEL IN POTABLE WATER	FISH	AQUATIC LIFE
Dieldrin	0.1	0.025	0.0005
Endrin	0.05	0.01	0.0002
DDT	5	0.05	0.0002
Heptachlor	0.01	0.1	0.001
Aldrin	0.1	0.025	0.001
Lindane	5	0.5	0.002
Chlordane	0.3	0.025	0.004
Methoxychlor	100	2	0.0005
Toxaphene	0.5	0.25	0.001
2,4-D	2	-	-
2,4,5-TP (Silvex)	3	-	-
2,4,5-T	0.2	-	-
Organophosphorus Plus carbamates	10	-	-

* Levels expressed as $\mu g/l$ (parts per billion).

Model ecosystem studies with radiolabelled pesticides provide useful data about the comparative metabolism of pesticides in a variety of organisms. Studies with 14C hexachlorocyclopentadiene (raw material), chlordane (principal impurity), heptachlor and heptachlor epoxide (environmental pollutant) have shown heptachlor epoxide formed 22% of the extractable 14C in alga, 37% in snail, 49% in mosquito and 79% in fish (Lu et al., 1975). Data from such studies demonstrate the reasons for the environmental problems encountered with heptachlor ie the in vivo formation of the very stable heptachlor epoxide which does not readily undergo hydrolysis.

Brown (1978) and Edwards (1970) have discussed some of the sublethal effects of piscine exposure to cyclodiene insecticides. Such responses include lowered resistance to disease, decreased feeding rates and reduced reproductive performance.

Several studies have demonstrated the development by fish populations of cyclodiene resistance (Boyd and Ferguson 1964; Ferguson et al., 1964; Dzuik and Plagg, 1973). There have also been recorded instances of organophosphate (chlorpyrifos) resistance in the golden shiner and green sunfish (Pimentel, 1971).

Organophosphate compounds are considered much less toxic to fish than organochlorines. Applied at the usual dosage (0.5 ppm), chlorpyrifos has been found to cause no mortality in Gambusia (mosquito fish), but at twice that dosage 85% mortality has been calculated (Darwazeh and Mulla, 1974). The persistence of organophosphate residues in fish is also lower than that of organochlorrines. For example, a study reported by Khan (1977) indicates that 50% of heptachlor and dieldrin had been excreted in about one month, whereas chlorpyrifos and diazinon were reduced to the same extent in less than one week.

By contrast, there are reports that fish exposed to field applications of chlorpyrifos showed cumulative and severe toxic effects; those that survived still suffered from enzyme inhibition 69 days after the final chlorpyrifos application (Thirugnanam and Forgash, 1977). The authors cite reports which produce conflicting evidence on the toxicity of chlorpyrifos to fish, and point to the influence of species, environmental conditions and insecticide formulation.

In a study of the acute toxicity, bioconcentration and persistence of several pesticides, including synthetic pyrethroids, in the estuarine environment, Schimmel et al., (1983) concluded that chlorpyrifos "may represent a potential hazard for benthic species due to its high acute toxicity and persistence in sediments". In their discussion of earlier studies, the authors suggest that chlorpyrifos toxicity may be directly related to temperature.

2. TERRESTRIAL SYSTEMS

2.1 (a) Introduction

There are several mechanisms of pesticide loss from soil, including volatilisation, photodecomposition, chemical decomposition, adsorption, leaching, dilution, mechanical removal (erosion), uptake by plants and microbial decomposition. Nevertheless, persistent pesticides have been detectable in soil many years after application. The cyclodienes are generally recognised as the most persistent organic pesticides in the environment. The major pathway of microbial metabolism is epoxidation (Menzie, 1969), although hydrolysis, dehalogenation, reduction and hydroxylation also occur. The biological activity of heptachlor in the soil is prolonged by the biocidal potency of its epoxide. The conversion of aldrin and heptachlor to their epoxides in soil and on plants was demonstrated by Gannon and Biggar (1958a, b, c). Later Wilkinson et al. (1964) demonstrated by bioassay and chemical analysis that silt loam treated 9 years before with normal applications of aldrin and heptachlor still contained measurable amounts of their epoxides. Residues may also occur in crops grown in soil treated many years previously (see Table 7).

The persistence of organochlorines in soil is well documented (refer Table 6). The organochlorines are strongly adsorbed onto soil particles, and this property combined with their extremely low water solubility renders them practically immobile in soil. Although they have low vapour pressures, volatilisation accounts for major losses from surface application. Vapour loss decreases sharply where pesticides are incorporated into the soil (rather than applied to the surface).

Table 6. Persistence of organochlorine insecticides in soil: applied at about 1 lb/acre (1.1 kg/ha). (Edwards, 1973)*.

INSECTICIDE	HALF-LIFE YEARS	95% DISAPPEARANCE YEARS
Aldrin**	0.3	3
Isobenzan	0.4	4
Heptachlor	0.8	3.5
Chlordane	1.0	4
Lindane	1.2	6.5
Endrin	2.2	7
Dieldrin	2.5	8
DDT	2.8	10

* cited Brown, 1980
** but much of the disappeared aldrin persists as dieldrin

Nash and Woolson (1967) reported that 16% of an original heptachlor application was detected in soil 14 years after treatment. In later laboratory experiments wherein soils were artificially incubated, 16 pesticides were ranked according to their rate of degradation in soil (Laskowski et al., 1985). Malathion (the least persistent) was 50% degraded in a day, chlorpyrifos in 60 days and heptachlor in 2000 days. Only DDT (3800d) and endrin (4300d) were more persistent than heptachlor under those conditions. In more recent laboratory studies on disappearance rates, Chapman and Chapman (1987) found that soil type influenced the relative importance of degradation and volatilisation. (It is generally accepted that the content of organic matter in soil is one of the major factors influencing the persistence of pesticides).

However the importance of field trials in establishing environmental behaviour of pesticides is underlined by the discovery of phenomena such as enhanced degradation (see section B2.2).

The organophosphates are generally more soluble and have higher vapour pressures than the organochlorines, so they generally degrade more readily in soil. The half-life of chlorpyrifos in soil has been estimated as 80-100 days (Hartley and Kidd, 1983). By their chemical structures and properties, the organophosphates are susceptible to hydrolysis and oxidation (Eto, 1979). The rate of degradation increases with increased soil moisture, temperature and acidity (see Kaufman, 1981). Kearney et al. (1969) generally confirmed that organophosphates are less persistent in soils than some organochlorines, and that with some exceptions they dissipate within a few weeks of application.

Partition coefficients are, however, comparable with those reported for the organochlorines, indicating a strong propensity to accumulate in fat tissue.

The role of plants in insecticide distribution and metabolism has not been extensively investigated, although internal transport of systemic insecticides is clearly important in pest control. Under open-air conditions, the uptake of cyclodiene residues by plants is thought to be minimal. However Lichtenstein and coworkers (Lichtenstein et al., 1964; Lichtenstein and Schultz, 1965) have observed the translocation of organochlorines from soil to a variety of plants, and have recorded the epoxidation of heptachlor by plant tissue (Lichtenstein, 1959; Lichtenstein and Schultz, 1960).

The uptake of heptachlor and/or its epoxide by different plant species and even varieties is variable (see Table 7) but it has been demonstrated that these substances are translocated through the plant, even to the seeds of corn and soybeans (see Nash, 1981). The organophosphates, a more water-soluble group, are readily absorbed by, and translocated in, plants growing where these substances have been applied to the soil. *In vitro* studies with plant enzymes offer information on possible metabolic reactions, but in common with such studies on animal tissues, caution is indicated by the fact that intact organisms, functioning as part of a 'natural' ecosystem may function quite differently. Nevertheless, the importance of plant enzymes for the degradation of environmental xenobiotics is foreshadowed by studies on heptachlor (Weisgerber et al., 1974) and other cyclodienes (Weisgerber et al., 1975).

Goh et al. (1986a, b) were prompted to examine the dissipation of foliar residues of chlorpyrifos and dichlorvos by an alleged poisoning case involving children playing on a lawn which had been treated with those substances. They found that under autumn conditions (in California), and with adherence to recommended procedures, the residues in a lawn had dissipated to safe levels after 2 hours. However, they recommended that further investigation was required into safe levels for simultaneous exposure to more than one toxicant, and for repeated exposure to toxicants. Volatilisation of heptachlor from vegetation has also been examined (Taylor et al., 1977).

(b) Invertebrates

Organochlorines have been widely used for soil applications against wireworms, rootworms and root maggots. However they also reduce non-target Collembola and predaceous mites (Edwards 1965, 1969), predaceous carabid beetles (Davis, 1968; Hoffman et al., 1949), and ants (Hoffman et al., 1949; Brett and Rhoades, 1946). Heptachlor when employed for fire ant control at 1.25 lb/a caused a 70% population crash in a valuable predator, the carabine beetle *Calosoma calidum* (Rhoades 1962, 1963).

Organochlorines (Edwards et al., 1967b) and organophosphates (Edwards et al., 1968) have suppressed centipede populations, and a range of other soil invertebrates. In addition, such pesticides may kill arboreal spiders (Mansow, 1987).

Table 7. Pesticides in soil and movement into plants (Finlayson & MacCarthy, 1973).

PESTICIDE	(kg/ha)	CROP PERIODS AFTER FINAL APPLICATION	CROP	RESIDUE	AMOUNT (ppm)	REFERENCE
aldrin	28.0	5	cucumber	dieldrin	0.116	Lichtenstein et al. (1965b)
	5.0x2	3	carrot	aldrin/dieldrin	0.2	Bro-Rasmussen et al. (1966)
	5.6	3	soybean	aldrin/dieldrin	0.044	Bruce and Decker (1966)
	1.12x2	1	alfalfa	dieldrin	0.015	Moubry et al (1967)
	22.4	3	pumpkin	dieldrin	0.112	Bruce et al (1967)
	8.4	3	sugarbeet	aldrin/dieldrin	0.03	Onsager et al. (1970)
chlordane	11.2	3		chlordane	0.12	
DDT	15.0	3		DDT	0.5	Popov and Donev (1970)
	16.8	3		DDE:o.p-;p.p-DDT	0.11	Onsager et al. (1970)
	(old orchard to 1959)	9	alfalfa	DDE	0.017	Butler et al. (1970)
				o.p-DDT	0.030	
				p.p-DDT	0.054	
dieldrin	9.4	3	bean	dieldrin	0.5	Popov and Donev (1970)
heptachlor	5.6	3	soybean	hept/epoxide	0.038	Bruce and Decker (1966)
	22.4	3	pumpkin	hept/epoxide	0.036	Bruce et al. (1967)
	6.6	current	rutabaga	heptachlor	0.040	Saha and Stewart (1967)
				hept/expoxide	0.012	
				-chlordane	0.008	
	1.12	3	alfalfa	hept/epoxide	0.111	Moubry et al. (1967)
	28.0	10	carrot	hept/epoxide	0.223	Lichtenstein et al. (1970)
			radish		0.130	
			cucumber		0.068	
lindane	2.8	3	maize	lindane	0.6	Popov and Donev (1970)
methanear-senate	9.0x4	current	cottonseed	arsenic	5.2	Johnson and Hiltbold (1969)
			soybean		4.5	
			sorghum		3.3	
			corn		2.4	
organochlorines	several	1	sugarbeet	dieldrin	0.07	Harris and Sans (1969b)
			carrots		0.4	
picloram	1.12	1	grass	picloram	12.0	Getzendaner et al. (1969)

Organophosphates have also reduced Carabid populations (Edwards et al., 1967), but not in all cases (Griffiths et al., 1967). In a recent investigation Baker (1986) found that isofenphos and chlorpyrifos were comparably effective in controlling scarabid beetle pests under artificial conditions, but acknowledged that insecticide performance in the field may be influenced by other factors. In both greenhouse and field tests Riley (1986) found that isofenphos gave consistently good control of the sugarcane beetle, whereas the effectiveness of chlorpyrifos was more variable. Isofenphos has also been suggested as a promising insecticide for the control of stem borer in tobacco crops (Prasad, 1985), and together with chlorpyrifos, has reduced the thrip population in onion crops (Mayer et al., 1987).

In addition, chlorpyrifos and isofenphos have reduced the damage to potato crops by cutworm (Rajendran, 1986), and chlorpyrifos has been effective against false wireworm on tobacco plants (Eulitz, 1986).

Heptachlor has reduced earthworm populations by 25% when applied to cropland at 1.25 lb/a (1.39 kg/ha) for fire ant control (Rhoades, 1962, 1963). Given the large volumes of earth which are annually processed through the guts of earthworms, it is not surprising that if they survive pesticide applications, they accumulate large concentrations of residues in their tissues. A long term (11 years) study of organochlorine persistence (Beyer and Gish, 1980) found that on average there was 10 times more heptachlor epoxide in earthworms than in the soil they inhabited (dry weight basis). The average time for initial residues of heptachlor epoxide to be reduced by 50% was 3.2 years for soil and 3.0 years for earthworms. These workers commented that when heptachlor was applied at rates as low as 2.2 kg/ha, heptachlor epoxide levels in earthworms reached concentrations potentially hazardous to woodcock. By contrast, chlorpyrifos seems to be less damaging to earthworm populations, even when applied at high rates (Whitney, 1967), and there is little evidence that earthworms concentrate organophosphates in their tissues (Edwards and Thompson, 1973).

2.2 THE VERTEBRATES

(a) Introduction

With respect to the effects of biocides on vertebrate wildlife, most attention has been focussed on birds and mammals, with few references to amphibians and reptiles. Given the dependence of most frogs on water, and the physiological vulnerability of their eggs and tadpoles, it could be expected that biocide contamination of aquatic ecosystems might have both direct and indirect adverse effects on such fauna. Similarly, tortoises may be at risk as a result of long-term cumulative effects when the organisms which constitute their diet are exposed to persistent pesticides.

(b) Birds

The responses of birds to pesticide exposure have been well documented. Table 8 describes the acute toxicity of selected pesticides to some avian species. Of special concern have been the raptors, which are at particular risk because of their position in the food chain. However, toxicity by direct uptake of treated grain, and even of granular formulations of pesticide (McEwen and Stephenson, 1979; Keeling, 1984) has been recorded.

The cyclodiene biocides including heptachlor, are acutely toxic to birds (see Table 8). The practice of coating seed with aldrin, dieldrin and heptachlor (for bulb fly protection) in England resulted in extensive kills of birds feeding on the seeds. In 1961 about 80 incidents of bird mortality were reported, with as many as 500 dead wood pigeons being counted in some roosts (Turtle et al., 1963): pheasants, hawks and owls were also killed. One of the largest incidents involved a 4000 acre estate in Lincolnshire where birds of 18 species were killed, including 5668 wood pigeons, 118 stock doves, 89 pheasants and 59 rooks (Prestt and Ratcliffe, 1970). Feeding experiments confirmed that the cyclodiene seed-dressings were responsible (Turtle et al., 1963), and gave calculated an LD_{50} (pigeon) of 167 mg/kg for heptachlor. In 1962 the use of aldrin, dieldrin and heptachlor for seed-dressing ceased in Britain. Experience in the Netherlands confirmed the secondary poisoning of predator birds; corpses of buzzards and long-eared owls (predaceous on the wood pigeon) and of the European sparrow hawk (predaceous on finches) were found along with the dead wood pigeons after sowing of dressed wheat seed (Fuchs, 1967). However, recovery from the seed-dressing kills in England was very rapid; a wood pigeon population in East Anglia which had suffered a 20% reduction in 1961 recovered to a normal level in the following year when dressings were suspended (Murton and Vizoso, 1963). In the USA, the inauguration in 1957 of a campaign to eradicate the imported fire ant with heptachlor at 2 lb/a (2.2 kg/ha) led to extensive bird kills. On four farms in Louisiana, 222 corpses of 28 different species were found after the treatment (Smith and Glasgow, 1963). In Alabama heptachlor at 2 lb/a (2.2 kg/ha) significantly reduced the songbird population (DeWitt and George, 1960). In 1960 the dosage of heptachlor was adjusted downwards to 0.25 lb/acre (0.28 kg/ha) but there was still a 17% mortality among quail, as compared with 61% with 2 lb/a (2.2 kg/ha) dosage (Kreitzer and Spann, 1968). When woodcocks fed on earthworms containing 3 ppm heptachlor, half of them were killed in 38 days (Stickel et al., 1965). Woodcock wintering in the South accumulated heptachlor epoxide from worms in treated fields and carried the residues north with them in the spring (Wright, 1965). Heptachlor epoxide was transmitted via the eggs to young hatchlings on the Canadian breeding grounds.

Henny et al., (1983) examined the effects of heptachlor seed treatment for wireworm on local avifauna. They concluded that there was significant transport of the residues up through the food chain and consequent accumulation of heptachlor epoxide in American kestrels. As a result, reduced productivity and adult mortality were recorded in these raptors. (Henny et al., 1983). In a related study in the same region, Blus et al. (1985) found high levels of heptachlor epoxide in eggs of magpies, mallards and pheasants, and diagnostically lethal (heptachlor epoxide) residue levels in the brains of 9 birds (4 species). Most of the avifauna in the area contained residues of heptachlor epoxide and related compounds. Blus and coworkers (1984) also showed that heptachlor exposure had reduced reproductive success, and caused adult mortality and population decline in Canada geese.

In a comparison of the chronic toxicities of 31 insecticides to bobwhite quail (Heath et al., 1972) heptachlor was the fourth most toxic, exceeded only by endrin, aldrin, and dieldrin. Bacher (1967) observed that exposure to organochlorines resulted in decreased egg production, depressed egg fertility and sperm production, and high chick mortality in pheasant and

Table 8. Acute toxicity of selected pesticides to some species of birds (McEwen & Stephenson 1979).

	LD_{50} g/kg[a]				LC_{50} ppm[b]			
PESTICIDE	HOUSE SPARROW	COTURNIX	MALLARD	PHEASANT	BOBTAIL QUAIL	COTURNIX	MALLARD	PHEASANT
Aldrin			520	16.8	39	35	160	55
Chlordane			1200		320	325	825	450
DDT		841	2240	1296			1025	500
Dieldrin	47.6	69.7	381	79	39	52	200	52
Endosulfan			33		850	2175	1000	1275
Endrin			5.6	1.8	15	16	21	11
Heptachlor			2000		95	88	575	262
Methoxychlor			2000		5000	5000	5000	5000
Toxaphene			70.7	40		625		525
Temephos	50.1	270	90	31.5	100	250	1500	160
Azinphosmethyl			136	75	450	650	1950	1900
Chlorpyrifos	21	17	75	13		282		
Diazinon			3.5	4.3				
Dimethoate			41.7			350	1000	350
Ethion								
Fenitrothion			150					475
Malathion			1485		3500	2150	5000	3500
Parathion	3.4	6.0	2.0	12.4	190	45	262	365
Phosphamidon			3.0		25	105	750	75
Carbaryl		2290	2179	2000	5000	5000	5000	5000
Carbofuran	1.3		0.4	4.2				
Propoxur	12.8	28.3	11.9					
Allethrin			2000					
Rotenone			2000	1414				
Amitrol			2000			5000	5000	5000

Table 8. Acute toxicity of selected pesticides to some species of birds (McEwen & Stephenson 1979) (cont'd).

	LD_{50} g/kg[a]				LC_{50} ppm[b]			
PESTICIDE	HOUSE SPARROW	COTURNIX	MALLARD	PHEASANT	BOBTAIL QUAIL	COTURNIX	MALLARD	PHEASANT
Atrazine			2000		750		5000	5000
Dalapon						5000	5000	5000
Dicamba				740				
Dichlorbenil			2000	1189		5000		1750
Diquat			564			1500	5000	3750
Endothal								
MCPA								
Monuron						5000	5000	4500
Paraquat								
Picloram			2000	2000			5000	5000
Prometone								
Simazine						5000	5000	5000
Trifluralin			2000	2000				
2,4-D		668	1000	472	5000	5000	5000	5000
2,4,5-T(acid)						5000	5000	1775
Copper sulfate			2000	2000				
Dichlone			2000					
Nabatham		2120	2560	707		5000	2400	5000
Benomyl								
Captan					3000	5000	5000	5000
Mercury[c]		668	2262	360		100	45	150

(a) Dosage given orally in a capsule (Tucker and Crabtree, 1970).

(b) ppm in the diet fed to 2 week old chicks for 5 days followed by untreated feed for 3 days (Heath et al. 1970 (cited by Pimentel, 1971); and Stickel, 1965).

(c) Mercury as "ceresan M" (N-(ethylmercuri)-p-toluene sulphonanilide) 3.2% Hg.

quail. Heptachlor epoxide has been detected at low levels in black duck (Anas rubripes) eggs from the Atlantic Flyway (Haseltine et al. 1980), and a survey of starlings from over 100 sites throughout continental USA detected heptachlor epoxide (as well as DDE, PCBs and dieldrin) in more than 50% of the 10-starling pools (Bunck et al., 1987).

When 33 ospreys, found dead or moribund in the eastern USA between 1964-1973, were necropsied, organochlorines were detected in all birds (heptachlor epoxide in 38%), generally at higher concentrations in adults than in immatures. There was also evidence of heavy metal contamination (Wiemeyer et al., 1980). Additionally, there are a considerable number of field studies correlating organochlorine residues with decreasing eggshell thickness (and decreasing population) (see Brown, Ch 9, 1978).

In a 2-year study examining the effects of chlorpyrifos on the reproduction of mallard ducks held in outdoor pond enclosures, Meyers and Gile (1986) found that birds receiving 80 ppm chlorpyrifos in their diet hatched significantly fewer ducklings per successful nest, and that even at lower dosage rates (8 ppm) no ducklings on treatment ponds survived to 7 days. In a related study, the same workers (Gile and Meyers, 1986) found that chlorpyrifos exposure in mallards reduced adult body weight, brain acetylcholinesterase activity, egg production, egg shell thickness, egg weight and day 0 duckling weight.

There appears to be little evidence that birds have developed resistance to insecticides. On the other hand, their migratory and reproductive patterns may compound their susceptibility. It would seem that birds carrying high residues of persistent organochlorine biocides in the adipose tissues may be poisoned by these when stress conditions (eg migration, moulting, reproduction) require the utilisation of this fat reserve: as the fat is metabolised the biocide is released ("lethal mobilisation").

(c) Mammals

Pesticides may be absorbed by mammals through the skin, lungs and gastrointestinal tract. As in other taxa, cumulative pesticides, such as heptachlor, are then stored in fat tissues (Shewchuk, 1981; McNulty, 1984).

Residues of heptachlor epoxide are relatively wide-spread in wildlife but at generally low levels. Nevertheless cyclodiene biocides have caused considerable mortality among non-target wild mammals. Heptachlor granules applied at 2 lb/a (2.2 kg/ha) for fire ant control killed many raccoons and rabbits (Rudd, 1964), opossums and other mammals in farms in Louisiana (Smith and Glasgow, 1963). The use of heptachlor in seed dressings resulted in the death of 1300 foxes in England in 1959/60 (Taylor and Blackmore, 1961). Poisoning of dogs and cats was also reported in association with heptachlor seed-dressing in Britain (Turtle et al., 1963) and in areas of the US where heptachlor was used for fire ant control (Scott et al., 1959; DeWitt and George, 1960). Table 9 indicates the acute toxicities of a number of biocides to the laboratory rat. The LD_{50} of isofenphos for the laboratory rat is given by Worthing (1979) as 28-39 mg/kg.

In Britain, the use of heptachlor and other organochlorines has been implicated in the decline of the otter population: otters, by virtue of their diet and their position in the food web, were thought to have been accumulating harmful residues. However, the recent banning of organochlorines seems to be linked with the reappearance of otters in their former riverside habitats (Scheel and Ross, 1988).

Mouse populations have shown some evidence of both genetic and induced resistance to organochlorines (DDT, endrin) (Pimentel, 1971).

Table 9. Acute oral toxicity of insecticides and other pesticides to the Laboratory Rat, Rattus norvegicus; LD_{50} in mg/kg (after Pimentel, 1971).

Parathion	13	Naled	430
Azinphosmethyl	16	Trichlorfon	500
Endrin	20	2,4,5-T	500
Mexacarbate	20	Carbaryl	560
Monocrotophos	21	Fenitrothion	680
Phosphamidon	28	2,4-D ester	750
Sodium arsenite	30	Lead arsenate	800
Methyl parathion	42	Dicofol	850
DNOC	45	Dalapon	970
Aldrin	50	Pyrethins	1300
Lindane	90	Malathion	1650
Dieldrin	100	Chlorobenzilate	1950
Endosulfan	110	Ovex	2025
Heptachlor	115	Atrazine	3080
Chlorpyrifos	150	Diuron	3400
Toxaphene	160	TDE	3400
Dimethoate	215	Temephos	5000
DDT	250	Methoxychlor	6000
Fenthion	310	Captan	9000
2,4-D	370		

* Note: Since man is often significantly more susceptible to such toxins than rats (Metcalf, 1975), rat LD_{50} values should be extrapolated with caution.

Marine mammals, which are large predators, have the capacity to accumulate high levels of fat-soluble pollutants. Heptachlor residues have been measured in harbour seals and white-beaked dolphins (Kerkhoff et al., 1981) and arctic harp seals (Ronald et al., 1984). The latter authors point to the sub-lethal effects of such residues, which may include lowered reproductive rate through abortion or decreased reproductive success. It was clear that transplacental transfer also occurred.

In the mid sixties, an experiment in the USA revealed that heptachlor was detectable in the milk and fat of dairy cows fed heptachlor (Bruce et al., 1965). In a subsequent feed-off period, heptachlor epoxide residues in body fat declined slowly, with detectable residues present 23 months later in some animals. Later, in Australia fatalities were recorded amongst horses and cattle grazed on heptachlor-treated pasture (Dickson et al., 1983). In northern NSW, cows continuously exposed to heptachlor produced milk fat with residues exceeding the maximum acceptable limit (Gilbert and Lewis, 1982). It had earlier been shown that there was accumulation of heptachlor epoxide in the body fat of sheep grazed on treated land or pasture, even after withholding periods of 5 - 45 weeks (Solly, 1967; Solly et al., 1968) Not surprisingly, Harradine and McDougall (1986) confirmed a similar phenomenon in cattle. They found that when cattle were grazed on land in NSW that had been previously treated with heptachlor prior to planting potatoes or maize, their fat contained heptachlor epoxide residues which exceeded the maximum acceptable limit of 0.2 mg/kg. These levels of contamination were reached in less than one month after exposure, and the half-life of heptachlor epoxide in the body fat of steers was calculated at 11 weeks. Given that the decline of soil residues during the 16 month experimental period was negligible, a finding which those authors acknowledge to be consistent with earlier reports that the half-life of heptachlor in soil is 7-12 years, Harradine and McDougall conclude that the fat of cattle grazed on heptachlor-treated paddocks will exceed the maximum residue limit, even when the grazing occurs 'many years' after treatment.

Several of the organochlorines, including heptachlor, are suspected of human carcinogenicity (Cawcutt and Watson, 1984) and heptachlor has been associated with human leukaemia (Epstein and Ozonoff, 1987). Reuber (1987) recently reviewed all available studies on the carcinogenicity of heptachlor and heptachlor epoxide in animals. He concluded that the organchlorines induced a number of neoplastic conditions, including carcinomas and sarcomas, in rats and mice, and that they cause toxic changes (demonstrated mainly in male rats) which included renal fibrosis, testicular atrophy, cardiac fibrosis and polyarteritis. On the basis of extensive evidence, heptachlor was considered carcinogenic in these mammals. Reuber concludes his review with the recommendation that, since tumour formation is similar amongst mammals, and since virtually every human carcinogen has also been shown to cause cancer in other experimental mammals, substances like heptachlor must be considered a carcinogenic hazard to humans.

Illness after overexposure to heptachlor and other chlorinated hydrocarbon biocides has been reported in those concerned with application, mixing and formulation of these products. There are many cases on record of poisoning by accidental consumption especially with children. Since chlorinated hydrocarbons act on the central nervous system, exposure may cause convulsions and/or coma; in mild cases, nausea and vomiting. Measurable amounts of heptachlor epoxide have been found in mother's milk (Savage et al., 1973; Kodric-Smit et al., 1980); the significance of these low levels is unknown. In 1972, the FAO/WHO recommended an acceptable daily intake (ADI) for heptachlor (-epoxide) of 0.005 mg/kg body weight. In the US, the daily intake between 1965-70 was 0.000014 -0.000028 mg/kg, well within acceptable levels. The Australian recommended maximum residue limits (for heptachlor) in food are given in Table 10.

Table 10. Recommended maximum residue limits in some food crops for heptachlor, including its epoxide (Department of Primary Industry, (1979).

FOOD	MAXIMUM RESIDUE LIMIT (mg/kg)
crude soya bean oil	0.5
fat of meat, carrots	0.2
milk and milk products (fat basis)	0.15
all other vegetables, eggs	0.05
raw cereals, tomatoes, cotton seed, soya beans, edible soya bean oil	0.02
pineapples, citrus fruit	0.01

Chlorpyrifos has been considered the "latest advance in controlling fleas in dogs and cats"; in recent trials in the US, chlorpyrifos incorporated into PVC collars was reported to have provided effective control of fleas for up to 11 months without any significant adverse reactions (Higgins and Jarvis, 1986). However, in another study, office workers were reported to have developed symptoms compatible with organophosphate poisoning after chlorpyrifos exposure. The pattern of recovery in biochemical parameters over the subsequent 3 months suggested that the absorbed chlorpyrifos had been redistributed to a second body compartment with slow release of the still active substance into the bloodstream (Hodgson et al., 1986).

Exposure of a llama to chlorpyrifos was reported as the suspected cause of fatal toxicosis (Pearson et al., 1986). Yet when cattle were fitted with chlorpyrifos-impregnated eartags, Byford et al., (1986) found that tissue levels of chlorpyrifos measured during a 3 month monitoring period were not significantly greater than background levels in control animals. Clearly, dosage rates are very important.

Organochlorines are lipophilic compounds absorbed and stored in body fat, and, as chemically stable substances, may become increasingly concentrated as they pass up through the food web.

D. SYNTHESIS AND CONCLUSIONS

The intrinsic properties of the organochlorines endow them with a potential for environmental damage. The literature affords ample evidence of the persistence of organochlorines in the environment and of their widespread contamination of non-target wildlife. Bioaccumulation and biomagnification of residues occur, particularly amongst the hydrobiota. At high exposure levels, heptachlor and its toxic epoxide cause death across a broad spectrum of animal life by disrupting the function of the nervous system. Non-lethal exposure may cause hepatotoxicity, behavioural anomalies, reproductive failure and neoplasms. There is a strong suggestion of carcinogenicity, but epidemiological studies are insufficient to fully evaluate the carcinogenic hazard of heptachlor for the human species.

Very little research has been undertaken on the physicochemical and biological behaviour of heptachlor and its epoxide under Australian conditions. We know something of its effects on stock grazing contaminated pasture [C 2.2(c)] and of its acute effects on two aquatic species (Davis and Garland, 1986), but insufficient information is available on the toxicity of heptachlor for terrestrial species. It is important that research in this area include investigation of sub-lethal effects, since they may be highly detrimental to the long term stability of populations, communities and ecosystems.

These conclusions point to a need for careful consideration of the use of such chemicals. On the other hand, there are risks in turning quickly to new products. In the past, the time lag between the introduction of individual biocides overseas to Australia has resulted in generally lower rates of application here because we have been able to learn from overseas experience. Foreshortening of this time lag requires care in examining toxicity, persistence and environmental hazards before widespread application of biocides. In many parts of the world, approved uses of heptachlor have been gradually withdrawn over a period of a decade or more. In 1982, the US Department of Agriculture advised: "No chemical control of insects should be undertaken unless the expected benefits outweigh possible hazards to other animals. To minimize damage to fish and wildlife, do not use persistent chlorinated hydrocarbon insecticides when alternative insecticides of lesser hazard are available".

In the USA, registration standards on heptachlor usage as a termiticide note that there may be an oncogenic risk, that exposure may pose a "significant health risk of chronic liver effects to occupants" of treated structures, and that the termiticide use of heptachlor is associated with optic neuritis (Anon. 1987a). The standards also noted that heptachlor was classified as Group B2 (probable human) carcinogen.

More recently, as a result of an agreement between Velsicol (the manufacturer of heptachlor/chlordane) and the US EPA, it is likely that heptachlor (as a termiticide) will be withdrawn from indoor use, that sales of the product will be halted, and that further restrictions will be applied to the use of heptachlor. The agreement does not change the status of export products. The US EPA listed four alternative pesticides for termite control: chlorpyrifos, permethrin, fenvalerate and isofenphos (Anon, 1987b).

In Western Australia, organochlorines have been employed for more than 30 years to combat the Argentine ant problem. The continuing presence of these ants in the Perth region attests to the failure of the eradication programme. It may be that ecological imbalances arising from damage to the populations of predators and competitors of the pest, have actually created favourable conditions for the ants. There is also the possibility of insecticide resistance, since cyclodiene resistence has been recorded in the Argentine ant (Georghiou and Mellon, 1983). The lack of long term quantitative ecological investigations of these phenomena denies us conclusive evidence.

Nevertheless, the Argentine ant is a tenacious and potentially serious pest with the capacity to damage agricultural markets, domestic hygiene and safety, and natural habitats (see Porter, 1982). The design of an appropriate integrated pest management strategy should be based on:

(i) detailed information on the relationships of the Argentine ant to other species (predators, competitors etc);

(ii) detailed information on the seasonal influences of abiotic components of the environment on the behaviour of the Argentine ant;

(iii) investigation of possible biological control agents;

(iv) thorough documentation of acute and sub-lethal toxic effects of any proposed insecticide on the terrestrial and aquatic species which may be exposed. Target-specific insecticides should be selected; and

(v) monitoring the biological effects and ecological impacts of the treatment, including the possible development of resistance.

The new generation synthetic pyrethroids offer the promise of increased potency against insects combined with safety to mammals. They are becoming increasingly important as their favourable combination of properties is recognised more widely and compounds with additional advantages are introduced. Increasingly they are being used in combination with synthetic insect growth regulators which are highly specific in their action on insects and which are also readily decomposed.

Biological control might be expected to be the least ecologically damaging and many recent studies have focussed on the behaviour, and especially the trailing behaviour, of the Argentine ant (Cavill et al., 1979; Briese and MaCauley, 1980; Robertson et al., 1980). Observations have also been made on the recruitment of nestmates to food by Argentine ant workers (Van Vorhis Key and Baker, 1986) and on bait preferences in this species (Baker et al., 1985). Interestingly, sucrose water was so well-liked by Argentine ants that the incorporation of emulsifiers and lethal toxicants into the solution did not deter them from feeding on these baits. Further research on such behaviour may suggest more efficient methods of bait application and formulation. In other species, the use of predators, parasites, disease and sterilisation have been investigated with some success.

Environmental concerns about biocides are neither resolved nor well-defined. Indiscriminate use of biocides, particularly persistent biocides, has the demonstrated potential to disrupt ecological patterns, but time and the dynamics of nature will determine whether in the long term these disruptions are significant. Clearly the nature of the biocide of choice, its formulation, application rate and time of application require close scrutiny.

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APPENDIX 3

Review Paper on the Risks to Human Health Associated with Heptachlor Use

HUMAN HEALTH ASPECTS OF HEPTACHLOR

A discussion paper prepared for

the ENVIRONMENTAL PROTECTION AUTHORITY OF WA

by

ROGER DREW, Ph.D.

March 1988