MOSQUITO INVESTIGATION Nº2.
SHIRE OF WANNEROO

BY ANDREW BLAIR

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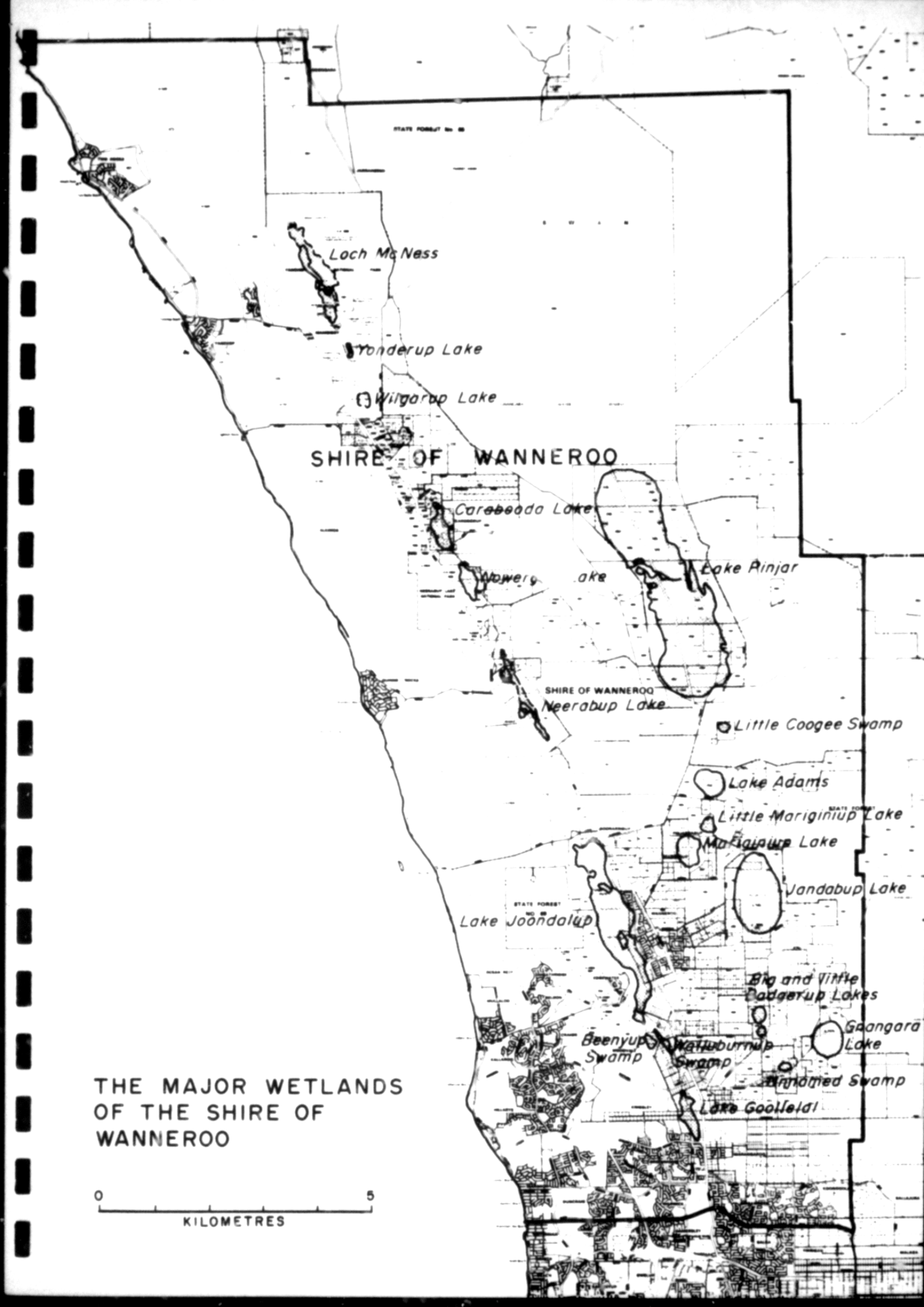
Loch McNess
Yonderup Lake
Wilgarup Lake
SHIRE OF WANNEROO
Carabooda Lake
Lake Pinjar
SHIRE OF WANNEROO
Neerabup Lake
Little Coogee Swamp
Lake Adams
Little Mariginiup Lake
Mariginiup Lake
Jandabup Lake
STATE FOREST
Lake Joondalup
Big and Little Caddenup Lakes
Gnangara Lake
Beenyup Swamp
Wanneroo Swamp
Unnamed Swamp
Lake Goollelal
THE MAJOR WETLANDS OF THE SHIRE OF WANNEROO
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KILOMETRES

DEPARTMENT OF CONSERVATION AND ENVIRONMENT

MOSQUITO INVESTIGATION NO. 2

Shire of Wanneroo

by

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DEPARTMENT OF CONSERVATION
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PERTH 1978

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MOSQUITO SPECIES	IMPORTANCE AS PESTS Present (rank order)	IMPORTANCE AS PESTS Potential (relative)	BREEDING HABITAT - LOCATION OF LARVAE AND PUPAE	ACTIVITY PERIODS (BITING TIMES)	FACTORS PREVENTING ACTIVITY	CONTROL MEASURES SECTION 9.1.2	CHEMICAL CONTROL MEASURES SECTION 9.1.3	REMARKS
Coquillettidia linealis	1 (highest)	High (see §8.1)	Unknown. Suggestion (§3.3 and 8.1) is that breeding is associated with Bulrushes.	Maximum biting intensity - 15 mins after sunset, but biting may occur all night at lower intensity; crepuscular[1] activity.	Wind speed 10 km per hour or greater. Rain. Sunlight - dry heat.	Unusual larval behaviour (§3.3) means that larvicidal fish[2] will be of little control benefit.	Adulticides[3] applied during twilight period.	Control of larvae is impossible while the breeding habitat is unknown. A particularly vicious mosquito, attacking in swarms, biting legs and arms, (§3.3 and 5.6.1) enters residential areas but not houses. Caution - Avoid extension of Bulrush distribution.
Culex fatigans	2	High (§8.1)	Any shallow, fresh water pools, fouled or otherwise, without larvicidal fish[2]. Specifically - cattle-trampled lake fringes, road drains and domestic waters.	Generally crepuscular[1], may bite during day in cool, shady places.	Wind speed 10 km per hour or greater. Rain. Sunlight - dry heat.	Larvicidal fish[2]. Prevent cattle entering swamp and lake fringe areas. Prevention of surface standing domestic water, (cover wells and drains, etc.)	Larvicides[4] applied directly to breeding habitats. Adulticides[3] applied during maximum activity periods.	Described as a domestic mosquito. Breeds in association with man. Readily enters dwellings. Attacks more as an individual than as a swarm (may be due to low numbers). Biting not as vicious or as persistent as other species. (§3.1.1 and 5.6.3) Caution - Prevent standing domestic water, cover wells, etc.
Culex annulirostris	3	Highest (§8.1)	Any shallow, fresh water pools (maybe fouled) usually vegetated without larvicidal fish[2].	May bite at any time of day near daytime resting places. Moves out and bites elsewhere during twilight and night.	Wind speed 10 km per hour or greater. Rain. Avoids direct sunlight, but may be active in shady places.	Larvicidal fish[2]. Prevent cattle entering swamp and lake fringe areas. Prevent other degradation of wetland sedge and Bulrush vegetation.	Larvicides[4] applied directly to breeding habitats. Adulticides[3] applied during maximum activity periods.	A vicious mosquito. Attacks in swarms. Potential importance as a pest is very high as it will bite during the day - its activity is not restricted to evening periods. Its potential to become a pest is likely to increase with increased distvrbance of wetland vegetation. (§3.2 and 5.6.2) Caution - Prevent disturbance of swamp and lake fringe areas.
Anopheles annulipes	4 (lowest)	Low (§8.1)	Shallow, fresh water, well vegetated, generally shaded pools, without fish. Sometimes fouled water (cattle-disturbed areas).	After sunset.	Wind speed 10 km per hour or greater. Rain. Sunlight - dry heat.	Larvicidal fish[2]. Prevent cattle entering swamp and lake fringe areas.	Larvicides[4] applied directly to breeding habitats. Adulticides[3] applied during maximum activity periods.	Feeds extensively on cattle, rabbits and other animals; this decreases its status as a pest to man. (§3.5 and 8.1)
Culex australicus	None	None	Any shallow, usually vegetated fresh water pools, without larvicidal fish[2]. Cattle-trampled lake fringe areas.	After sunset.				This is a bird-biting mosquito species. (see §3.1.2 and 8.1 of text)
Culiseta atra	None	None	Not found.					(see §3.4 and 8.1 of text)

[1] Crepuscular means appearing or active in the twilight period.
[2] Larvicidal fish are fish which feed upon mosquito larvae.
[3] Adulticides are chemicals which kill adult mosquitoes.
[4] Larvicides are chemicals which kill the larval and pupal stages of mosquitoes.

SUMMARY

A research programme was jointly sponsored by the Shire of Wanneroo and the Department of Conservation and Environment during the summer of 1977 - 1978 to obtain objective information about the extent of mosquito breeding and nuisance to residents in order to assess the need for control measures.

The research programme undertaken had two parts :

The first part was a qualitative study of Lake Joondalup, Lake Goollelal and Beenyup and Walluburnup Swamps to identify the mosquitoes occurring in the area, to locate their breeding sites and to determine whether breeding sites could be related to specific features of vegetation in the wetlands. This part of the programme is reported in Chapters 2, 3 and 4.

Six species of mosquitoes were found to occur in the area. Three species bite humans and are potential pests. They are *Culex fatigans*, *Culex annulirostris* and *Mansonia (Coquillettidia) linealis*. *Anopheles annulipes* occurs but, although it occasionally bites humans, it is known to feed mainly on other mammals. *Culiseta attra* is not considered to be of great importance. *Culex australicus* is not a man-biting mosquito.

The study area was surveyed to detect identifiable areas which could be related to specific mosquito breeding sites. The study area was divided into 15 'Type Areas' on the basis of vegetation and other features. These areas are described, illustrated and mapped for ease of future location.

The major breeding sites were restricted to swampy fringe areas located on the eastern margins of both lakes. Mosquito breeding appears to be potentially possible in any pockets of water in which larvicidal fish are not present. Mosquito breeding may occur in dense stands of Bulrush and sedge which have been disturbed and trampled by stock and which contain exposed pools of fouled water. Fence-post holes, holes created by fallen trees, ditches and road drains are potential breeding sites. However, dense, undisturbed stands of Bulrush and sedge do not provide a breeding habitat. The larval stages of *Coquillettidia* have never been found either here or elsewhere and thus breeding sites could not be identified. Considerable effort failed to locate the larvae of this species associated with commonly occurring swamp plants.

The second part of the investigation set out to obtain quantitative data about the occurrence of adult mosquitoes in the study area by means of three different trapping programmes.

1. The distribution and relative abundance of the species of mosquitoes captured in guinea pig-baited traps set repeatedly at eight established sites on the perimeter of the wetlands of the study area.

2. Determination of human-biting species and the specification of critical periods of biting activity, by means of the investigator providing human bait.

3. Surveys of residential areas by issuing vials and requesting residents to capture mosquitoes which bit them.

These investigations are reported in Chapters 5, 6 and 7.

Four species of mosquitoes were captured in animal-baited traps. *Culex annulirostris* (35 per cent of total catch) and *Coquillettidia* (32 per cent of total catch) were captured with the greatest frequency; *Culex fatigans* represented 24 per cent of the total catch and *Culiseta* 9 per cent. *Coquillettidia* was the most widespread species, being captured at all eight trap sites. It was trapped in greatest numbers at the east and north-east of Lake Joondalup. *Culex annulirostris* occurred with the greatest frequency at the northern end of Lake Joondalup and its occurrence was related to the location of a breeding site in swampland to the north of Lake Joondalup. *Culex fatigans*, known to be a domestic mosquito, was closely associated with residential development. The occurrence of *Culiseta attra* was transitory on the east side of Lake Goollelal for the most part.

Surveys using human bait showed that *Coquillettidia*, *Culex fatigans* and *Anopheles annulipes* do not bite during the day. *Culex annulirostris* would bite viciously during the day within the confines of its day-time resting places. *Coquillettidia* showed no biting activity until about 10 minutes after sunset, a maximum biting rate was reached within 15 - 20 minutes after sunset and biting activity was limited largely to a period of about 50 minutes after sunset.

Information gained by distributing vials to residents, asking them to capture pest mosquitoes and to hand in the vials the following day, showed that three species of mosquitoes were to be found in the residential areas, *Coquillettidia*, *Culex fatigans* and *Anopheles*. *Coquillettidia* was the major pest species and made up 74 per cent of the mosquitoes caught. *Culex fatigans* represented 23 per cent of the mosquitoes caught and *Anopheles* 3 per cent.

Of 113 residents questioned, 10 per cent thought that there was a real mosquito problem, 42 per cent thought there was something of a problem and 48 per cent thought there was no problem at all.

The last sections of the report (Chapters 8, 9 and 10) deal with an overview of the mosquito situation in the study area, a discussion of control measures and recommendations to the Shire of Wanneroo.

With regard to control of the aquatic larval and pupal stages, the most important measures relate to elimination of breeding sites by preventing incursions of stock into swamp lands and lake fringe areas and the prevention of dumping waste on swampland. The drawbacks of chemical control of larvae and pupae are discussed.

Control of adult mosquitoes can be achieved by means of chemicals. The use of Dibrom 14 for this purpose is discussed with reference to methods and rates of application, and application strategy.

Recommendations to the Shire of Wanneroo are, in summary :

1. Larval control by elimination of breeding sites should be undertaken. Such measures will require the co-operation of landowners and others with access to wetland fringes.

2. Efforts should be made to find the breeding sites of *Coquillettidia linealis*.

3. Surveys of known mosquito breeding sites should be carried out in spring and early summer to monitor the build-up of pest species.

4. An ongoing trapping programme using animal-baited traps should be undertaken with traps located at key areas. Such a programme will enable Health Department staff to be aware of potential pest problems.

5. Residents should be informed of the patterns of biting of pest species of mosquitoes so that they can avoid peak biting times for their outdoor activities.

6. Before large scale control measures are undertaken the extent of the mosquito problem should be evaluated and opinions of residents should be elicited.

7. Should chemical control measures be instituted the application strategy outlined in this report (9.2.1.) is recommended for initial control. This strategy can be modified in the light of the effectiveness of the control measure as determined by ongoing monitoring programmes.

Appendices are included in which methods of maintaining larval, pupal and adult mosquitoes in the laboratory are described and specifications are given for the construction of a chicken-baited mosquito trap.

ACKNOWLEDGEMENTS

The help offered by Mr Ray West, Senior Health Surveyor with the Shire of Wanneroo, is acknowledged with gratitude.

Thanks are also extended to the Zoology Department of the University of Western Australia, for making available a microscope and the facilities of a constant-temperature room.

PART I : CHAPTERS 2, 3 and 4

DESCRIPTION OF STUDY AREA, IDENTIFICATION OF MOSQUITO SPECIES AND RECOGNITION OF HABITAT TYPES.

1. INTRODUCTION

This report represents the findings of a research programme jointly sponsored by the Department of Conservation and Environment and the Shire of Wanneroo.

Within the Shire there are many wetland areas and, with the growth of the Shire, high density residential blocks are currently being developed close to two such wetlands, namely Lakes Joondalup and Goollelal.

These wetlands were recognised as mosquito breeding sites. It is the Shire's concern that mosquito breeding may cause a high nuisance level within residential areas, and that chemical mosquito control measures may be required.

In the event that such control measures are necessary it is vital, for efficiency and effectiveness, to have some knowledge of the mosquito situation within the area. This research programme was therefore undertaken to :

(1) Identify the species of mosquitoes occurring in the area and determine those species likely to cause nuisance.

(2) Locate breeding sites and habitats of mosquito species.

(3) Gather information on the biology of the pest species.

(4) Develop a mosquito control programme and a means of monitoring the effectiveness of such a programme.

Investigations were carried out within the study area constituted by Lakes Joondalup and Goollelal, their associated fringing wetlands and the extensive swamplands lying between the two lakes.

With time permitting, field studies were to be extended to other wetlands in the Shire of Wanneroo in order to determine the extent of mosquito-breeding areas.

In addition, an existing key to the mosquito species of the Perth region was reviewed and modified with the aim of producing a readily accessibly guide to local species, for general distribution. This key is to be issued as a separate document. (Department of Conservation and Environment, Bulletin No. 42).

Finally, an extension of the research period allowed some time for investigation into the efficiency of the chemical insecticide Dibrom 14, used in mosquito control as an ultra low volume (ULV) aerosol spray.

2. DESCRIPTION OF STUDY AREAS

With regard to mosquito breeding sites, vegetation and topography within the study area are important variables that play a role in determining the extent of breeding. It is for this reason that a detailed description of the study area is given as a prelude to the discussion on mosquitoes.

The vegetation of Lake Joondalup has been previously described by Congdon and McComb (1976). Their work provides a basis for identification and description of the area, to which personal observations have been added.

Descriptions of Lake Goollelal, Beenyup and Walluburnup swamps are based on personal observation alone.

2.1 Lake Joondalup (See Map 1)

Lake Joondalup is a shallow closed body of fresh water 8 km long and 1.2 km wide at its broadest point. The depth varies seasonally but according to M.W.B.* records has never exceed 3.3 m.

The lake is situated 6 km from the ocean and its water surface is some 18 m above mean sea level.

It is approximately 6.1 sq km (610 hectares) in area and is described as being situated in a calcareous stable dune system. There is no surface outlet for the lake.

The western bank of Lake Joondalup is relatively steep, the land rising quickly from the water's edge. Although some of the western slopes have been used for the grazing of agricultural animals, much of the land is virgin bush and there has been minimal disturbance of the fringing zone of the lake.

The south-western bank has seen the development of the residential area of Edgewater (but this is set back from the lake's edge), while the mid-west bank is the site of the newly formed, Joondalup Development Corporation's building programme. There are no inhabited dwellings in the area.

Six large subdivisions (market garden-size plots, with residences) span the width of the northern edge of the lake. The land here rises less steeply than on the western edge, but the slope is still relatively steep. The vegetation fringe of the lake has been little disturbed in this area.

The eastern bank slopes away from the lake more gently and has been the site of much interference by man, initially with market gardens and farms and subsequently with the development of residential areas.

* M.W.B. = Metropolitan Water Supply, Sewerage & Drainage Board.

At some earlier date of man's association with Lake Joondalup, the water level was lower than it presently has been, consequently market gardens were cultivated on land that is today submerged. This is evidenced by the appearance of partially, and fully submerged fence lines situated in the lake. In some areas on the eastern bank, drainage ditches mark the extent of the market gardens.

Most of this interference has been centred on the lower two-thirds of the eastern bank (i.e. more southerly areas). Parts of the north-eastern shore have seen the construction of levee banks, presumably to prevent the flooding of potentially arable land. One steeper sided section of the north-eastern shore remains as virgin bush.

Congdon and McComb (1976) recognised six vegetation associations at Lake Joondalup. These are :

1. Open Water
2. Sedge Communities
3. Bulrush Communities
4. Paperbark Forest
5. Eucalyptus Forest
6. Acacia Woodland.

Only the first four of these associations are of particular relevance to mosquito breeding (see Map 1.) These are discussed below under the following headings :

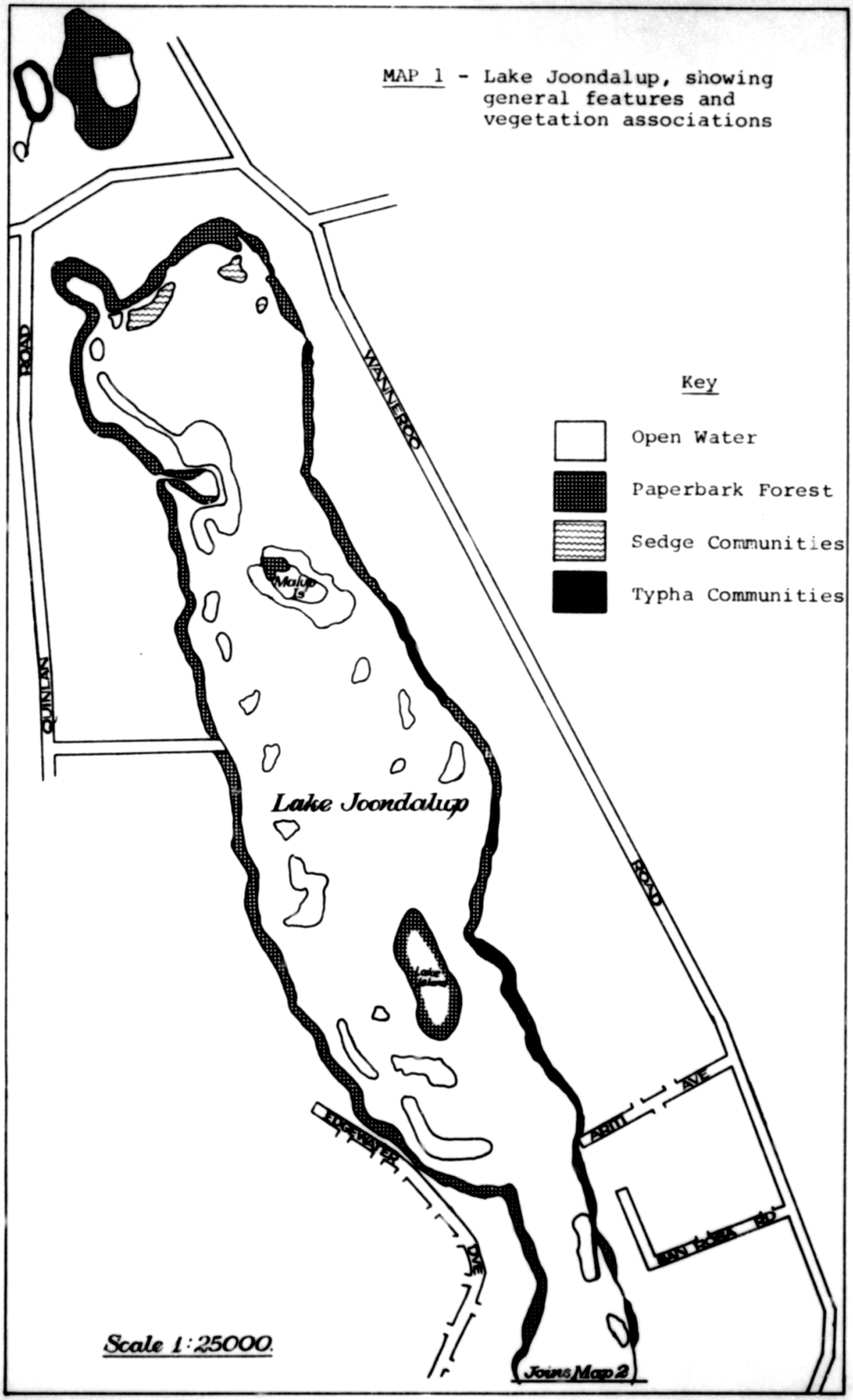
1. Shallow Open Water and Littoral Fringes, incorporating (1), (2) and (3) above, and

2. Paperbark Woodland.

1. Shallow Open Water and Littoral Fringes. The shallow waters of the lake have dense areas of submerged Stoneworts (*Nitella congesta, Chara baueri*) and Pondweed (*Potomogeton pectinalis*). *Najas marina* and Milfoil (*Myriophyllum*) are also found in tne shallow waters but are more common in the deeper waters at the northern end of the lake. The floating plants Duckweed, (*Lemna minor*) and *Azolla* are found in fringing sedge communities and isolated pools.

The waters of the lake are fringed with sedges and Bulrush. The sedge *Baumea articulata* (which may also be referred to as *Machaerina articulata* or *Cladium articulatum*) is the dominant fringe plant (see Figs. 1 and 2). It attains a height of 1 to 2 metres and, through decomposition, is the main contributor to fibrous peat on the lake margins and sedge banks. On the western and north-eastern margins of the lake *Baumea* occurs in dense, pure stands, creating a fringing sedge zone. It fringes the two islands within the lake, and occurs as dense stands situated on mud banks.

Where the margins of the lake have been disturbed by use for agricultural purposes (grazing or cropping),


MAP 1 - Lake Joondalup, showing general features and vegetation associations
Key
Open Water
Paperbark Forest
Sedge Communities
Typha Communities
QUINLAN ROAD
WANNEROO ROAD
Lake Joondalup
ASHLEY AVE
EDGEWATER DR
Scale 1:25000.
Joins Map 2

for road or pipeline construction, or simply for access to the water's edge, *Baumea* is replaced by the Bulrush *Typha domingensis*. *Typha* may occur in pure dense stands, mainly restricted to the lower south-eastern margins of the lake, or it may be found in pure sparse stands, or it is seen growing as a mixed stand with *Baumea*. (See Figs. 5 and 6).

2. Paperbark Woodland - A woodland of Swamp Paperbark (*Melaleuca rhaphiophylla*) borders the fringing sedge communities, and is mainly restricted to the west and north-eastern banks of the lake. The Paperbark Woodland is restricted to a narrow zone between the high water mark of winter and the low water level of summer. This woodland often includes *Eucalyptus rudis*.

Just above high water mark a transitional community can be recognised between the Paperbark Woodland and the surrounding Eucalypt forest. It consists of a number of species which occur in both communities.

The topography of the lake and its surroundings, as described above, restrict the distribution of low-lying fringing swamp (i.e. shallow pools of water separated from the main body of the lake, or water-logged ground) to the eastern border.

The western margin of Lake Joondalup has more distinct, well-defined edges, sandy soils run down into the water, and there are no extensive swampy areas.

2.2 Lake Goollelal (see Map 2)

Lake Goollelal is situated 3 km south of Joondalup, with a maximum length of 1.65 km, average width of 0.5 km and surface area of 0.58 sq km (58 hectares).

The western bank of Lake Goollelal, like that of Joondalup, rises relatively steeply from the water's edge. However, its eastern bank is not as low-lying as that of Lake Joondalup and hence there are no extensive marsh and swamp fringes associated with the eastern bank.

The lake fringes have seen much interference by man and most of the fringing vegetation has been disrupted by market gardening on the east bank and northern parts of the west bank. Vegetation on the south-west of the lake, where there is a low-density residential area, and on the northern margin, remains relatively undisturbed. Vineyards have been established on the north-eastern slopes of the lake surrounds. They do not however, run close to the lake and have not encroached on the fringing vegetation

Water for industrial and agricultural purposes is withdrawn from the lake in various places.

Goollelal is deeper than Lake Joondalup and the build-up of ligno-peat, deposited through decomposition of aquatic flora, is nowhere near as extensive as in the more northerly lake. Lake Goollelal has sandy edges and bottom, with only small zones of rotting peat material. Thus the water is clearer than in Lake Joondalup.

The vegetation associations of the lake area have been extensively altered by man's presence. Nearly the whole of the eastern bank, through the influence of agriculture, has been dominated by the Bulrush *Typha*. There is no zone of Paperbark Woodland on this bank.

Typha is also found on the north-western fringe where the market gardens were established, and it is encroaching on the southern and northern reaches of the lake.

The natural sedge *Baumea* is found on the south-western bank and northern margin but these land stands are now being infiltrated by the Bulrush. In these areas there is also a fragmented zone of Paperbark Woodland (*Melaleuca rhaphiophylla*). Casuarinas are also found amongst this woodland.

There are extensive sedge banks (dominated by *Baumea*) in the middle of the Lake.

The introduced alien noxious waterweed *Eichhornia crassipes* (Water Hyacinth) is established within the lake. The most extensive meadows of this undesirable plant are located at the southern edge of the lake but small areas are being established throughout. The Agricultural Protection Board (APB) is spraying the lake with the herbicide Diquat in an attempt to control the spread of Water Hyacinth and prevent it from choking the whole of the lake.

Lake Goollelal drains into Lake Joondalup (via Walluburnup and Beenyup swamps) through an open stream leaving its northern bank and entering Lake Joondalup at its most southern extension.

2.3 Beenyup and Walluburnup Swamps (see Map 2)

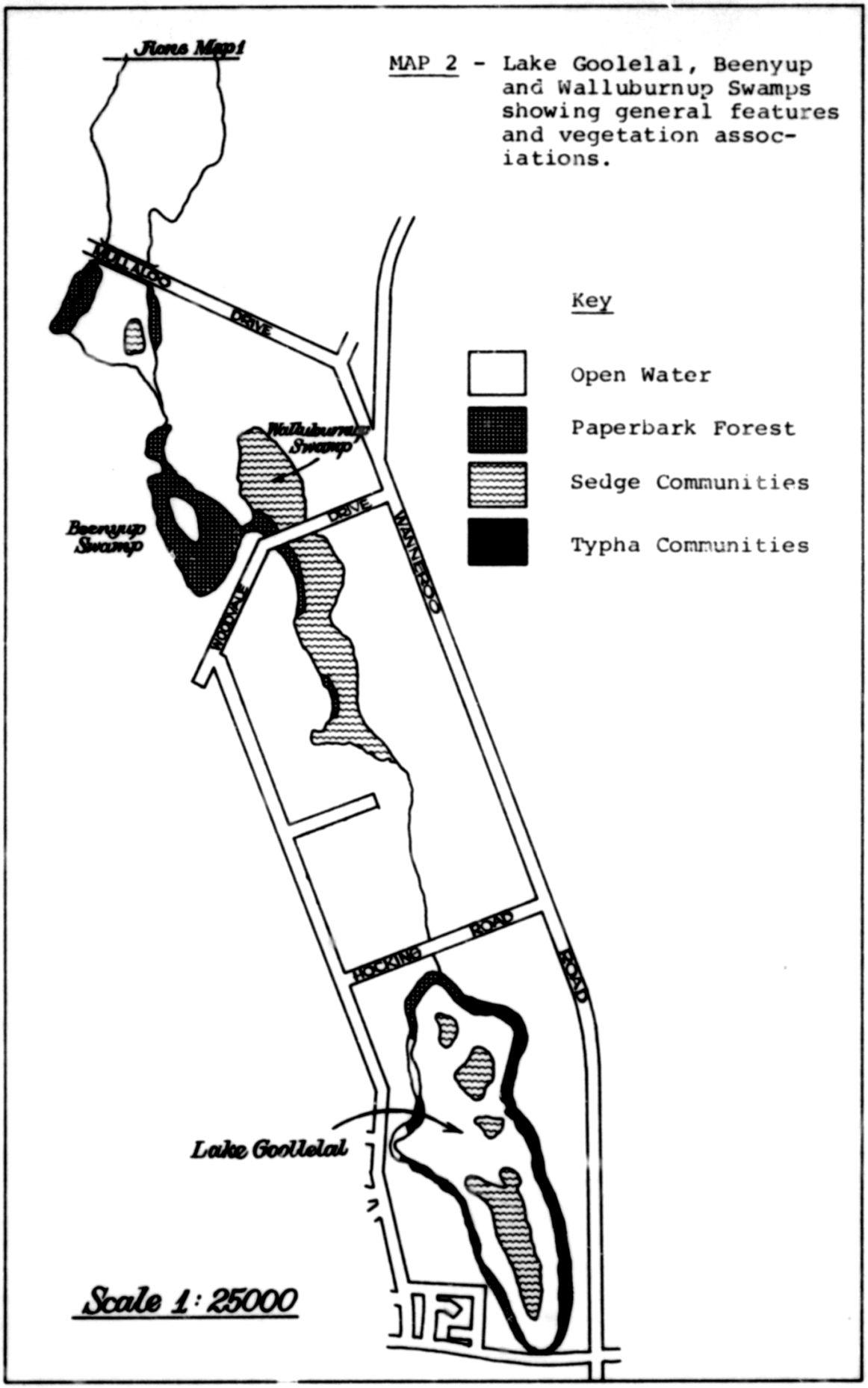
Lying in the same north-south depression, between Lake Goollelal in the south and Joondalup to the north is a tongue of swampland which forms the drainage between the two lakes.

Beenyup swamp, although appearing on the map as such, is more aptly described as a semi-permanent lake. The swamp has a central area of open water surrounded by a variously wide zone of dense paperbark woodland.

Dense stands of *Typha* fringe the open water. Sparse stands (often individual plants) of *Baumea* and *Typha* and various grasses grow within the Paperbark Woodland.

The swamp is contained within a definite basin and is surrounded by agricultural pasture, on which horses and cattle graze. In winter the whole of the swamp is inundated, right to the edge of the basin. During summer, the water extending under the woodland fringes dries, leaving only a small amount of water in the centre of the swamp.

Walluburnup swamp is a true sedge swamp in that the ground is saturated for most of the year and shallow surface water is present after winter, (only drying towards the middle of summer). It is an extensive sedge area, dominated by *Baumea* but containing other sedge species, and is now being infiltrated by *Typha* and introduced grasses and weeds. Within the swamp, usually growing beside the drainage stream, are small Paperbarks. Due to the tall growth of the vegetation the northern parts of the swamp area are virtually impossible to traverse. The drier southern end however has been given over to agriculture, where cattle and horses graze within the boundaries of fenced paddocks in which the natural vegetation is all but gone.



MAP 2 - Lake Goolelal, Beenyup and Walluburnup Swamps showing general features and vegetation associations.

3. DESCRIPTION OF MOSQUITO SPECIES FOUND WITHIN THE STUDY AREAS

A brief description of some important points of general mosquito biology is included as an introduction to consideration of the species found in the Study Area.

Mosquitoes are classified as Culicidae which is a "family" grouping within the insect Order Diptera. This order of insects includes the bushflies and blowflies, the midges, march flies and fruit flies, among others.

The life cycle of the mosquito is divided into two distinct phases - the aquatic larval and pupal stages, and the winged adults.

The larvae live entirely within water. They breathe air through a respiratory siphon on the dorsal side of the last abdominal segment. To breathe the larvae must surface and protrude the siphon through the water - air interface. The larvae are either selective filter feeders, extracting nutrients from the water, or predators attacking much small organisms.

The usual method of catching mosquito larvae is the dipping technique. "Dipping" simply means using a container to dip up a water sample. Mosquito dippers are usually long-handled ladle-type containers.

The larvae pass through four instars, or stages, to the pupal stage (still aquatic), from which the adult emerges.

Only female mosquitoes take blood and, in most species, a blood meal is necessary for the production of fertile eggs. The males do not "bite", but feed on plant nectar. Different species of mosquitoes are attracted to different ranges of vertebrate host animals: for instance, some mosquitoes are attracted only to birds and will not feed on mammals. Therefore not all mosquitoes are regarded by man as pests.

The adult mosquitoes are usually active during the evening and night. The term "crepuscular" is applied to mosquitoes whose activity is restricted to periods of dim light at dusk or dawn. Some species are active during the day within shady areas but most mosquitoes seek cool resting places and remain inactive in daylight.

Female mosquitoes are believed to be attracted to the host animal by a variety of ways. It is known that mosquitoes are attracted to carbon dioxide and may use this respiratory product to host-seek. Visual and auditory attraction is presumed to be important, and it is thought that body warmth (from the host) may also play some role.

Six species of mosquito were found to be present in the study area during the summer of 1977-1978. Methods used to determine the species present were: surveys of breeding sites and rearing captured larvae to adulthood; and trapping of adults using both animal-baited traps and human bait surveys.

A brief resume of important aspects of the biology of each species is given below. The material is taken from reference literature (Marks 1973, Dobrotworsky 1965) and personal observation.

3.1 The *Culex pipiens* species group, or complex.

In Australia this complex is represented by the species *fatigans*, *molestus* and *australicus*, which have been treated as subspecies of *Cx pipiens*, and by *Cx globocoxitus*.

Cx fatigans and *Cx molestus* have been recorded as interbreeding freely (Dobrotworsky 1965) and natural hybrid populations have been recorded in Melbourne.

Cx pipiens australicus, unlike *fatigans* and *molestus*, is primarily a rural mosquito and the available evidence indicates that in nature, *australicus* is reproductively isolated from these two subspecies.

Evidence also suggests that *Cx globocoxitus* is almost completely isolated from both *fatigans* and *australicus* but not from *molestus*.

The only members of this complex that could be identified from the study area were *Cx fatigans* and *Cx australicus*, however there was also present a range of specimens which exhibited taxonomic qualities of the complex but could not be assigned to either species. They are regarded here as being closely related to either or both of these species.

3.1.1 *Culex (Culex) pipiens fatigans* (Wiedeman) (referred to in the text as *Cx fatigans*)

Cx fatigans is described as a domestic mosquito. It is characteristically found breeding in more or less foul water in domestic situations such as pools, drains and septic tanks, in fact in any polluted water close to human habitation.

The species readily enters houses and shelters to attack man and domestic animals at night. Adults rest in dark corners of buildings and probably seldom travel more than one kilometre from their breeding place, (greatest recorded distance is about 5 km).

Cx fatigans, which is an introduced species, has been recorded elsewhere as being a carrier of periodic filariasis, also bird malaria and heartworm of dogs.

During this study *Cx fatigans* was found breeding in small pools fringing lakes, in cow hoof prints and swampy ground fouled by cattle, and in one road drain. In swampy areas affected by cattle the species was found breeding in association with *Cx annulirostris*, *Cx australicus* and *Anopheles annulipes*.

Adult *Cx fatigans* could be found in doorways and shady resting areas in houses sampled in the residential areas. It was trapped in guinea pig-baited traps and was caught biting during the early evening periods. At such times it was the least common of three biting species.

3.1.2 *Culex (Culex) pipiens australicus* (Dobrotworsky and Drummond) (referred to in the text as *Cx australicus*)

This is described as a rural mosquito and the larvae have been found in a variety of ground pools, rock pools and large artificial containers - fresh or slightly brackish, clean or polluted water. This species often occurs with *Cx fatigans* where pollution is not too high. The larvae are rarely found in completely shaded areas. *Cx australicus* is not a man-biting mosquito, it attacks birds and small mammals by night (but not guinea pigs). It is attracted to light and has been recorded in houses, in large numbers.

Cx australicus is not a known disease carrier for man but transmits myxomatosis to rabbits.

During this study, larvae of this species were observed in cow prints and in swampy areas fouled by cattle. They were not recorded in residential areas and were not collected in guinea pig-baited traps.

3.2 *Culex (Culex) annulirostris* (Skuse) (referred to in the text as *Cx annulirostris*)

Cx annulirostris is described as a vicious mosquito which may bite during the day but is particularly active after sunset. It attacks man and a wide variety of birds and mammals. It is very widely distributed and one of the chief non-domestic pest species in Australia.

It may breed in fresh or brackish ground pools, swamps, streams, ditches or channels, shaded or sunlit, usually with vegetation. The species may breed in plague numbers in low-lying grassy areas where water lies for two or three weeks after heavy rain. The adults probably travel at least seven kilometres from breeding places.

Cx annulirostris has been recorded as transmitting periodic filariasis, Murray Valley encephalitis, Ross River virus, and heartworm of dogs.

During the study the species were found breeding in cow hoof prints in association with either or all of *Cx australicus, Cx fatigans* and *Anopheles annulipes*. The water in which the larvae were found was often muddy and fouled.

Cx annulirostris larvae were also found in a restricted area at the edge of an ornamental lake near the Shire of Wanneroo Recreation Centre. This was an unusual habitat in that the lake is stocked with the predatory fish *Gambusia affinis*, but the larvae could be found amongst dense tangles of aquatic weeds, and grasses growing in and on the fringes of the lake.

The most extensive breeding area for *Cx annulirostris* was found to be a small lake immediately north of Lake Joondalup. Here the larvae were widely distributed but occurred in low density. The lake is densely vegetated with Paperbark trees, creating a well-shaded area. Dotted amongst the Paperbark trunks are small sparse stands of *Baumea*. Early in the season, when the water levels were higher, *Cx annulirostris* larvae were restricted to the shallow fringes of the lake and could be found harbouring around the bases of the paperbarks, amongst the sedge stands or in association with dense clumps of the filamentous alga *Spirogyra* sp. which was common in the fringes of the lake.

Generally, mosquito breeding is restricted to shallow water (less than 35 cm) and this condition was observed with *Cx annulirostris* in this situation. As the water level fell, more of the lake became available to the larvae. The water level dropped to the extent where larvae could be found throughout the lake and were still present in fringe areas, living in thick "ooze" (decaying plant matter and mud) covered only by a thin sheet of clear water.

Because of the low density of larvae but large area in which they could be found, larvae in this habitat virtually had to be hunted to be caught - random dig sampling collection methods would have produced few larvae.

Study of this breeding area revealed that the female *Cx annulirostris* would not actively host-seek during the day, beyond the day-time resting area of the adults. In this case adults harboured on virtually any foliage within the swamp and close to the water. Adults would bite during the day only within heavily shadowed areas. They would not bite outside the periphery of the lake or swamp area. Biting rates during the day could be as high as 200 *Cx annulirostris* within one hour, from 1.20 p.m. to 2.15 p.m. (see Chapter 6, Table 3).

3.3 *Mansonia (Coquillettidia) linealis* (Skuse) (referred to in text as *Coq. linealis*)

Coquillettidia linealis is described by Dobrotworsky as a vicious day-biting mosquito which attacks man as well as domestic animals. (This species was observed to bite only after sunset during the course of this study; see Chapter 6, Table 3, Figs. 31, 32). Adults are usually common from December to March (in Victoria). The larvae and biology of this species are unknown.

The larvae of the genus *Mansonia* have a specialised respiratory habit. The valves of the respiratory siphon of the larvae are modified into piercing apparatus. The larvae pierce the stems and roots of aquatic vascular plants and derive their oxygen supply directly from such plants. The habit alleviates the necessity for the larvae to surface. Hence the larvae remain firmly attached to the plants and escape many predators and observation by biologists. Bates (1949) indicates that "larvae of the subgenus *Coquillettida* are found in the mud among the roots of grasses, bulrushes and other plants." The larvae of this species has not been found in the field. Although fertile eggs have been conceived and matured within the laboratory (Dobrotworsky 1965) the larvae could not be successfully reared, and hence the life cycle has not been fully studied.

The species is not recorded as being a disease carrier.

Observations at Lake Joondalup indicate that the maximum biting activity of *Coq. linealis* occurs approximately 15 minutes after sunset (refer to biting - frequency histogram, Figure 31). The mosquito, like most pest species, attacks the host in swarms when numbers are high. The mosquitoes appear to fly low to the ground, presumably to escape high wind velocities and to remain in close proximity to a resting surface in case of wind gusts. Because of this, exposed legs, ankles and feet are particularly vulnerable to attack. The flying activity of these mosquitoes is severely restricted by wind velocities of as low as 10 km per hour. Thus on windy evenings *Coq. linealis* is unlikely to be a nuisance.

3.4 *Culiseta attra*

Little information has been gathered on this species. *Culiseta* is a small genus of thirty-eight species most of which are restricted to cooler areas.

Culiseta attra is the only member of the genus recorded in Western Australia, its distribution is restricted to the south-west regions.

During this study twenty-one specimens were trapped in guinea pig-baited traps, over five weeks and the presence of this species was regarded as a transitory occurrence.

No larvae were observed, and the adults were not sampled in residential or human bait catches.

3.5 *Anopheles (Cellia) annulipes* (Walker) (referred to in text as *An annulipes*)

This mosquito is recorded as breeding in a variety of temporary and permanent ground pools, streams and swamp edges, also amongst floating weeds or other vegetation away from banks. The habitat is usually sunlit or only partly shaded, but may occasionally be in deep shade. The water may be polluted, fresh or brackish. *An annulipes* bites by night, particularly around dusk and dawn, or by day in heavy shade.

It does bite man but feeds extensively on cattle and rabbits. It will enter houses.

The species is capable of transmitting malaria and filariasis (no recorded cases in southern Australia).

During the study *An annulipes* was found breeding in cow hoof prints and in holes fringing the lakes, i.e. fence post holes, uprooted tree holes, etc.

One extensive breeding area for this species was found in the southern end of Lake Joondalup, beside Mullaloo Drive. Here the larvae existed amongst a dense mat of grasses and weeds on an exposed edge of the lake despite the presence of larvicidal fish. This habitat subsequently dried out and ceased to serve as a breeding site.

This mosquito was caught during human-bait sampling at evening. Two specimens were collected from the residential area. No specimens were collected from guinea pig-baited traps.

4. SURVEY OF MOSQUITO BREEDING SITES - DESCRIPTION OF HABITAT TYPES WITH NOTES ON BREEDING

4.1 Method

Mosquito breeding sites are located by observation of, and sample-dipping for, larvae and pupae. By carefully watching the water surface larvae and pupae may be observed as they rise to breathe.

While surveying a habitat care must be taken not to disturb the larvae and pupae. If they are disturbed by sound, water movements, or shadows cast on the water, they will swim to the bottom of the pool and hide in the mud or amongst aquatic vegetation. Therefore it is important to move slowly and carefully through the water, and stop regularly and remain still while observing a large area of the habitat. Dense vegetation masses, such as sedges, grasses and bulrushes, should be searched particularly well as larvae may be harbouring within.

Occasionally dip samples should be taken within vegetation clumps, of the mud and debris at the bottom of the pool, or in inaccessible places. Here a small dipper is used to sample part of the water. The contents of the dipping container, often muddy water, should be emptied into a shallow white dish for observation; here larvae should become readily apparent if present.

The whole of the study area was surveyed in this way for mosquito breeding habitats.

In surveying such a large area recurrence of habitat types is frequent and it is often acceptable to pass over areas where the area "Type" has been already thoroughly investigated.

4.2 Description of Surveyed Area Types

Fifteen broad area types were identified during the study. Of these ten were found to be breeding, or potential breeding, areas for mosquitoes. However, it must be noted that all of these areas are small in size. The extent of all area types is shown on Maps 3 and 4. Mosquito breeding sites are shown superimposed on these maps as overlays. Representative photographs of most habitat types are included with a description of the habitat.

4.2.1 Area Type 'A' - (Figs. 1 and 2) includes most of the west margin of Lake Joondalup, the northern end and a small stretch of the north-eastern shoreline of the lake.

Here the edges of the lake have more or less definite boundaries and the sandy banks rise steeply away from the lake. There is a fringing, variously wide, dense *Juncus pallidus* zone lying immediately beside and overlapped by a Paperbark Woodland.

The water is clear. Decaying plant matter is present but often not extensive.

Introduced grasses and weeds grow down to and into the water's edge in places along the western bank. The mosquito fish, *Gambusia affinis* is plentiful. No mosquito larvae were observed in area type 'A'.

FIGURE 1 - Type 'A' area - taken on the west bank of Lake Joondalup near Quinlan Road, showing the lake in the background with a dense stand of *Baumea* extending into the lake, and Paperbarks representative of the woodland zone.

FIGURE 2 - Type 'A' area - taken on the west bank of Lake Joondalup beside Edgewater Drive near Trapping Site 3. The foreground shows the dried foreshore of the lake (this was inundated at the beginning of the study). An isolated dense stand of *Baumea* extends into the lake. On the right of the picture can be seen the fringing sedge and overlapping woodland zones.

4.2.2 Area Type 'B' - (Fig. 3) is situated on the north-east margin of Lake Joondalup. This is a flat basin of dense Paperbark Woodland with some Flooded Gums. The area is restricted and lies on the edge of the lake proper. It has a sparse understorey of *Baumea* and a variety of other vegetation types including *Typha*, grasses and weeds. The floor of the basin is covered with a layer of rotting vegetation matter, often up to 60 cm deep.

The flat basin is such that in mid-summer it dries out completely but is inundated to a depth of perhaps 40 cm in winter. Receding or rising water levels create small isolated pools in depressions, holes, etc. These are potential breeding sites before larvicidal fish are reintroduced (with rising water) or if fish are not left behind in pools (with falling water level). If sufficient water is available, fish are present and, in such cases, larvae could not be sighted. During the survey *An annulipes*, *Cx annulirostris*, *Cx fatigans* and *Cx australicus* were sampled from fallen tree-hole pools in the area.

FIGURE 3 - Type 'B' area - taken on the north-east margin of Lake Joondalup near Trapping Site 7. The lake is behind the dense woodland of Paperbarks. The area has recently dried out making ideal conditions for the rapid growth of the undergrowth species, as seen in the mid-ground. In the foreground Bulrushes (*Typha*) are present.

4.2.3 Area Type 'C' - occurs on the east edge of Lake Joondalup extending from the northern limit of the residential area south to the northern limit of the APB quarantine area. (See Map 3). Along this section of the lake, fringing areas behind the lake vegetation have been reclaimed for recreation, the vegetation has been cleared and grass planted.

The lake's vegetation fringe is either pure dense *Baumea* or a mixture of *Baumea* and *Typha*, usually occurring in not-so-dense stands. The rushes and sedges appear to have been burnt at some stage. There is no Paperbark Woodland.

No larvae were captured in this type habitat but it is reported as a potential breeding area, especially if abused or disturbed, for instance by dumping of rubbish, trampling of vegetation, etc. which is made easier by the close proximity of the grassed recreation zone.

Note: The APB quarantine area is basically type 'A' habitat except for extended dense sedge areas. There is a Paperbark Woodland and fringing dense *Baumea*. Three open drains cut through the quarantine area. Larvae of *Cx fatigans* and *An annulipes* were taken from one of these drains.

4.2.4 Area Type 'D' - (Figs. 4 and 5) extends south from the Recreation Centre to Ariti Avenue (where the sewer line crosses lake). It is characterised by a relatively wide, dense belt of mixed sedges dominated by *Baumea* with some intrusion by *Typha* which, in this area, fringes the lake's edge. There is no Paperbark Woodland.

The naturally dense character of the vegetation limits the breeding potential of the area. However, at the time of surveying, cattle were maintained in the area and larvae of *Cx australicus*, *Cx fatigans* and *An annulipes* were found in cattle tracks and hoof-prints.

It should be noted that landward fringes of this area are being reclaimed to provide grassed recreation areas.

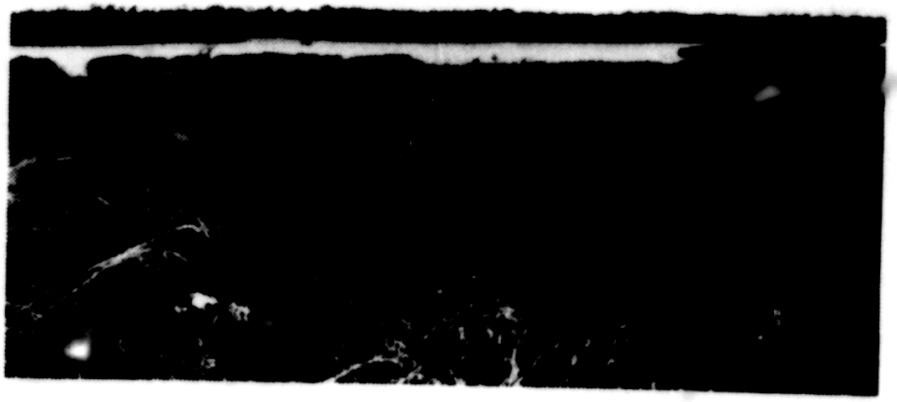


FIGURE 4 - Type 'D' area - taken on the east side of Lake Joondalup beside Ariti Avenue. The photograph shows a wide fringing sedge zone, dominated by *Baumea*, with dense *Typha* fringing the water. The fence posts indicate farming activity. A cow is wandering through the sedge in the centre of the picture.

FIGURE 5 - Type 'D' area - same area as Figure 8, taken looking back from the lake. This shows the fringing *Typha* in the area. Note the low water level exposing the bases of the rushes.

4.2.5 Area Type 'E' - (Fig. 6) extends south from Arit. Avenue. It is a low-lying area of fractured and dislocated shoreline. It is variously vegetated with dense to light stands of *Baumea*, light stands of *Typha* and mixed light stands of the sedge and Bulrush.

Most of this vegetation is established on a peat bank cushion. On firmer ground, restricted to peripheral regions and small "islands", Paperbark Woodland is established, and in parts Eucalypts may be found.

This area would be inundated in winter and the receding waters of summer create isolated pools. The sparsity of the sedge and Bulrush formations permits breeding in the area, assuming *Gambusia* are not present in such pools.

Market gardens were established behind this low-lying area and the remnants of these are on an extensive flat belt of land following the contours of the lake's edge and intersected regularly by drainage channels which lead back into the lake. At the time of the survey some of these drainage channels were still flowing or contained permanent pools of water. No larvae were observed in these drains, this may be accounted for by the clean, clear, fresh nature of the water, the fact that in parts the water was flowing or that pools were only temporary. Fish were present in the larger, more permanent pools. Such drains are potential breeding sites.

4.2.6 Area Type 'F' - the southern reaches of area type 'E' merge into this type area. Here the lake's edge is more definite but the sedge communities, mainly an area of dense *Baumea* with some Paperbark trees and minimal infiltration by *Typha*, extend further back from the lake.

Area 'F' was difficult to survey as the sedge is very dense and impenetrable.

No larvae were observed in the area.

FIGURE 6 - Type 'E' area - taken on east side of Lake Joondalup looking south from Ariti Avenue at the lake's edge in front of San Rosa Road. Notice the Bulrush fringe on the left of the picture and, in the close background, a dense stand of sedges. On firmer ground the Paperbark Woodland is established, some Eucalypts are also present.

4.2.7 Area Type 'G' - (Figs. 7 and 8). Type 'G' areas are created through reclamation of fringe sedge areas that pocket out from the lake's edge. A small area occurs at the north-east edge of Lake Joondalup and a larger area at the south-east margin of the lake. These areas are now utilised for grazing of cattle. The dense sedge stands have been removed and replaced by introduced grasses (Buffalo, etc.) Some Bulrushes are present. Any sedges that may remain are trampled underfoot by cattle. The land is saturated, except towards the middle of summer, and all depressions in the surface immediately fill with water. Such depressions are mainly caused by cattle. This creates an ideal breeding habitat for *Cx annulirostris*, *Cx fatigans*, *Cx australicus* and *An annulipes*.

FIGURE 7 - Type 'G' area - taken on the south-east margin of Lake Joondalup. Behind the grazing area a dense sedge stand fringes the lake. The fenced areas (in foreground) are cleared and grassed, and for much of the year are waterlogged.

An excellent example of the effect of cattle and clearing on these lake fringe areas is situated at the larger of these two pockets of Type 'G' areas. Here an old fence-line runs parallel to the lake's edge. Cattle are permitted to graze up to the fence. Beyond the fence and running to the lake the vegetation is a tall dense stand of *Baumea* with some intrusion by *Typha*. Despite the sampling difficulties it was evident that no larvae were present among the sedges and Bulrushes. However, on the agricultural side of the fence the cattle had trampled much of the sedge, creating tracks which were filled with water and larvae were readily evident.

This example illustrates the abrupt cut-off between the presence and absence of breeding, and shows the marked effect of disturbing the natural vegetation.

FIGURE 8 - A more distant view of that area shown in Figure 7. This picture illustrates the extent of the area and shows the form of the marsh area as it extends from the lake. Notice that the marsh is flanked on both sides by high ground.

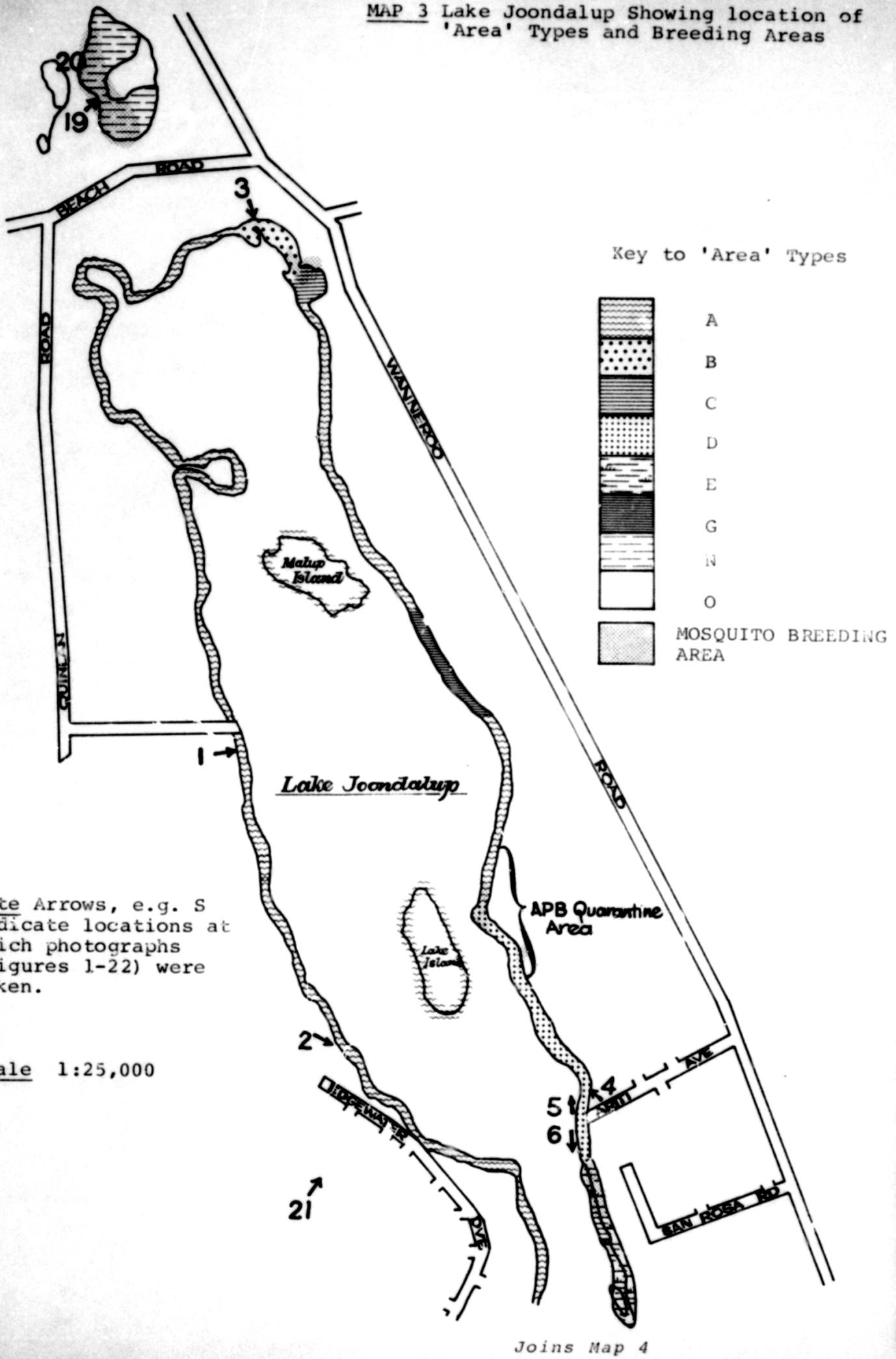
4.2.8 Area Type 'H' - (Figs. 9 and 10) At the southern limits of Lake Joondalup, bordering Mullaloo Drive, sandy shorelines are present with no vegetation, no Paperbark Woodland (in some instances dead timber) and no peat material. No larvae were found in such areas.

Although much of Lake Joondalup south of Mullaloo Drive is like this there are parts of the lake fringed with variously dense Paperbark Woodland.

FIGURE 9 - Type 'H' area - taken from Mullaloo Drive looking north-west at theshoreline parallel to Edgewater Drive. In the foreground along the Mullaloo Drive causeway a dense stand of Bulrushes is present. The shoreline in the centre of the photograph is sandy and bare, except for dead Paperbark trees. Notice the fence situated in the middle of the lake, indicating that the water level, despite the dry season, is somewhat higher at present than it has been at some time in the past.

FIGURE 10 - Type 'H' - taken from Mullaloo Drive looking north-east (i.e. opposite shoreline to that shown in Figure 12). This photograph illustrates the completely bare shoreline.

MAP 3 Lake Joondalup Showing location of 'Area' Types and Breeding Areas



Note Arrows, e.g. S indicate locations at which photographs (Figures 1-22) were taken.

Scale 1:25,000

Joins Map 4

4.2.9 Area Type 'I' - (Fig. 11) is represented by a successional stage from Type 'H' areas when some vegetation form is established on denuded shorelines. Type 'I' area is small and represented by grassy shoreline verges immediately south of Mullaloo Drive on the east margin of Lake Joondalup. Here a dense cover of grasses and weed, etc. has been established, thus creating a habitat in which mosquito breeding may occur. At the time of surveying *An annulipes* larvae were located amongst the densely tangled mat of vegetation growing in some 20 cm of water. This area subsequently dried out as shown in Figure 11.

4.2.10 Area Type 'J' - (Figs. 12 and 13) is that found in Beenyup swamp. This is a dense Paperbark Woodland the floor of which is variously vegetated with sedges, Bulrushes and grass species. In winter it is inundated. Water draining from Lake Goollelal enters the swamp, thus partly replenishing the water level during drier months.

FIGURE 11 - Type 'I' Area - taken from Mullaloo Drive looking south along the east shoreline of Lake Joondalup. Early in the season (November) the water level was as high as the first line of trees. At that time the grassy verge was submerged.

Centrally the swamp is an open lake. *Gambusia* are present.

Culex australicus larvae were found in the peripheral regions of the swamp in small isolated pockets of water. Breeding was however not widespread, presumably due to the abundance of fish. This area is very similar to area Type 'B'. Rising and falling water levels create new pools suitable for breeding, presuming fish are not present.

4.2.11 Area Type 'K' - (Figs. 14 and 15) is represented by Walluburnup Swamp. This is a long broad tongue of swamp lying in a gently sloping valley between Lake Joondalup and Lake Goollelal. Water from the latter lake drains through the area. Along this water course there is a woodland of small Paperbarks, many of which are dead, and the area is virtually impenetrable. Fringing out from the central Paperbark Woodland is a broad dense zone of sedges, Bulrushes and tall introduced grasses (dominated by *Baumea*). Larvae were found in cow prints in the northern reaches of the swamp area.

FIGURE 12 - Type 'J' Area - taken in Paperbark Woodland fringing Beenyup swamp. At the time of photographing the area was dry, however in winter the area would be inundated possibly to the log in the foreground. Notice the open areas where the sun penetrates, contrasting with the particularly dense, well shaded areas.

The southern reaches of the swamp are higher and drier and no larvae were sampled in this area, however, with the grazing of horses and cattle the area is cited as a potential breeding area.

FIGURE 13 - This photograph was taken in the centre of Beenyup swamp. Notice the expanses of open water, the "islands" of vegetation and the clumps of sedge (*Baumea*). Circumjacent to this central lake area is the Paperbark Woodland as seen in the background.

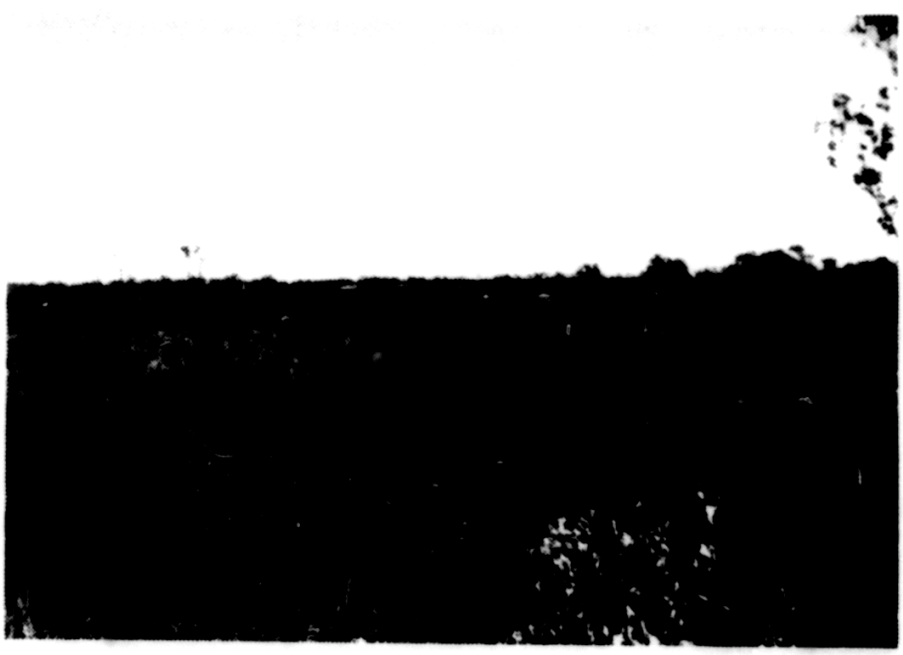


FIGURE 14 - Type 'K' Area - taken at northern end of Walluburnup swamp. The sedge area has recently been burnt and is only just rejuvenating at the time of photographing. The green is *Baumea*, the brown tinged vegetation in the centre is *Typha*. Notice the sparsely scattered Paperbarks.

4.2.12 Area Type 'L' - (Figs. 16 and 17) The west side of Lake Goollelal constitutes a further habitat type. It has a steep-sided bank with a narrow fringe of Bulrushes and the sedge *Baumea*. The Bulrush predominates. The permanent fringe water is choked with Water Hyacinth. Short stretches of the fringe are heavily wooded with Paperbarks and introduced tree species, (i.e. Weeping Willows). Fish are abundant. No larvae were observed along the whole of the west side of Lake Goollelal.

FIGURE 15 - Southern reaches of Walluburnup Swamp. The actual swamp area is in the centre of the photograph, behind the bare foreground. The central line of trees fringes the open drainage creek. Notice the swamp area still maintains a green cover but at the time of photographing the surface was quite dry. Horses graze in the area, and may create breeding places within the area.

FIGURE 16 - Type 'L' Area - taken looking north along west bank of Lake Goollelal. Notice the mixture of *Typha* and *Baumea* with a few trees fringing the lake.

FIGURE 17 - Type 'L' Area - taken of the west bank of Lake Goollelal. Notice the Water Hyacinth (*Eichhornia crassipes*) densely covering the water surface amongst the fringing *Typha*. Also present in background is a stand of *Baumea* (back left corner).

4.2.13 Area Type 'M' - (Fig. 18) is represented by the east fringe of Lake Goollelal, which rises less steeply than the opposite bank. This margin is heavily vegetated with *Typha* occurring in pure, dense stands. There is no Paperbark Woodland.

Skirting the lake proper is a dense fringe of Water Hyacinth. More northerly edges of this bank are still covered by pure stands of *Baumea*, and the northern edge of the lake is fringed with Paperbark Woodland.

Larvae of *Cx annulirostris* and *Cx fatigans* were readily collected in this area where cattle had trampled down the Bulrushes to form tracks.

4.2.14 Area Type 'N' - (Figs. 19 and 20) is represented by the small lake to the north of Lake Joondalup. It is densely wooded with Paperbarks, amongst which grow sparse stands of *Baumea*. Dense mats of algae may be present. There are no fish.

Larvae of *Cx annulirostris* are found in the shallows, associated with some form of vegetation for protection.

FIGURE 18 - Type 'M' area - taken looking north along the east margin of Lake Goollelal. A dense fringe of Bulrushes lies at the lake edge. No trees fringe onto the lake although trees are growing further away from the water's edge. A market garden runs right down to the Bulrush fringe and cultivated land can be seen at the lower righthand corner. The late summer season is reflected in the character of the Bulrush stand which is brown and dying. In some places it may have been burnt.

FIGURE 19 - Type 'N' area - taken within the small lake immediately north of Lake Joondalup. Note the dense Paperbark Woodland, the sparse sedge stands and the expanses of open water and mud.

FIGURE 20 - Type 'N' area - close-up of that area shown in Figure 19. In this habitat larvae were found harbouring around the bases of Paperbarks, within sedge clumps or within the algal masses, (e.g. *Spirogyra* as seen in foreground).

4.2.15 Area Type 'O' - (Figs. 21 and 22) The final area type is that of open water and pure, dense, stands of *Baumea* which are dispersed within both Lakes Joondalup and Goollelal. These areas were surveyed (only Joondalup) using the Shire's punt.

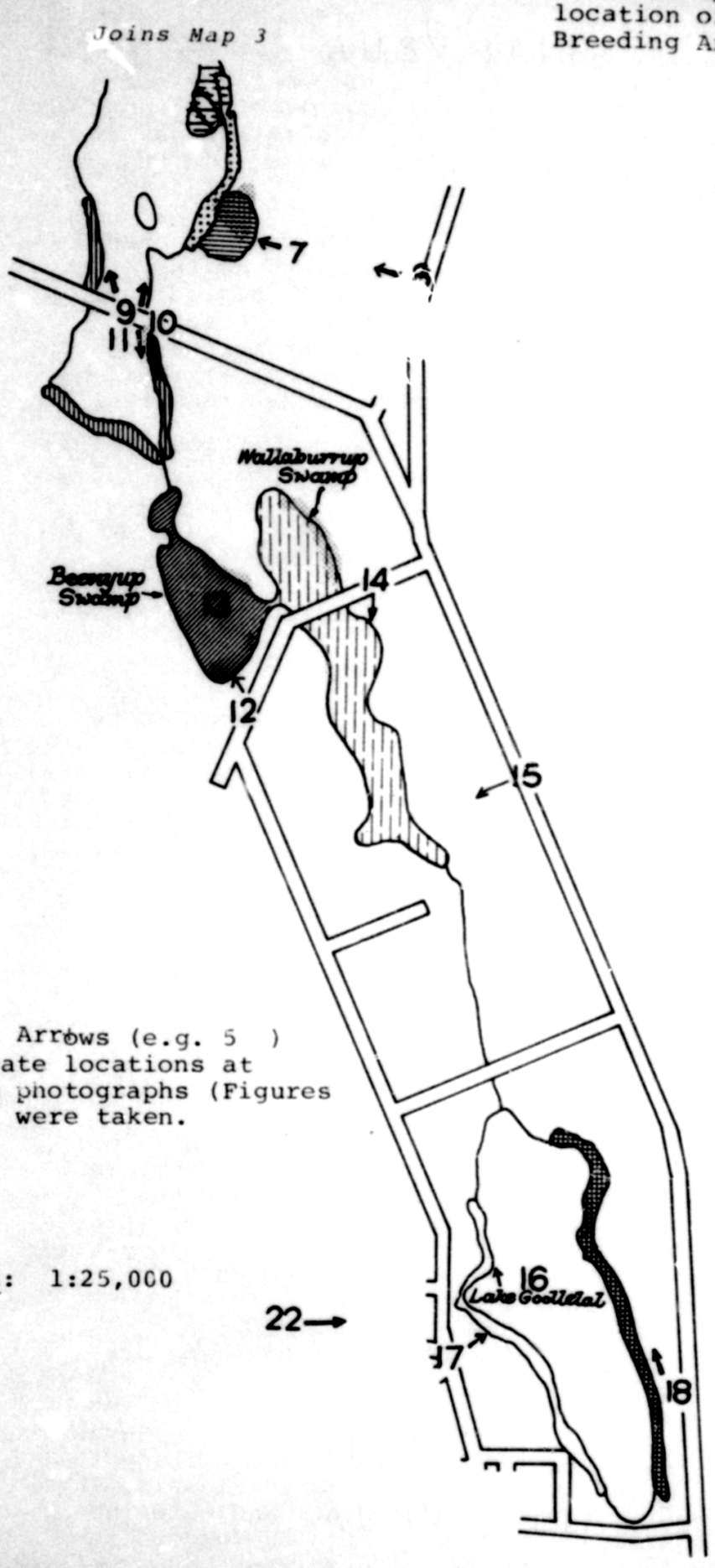
No larvae were observed within the submerged algal species in the lake either in shallow or deep water. Similarly larvae were not found amongst the sedge beds.

The water of the lakes proper is relatively clear and deep, it abounds with fish, and in all attributes does not appear conducive to the breeding of mosquitoes.

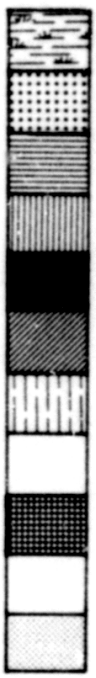
FIGURE 21 - Type 'O' area - taken of central Lake Joondalup, looking east. Notice the large expanses of water, interrupted by the sedge beds. Lake Island is featured in the centre of the scene.

FIGURE 22 - Type 'O' area - taken of central Lake Goollelal looking eastwards.

MAP 4 - Lake Goolelal, Beenyup and Walluburnup Swamps showing location of 'Area' types and Breeding Areas.



Key to 'Area' Types



Note Arrows (e.g. 5) indicate locations at which photographs (Figures 1-22) were taken.

Scale: 1:25,000

4.3 Survey of Possible Breeding Habitats of *Coquillettidia Linealis*

Due to the unusual respiratory habit of this species (see Section 3.3) alternative surveying methods for location of larvae must be employed because they do not come to the surface to breathe. In this study emergence traps were used in an attempt to find the breeding areas.

Emergence traps are sturdy five-sided wire mesh cages, designed to entrap mature adult mosquitoes as they emerge from the pupal stage. The trap is placed in the water over a specific vegetation form. Larvae of *Coq. linealis*, if attached to the vegetation, would not be disturbed. However, the adults when mature would emerge into the trap and could be collected (see Fig. 23).

Emergence traps were placed over areas of *Baumea*, *Typha* and Water Hyacinth selected as possible vegetation types to be utilised by the larvae.

The sedges and Bulrushes were cut low to the water so as to fit the emergence traps. The traps were left in one place up to a week, but were often removed earlier than this (after three days).

The tests were carried out in the Beenyup Swamp and Lake Goollelal areas as *Coq. linealis* was known to be relatively abundant in these areas (from trapping, etc.) This technique is slow, as only a very small part (largest trap covered an area of 0.25 sq metres) of the vast vegetation cover can be sampled at any one time. The breeding habitat was not located through this method.

An alternative method was also employed. This required the uprooting of possible vegetation types. The lower stems and roots of these plants were then briskly washed in a large white bowl of clean water. The washing action should dislocate larvae from the stems and roots to which they may be attached. The larvae would then be visible in the water, against the white sides and base of the bowl.

The same three vegetation types as were sampled with emergence traps were tested in this way. However, the test proved to be impracticable for the sedges and Bulrushes, as these could not be uprooted easily. The extensive root systems held firmly to the mud and peat, and the stems were usually broken, after much effort, without freeing the roots.

The larvae of *Coquillettidia linealis* were therefore not sighted.

Only three plant species, *Baumea*, *Typha* and Water Hyacinth, were tested as they were considered the most likely to harbour larvae of the species. They were extensive in range, flourished in the submerged state and were the most numerous of the aquatic species. The few other aquatic species found in the area (different sedge species) were restricted to small, usually inaccessible pockets.

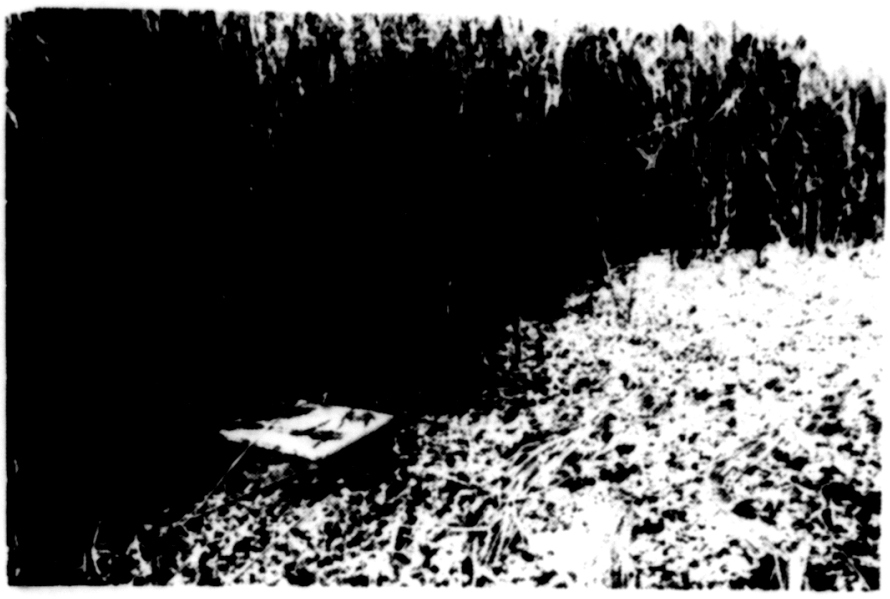


FIGURE 23 - An emergence trap set over Water Hyacinth on the western edge of Lake Goollelal. A zone of *Baumea* stands behind the Hyacinth fringe.

4.4 Conclusions - Larval Surveying and Location of Mosquito Breeding Habitats

The waters of the lake "proper" (both Joondalup and Goollelal) do not constitute a mosquito breeding habitat. The water depth is often too great, the water too clear, the necessary vegetation associations are lacking and the mosquito fish *Gambusia* too abundant.

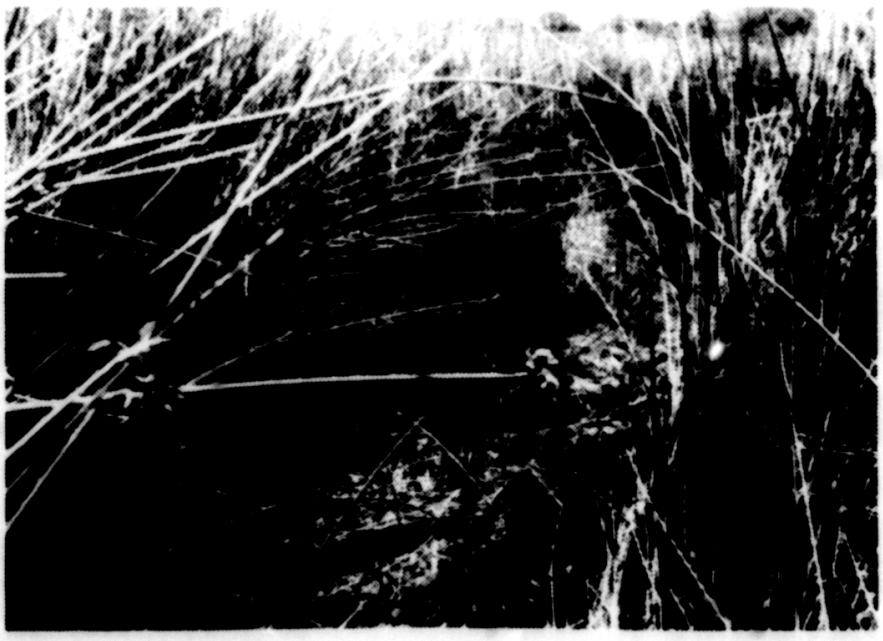
Mosquito breeding is restricted to swampy fringe areas located on the eastern margins of both Lakes Joondalup and Goollelal. Mosquito breeding appears to be potentially possible in any pockets of water in which the larvicidal fish are not present, as exampled by the extensive *Cx annulirostris* breeding habitat north of Lake Joondalup.

Larvae will generally not be found in clear water of low nutrient content, flowing or otherwise. Larvae cannot be found in shallow water in dense stands of sedges, Bulrushes or a mixture thereof (see Figure 27 for example). In such areas access to the water by female mosquitoes is limited, and thus it is difficult for eggs to be laid on or in the water.

However, when such dense stands are disturbed and vegetation trampled, creating exposed pools of fouled water, then breeding of *Culex* and *Anopheles* may occur. Figures 24, 25 and 26 show mosquito breeding sites in disturbed areas. Figures 24 and 25 illustrate mosquito breeding sites caused by cattle trampling sedges in a Type 'G' area. This area is particularly vulnerable because it is low-lying with a high watertable. Figure 26 shows

a breeding site in a Type 'M' area associated with uncontrolled dumping. Any deep holes (e.g. fence post holes, uprooted tree holes, ditches, wells, etc.) fringing the lakes and partially filled with water, if not colonised with fish, will create breeding habitats for mosquitoes.

A characteristic breeding site for *Cx fatigans* is in road drains. During the study only one drain containing water could be located, this was in the Recreational Centre carpark. As was to be expected it was a large breeding site for this domestic species. All road drains are potential breeding sites for *Cx fatigans*.



FIGURES 24 & 25 - Two examples of the disturbance of sedge stands by cattle. In both pictures *Baumea* has been trampled underfoot, creating tracks or large areas of cleared ground. Breeding of all mosquitoes was evidenced in such trampled areas.

FIGURE 26 - An example of man's disruption of a fringe area, taken on the east side of Lake Goollelal. Breeding of *Cx fatigans* was recorded at this site in pools of water around the rubbish.

The dissociation of mosquito breeding areas from those in which *Gambusia* are present is not absolute. On two occasions mosquito larvae were collected in water in which the predatory fish were abundant.

On both occasions the larvae were harbouring amongst dense tangles of vegetation (couch grass) and were presumably escaping the notice of fish, (the fish may not have been able to penetrate the vegetation mass.)

Extensive breeding by all mosquitoes is usually associated with some form of vegetation either aquatic, or plants verging on the water's edge, their foliage extending into the water. The vegetation provides for the larvae visual protection from predators. However, in some examples (e.g. *Cx annulirostris*) larvae may be found in very shallow, vegetation-free areas and utilise the ooze of ligno-peat and mud to escape predators.

FIGURE 27 - An example of a dense stand of *Typha*, in which breeding is regarded as highly unlikely. At the time of photographing the pool around which the Bulrushes are growing is dry, but, with a rise in water level the stand of Bulrushes would be inundated.

FIGURE 28 - An example of a sparse stand of *Typha*, in which breeding is possible. Such a stand is easily penetrated, as individual plants are widely separated.

PART II : CHAPTERS 5, 6 and 7

TRAPPING SURVEYS TO DETERMINE OCCURRENCE AND PEST STATUS OF ADULT MOSQUITOES

The following three chapters describe three activities which, together, are useful in any mosquito investigation programme. The three activities are -

1. A trapping programme using animal-baited mosquito traps.

2. A survey of those mosquito species, present within the study area, that are attracted to a human host.

3. A survey of mosquito species present within the residential areas.

These three steps contribute to the following logical progression -

1. The identification of all mosquito species present in the area.

2. The identification of potential nuisance species.

3. The identification of actual nuisance species.

5. ADULT MOSQUITO TRAPPING PROGRAMME

5.1 Aims of a Trapping Programme

The objectives of a mosquito trapping programme are three-fold :

1. In the short term, to identify mosquito species present in the area.

2. To determine the distribution of species throughout the area. This may give some evidence as to the location of breeding sites and flight patterns of adult mosquitoes.

3. In the long term to gain information on population dynamics of mosquito species within the area. This is limited to relative increases or decreases in population sizes and comparisons between species, and may be termed monitoring of mosquito populations.

The programme described below fulfilled the two short term objectives. The data obtained from it can form the basis for ongoing monitoring to fulfil the third, long term, objective.

5.2 Description of the Programme

A nine-week mosquito trapping programme was initiated on 9 January 1978. Traps were set twice weekly (usually Monday and Thursday nights) for the first five weeks, and once weekly (Wednesday night) for the remaining four weeks.

Eight small guinea pig-baited traps (see Fig. 29) were placed at eight trapping sites, six around Lake Joondalup and two around Lake Goollelal (see Maps 5 and 6 for position of sites). Guinea pigs were used as bait animals as they are small mammals in general attractive to the mosquito species which attack humans. Their size is both convenient for trap dimensions and for the housing of the animals. Other bait animals include small birds (e.g. pigeons or chickens) and other small mammals (e.g. rabbits).

The traps were set between 4.30 p.m. and 6.00 p.m. and collected the following morning between 7.30 a.m. and 8.30 a.m. The traps were all hung from convenient tree limbs 1 - 2 metres from the ground.

Individual guinea pigs were selected at random and placed in the traps. The traps, numbered 1 to 8, were selected at random to be stationed at each site on a particular night.

FIGURE 29 - The type of mosquito trap used in the programme.

Traps were also set irregularly at Beenyup swamp and the small lake immediately north of Lake Joondalup.

It is generally accepted practice in monitoring programmes that note is taken of the prevailing weather conditions and of the position and characteristics of the trapping sites. Particular note is taken of weather conditions such as wind speed, air temperature and relative humidity because these factors may influence whether the mosquitoes leave their resting sites to seek blood meals and may determine the distance they will travel.

Records of weather conditions on all trapping nights are given in Table 1. These data were collected from the Bureau of Meteorology and were recorded in Perth, 40 km south of Wanneroo. No record of local weather conditions is maintained at Wanneroo.

A description of all trapping sites is given in Section 5.3. It will be mentioned later what influence the trapping site may have on the data. The trapping data are given in Table 2.

5.3 Description of Trapping Sites

Site 1, west bank of Lake Goollelal - trap hung 2 m above the ground in a wattle tree, part of a small sparse grove. The trap was some 6 m from the water's edge, situated behind a fringing zone of Bulrushes.

The site was exposed to the full force of the wind, there being little other tree cover in the area. The trap did not sway in the breeze.

TABLE 1 - Summary of the important weather conditions on each trapping night. The range of each factor is given so that the earlier value is shown first and the later value is shown second.

Date (1978)	Temperature Range ^0C	Relative Humidity Range %	Wind Data				
			Maximum Gust (knots)	Minimum Velocity (knots)	Range of Av. Velocities (knots)	Mean Velocity throughout (knots)	Direction
9-10/1 time	36 - 25 1800 - 0600	25 - 51	32 0255	0 2100 - 2200	12 - 4	7.5	SW - E pm - am
12-13/1 time	40.6 - 23 1800 - 0800	12 - 83	22 0200	0 2100 - 2200	10 - 2	5.8	Westerly quadrant
16-17/1 time	22.3 - 17 1800 - 0600	48 - 67	21 0700	3	3 - 8	5	SSW - E
19-20/1 time	33 - 23 1800 - 0600	26 - 75	18 1900	0	8 - 2	6	SSW
23-24/1 time	25 - 18 1800 - 0600	61 - 43	22 1900	0	13 - 0	5.3	SSW - ESE
26-27/1 time	35 - 18 1800 - 0545	30 - 65	24 2250	5	14 - 7	9.5	ESE - E
31/1-1/2 time	30 - 23 1700 - 0600	76 - 47	17 0515	2	2 - 12	5.6	SSE - ESE
2-3/2 time	25 - 17 1700 - 0600	53 - 66	34 1950	0 0600 - 0800	16 - 3	10	WSW quadrant
6-7/2 time	29 - 22 1700 - 0600	63 - 57	22 1715	0 0100 - 0800	12 - 0	3.6	SSW - ESE
9-10/2 time	24 - 16 1700 - 0600	57 - 79	27 1720	3	14 - 3	8.3	SSW - S
16-17/2 time	32 - 24 1700 - 0500	41 - 61	18 1700	0 2400 - 0800	9 - 0	2.2	SW
22-23/2 time	33 - 22 1700 - 0700	50 - 80	20 1700	0 2000 - 0800	8 - 0	1.0	WNW
1 - 2/3 time	32 - 25 1700 - 0600	31 - 50	18 0330	0	0 - 4	1.0	SSW - SSE
8-9/3 time	25 - 16 1700 - 0615		18 1730	0 2100 - 0800	8 - 0	1.3	SW

Site 2, east bank of Lake Goollelal - the trap was hung 1.2 m above the ground on the limb of a healthy Weeping Willow tree, the only tree on the lake edge in the area. The tree was growing at the edge of the winter water level. There was a dense fringing zone of Bulrushes and a wide belt of Water Hyacinth. Immediately beside the trap site (for the first week) was a *Cx fatigans* breeding site. This subsequently dried up. Some 9 m away from there, was a chicken coop. The trap hung amongst the foliage of the Willow and was thus partially protected from the wind. The trap would move as the limb from which it hung was blown by the wind.

Site 3, south-west side of Lake Joondalup, beside Edgewater Drive - this trap was hung 1.8 m above the ground from the limb of a Paperbark tree, amongst a dense Paperbark Woodland. The site was some 12 to 16 m from the water's edge. There was no continuous dense fringe of sedge between it and the water. It was a well-sheltered site being influenced little by the wind, as the limestone hills rose up behind the lake.

Site 4 - this site is beside Quinlan Road on the mid-west side of Lake Joondalup. The trap was hung 2 m above the ground from the limb of a Paperbark amongst a dense woodland. It was some 15 m from the water. A dense stand of *Baumea* fringed the lake.

The site was well protected from the wind at the bottom of the steeply rising ground to the west.

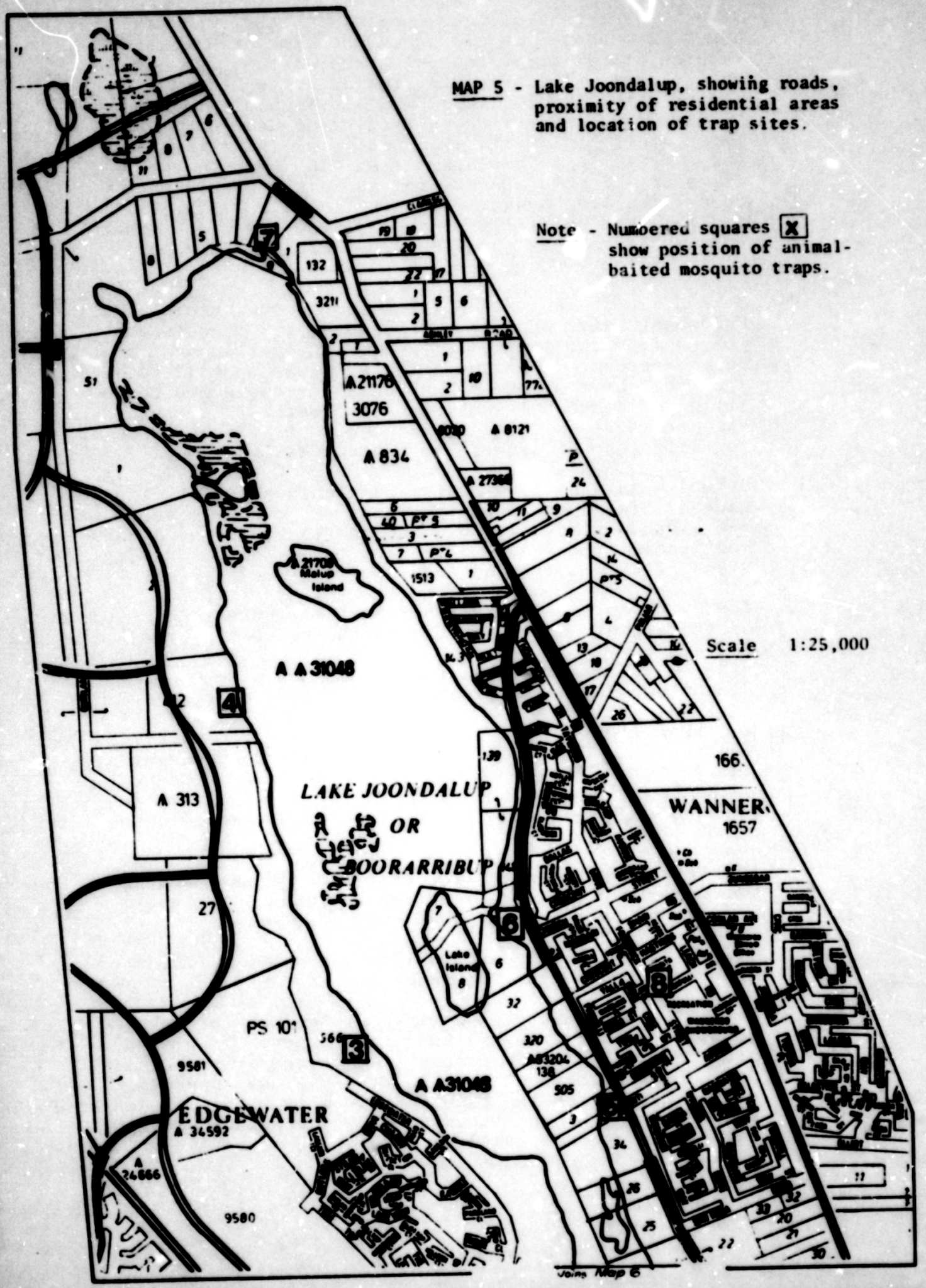
Site 5 - this site is on the lower east side of Lake Joondalup, at the termination of Ariti Avenue.

The trap was hung 2 m above the ground, from a tall Tuart tree. The site fringed an extensive sedge area, but was some 100 m from the lake edge. Dense stands of Bamboo were growing beside the site. The site was exposed to the wind, but the trap did not move in the wind.

Site 6 - the site is on the east side of Lake Joondalup opposite Lake Island. The trap was hung 1.2 m above the ground on the side of a large Tuart tree.

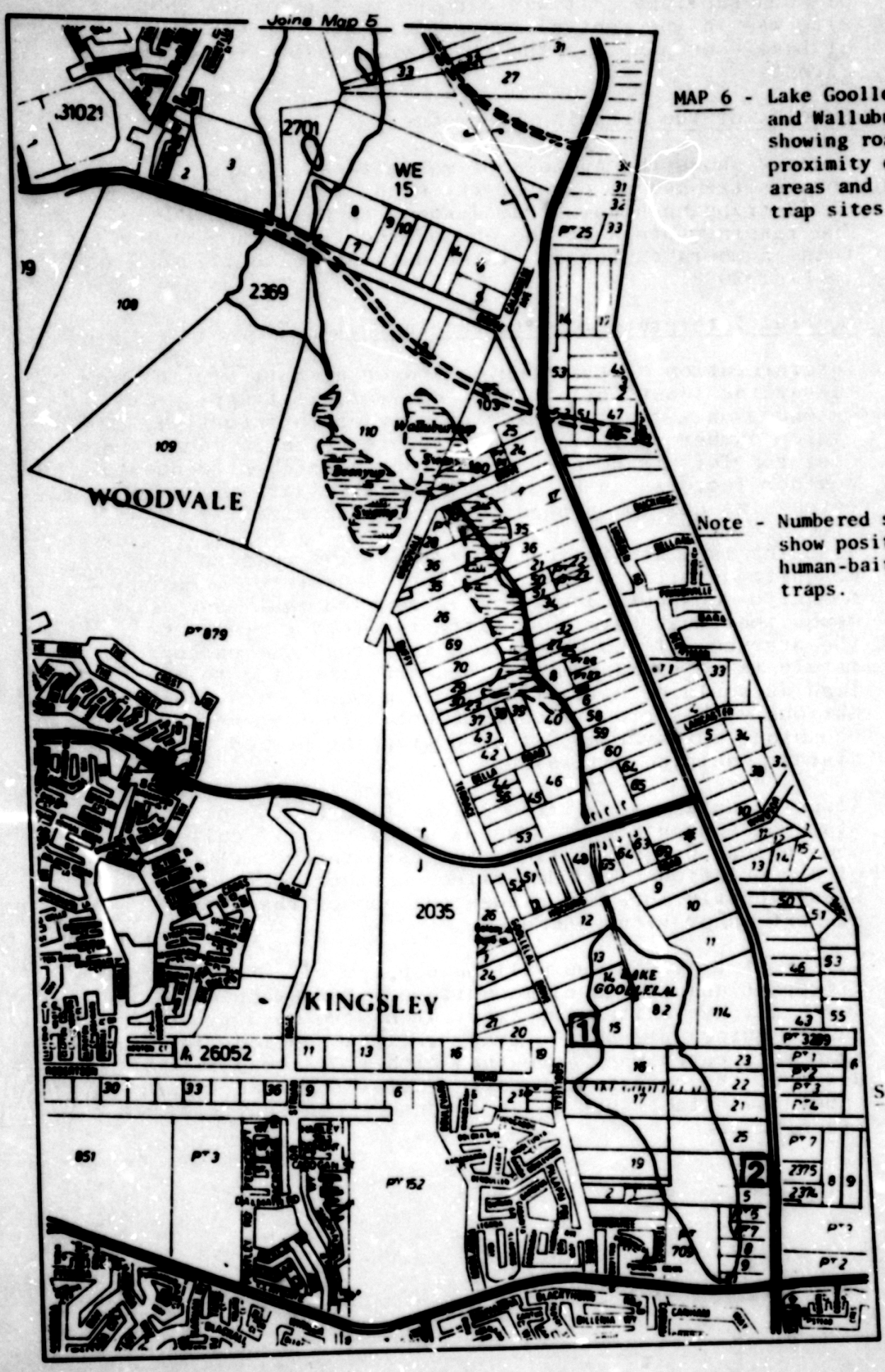
It was in a very exposed position, some 50 m from the water's edge, behind the Paperbark Woodland.

Site 7 - located at the north-east "corner" of Lake Joondalup. The trap was hung 1.8 m above the ground from the limb of a Paperbark tree on the fringe of a dense Paperbark Woodland. Initially close to pools, as the area dried the trap was 100 m from the lake edge. Between the trap and the water was a woodland of Paperbarks, and a dense stand of *Baumea*.



MAP 5 - Lake Joondalup, showing roads, proximity of residential areas and location of trap sites.

Note - Numbered squares [X] show position of animal-baited mosquito traps.



MAP 6 - Lake Goollel, Beenyup and Walluburnup Swamps showing roads and proximity of residentia areas and location of trap sites.

Note - Numbered squares ☒ show position of human-baited mosquito traps.

Scale 1:25,00

Site 8 - here the trap was some 1.5 m from the ground, hung from a Red-gum sapling, which was part of a grove of such saplings. It was exposed to the wind. The site was in the central residential area on the east side of Lake Joondalup, in the front yard of 58 Frederick Street.

5.4 Results of the Trapping Programme

Table 2 shows the numbers of mosquitoes of each species trapped at each of the eight trapping sites on 13 trapping nights from January to March, 1978. The running totals at the end of the table show the total numbers captured. These data are also illustrated in Fig. 30.

5.5 General Interpretation of Trapping Data

Interpretation of trapping data over a short period is, to say the least, difficult. However, if trapping is extended on a regular basis (weekly or fortnightly), over a number of years then interpretation is made easier. This is because variation in catch size due to weather factors can be dissociated from variations in catch size due to changes in population size.

Trapping is a statistical exercise. The chances of a mosquito entering a trap are low. Therefore, when one mosquito does get caught, it is assumed that many more mosquitoes must have been attracted to the trap. On the average, if two mosquitoes are trapped then approximately twice as many mosquitoes are attracted to that trap as would be attracted if one mosquito was caught. Obviously this proportion does not hold for every occasion, but over an extended trapping period the average would be maintained.

Trapping data gives little information as to the absolute state of a population. The data however, if collected over a long period of time, indicate the relative state of a population (i.e. determines whether there were significantly more mosquitoes one summer than were present in previous summers).

Different trap designs will be capable of catching different quantities of mosquitoes. For example, a large chicken-baited trap may catch more mosquitoes than a guinea pig-baited trap, while a suction light-trap will catch many more than either of these two. However, the comparative catch ratios (between traps) should be established so as to ensure continuity of trapping data.

TABLE 2 · Numbers of mosquitoes of four species captured in guinea pig-baited traps at eight trap-sites sampled on 14 occasions from 9 January - 9 March, 1978.

Date traps set and no. of each sp of mosquitoes caught	Number of mosquitoes captured at named trap-sites (no. of site in parentheses)								Total No. of each species
	(1) West side Lake Goollelal	(2) East side Lake Goollelal	(3) Edgewater Drive Picnic Area	(4) Quinlan Road Picnic Area	(5) Ariti Avenue	(6) Joondalup Reserve	(7) Puich's, NE Lake Joondalup	(8) Residential Area (control)	
9-10/1/78									
Coq. lin. a.	0	3	1	4	6	5	5	1	25
Cx ann. b.	0	0	0	0	0	0	5	0	5
Cx fat. c.	0	0	0	0	2	1	0	0	3
Cu. att d.	0	0	0	0	0	0	0	0	0
Total	0	3	1		8	6	10	1	33
12-13/1/78									
Coq. lin.	-	1	-		0	0	0	0	1
Cx ann.	-	0	-	0	0	0	4	0	4
Cx fat.	-	0	-	0	1	0	0	0	1
Cu. att	-	0	-	0	0	0	0	0	0
Total		1		0	1	0	4	0	6
16-17/1/78									
Coq. lin.	0	0	0	0	0	0	0	0	0
Cx ann.	0	1	0	0	0	0	2	0	3
Cx fat.	0	2	0	0	1	1	0	0	4
Cu. att	0	1	0	0	0	0	1	0	2
Total	0	4	0	0	1	1	3	0	9
19-20/1/78									
Coq. lin.	0	2	0	0	0	7	1	0	10
Cx a-n.	0	0	0	2	0	1	6	0	9
Cx fat.	0	4	0	0	2	1	0	0	7
Cu. att	0	4	0	0	0	0	0	0	4
Total	0	10	0	2	2	9	7	0	30
23-24/1/78									
Coq. lin.	0	0	0	2	1	1	0	0	4
Cx ann.	0	0	0	0	0	0	5	0	5
Cx fat.	0	3	0	0	1	0	0	0	4
Cu. att	0	1	0	1	0	0	2	0	4
Total	0	4	0	3	2	1	7	0	17
26-27/1/78									
Coq. lin.	0	1	0	1	0	0	2	1	5
Cx ann.	1	0	1	2	0	0	3	0	7
Cx fat.	0	0	0	0	0	0	0	0	0
Cu. att	0	0	0	0	0	0	0	0	0
Total	1	1	1	3	0	0	5	1	12
31/1-1/2/78									
Coq. lin.	0	0	0	0	1	1	0	2	4
Cx ann.	0	0	0	2	0	0	1	0	3
Cx fat.	0	2	0	0	0	0	0	0	2
Cu. att	0	4	0	0	0	0	0	0	4
Total	0	6	0	2	1	1	1	2	13
2-3/2/78									
Coq. lin.	0	0	0	0	0	0	1	0	1
Cx ann.	0	0	0	2	0	0	1	0	3
Cx fat.	0	4	0	0	0	0	0	0	4
Cu. att	0	2	0	0	0	0	0	0	2
Total	0	6	0	2	0	0	2	0	10
6-7/2/78									
Coq. lin.	1	1	0	1	0	5	2	2	12
Cx ann.	0	0	0	4	0	0	5	0	9
Cx fat.	0	1	0	0	0	1	0	1	3
Cu. att	0	4	0	0	0	0	0	0	4
Total	1	6	0	5	0	6	7	3	28

continued ...

TABLE 2 (concluded)

Date traps set and no. of each sp of mosquitoes caught	Number of mosquitoes captured at named trap-sites (no. of site in parentheses)								Total No. of each species
	(1) West side Lake Goollelal	(2) East side Lake Goollelal	(3) Edgewater Drive Picnic Area	(4) Quinlan Road Picnic Area	(5) Ariti Avenue	(6) Joondalup Reserve	(7) Puick's, NE Lake Joondalup	(8) Residential Area (control)	
9-10/2/78									
Coq. lin.	0	0	0	0	0	0	0	0	0
Cx ann.	0	0	0	2	0	0	1	0	3
Cx fat.	0	0	0	0	0	0	0	0	0
Cu. att	0	0	0	0	0	0	0	0	0
Total	0	0	0	2	0	0	1	0	3
16-17/2/78									
Coq. lin.	0	0	0	0	0	0	0	1	1
Cx ann.	0	1	0	0	0	0	3	0	4
Cx fat.	0	3	0	0	1	0	0	2	6
Cu. att	0	1	0	0	0	0	0	0	1
Total	0	5	0	0	1	0	3	3	12
22-23/2/78									
Coq. lin.	0	0	0	0	0	0	1	1	2
Cx ann.	0	0	0	0	0	0	0	0	0
Cx fat.	0	2	0	0	6	1	0	1	10
Cu. att	0	0	0	0	0	0	0	0	0
Total	0	2	0	0	6	1	1	2	12
1-2/3/78									
Coq. lin.	0	0	0	0	0	0	0	4	4
Cx ann.	1	0	1	5	0	0	11	0	18
Cx fat.	0	1	1	0	4	0	0	0	6
Cu. att	0	0	0	0	0	0	0	0	0
Total	1	1	2	5	4	0	11	4	28
8-9/3/78									
Coq. lin.	0	0	0	0	0	0	0	0	0
Cx ann.	0	0	0	0	0	0	4	0	4
Cx fat.	0	2	0	0	0	0	0	0	2
Cu. att	0	0	0	0	0	0	0	0	0
Total	0	2	0	0	0	0	4	0	6
RUNNING TOTAL									
Coq. lin.	1	8	1	8	8	19	12	12	69[1]
Cx ann.	2	2	2	19	0	1	51	0	77[2]
Cx fat.	0	24	1	0	18	5	0	4	52[3]
Cu. att	0	17	0	1	0	0	3	0	21[4]
Total	3	51	4	28	26	25	66	16	219
Percent of total catch	1	23	2	13	12	12	30	7	

[1] 32%
[2] 35%
[3] 24%
[4] 9%

ABBREVIATIONS - *a. Coquillettidia linealis;*
b. Culex annulirostris;
c. Culex fatigans;
d. Culiseta attra.

The population of mosquitoes is generally higher close to breeding areas. It therefore follows that catch sizes increase with increasing proximity to breeding areas. This fact may be utilised in order to locate breeding areas through the trapping of adult mosquitoes, (usually through a broad grid formation of trap sites).

Weather conditions, particularly wind direction and velocity, have an extremely important influence on trapping data, and must always be considered. Such parameters usually affect the relative number of mosquitoes trapped over a short period of time, i.e. fluctuations in number from day to day or week to week.

The micro-site of a trap (i.e. the exact positioning of a trap) is also very important and will have a variable effect on the relative size of the catch. However, such effects are usually unavoidable, (no two sites are the same), and can only be considered when analysing the results.

Finally it must be noted that mosquito species differ in their "catchability". Some mosquito species readily enter a trap, while others may be trap-shy, despite the fact that the trap is baited by an acceptable host animal.

For further discussion on the theory of trapping refer to Service (1976).

5.6 Discussion of Trapping Data (see Table 2)

The number of mosquitoes trapped appears low. These low figures must be considered as a reflection on the population size rather than on the efficiency of the trapping technique. The traps were shown to be capable of catching many more mosquitoes. Traps set at the *Cx annulirostris* breeding area north of Lake Joondalup caught up to 16 *Cx annulirostris* per trap per night. (Trapping on 24 January 1978). While this figure may still be considered low it is considerably more than the average catch per trap per night, and indicative of the fact that the capacity of the traps was not extended during the programme.

Similarly past experience has shown that the same traps may catch up to 30 mosquitoes (species - *Aedes vigilax*) in one trapping night (Blair 1977).

Therefore the low numbers are a reflection of the population size of the species involved. The low number of mosquitoes trapped in no way indicates a low population level (in absolute terms), but merely states that at a higher population level more mosquitoes would have been trapped. From this it follows that, if standard trapping procedures are followed from year to year, comparison of numbers of mosquitoes trapped in a given period in one year with those trapped in an equivalent period in another year will give a measure of the relative levels of mosquito population.

To some extent the low catches in animal-baited traps may reflect the prevailing weather conditions which were hot and dry with water levels falling within the wetlands. Although day to day weather conditions were recorded, correlations between catch-size and species content and weather parameters could not be detected. To detect relationships between trapping data and weather it will be necessary to have a greater body of data so that seasonal differences become apparent.

The range of total number of mosquitoes (all species) trapped per night, per eight traps, was 6-33. This range is attributed in part to -

(a) natural variations in trapping numbers (the variance statistic),

(b) variations in weather conditions (affecting mosquito activity), and

(c) changes in population sizes for specific species.

Unfortunately the large component of variation attributable to (a) and (b) above overwhelms any significant variation due to (c) above. This makes analysis of the data by strict statistical methods futile. However, it is possible to detect trends, the statistical significance of which can be determined when more data are available. These trends are discussed in Sections 5.6.1 to 5.6.5 below.

5.6.1 *Coquillettidia linealis*

A third of the total number of mosquitoes caught were of this species, however this figure does not adequately reflect the contribution the species makes to the mosquito population. The results would indicate it is well distributed (the only species to occur at all trapping sites) in relatively high numbers (19-76 per cent of all mosquitoes trapped at each site). The most important result is that of the comparatively high number of *Coq. linealis* present in the residential area, and adjacent shoreline regions.

5.6.2 *Culex annulirostris*

This species contributed to just over a third of the total catch. However, after examination of the results it is seen that this figure is misleading as to the status of the species within the whole mosquito situation as 91% of those *Cx annulirostris* trapped were taken from only two sites (Sites 4 and 7 on the north and north-west of Lake Joondalup).

Larval surveying indicated that after the end of December no breeding was occurring along the west, north or north-east margin of Lake Joondalup, It is therefore known that adult *Cx annulirostris* were migrating from the known breeding area 0.6 km north of the lake. The mosquitoes were traversing dry bush

to reach the northern extremity of Lake Joondalup, where they remained in highest concentration (as reflected in the high count at Site 7). From here the mosquitoes filtered down the western margin of the lake at least as far as Site 4 (Quinlan Road) where they were trapped in relatively high numbers. Presumably they also moved down the eastern margin but did not reach Site 6 in any large number.

Therefore the northern build-up of *Cx annulirostris* is accounted for.

Otherwise the species is distributed in low numbers, presumably breeding in cow hoof-prints and other disturbed areas. This species is however conspicuous by its absence from the residential area.

5.6.3 *Culex fatigans*

Cx fatigans contributed to approximately one-quarter of the total catch. Its distribution is restricted to residential, market garden and other disturbed lake fringe areas. This is reflected in the trapping results by relatively high counts at Sites 3, 5, 6 and 8, all of which were close to or within built-up areas (see Map 5).

The less disturbed or untouched lake fringe areas, with low or no residential build-up, exhibited low counts of this species. (*Cx fatigans* is not recorded at Sites 1, 4 and 7). It is significant that *Cx fatigans* was trapped within the residential area, as this confirms its status as a domestic mosquito (see Section 3.1.1).

5.6.4 *Culiseta attra*

This mosquito was only recorded at three trapping sites, and then only over a five-week period. It makes up less than 10 per cent of the catch.

It is interesting to note that *Cul. attra* was only recorded at the northern and southern extremes of the study area. Its distribution is certainly limited, and it could be that the species was migrating to the area from other lakes in the dune system. However, the relatively high count at Site 2 suggests that a small breeding site may be situated within that area.

5.6.5 Some Further Discussion

The low numbers of mosquitoes trapped at Sites 1 and 3 are accounted for by the position of the sites on the west banks of the two lakes and by the prevailing south-westerly breeze. No breeding sites were located within the western margins of the lakes. Therefore mosquitoes would necessarily have to fly, or be wind carried, from the breeding sites on the east margins. The prevailing breezes are not conducive to such passage. Results anomalous to this hypothesis occur at Site 4. The large number of *Cx annulirostris*

trapped at this site is accounted for. However, the number of *Coq. linealis* trapped at the site was also considerable.

It is useful to summarise briefly as follows :

Figure 30 has been included as a visual summary of the running total results shown at the end of Table 2. These histograms serve to highlight points that have been mentioned elsewhere :

1. The three sites close to, or in, the residential areas are sites 5, 6 and 8. At all three sites *Cx fatigans* and *Coq. linealis* are in high proportion whereas *Cx annulirostris* is either absent or occurs in only very low proportion. This is indicative of the relative pest status of the three species.

2. *Cx fatigans* was never trapped at sites 1, 4 and 7. Each of these sites, especially 4 and 7, are well removed from high-density residential areas. This confirms the domestic nature of *Cx fatigans*.

3. *Coq. linealis* had the widest distribution, being trapped at all eight sites.

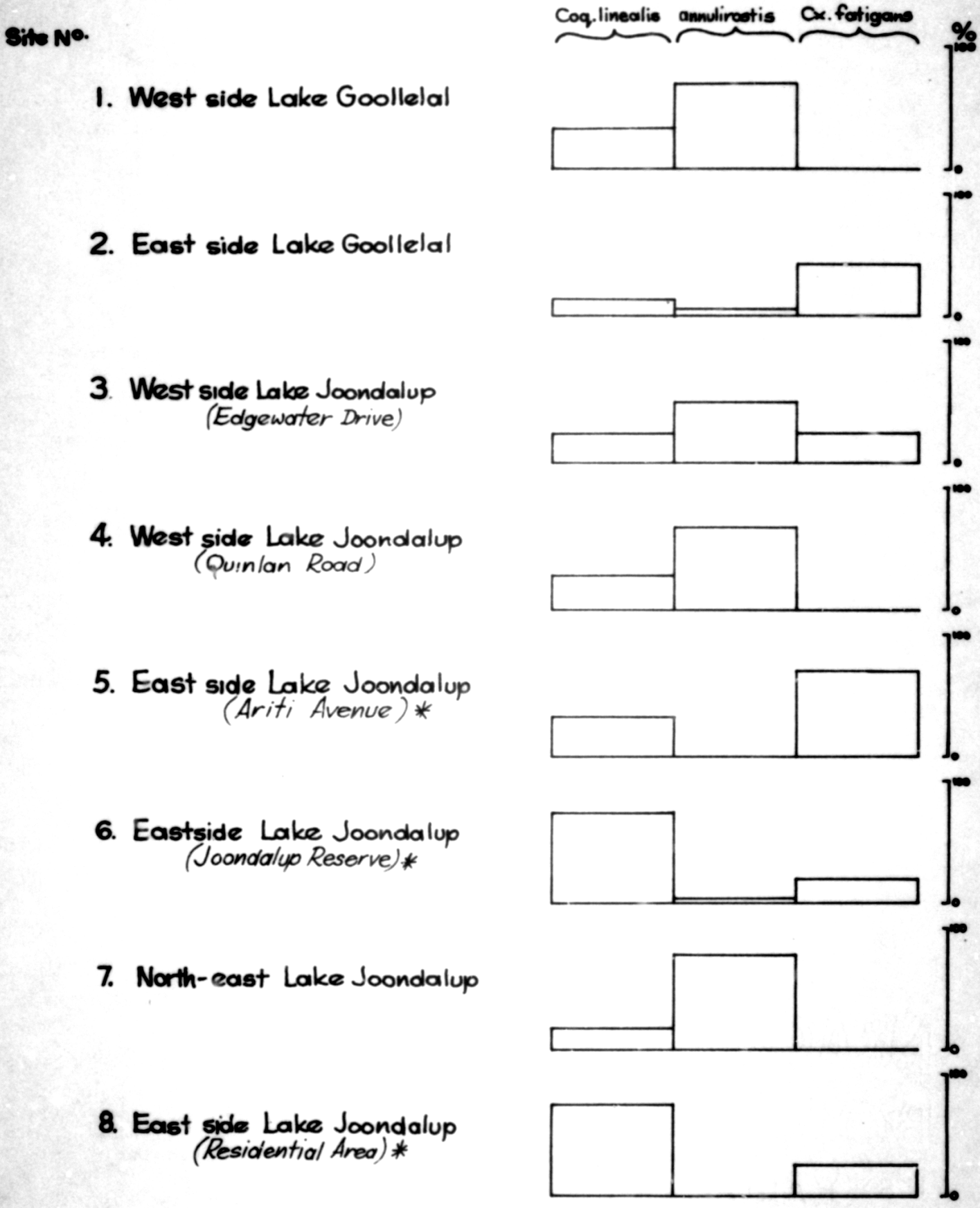
The other three species recorded during the study are not included in Figure 30 because, as stated elsewhere :

1. *Cx australicus* was not trapped because it does not bite guinea pigs (or humans).

2. *Anopheles annulipes* was not caught in guinea pig baited traps, but it was caught, in low numbers, during human-bait surveys.

3. *Culiseta attra* was caught in guinea pig-baited traps only rarely; its host preferences are not known but it is not regarded as a potential pest species.

Figure 30. *Final proportions (%) of three mosquito species trapped at each of eight trapping sites*



N.B. * *Indicates sites close to, or within residential areas.*

6. HUMAN BAIT SURVEYS FOR MOSQUITO SPECIES

Human bait surveys refer to the sampling of adult female mosquitoes by the positioning of a person to act as human host animal and the subsequent catching of all (as many as is practicable) mosquitoes landing on that person. All such surveys undertaken during the study were carried out by one person, the investigator. This type of survey indicates the human-biting mosquito species present in the area, their distribution and activity. Quantitative and qualitative data can be collected in this way.

Table 3 lists the human-bait surveys undertaken within the study area. In addition, it must be remembered that any field work within the area constitutes a human-bait survey, as a "human bait" is exposed to those mosquitoes that may be present. Therefore all larval surveys could also be regarded as human bait surveys for adult female mosquitoes. These casual observations indicated that adult, female mosquitoes do not actively host-seek within the study area during the day, except for those *Cx annulirostris* biting within their breeding area north of Lake Joondalup.

Figures 31 and 32 show the results of two human-bait surveys. These are representative of other surveys undertaken in the same manner.

6.1 Results of Human Bait Surveys

It is evident that *Coquillettidia linealis* does not actively host-seek during the day. Similarly with *Culex fatigans* and *Anopheles annulipes*. *Culex annulirostris* was found to bite during the day but only within the confines of the day-time resting place of the adults within the breeding area.

Coquillettidia linealis was the only species caught from the residential area during such human bait surveys undertaken by the investigator. However, results contained in Chapters 5 and 7 indicate that other species are present within the residential areas.

Figure 31 shows the biting activity of *Coq. linealis* on 10 January at site 6 and similar patterns were observed on all other occasions. The graph shows no activity by the mosquito until approximately ten minutes after sunset.

A maximum biting rate has been reached within 15-20 minutes. This is followed by a small decrease in activity and level off rate for some 15 minutes. Subsequently there is a dramatic decrease in activity and a long tail of activity. The surveys were terminated after two consecutive five minute intervals were reached in which no bites were received. This low biting activity is assumed to have extended well into the night. The critical period for biting activity is for approximately the first 50 minutes after sunset. Experience indicates that the high biting activity sustained in this period is extremely uncomfortable and in

TABLE 3 - Human-bait Surveys undertaken within the study area.

DATE	SURVEY SITE	DURATION	DURATION OF BITING	NUMBER & SPECIES CAUGHT
21 Nov.	Site 6	5.00 - 7.30 pm	7.15 - 7.30 pm	34 *Coq. linealis*
13 Dec.	Quinlan Rd Site 6	6.30 - 7.30 pm 8.00 - 8.30 pm	7.30 pm -	1 *Cx annulirostris*; 1 *Coq. linealis* 0: strong wind
19 Dec.	Site 6	7.00 - 8.10 pm	7.55 - 8.05 pm	1 *Coq. linealis*; 1 *Cx annulirostris*; 2 *An. annulipes*
20 Dec.	Site 2	6.30 - 8.15 pm	7.55 pm	1 *Cx annulirostris*
10 Jan.	Site 6	6.30 - 9.30 pm	7.50 - 9.30 pm	75 *Coq. linealis*
12 Jan.	Residential area	7.30 - 8.40 pm	7.53 - 8.02 pm	3 *Coq. linealis*
25 Jan.	Nofish Lake*	1.20 - 2.15 pm	1.20 - 2.15 pm	204 *Cx annulirostris*
26 Jan.	Site 3	7.25 - 9.30 pm	7.49 - 9.00 pm	33 *Coq. linealis*; 4 *Cx annulirostris*; 2 *Cx fatigans*
6 Feb.	Nofish Lake* Site 3	6.30 - 7.30 pm 7.50 - 8.05 pm	6.30 - 7.30 pm 7.50 - 8.05 pm	100 *Cx annulirostris* 3 *Cx annulirostris*; 2 *Coq. linealis*; 1 *Cx fatigans*
22 Feb.	Site 3	7.00 - 8.30 pm	7.25 - 8.15 pm	29 *Coq. linealis*
3 Mar.	Nofish Lake*	12.00 - 1.00 pm	12.00 - 1.00 pm	150 *Cx annulirostris*
7 Mar.	Nofish Lake*	11.00 am - 1.30 pm	11.00 am - 1.30 pm	150 *Cx annulirostris*
8 Mar.	Nofish Lake*	11.00 am - 1.30 pm	11.00 am - 1.30 pm	200 *Cx annulirostris*

* Nofish Lake - *Cx annulirostris* breeding habitat north of Lake Joondalup - Area Type N, Figs. 19 and 20

these surveys arms and legs were covered, the mosquitoes being caught off the feet, ankles and hands. However, the low biting rate (after 8.30 p.m.) was acceptable and caused little discomfort.

The survey conducted on 26 January 1978 (Fig. 32) shows a lower rate of activity with the inclusion of two other mosquito species. The activity peak remains similar in time.

Figure 31. Biting Frequency Histogram taken at Site No. 6 on the 10-2-78

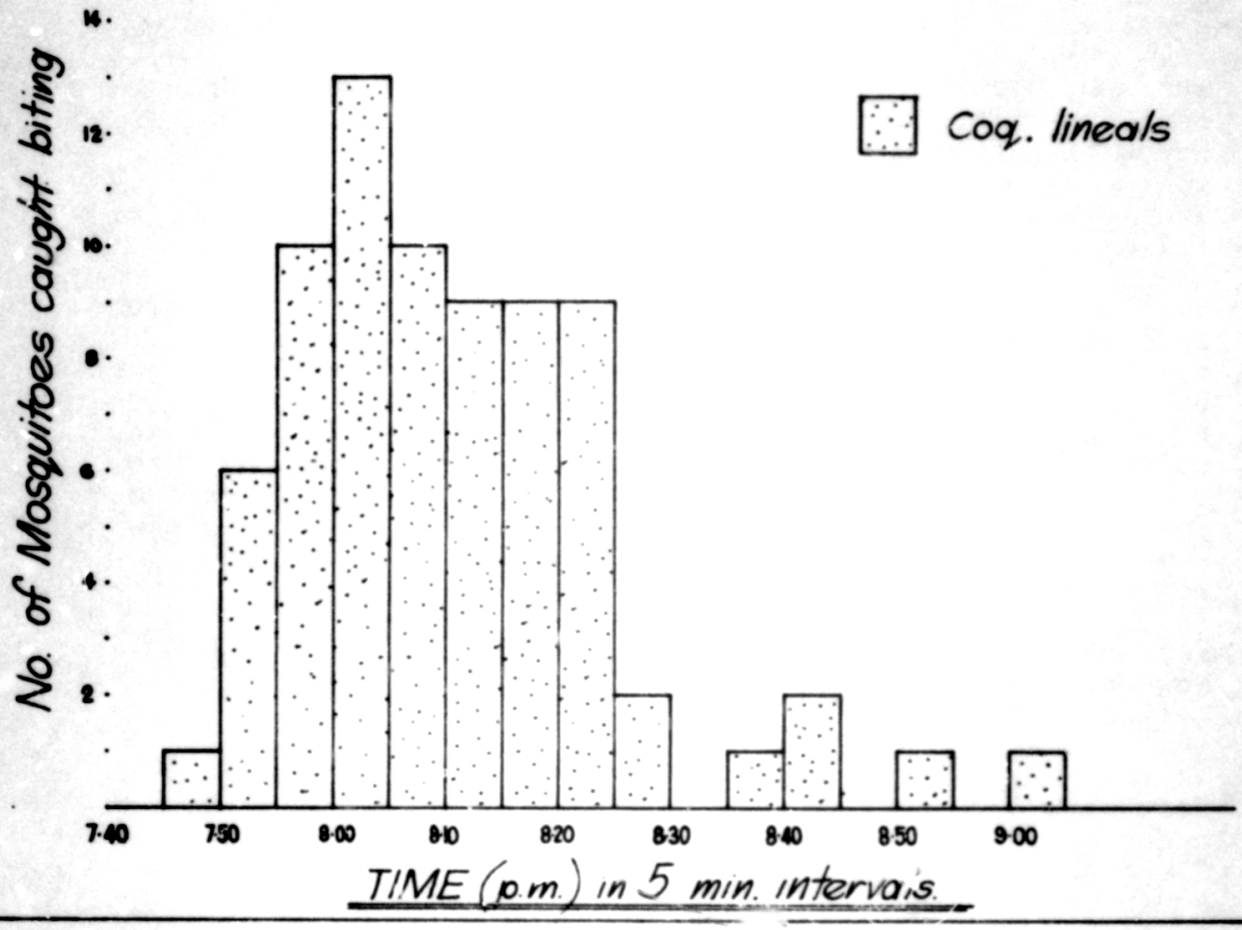
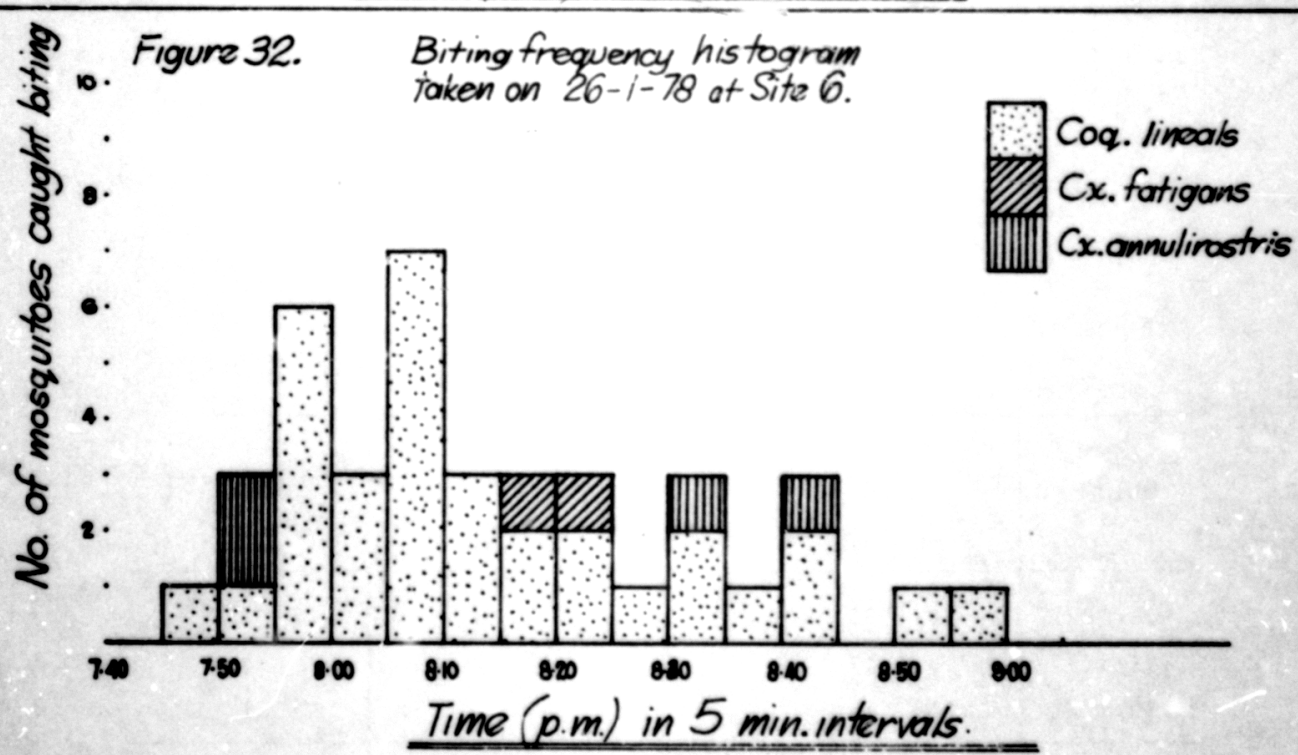


Figure 32. Biting frequency histogram taken on 26-1-78 at Site 6.



N.B. Sunset approximately 7·35 p.m.

7. SURVEY OF MOSQUITO SPECIES PRESENT IN RESIDENTIAL AREAS - DETERMINATION OF PEST SPECIES

Having identified the species of mosquito present in the study area it is important to determine the species that are invading the residential areas and causing a nuisance.

The most effective method of doing this is to ask people resident within the area to catch those mosquitoes that are biting them.

The method that has proved successful in this respect is as follows :

Small plastic vials are distributed randomly within suburbs. Accompanying each container is a broadsheet stating the aims of the study and the most effective method of catching biting mosquitoes. A copy of such a broadsheet is included (see Appendix I). The vials are distributed on one day and collected the following day, giving the residents only one evening to catch whatever mosquitoes are present. Wherever possible, contact is made with the people involved, so that some information can be gained as to the extent of the mosquito problem.

Personal contact also ensures a higher return of vials. However, in some cases vial and broadsheet are left in letterboxes.

In this way three sections of the residential area on the east bank of Lake Joondalup were sampled on three separate occasions. On 14 December 1977 thirty-eight vials were distributed between San Rosa Road and Ariti Avenue in the south of the area. On 20 December, ninety-six vials were distributed to houses north of Church Street to the northern limit of the residential area. On 18 January 1978 twenty vials were distributed to houses between Church Street and Ariti Avenue (centre block residential area).

Refer to Maps 5 and 6 for the location of residential areas.

TABLE 4 - Summary of Results from survey of residential areas, showing the number of each of three species of mosquito and the number of chironomids caught by residents on three survey dates.

DATE	SPECIES						
	Coq. linealis ♂	*Coq. linealis* ♀	*Cx fatigans* ♂	*Cx fatigans* ♀	*An annulipes* ♀	3 Species of Chironomidae
14-15/12/77	10	28	1	4	0	31
20-21/12/77	0	17	3	5	1	44
18-19/1/78	0	5	1	5	1	11
TOTAL	10	50	5	14	2	86

The results of these surveys are summarised in Table 4. Three species of mosquito were caught within the residential zone.

Coquillettidia linealis must be considered the dominant pest species.

Culex fatigans contributes to the nuisance level significantly, while the effect of *Anopheles annulipes* is considered minimal.

Householders were asked to capture mosquitoes which settled on exposed skin (see Appendix I). If this direction had been followed only females seeking a blood meal would have been represented in collections. The occurrence of a number of male mosquitoes in the collections suggests that householders captured some non-biting mosquitoes from their houses or gardens. It also indicates that mosquito populations are resting within the residential areas rather than that the females are making feeding forays from the wetland fringes.

Three species of Chironomidae (midges) were also caught during the survey. These were all subsequently identified by Dr D. Edwards of the Zoology Department of the University of Western Australia, as non-biting midges. These species do not represent a nuisance other than being attracted to lights, and it is from around lights that these specimens were taken (as was confirmed by many residents).

It is suggested here that the relatively large number of Chironomids caught in the residential surveys reflects the relatively low number of mosquitoes present in the area at the time of the surveys. With biting mosquitoes present who would sample harmless insects from around lights?

Local opinion towards the mosquito pest situation can be gauged as a spin-off from the residential surveys. With the distribution of vials and pamphlets residents are asked if they feel there is a real mosquito problem within their area. The first answer that is given is noted. The opinions of people living in the areas surveyed are divided into three levels of feeling towards the mosquito situation. The results tabulated in Table 5 are given here, not as an exacting opinion poll, but merely as the only written evidence available, that indicates to some extent the situation within the residential areas on the east bank of Lake Joondalup.

Only about 10 per cent of the 113 residents questioned thought that there was a real mosquito problem, while roughly half thought that there was no problem at all. In account of some of the opinions it is mentioned that while a minority of people actively recreate out of doors in the dusk and twilight periods many people remain indoors. Those that are regularly outside in the evening periods appear worried by mosquitoes, but not constantly. It is usually on quiet, still, warm summer nights that the mosquito problem is at its worst.

TABLE 5 - Summary of responses from residents who co-operated in surveys of residential areas in which they were asked to catch biting mosquitoes and to comment on the nature of the mosquito problem.

Area Surveyed		Opinion - The mosquito situation is a - *REAL PROBLEM*	*PROBLEM*	*NO PROBLEM*	Total No. of Respondents
Northern Area	No.	3	32	38	73
	%	4%	43%	52%	
Middle Area	No.	2	2	6	10
	%	20%	20%	60%	
Southern Area	No.	7	13	10	30
	%	23%	43%	33%	
TOTAL	No.	12	47	54	113
	%	10%	42%	48%	

Those people who stay inside are obviously not annoyed by mosquitoes and indicate that there is never a problem. Many people accept that they may be occasionally bitten by mosquitoes as a normal state of affairs.

PART III : CHAPTERS 8, 9 and 10

OVERVIEW, CONTROL MEASURES AND RECOMMENDATIONS

8. CONCLUSIONS - OVERVIEW OF THE GENERAL MOSQUITO SITUATION WITHIN THE STUDY AREA

8.1 Lake Joondalup, Lake Goollelal and Beenyup and Walluburnup Swamps

The study was undertaken in the summer of 1977-78 between 19 November and 2 March and its findings, assumptions, conclusions and predictions should be viewed with these seasonal restrictions in mind.

This was an exceptionally dry, hot summer which had followed other dry seasons. All information was gained within this period, and the prevailing conditions will obviously have affected the mosquito situation within the area.

Six species of mosquito were found to occur within the study area. Two of these are regarded as of no concern, namely *Culiseta attra* and *Culex australicus*, due to their disregard for the human host. *Coquillettidia linealis* is the dominant pest species. It is a vicious mosquito which is active at dusk (crespuscular) and attacks the host in large numbers. Unfortunately its breeding habitat has not been located. A related species, *Mansonia uniformis*, utilises Water Hyacinth, grasses and sedges in eastern Australia (Marks, 1973) but efforts made during this study failed to find the larvae of *Coquillettidia linealis* associated with these plants (see Chapter 4, p.16). Whereas *Mansonia* tends to utilise floating aquatic plants, larvae of some species of *Coquillettidia* are found in the mud among rooted plants such as Bulrushes (*Typha*) (Bates 1949). It is therefore reasonable to suggest that some future efforts to locate the breeding sites of this species be directed towards areas of *Typha*. If *Typha* is found to be utilised by the larvae of *Coquillettidia linealis* then breeding of the species can be expected to become more extensive as more of the wetland fringes are disturbed by human activities.

Coquillettidia linealis enters the residential areas in large numbers, evidenced by the residential surveys (Section 7). Both male and female mosquitoes utilise day-time resting places within the suburbs. As the males do not take blood-meals, their presence in and around houses suggests that the adults may move into, and remain in, the residential areas rather than that the females make nightly feeding migrations from the wetland fringes. In this way a large build-up in the mosquito population may occur within suburban areas, recruitment taking place from the wetland breeding areas. It must also be remembered that females must return to the breeding areas to lay their eggs.

Coq. linealis has maximal biting activity within a fifty minute period at dusk, followed by a low level of activity. It was not observed to be active during daylight hours. It cannot actively host-seek with wind velocities of around at least 10 km per hour.

The species can be trapped in animal-baited traps and its population can therefore be monitored.

Culex fatigans is regarded as the second-most important pest species. Its distribution is associated with "built-up" areas and breeding occurs in disturbed lake fringes, swamps, road drains and septic tanks (see Section 3.1.1 and Chapter 4, particularly Section 4.4). Described as a domestic mosquito, it characteristically occurs within residential areas and readily enters dwellings. Capture of both males and females within the residential areas indicates that this species is well established there. *Cx fatigans* is not as vicious a mosquito as the other species and does not attack hosts in such numbers nor with such determination as do, for example, *Cx annulirostris* or *Coq. linealis*.

Culex annulirostris and *Anopheles annulipes* are considered as lesser pest species but their pest status should be qualified. Potential breeding sites of *Anopheles* are widely distributed throughout the study area, wherever there are permanent or temporary pools (see Section 3.5). The adults are widely distributed but occur in low numbers. With an increase in the number of breeding sites, which could occur with an increase in water level, this species could become more of a pest.

During the study period *Culex annulirostris* was found to be only a minor pest species. Nevertheless, it should be considered carefully because of its high breeding potential and because it will bite viciously during the day (see Section 3.2). Breeding sites are widely distributed but the numbers of adults captured were small, except of course in the extensive breeding area north of Lake Joondalup (Type N Area, see Figs. 19 and 20). Here breeding had occurred unchecked and the species was found to be present in high density and to be migrating to the northern margins of Lake Joondalup. Measures can be introduced to control this particular situation (see Chapter 9). *Culex annulirostris*, because it will bite during the daytime as well as at night, because potential breeding sites could develop, and because it will migrate from its breeding sites, could become the most important pest species in the area.

It is assumed that, for all species, the breeding potential of the study area is far greater than the level of breeding observed during the study. This assumption is made because the summer during which the study was made was unusually hot and dry. With a wet summer many more breeding habitats would be created and held viable and high summer temperatures would be ideal for increasing larval and pupal growth rates. Under such conditions mosquito populations could be expected to be much greater than those observed in the summer of 1977-1978.

Summer conditions are not the only consideration to be taken into account. Heavy winter rainfall could increase the number of breeding sites beyond those observed during this study. Increased water levels resulting from a wet winter and spring would increase the breeding habitats and result in increased populations of adult mosquitoes, leading to a significant pest problem.

8.2 Other Wetlands in the Shire of Wanneroo

During this study, brief observation was also made of other wetland areas within the Shire. On the basis of findings made on the mosquito breeding situation in and around Lakes Goollelal and Joondalup, certain predictions may be made. It should be mentioned that the surroundings of these lakes are in less residentially developed areas. Consequent to the long dry summer the smaller of these wetlands were dry.

These observations relating to other wetlands are made on the basis of the breeding habitats of those mosquito species found at Lake Joondalup. The breeding habitat of *Coq. linealis* was not observed, and can therefore not be identified in these wetlands. However this situation provides an opportunity to investigate the breeding habitat of this species, and in particular to test the theory that *Coq. linealis* breeds in association with *Typha* species. This could be done by trapping for mosquitoes at two well separated lakes (well separated to minimise the chances of migration between breeding areas) one with no *Typha* intrusions, and one with extensive *Typha* infected areas. The trapping results would give information which may help to resolve the question.

8.2.1 Lake Mariginiup

This is a small, relatively steep-sided lake with a wide, fringing zone of *Baumea articulatum*, and a central stretch of open water. The sedge zone is variously, very dense to sparse and is some 80 - 150 m wide. There is a conspicuous absence of fringing Paperbark Woodland, the scrub and Tuart Woodland growing right down to the edge of the lake, that is immediately behind the *Baumea*.

The steep-sided nature of the lake's surroundings indicates that little mosquito breeding would occur in the main part of the lake. Added to this fact, predatory fish are present. However if breeding were to be a problem, it is suggested that it would be more pronounced at the southern edge of the lake which rises less steeply than other peripheral areas. Here water suitable for mosquito breeding (shallow, vegetated, isolated pools) may accumulate in early spring or late autumn.

Lake Mariginiup has been little disturbed by man. There have been no *Typha* infiltrations and little cattle disturbance. This situation should be maintained.

8.2.2 Lake Jandabup

This is a slightly larger lake than Mariginiup. It has steep surrounding slopes, with no fringing Paperbark Woodland and a very wide, dense, fringing zone of *Baumea* (50 to 200 m). There is a stretch of open water in the centre of the sedge. No *Typha* intrusions were observed.

This lake would be impossible to examine extensively for mosquito larvae, as the sedge is too dense and extensive. It is assumed that no breeding would occur within the dense sedge or in the main body of the lake, as fish are abundant. Breeding areas may be created on the fringe of the lake (behind the sedge zone) with increasing water levels. This assumption is particularly valid for the western margin of the lake, where evidence of cattle disturbance of the sedge stands is obvious.

8.2.3 Lake Gnangara

Lake Gnangara is one of the larger lakes. Much of the lake foreshore is white sand with only isolated patches of sedge. At the time of observation the water level was very low. When replenished with water the lake would appear as a large open expanse of water with a small fringing zone of wetland vegetation. At the northern end there is some Paperbark Woodland, with a sedge understorey, this would be, with the advent of increased water level, the most likely mosquito breeding area. It is assumed that Lake Gnangara would cause few mosquito problems.

8.2.4 Badgerup Lake

This is a small wetland with extensive *Typha* meadows and marginal Paperbark Woodland. It would probably have a small area of open water during less extreme summers. This area is seen as a potential breeding area. The residential sprawl will presumably reach the wetland in the near future. With a build-up in population, and continued degradation of the lake and surrounding swamp areas, a mosquito problem would be likely.

8.2.5 Small Wetland at the Corner of Gnangara and Sydney Roads

This area was completely dry when observed. It is a degraded wetland with extensive *Typha* meadows and some natural sedges, and is used extensively for grazing of agricultural animals. It is seen as a potential breeding area, and may cause concern if surrounding residential development is undertaken.

9. POSSIBLE CONTROL MEASURES

Control will be discussed under two naturally distinct headings, Control of Larvae and Pupae and Control of Adults.

9.1 Control of Larvae and Pupae

9.1.1 Elimination of Breeding Sites

The most basic method of mosquito control is the elimination of their breeding sites. If this can be achieved then the need for control of adults is removed. In order to eliminate the breeding sites it is first necessary to know the area thoroughly so that control measures are directed only to susceptible locations. The study area was surveyed to determine the distribution of such areas and the results of the survey are given in Chapter 4. The positions of breeding sites are shown as overlaps to Maps 3 and 4. From these maps it can be seen that the breeding sites are localised. It was found that most were associated with disturbance to low-lying areas adjacent to the wetlands. Acknowledging that mosquito breeding is promoted by such disruption of the wetland fringes, a measure of control can be achieved by :

(a) preventing cattle, sheep and horses from grazing in swampland areas, thus eliminating a large area of breeding habitat by stopping the formation of isolated pools and hoof-print and track-pools of fouled water which constitute the breeding habitat of four species of mosquitoes (see Figs. 24 and 25 for examples of such breeding sites);

(b) preventing the indiscriminate dumping of rubbish and disturbance of fringe areas, mainly caused by occupiers of land bordering the wetlands (see Fig. 26).

Breeding sites could also be eliminated by the extensive reclamation of swamplands and lake fringe areas on the eastern margins of the two lakes. This however is seen as a drastic measure which would destroy much of the wetland area and could in some circumstances create new breeding sites on the fringe of the reclaimed land. To reclaim many of the mosquito breeding habitats in this way would be met with opposition on many fronts, not least because a large part of Lake Joondalup is a Flora and Fauna Reserve. However, reclamation of particular areas may be considered worthwhile.

The western shores of Lake Joondalup and Lake Goollelal are not potential breeding areas (see Sections 4.2.1 and 4.2.12) because the banks are relatively steep and standing,pools of water are not formed away from the main water body.

9.1.2 Biological Control

This is effected mainly by larvicidal fish. The Department of Fisheries and Wildlife is attempting to restrict the spread of the introduced species *Gambusia affinis*, therefore acceptable predatory fish species should be introduced into areas otherwise unstocked. The only area unstocked with *Gambusia* identified during this study was that of the *Culex annulirostris* breeding habitat north of Lake Joondalup.

Biological control is also carried out by other predatory organisms within the wetlands (mainly crustacea and insects) and although no direct measures can be taken to increase these populations, no action should be involved which may jeopardize their standing.

9.1.3 Chemical Control

Chemical control of larvae and pupae necessitates the direct application of chemical larvicides into breeding habitats. Some of the methods available for carrying out such control are as follows:

9.1.3.1 Aerial application of granulated larvicide (e.g. ABATE). This method produces a blanket coverage of large areas with slow-release larvicide. The method is unacceptable:

(a) Because the chemical would be applied indiscriminately to breeding and non-breeding areas alike. As the breeding areas are known to be very localised such blanket applications would be both unnecessary and wasteful.

(b) Because the insecticide is not sufficiently specific to mosquito larvae and may affect other aquatic organisms, including predatory organisms (see 9.1.2), which are important components of the food of waterfowl using the wetlands, particularly the Fauna Reserve on Lake Joondalup.

9.1.3.2 Application of granulated or liquid larvicides by vehicle-mounted apparatus or by hand from a vehicle. This method is preferable to aerial application because the larvicide is applied only to known breeding sites. There are however some difficulties with application from vehicles in the study area:

(a) Many breeding habitats cannot be reached by vehicle (for example breeding sites within Paperbark Woodland on the north-east of Joondalup and Beenyup Swamp).

(b) Many habitats can only be reached by travelling over wetland vegetation (for example most of the breeding sites on the eastern shore of Lake Joondalup).

Previous experience (Blair 1977) has shown that by taking vehicles into breeding areas many new breeding habitats are formed by track marks, bog holes and wheel ruts. The damage caused is similar to that caused by grazing animals encroaching on wetland vegetation (see Section 9.1.1). The use of chemical larvicide applied from vehicles should be restricted to breeding areas close to established roadways and tracks.

9.1.3.3 Application of liquid larvicides by back-pack sprays, and application of granulated larvicide or slow-release briquettes by hand.

Using these methods of application, chemical control of larvae and pupae can be undertaken on foot. This method is only feasible for small, localised habitats. Within the areas concerned this approach would be inefficient and difficult, except for an agricultural swampland, where cattle are grazing. In such areas one man could conceivably cover enough area to control breeding, however with the presence of cattle the distribution of poisons is unacceptable. However, the mosquito breeding within these areas could also be controlled by the management of stock (Section 9.1.1).

9.1.3.4 Chemical control of road drain breeding habitats of *Culex fatigans*. This can be achieved by method 9.1.3.3 above so long as precautions are made that insecticides do not enter the lake systems.

9.1.4 Conclusions on Control of Larvae and Pupae

Control measures 9.1.1 (b) and 9.1.2 should be initiated as a matter of course. Landowners, market gardeners and farmers should be enlightened as to what may constitute a breeding habitat within their properties and prevention of mosquito breeding could be controlled in much the same way as fly control is currently undertaken.

Chemical control of larvae and pupae is not seen as an acceptable proposition for four reasons. Firstly, the breeding habitat of the main pest species (*Coq. linealis*) has not been located, therefore it is not known where the larvicide should be applied. Secondly, insecticides are poisons and should be treated as such. Introduction of such elements directly into the water has a vast effect on many other "non-target" organisms. Thirdly, breeding has been observed to be in relatively low density but over a wide area. Many areas are inaccessible by vehicle and difficult to reach on foot, making control virtually impossible. Finally such chemical control methods, if utilised would destroy a large part of the wetland environment, either by damaging the fringing vegetation or affecting non-target organisms in the lake.

9.2 Control of Adult Mosquitoes

The control of adult mosquitoes is restricted entirely to application of chemical insecticides.

Within the Wanneroo situation there are certain factors that must be taken into account in respect of this. Adult mosquitoes are widely distributed around both Lakes Joondalup and Goollelal. Breeding is occurring, and hence adults are present, within prescribed Flora and Fauna reserves. High-density residential areas are situated close to breeding areas. Diverse agricultural interests are undertaken in close proximity to wetland and residential areas, i.e. market gardening, cattle grazing, chicken raising, horse agistment, some apiary sites, etc. With these points in mind the type of insecticidal control method to be used is limited. Any control measure introduced must take into account the harmful effects on the natural, human and industrial environments while effectively curbing mosquito numbers. It is here noteworthy, that there is no acceptable control measure that will eliminate all mosquitoes. A control programme should be designed to lower the nuisance factor (if and when it arises) for the benefit of a large number of people.

The Shire of Wanneroo had, prior to this study, geared to mosquito control using Ultra Low Volume (ULV) ground application of Dibrom 14 insecticide. The equipment to be used being a LECO Mini II ULV cold aerosol generator, which is designed for dispersing insecticides at an ULV rate with droplets of optimum size. This unit, though portable, was to be mounted on the back of a four-wheel drive vehicle.

Dibrom is the registered trade mark of the Chevron Chemical Company for the organophosphate insecticide commonly known as "naled". Dibrom 14 is described as a fast-acting, short-residual organophosphate insecticide which decomposes by hydrolysis and biological degradation. It is recommended for use in four ways (1977 label recommendations).

1. By air, diluted in fuel or diesel oil to deliver 0.05 to 1 lb (22.7 g - 454 g) actual Dibrom per acre.

2. By ULV aircraft at the rate of 0.05 to 1 fl. oz. (1.2 ml - 23.8 ml) Dibrom 14 per acre.

3. By thermal foggers, diluted in fuel or diesel oil, 3.1 qts (2.95 l) Dibrom per 99 gallons (377 l) oil.

4. By ground ULV non-thermal applicators diluted in soybean oil to deliver 0.02 lbs (9.1 g) actual Dibrom per acre.

The ULV application of Dibrom 14 is a well accepted control measure in the United States and other countries and its use is well documented in such international journals as "Mosquito News", however it has seen little use in W.A., and virtual no use as a non-thermal aerosol.

The Department of Fisheries and Wildlife, under whose jurisdiction the Flora and Fauna reserves are placed, has indicated that it is opposed to the use of insecticides mixed with fuel or fuel oil, in close proximity to reserves. This is due to the effect of such solutions on the vegetation with which they contact. This immediately limits the method of application of Dibrom 14 to either method 2 or 4.

Aerial ULV application of Dibrom 14 is considered to be completely out of the question at this stage for the following reasons.

(i) Residential, industrial and agricultural areas are situated close to the wetland areas.

(ii) Most of the wetland is designated a Flora and Fauna Reserve.

(iii) The mosquito situation within the area is not seen as extremely serious.

(iv) Breeding, although widely distributed, is not extensive and only occupies a small percentage of the total wetland area, hence the adult mosquito population is not densely distributed throughout the wetland area.

(v) Aerial ULV application is designed to blanket-treat a large area, and little control can be placed on the drift and dispersion of the insecticide with consequent effects such as the killing of non-target insects (e.g. bees), effects on insectivorous birds, the spotting of automobile paint work, etc.

(vi) Effective, efficient control of mosquitoes in this situation is seen to be the localised, discrete, ULV application of insecticide under optimum conditions.

For all of the above reasons, should insecticide control methods have to be implemented within the area, then the ULV cold aerosol application of Dibrom 14 is, under the circumstances, a reasonable choice.

9.2.1 Application Strategy

It is well accepted that ULV application of insecticides should take place during periods of maximum flight activity of target pest species. Along with this, weather conditions play an important role in the

effectiveness of ULV sprays and must be considered. Wind is especially important and determines the drift characteristics of the insecticide.

Coquillettidia linealis is the major pest species and has a maximum activity period for the first one hour after sunset. It is known that the species breeds within the wetland areas and enters the residential areas on the eastern bank of Lake Joondalup. It is therefore suggested that a control zone be created between the residential and lake areas on the east of Lake Joondalup. This would be achieved by applying insecticide along a prescribed "application track" during the optimum twilight period and under suitable weather conditions. The prevailing wind direction at this time is south-westerly which will tend to carry the aerosol towards residential areas, however one component of the drift will tend to follow the lake's edge. As aerosols applied in this way are presumed to have an effective swath width of some 100 metres, the insecticide will have been largely dissipated before reaching residential areas. The area concerned, to be used as a control zone, is largely recreational land (ovals, grassed areas, etc.) and provides ideal conditions for aerosol application, i.e. no vegetation to obstruct aerosol drift. Natural surrounding bush extends north and south of the recreational zone and here four-wheel-drive tracks may initially have to be created to provide access for insecticide application.

It has been shown elsewhere in this report that trampling of vegetation can produce additional mosquito-breeding sites. As well as providing for ease of access, established tracks would be necessary to limit damage to vegetation. Control would naturally have to work in with recreational activities. It is assumed that the aerosol would be applied as close to the lake's edge as possible (i.e. behind fringing lake vegetation) however the prevailing wind would ensure that the aerosol is carried away from the lake.

Human-bait surveys and trapping results have indicated that the pest species is abundant within the recreational areas beside the lake. It is also obvious that a large component of those mosquitoes entering the residential areas must traverse this zone. This control measure is seen as a possible means of limiting the number of mosquitoes reaching the populated areas. The frequency of application, the extent of the "control" zone (north-south extensions) and the exact track to be taken are variables the importance of which can only be determined in time and with experience. Similarly the effectiveness of such a programme is unknown and will only become clear in time. However, it is proposed here as an initial step in the evolution of an effective control procedure. This proposed strategy will put some method into the difficult initiative stages and hopefully stop the random and indiscriminate application of insecticide within the area.

10. RECOMMENDATIONS TO THE SHIRE OF WANNEROO

The following recommendations are made in respect of the mosquito situation within the area.

10.1 Larval control methods suggested in Section 9.1.4 should be undertaken. The procedures, while being relatively simple to put into practice, will have the effect of limiting mosquito breeding and ultimately the size of the adult population.

10.2 It will be worthwhile, in the long term, to make some effort to locate the breeding habitat of the pest species *Coquillettidia linealis*.

10.3 In spring and early summer mosquito breeding surveys (see Section 4.1) should be carried out to determine the extent and build-up of breeding within wetland areas. Such information will give indications as to the extent of the potential mosquito problem in the summer period.

10.4 An adult mosquito trapping programme should be undertaken, so as to monitor mosquito populations. Chicken-baited traps should be set on a regular basis (see Appendix IV) throughout the year, at least, at four trapping sites. It is suggested that chickens would be preferable to guinea-pigs as they are hardier animals, are less likely to be affected by temperature extremes, and require less looking after. A supply of chickens should be easily obtained as poultry farms abound in the vicinity. There should be one trap-site at Lake Goollelal and three sites at Lake Joondalup with at least one in the residential areas. The extent of the programme is obviously dependent on the resources available, but it should be noted that the larger the programme (within reason) the more information will be available on which to make decisions.

10.5 A greater understanding of the mosquito situation may lead to a lessening of the problem. The whole mosquito problem is brought about by the nuisance factor of biting mosquitoes within residential areas, situated close to wetland areas.

It is fortunate that the pest species is limited to a short period (approximately one hour) of activity after sunset. It is similarly fortunate that such activity cannot be sustained during periods of moderate (greater than 15 km per hour) wind velocity. Residents should be educated as to these facts. Outside recreational periods may be modified so as not to coincide with the maximal mosquito activity period.

A programme to inform the public about the mosquito situation should be undertaken. Control measures are not infallible unless the wetlands are eliminated completely (an alternative no one would countenance), all stormwater is disposed of immediately and all bodies of water, no matter how small, are continually monitored. Therefore breeding will continue to occur at a low level and a few mosquitoes will continue to enter the residential areas. Unless residents are aware of these aspects of the problem and of patterns of mosquito biting activity they will tend to be critical of control measures which may appear incompletely effective.

10.6 It is important to gauge the real mosquito situation through the opinion of the people concerned (i.e. the residents). Justification for chemical control measures must be given and such justification lies only in the extent to which the mosquito nuisance worries the residents within the area. Any insecticidal control measure must benefit a large number of people before it is economically and morally acceptable on social and environmental grounds.

This point of view requires elaboration. Because of man's capacity to alter aspects of the environment by his activities he should accept responsibility for the outcome of these activities. Control of insects by the use of chemical agents is one such activity and the decision to use such methods must be taken with the clear understanding that:

(i) The effect of insecticides can never be restricted specifically to the target-organism. Chemicals may affect a range of plants and animals other than the target and the consequences of their use are not always apparent at the outset.

(ii) Those residents who dislike the use of insecticides must still suffer exposure once the insecticide is released as no one can control its movements.

The opinions of the residents, as to the standing of the mosquito nuisance factor within the area, may be openly or subtly solicited by the Shire, or given voluntarily by residents, in the form of written complaints.

The benefits of such a procedure are three-fold, in that it:

(i) provides evidence, as to the justification of insecticide use (should such a control be required), to be offered to the relevant Government departments;

(ii) provides protection, for the Shire's action, against criticism from within the Shire, as shall surely occur if spraying is undertaken; and

(iii) allows the Shire to investigate the cost-benefit aspect of a control procedure. This point is important because chemical control measures are costly both in terms of materials, equipment and manpower. Thus the question could be asked: how highly do people rate the hour or so after dusk? Is it worth some thousands of dollars to have it free from insect pests?

10.7 If insecticide control is justified and necessary, then it is recommended that the application strategy suggested in Section 9.2.1 be undertaken initially and that any necessary modification be made after assessment of its effectiveness. Such effectiveness may be gauged through opinion of residents and through the monitoring programme.

APPENDIX I

Sample broadsheet issued with vials during residential surveys.

Department of CONSERVATION and ENVIRONMENT

MOSQUITO CONTROL PROGRAMME - SHIRE OF WANNEROO

The Department of Conservation and Environment is currently working in cooperation with the Shire of Wanneroo in surveying mosquito populations in your area.

As a resident your cooperation could be invaluable.

Information is required as to the species of mosquito present in the residential areas. In particular, it is important to determine which mosquitoes, if any, are achieving pest status. Your help could contribute to the initiation of an effective and efficient mosqutio control programme.

We are distributing small plastic containers (vials) and invite you to go out of doors for a short period at sunset, or whenever mosquitoes are a problem, and catch a few of these biting pests. It is essential that the mosquitoes are caught alive and intact. The containers will be subsequently collected and the mosquitoes identified.

Technique : Mosquitoes can be caught easily using the following method:

When one lands on exposed skin, and has settled, it is caught merely by placing the uncapped vial over it. By edging the vial across the skin, the mosquito, on being disturbed, will fly to the bottom of the vial, the cap is then quickly replaced. Several mosquitoes can be caught in the one container if care is taken.

The cotton wool at the base of the vial is to protect the mosquito from extensive damage. To protect them further so that they can readily be identified, the captured mosquitoes should be left in a cool place, where they remain less active, until collected.

It would help further if the time of capture could be written on the vial.

Your help and cooperation in this identification programme will be greatfully appreciated by us, and will ultimately help you.

Any enquiries may be directed to this Department or the Health Department of the Shire of Wanneroo.

Date of Distribution of vials : .....

Anticipated Date of Collection: .....

APPENDIX II

The Maturation of Mosquito Larvae and Pupae in the Laboratory

Larvae and pupae were collected in the field by dipping, and placed in two-litre plastic containers with water, mud, debris and some vegetation (algae or small aquatic plants) from the natural breeding habitat. The density of larvae and pupae within the container varied, but often exceeded three hundred immature stages.

The containers were taken back to the laboratory where maturation took place. A food source, yeast, was often added in small quantities, however maturation could be sustained without addition of a food supplement. Presumably there was sufficient food available within the water and debris collected from the field. By no means all the larvae maintained within a two-litre container matured to adulthood.

To collect the adults as they emerged from the pupal stage a catching chamber was placed over the two-litre container. From the catching chamber adults could be pooted[1] out. In this way adults were collected for identification and experimentation.

One problem with this method however was the stagnation of the water collected in the field. While the water contained nutrients necessary for growth, its confinement utlimately lead to stagnation and fouling, thus killing all the larvae that had not matured. To avoid this situation the clear water and larvae were separated from the mud and debris using a large plastic funnel. This was an effective but time-consuming method.

[1] A pooter is a length of plastic tubing with a sieve fitted, used to suck up mosquitoes. It is commonly described as an aspirator.

APPENDIX III

Maintenance of Adult Mosquitoes in the Laboratory

It was necessary, during the study, to maintain adult mosquitoes within the laboratory. Adults were both laboratory reared and caught in the field. Adults of the *Cx annulirostris* and *Cx fatigans* species were maintained in a constant temperature room at 25^{0}C and 50 per cent relative humidity, contained within two-gallon plastic buckets. The buckets were modified with fixed netting covers over the open ends and access holes (12 cm in diameter) cut in the sides. Each access hole was sleeved with a stocking length to prevent escape of the mosquitoes. The adults were fed a 10 per cent honey/water (by volume) solution. Cotton wool balls soaked in the solution were placed on the netting covers of the buckets, from where mosquitoes could siphon the solution.

The most success was gained with adult *Cx annulirostris* females caught in the field. These specimens could be maintained in the constant temperature room for over 10 days. A small percentage was lost each day presumably due to natural deaths. (The samples being a random cross-section of the natural population).

APPENDIX V

Construction of a Chicken-Baited Trap

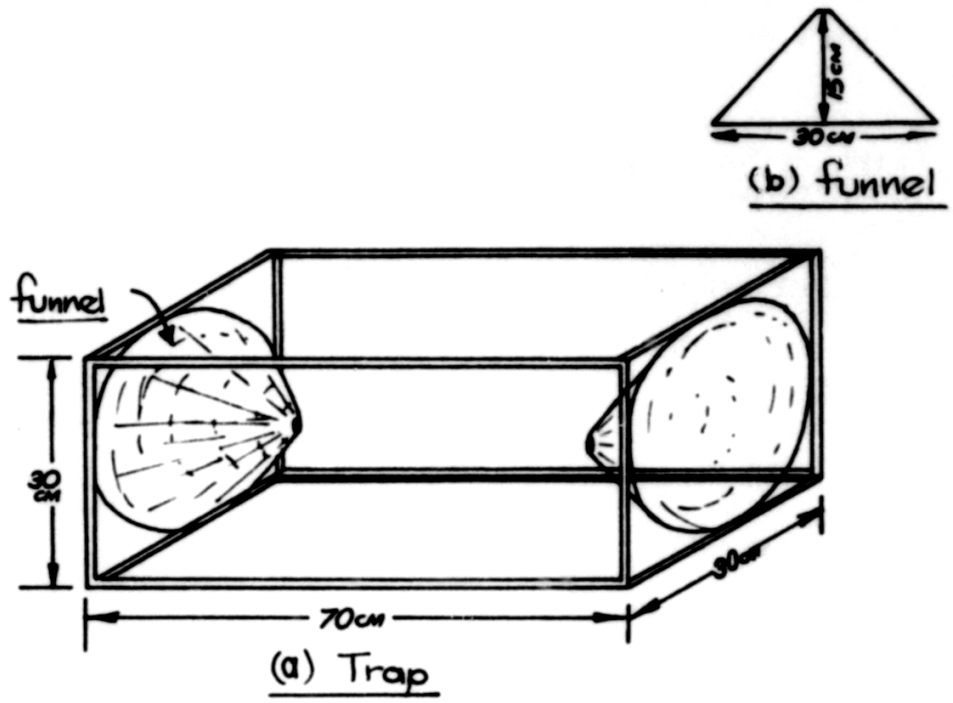


FIG. 1 - Diagram showing the form and dimensions of a chicken-baited trap.

The dimensions of the trap are given above.

The frame should be of light metal preferably aluminium. The netting should be metal, not plastic which will be pecked to pieces by the chicken. The base of the trap can be either sheet metal or a grating covered with netting. The lid or top of the trap should be hinged to allow for easy placement and removal of the bird. Within the lid should be a sleeved hole at least 14 cm in diameter (big enough to fit a hand through). This is to allow for the removal of the mosquitoes. The ends of the trap should be pyramidal, the apex having an entrance hole 2.5 cm in diameter. The base angle of the pyramid could be as steep as 45^0 as shown in the diagram, however the base angle should be no less than 30^0, so as to ensure a relatively steep-sided entrance funnel.

Construction of traps is variable but the following factors should ideally be achieved.

- lightweight
- maximum exposure of bait animal, i.e. no closed-in sides
- easy access to bait animal
- easy removal of mosquitoes
- low cost

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