INVESTIGATIONS INTO MORE EFFECTIVE CONTROL OF NUISANCE CHIRONOMIDS (MIDGES) IN METROPOLITAN WETLANDS, PERTH, WESTERN AUSTRALIA

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1988

Investigations Into More Effective Control of Nuisance Chironomids (Midges) in Metropolitan Wetlands, Perth, Western Australia

A Report on Studies from September 1987 to May 1988

Prepared for The Midge Research Steering Committee

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May 1988

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Acknowledgements

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This study was funded jointly by the three State Government and six local authorities listed above and the support of these organisations is gratefully acknowledged. This study was initiated and guided by the Committee and the individual members, who are listed below, are thanked for their interest, constructive comments and assistance in many ways throughout the course of the study.

Midge Research Steering Committee

Mr J. Lane	CALM (Chairman)
Dr R. Humphries	EPA (Co-chairman)
Mr A. Moore/Mr C. Watts	SPC
Ms J. Boyer/Mr C. Spasesk	SPC
Mr J. Stubbs	City of Armadale
Mr D. Ashby/Mr P. Oorjitham	City of Cockburn
Mr A. Smith/Mr G. Dunn	City of Melville
Mr A. Van Leeuwen	City of Perth
Mr J. Sutton	City of Stirling
Mr R. West	City of Wanneroo
Dr D. Edward	University of W.A.

The Chairman, Mr Jim Lane, and Co-Chairman, Dr Bob Humphries, are especially thanked for their close involvement and interest in the study from its onset.

Members of each of the six local authorities assisted by carrying out the collection of adult midge samples from residents living near each of the study lakes and also supplied information on the spraying histories of the lakes. Perth and Wanneroo City Councils continued their existing midge larval sampling programmes and provided us with samples of their collections for identification. Perth City Council generously provided materials and expertise for the design, construction, placement and removal of the enclosures used in the Lake Monger pesticide trial. Cockburn City Council donated temephos pesticide for use in the laboratory trials.

Many individuals and companies provided information and samples of pesticides for use during the study. We are grateful to Mr S. Broadbent (Wellcome Australia) and Mr B. Brunsdon (J.B. Brunsdon and Co.) for their assistance and also to the following companies: Robert Linton, Nufarm

Chemicals, Bayer Australia, Dow Chemicals and Sandoz Australia.

Dr D. Cooper (Waite Agricultural Research Institute) and Mr G. Pearson (CALM) provided technical information relevant to the laboratory pesticide trials. Mr B. McDougall (Murdoch University), Mr J. Kite (Water Authority of Western Australia) and Mr D. James (of Forrestdale) supplied data on changes in lake depths. Mr R. Emery (Department of Agriculture) assisted with probit analyses. Dr D. Macey and Dr R. Hilliard (Murdoch University) carried out electrofishing at Lake Monger. Many residents participated in the adult nuisance assessment programme and allowed us to place thermometers on their properties. The Centre for Water Research Nutrient Laboratory at the University of Western Australia carried out nutrient analyses of water samples and meteorological data was obtained from the Bureau of Meteorology.

We are grateful to Ms N. Hill for her enthusiastic involvement in the project for four months over the summer period. Ms V. Wilson, Ms B. Wienecke and Ms C. Williams are thanked for their sorting of larval samples. Ms S. Balla was involved in the initial stages of the project and drew the adult midge and larva featured on the cover. Mr S. Rolls helped with computer-related problems and Mr M. Lund provided data on his laboratory rearing of midge larvae. Mrs C. Hubbard and Mrs L. Hood typed part of the manuscript.

The study was carried out in the School of Biological and Environmental Sciences at Murdoch University and the provision of laboratory facilities, vehicles and other logistical support is gratefully acknowledged.

SUMMARY

1. A Midge Research Steering Committee was established in Perth in August 1987 to oversee research into more effective and environmentally acceptable methods of reducing the nuisance caused by non-biting midges (chironomids) to nearby residents of Perth's major wetlands. The Committee was formed in response to concerns about the decreasing effectiveness, increasing cost and potentially harmful environmental effects of midge control methods.

The Committee comprised representatives from six local authorities responsible for midge control in the Perth area; the Cities of Armadale, Cockburn, Melville, Perth, Stirling and Wanneroo and three State Government departments; the Environmental Protection Authority, the Department of Conservation and Land Management and the State Planning Commission plus a specialist scientific advisor from the University of Western Australia. Research into the midge problem has been carried out by our study team (J.A. Davis, S.A. Harrington and A.M. Pinder) in the School of Biological and Environmental Sciences at Murdoch University from September 1987 to May 1988.

2. A literature review was carried out to appraise available and potential midge control options. This task was given the highest priority because information was required by local authorities for the planning of control measures for the spring and summer of 1987/88. On the basis of available literature and information obtained from pesticide companies two organophosphates, Abate (temephos) and Dursban (chlorpyrifos), appeared to be the most suitable chemical control options for 1987/88 because of low cost, availability in granular form, effectiveness and low toxicity to mammals and birds. Only Abate is currently registered for use against midges in Western Australia although other compounds may be used for trial purposes if approved by the Health Department of W.A.

3. Laboratory trials were carried out to determine the susceptibility of larval midges to Abate (temephos), Dursban (chlorpyrifos) and Teknar (Bti). The effectiveness of these pesticides was found to vary with different species and for the same species from different lakes. Abate was ineffective against *Chironomus australis* at the rates currently recommended for field use (75-150gAI/ha) and the results obtained for *C. intertinctus* and *C. alternans* were variable. Resistance to Abate appears to have developed in these species.

Abate produced a mortality of 96% in larvae of the major test species, *Polypedilum nubifer*, in the laboratory. However monitoring of larval densities of *P. nubifer* before and after Abate treatments at North Lake indicated that only the first spraying resulted in a comparable mortality rate (80%) in the field. Subsequent sprayings appeared to be ineffective in reducing larval numbers. The decrease in effectiveness of Abate against *P. nubifer* after successive treatments suggests problems with resistance and

indicates that an alternative to Abate must be found for the 1988/89 summer.

Dursban 480 (chlorpyrifos) achieved 95% to100% mortality in *C. australis*, *C. intertinctus* and *C.alternans* at rates low enough to be used in the field. On the basis of laboratory trials and field tests at Lake Monger this pesticide would be an effective short-term alternative to Abate. Disadvantages associated with the use of this pesticide however include its high toxicity to the non-target fauna and that, similar to Abate, problems with resistance will develop.

Teknar (Bti) caused high mortality in two species, *C. intertinctus* and *C. alternans*, but not in *C. australis*. From an ecological viewpoint the use of Bti and IGR's (Insect Growth Regulators) would be much preferable because these compounds have low toxicity to other fauna apart from some species of Diptera. Overseas researchers have had variable results with the use of Bti to control midges but some success with IGR's and synthetic pyrethroids. Given the urgent need to find an alternative to Abate we suggest that laboratory and field trials be conducted on at least one synthetic pyrethroid, one IGR and Bti (if available in a granulated form) prior to the summer of 1988/89.

4. Field trials of the susceptibility of *C. australis* to Dursban (chlorpyrifos) were conducted using enclosures at Lake Monger with the assistance of the Perth City Council. Chlorpyrifos was found to be effective in reducing larval densities in the field and the field results corresponded well with the results achieved with the same dose rate in the laboratory. Field enclosures similar to those used at Lake Monger (but of a more flexible design to allow for changing water levels) should be used for field trials of pesticides and as control areas for spraying programmes conducted in 1988/89.

5. A regular (fortnightly) larval monitoring programme was conducted at four lakes, Booragoon Lake, Forrestdale Lake, Jackadder Lake and North Lake, by the Murdoch study team during the spring and summer of 1987/88. Physico-chemical and nutrient data were also recorded for each sampling occasion. Regular larval sampling programmes were also conducted at two lakes, Lake Goollelal and Lake Monger, by the Wanneroo and Perth City Councils respectively. Representative samples of larvae from these programmes were given to the Murdoch study team for identification. Information on the life histories of the major species present as larvae in each lake was obtained by measuring head capsule widths of larvae collected in the monitoring programmes. A qualitative adult sampling programme and assessment of midge nuisance levels was conducted by a small number of residents near each lake who collected adult midges from their houses each week and completed midge nuisance level score sheets. This component of the study was coordinated by members of each of the local authorities on the Midge Research Steering Committee.

6. The occurrence of peaks in larval abundance and the pattern of change in larval abundance and species composition differed at each of the lakes studied. *C. alternans* was the most abundant larval species at Booragoon Lake, *C. australis* at Lake Monger and *P. nubifer* at Jackadder Lake, North Lake and Lake Goollelal. Species dominance changed over time at Forrestdale Lake with four species, *C. australis*, *Dicrotendipes conjunctus*, *P. nubifer* and *Tanytarsus fuscithorax* becoming dominant in succession. *P. nubifer* was the major pest species and densities of larval *P. nubifer* recorded at a lake had a direct relationship to the levels of adult nuisance occurring in lakeside suburbs. Suburbs adjacent to lakes with low numbers of *P. nubifer* and other larval chironomids (Booragoon and Jackadder) experienced virtually no midge problems whilst suburbs adjacent to lakes with higher numbers of larvae (North and Forrestdale) experienced moderate to extreme problems. In addition to *P. nubifer*, adults of *C. intertinctus* and *T. fuscithorax* were also recorded in pest proportions on some occasions.

7. The threshold level for densities of larval *P. nubifer* which resulted in nuisance swarms of adults was found to be approximately 2,000 larvae/m^2 or greater. This result indicated that if larvicides are to be used effectively a lake should be treated as soon as densities of *P. nubifer* reach 2,000 larvae/m^2 and on subsequent occasions thereafter when this level is exceeded. This approach requires that a regular larval monitoring programme must be undertaken at lakes where a midge problem is anticipated.

8. Larvae of *P. nubifer* are most abundant in the littoral (near-shore) regions of permanent (deeper) lakes and more evenly dispersed across shallower lakes. As a consequence, monitoring and treatment programmes should focus on the littoral region of permanent wetlands for maximum effectiveness.

9. All larval populations sampled tended to be dominated by relatively large numbers of fourth (last) instar larvae. This is a consequence of the fact that half or more of the life cycle of *Chironomus* spp. and other chironomids is spent in the fourth instar. First and second instar larvae were not well represented. First instar larvae are usually planktonic and would not have been sampled by our methods (coring). Second instar larvae were probably too small to be detected by the sorting methods used. No synchrony of development was detected in the species studied although a greater sampling frequency may have been needed to detect synchrony in *P. nubifer* which has a life cycle of three to five weeks at summer temperatures.

10. The results obtained in this study support previous suggestions (Ali, 1980) that high midge densities occur as a response to nutrient enrichment. A definite cause and effect relationship has not been established by this study but the lakes at which midge problems occurred, North Lake and Forrestdale Lake, were the two most enriched lakes. In addition, the peak in abundance of larvae of *P. nubifer* that occurred in North Lake in early December may have been a response to the algal bloom that had occurred at the lake in late October. The subsequent breakdown of this bloom would have provided a large food source to the larval midges inhabiting the lake sediments. Similarly, the peak in abundance of larvae of *P. nubifer* at Forrestdale Lake in early January may have been a response to the algal bloom that occurred at the lake in late November.

11. Short term options for the control of midges in 1988/89 include the use of an alternative pesticide to Abate and the timing of treatments to take place when densities of larvae of *P. nubifer* reach 2,000 larvae/m^2. This approach requires that a regular larval monitoring programme be conducted and that control enclosures be set up to enable the effectiveness of treatments to be properly assessed. This approach should be trialled in at least one lake and would be most profitably applied to North Lake, Lake Monger and Forrestdale Lake, given their history of midge problems. Light traps also appear to have the potential to be effectively employed in midge control in 1988/89.

12. Longer-term approaches to midge control include the urgent need for the reduction of nutrient inputs to lakes and prevention of large algal blooms. Possible approaches include the reduction or treatment of enriched drainage waters, changes in land-use activities in lake catchments (agricultural, horticultural and parks and gardens fertiliser practices may need to be modified), the planting of fringing rushes to act as natural nutrient filters and species such as *Melaleuca* to increase the tannin content of lake waters, and within-lake manipulation, such as the removal of enriched sediments or sediment capping.

The replanting of vegetation around lakes is also a longer term option that must be given high priority. Midges are passive fliers and the capacity of fringing vegetation to act as a physical barrier to prevent the passage of adult midges from the immediate lake environs to nearby housing is considerable. A well developed band of fringing vegetation may also serve to keep lakes cooler. This is important because the growth of the pest species *P. nubifer* is favoured by warmer water temperatures.

INTRODUCTION

Non-biting midges (chironomids) have a world-wide distribution and occur in both running waters (streams and rivers) and standing waters (lakes and wetlands) and waters that range from fresh to saline. Larval chironomids are a major component of the invertebrate fauna of the wetlands of the Swan Coastal Plain and the adults often form large nuisance swarms in the suburbs adjacent to wetlands during the warmer summer months. Many of the urban wetlands are treated for midge control during spring and summer with an organophosphate pesticide, Abate (temephos). Poor results in recent years have indicated that the effectiveness of this pesticide is decreasing. The potential for insect populations to develop resistance to pesticides is well known and the length of time over which some wetlands have been treated (10 years or more) suggests that resistance may have developed. Some evidence also indicates that the worst midge problems are experienced near lakes that are excessively nutrient-enriched. Nutrient enrichment is a consequence of the urban and semi-rural land use activities occurring within lake catchments. Midge problems are not unique to Perth and elsewhere in the world such problems have been linked to poor water quality (Ali, 1980).

A Midge Research Steering Committee was established in Perth in August 1987 to oversee research into more effective and environmentally acceptable methods of reducing the nuisance caused by non-biting midges to nearby residents of Perth's major wetlands. The Committee was formed in response to concerns about the decreasing effectiveness, increasing cost and potentially harmful environmental effects of midge control methods.

The Committee comprises representatives from six local authorities responsible for midge control in the Perth area; the Cities of Armadale, Cockburn, Melville, Perth, Stirling and Wanneroo and three State Government departments; the Environmental Protection Authority, the Department of Conservation and Land Management and the State Planning Commission plus a representative from the University of Western Australia.

Research into the midge problem has been carried out by our study team (J.A. Davis, S.A. Harrington and A.M. Pinder) at Murdoch University from September 1987 to May 1988. The objectives of our study were:

1. To review the relevant literature and to appraise available and potential control options.
- This task was given the highest priority because information was required by local authorities for the planning of control measures for the spring and summer of 1987/88. A written report was provided to the Committee by September 30 1987 and an updated description of this component of the study is provided in this report.

2. To design and conduct laboratory trials to assess the effectiveness of Abate (temephos) and other available larvicides which, on the basis of the literature review, appeared to be the most promising.

3. To design and conduct field tests of larvicides.

4. To undertake a regular monitoring programme to assess larval densities in selected urban wetlands.
- The major aims of this component of the study were to determine the species composition and abundance of larval populations in selected wetlands and to determine the population dynamics of the most abundant species. The influence of temperature and other environmental parameters on development rates and adult emergence would also be investigated. The results of this part of the study would be used to improve the timing of the application of larvicide-based control measures. Consideration would also be given to the development of simple cost-effective methods to monitor larval numbers which would be suitable for use by local government staff.

5. To identify nuisance species.
- This would be achieved by sampling adult midges near selected wetlands to determine species composition and abundance and by seeking an assessment of nuisance levels from nearby residents. The combined results of objectives 4 and 5 would improve the knowledge of the population dynamics of the pest species and determine whether the onset of nuisance swarms can be reliably predicted from a knowledge of larval densities.

6. To commence preliminary investigations into longer-term control options.
- These studies include the investigation of eutrophication control, vegetation buffer zones and light traps. Incorporated with these studies is the necessity to investigate the influence of nutrient enrichment, temperature, water depth and other environmental factors on chironomid production, development rates and timing of adult emergence. These studies are necessary to enable predictively-based control programmes to be established, however the data obtained from this study alone would not be sufficient for this purpose. Rather, data sets that span a two or three year period are required for this purpose because environmental conditions may vary considerably from year to year.

This study represents library research, laboratory pesticide trials and field sampling carried out over the 8 month period from September 1987 to April 1988. Some aspects of the study, for example a quantitative assessment of adult emergence and further replication of laboratory toxicity trials, needed more time than was available in this study. A more intensive study of some of these aspects will be undertaken in 1988/1989.

LITERATURE REVIEW AND APPRAISAL OF CONTROL OPTIONS

INTRODUCTION

The following information on options for the control of chironomids (midges) in Perth wetlands during the spring and summer of 1987/1988 was compiled over the three week period, 2 September to 25 September, 1987, to fulfil the immediate requirements of the Midge Research Steering Committee. A verbal report and discussion of this information was presented at the meeting of the Steering Committee on 30 September, 1987.

Since that time, further information which has come to hand from companies and inter-library loans has been incorporated into this review, resulting in an updated version which is presented overleaf. An appraisal of the effectiveness of a prototype light trap made to a design presented here, is also included.

Information was obtained from both a rapid assessment of scientific papers referenced in two key review articles and library searches, and from consultation with individuals and companies. A detailed list of these sources is given later in this chapter.

For ease of interpretation, all of the information obtained for the main chemical and biological control options is summarised on one page, the 'Summary Table' (Table 1). The more detailed information on which this table is based is presented in tabular form (Tables 2 to 12) on the following pages. A separate page is devoted to each main option.

Information pertaining to the registration of various chemicals is given after the 'Control Options' section.

At the present time, only one compound, 'Abate' (temephos), is registered for use against chironomids in Western Australia. However the Health Department of Western Australia has indicated that temporary registration, at least on a trial basis, should be possible for most of the compounds listed in this report.

Samples of most of the compounds listed in the Summary Table have been obtained and laboratory testing of several of these (temephos, chlorpyrifos and Bti) was carried out at Murdoch University. Further compounds could be tested in the latter half of 1988, depending upon the recommendation of the Steering Committee.

SOURCES OF INFORMATION

LITERATURE

1. Key papers used as starting point:

Ali, A. (1980). Nuisance chironomids and their control: a review Bull. Ent. Soc. Am. **26** : 3-16.

Blair, A. (1979). Control of mosquitoes and non-biting midges in Perth and outer urban areas. Department of Conservation and Environment, Western Australia. Bulletin No. 66. 75 pp.

2. On-line computer search using Aquatic Science Abstracts

Keywords: Midge and Chironomid and Mosquito with Insecticide and Larvicide
Midge and Chironomid and Mosquito with Biological control and *Bacillus thuringiensis*

Cost: $201 (on-line cost) and $150 (cost of 293 Abstracts generated).

3. Manual search of Biological Abstracts from 1985 to 1987 (Vol. 84 No. 1)

Keywords: Chironomid(ae), Larvicide

4. Libraries visited: Murdoch University Library
Department of Agriculture Library
Department of Health Library

5. Inter-library loans obtained where necessary.

6. Personal communication:

Mr Peter Liehne - Senior Medical Entomologist
Commonwealth Department of Health
- advice on mosquito and midge control

Ms Karen Brain - Pesticides section
Department of Agriculture, Western Australia

- Advice on pesticide registrations - as given on separate sheet overleaf

Mr Steve Broadbent - Wellcome Australia

Mr Michael Cousins - Health Department, Western Australia

- Advice on temporary registration of pesticides
- As given on summary

7. Companies

As given on separate sheet overleaf

COMPANIES CONTACTED FOR INFORMATION ON CHEMICAL/BIOLOGICAL MIDGE CONTROLS

Diazinon 'Neocid 200P'	Ciba Geigy Australia Ltd 105 Sheffield Road Welshpool Ph: 451 8711	Supplied some information but suggested we contact Robert Linton, the supplier
	Robert Linton Pty Ltd 55 Canning Highway Victoria Park Ph: 361 6922	Information on prices, etc.
Fenthion 'Baytex 550' 'Baytex Dust'	Bayer Australia Ltd 76 Oats Street Carlisle Ph: 361 5466	Price, application rates, etc.
Maldison 'Maldison ULV'	Nufarm Chemicals Pty Ltd Mason Road Kwinana Ph: 419 2199	Price, application rates, etc.
Chlorpyrifos 'Dursban 480' Granules	Dow Chemical (Aust.) Ltd 58 Kishorn Road Applecross Ph: 364 7777	All information on 'Dursban 480' except wholesale prices. No information on granules, except that they are available if needed.
	David Gray and Co. Pty Ltd Rawlinson Street O'Connor Ph: 337 4933	Price information
Methoprene 'Altosid'	Sandoz Australia Pty Ltd 33 Ryde Road Pymble NSW 2073 Ph: (02) 498 1799 (Mr Leyland Minter, Crop Protection Section)	Contact 'Zoecon' - the Consumer and Animal Health Division of Sandoz

Bti	Biocontrol Limited PO Box 515 Warwick Qld 4370 Ph: (076) 614 488 (Mr Stephen Sexton)	Granules - experimental stage of production only - for mosquitoes (floating granules)
	Robert Linton Pty Ltd 55 Canning Highway Victoria Park Ph: 361 6922	Supplier of Teknar in W.A. To supply information.
	Wellcome Australia 53 Philips Street Cabarita NSW 2137 Ph: (02) 736 0666	Referred us to Biocontrol for information on Bti granules
	Sandoz Australia Pty Ltd 33 Ryde Road Pymble NSW 2073 Ph: (02) 498 1799 (Mr Leyland Minter and Mr Philip Morrow, Crop Protection Section)	To send Teknar and information on application, etc.
	Biochem Products USA 5 telephone numbers	Contacted re Bti formulations - Bactimos Briquets, Granules, Wettable Powder, Flowable Concentrate. Appear to be out of business.
	Salisbury Laboratories USA	Contacted re Bti formulations - forwarded copy of telex to sister company Duphar B.V. in Holland
	J.B. Brunsdon and Co. PO Box 192 Newport Beach NSW 2106 Ph: (02) 991 768	Australian agent for Duphar
	Ray Davidson Ph: (09) 531 2022	Development of Bti briquettes

Table 1.

SUMMARY TABLE (Abbreviations: Effectiveness Rating: +++ = high, ++ = moderate, + = low
Recommendation: ** = to be tested now, * = may be tested later)

Insecticide	Availability	Price/ha (excluding diluents) for midge	Effectiveness Against Chironomids	Effects on Non-Target Organisms	Lab. Testing

Table 2.
CHLORPYRIFOS (DURSBAN) - Organophosphate (00-diethyl 0-3,5,6-trichloro-2-pyridyl phosphorothioate)

Availability: Dursban 480 (Emulsifiable concentrate) (480g/L) - produced by Dow Chemicals (Aust.) Ltd. - available from Gray and and Co. Pty. Ltd.
Granules - produced by Dow Chemicals (Aust.) Ltd. - no information available as yet.

Price: Dursban 480 \$ 26.15 for 1 litre
\$112.85 for 5 litres
\$435.85 for 20 litres

Application rates and methods: Dursban 480 - 208-1167 ml/ha (100-560 g AI/ha) for midge larvae
29-110 ml/ha (13.92-52.8 g AI/ha) for mosquito larvae
Ground and aerial spraying for mosquitoes, rate depends on vegetation cover

Human health hazards: No evidence of carcinogenicity
Prolonged dermal contact may cause skin irritation
Ingestion of amounts incidental to industrial handling not likely to cause injury although larger amounts would be serious to fatal
The product should not be inhaled
Safety precautions: respirator, gloves, boots, overalls and goggles are recommended

Specificity to Chironomid larvae:

A) Laboratory studies:

. Oral LD_{50} male rats 96-174 mg/kg . Oral LD_{50} male rats 205-270 mg/kg . Dermal LD_{50} rats 200 mg/kg	Dow Chemicals (Aust.) Ltd. (1987)
. Over 4-5 months use the efficacy of this larvicide against *Chironomus decorus*, *C.utahensis*, *Procladius sublettei*, *P.freemani* declined	Ali and Mulla (1978a)
. LC_{90} of 0.9 ppb against *Chironomus decorus* (i.e. effective)	Mulla and Khasawinah (1969)
. LC_{90} of 1.5 ppb against *C.decorus*	Ali and Mulla (1976)
. LC_{90} of 750 ppb against Organophosphate resistant *C.decorus*	Pelsue and McFarland (1971) in Ali (1980)
. LC_{90} of 3.8 ppb against *Chironomus utahensis*	Ali and Mulla (1977a)
. LC_{90} of 23 ppb against *Cricotopus* spp.	Ali and Mulla (1977a)
. LC_{90} of 14-160 ppb against *Dicrotendipes californicus*	Ali and Mulla (1980)
. LC_{90} of 1.3 ppb against *Procladius sublettei* and *P.freemani*	Ali and Mulla (1977a)
. LC_{90} of 3.1 ppb against *Tanytabus* sp.	Ali *et al*. (1978)
. LC_{90} of 4.6 ppb against *Tanytabus* spp.	Ali and Mulla (1976)

B) Field studies:

. 0.140 kg Ai/ha controlled *Procladius freemani*, *P.sublettei* (74-99%) for 10 weeks	Ali and Mulla (1977a)
. 0.220 kg AI/ha controlled both *Chironomus* (89-100%) and *Procladius* (84-100%) for 6-8 weeks in fingers of man-made lake	Ali and Mulla (1977a)
. 0.110-0.280 kg/ha gave excellent control of Tanypodinae and Chironomidae for 1-5 months depending upon rate and nature of habitat	Mulla et al. (1971)
Rates >0.56 kg AI/ha suppress larvae for 3-4 weeks in general, in California	Ali (1980)

Effects on non target organisms:

. Highly toxic to bees - should not be sprayed when apiary bees are foraging	Dow Chemicals (Aust.) Ltd. (1987)
. High to very high toxicity to fish	Muirhead-Thomson (1971). British Crop Protection Council (1977) in Blair (1979)
. Aerial spraying presents potential hazards to fish and birds though overall chlorpyrifos has low mammalian and avian toxicity	Mulla *et al*. (1979)
. 0.22 kg AI/ha reduced amphipod and cladoceran populations in treated areas, but these quickly recovered by repopulation from untreated areas	Ali and Mulla (1978b) in Mulla *et al*. (1979)
. Some effect on cladocera, amphipoda and mayfly naiads when larvicide used in field but these usually reappear with target organisms	Brust *et al*. (1971) in Mulla *et al*. (1979)
. After 2-3 applications of 0.028 kg/ha the predaceous insect populations (beetles, Hemipterans) declined	Hulbert et al. (1972) in Mulla et al. (1979)

Table 3.

DIAZINON (Neocid) - Organophosphate (00-diethyl 0-2-isopropyl-6-methyl pyrimidin-4-yl-phosphorothioate)

Availability: Produced by Ciba Geigy Aust. Ltd
Available from Robert Linton and Co. as Neocid 200P - registered for use against mosquitoes but not against midges

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Price: $99.50 for 5 litres
$386.00 for 20 litres

Application rates and methods: (for mosquitoes)
For spraying - 1 litre/20 m^2 20 m^2 : dilute product first 500 ml/100 litres H_2O
For misting - 700 ml/ha
Neocid generally has residual action for 2-3 weeks (product label)

Human health hazards: Avoid contact with skin and inhaling vapour
: Wear protective clothing when applying or mixing, i.e. rubber gloves, overalls, face shield

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Specificity to Chironomids:

A) Laboratory studies:

. LC_{98} 1.12 kg AI/ha *Tendipes plumosus* — Hilsenhoff (1959)

B) Field studies:

N/A

Effects on non target organisms:

. High toxicity to Cladocera

0.9 ppb - EC_{50} for *Daphnia*	) Very high compared to) Pyrethrins and some) Organochlorines, e.g.) Lindane and Heptachlor	Muirhead-Thomson (1971)
2 ppb - EC_{50} for *Simocephalus*		

. Highly toxic to honey bees — British Crop Protection Council (1977) in Blair (1979)

Table 4.
FENTHION (Baytex) - Organophosphate (00-dimethyl 0-4-methylio-m-tolyl phosphorothioate)

Availability: Available from Bayer Australia Ltd. as (a) Baytex 550 (Emulsifiable Concentrate) 550 g/L - registered for use against mosquito adults, but not midges
(b) Baytex Dust - not registered for use against mosquitoes or chironomids

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Price: Baytex 550 - 5 litres for $133.42
Baytex Dust - 25 kg carton of 10 x 2.5 kg packets $207.64

Application rates and methods: Baytex 550 - 204-1018 ml/ha (112-560 g AI/ha) for midge larvae
300 ml/ha (165 g AI/ha) for mosquito larvae

Human health hazards: There is no indication of Baytex 550 being carcinogenic according to the product data sheet.
: Skin and eye contact to be avoided, as is inhalation of vapour.
: Overalls, boots, gloves and face shields should be worn.

Specificity to Chironomid larvae:

A) Laboratory studies: Oral LD_{50} rats 200-300 mg/kg - Bayer Aust. Ltd. (1985)
Dermal LD_{50} rats 1168-2830 mg/kg

. LC_{90} of 31 ppb against Chironomus decorus	Mulla and Khasawinah (1969)
. LC_{90} of 2000 ppb against Organophosphate resistant C.decorus	Pelsue and McFarland (1971) in Ali (1980)
. LC_{90} of 1160 ppb against Chironomus utahensis	Ali and Mulla (1977a)
. LC_{90} of 34 ppb against Cricotopus spp.	Ali and Mulla (1977a)
. LC_{90} of 48-540 ppb against Cricotopus spp.	Ali and Mulla (1980)
. LC_{90} of 110-390 ppb against Dicrotendipes californicus	Ali and Mulla (1980)
. LC_{90} of 14 ppb against Procladius spp.	Ali and Mulla (1977a)
Poor activity against Procladius freemani	Ali et al. (1978)
. LC_{90} of 8.8 ppb against Tanytarsus spp.	Ali et al. (1978)
. Granular fenthion (25 ppb) lethal to Chironomid larvae	Muirhead-Thomson (1971)

B) Field studies:

. 0.56 kg AI/ha	Controlled midge larvae for 4, and over 7 weeks in two Californian lakes.	Mulla et al. (1971)
. 0.56 kg AI/ha	Did not control larvae in Californian lake.	Mulla et al. (1971)
. 0.225 kg AI/ha	Eliminated Chironomids from experimental ponds for 5 weeks	Patterson and von Windeguth (1964) in Ali (1980)
. 0.22-0.28 kg/ha (~ 4 ppb)	Controlled Glyptotendipes paripes	Patterson and Wilson (1966)

Effects on non target organisms:

. High level of toxicity to birds	Mulla et al. (1979)
. Low toxicity to fish	Muirhead-Thomson (1971)
. Oral toxicity to birds 6-25 mg/kg	Tucker and Haegele (1971) in Mulla et al. (1979)
. 5000 ppb (in diet) gave no chronic effects to Mallards	von Windeguth and Patterson (1966) in Mulla et al. (1979)
. >0.9 ppb causes 100% mortality of Daphnia (Cladocera)	Muirhead-Thomson (1971)
. >1000ppb causes 100% mortality of Cyclops (Cladocera)	Muirhead-Thomson (1971)
. High toxicity to Cladocera (as with most organophosphates) but not to Ostracoda of Copepoda	Muirhead-Thomson (1971)
. 50-250 ppb caused high mortality of Mayfly, Stonefly and Amphipod species	Gaufin et al. (1961, 1965) in Mulla et al. (1979)
. If lakes are deep or if only some areas of lakes treated then invertebrate species usually recover (though this may take weeks to months)	
. High toxicity to bees	British Crop Protection Council (1977) in Blair (1979)

Table 5.

MALATHION (Maldison) - Organophosphate-5- 1,2-Di(ethoxycarbonyl)ethyl dimethyl phosphorothiolothionate

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Availability: Available from Nufarm Chemicals Pty Ltd as Maldison ULV (1180 g/litre)
Not registered for use against midges

Price: $166.00 for 20 litres
$1587.00 for 203 litres

Application rates and methods: 120-760 ml/ha (140-897 g AI/ha) for midge larvae
300-400 ml/ha (354 - 531 g AI/ha) for mosquito larvae
by a) Aircraft equipped for ultra low volume application, or
b) Modified misting machines for ground application

Human health hazards: Skin contact and inhalation of vapour is dangerous
Safety precautions: Gloves and face shield to be worn when preparing spray and while spraying

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Specificity to Chironomid larvae:

A) Laboratory studies:

. LC_{90} of 210 ppb against *Chironomus decorus* (organophosphate resistant)	Ali and Mulla (1980)
. LC_{90} of 13 ppb against *Chironomus utahensis*	Ali and Mulla (1977a)
. Malathion toxic to *Chironomus plumosus* (granular)	Hilsenhoff (1960, 1962)
. LC_{90} of 350 ppb against *Cricotopus* spp. (organophosphate resistant)	Ali and Mulla (1980)
. LC_{90} of 64 ppb against *Cricotopus* spp.	Ali and Mulla (1977a)
. LC_{90} of 260-1420 ppb against *Dicrotendipes californicus* (organophosphate resistant)	Ali and Mulla (1980)
. LC_{90} of 14 ppb against *Procladius* spp. in residential recreational lakes (man-made)	Ali and Mulla (1977a)
. Malathion only slightly toxic to *Procladius freemani*	Ali *et al*. (1978)
. Repeated use of Malathion against *Chironomus decorus* and *Procladius* spp. resulted in declining efficacy	Ali and Mulla (1978a)
. 0.841 kg/ AI/ha produced 97% *Tendipes plumosus* mortality in 7 days	Hilsenhoff (1959)

B) Field studies:

. 500 ppb and 1000 ppb gave good control of midge larvae (but these levels are very high) (aerial spraying)	Patterson *et al*. (1966)
. 0.14 kg AI/ha (ULV aerial spray) was effective against adults for four days	Patterson and Wilson (1966)
. 0.56 kg AI/ha controlled midge larvae for 2-3 weeks in Californian Lake	Mulla *et al*. (1975) in Ali (1980)
. 0.897 kg AI/ha gave no control of *Tendipes plumosus* larvae in a 20 ft deep lake	Hilsenhoff (1962)
. 0.14 kg AI/ha gave 100% and 90% mortality of *Chironomus fulvipilus* larvae after 24 hours in two aerial spray trials	Patterson et al. (1966)

Effects on non target organisms:

. Very low avian and mammal toxicity	Mulla *et al*. (1979)
. Toxic to bees - should not be sprayed when apiary bees are foraging	Nufarm Chemicals Pty. Ltd.
. At larvicidal rates (7-100 ppb) high mortality of caddisfly and mayfly larvae and *Gammarus* (Amphipoda) were recorded	Gaufin (1961, 1965) in Mulla *et al*. (1979)
. In ponds malathion caused 70% *Gambusia affinis* mortality at 0.56 kg AI/ha	Mulla and Isaak (1961)
. Malathion may be more toxic to some Cladocera, Amphipoda and Plecoptera than mosquitoes, but this is dependant upon specificity and habitat	Mulla *et al*. (1979)
. Malathion shows high to very high toxicity to fish	Muirhead-Thomson (1971)

Table 6.
TEMEPHOS (Abate) - Organophosphate ($000^{1}0^{1}$-tetramethyl 00^{1}-thiodi-0-p-phenylene-diophospharothioate)

Availability: Produced by Cyanamid
Available from Robert Linton and Co. as a) 10SG (1% granular) (10 g/kg) - registered for use against midge larvae
b) 50SG (5% granular) (50 g/kg) - registered for use against midge larvae
c) 100E (emulsifiable concentrate) (10%)

Price: 10SG \$125.00 for 20 kg
50SG \$265.00 for 20 kg
100E \$107.00 for 5 litres

Application rates and methods: 10SG 5-10 kg/ha (50-100 g AI/ha) for ground application for midge larvae
50SG 1-2 kg/ha (50-100 g AI/ha) for aerial application for midge larvae

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Human health hazards: Poisonous if inhaled or ingested, skin contact should be avoided
: Safety precautions: gloves, face shield, overalls
: No symptoms felt when fed 256mg AI/man/day for 5 days (British Crop Protection Council (1977) in Blair (1979))

Specificity to Chironomid larvae:

A) Laboratory Studies:

. LC_{90} of 2 ppb against *Chironomus decorus* in California	Ali and Mulla (1976)
. LC_{90} of 42140 ppb against *Chironomus decorus* i.e. not effective	Ali and Mulla (1980)
. LC_{90} of 4.7 ppb against *Chironomus utahensis*	Ali and Mulla (1977a)
. LC_{90} of 25 ppb against *Cricotopus* spp.	Ali and Mulla (1977a)
. LC_{90} of 182 ppb against *Cricotopus* spp.	Ali and Mulla (1980)
. LC_{90} of 60 ppb against *Procladius freemani*	Ali and Mulla (1977a)
. LC_{90} of 60 ppb against *P.freemani*	Ali and Mulla (1978a)
. LC_{90} of >5000 ppb against *P.freemani* i.e. ineffective	Ali *et al*. (1978)
. LC_{90} of 1090 ppb against *Dicrotendipes californicus*	Ali and Mulla (1980)
. LC_{90} of 4.6 ppb against *Tanytarsus* spp.	Ali and Mulla (1977b)
. LC_{90} of 7.2 ppb against *Tanytarsus* spp.	Ali *et al*. (1978)
. LC_{90} of 310 ppb against *Tanypus grodhausi* (Abate resistant)	Ali and Mulla (1980)

B) Field studies:

. 0.28 kg AI/ha in 1-2 m effectively controlled *Tanytarsus*, *Chironomus* and *Cryptochironomus*	Blair (1979)
. 0.17 kg AI/ha in <1 m effectively controlled *Tanytarsus*, *Chironomus* and *Cryptochironomus*	Blair (1979)
. 0.28-0.56 kg AI/ha (granular) eliminated *Tanytarsus* spp. for up to 2 weeks but had no effect on *Chironomus* or *Procladius*	Johnson and Mulla (1981)
. 0.28 kg AI/ha in running water gave excellent control of *Procladius*, *Chironomus* and *Tanytarsus* for 4-5 weeks	Johnson and Mulla (1981)
. 0.28 kg AI/ha (in fingers of North Lake (man-made lake, California)) gave good control of *Chironomus utahensis* for 6 weeks - *Procladius* not affected	Ali and Mulla (1977a)
. 0.17 kg AI/ha (in main lake area of South Lake (man-made lake, California)) gave mediocre control of *Chironomus decorus* and *Chironomus utahensis* - *Procladius* spp. resistant to Abate	Ali and Mulla (1977a)
. 0.56 kg AI/ha granular Abate gave 99% control of *Glyptotendipes barbipes* after 10 days in sewage lagoons, and 100% after 14 days	Bickley and Ludlam (1968)

Effects on non target organisms:

. Abate is generally low in toxicity to birds and mammals	Mulla *et al*. (1979)
and has low toxicity to fish	Muirhead-Thomson (1971)
. Up to 0.112 kg/ha had no effect on Ostracoda and Isopoda	Cooney and Pickhard (1974) in Mulla *et al*. (1979)
. 0.056-0.112 kg/ha was toxic to Cladocera, but not to Coleoptera, Ostracoda or Copepoda	Mulla *et al*. (1979)
. 0.034 kg/ha of liquid Abate reduced odonatan populations as well as Cladocera, but not Amphipoda, Isopoda, *Paleomonetes* (Decapoda), or rotifers	Mulla (1966) in Mulla *et al*. (1979)
. At mosquito larvicidal rates and 4 x larvicidal rates no effects were observed on *Gambusia affinis*	Mulla *et al*. (1979)
. Slow release formulations had no effect on Mollusca, Ostradoca or Copepoda	Barnes and Webb (1968) in Mulla et al. (1979)

Table 7.

OTHER ORGANOPHOSPHATES

(Little information available)

Dichlorvos	Toxic to *Chironomus plumosus*	Hilsenhoff (1960, 1962)
Trichlorfon	Toxic to *Chironomus plumosus*	Hilsenhoff (1960, 1962)
EPN	Toxic to *Chironomus plumosus*	Hilsenhoff (1960, 1982)
	Resistance problems	Patterson (1964, 1965)
BHC	Resistance problems	Patterson (1964, 1965)
Phosdrin	Toxic to *Chironomus plumosus*	Hilsenhoff (1960, 1962)
Enthion	LC_{90} = 1160.0 ppb for *Chironomus utahensis*	Ali and Mulla (1977a, 1978a)
Ethyl parathion	LC_{90} = 1.0 ppb for *Tanypus grodhausi*	Mulla and Khasawinah (1969)
	LC_{90} = 23.1 ppb for *C.utahensis*	Ali and Mulla (1977a)
	LC_{90} = 29.0 ppb for *Cricotopus* spp.	Ali and Mulla (1977a)
Methyl parathion	LC_{90} = 470.0 ppb for *C.utahensis*	Ali and Mulla (1977a, 1978a)
	LC_{90} = 74.0 ppb for *Procladius* spp.	Ali and Mulla (1977a, 1978a)
	LC_{90} = 450.0 ppb for *Cricotopus* spp.	Ali and Mulla (1977a, 1978a)
Phenthoate	LC_{90} = 8.1 ppb for *C.utahensis*	Ali and Mulla (1977a, 1978a)
	LC_{90} = 5.4 ppb for *Procladius* spp.	Ali and Mulla (1977a, 1978a)
	LC_{90} = 15.0 ppb for *Cricotopus* spp.	Ali and Mulla (1977a, 1978a)

Table 8.
Bti (Bacillus thuringiensis israelensis)

Availability: 1. Teknar emulsifiable concentrate. Available from Robert Linton and Co., Perth
Produced by Wellcome, Australia

2. Granules. Not available in Australia. Currently being developed by Biocontrol, Queensland and Sandoz, Sydney
Directions overleaf for on-site granule formulation

3. Briquettes. Currently being developed by Ray Davidson in W.A.

4. Wettable powder ABG-6108). Produced in USA by Abbott Laboratories — Ali (1981)

Price: 1. Teknar $320.00 for 20L

Application rates and methods: 1. Teknar. 15-60 litres/ha (6 x 10^5 IU/l) for midges
0.6-2.4 litres/ha for mosquitoes
2. Wettable powder (ABG-6108) 1-10 kg/ha (1-10 x 10^9 IU/kg) for midges — Ali (1981)

Human health hazards: No records of any human health hazards.

Specificity to Chironomid larvae:
A) Laboratory studies:

LC_{90} for 3rd instar larvae (no food) in ppb

Formulation	*Glyptotendipes paripes*	*Chironomus decorus*	*Chironomus crassicaudatus*	*Tanytarsus* spp.	Reference
IPS-78 Wettable powder	13140	8610	10560	11380	)
R-153-78 Wettable powder	9840	4560	4920	6340	)Ali *et al*. (1981)
ABG-6018 Wettable powder	32380	30760	47020	22610	)
SAN-402-WDC Flowable Concentrate	23590	26980	28360	-	)

*Note 1st instar larvae more susceptible than 3rd instar. Provision of food impaired effectiveness of Bti. — Ali *et al*. (1981)
R-153-78 invariably the most active formulation.

Chironomus tepperi (rice midge) LC_{90} (1st instar) = 100-200 ppb)
Bactimos Wettable Powder LC_{90} (4th instar) = 790 ppb) Treverrow (1985)
At 100-400 ppb, about half of the newly hatched larvae are killed before)
emerging from egg mass)

B) Field studies:
. 1-10 kg/ha gave 18-88% reductions in Chironomini and Tanytarsini — Ali (1981)
. 0.25 and 1.0 kg/ha affected midges, but only short term due to reinfestation from surrounding areas. — Miura *et al*. (1980) in Ali *et al*. (1981)
. Present formulations of Bti are 13-75 times more effective on mosquito larvae than midge larvae, i.e. different formulations needed for midge control. — Ali *et al*. (1981)
4th instar larvae that have ceased feeding are not susceptible to BTi.

Effects on Non-Target Organisms:
No effect on non-target invertebrates — Ali (1981)
At minimum field rates, produced no mortality of beneficial insects. — Reviewed in Mulla et al.(1979)

Instructions for On-site Production of Bti Granules

The following two methods for making sand-based Bti granules have been obtained via personal communications. The information on these methods for producing Bti granules arrived too late to be used in this study. In addition, the wettable powder is not currently available in Australia.

1. Sand quality siliceous granulometry 0.6 to 1.2mm to be mixed with 30cc vegetable or mineral oil. When mixed add 40g Bactimos wettable powder.

   This formulation was recommended by Barry Brunsdon (J.B. Brunsdon and Co.), the Sydney agent for Duphar in Holland.

2. 2.8kg of sand and silicon to be mixed with 1.2kg Teknar emulsifiable concentrate.

   The Gold Coast City Council has used this formulation for mosquito control (rate 4kg/ha). However, it has had limited success, perhaps because the filter-feeding larvae find sand grains too large.

Table 9.

INSECT GROWTH REGULATORS (Hormones that inhibit development to the adult stage)

METHOPRENE (Isopropyl (2E,4E)-11-methoxy-3,7,11-trimelthyl-2,4-dodecadienoate) "Altosid"

Availability:	In Australia, as aerosol, foggers, emulsifiable concentrates (none suitable for midge control)	George Lindell, Zoecon; pers. comm.
	In USA, as briquettes, pellets, microencapsulation (all three are slow release) and spray	George Lindell, Zoecon; pers. comm.
Price:		
Application rates and methods:	LC_{50} for mosquitoes is 0.001 kg AI/ha (0.1 ppb)	Broadbent (1987b)
	Briquettes applied by hand dispersal, pellets and microencapsulation by aircraft	George Lindell, pers. comm.
	Range of activity is 0.04-0.1 kg/ha and lasts 4-10 days if applied as a slow release formula	Mulla et al. (1979)
Human health hazards:	Extremely safe; even used in human drinking water	Broadbent (1987b)

Specificity to Chironomidae:

A) Laboratory studies:

N/A

B) Field studies:

. 0.028 kg AI/ha gave a reduction in midges	Breaud *et al*. (1977)
. 0.28 kg AI/ha (6ft deep lake) inhibited midge emergence for 1-3 weeks Less effective after successive treatments. Does not reduce larval populations significantly	Mulla *et al*. (1976)
. Effective against OP-resistant *Chironomus* spp. and also *C.stigmaterus* and *Tanypus grodhausi*	Mulla *et al*. (1974)
. Slow-release encapsulated formulation (100-200 ppb) controlled *Chironomus*, *Procladius* and *Tanytarsus* for 1-2 weeks	Mulla *et al*. (1974)

Effects on non-target organisms:

. When used at recommended rate, no effect on mammals, wildfowl, amphibians, fish, crustaceans or non-target invertebrates	Broadbent (1987b)
. At 0.028 kg AI/ha, reduction (but no elimination) of *Hyatella azteca* (Amphipoda), crustaceans, mayflies, odonatans, snails, some Coleoptera	Breaud et al. (1977)
. At practical rates this IGR is not expected to have any direct acute effect on most aquatic organisms. Most sensitive are diving beetles and mayfly naiads	Mulla *et al*. (1979)
. LC_{50} (dietary) of >0.0046 kg/kg for chickens	Royal Society of Chemistry (1986)

Table 10.

OTHER IGR's - generally not available in Australia

DIFLUBENZURON (Dimilin) - available in small quantities only	
Rate of application for mosquitoes: 0.02-0.04 kg AI/ha (25% wettable powder)	Julin and Sanders (1978)
Chironomids: LC_{90} = 6.0 ppb for Chironomus decorus,	
LC_{90} = 4.1 ppb for Glyptotendipes paripes	Ali and Lord (1980a)
0.029-0.22 kg AI/ha effective midge control on most species	
for 3-5 weeks, C.decorus for only 1 week	Ali and Lord (1980), Ali and Mulla (1977a)
Non-target organisms: 0.028-0.156 kg AI/ha affects copepods, collembolans,	
cladocerans, amphipods, mayflies. Fish not affected	Apperson et al. (1978b)
at lower rates; at higher rates, sometimes drastic	Julin and Sanders (1978)
effects on invertebrates, but recover eventually	Ali and Mulla (1978b)
DIMILIN TH-6040	
Chironomids: 0.1-0.25 kg AI/ha inhibits midge emergence for 5-10 weeks.	Mulla et al. (1976)
Also reduces larval species. A resistant species, Labundinia	
maculata arrived from adjacent source and became abundant	
BAY SIR-8514	
Chironomids: LC_{90} = 22.0 ppb for C.decorus, LC_{90} = 7.6 ppb for G.paripes	Ali and Lord (1980a)
0.056 and 0.112 kg AI/ha (25% wettable powder), excellent	
control of Tanytarsus spp. Goeldichironomus holoprasinus and	
some control of C.decorus for 3 weeks	
Non-target organisms: Moderate and temporary effects on copepods,	Ali and Lord (1980b)
collembolans, mayflies, notonectids, corixids,	
coleopterans, amphipods	
UC-62644	
Chironomids: LC_{90} = 3.1-5.7 ppb for C.decorus and G.paripes	Ali and Stanley (1981)
0.025 kg AI/ha (5.5 ppb) gave 99% control of emergence for	
4 weeks and also a significant death of larvae	
Non-target organisms: Moderate and temporary effects on rotifers, copepods,	Ali and Stanley (1981)
cladocerans, Chaoborus sp., mayflies, notonectids,	
corixids, coleopterans. Most recovered in 2-3 weeks	
STAUFFER M-678	
Chironomids: LC_{90} = 50.0 ppb for C.decorus, LC_{90} = 69.0 ppb for G.paripes	Ali and Lord (1980a)
0.056 and 0.112 kg AI/ha (emulsifiable concentrate) gave 30%	
and 70% control respectively	
Non-target organisms: 0.22 kg AI/ha - no significant effects on Cladocera,	Ali and Lord (1980b)
copepods, Hydrachnellae, Hirudinea or Oligochaeta	

Table 11.

SYNTHETIC PYRETHROIDS

Midge control in Australia:	Deltamethrin (Cislin 10) and Fenvalerate (SD-43775) are currently in (unregistered) use in Queensland	Broadbent, pers. comm.
	Decamethrin produced by Hoechst Aust. Ltd. as a) 25 g/L Decis 25 EC b) 5 g/L Decis 5 ULV	
	Fenvalerate Produced by Shell Chemicals Aust. Ltd. as a) Sumicidin 75 insecticide (75 g/L) b) Sumicidin 200 insecticide (200 g/L) c) Sumicidin ULV insecticide (40 g/L)	The Pesticides Section, Health Dept. of Western Australia (1986)
Human health hazards:	Synthetic Pyrethroids have low mammalian toxicity	Broadbent (1987a)
Specificity to Chironomidae:		
Laboratory studies		
. FMC-45498 (Decamethrin)	LC_{90} = 0.1 - 7.3 ppb	Ali and Mulla (1978b, 1980)
. FMC-45497 (Decamethrin analogue)	LC_{90} = 0.1 - 12.0 ppb	Ali and Mulla (1978b, 1980)
. FMC-35171	LC_{90} = 4.0 - 85.0 ppb	Ali and Mulla (1978b, 1980)
. SD-43775 (Fenvalerate)	LC_{90} = 7.6 - 420.0 ppb	Ali and Mulla (1978b, 1980)
. Neopynamin	LC_{90} = 14,500-25,000 ppb	Mulla and Khasawinah (1969)
Effects on non-target organisms:		
	. In general, highly toxic to fish and crustacea	Steven Broadbent, pers. comm.
	. Adverse effects on mayflies	Mulla et al. (1980)
	. Most are toxic to mayfly and dragonfly naiads	Mulla et al. (1978a)
	. With the exception of FMC-33297 and SD-43775, most pyrethroids had a wide margin of safety to fish at larvicidal rates	Mulla et al. (1978b) in Mulla et al. (1979)
	. Toxic to bees and fish	Royal Society of Chemistry (1986)
	. Aquatic fauna (invertebrate) may be affected by Decamethrin, especially crustacea	Worthing and Walker (1983)

Table 12.
OTHER CONTROLS

a) Feasible in the short term

Light attraction/trapping - 100-W incandescent lamps. White preferred over yellow, and both preferred over red, orange, green or blue. Differences in response mainly due to light intensity rather than colour. No difference between incandescent and fluorescent light (Ali *et al*. 1986 (abstract only)).

Light traps with electric grids (zappers) have proved unsuccessful in midge control (Hilsenhoff 1959).

b) Not feasible in short term
(Compiled from Ali (1980) and other sources)

Physical/cultural	
Rotational flooding and drying of breeding source	Anderson *et al*. (1964) in Ali (1980)
Increase in water depth	Ali and Mulla (1976b) in Ali (1980)
Removal of substrate material	Ali *et al*. (1976b, 1977b) in Ali (1980)
Biological	
Viruses. Entomopoxvirus. *Chironomus decorus* regulated in lab. conditions and storm drains	Reviewed in Ali (1980)
Fungal pathogens, *Coelomomyces* spp. Reported to exist in many populations of midges	Reviewed in Ali (1980)
Protozoa. Microsporidia and ciliophores. Usually unspectacular natural control in some midge populations	Reviewed in Ali (1980)
Nematodes. Occasional effective control	Reviewed in Ali (1980)
Predators. Water mites. Feed on midge eggs	Wiles (1982)
Planaria. *Dugesia dorotocephala*. Effective in lab. and semi-field conditions.	Legner *et al*. (1975)
Potential for mass rearing of *Dugesia*	Tsai and Legner (1977) in Ali (1980)
Fish. Carp. Short-term control but undesirable effect on ecosystem.	Bay and Anderson (1965) in Ali (1980)
Mosquito fish, *Gambusia affinis*. Little control-feeds on midges only when under food stress	Bay and Anderson (1966) Lloyd (1986)
Chemical	
Organochlorines. Toxic to fish and invertebrates. Resistance in midge larvae. Environmentally unacceptable because of long residence times and biomagnification in food chains (i.e. persistence in the environment).	Reviewed in Ali (1980)

LIGHT TRAP DESIGNS

Both designs (Figs 1, 2 and 3) incorporate a light source to attact midges to the trap. This should be a powerful incandescent or mercury vapour lamp without a filter. Mirrors may be used, as is shown in design one, to increase the attractiveness to midges. A wire grid over the open sides prevents birds entering. Design one blows midges around the light into a bag. This bag must be porous (e.g. hessian), to allow air to flow through. Design two has a fan to suck midges into a removable bag. This design is also shown in three dimensions. Both traps are attached to a pole at an appropriate height. A conceivable problem with design one may be that midges are actually prevented from entering the trap due to the downward airflow.

These plans are based on insect sampling traps which were not designed to control midges (merely sample) and may not have the desired effect. Some modifications may be necessary, and it is suggested that <u>a makeshift (cheap) version be constructed</u> (using a large drum for example) <u>for testing</u>.

The light and fan may be controlled by a timing device so that it operates only between dusk and dawn or for several hours at dusk (e.g. 1700 hr to 2000 hr).

A small prototype of design one was built by the Cockburn City Council (Fig. 4) using white fluorescent tubes as a light source. Trials at Bibra Lake at dusk showed that this light trap successfully attracted large numbers of midges.

In addition, J. and T. Starkey Engineers of Perth has designed and built a prototype of an electric insect killer. A photograph and brief details of this design are shown in Fig. 5.

Designs One and Two

1. Fan blade
2. Fan motor - must be fairly powerful in design two
3. Mirrors - not shown on design two
4. Light bulb
5. Light bulb mount and socket
6. Light support brackets
7. Funnel
8. Grid to prevent entry of birds - holes 25 mm square
9. Entrance to capture tunnel
10. Support pole
11. Grid to prevent entry of birds
12. Wiring to bulb and fan motor
13. Door to removable collection bag
14. Support bracket
15. Removable collection bag
16. Bracket for fan

DESIGN ONE

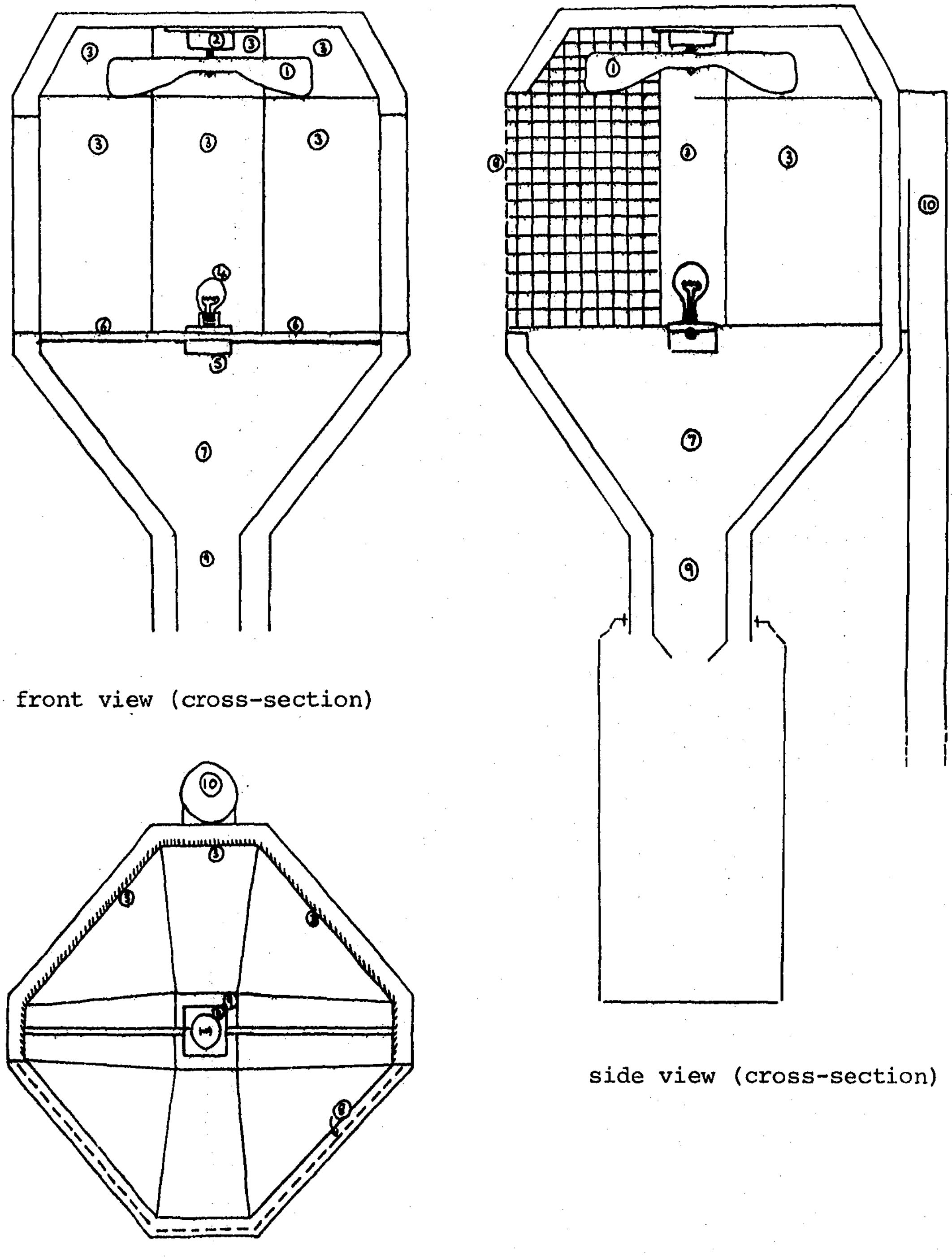
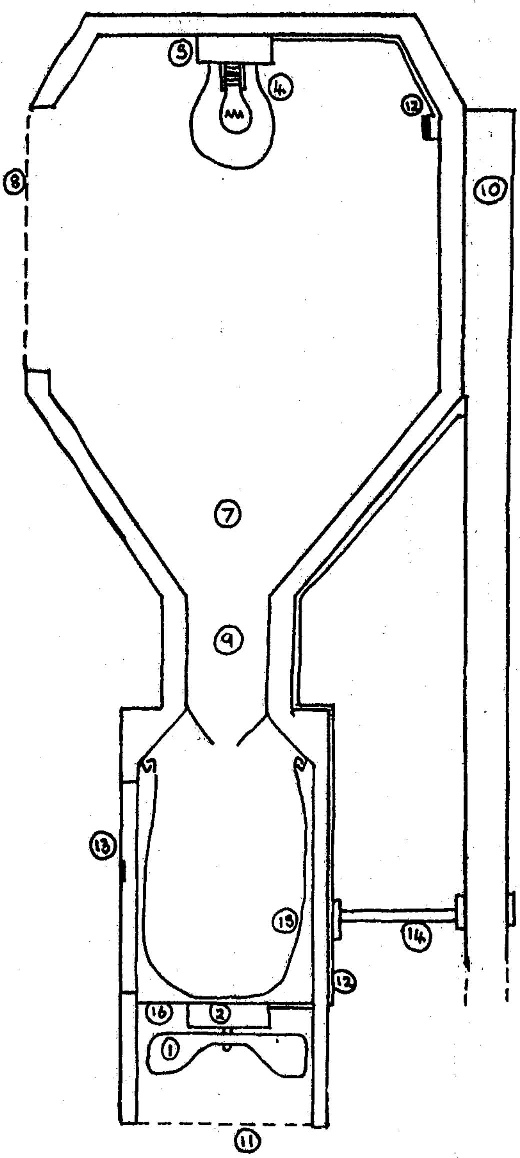


Figure 1. Light trap design one, showing front view, side view and the view from above.

DESIGN TWO



side view (cross-section)

Figure 2. Light trap design two showing the side view.

DESIGN TWO

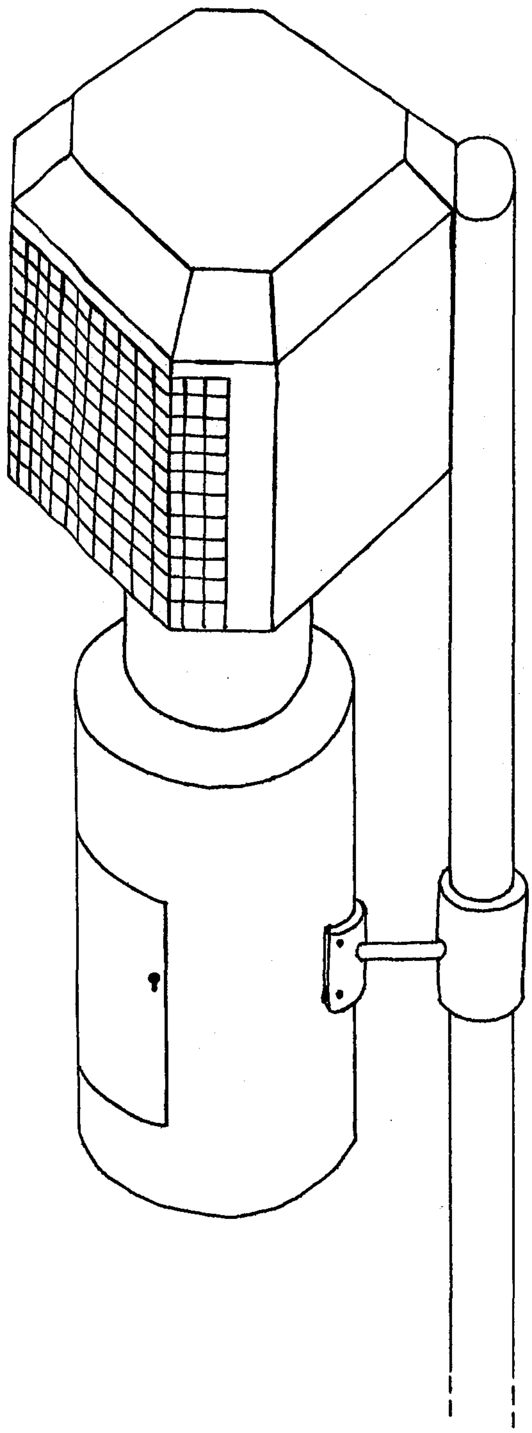


Figure 3. Light trap design two showing the trap attached to a support pole.

Figure 4. Prototype light trap constructed by Cockburn City Council.

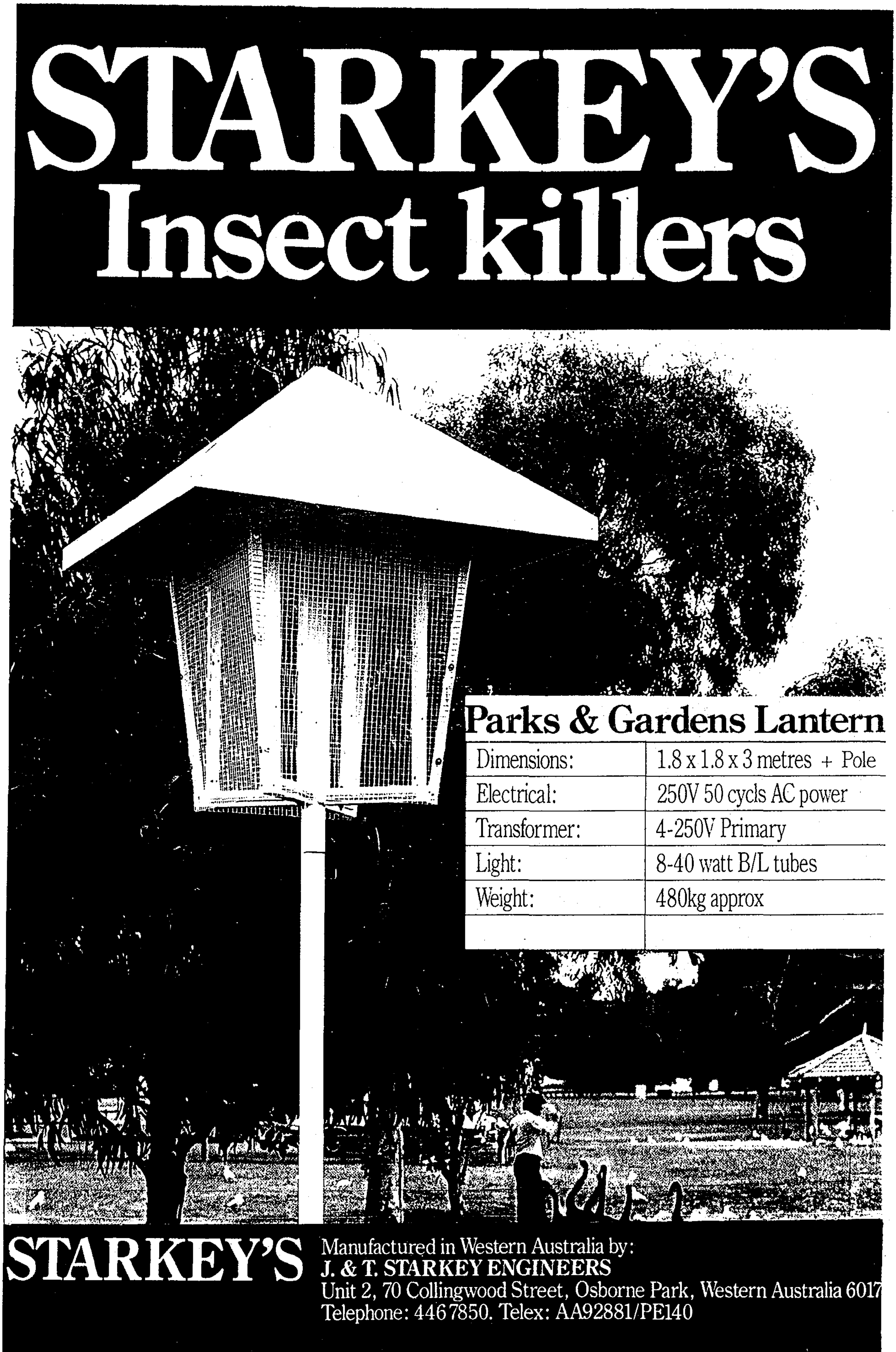


Figure 5. The electric insect killer produced by J. and T. Starkey Engineers of Perth.

PESTICIDE REGISTRATION INFORMATION

The Department of Agriculture (Pesticide Section) provided the following list of the pesticides registered in Australia for midge and mosquito control.

Their information was obtained from:

> QAC PESKEM USES: Pests, Department of Plant Protection, Queensland Agricultural College (1986).

EXTRACT FROM QAC PESKEM

PEST	AREA	ACTIVE CONSTITUENT	TRADE NAME (EXAMPLES)	COMPANY	RATE FOR PRODUCT Per 100L	Per ha	SCHEDULE
Mosquito larvae	Still water	B.t. israelensis	Mozkil*	Biocontrol		1-2 L	Up to 30 cm
			Mozkil*	Biocontrol		2-4 L	Polluted
			Mozkil*	Biocontrol		500 ML-1L	Polluted
		Maldison	Maldison ULV*	Nufarm		200-300 ML	Adults
			ULVC Malathion* 117%	Terra		300 ML	-
			ULVC Malathion* 117%	Terra		400 ML	Larvae
Mosquitoes	Aquatic area	Chlorpyrifos	Deter	A C L	2 ML/10000L		Impounded
		Chlorpyrifos	Deter	A C L		29-106 ML	Larvae
		Chlorpyrifos	Deter	A C L		56-106 ML	Adults
	Breed area	Chlorpyrifos	Deter	A C L		29-106 ML	Larvae
			Deter	A C L		56-106 ML	Adults
		Diazinon	Naocid 200F*	Ciba-Geigy		-	-
		Fenthion	Baytex 550*	Bayer		300 ML	Larvae
			Baytex Dust*	Bayer		-	Dust
		Maldison	Malathion 100*	D H A		300-500 ML	-
			Maldison 50	Pharma		1 L	Larvae
			Maldison ULV*	Nufarm		300-450 ML	Larvae
		Temephos	Abate 10SG*	Cyanamid	1 G/SQ M	5-10 KG	-
			Abate 50SG*	Cyanamid		1-2 KG	By aircraft
	Still water	B.t. israelensis	Teknar*	Wellcome		600 ML-2.4 L	Larvae
		Chlorpyrifos	Dursban 480*	Dow	20 ML/100 CU M		Polluted
		Diazinon	PCO Neocid 800*	Ciba-Geigy	125 ML		Larvae
Midges	Breed area	Temephos	Abate 10SG*	Cyanamid	1 G/SQ M	5-10 KG	-
			Abate 50SG*	Cyanamid		1-2 KG	By aircraft

*Registered for use in Western Australia

CONCLUSIONS

On the basis of the available literature and information obtained from pesticide companies, temephos and chlorpyrifos appeared to be suitable chemical control options for the 1987/88 season. They were considered to be suitable because of their low cost, availability in granular form, effectiveness and low toxicity to mammals and birds. Laboratory testing of the toxicity of these compounds to local species of chironomids was carried out during the study period. In addition, laboratory testing of Bti (liquid Teknar) was undertaken because preliminary testing by Grant Pearson (CALM), early in 1987, revealed that the compound appeared to be effective against at least one species. The results of these tests are presented and discussed in the Pesticide Susceptibility Tests section.

From an ecological and environmental point of view, the use of Bti and IGR's (Insect Growth Regulators, e.g. methoprene) would be much preferable. These compounds have low toxicity to all other fauna apart from some species of Diptera. In the longer term they must be regarded as more suitable options because resistance is likely to develop to any or all of the organophosphates. The time available for the 1987/1988 study precluded the testing of all but the most suitable compounds (temephos, chlorpyrifos and Bti).

The formulation of Bti that is available in Australia is a suspension concentrate ("Teknar") which was formulated for the control of mosquito larvae. Chironomid larvae, being bottom dwellers, would be more effectively controlled by a sinking granular formulation of Bti. Such a formulation is not currently available in Australia and neither is the dry powder form of Bti that could be used to make Bti granules (see instructions on page 20 of this report).

Overseas researchers have had some success in controlling chironomid larvae with synthetic pyrethroids and IGR's. It is suggested that laboratory (and perhaps field) trials using examples of these compounds should proceed during the latter part of 1988. Small amounts of one synthetic pyrethroid (Perigen 500, a formulation of permethrin) and two IGR's (Dimilin and Altosid, formulations of diflubenzuron and methoprene, respectively) have already been obtained.

Another control option that should be considered is the use of a combination of pesticides. For example, the application of temephos in combination with an IGR (diflubenzuron) has been found to be more effective in the control of midges than either of the controls used alone.

Since the presentation of the literature review to the Midge Research Steering Committee in September 1987, further efforts have been made to obtain Bti in granular form. It appears that several companies (including Wellcome and Sandoz) are still attempting to produce such a formulation. However, the likely high cost of Bti granules or Teknar concentrate (for on-site production of granules) in amounts necessary for midge control may make it economically unsuitable. In addition, laboratory trials run by the Murdoch team, Grant Pearson (CALM) and those cited in the literature, have not shown conclusively that Bti is an effective control agent for chironomids.

The successful use of a light trap for attracting adult midges has been demonstrated on a small scale by the Cockburn City Council. The potential of this control option is clear, however at this stage, further development is necessary.

The findings presented in this chapter result from our appraisal of the literature and liaison with individuals from pesticide companies. The 'Conclusions' section presented here primarily discusses these findings in isolation. The final chapter in this report includes a discussion of these conclusions in the light of the experimental work carried out during the course of the study.

PESTICIDE SUSCEPTIBILITY TESTS

INTRODUCTION

Three series of pesticide susceptibility tests were carried out in October and November 1987 and February 1988. Lake Monger and North Lake were both known to have dense larval populations and severe adult midge problems so it was decided to test larvae from these lakes first. The World Health Organization recommends that each test is run on three separate occasions (Russell, 1986) to account for possible variations in larval susceptibility. This variation may be due to differences in populations present at different times, diet or growth regimes. The need to repeat the tests in this way meant that larvae from only a small number of lakes could be tested in the time available. For this reason pesticide trials were carried out mainly on larvae from North Lake and Lake Monger, but additional trials tested larvae from Forrestdale Lake and Lake Claremont.

Following the completion of the pesticide literature review in September 1987, a decision was made to focus our efforts on three pesticides; temephos, chlorpyrifos and Bti. The former two were chosen for testing because on the basis of cost, availability in granular form, effectiveness and low toxicity to mammals and birds, both appeared to be suitable chemical options for the 1987/88 summer. From an ecological and environmental viewpoint the use of Bti and IGR's would be preferable because of the low toxicity of these compounds to all other fauna, apart from some species of Diptera. However the limited time available to carry out the susceptibility tests (because of the time needed to conduct our field monitoring programme) restricted our laboratory testing of such control agents to Bti.

METHODS

Collection of Larvae
A sweep net (250µm mesh size) was used to collect larvae from the lake sediments. The larvae, along with collected sediment, were placed in aerated buckets of lake water for acclimation at laboratory temperatures. It was found that if no sediment was provided then the aeration during acclimation overly stressed the larvae, leading to low survival. Acclimation times and temperatures are given in the descriptions of each trial.

General Experimental Methods
The experimental design of the pesticide trials was based on the method recommended by the World Health Organization for mosquito larvae susceptibility tests (Russell, 1986). This design was easily adapted for chironomid trials. The following description of methods includes those aspects that applied throughout the series of trials. Each trial varied slightly from this and such details are discussed separately overleaf.

Following acclimation, between 10 and 20 larvae (depending upon abundance of larvae in the lake) were placed into small plastic cups with 25ml of filtered lake water. If the larvae had begun to pupate they were not used.

This procedure was carried out immediately prior to the start of the experiment. No attempt was made to separate species prior to testing so as to avoid undue handling of the larvae.

The containers used as test vessels were either 0.25 or 1.0 litre glass beakers, or 8.0 litre plastic buckets. (Fig. 6A) Into these were added sufficient washed white quartz sand to cover the bottom to a depth of 2mm, to reduce stress and thus mortality as well as any cannibalism (Mulla and Khasawinah, 1969) (Fig. 6B). Enough filtered lake water was added so that addition of the pesticide and larvae would result in the required concentration. After addition of pesticide to the test vessels the liquid was stirred to ensure mixing. No aeration was used because this had been found to contribute to high mortality through the occurrence of excessive water movement. Lastly, the 25ml of water containing the larvae were added to the test containers.

Three replicates were used for each combination of pesticide, concentration and container size (the WHO recommends a minimum of two). In addition three control containers (containing larvae and water but no pesticide), were included for each container size used in the trial.

After a designated time, the midges were removed and scored as alive or dead, and preserved in ethanol for subsequent identification. Larvae were classified as alive if any voluntary movement could be observed before or after manipulation with tweezers. If larval mortality in the controls was greater than 20% then the test data were not used. In order to determine if the 24 hour trial period was sufficient, notes were made during the November trials as to whether or not the live larvae appeared stressed, (a stressed larva was flaccid, pale and inactive compared to a healthy larva). After examination of these results a decision was made to use a 72 hour trial period. In the February trials dead larvae were removed and scored after 24 and 48 hours, with the remainder being scored as dead or alive after 72 hours.

Experimental Methods Specific to Each Test

The concentrations used in each trial are given in the summary tables of results (Tables 13 to 20). Additional trials of Abate, Dursban and Bti against *P.nubifer* from Forrestdale Lake were carried out during December 1987. However, the data could not be used due to high mortality (greater than 20%) in the controls.

<u>1st trial series - October 1987</u>

a) Lake Monger
- larvae acclimated for 24 hours at 20°C ± 1°C
- experiment ran for 24 hours at 20°C ± 1°C.
- non-target fauna (corixids) exposed to median rates.
- Abate 50SG, Dursban 480 and Teknar tested against *C. australis* and *C. alternans*.

b) North Lake
- larvae acclimated for 24 hours at 20°C ± 1°C.
- experiment ran for 24 hours at 20°C ± 1°C.

- Abate 50SG, Dursban 480, and Teknar tested against *C. alternans* and *C. intertinctus.*

2nd trial series - November 1987

a) Lake Monger
- larvae acclimated for 24 hours at 20°C ± 1°C.
- experiment ran for 24 hours at 20°C ± 1°C.
- Abate 50SG, Dursban 480 and Lorsban 15G tested against *C. australis.*

b) Forrestdale Lake
- larvae acclimated for 24 hours at 20°C ± 1°C.
- experiment ran for 24 hours at 20°C ± 1°C.
- non-target fauna (corixids) exposed to median rates.
- Abate 50SG, Dursban 480 and Teknar tested against *C. australis.*

3rd trial series - February 1988

North Lake, Lake Claremont, and Lake Monger
- larvae acclimated for 72 hours at 25°C ± 1°C.
- experiment ran for 72 hours at 25°C ± 1°C.
- Abate 50SG tested against C. australis (Lake Monger and Lake Claremont) and P. nubifer (North Lake).

Mixing and Addition of Pesticides
The low concentrations of pesticides required and the low volumes of the test containers (0.25 and 1.0 litre glass beakers), meant that it was not possible, in most cases, to add commercial formulations directly to the test containers. Often only a single grain per beaker would have been needed if granules were added directly. Also, very small amounts of pesticide may not contain exactly the amount of active ingredient specified in the formulation. For example, the actual amount of temephos on a single grain of sand may not have been 5% of the granule weight (Abate 50SG is 5% active ingredient). Therefore the following method was used to ensure that accurate concentrations were obtained. Granular temephos (Abate 50SG) was mixed in 5 - 10 litres of filtered lake water to give a concentrated solution. This was left for several hours so that the active ingredient would dissolve off the sand grains before the solution was used. An aliquot of this concentrate was then added to the test containers to give a correct final concentration. In some cases both direct addition of granules and the concentrated solution was used to compare these methods. Similar concentrated solutions were prepared for Dursban 480 and Teknar.

The February trials involved higher larvicide concentrations and used 8.0 litre plastic buckets as test containers. This meant that larger amounts of Abate 50SG granules could be accurately weighed and added directly.

Analysis of Test Data
Initially the data from each experiment were plotted on standard linear-linear scales as mean % mortality against concentration of larvicide.

The result of plotting dose response data on such scales is usually a sigmoidal curve. This type of curve indicates that low doses cause low mortality, increasing doses cause increasingly higher mortality, until eventually the highest doses no longer lead to significantly higher mortality. From this type of graph the LD50 (the concentration of larvicide that causes 50% mortality, i.e. lethal dose 50%) is easily read. However in such experiments as chironomid susceptibility tests, the LD50 is of little value, as a 50% control rate is considered too low. The LD90 or LD95 is a more useful value, but such values may not be accurate when read from the graph, as the curve is often very flat around the 90 - 100% mortality rate.

Probit techniques straighten the curve by mathematical transformation of the dose-response data. From the resulting straight line the LD90 or LD95 may be determined with greater accuracy. Probit analysis was carried out using the SPSS-X statistical package on the mainframe (Sperry 1100) computer at Murdoch University, and on a personal computer at the Department of Agriculture. With the aid of this computer program the process is made even more accurate, as the program generates lethal doses for 0.1 - 99% mortality. For a more detailed account of the methods employed in probit analysis refer to Finney (1971) and Swaroop (1966).

This type of analysis is increasingly accurate with larger data sets, hence its use was restricted to where the range of concentrations was large, and where tests of the same species from the same lake had been carried out more than once.

Using probit analysis it is sometimes possible to determine if a population of animals has developed resistance to a particular larvicide. In such cases a goodness-of-fit test (chi- squared test) reveals that the data do not closely fit a straight line. However other factors can also cause a non-linear line, and so such a result does not necessarily indicate resistance (Swaroop, 1966). To determine if resistance has arisen it is necessary to compare results from the suspected population to results from a population that has never been exposed to the larvicide.

RESULTS

The results presented here are for mortality after 24 hours exposure to the pesticide, as recommended by the World Health Organization. For the longer tests carried out during the February trials (refer to methods) 100% mortality was recorded after 48 and 72 hours hours in all cases. However, high mortalities (greater than 20%) were also recorded for many of the controls after 48 hours and 72 hours, and so these data are not considered further.

Abate 50SG (granular temephos)
At rates of 37.5 and 75gAI/ha (0.75 and 1.5kg product/ha) Abate 50SG proved ineffective against *C. australis* as evidenced by the data in Table 13. The maximum kill achieved at these rates was 57.3% for larvae from Lake Claremont using 75gAI/ha (1.5kg product/ha). On other occasions much lower results were obtained at this rate; for example mortalities of less than

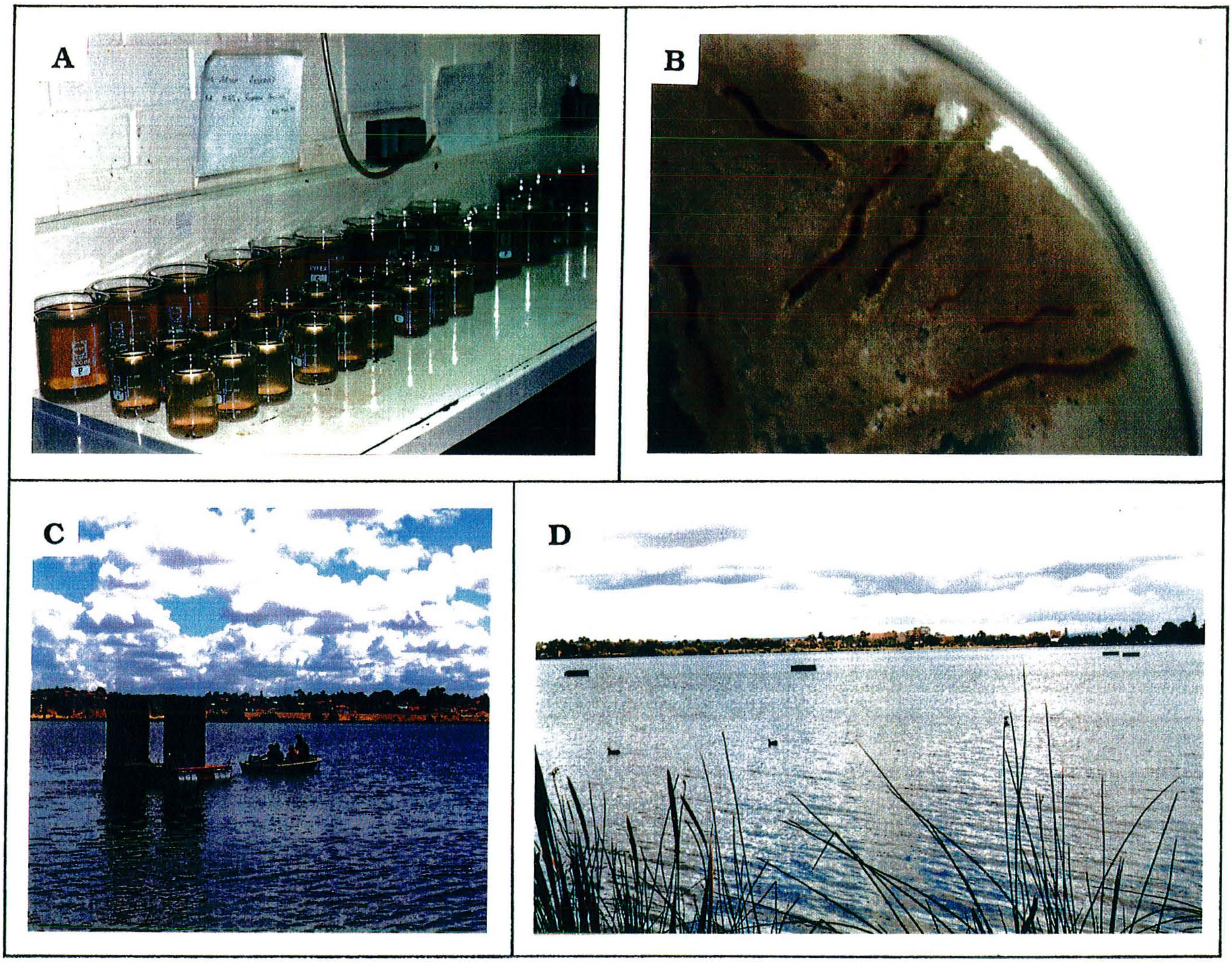


Figure 6. Photographs showing pesticide testing procedures. **A**: Laboratory layout showing test beakers containing midge larvae, **B**: View of bottom of test beaker showing *C. australis* larvae and tubes built from sand substrate, **C**: Enclosures for field pesticide experiment being towed on Lake Monger prior to their placement, **D**: Lake Monger, showing four of the six enclosures in position.

Table 13. Results of 24 hour laboratory susceptibilty tests of **Abate 50SG** (granular temephos) against *Chironomus australis* and *Chironomus alternans*, showing mean % mortality ± standard error at various concentrations. (G=granules, S=solution made from granules, refer to methods).

Chironomus australis

Lake/Date		Concentration (gAl/ha) 37.5	75	150	300	600	10 000	100 000	3 162 278
		Mean % Mortality ± S.E. (sample size)							
Monger/Oct-87	S	0.0±0.0(26)	9.5±5.8(33)	46±13.4(32)					
	G		3.3±3.3(33)	17.3± 5.2(38)					
Monger/Nov-87	S			10.3± 5.8(56)	40±5.8(124)	26± 4.7(57)			
	G				18±3.8(57)				
Monger/Feb-88	G		28.3± 3.3(43)			22.7±4.4(48)	17.7±5.2(46)	81.3±9.5(52)	97.3±2.7(45)
Forrestdale/Nov-87	S	9.2± 5.3(60)	22.1± 3.4(164)	37.1± 5.4(52)					
Claremont/Feb-88	G		57.3±9.6(34)			77.7±22.3(45)	91.7±1.5(48)	96.0±4.0(50)	100.0±0.0(41)
Mean % Mortality of all Tests	**S**	**4.6± 3.1**	**17.6±3.4**	**31.1±7.0**	**40.0±5.8**	**26.0±4.7**			
	G		**29.7± 8.4**	**17.3±5.2**	**18.0±3.8**	**50.2±16.0**	**54.7±16.7**	**88.7±5.7**	**98.7±1.3**

Chironomus alternans

Lake/Date		Concentration (gAl/ha) 37.5	75	150	300	600	10 000	100 000	3 162 278
		Mean % Mortality ± S.E. (sample size)							
Monger/ Oct-87	S	34.4±21.9(28)	65±12.6(23)	66.7±16.7(24)					
	G		38.3± 9.6(18)	69.3± 5.2(12)					
North/Oct-87	S	82.0± 9.3(45)	98.3± 1.7(72)	100 ± 0.0(44)					
	G		97.7± 2.3(45)	87.2±7.3(32)					
Mean % Mortality of all Tests	**S**	**58.2±15.1**	**87.2± 6.7**	**84.7± 7.2**					
	G		**68.0±14.0**	**76.5± 9.5**					

Table 14. Results of 24 hour laboratory susceptibility tests of **Abate 50SG** (granular temephos) against *Chironomus intertinctus* and *Polypedilum nubifer*, (including data obtained by Grant Pearson, C.A.L.M.) showing mean % mortality ± standard error at various concentrations (G= granules, S= solution made from granules, refer to methods).

Chironomus intertinctus

Lake/Date		Concentration (gAl/ha)							
		37.5	75	150	300	600	10 000	100 000	3 162 278
		Mean % Mortality ± S.E. (sample size)							
North/Oct-87	S	16.7±16.7(7)	86.1± 9.0(36)	100± 0.0(11)					
	G		66.7±19.3(7)	75.7± 6.8(19)					

Polypedilum nubifer

Lake/Date		Concentration (gAl/ha)							
		37.5	75	150	300	600	10 000	100 000	3 162 278
		Mean % Mortality ± S.E. (sample size)							
North/Feb - 88	G		96.0± 4.0(42)			96.7± 3.3(29)	100± 0.0(65)	100±0.0(48)	100±0.0(53)

Polypedilum nubifer Tests carried out by Grant Pearson (CALM)

Lake/Date		Concentration (gAl/ha)							
		12.6	25	50	80	205	250	24910	Controls
		Mean % Mortality (sample size)							
Gingin wetland		10(20)		75(20)	80.0 (20)				0(20)
Forrestdale Lake					5(20)	15(20)	55(20)	65(20)	0(20)

Table 15. Results of 24 hour laboratory susceptibility tests of **Abate 50SG** (granular temephos) against corixids (Micronecta robusta) showing mean % mortality ± standard error at various concentrations (S= solution made from granules, refer to methods).

Corixids

Lake/Date		Concentration (gAl/ha)							
		37.5	75	150	300	600	10 000	100 000	3 162 278
		Mean % Mortality ± S.E. (sample size)							
Monger/Oct - 87	S		0.0± 0.0(21)						
Forrestdale/Nov - 87	S		9.1± 9.1(31)						
Mean % Mortality of all Tests	S		**1.8± 1.8**						

Table 16. Results of 24 hour laboratory susceptibilty tests of **Lorsban 15G** (granular chlorpyrifos) against *Chironomus australis*, showing mean % mortality ± standard error at various concentrations (G=granules, S=solution made from granules, refer to methods).

<u>Chironomus australis</u>

Lake/Date		Concentration (gAl/ha)				
		25	50	100	200	400
			Mean % Mortality +S.E. (sample size)			
Monger/Nov - 87	S	10.7± 5.4(58)	16.0± 3.0(119)	14.3± 5.5(63)		
	G		33.3± 8.6(60)			

Table 17. Results of 24 hour laboratory susceptibility tests of **Dursban 480** (liquid chlorpyrifos) against *Chironomus australis* and *Chironomus alternans*, showing mean % mortality ± standard error at various concentrations (L= solution made from liquid product, refer to methods).

Chironomus australis

Lake/Date		Concentration (gAI/ha) 25	50	100	200	400
		Mean % Mortality ± S.E. (sample size)				
Monger/Oct-87	L			95.0± 2.5(40)	95.0±5(53)	100± 0.0(51)
Monger/Nov-87	L	6.0± 3.2(48)	38.0±12.7(60)	42.0±11.5(60)		
Forrestdale/Nov-87	L	48.3±10.3(55)	69.3± 6.9(50)	82.3±10.7(58)		
Mean % Mortality of all Tests	L	**27.2±10.6**	**53.7±9.5**	**62.2±11.4**	**95.0± 5.0**	**100± 0.0**

Chironomus alternans

Lake/Date		Concentration (gAI/ha) 25	50	100	200	400
		Mean % Mortality ± S.E. (sample size)				
Monger/Oct-87	L			100± 0.0(16)	100± 0.0(13)	100± 0.0(6)
North/Oct-87	L			100± 0.0(33)	100± 0.0(46)	91.0± 9.0(40)
Mean % Mortality of all Tests	L			**100± 0.0**	**100± 0.0**	**95.5±5.4**

Table 18. Results of 24 hour laboratory susceptibility tests of **Dursban 480** (liquid chlorpyrifos) against *Chironomus intertinctus* and corixids (*Micronecta robusta*), showing mean % mortality ± standard error at various concentrations (L = solution made from liquid product, refer to methods)

Chironumus intertinctus

Lake/Date		Concentration (gAI/ha)				
		25	50	100	200	400
		Mean % Mortality ± S.E. (sample size)				
North/Oct 87	L			100± 0.0(23)	100± 0.0(9)	90.9± 9.1(17)

Corixids

Lake/Date		Concentration (gAI/ha)				
		25	50	100	200	400
		Mean % Mortality ± S.E. (sample size)				
Monger/Oct-87	L				78±22(17)	
Forrestdale/Nov-87	L			90.3± 5.8(30)		

Table 19. Results of 24 hour laboratory susceptibility tests of **Teknar** (liquid Bti) against *Chironomus australis*, *Chironomus alternans*, *Chironomus intertinctus* and corixids (*Micronecta robusta*), showing mean % mortality at various concentrations (L = solution made from liquid, refer to methods).

Chironomus australis

Lake/Date		Concentration (l/ha)		
		15	30	60
		Mean % Mortality +S.E. (sample sizes)		
Monger/Oct-87	L	3.3± 3.3(52)	15.3± 8.0(49)	13.0± 7.2(58)
Forrestdale/Nov-87	L	25.9±12.3(44)	36.3± 6.7(49)	63.1±9.8(53)
Mean % Mortality of all Tests	L	**14.6±7.6**	**25.8±6.6**	**37.9±12.4**

Chironomus intertinctus

Lake/Date		Concentration (l/ha)		
		15	30	60
		Mean % Mortality +S.E. (sample sizes)		
North/Oct-87	L	7.7±11.2(15)	100± 0.0(14)	94.3±5.7(12)

Chironomus alternans

Lake/Date		Concentration (l/ha)		
		15	30	60
		Mean % Mortality +S.E. (sample sizes)		
Monger/Oct-87	L	25.0±25.0(6)	50.3±25.3(13)	100(2)
North/Oct-87	L	73.3± 8.3(30)	88.0± 4.0(44)	100± 0.0(40)
Mean % Mortality of all Tests	L	**62.8±17.5**	**69.2±14.2**	**100± 0.0**

Corixids

Lake/Date		Concentration (l/ha)		
		15	30	60
		Mean % Mortality +S.E. (sample sizes)		
Monger/Oct - 87	L		0.0±0.0(21)	
Forrestdale/Nov - 87	L		3.3± 3.3(21)	
Mean % Mortality of all Tests	L		**2.0± 2.0**	

Table 20. Results of 24 hour laboratory susceptibility tests showing mean % mortality ± standard error of controls of all species tested.

		Species				
Lake/Date		C.australis	C.alternans	C.intertinctus	P.nubifer	Corixids
			Mean % Mortality +S.E. (sample sizes)			
Monger/Oct - 87		1.3± 1.3(106)	0.0± 0.0(3)			0.0± 0.0
Monger/Nov - 87		1.6± 1.0(122)				
Monger/Feb - 88		0.0± 0.0(134)				
North/Oct - 87			1.2± 1.2(71)	0.0± 0.0(33)		
North/Feb- 88					3.8± 2.3(86)	
Forrestdale/Nov - 87		1.0± 1.0(100)				10.4± 5.8(28)
Claremont/Feb - 88		2.3± 1.6(120)				

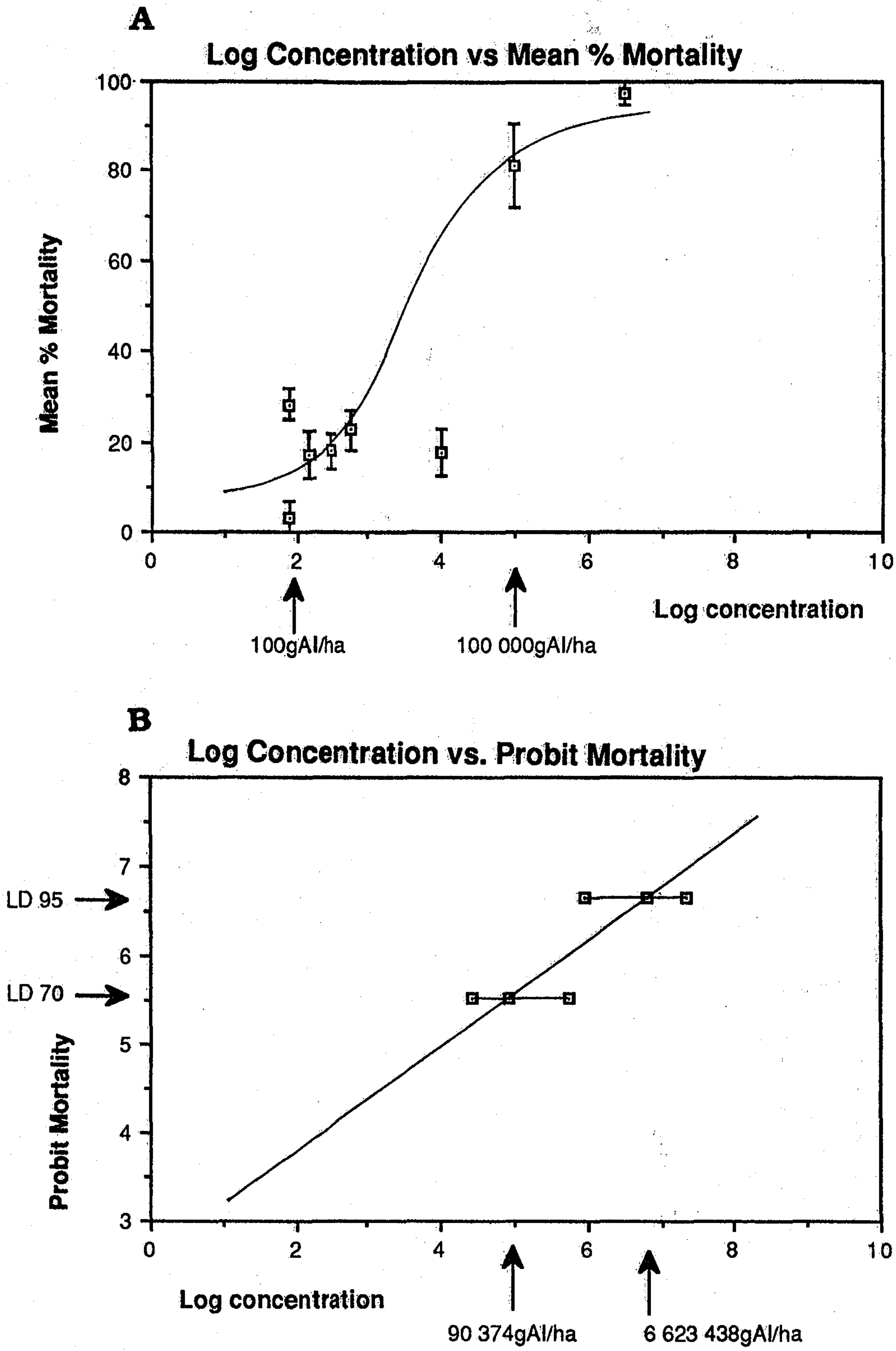
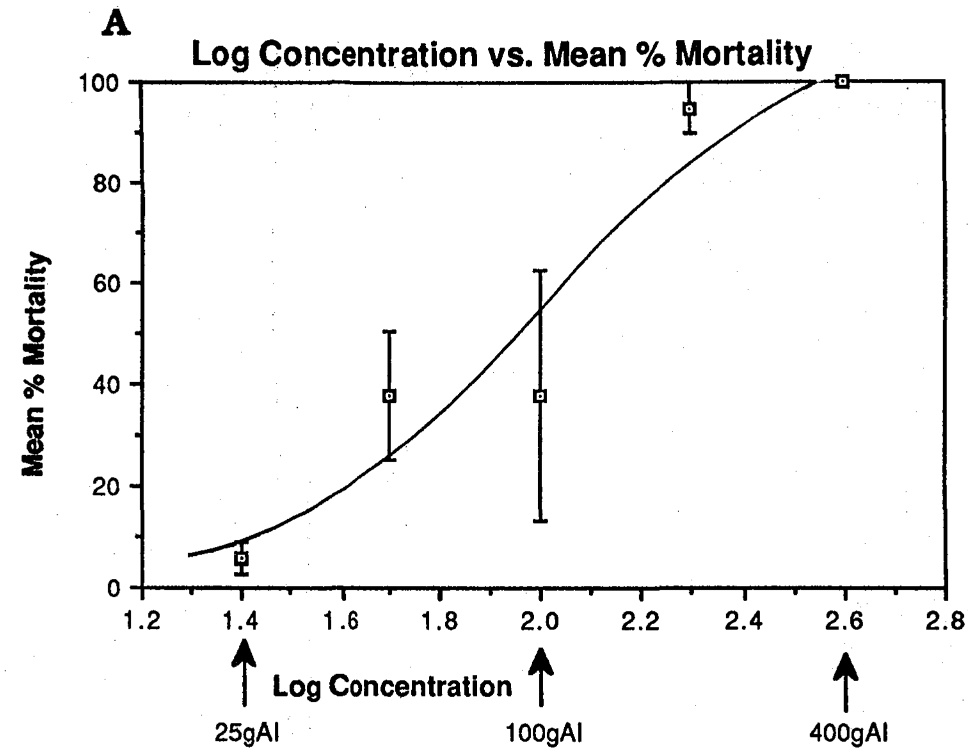


Figure 7. Results of 24 hour laboratory susceptibility tests, showing **A**: log concentration of **Abate 50SG** (granular temephos) vs. mean % mortality and **B**: log concentration of Abate 50SG vs. probit mortality, of *Chironomus australis* from Lake Monger.



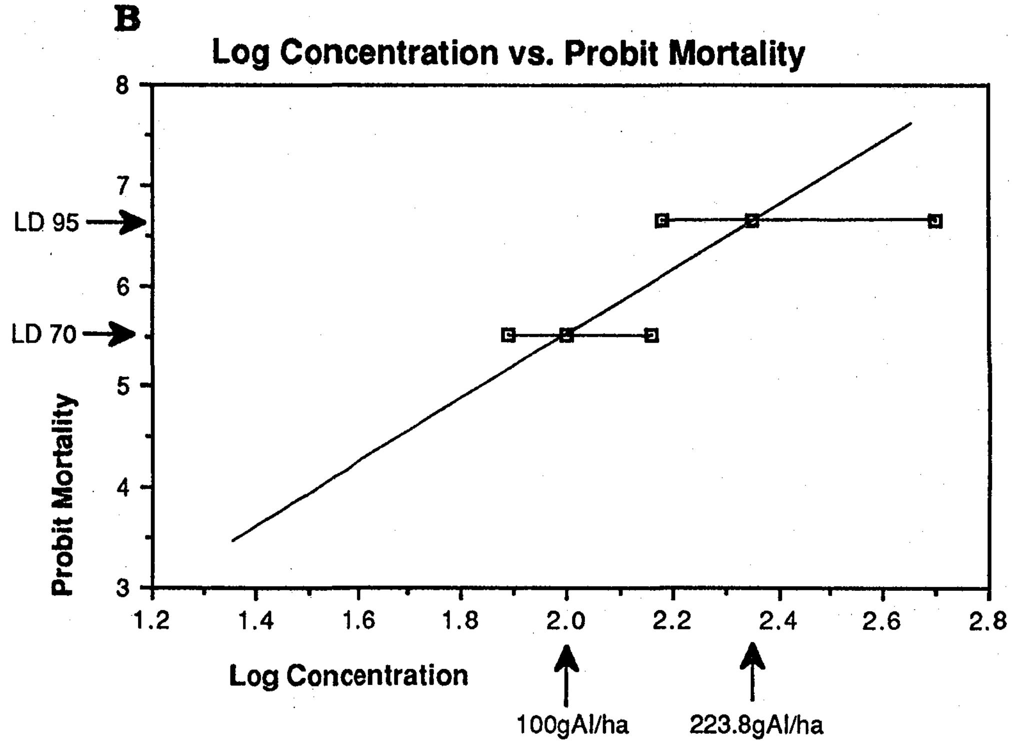


Figure 8. Results of 24 hour laboratory susceptibility tests, showing **A**: log concentration of **Dursban 480** (liquid chlorpyrifos) vs. mean % mortality and **B**: log concentration of Dursban 480 vs. probit mortality, of *Chironomus australis* from Lake Monger.

10% were recorded against a sample of this species from Lake Monger. Increased rates of 150 to 600gAI/ha against *C. australis* from Lake Monger did not result in very much higher mortalities. To determine what doses would be required to obtain 90 to 95% mortality of this species the dose was raised in February to very high levels (10 000 to 3 162 278gAI/ha or 200 to 63 245kg product/ha). At 10 000gAI/ha the required mortality was obtained for *C. australis* larvae from Lake Claremont but not from Lake Monger (Table 13). At 100 000 and 3 162 278gAI/ha (200 and 63 245kg product/ha), consistently high results were obtained for *C. australis* at both lakes.

Sufficient data were obtained from the susceptibility trials of Lake Monger *C. australis* for Abate 50SG to carry out probit analysis. The results of this analysis enabled us to more accurately determine the concentrations needed to give specific mortalities. According to the computer generated analysis (Fig. 7), a dose of 6.23×10^6 gAI/ha (124 600kg product/ha) would be required to give 95% mortality, and 1.65×10^6gAI/ha (33 000 kg product/ha) would give 90%.

Abate 50SG appeared to be more effective against the other species of midge that were tested. 150gAI/ha (3kg product/ha) achieved between 66.7 and 100% mortality of *C. alternans*, and 75.7 to 100% of *C. intertinctus* (Table 13 and 14). This pesticide was most effective when used against *P. nubifer* from North Lake; a normal field rate of 75gAI/ha (1.5kg product/ha) resulted in 96.0% mortality in the laboratory trials. A rate of 80gAI/ha (1.6kg product/ha) achieved only 5.0% mortality of *P. nubifer* from Forrestdale Lake in tests carried out by Mr Grant Pearson of the Department of Conservation of Land Management. In the same tests 80gAI/ha achieved 80% mortality of *P. nubifer* from a Gingin lake.

The susceptibility of one group of non-target invertebrates, the corixids (*Micronecta robusta*) to Abate 50SG (75gAI/ha or 1.5kg product/ha) was tested on two occasions. Very low mean mortalities of 0 and 9.1 % were recorded (Table 15).

Dursban 480 (liquid chlorpyrifos)
During the first trials the mortality of Lake Monger *C. australis* was 95% to 100% when exposed to rates of 100 to 400gAI/ha (0.21 to 0.83 l product/ha), as the data in Table 17 show. Ninety to 100% mortality was also recorded for the two other species tested in October (*C. alternans* and *C. intertinctus*) at these doses. On the assumption that even lower concentrations might be as effective, the next series of trials involved rates of between 25 and 100gAI/ha (0.05 to 0.21 l product/ha). At the highest of these rates (100gAI/ha), the Forrestdale Lake and Lake Monger *C. australis* suffered 82.3 and 42.0% mortality respectively. Concentrations of 25 and 50gAI/ha resulted in mortalities of between 6.0 and 69.3% for *C. australis* at these two lakes. By analysing the Dursban 480 data for Lake Monger using probit analysis it was determined that 95% mortality should result from exposure to 223.8gAI/ha or 0.47 l product/ha (Figure 8).

Corixids were exposed to rates of 100 and 200gAI/ha (o.21 and 0.42 l product/ha) in two separate tests. The data in Table 18 suggest that the corixids are very susceptible to Dursban at these rates.

Lorsban 15G (granular chlorpyrifos)
At rates of 25 to100gAI/ha (0.17 to 0.67kg product/ha) a maximum mortality of 33.3% was obtained for *C. australis* from Lake Monger. These results were much lower than those achieved through the use of Dursban 480.

Teknar (Bti)
The mortality of *C. australis* when exposed to 15 to 60 l/ha ranged from 3.3% (15l/ha) to 63.1% (60 l/ha) (Table 19). The corresponding results for *C. alternans* were consistently higher, 60 l/ha giving 100% mortality for larvae from North Lake and Lake Monger. Similar high rates (100 and 94%) were recorded when *C. intertinctus* was subjected to 30 and 60 l/ha respectively.

The data in Table 19 show that corixids were not susceptible to Bti at rates that caused high midge mortality.

Summary
From the results attained in the laboratory susceptibility trials it is evident that the effectiveness of tested pesticides varies from species to species. This is most apparent for Abate. *C. australis* does not appear to be highly susceptible to this pesticide at rates currently rcommended for field use. However, much higher mortalities were achieved when *C. alternans* and *C. intertinctus* were exposed to such rates. *P. nubifer* appears to be the species that is most susceptible to Abate under laboratory conditions.

Dursban 480 was more effective in killing *C. australis* than Abate, with high mortality occuring at 200gAI/ha (0.42 l product/ha). For *C. alternans* and *C. intertinctus* 100% mortality was recorded at 100gAI/ha (0.21 l product/ha).

High mortality of *C. alternans* and *C. intertinctus* occurred when exposed to Bti at rates of 30 to 60 l/ha. These rates were not as effective when Bti was used against *C. australis*.

DISCUSSION

At rates usually used in the field (75 to 150gAI/ha or 1.5 to 3kg product/ha)) Abate (temephos) is not effective against *C. australis* in the laboratory. Similarly *C. intertinctus* and *C. alternans* did not always suffer high mortality at these rates. This may indicate that resistance has arisen in these species. To test this more conclusively populations that have never been exposed to Abate need to be tested in the laboratory. The results indicate that increasing the application rate of Abate may not be an effective option for the control of *C. australis*.

The 96% mortality rate achieved with 75 gAI/ha (1.5kg product/ha) of Abate against *P. nubifer* in the laboratory trials corresponds well to the mortality rate of 80% (approximate) of *P. nubifer* achieved after the first treatment at the same dose rate, at North Lake(Fig 20). Field results could be expected to be lower, for the same dose rate, than laboratory results because of the lack of control over field conditions and the possible variability in field application. In the field the effectiveness of Abate appeared to decrease after subsequent sprayings. A reduction of less than 10% had occurred in the numbers of *P. nubifer* three days after the second treatment of the lake. The apparent change in susceptibility after successive treaments has been noted by other workers and indicates that **alternative larvicides** to Abate need to be adopted for the control of *P. nubifer* in Perth wetlands.

Dursban 480 (chlorpyrifos) achieved 95 to 100% mortality against *C. australis*, *C. intertinctus* and *C. alternans* at rates low enough to use in the field. On the basis of laboratory susceptibility trials and a field trial at Lake Monger (refer to Field Trial of Chlorpyrifos section) this pesticide would be an effective short-term alternative to Abate. The main disadvantage to consider is that this pesticide is highly toxic to the non-target fauna (both vertebrates and invertebrates). Also resistance is likely to become a problem in the long-term.

Teknar caused high mortality to two species (*C. intertinctus* and *C. alternans*), but not to *C. australis*. Considering the environmental desirability of this pesticide it should not be ruled out as an alternative, especially if different formulations can be obtained. Further testing is required to assess the potential of this option.

Overall, the laboratory susceptibility tests have shown that Abate was not effective in achieving high mortality of some *Chironomus* species, indicating that resistance has developed in at least one (*C. australis*). In addition Abate appeared to be ineffective against *P. nubifer* with repeated treatments. Of the two alternatives tested, Dursban 480 was shown to be very effective against the species tested.

Further laboratory and field trials of other larvicides, including Bti (in granular formulation), synthetic pyrethriods and IGR's are now required so that effective alternative larvicides to Abate can be determined for use on at least a trial basis in 1988/89.

FIELD TRIAL OF CHLORPYRIFOS

INTRODUCTION

The effectiveness of Dursban 480 (chlorpyrifos) in the field against midge larvae was tested at Lake Monger between November 1987 and January 1988. The experiment was carried out with a set of six enclosures (three treatments and three controls). Ideally all pesticide tests conducted in the laboratory should have been followed up with a field testing programme. However time and available funding permitted only one set of field tests to be conducted. A decision was made to test chlorpyrifos as it was considered to be the most likely short term alternative to temephos at Lake Monger. Tests were carried out at this lake with the help of the Perth City Council, who provided the support and expertise required to construct and install the enclosures.

METHODS

The Perth City Council constructed six enclosures which consisted of 2m x 2m x 2m wooden frames, around which was wrapped thick (100μm) black plastic on four sides. These were placed randomly (in pairs) in the central part of Lake Monger on the 20 November 1987, as is shown in Figs. 6C and 6D.

The surface area of each enclosure was envisaged as consisting of a grid with 16 equal squares. Samples were taken at random but not repeated locations on this grid. This ensured that samples were not taken from the same area of the enclosed substrate on subsequent sampling dates. On the 23 November samples of the bottom sediment were taken from each enclosure to determine larval density prior to addition of the pesticide. On the following day 100gAI/ha (0.2ml) of Dursban 480 was added using a hand operated sprayer to three of the enclosures selected at random. Subsequent monitoring of larval density occurred on 27 November (three days later), 1 December (one week later) and 15 December (three weeks later), and on the13 January (six weeks later).

A corer of 10.9 cm diameter was used to take four samples of sediment on each occasion. At the same time a water sample was taken for chlorophyll-a /phaeophytin, total nitrogen and total phosphorus analysis. On four occasions oxygen and temperature measurements were taken at the surface, and depths of 0.5, 1.0 and1.5 metres. Cores were later sorted and the larvae identified at Murdoch University

On the 28 November an attempt was made to catch sufficient fish (Carp and Redfin Perch), on which to carry out susceptibility tests. Only two Carp and one Redfin Perch were caught by electrofishing and consequently no tests were carried out.

RESULTS

Effects of Chlorpyrifos on Larval Density
C. australis was the only species present in all samples on all sampling occasions and so the following results refer to this species alone.

On the basis of the results of two factor analysis of variance it was concluded that the siting of the enclosures had no significant effect on the larval numbers prior to treatment (d.f.= 2,18, F=0.006). Also, the larval densities of enclosures assigned as controls were not significantly different to those assigned as test enclosures (d.f.=1,18, F=2.841). The substrate was thus assumed to be homogeneous in relation to larval density. Therefore further analysis of variance only considered the effects of pesticide addition. This allowed the data to be plotted as the mean larval density for treated vs. control enclosures, rather than considering each enclosure separately.

Prior to the addition of chlorpyrifos the mean number of larvae per square metre in the enclosures designated as controls was 2843, compared to 3098.2 in the test enclosures (Fig. 9)

Three days after the addition of pesticide the mean larval density of the treated enclosures fell to 314.9 per square metre (a decrease of 89.8%) (Fig.9) In the control enclosures however the mean larval density decreased by only 1.0%. A statistically significant difference was found between the larval density of the control and treated enclosures (Table 21). The mean larval density of the treated enclosures was 89.8% lower than that of the controls.

After a further four days the density of larvae in the treated enclosures had dropped to a mean of 63.7 per square metre (97.9% lower than prior to treatment). However, the mean density of larvae in the controls had also decreased by 48.9%. Despite this, the treated enclosures on average contained 95.6% fewer larvae than the controls. The difference between the larval densities of test and control enclosures was still statistically significant (Table 21).

Three weeks after treatment the mean larval density in the treated enclosures had fallen to zero per square metre, compared to 339.5 per square metre in the control enclosures. Further monitoring revealed no recovery of larval numbers in either treated or control enclosures.

Environmental Conditions within the Enclosures
The water within the enclosures remained moderately alkaline throughout the study period (Fig 10). After an initial fall in both the treated and control enclosures the pH in the treated enclosures increased to pre-treatment levels. The pH of the control enclosures remained low.

A continuous increase in the conductivity of both control and treated enclosures was observed over the study period although the water never rose above 1100μS/cm (0.55ppt) (Fig. 10). While the conductivity in the control

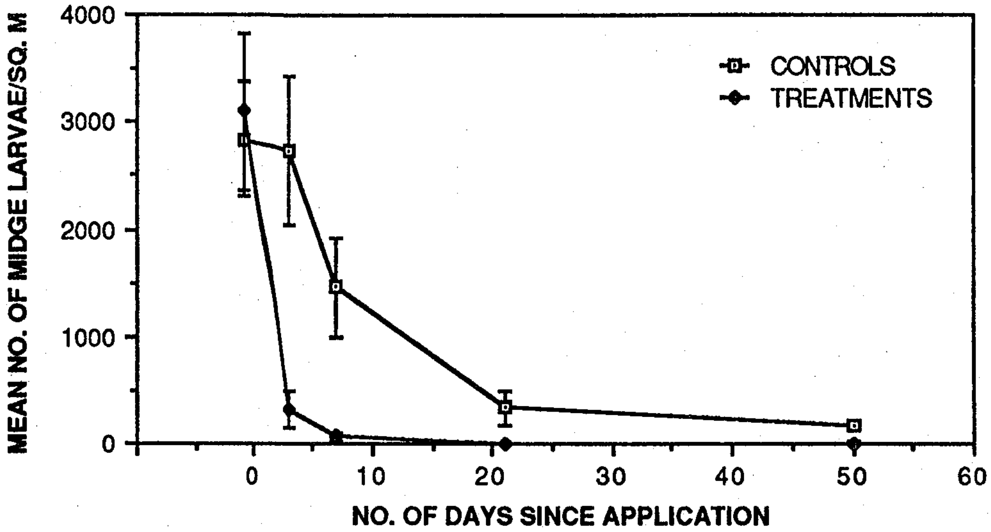


Figure 9. Changes in the number of chironomid larvae per square metre within the control and treated enclosures, during the field trial of Dursban 480 (chlorpyrifos) at Lake Monger, November 1987 to January 1988.

Table 21. Results of one-way analyses of variance, comparing the number of larvae per square metre in control and treated enclosures.

TIME OF SAMPLING	Degrees of freedom	F Value	Significance
PRIOR TO SPRAYING	1, 18	0.006	N.S.
THREE DAYS AFTER SPRAYING	1, 23	5.49	* *
SEVEN DAYS AFTER SPRAYING	1, 20	0.94	*

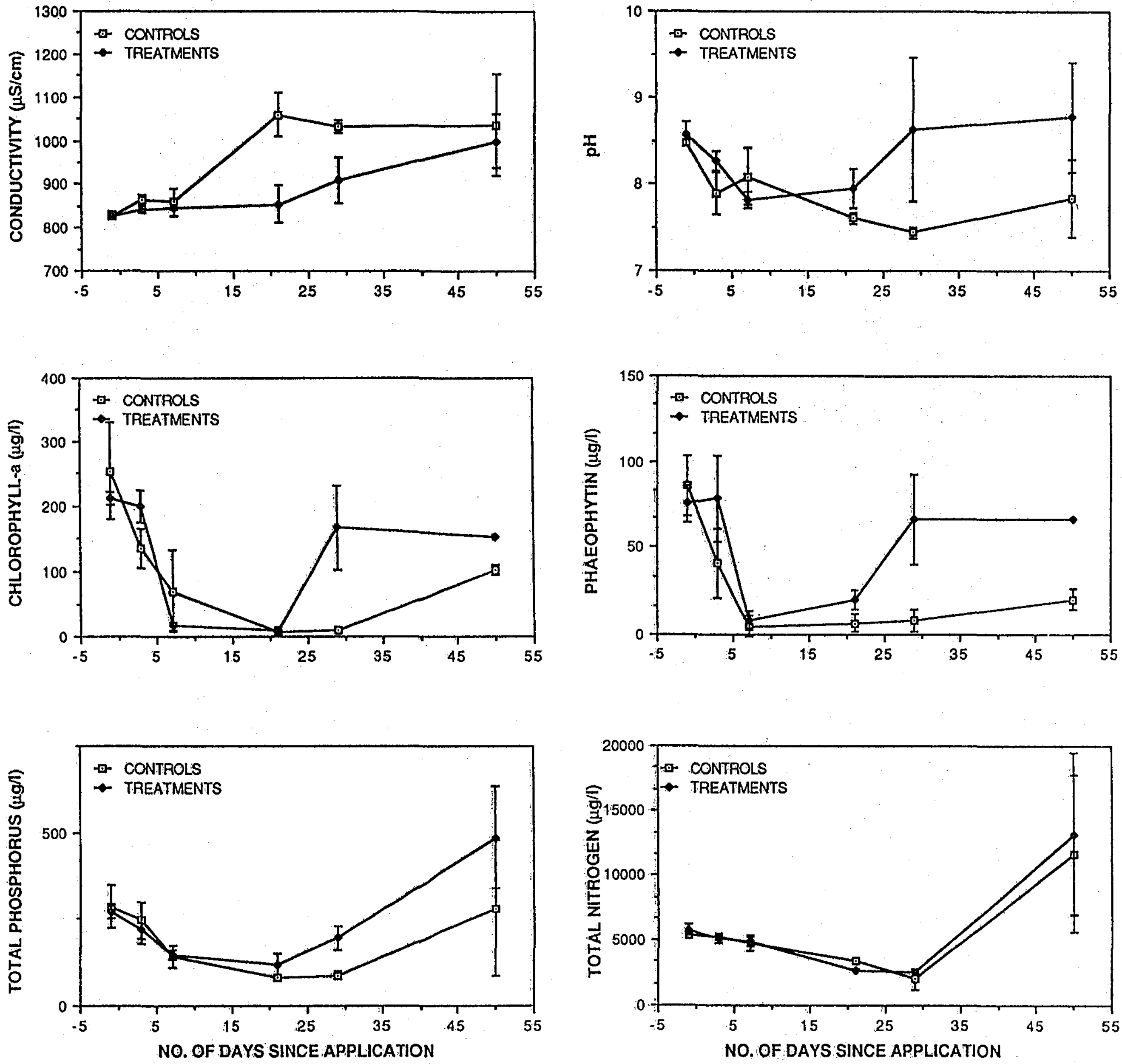


Figure 10. Changes in conductivity, pH, concentrations of chlorophyll-a, phaeophytin, total phosphorus and total nitrogen within the control and treated enclosures, during the field trial of Dursban 480 (chlorpyrifos) at Lake Monger, November 1987 to January 1988.

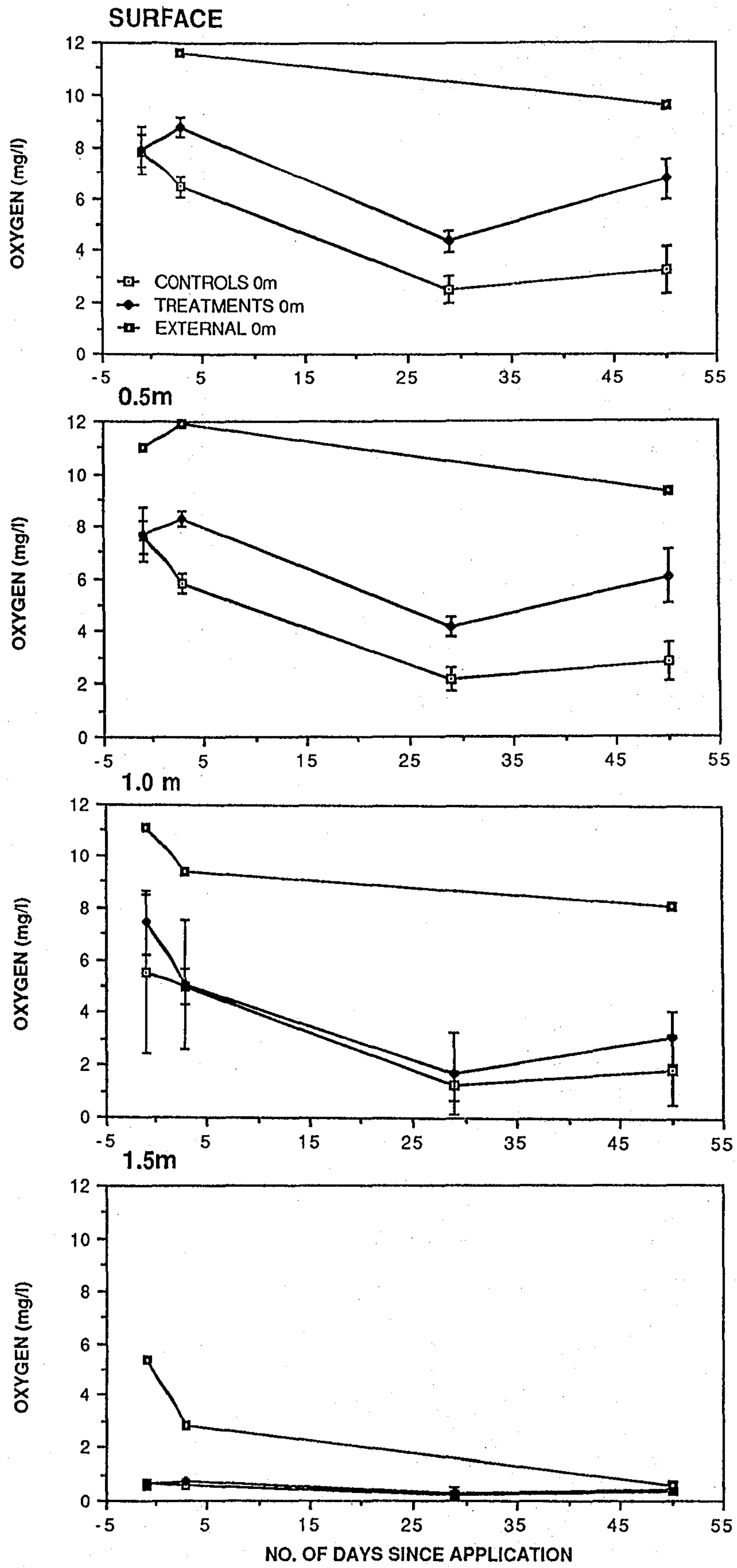


Figure 11. Changes in the concentration of dissolved oxygen within the control and treated enclosures and outside of the enclosures, at the water surface and at depths of 0.5, 1.0, and 1.5m, during the field trial of Dursban 480 (chlorpyrifos) at Lake Monger, November 1987 to January 1988.

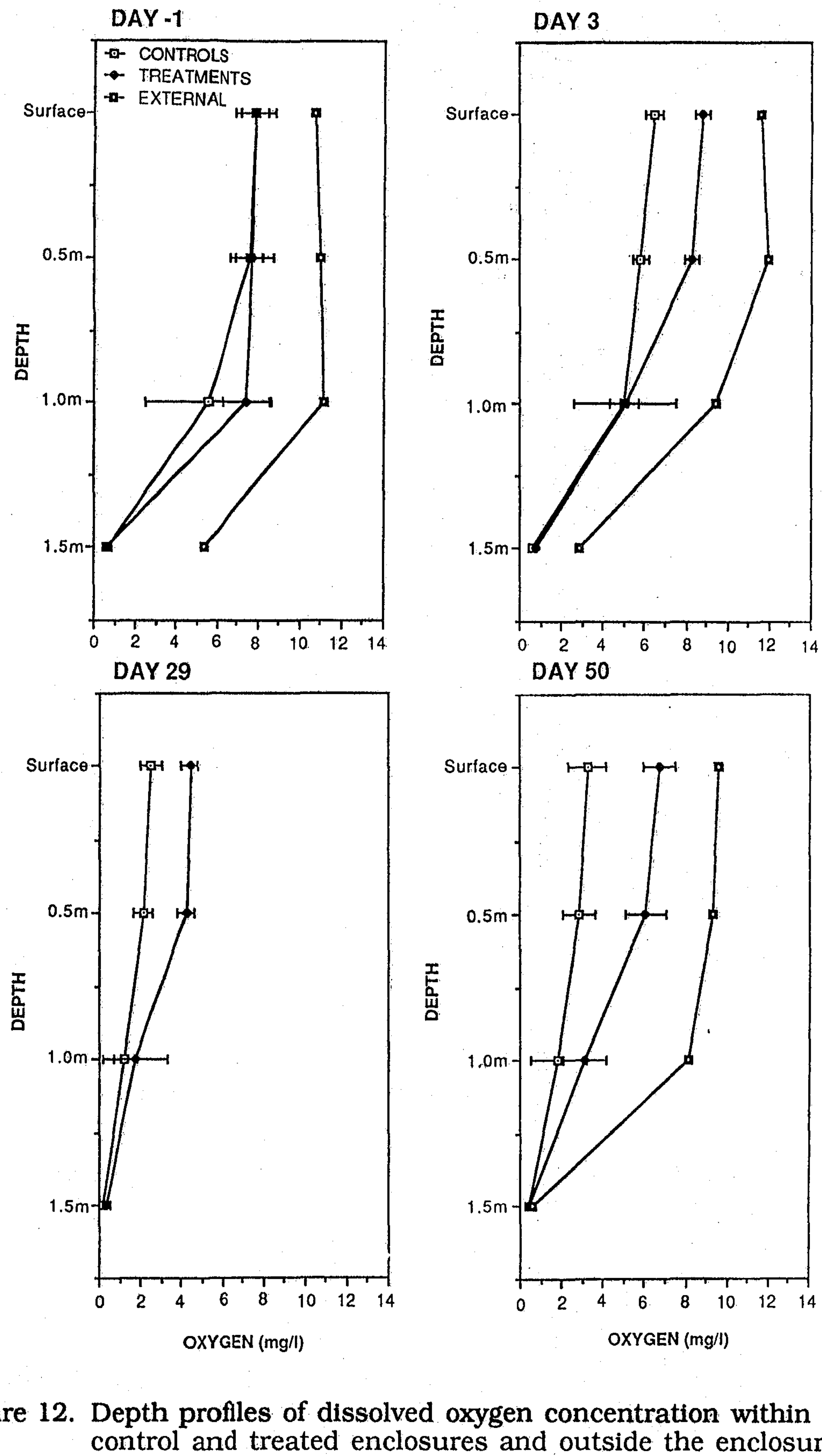


Figure 12. Depth profiles of dissolved oxygen concentration within the control and treated enclosures and outside the enclosures, on four sampling occasions during the field trial of Dursban 480 (chlorpyrifos) at lake Monger, November 1987 to January 1988.

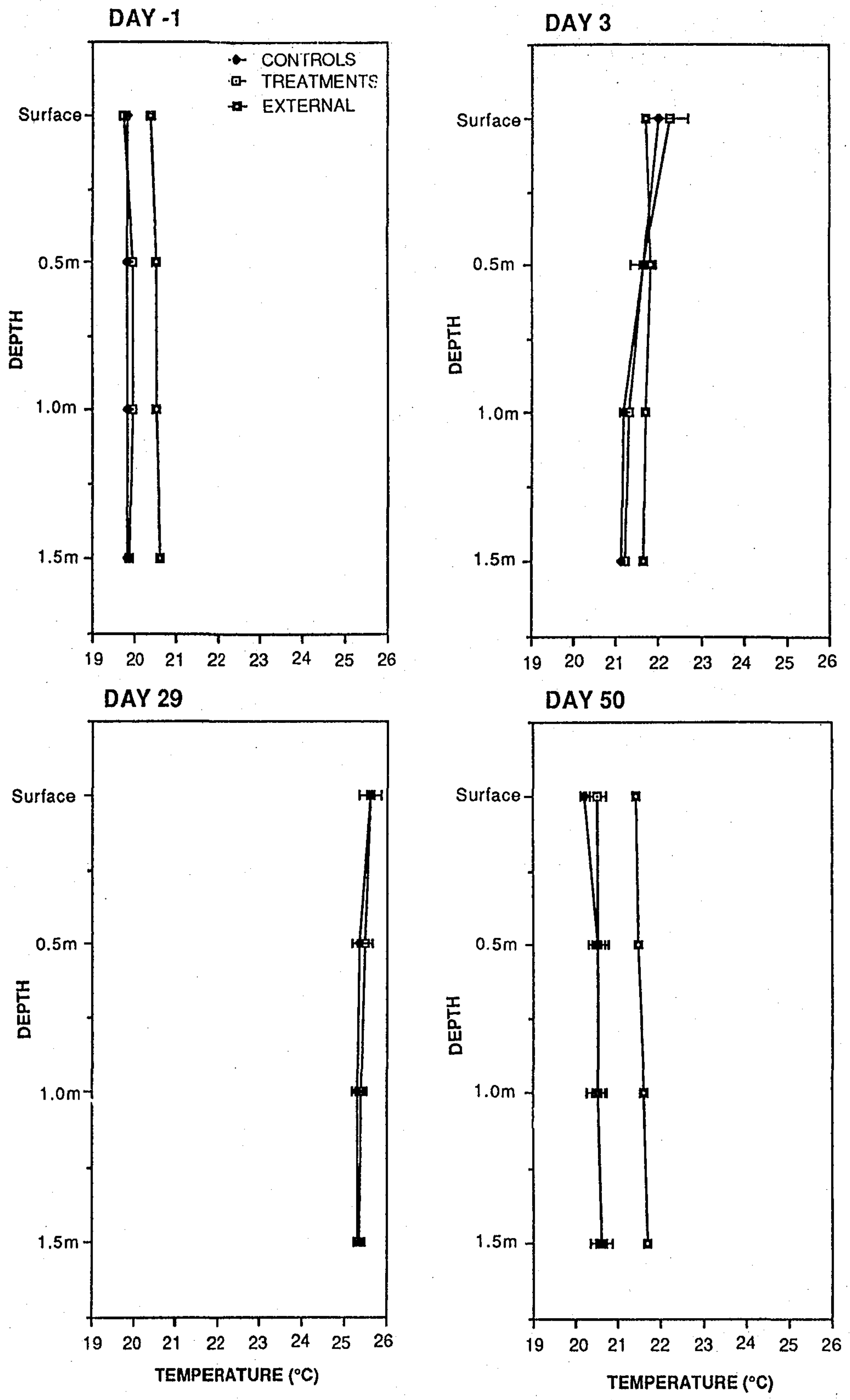


Figure 13. Depth profiles of water temperature within control and treated enclosures and outside the enclosures, on four sampling occasions during the field trial of Dursban 480 (chlorpyrifos) at Lake Monger, November 1987 to January 1988.

enclosures rose more quickly than the treated enclosures, the final conductivity was approximately the same.

From the data in Fig. 10 it can be seen that the total phosphorus concentration became higher in the treated enclosures than in the controls. The overall pattern of change however was similar in both. No difference in total nitrogen was observed between treated and control enclosures (Fig. 10). An initial fall followed by a large rise was recorded in both.

Until day 21 there appeared to be little difference in chlorophyll-a concentrations between control and treated enclosures. After this time the concentration of chlorophyll-a in the treated enclosures rose more rapidly, and to a higher level, than the controls.

The concentration of dissolved oxygen of the water within the enclosures was consistently lower than that of the surrounding water. This situation had arisen within three days of the placement of the enclosures (Figs 11 and 12). In general, the oxygen concentration fell within the enclosures until the 29th day. Measurements on day 50 showed a slight increase had occurred at all depths. External to the enclosures an overall decrease had also occurred over the monitoring period. However, only at the lowest depth did the external oxygen concentration decrease to the same level as within the enclosures. As is usual the lowest oxygen concentrations were recorded at the lowest depth. While the oxygen concentrations at 1.5m changed little over time, the levels were initially much lower than the surrounding water. At the surface, 1.0 and 1.5m the treated enclosures generally had higher oxygen concentrations than the controls, although the patterns of change were similar in both.

Compared to the water temperature outside the enclosures the temperature within was usually 0.5 to 1.0 °C lower (Fig. 13). An overall range of 19.7 to 25.6°C was recorded within the enclosures, and no difference between treated and control enclosures was observed.

DISCUSSION

Effects of Chlorpyrifos on Larval Density

The results show that chlorpyrifos is effective in reducing larval numbers in an experimental field situation. Due to effects of the enclosures on the larval populations the length of time that chlorpyrifos remained effective in controlling the larvae is unknown.

Results obtained in this field trial correlate well with those from the laboratory testing of chlorpyrifos. After 72 hours a reduction in larval density of 89.8% occurred in the treated enclosures after the addition of 100gAI/ha of Dursban 480. According to the probit analysis of the Lake Monger *C. australis* data, 100gAI/ha should result in 70% mortality after 24 hours. Allowing for the time difference, the results of the field and laboratory trials are comparable.

Similar results were obtained by Mulla and Khasawinah (1968) using 41%

emulsifiable concentrate Dursban (Dursban 480 is a 48% emulsifiable concentrate) in sewage oxidation pond enclosures. At rates of 220 to 280gAI/ha, 100% mortality of *C. stigmaterus* was obtained after 72 to 96 hours. The use of a 1% granular fomulation resulted in 83% mortality of this species at the same rate. In the Lake Monger trial the application of 100gAI resulted in 89.8% mortality of *C. australis* after 72 hours.

In whole field applications of 1% granular chlorpyrifos, Ali and Mulla (1978a) recorded over 90% control of *Chironomus* spp. at rates of 110 and 220gAI/ha.

Results from the literature such as these, along with the results obtained in the present study, suggest that chlorpyrifos would be an effective, though environmentally undesirable (because of high toxicity to non-target fauna), alternative to Abate in the short-term. In the long term resistance is likely to develop as it appears to have done for Abate.

A priority of future research during 1988/89, would be the further use of enclosures for field trials of other pesticides, and as controls to assess the effectiveness of the spraying programmes.

Environmental Conditions within the Enclosures

The environment within the enclosed waters underwent some marked changes during the course of the experiment. The initial drop in phosphorus concentration in both control and treated enclosures is paralleled by the rapid decrease in chlorophyll-a concentration. A reduced chlorophyll-a concentration (i.e. reduced photosynthesis) often causes a drop in pH (Moss, 1980). The cause of the decrease in dissolved oxygen concentration may be attributed to the lack of circulation as well as changes in algal growth. While it is not clear what initiated these changes, the differences between the treated and control enclosures suggest that it was a chlorpyrifos-induced effect. Decreasing water depth as summer progressed was clearly the most likely cause of the increasing conductivity, and may also explain the rise in phosphorus concentrations after day 21.

Some problems were encountered with the enclosures and it is evident that they can only be used once in the same site. The main problem was that the lack of water movement caused decreased oxygen concentrations after only a short period especially at 1.5m. This may have caused the eventual fall in larval numbers in the control enclosures. Future use of enclosures should involve sampling of water and larvae external to the enclosures for comparison. The enclosures are necessarily isolated from the surrounding water, so the planktonic 1st instar larvae would not have recolonised the enclosed substrate. Data from the head capsule measurements suggests asynchronous life cycles for *C. australis*, and since adults of this species are known to lay eggs over the entire lake surface (Edward,1964), recolonization of the enclosed substrate might have been expected. It is possible that the enclosures prevented or inhibited egg laying by adult females, or the eggs and any hatched larvae did not survive in the oxygen poor water. The fact that the larval numbers did not increase may reflect the lack of recolonization and the low oxygen concentrations.

Similar enclosures are presently being used in an honours project being undertaken by Natalie Hill at Murdoch University to assess the impact of Abate on non-target organisms at North Lake. These enclosures differ from the ones used at Lake Monger, in that they are portable and are flexible to allow for changes in water depth.

LARVAL AND ADULT MONITORING PROGRAMMES

INTRODUCTION

A regular (fortnightly) monitoring programme was undertaken at four lakes, Booragoon Lake, Forrestdale Lake, Jackadder Lake and North Lake, to determine the species composition and abundance of larval populations. In addition regular sampling programmes were already being undertaken at two lakes, Lake Goollelal and Lake Monger, by the Wanneroo and Perth City Councils respectively, and samples of larvae collected from these lakes were given to the Murdoch study team for identification. The results of this component of the study would be used to improve the timing of the application of larvicides. Qualitative collections of adult midges were made by residents living near each lake and residents were also asked to score the level of midge nuisance they had experienced during the previous week or fortnight. This data would enable the major pest species to be identified and provide an estimate of the larval densities which resulted in the occurrence of nuisance swarms.

DESCRIPTIONS OF STUDY SITES

Booragoon Lake (Fig. 14A)
Booragoon Lake is a permanent lake of 11.4 ha, including 3.8 ha of open water and 7.6 ha of emergent trees that are the nesting sites of many waterbirds. The lake is approximately 2m deep and is surrounded by a band of vegetation, mostly paperbarks (*Melaleuca rhaphiophylla*) and flooded gums (*Eucalyptus rudis*). The lake is 11 km south of the centre of Perth and is located within the City of Melville. It lies in an urban setting, bounded by the suburbs of Booragoon and Brentwood, and by Leach Highway on its southern side.

Forrestdale Lake (Fig. 14B)
Forrestdale Lake is a large and shallow (<1.5m) temporary waterbody. Its 231.8 ha are made up of 221.1 ha of open water and 10.7 ha of sedgeland. The lake is an A class Nature Reserve and is important as a waterbird habitat and breeding ground. In recent years the lake has been dry from approximately December until April. The lake is located 24 km southeast of the city in the City of Armadale. The suburb of Forrestdale is sited on the northeast side of the lake and the rest of the lake perimeter is fringed by *Typha* and woodland.

Jackadder Lake (Fig. 14C)
Jackadder Lake is a permanent lake of 7.18 ha of open water, with a small island of 0.12 ha. The lake is 1.5 - 3m deep, but with a deeper (>4m) channel on the western side. It is located 8 km northwest of the centre of Perth within the City of Stirling. The lake setting is dominated by lawns and parkland and the surrounding suburb of Woodlands. Little natural vegetation remains and there is an almost complete lack of fringing rushes or reeds.

North Lake (Fig. 14D)
North Lake is a permanent lake of approximately 27 ha area and 2 - 3m depth. It is located 14 km south of the city centre in the suburb of North Lake and the City of Cockburn. It is bounded by the suburb of Kardinya to the northwest and the Murdoch University playing fields to the northeast. Farrington Road runs close to the lake on its northern side. A band of mixed grassland and woodland separates the lake from developed areas and is more extensive on the southern and eastern sides of the lake. Parts of the lake margin are vegetated by *Baumea* sp. and a number of introduced sedges and herbs. Two drains run into the lake, one from the suburb of Kardinya and the other from the Murdoch University farm.

Lake Goollelal (Fig. 14E)
Lake Goollelal is a shallow permanent lake of 75 ha located within the suburb of Kingsley in the City of Wanneroo. A dense fringe of rushes surrounds most of the lake. On the western side is the older residential area and to the east lies a new housing subdivision, bounded by Wanneroo Road. A vineyard and nursery are situated to the northeast of the lake.

Lake Monger (Fig. 14F)
Lake Monger is a deep permanent lake of 65 ha open water. It is located 4 km northwest of the city centre in the City of Perth. It is bounded by the innercity suburbs of Wembley to the west and Leederville to the east, and by the Mitchell Freeway to the northeast. The lake is surrounded by a discontinuous band of fringing rushes and beyond that, by lawns and parkland.

LAKE SPRAYING HISTORIES

The following section provides tabulated information (Tables 22-26) on the history of the application of Abate pesticide to five of the six lakes that were monitored for chironomids. The information was supplied at our request by the councils concerned and has been summarized for the purpose of this report. Some councils supplied details that covered a longer period than others, so the tables are not strictly comparable. No detailed records of the spraying history of Booragoon Lake have been kept by the City of Melville although it has been sprayed on several occasions, so a table is not included for that lake.

METHODS

General

Four lakes; Booragoon, Forrestdale, Jackadder and North Lakes; were sampled on a fortnightly basis by the Murdoch University study team. At these lakes, the lake substrates were sampled for chironomid larvae with a 9.8cm corer. In addition, on each sampling occasion a number of environmental parameters, including water depth, water and air temperatures were recorded. Water samples were taken for the analysis of pH, conductivity, total phosphorus, total nitrogen, chlorophyll-a and phaeophytins.

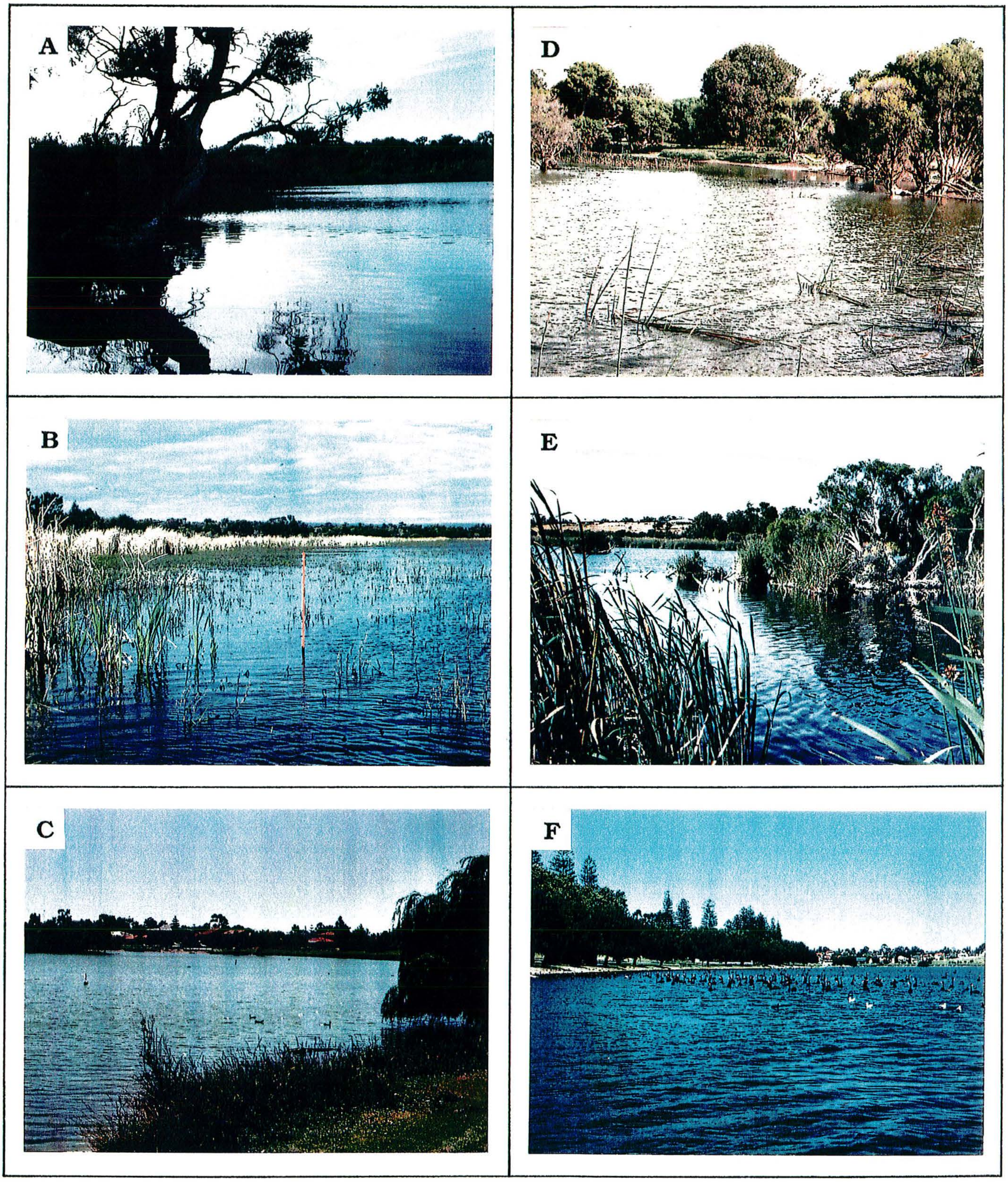


Figure 14. Photographs showing each of the six lakes studied.
A: Booragoon Lake, **B**: Forrestdale Lake, **C**: Jackadder Lake,
D: North Lake, **E**: Lake Goollelal, **F**: Lake Monger.

Table 22. Spraying history of Forrestdale Lake; 1975/76 to 1986/87. Abate 50SG was used on all occasions and was applied to the lake aerially. The total cost includes the cost of the Abate and the hire aircraft.

YEAR(S)	RANGE OF SPRAYING DATES	NUMBER OF APPLICATIONS	RATES APPLIED kg/ha (kg AI/ha)	TOTAL AMOUNT OF ABATE APPLIED/ha kg/ha (kg AI/ha)	COST OF APPLICATION ($)		EFFECTIVENESS
					ABATE	TOTAL COST	
1975/76	Nov - Feb	3	1.0 (0.05)	3.0 (0.15)		4553.00	Effective
1976/77	Nov - Feb	3	1.0 (0.05)	3.0 (0.15)		4613.00	Effective
1977/78	Sep - Dec	3	1.0 (0.05)	3.0 (0.15)		6082.00	Effective
1978/79	Oct - Jan	3	1.0 (0.05)	3.0 (0.15)		6841.00	Effective
1979/80	Nov - Dec	2	1.0 (0.05)	2.0 (0.15)		4856.00	Effective
1980/81	Nov - Dec	2	1.0 (0.05)	2.0 (0.15)		5951.00	Effective
1981/82	Nov - Mar	3	1.0 (0.05)	3.0 (0.15)		6173.00	Effective
1982/83	Nov - Dec	2	1.0 (0.05)	2.0 (0.15)		6987.00	Effective
1983/84	Nov - Feb	3	1.0 (0.05)	3.0 (0.15)		12041.00	Effective
1984/85	Dec	2	1.0 (0.05)	2.0 (0.15)		8160.00	One spray effective
1985/86	Oct - Dec	2	1.0 (0.05)	2.0 (0.15)		8166.00	Effective
1986/87	Oct - Feb	3	1.0 (0.05)	3.0 (0.15)		14650.00	Effective
TOTALS		31		31 (1.55)		$89,073	

Table 23. Spraying history of Jackadder Lake; 1978/79 to 1986/87. Abate 10SG was used on all occasions and was applied to the lake from a boat. For five years prior to this liquid Abate was applied. The area of the lake sprayed is assumed to be 7.18ha.

YEAR(S)	RANGE OF SPRAYING DATES	NUMBER OF APPLICATIONS	RATES APPLIED	TOTAL AMOUNT OF ABATE APPLIED/ha	COST OF APPLICATION ($)		EFFECTIVENESS
					ABATE	TOTAL COST	
			kg/ha (kg AI/ha)	kg/ha (kg AI/ha)			
1978/79			5.57 (0.056)				
1979/80			5.57 (0.056)				
1980/81			5.57 (0.056)				
1981/82			5.57 (0.056)				
1982/83			5.57 (0.056)				
1983/84			5.57 (0.056)				
1984/85			5.57 (0.056)				
1985/86	Jan - Apr	4	5.57 (0.056)	22.28 (0.2228)			
1986/87	Oct - Mar	7	5.57 (0.056)	38.99 (0.3899)			
TOTALS		11		61.27 (0.6127) +			

Table 24. Spraying history of North Lake; 1974/75 to 1986/87. Abate 50SG was applied on all occasions and was applied to the lake aerially. The area of lake sprayed is assumed to be 27ha. The total costs include the cost of the Abate and the hire aircraft.

YEAR(S)	RANGE OF SPRAYING DATES	NUMBER OF APPLICATIONS	RATES APPLIED kg/ha (kg AI/ha)	TOTAL AMOUNT OF ABATE APPLIED/ha kg/ha (kg AI/ha)	COST OF APPLICATION ($) ABATE	COST OF APPLICATION ($) TOTAL COST	EFFECTIVENESS
1974/75-78/79		15+	1.12 (0.056)	16.8 (0.84) +			
1979/80	Nov - Feb	4	1.0 (0.050)	4.0 (0.2)	468.72	1060.80	
1980/81	Nov - Feb	4	1.0 (0.050)	4.0 (0.2)	609.12	1246.80	
1981/82	Nov - Feb	4	1.0 (0.050)	4.0 (0.2)	682.56	1358.40	
1982/83	Dec - Feb	2	2.0 (0.10)	4.0 (0.2)	739.80	1152.00	
1983/84	Nov - Feb	1 3	2.0 (0.10) 1.0 (0.050)	5.0 (0.25)	1194.30	2025.00	
1984/85	Nov - Feb	2 2	1.0 (0.050) 2.0 (0.10)	6.0 (0.3)	1409.40	2364.00	
1985/86	Dec - Mar	5	1.0 (0.050)	5.0 (0.25)	1270.30	2461.50	
1986/87	Dec - Mar	5	1.5 (0.075)	7.5 (0.38)	2316.60	3661.95	
TOTALS		**47+**		**56.3 (2.82) +**	**$8,690.80**	**$13,797.49**	

Table 25. Spraying history of Lake Goollelal; 1980/81 to 1986/87. Abate 50SG was used on all occasions and was applied to the lake aerially. The area of the lake sprayed is assumed to be 75ha. The total cost includes the cost of the Abate and the hire aircraft.

YEAR(S)	RANGE OF SPRAYING DATES	NUMBER OF APPLICATIONS	RATES APPLIED kg/ha (kg AI/ha)	TOTAL AMOUNT OF ABATE APPLIED/ha kg/ha (kg AI/ha)	COST OF APPLICATION ($)		EFFECTIVENESS
					ABATE	TOTAL COST	
1980/81	Nov	1	1.6 (0.08)	1.6 (0.08)	676.80	779.28	Very effective
1981/82	Oct	1	1.6 (0.08)	1.6 (0.08	759.00	1116.00	Very effective
1982/83-84/85		0					
1985/86	Oct	1	2.13 (0.106)	2.13 (0.106)	1568.00	2093.00	Very effective
1986/87	Dec	1	1.85 (0.092)	1.85 (0.092)	1605.00	2280.00	Less effective
TOTALS		4		7.18 (0.359)	$4,608.80	$6,268.28	

Table 26. Spraying history of Lake Monger; 1968/69 to 1986/87. *Abate 100EC [l/ha(kgAI/ha)] was applied on all occasions except the final three spraying events in 1987 when Abate 50SG [kg/ha(kgAI/ha)] was applied. All applications were made by boat. The area of lake sprayed is assumed to be 65ha. The total costs include the cost of the Abate, spraying costs and the costs of any fogging operations.

YEAR(S)	RANGE OF SPRAYING DATES	NUMBER OF APPLICATIONS	RATES APPLIED *	TOTAL AMOUNT OF ABATE APPLIED/ha *	COST OF APPLICATION ($)		EFFECTIVENESS
					ABATE	TOTAL COST	
1968/69-73/74		?	5.26 (0.526)	?			
1974/75-75/76		4 - 6	5.26 (0.526)	26.3 (2.63)			
1976/77-82/83		0					
1983/84	Jan - Apr	3	3.8 (0.380)	11.4 (1.14)		3166.00	
1984/85	Oct - Feb	4 1	5.0 (0.50) 5.5 (0.55)	25.5 (2.55)		4055.00	Became less effective
1985/86	Oct - Feb	5 - 7	5.5-7.7 (.55-.77)	39.6 (3.96)		22000.00	Not effective
1986/87	Oct - Mar	2 3	7.7 (0.77) 1.23 (0.06)	15.4 (1.54) 3.69 (0.18)		50430.00	Not effective
TOTALS		22 - 26		12.00 kgAI/ha +		$79,651	

Regular sampling programmes were already being undertaken at two lakes, Lakes Goollelal and Monger, by the Wanneroo City Council and Perth City Council respectively. The councils continued their sampling procedures as before and provided samples of their collections to the Murdoch study team for species identification.

Collections of adult midges were made at each of the six lakes to assess the degree of nuisance caused by midges to residents living near the lakes and to determine the relationship between the composition and abundance of larval midges in each lake and the occurrence of nuisance swarms of adult midges in nearby suburbs. A small number of residents was asked to collect adult midges from their houses and to comment on the extent of the nuisance each week.

Meteorological data for Perth, including air temperature, rainfall and wind strength and direction were obtained from the Bureau of Meteorology and are presented in Figure 32.

Field and laboratory methods used in the monitoring programme are outlined below.

Larval Sampling (Fig. 15)
The larval sampling programme covered the spring and summer period between late October 1987 and early March 1988.

Booragoon, Forrestdale, Jackadder and North Lakes

Quantitative samples of the lake substrate were collected every fortnight from Booragoon Lake, Forrestdale Lake, Jackadder Lake and North Lake. A 9.8 cm diameter corer was used to sample the lake sediments in the littoral region of each lake whist a long-handled corer (10.9 cm diameter) was used from a boat to sample sediments from the deeper central regions of Booragoon, Jackadder and North Lakes. The top 5 cm of each core was placed in a labelled plastic bag with 100% ethanol preservative for storage until sorting and identification could be carried out in the laboratory. The type of substrate collected by each core and the depth of the water column at each sample site were recorded.

Larvae were separated from the substrate material by differential flotation in 10 litre plastic buckets containing 8 litres of saturated calcium chloride. Individual midge larvae were picked from the surface with fine forceps. The animals from each core were stored in vials of 70% ethanol and identified using keys by Edward (1964) and Martin (1986).

Determination of the number of samples to be collected at each lake
Because the microdistribution of many organisms is often clumped or contagious, large variations can occur when sampling natural populations and a small number of samples may be statistically inaccurate. One solution to this problem is to take a large number of samples (i.e. n>50). This approach is not usually economically feasible because of the large amount of time needed to sort and identify benthic samples. As a consequence, a

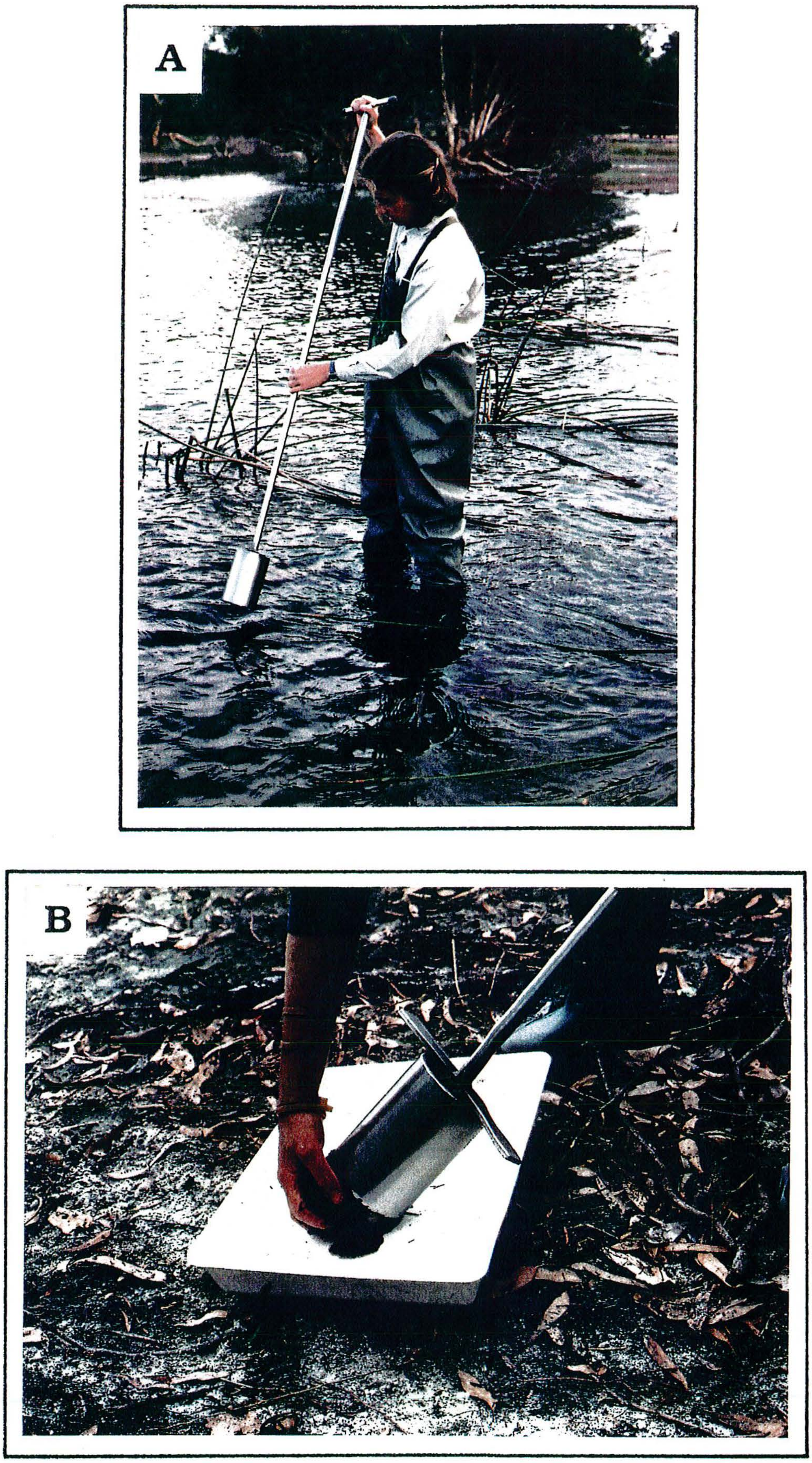


Figure 15. Photographs showing field sampling.
A: Sampling the lake substrate using a corer,
B: A core of sediment collected from the lake.

compromise has to be made between statistical accuracy and available funding (Elliot, 1977).

The results of this preliminary sampling indicated that the dispersion of chironomid larvae in Forrestdale Lake was highly clumped. A decision was made to accept a standard error (a measure of the amount of possible error in the sample mean) of 35% in the estimation of the population mean and, on the basis of the results obtained from 30 cores, a sample of 20 cores was found to be sufficient to provide an acceptable estimate of larval numbers in the lake.

<u>Location of sampling sites within each lake</u>
Forrestdale Lake is a shallow lake and could be sampled on foot over its entire area. However, it is large and for this reason, only the northern half was considered in this study. For the purpose of locating each of the 20 sample sites in the field, random number pairs were generated. These consisted of a degree-coordinate (between 270° and 90° for the northern half of the lake) and a number; 1, 2, 3 or 4. The appropriate coordinate was located in the field by making a compass sighting on a marker in the middle of the lake. The approximate distance from the central marker was selected according to the random number 1,2, 3 or 4; with 1 indicating the innermost part of the lake and 4 indicating the littoral area. For example, sample site "283° 3" is located at an angle of 283° from the marker in the middle of the lake and at an approximate position of three-quarters of the distance from the lake middle to the shore.

Booragoon, Jackadder and North Lakes all possessed shallow littoral zones that could be sampled on foot plus deeper central regions that necessitated the use of an alternative sampling method. At these three lakes, 20 cores were taken from the littoral zone, each located by the combination of a randomly generated degree-coordinate (0 to 360° because the entire lakes were sampled) and a number 1,2,3........20, indicating the number of paces to be taken from the waters edge towards the centre of the lake. For example, sample site "304° 14" is located at an angle of 304° from the centre of the lake and 14 paces in from the shore. In addition to the 20 littoral cores, a further 10 cores were taken from the deep middle section of each of the three lakes. These were not located by random numbers because the time required to do this was not available, but an effort was made to spread the sample sites over the middle area of the lake.

<u>Lake Goollelal</u>

Lake Goollelal was sampled every three weeks by the Wanneroo City Council. Samples of the lake substrate were taken from a boat using an 800 ml scoop attached to a long handle. The same ten sites were sampled on each collection date, with ten replicate scoops being taken at each site. The samples were sorted in the field by washing the sample through a sieve (mesh size 1.25 mm) and counting the number of midge larvae. The larvae from one scoop from each of the ten sites were identified by the Murdoch team.

Lake Monger

Lake Monger was sampled every fortnight by the Perth City Council. A 10 litre metal bucket on a rope was thrown from a boat and dragged across the substrate to obtain a sample. The same eight sites (all in deep water) were sampled on each occasion with one bucket sample being taken at each site. The samples were sorted in the field by sieving (mesh size 1.2 mm) and the resulting larvae were counted in the laboratory. Larvae from the eight samples were identified by the research team.

Larval Population Dynamics

Information on the life histories of the major species of midge present as larvae in each of the six lakes was obtained by measuring head capsule widths of larvae collected in the field monitoring programme. Head capsule width was used as the measure of body size because, unlike the softer thorax and abdomen, it maintains its size during preservation. Only those species that occurred in large numbers over a period spanning several sampling occasions were considered. The species measured at each lake are as follows:

Booragoon Lake:	*C. alternans*
Forrestdale Lake:	*P. nubifer, C. australis*
Jackadder Lake:	*P. nubifer*
North Lake:	*P. nubifer, C. alternans, C. intertinctus*
Lake Goollelal:	*P. nubifer*
Lake Monger:	*C. australis*

Where possible, 50 individuals (chosen at random) of a species from each sampling occasion were measured. Each larva was orientated so that the dorsal surface of the head capsule was in view. The width of the head capsule was measured at its widest point using a dissecting microscope with a calibrated ocular micrometer.

Adult Nuisance Assessment

Soon after the start of the larval sampling programme it became obvious that the Murdoch study team would not have the time to carry out both this programme and an intensive adult sampling programme at the six lakes. As a consequence, the adult sampling and nuisance assessment component of the project was very ably taken on by members of each of the respective local authorities.

This component of the study was carried out from approximately mid-November 1987 (depending on the lake concerned) to late February 1988.

A small number of residents (approximately six) living near each of the six study lakes was asked by their local authority to collect adult midges from their houses each week. Each resident was supplied with an aspirator for sucking up adult midges and vials of ethanol for preserving the midges. The resident was also given a nuisance level score sheet and asked to assess the degree of nuisance caused by midges during that week as "low, moderate, high or extreme" (see Appendix I).

The resulting samples and score sheets were collected each week by Council representatives and passed on to the Murdoch study team. The collections of adult midges were identified using keys by Freeman (1961) and counted. The percent occurrence of each species was calculated for each collection. A mean percent species composition was determined to indicate the relative nuisance of each species to residents at each lake. A numerical value was assigned to each level of midge nuisance as follows: low=1, moderate=2, high=3, extreme=4, and a mean value was calculated for each lake from the sheets handed in each week. In some cases score sheets were not available at weekly intervals.

Environmental Data

Information on water depth, water and air temperature and water quality was collected each fortnight from Booragoon, Forrestdale, Jackadder and North Lakes.

Lake depths were read from staff gauges (Booragoon, Forrestdale and North Lakes) or calculated from the mean of ten depths recorded at the centre of the lake (Jackadder Lake). Water and air temperatures were recorded by maximum-minimum thermometers placed in each lake and near each lake (mounted at 1.5 m above ground).

A water sample was collected on each sampling occasion. On return to the laboratory, pH and conductivity were measured. A sample of water was filtered for chlorophyll-a /phaeophytin analysis. Samples of water (100 ml) were frozen for analyses of total phosphorus and total nitrogen. Chlorophyll-a/phaeophytin, phosphorus and nitrogen analyses were carried out by the Centre for Water Research Nutrient Laboratory at the University of Western Australia. Data for air temperature, rainfall, windstrength and direction for the study period were obtained from the Bureau of Meteorology.

RESULTS

Larval and Adult Monitoring Programmes

Changes in larval densities at each of the four lakes sampled by the Murdoch study team (Booragoon, Forrestdale, Jackadder and North), over the period 22 October1987 to 4 March 1988 are given in Fig. 16. Levels of adult nuisance recorded at each lake are also given in Fig. 16 as a means of comparison of the relationship between these scores and larval densities. Only one lake, North Lake, was treated with Abate during the study period and the dates of three treatments are included on the North Lake figure. The lake was treated a fourth time on the 14 March, 1988 but time constraints dictated that data collected after the first week in March could not be analysed in sufficient time for inclusion in this report. The species composition of larval and adult populations sampled at the six lakes, Booragoon Lake, Forrestdale Lake, Jackadder Lake, North Lake, Lake Goollelal and Lake Monger, are given in Figs 17-22. Separate plots of larval densities in the littoral and central regions of each of the lakes sampled by the Murdoch study team are also given.

The occurrence of peaks in larval densities, the pattern of change in larval densities and the species composition of larval populations differed at all of the lakes studied (Figs 17-22). Adult species composition and nuisance levels also differed between lakes.

Larval densities were lowest in Booragoon Lake and Jackadder Lake and did not exceed 2000 larvae/m^2 on any sampling occasion. The level of adult midge nuisance in the vicinity was also scored as low (Jackadder Lake) or non-existent (Booragoon Lake).

Larval densities at Forrestdale Lake were higher and exceeded 2000 larvae/m^2 on two sampling occasions (6 January 1988 and 20 January 1988). Levels of adult nuisance were recorded as moderate throughout December and high in the week following the 6 January peak in larval density. The lake dried completely in February and larval monitoring was not continued after 3 February.

Larval densities at North Lake were very high, in comparison with densities at the former three lakes, throughout the sampling period with the exception of the first sampling occasion (21 October 1987). The maximum density recorded was 11570 ± 4077 larvae/m^2 in early December (9 December 1987). Levels of adult nuisance were recorded as high to extreme throughout December, January and February. Larval numbers fell by 78% (from 11570 ± 4077 larvae/m2 to 2596 ± 787 larvae/m^2) three days after the first Abate treatment at North Lake, a reduction of 34% (from 6016 ± 2162 larvae/m^2 to 3969 ± 994 larvae/m^2) occurred three days after the second treatment whilst a 58% increase (from 3280 ± 810 larvae/m^2 to 5181 ± 1460 larvae/m^2) occurred nine days (the next sampling occasion) after the third treatment.

Larval chironomids were more abundant in the littoral region (i.e. within 15m of the waters edge) of the three permanent (and deeper) lakes than in the central regions of these lakes, whilst similiar densities of larvae occurred throughout the littoral and central regions of the only seasonal (and shallower) lake, Forrestdale Lake. Larval populations in the five permanent lakes were usually dominated by a single species, *C. alternans* at Booragoon Lake, *C. australis* at Lake Monger and *P. nubifer* at Jackadder Lake, North Lake and Lake Goollelal. In contrast, species dominance changed over time at Forrestdale Lake with four species, *C. australis, D. conjunctus, P. nubifer* and *T. fuscithorax* becoming dominant in succession.

C. alternans was the most abundant larval species in the littoral region of Booragoon Lake early in the study, in November and December, whilst *P. nubifer* was dominant, albeit in very low numbers, in the later summer months. Comparison between the littoral and middle regions of Booragoon Lake is limited because the latter region was not sampled until January when the water level had dropped sufficiently to enable the use of the long handled corer. However *C. australis* was the most abundant species in this region of the lake in the later summer months. The composition of adult midges collected near the lake varied from *C. australis* to *C. alternans* to *P. nubifer*, but adult numbers were always so low as to make comparisons of little value. The lack of midge problems in the suburban region adjacent to

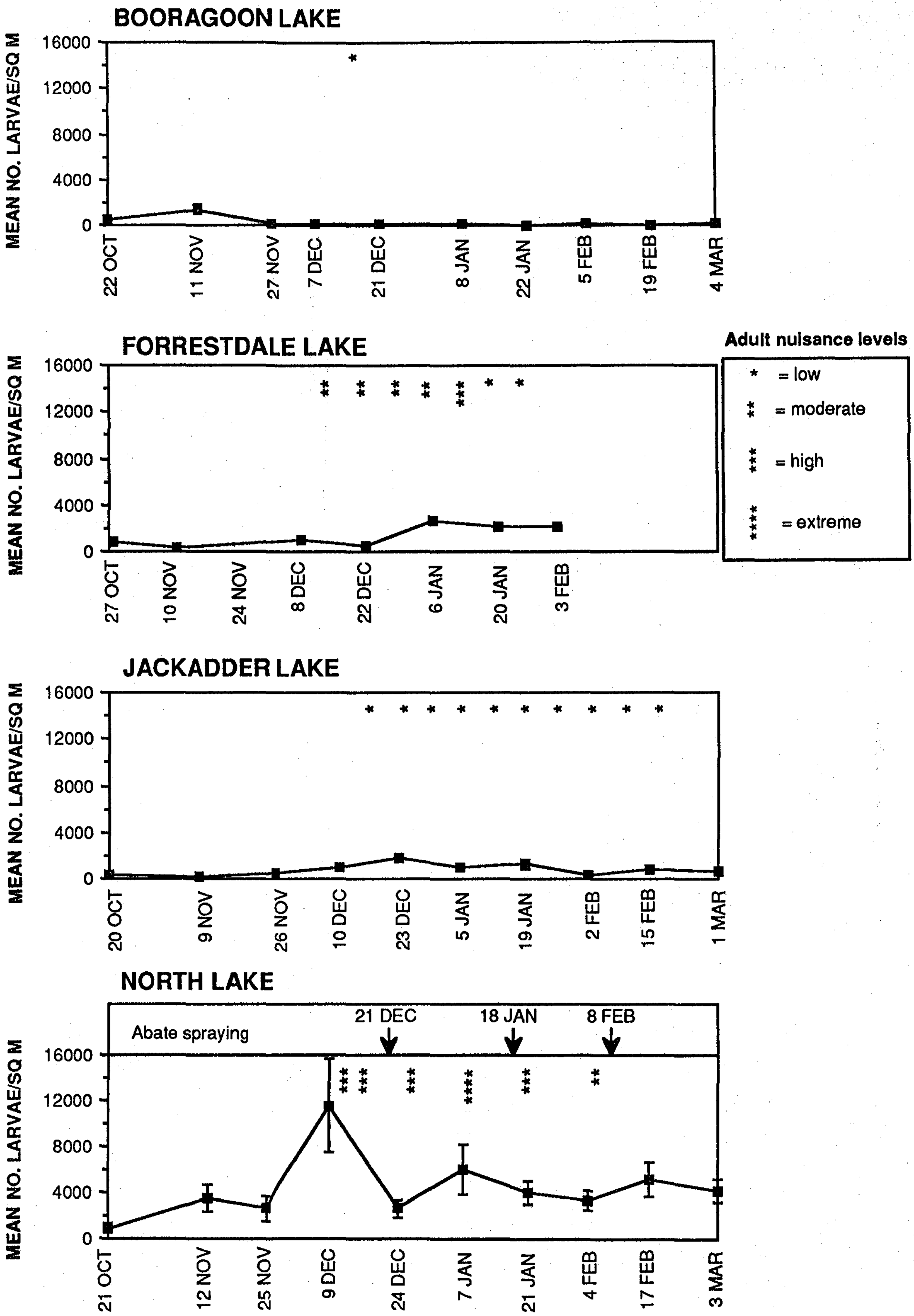


Figure 16. Changes in the mean number of chironomid larvae per square metre from the littoral sections of Booragoon, Forrestdale, Jackadder and North Lakes, October 1987 to March 1988. Means and standard errors are shown. Adult nuisance levels and the dates on which North Lake was sprayed are indicated.

BOORAGOON LAKE

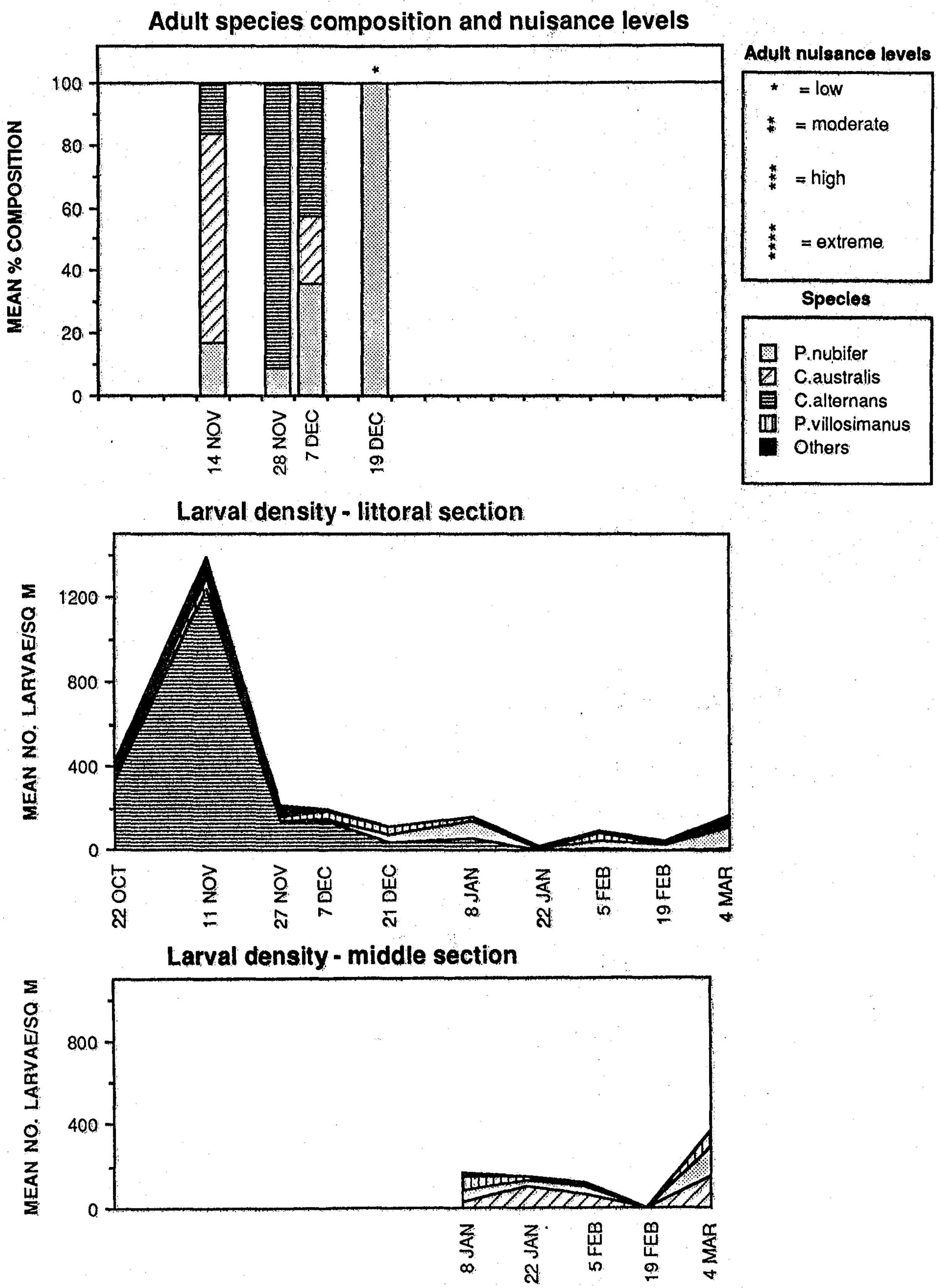


Figure 17. Changes in species composition and nuisance levels for adult chironomids and cumulative numbers of larvae per square metre for the littoral and middle sections of Booragoon Lake, October 1987 to March 1988. Collections of adults were made on only four dates, larval sampling of the middle section began on 8 January 1988.

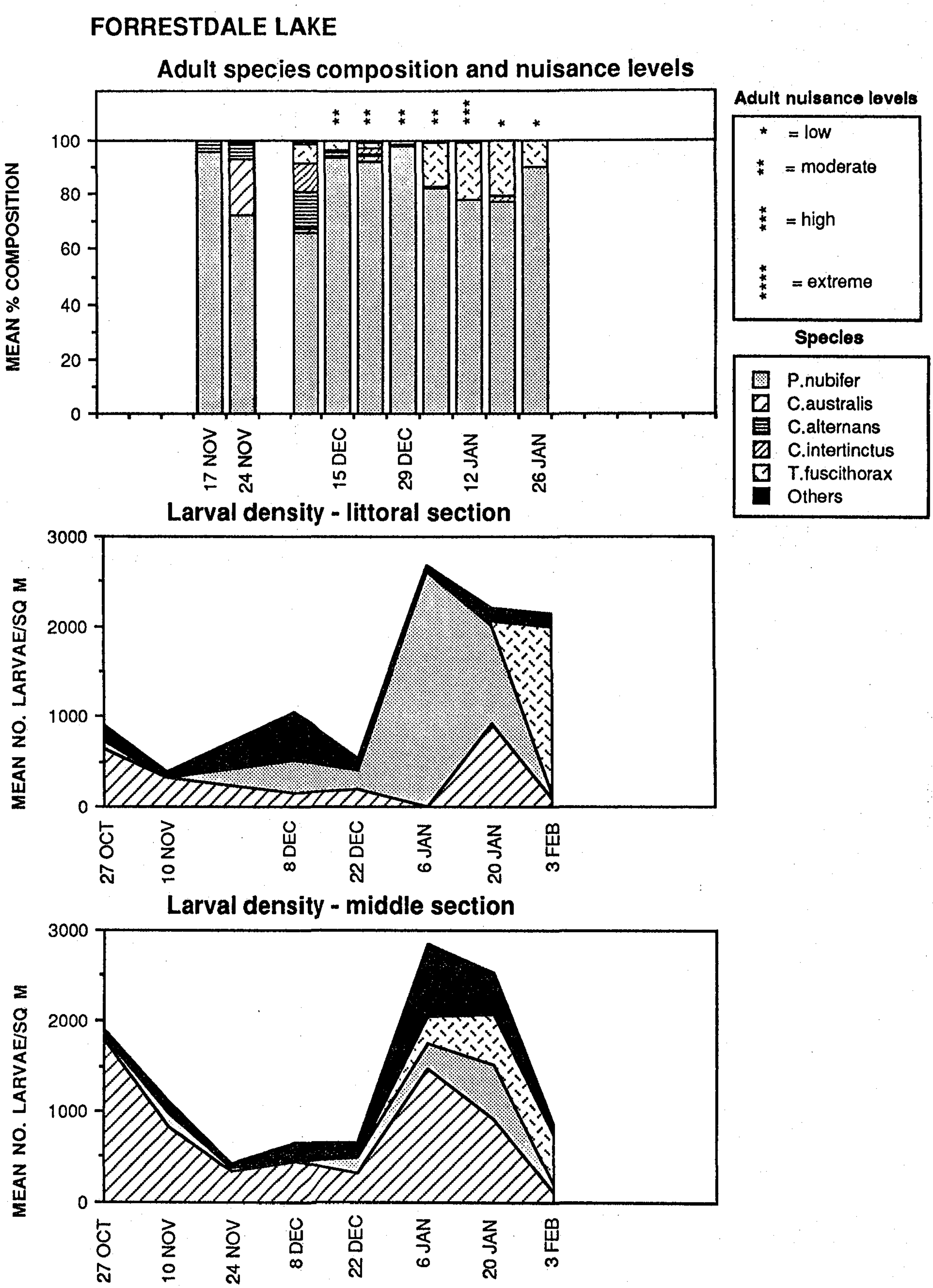


Figure 18. Changes in species composition and nuisance levels for adult chironomids and cumulative numbers of larvae per square metre for the littoral and middle sections of Forrestdale Lake, October 1987 to February 1988. Collections of adults were made on only ten dates, larval sampling ended on 3 February 1988 when the lake dried out.

JACKADDER LAKE

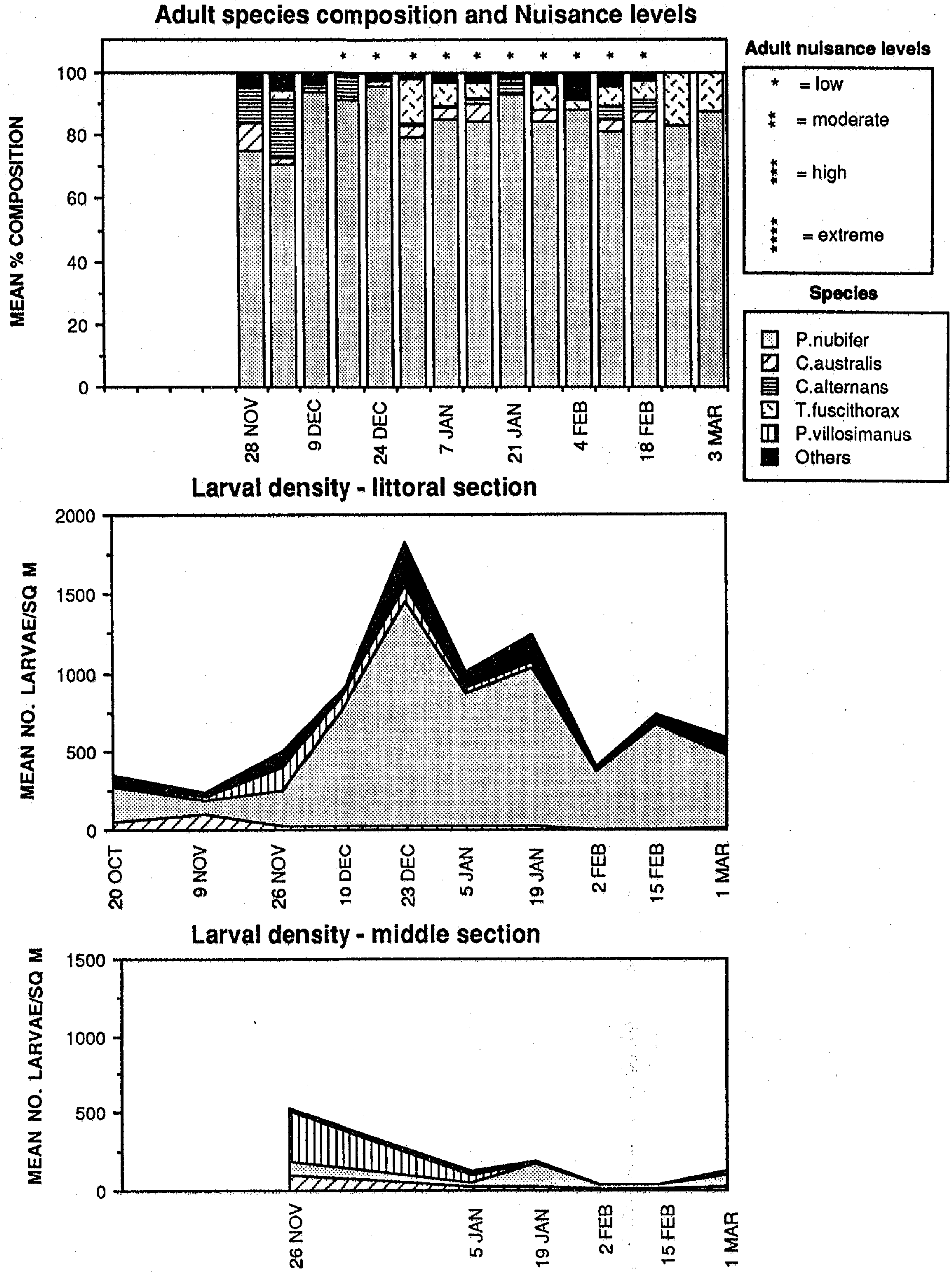


Figure 19. Changes in species composition and nuisance levels for adult chironomids and cumulative numbers of larvae per square metre for the littoral and middle sections of Jackadder Lake, October 1987 to March 1988. Collections of adults began on 28 November 1987, larval sampling of the middle section began on 26 November 1987.

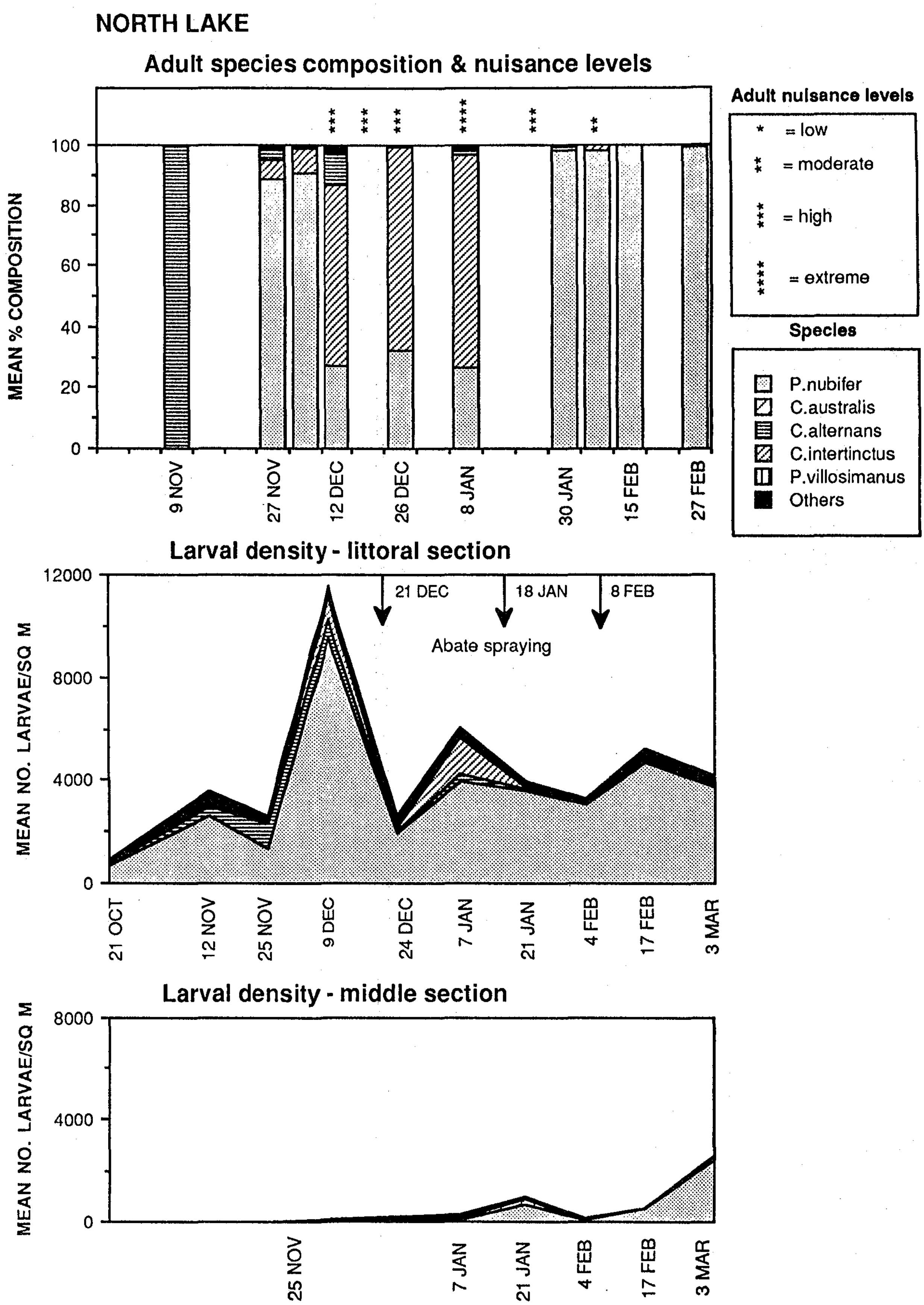


Figure 20. Changes in species composition and nuisance levels for adult chironomids and cumulative numbers of larvae per square metre for the littoral and middle sections of North Lake, October 1987 to March 1988. Collections of adults began on 9 November 1987, larval sampling of the middle section began on 25 November 1987.

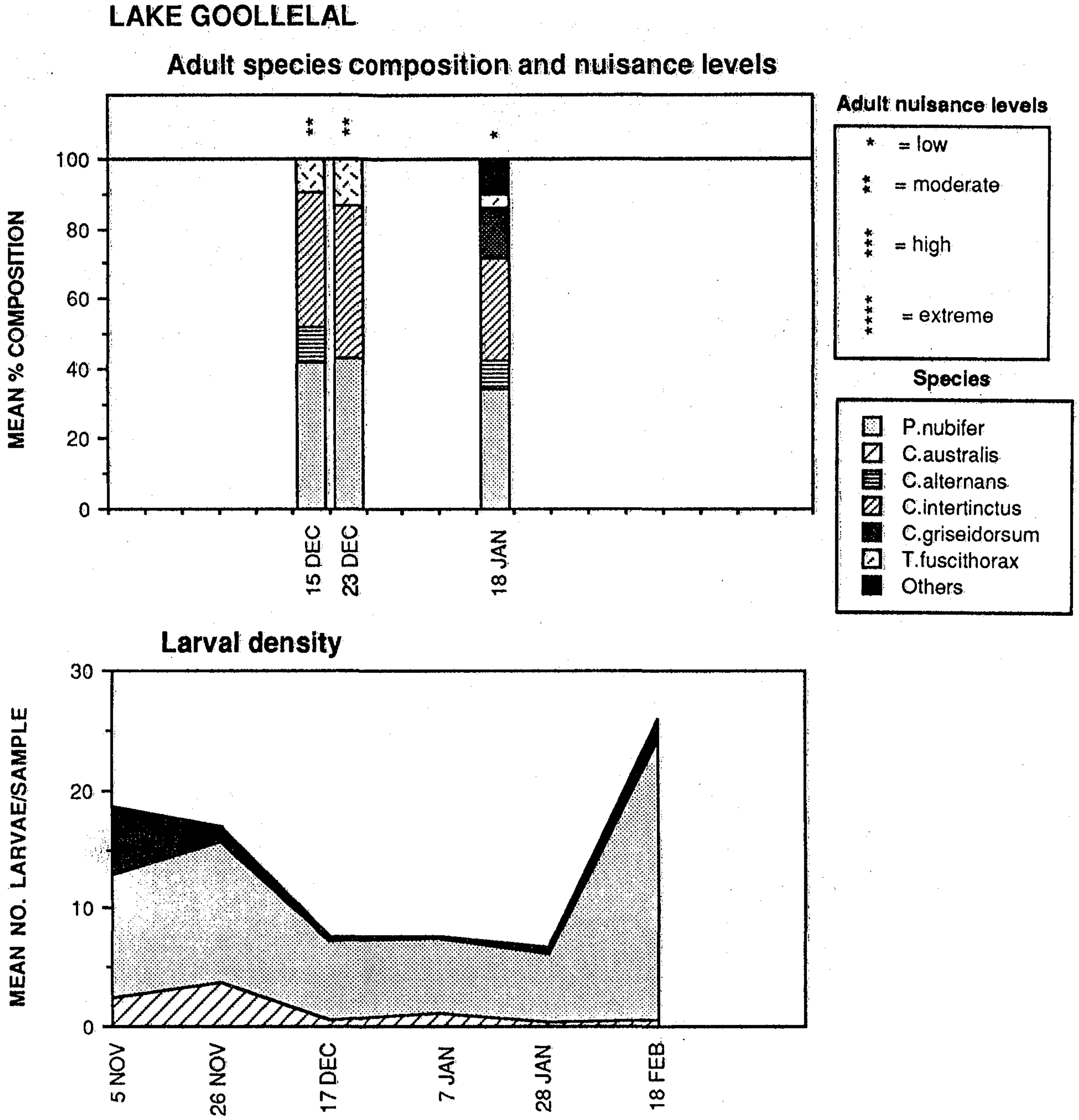


Figure 21. Changes in species composition and nuisance levels for adult chironomids and cumulative numbers of larvae per sample for Lake Goollelal, November 1987 to February 1988. Collections of adults were made on only three dates.

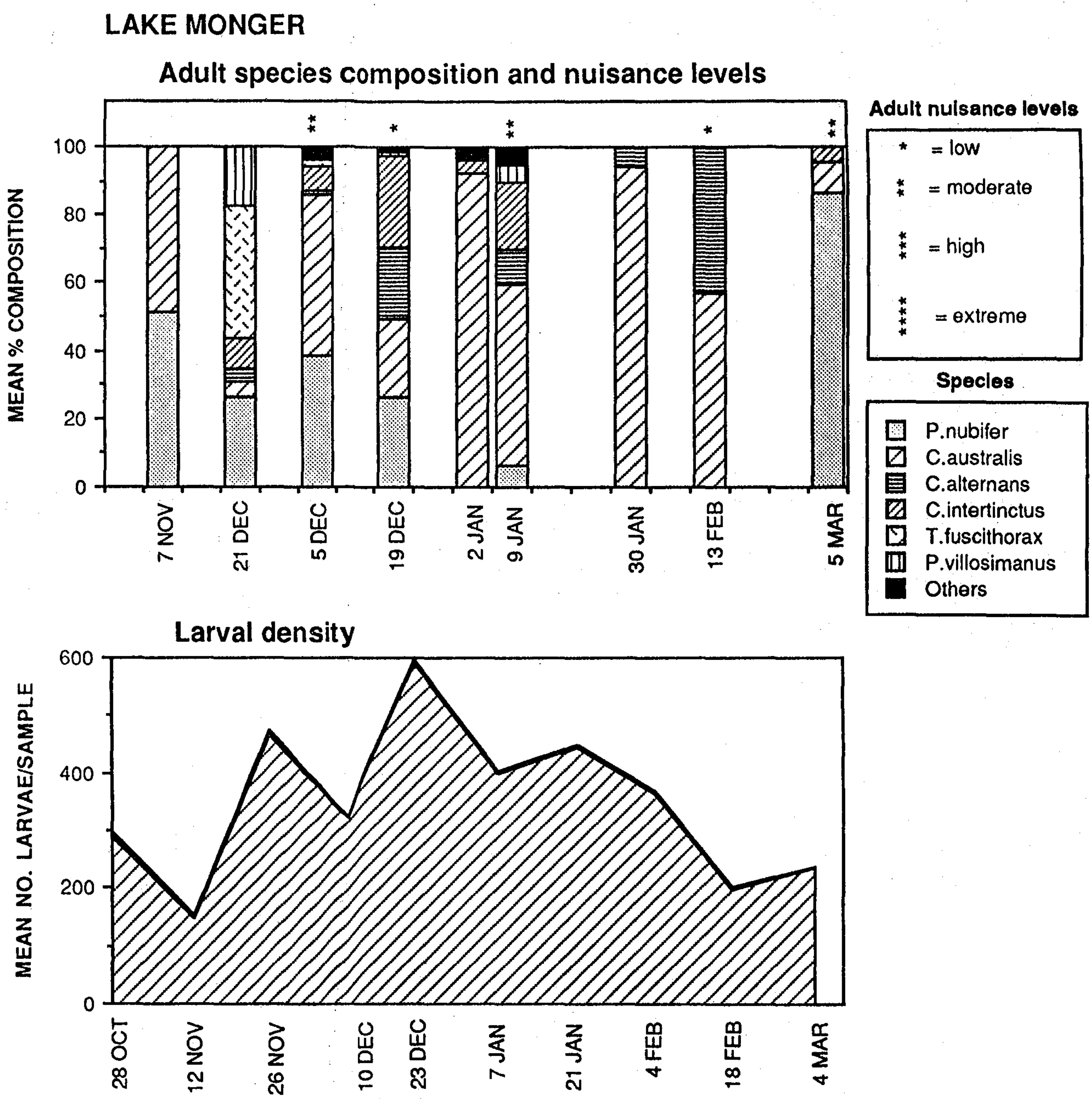


Figure 22. Changes in species composition and nuisance levels for adult chironomids and cumulative numbers of larvae per sample for Lake Monger, October 1987 to March 1988. Collections of adults began on 7 November 1987.

this lake meant that only one resident was prepared to complete a midge nuisance assessment sheet, and on only one occasion, and the level was recorded as low !

C. australis was the most abundant species throughout Forrestdale Lake in October and November but was replaced by *P. nubifer* in the inshore region of the lake in December and January. *Tanytarsus fuscithorax* became dominant in February just prior to the lake drying completely. *P. nubifer* was the most commonly collected adult midge in the suburb of Forrestdale on all sampling occasions, *C. australis* and *C. alternans* were recorded in November and early December and *T. fuscithorax* was present in January. The adult nuisance level was scored as moderate throughout December, high in the fortnight ending January 12 and low throughout the remainder of January.

P. nubifer was the dominant larval species in the littoral region of Jackadder Lake throughout the sampling period. *Procladius villosimanus* was dominant in the centre but was replaced by *P. nubifer* in late January, February and March. The adult species composition was similar to that recorded for the larvae in the in-shore region; *P. nubifer* was the most commonly collected adult midge throughout the study. In contrast, *T. fuscithorax* was present in a higher percentage in the adult collections than in larval samples. However, adult nuisance levels were recorded as low throughout the study period.

P. nubifer was the dominant larval species throughout the littoral and central regions of North Lake on all sampling occasions. Similarly, *P. nubifer* was dominant in adult collections in late November, early December and throughout February but *C. alternans* was the only species collected in early November and *C. intertinctus* was collected in large numbers in December and early January, despite the fact that it was not the dominant larval species at that time.

P. nubifer was the dominant larval species in Lake Goollelal on all sampling occasions whilst both *P. nubifer* and *C. intertinctus* were dominant in adult collections. Adult nuisance levels were scored as moderate or low and the low number of assessments recorded indicates that midges were not considered to be a problem by local residents during the study period.

C. australis was the dominant larval species in Lake Monger throughout the study period but adult collections also included significant percentages of *P. nubifer*, *T. fuscithorax*, and *C. alternans* in addition to *C. australis*. Adult collections however were small and nuisance levels were scored as moderate or low.

Larval Population Dynamics

Head capsule width was measured for four species of larvae, and for three of these species, larvae were measured from more than one lake.

P. nubifer

A total of 1404 *P. nubifer* head capsules were measured from Forrestdale, Jackadder, North and Goollelal Lakes (Figs 24, 26, 27 and 30). The results for all the lakes were very similar. Two size classes of larvae were apparent.

The majority of larvae had head capsule widths of 0.26 - 0.40mm. There was a second group of widths 0.16 - 0.24mm, though this group involved fewer individuals.

C. australis
Head capsules of 846 *C. australis* from Forrestdale Lake and Lake Monger were measured (Figs 25 and 31). Two groups of individuals were recognised and the existence of a third group (0.16 - 0.22mm) was suggested, especially at Forrestdale Lake, by the presence of a few smaller individuals. The head width range of the two major groups from the two lakes did not coincide exactly, with Lake Monger larvae being slightly larger. At Forrestdale Lake the size ranges were 0.64 - 0.86mm and 0.32 - 0.42mm, whereas at Lake Monger the ranges were 0.68 - 0.92mm and 0.34 - 0.46mm.

C. alternans
Head widths for 353 *C. alternans* larvae from Booragoon and North Lakes were measured (Figs 23 and 28). At both lakes most individuals had head widths between 0.46 and 0.66mm. A small number of individuals had head widths narrower than this range, but there were too few larvae to define any further groups.

C. intertinctus
This species occurred in large numbers at North Lake only. Data are presented for 228 head capsule measurements (Fig. 29). Most head widths fell in the range 0.50 - 0.68mm. Apart from this group, there were only a few smaller individuals.

Chironomid Production and Environmental Parameters
Weather data for Perth city comprising weekly maximum and minimum temperatures, weekly rainfall totals and maximum wind gusts and direction are given in Fig. 32. Changes in lake depths, temperature, conductivity and pH for the four study lakes are given in Figs 33 and 34, and changes in chlorophyll a, phaeophytin, total P and total N are given in Figs 35 and 36. Changes in larval densities at each lake over the same period are included with these figures as a means of comparison between changes in larval abundance and changes in environmental parameters.

Little can be said about the weather data recorded over the study period because of the short term nature of the data set. However, such data may be of value if collected over a longer time-scale (years) as trends between summer weather conditions and chironomid production may emerge. Investigation of the relationship between prevailing wind direction and strength and adult nuisance levels needs to be undertaken but on much finer spatial and temporal scales than those considered in this study.

Water levels decreased in all lakes over the study period as a result of evaporation. North Lake was the deepest of the four lakes whilst Forrestdale Lake was the shallowest and dried completely in February. The greatest range in water temperatures and the warmest temperatures were recorded at Forrestdale Lake. This is most likely to be a consequence of the shallowness of the lake allowing water temperatures to more closely follow air temperatures. This lake also became very saline as the water level fell

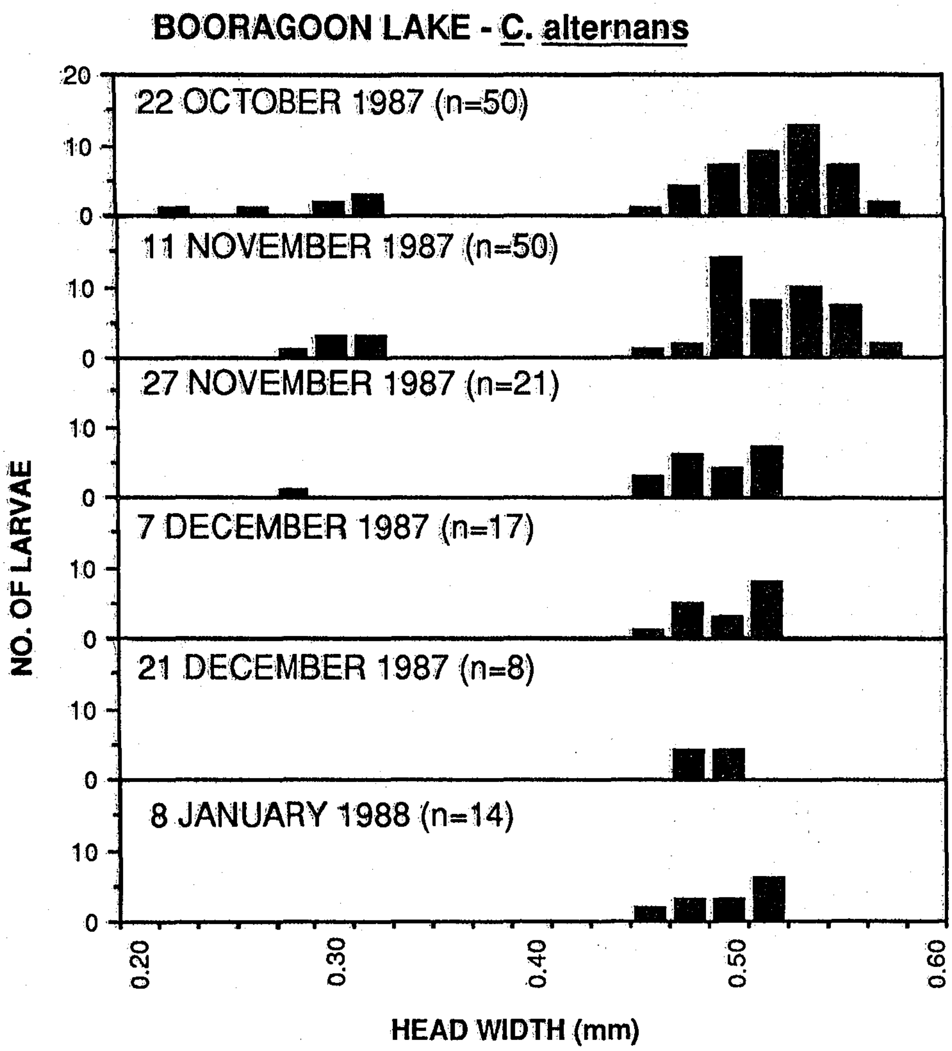


Figure 23. Changes in the size-frequency distribution of larvae of *Chironomus alternans* at Booragoon Lake, October 1987 to January 1988.

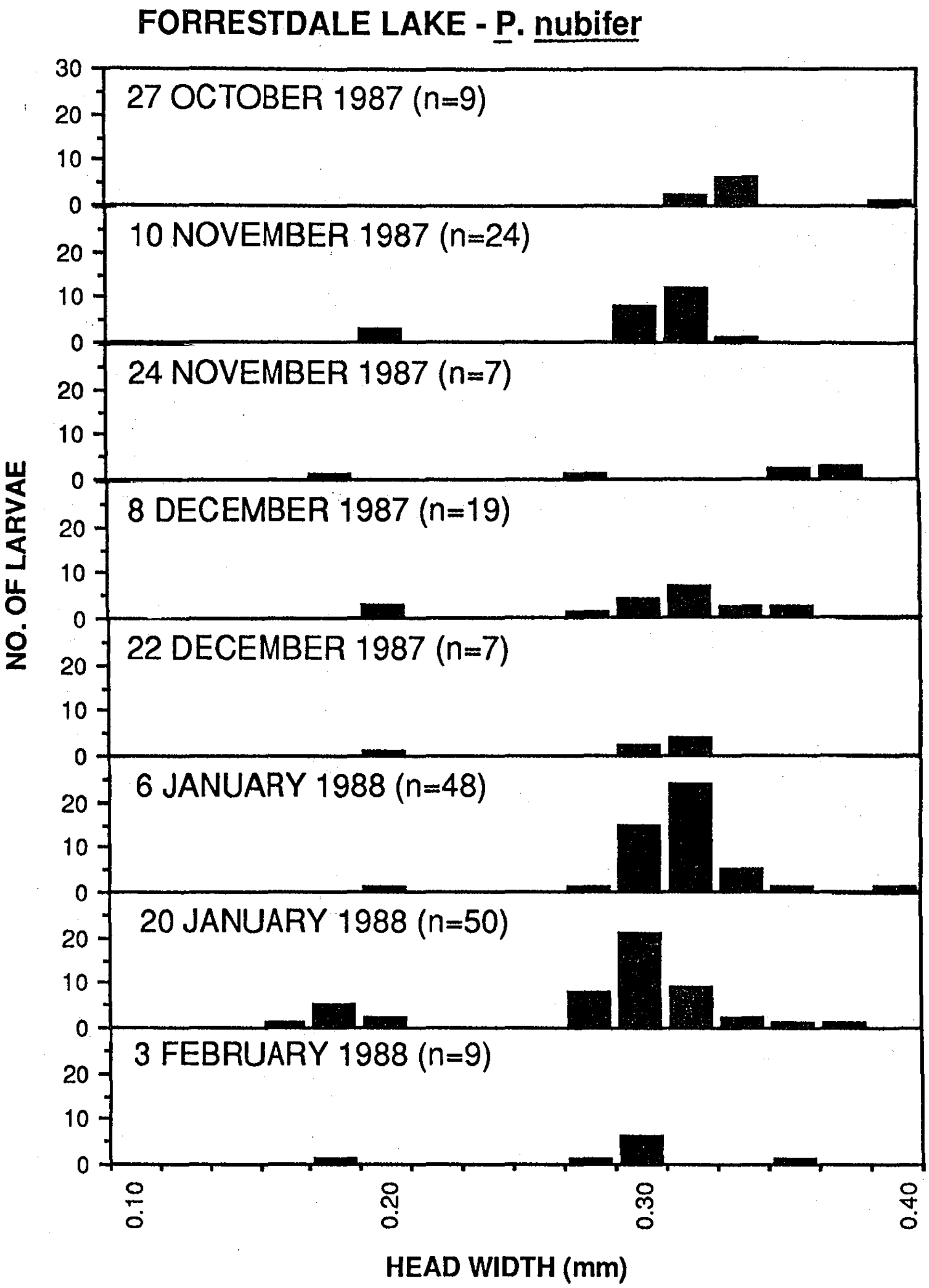


Figure 24. Changes in the size-frequency distribution of larvae of *Polypedilum nubifer* at Forrestdale Lake, October 1987 to February 1988.

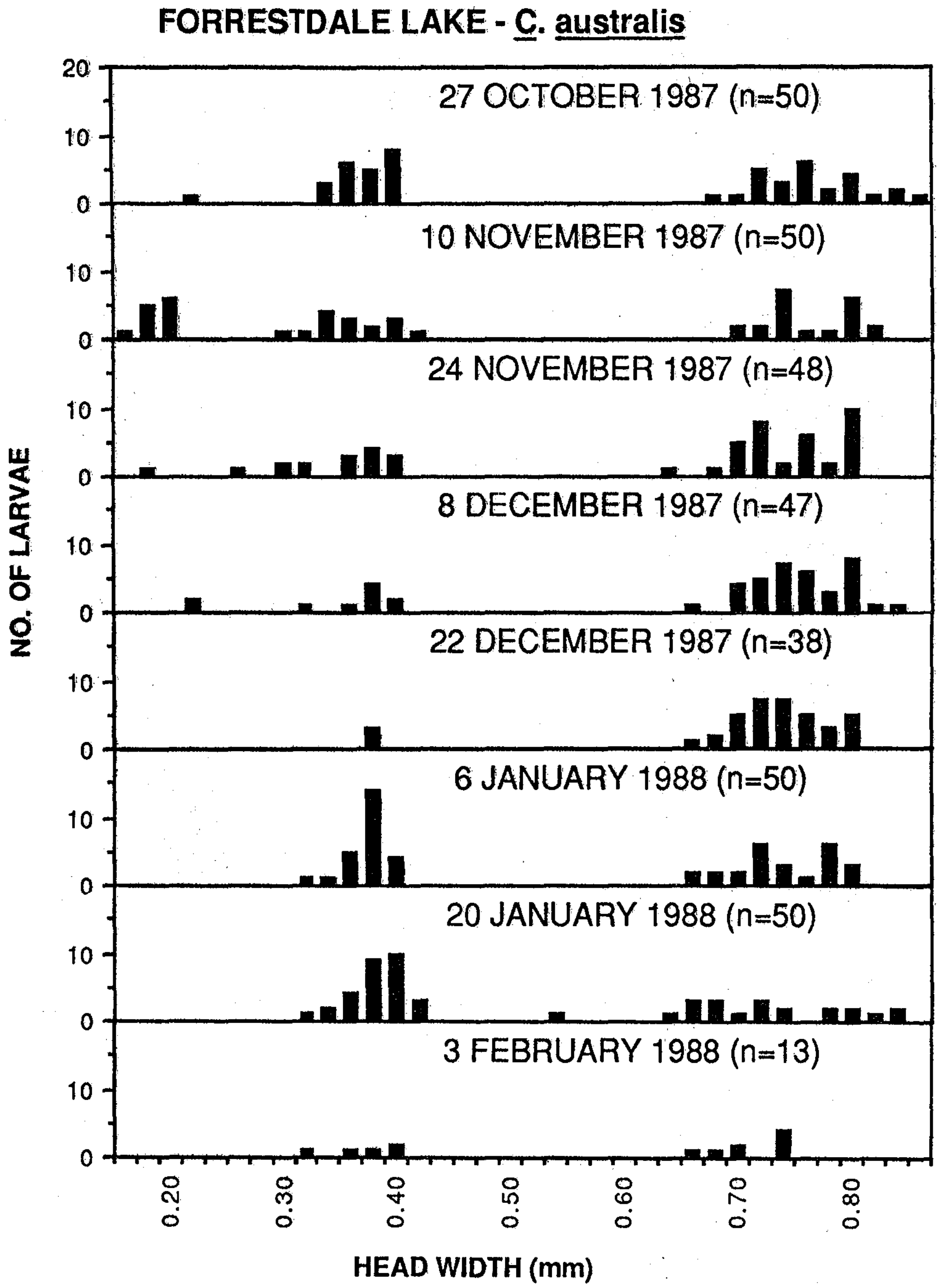


Figure 25. Changes in the size-frequency distribution of larvae of *Chironomus australis* at Forrestdale Lake, October 1987 to February 1988.

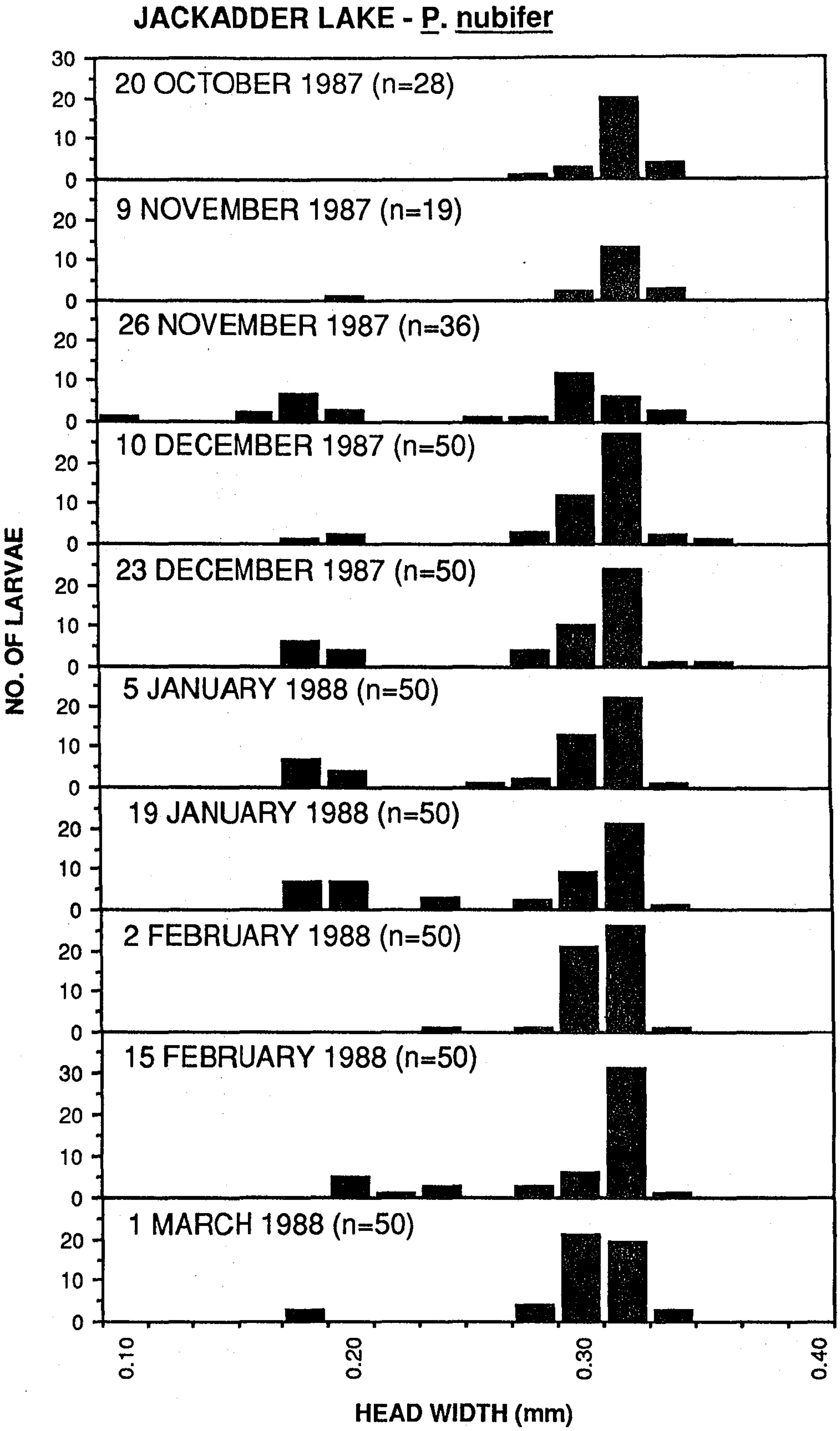


Figure 26. Changes in the size-frequency distribution of larvae of *Polypedilum nubifer* at Jackadder Lake, October 1987 to March 1988.

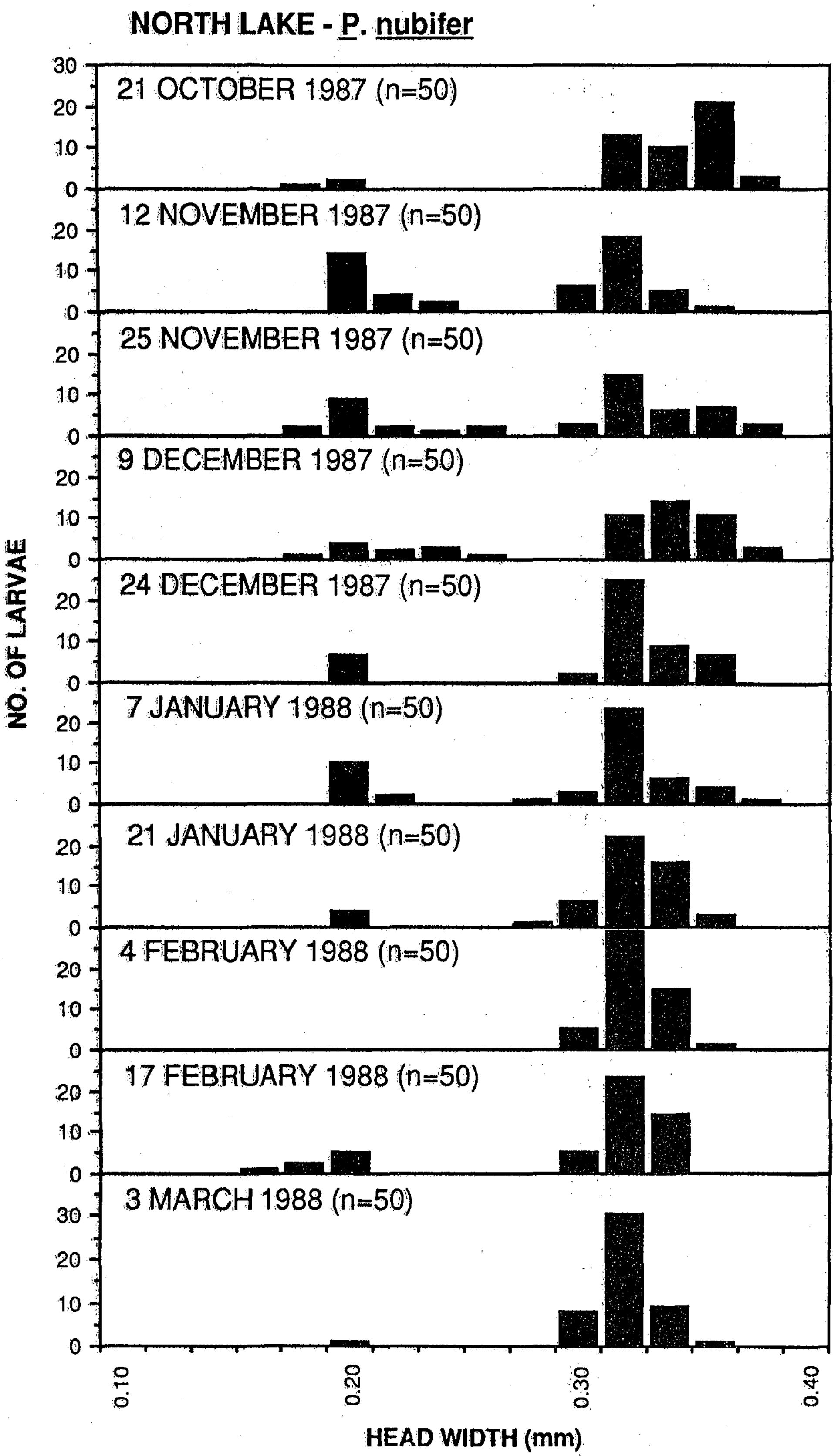


Figure 27. Changes in the size-frequency distribution of larvae of *Polypedilum nubifer* at North Lake, October 1987 to March 1988.

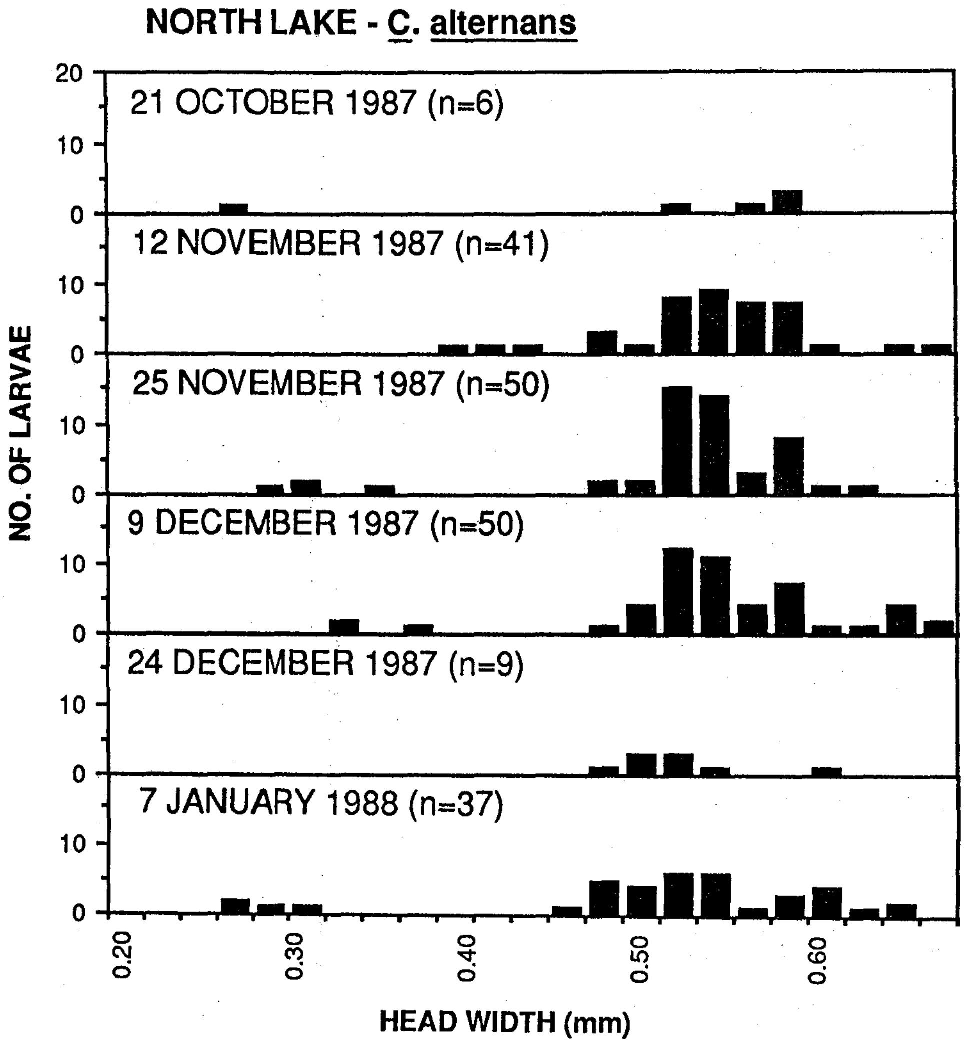


Figure 28. Changes in the size-frequency distribution of larvae of *Chironomus alternans* at North Lake, October 1987 to January 1988.

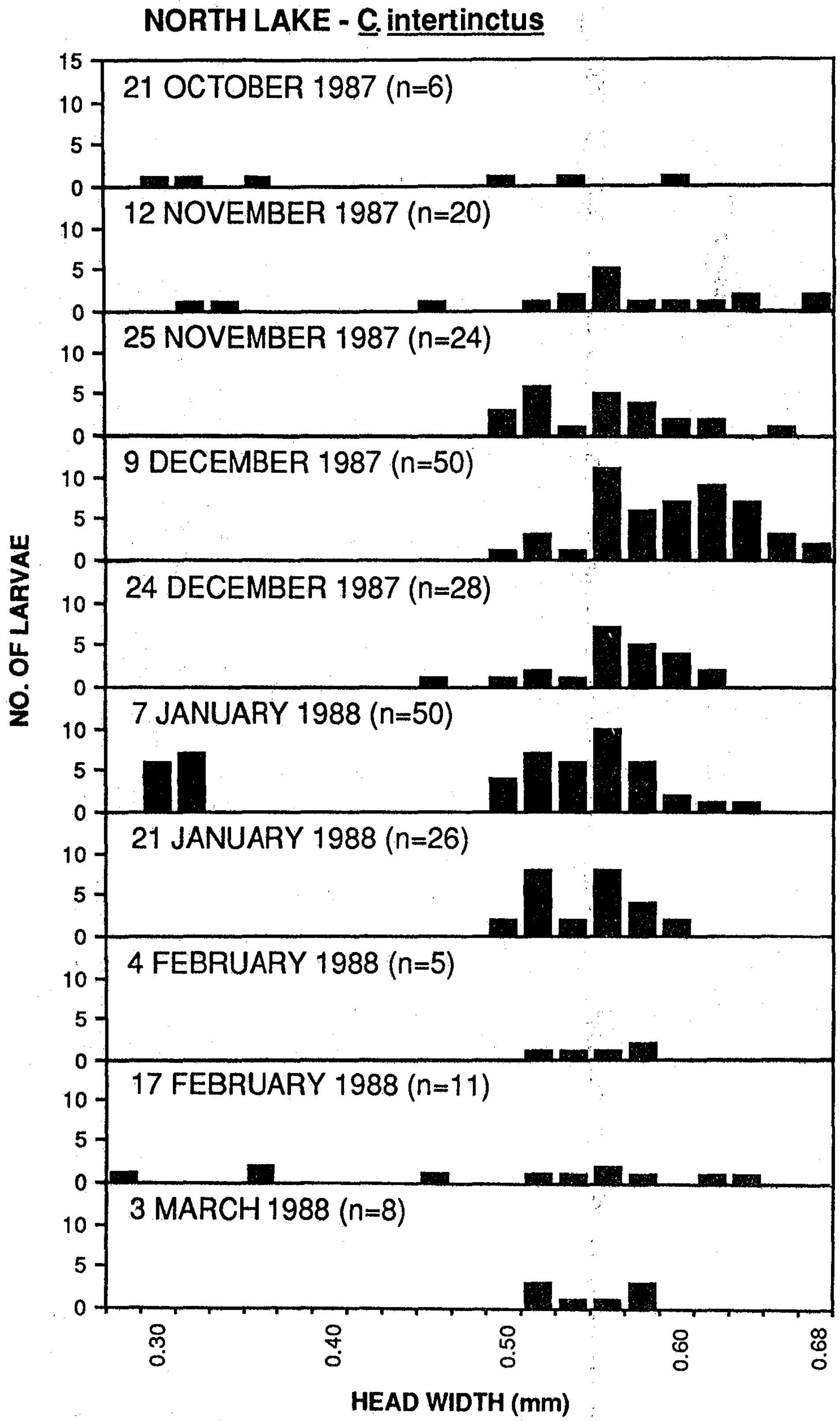


Figure 29. Changes in the size-frequency distribution of larvae of *Chironomus intertinctus* at North Lake, October 1987 to March 1988.

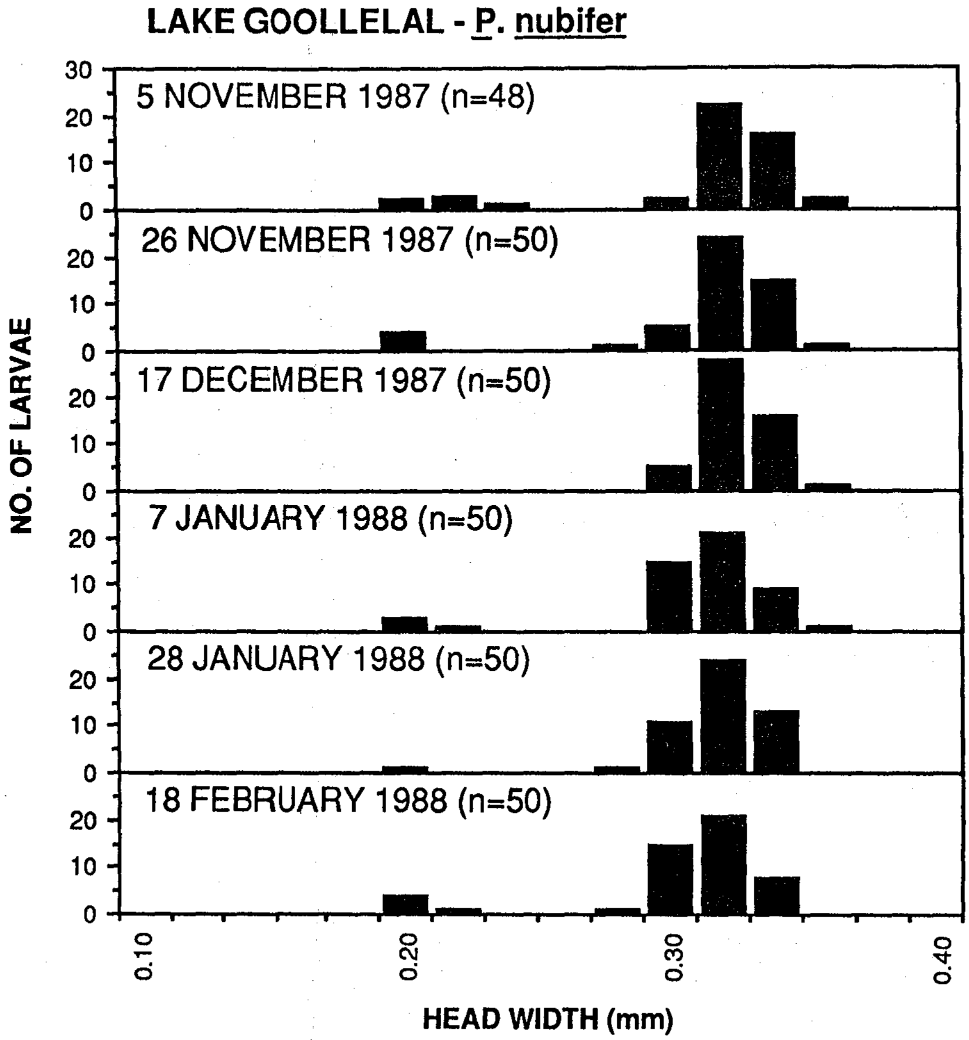


Figure 30. Changes in the size-frequency distribution of larvae of *Polypedilum nubifer* at Lake Goollelal, November 1987 to February 1988.

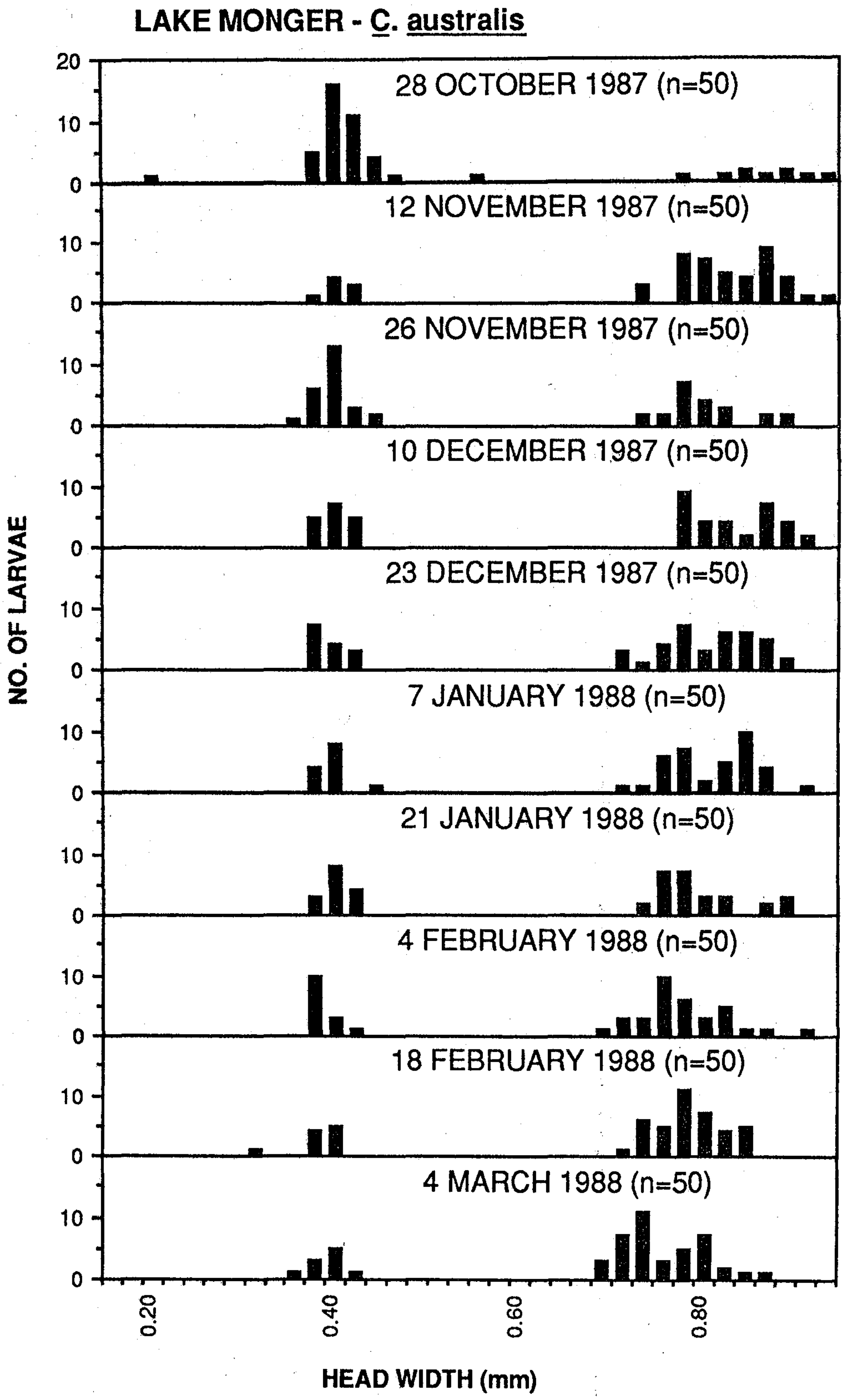


Figure 31. Changes in the size-frequency distribution of larvae of *Chironomus australis* at Lake Monger, October 1987 to March 1988.

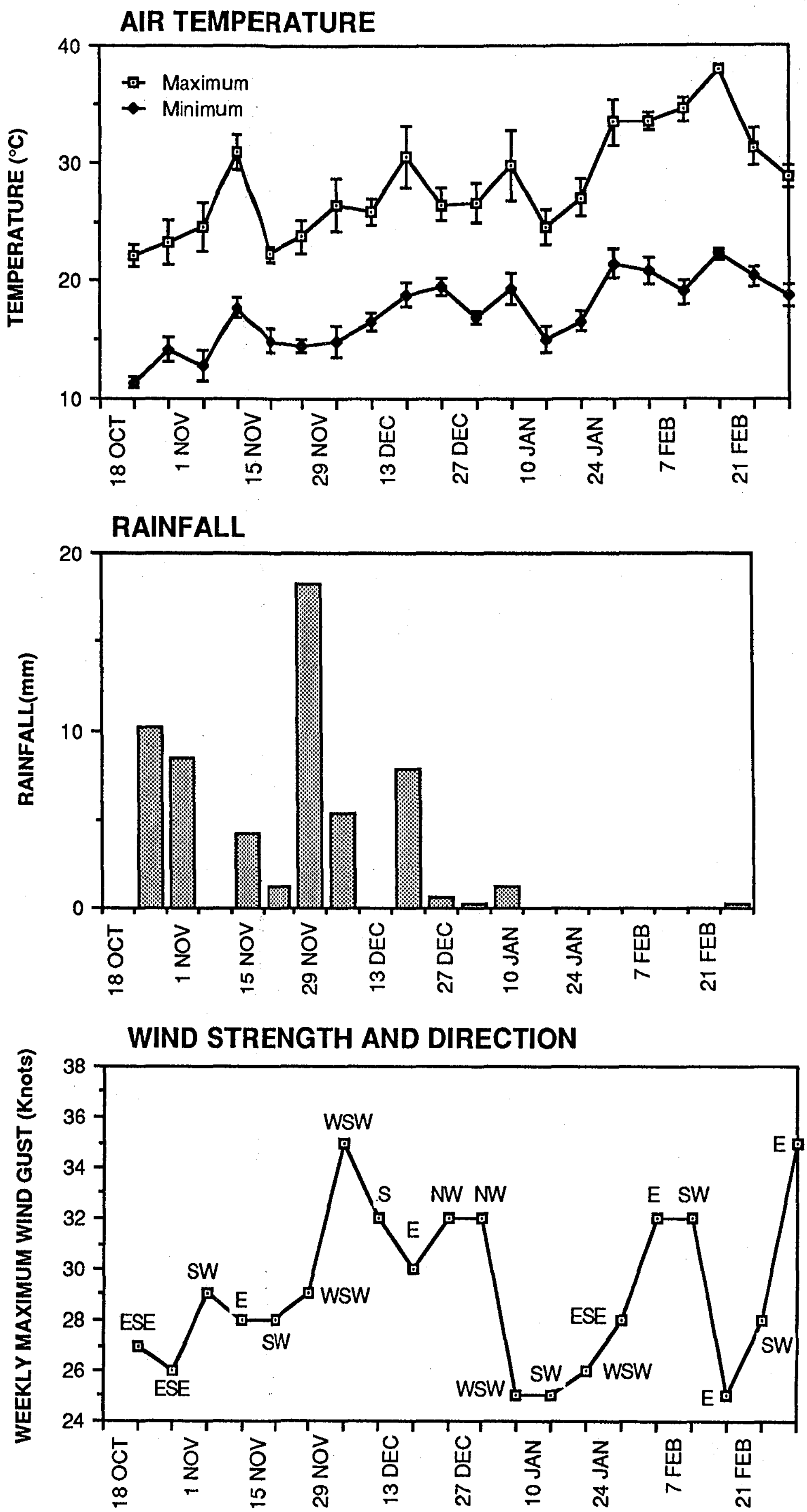


Figure 32. Weather data for Perth city for October 1987 to February 1988. Weekly maximum and minimum temperatures, weekly rainfall totals and the maximum wind gust for the week (and its direction) are shown.

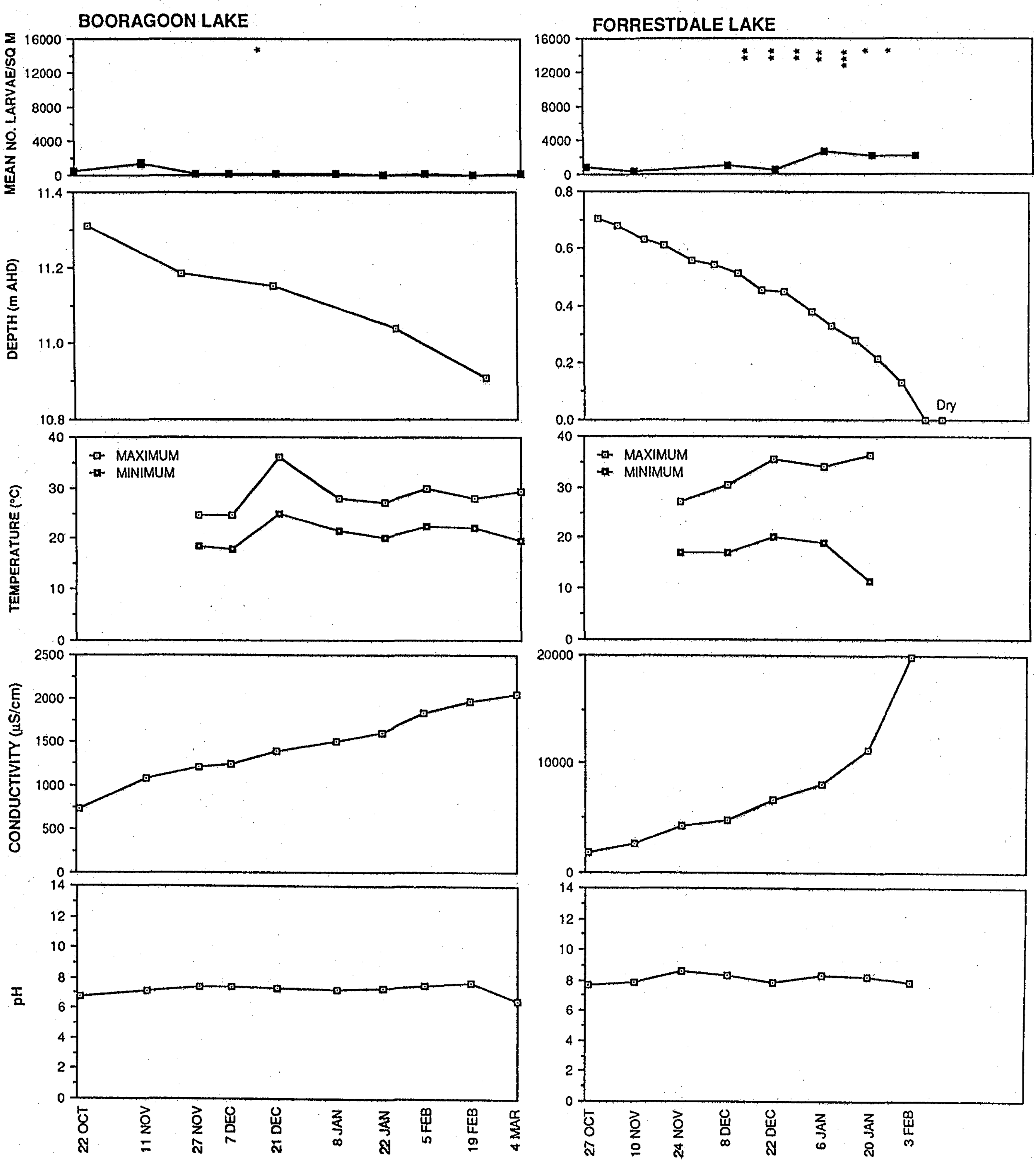


Figure 33. Changes in the total number of chironomid larvae per square metre and adult nuisance, lake depth, temperature, conductivity and pH at Booragoon Lake, October 1987 to March 1988 and Forrestdale Lake, October 1987 to February 1988 (when the lake dried out). The scales for conductivity for the two lakes are different.

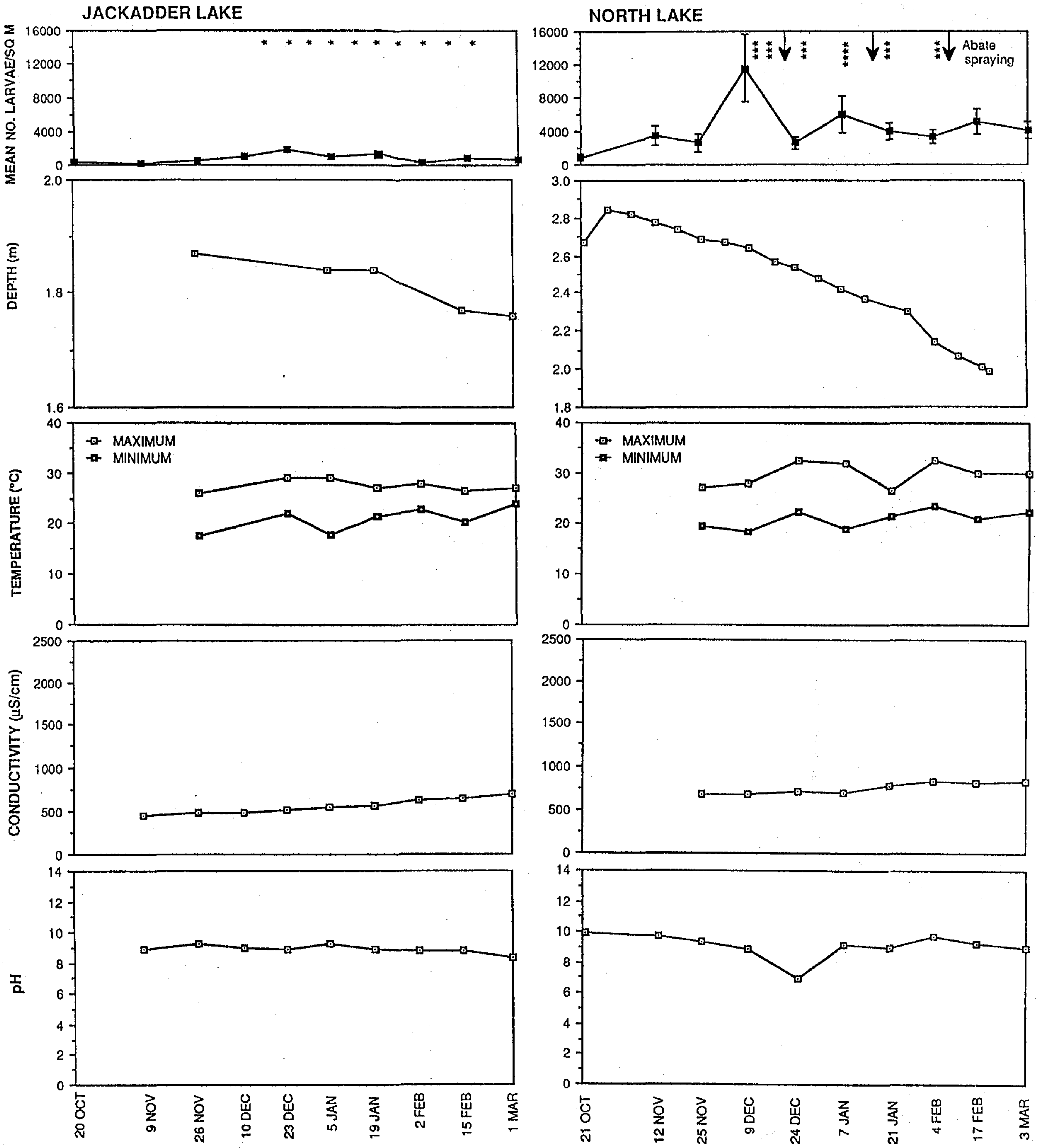


Figure 34. Changes in the total number of chironomid larvae per square metre and adult nuisance, lake depth, temperature, conductivity and pH at Jackadder Lake and North Lake, October 1987 to March 1988.

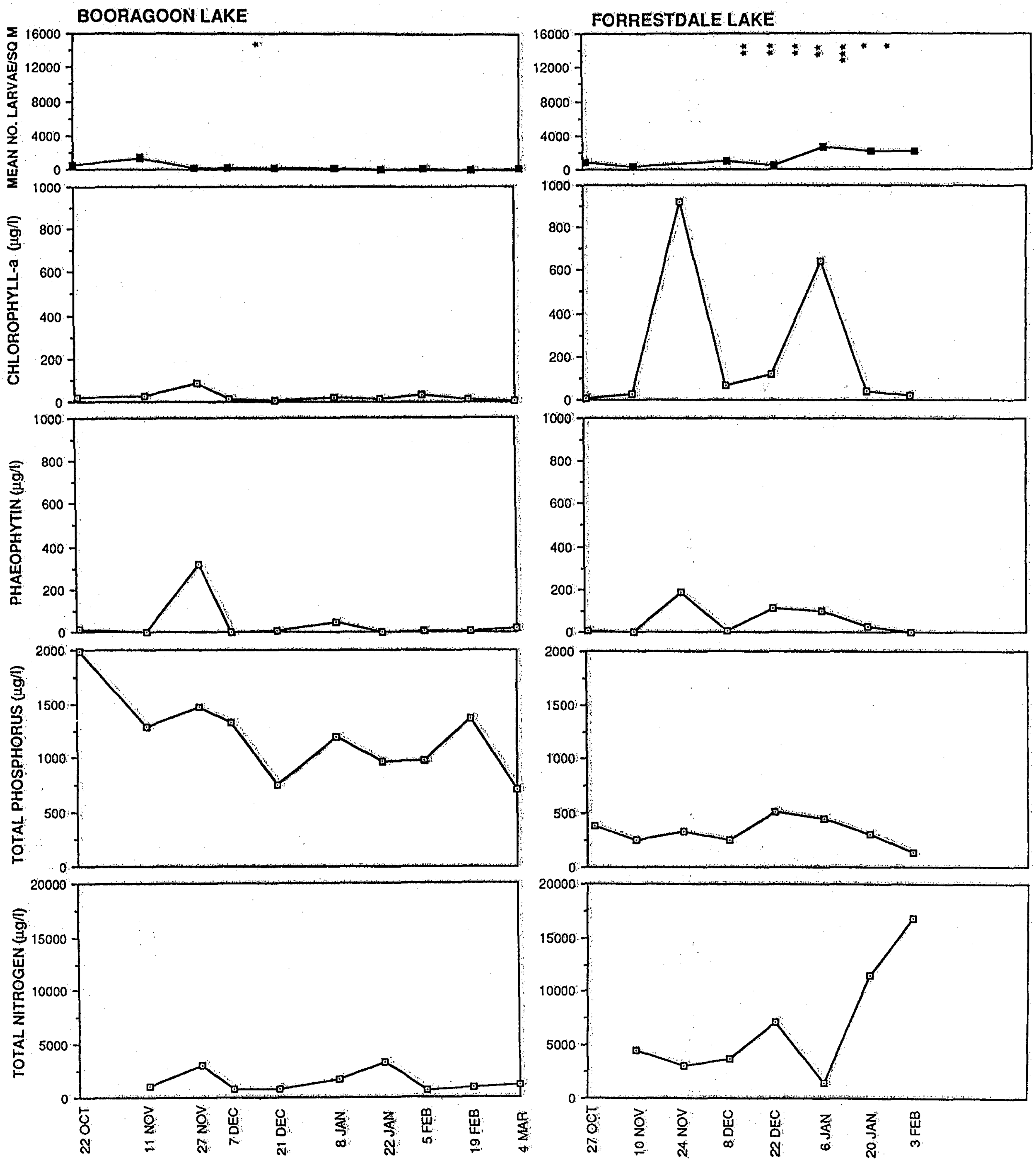


Figure 35. Changes in the total number of chironomid larvae per square metre and adult nuisance, concentrations of chlorophyll-a, phaeophytin, total phosphorus and total nitrogen at Booragoon Lake, October 1987 to March 1988 and Forrestdale Lake, October 1987 to February 1988 (when the lake dried out).

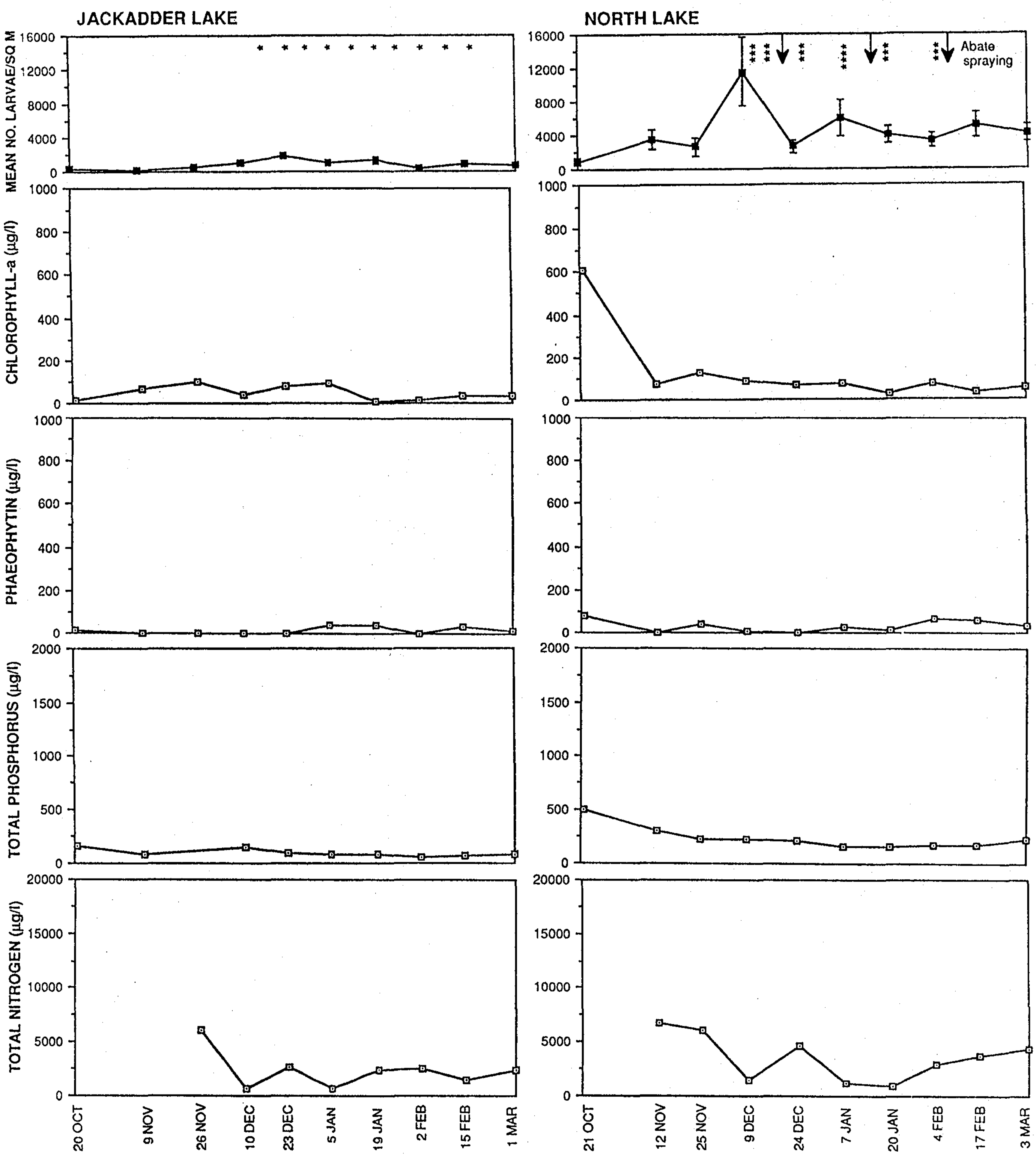


Figure 36. Changes in the total number of chironomid larvae per square metre and adult nuisance, concentrations of chlorophyll-a, phaeophytin, total phosphorus and total nitrogen at Jackadder Lake and North Lake, October 1987 to March 1988.

and was approximately 20X more saline than North Lake and Jackadder Lake and 10X more saline than Booragoon Lake.

The pH of Booragoon was approximately neutral whilst the other three lakes were alkaline. North Lake was extremely alkaline with pH values near 10.

Forrestdale Lake, North Lake and Jackadder Lake were eutrophic to hypertrophic, on the basis of chlorophyll-*a* concentrations. Large blooms were present in North Lake in spring (October) and in Forrestdale Lake in November and January. Concentrations of total P were extremely high in Booragoon Lake and were 4 to 10 times greater than the concentrations of total P recorded in the other three lakes. All lakes would be classified as hypertrophic on the basis of total P concentrations (>100 micrograms/L). Algal production in Booragoon Lake (as indicated by chlorophyll-a concentrations) was low despite high levels of total P. This situation could have arisen because the lake waters were very dark (due to the presence of tannins) and, as a consequence, algal growth was limited by low light availability. In this situation phosphorus levels would remain high because P was not being taken up by algal production. Total N levels were highest in Forrestdale Lake probably as a result of the breakdown in algal and macrophyte material that occurred as the lake dried out.

DISCUSSION

Larval and Adult Monitoring Programmes

Each of the four lakes sampled by the Murdoch study team exhibited differences in larval species composition and larval abundance and in the patterns of change in composition and abundance over time. These results indicate that until general models of chironomid production are obtained (and this would require a more extensive and longer term data set) each lake where a midge problem occurs must be monitored and managed individually. That is, the monitoring of larval populations at a lake will provide information that can only be considered relevant to that lake and not to others, however the same type of monitoring programme should be applicable to most lakes.

The results obtained for the lakes considered in this study indicate that the densities of larval *P. nubifer* recorded at a lake do have a **direct relationship** to the levels of adult nuisance occurring in lakeside suburbs. Suburbs adjacent to lakes with low numbers of *P. nubifer* and other larval chironomids (Booragoon and Jackadder) experienced virtually no midge problems whilst suburbs adjacent to lakes with higher numbers of larvae (North and Forrestdale) experienced moderate to extreme problems. Whilst this conclusion may appear to be somewhat trivial, it was necessary to demonstrate that this relationship was true for Perth wetlands. It was also important that a threshold level of larval densities which resulted in the occurrence of nuisance swarms be established. The results of this study indicate that high to extreme nuisance levels of adult midges were associated with densities of *P. nubifer* of approximately 2,000 larvae/m^2 or greater. A similar threshold for larval densities and the occurrence of nuisance swarms of adult midges had been noted in a smaller study conducted at Forrestdale Lake in 1985/86 (Davis et al., 1987). Much lower densities of larval *C. intertinctus* also appeared to result in nuisance swarms at North Lake (Fig. 20), however the qualitative nature of the adult sampling programme meant that is was difficult to determine whether adult *C. intertinctus* were really much more abundant than *P. nubifer* in December and early January or merely more easily collected because of their larger size.

The effectiveness of the Abate treatments at North Lake appeared to differ, in terms of the reduction of larval numbers, after each spraying. Whilst it is not possible to state conclusively what the effects of each treatment were because no untreated areas (i.e. controls) were employed, it appeared that a greater reduction in larval numbers occurred after the first treatment than the second or third. However because the levels of adult nuisance remained high to extreme throughout the treatment period, all three treatments must be considered to be ineffective in terms of nuisance control. The lack of effectiveness of the first Abate treatment, despite a reduction in larval *P. nubifer* of 80% (which may be partly or wholly attributed to the spraying rather than a mass emergence of adults because large numbers of dead larvae were observed) may be a consequence of the fact that larval densities still remained at approximately the suggested threshold of 2,000 larvae/m^2 (1,910 ± 435 larvae/m^2). At this density sufficient numbers of larvae were still present in the lake to sustain a continuing and high level of emergence. Larval numbers were not reduced below 2,000 larvae/m^2 after the second and third treatments. The reasons as to why the second and third treatments appeared to be much less successful than the first are not known but may be attributed to problems of resistance to the pesticide or problems with application.

These results suggest that for effective short term control to be achieved with larvicides it may be necessary to treat as soon as densities of larval *P. nubifer* reach 2000 larvae/m^2 and on subsequent occasions thereafter when this threshold is reached. This approach requires that regular sampling be carried out at each lake where a midge problem is anticipated. Attention needs to be given to the design and trial of a sampling programme that is similar to but simpler than the one undertaken for this study and which will result in quick but reliable estimates of larval density and species composition. A prototype monitoring programme should be tested at one or more lakes (in particular North Lake) in 1988/89. The larval sampling programme undertaken for this study was more thorough and so more time-consuming than a routine monitoring programme may be because baseline data were required for a number of lakes.

The results of the adult collection programme indicated that although *P. nubifer* must be considered to be the major pest species, both *C. intertinctus* (North Lake) and *T. fuscithorax* (Forrestdale Lake) are also pests. These species were collected in relatively large numbers during periods when the levels of adult nuisance were assessed by residents to be high or extreme.

The results of this study indicated that the shallow littoral or in-shore regions of lakes are the regions most likely to support large numbers of larvae of the pest species, *P. nubifer*. As a result, both monitoring programmes and spraying programmes should be directed more intensively to these areas. The apparently anomalous results obtained at Lake Monger (Fig. 22) where larval populations were dominated almost entirely by *C. australis* but adult populations also contained *P. nubifer*, *C. intertinctus*, *C. alternans* and *T. fuscithorax*, may be explained by the fact that the larval sampling programme at the lake did not contain littoral sites i.e. sites immediately adjacent to the water's edge. As a consequence, the sampling programme may have missed the species which were probably most abundant in these areas.

Larval Population Dynamics

The size-frequency graphs for head capsules for the four species of larvae suggest the presence of one (for *C. alternans* and *C. intertinctus*) or two (for *P. nubifer* and *C. australis*) distinct groups of individuals. In addition, there were a few smaller larvae. It is acceptable to interpret these groups as representing larval instars (Oliver, 1971) and because almost all chironomids have four larval instars (Oliver, 1971) the two groups were taken to represent 3rd and 4th instar larvae. This assumption is supported by the general agreement between our size ranges and those found by Edward (1964) for *P. nubifer* and M. Lund (pers. comm.) for *C. alternans* from lakes in the Perth region.

First and 2nd instar larvae were not well represented in our samples for any species. In general, 1st instar larvae are planktonic (Oliver, 1971) and as a result, would not have been sampled by cores taken from the substrate. The lack of 2nd instar larvae is more difficult to explain. Presumably 2nd instar larvae were too small to be detected by the sorting methods used in this study.

All of the larval populations considered were dominated by relatively large numbers of 4th instar larvae. This is not surprising because half or more of the life cycle of *Chironomus* spp. and probably other chironomids, is spent in the 4th instar. As a consequence of this unequal development rate, the 4th instar group may include more than one cohort of the population (Butler, 1987).

In analysing the size-frequency data we hoped to determine whether or not there was any synchrony in the development of larvae that would reflect synchronous egg laying by the adult females. In general, in the graphical representation of a synchronous population , a given cohort of animals should show a well-defined pulse through time (Omori and Ikeda, 1984). None of the plots show evidence of this, but the fortnightly or three-weekly (in the case of Lake Goollelal) sampling regime could be responsible for missing peaks in the developmental progression of larvae. Except for *P. nubifer*, which has a life-cycle of three to five weeks at summer temperatures (Edward, 1964), the midge species have life cycles that are sufficiently long for synchronous development to have been apparent.

Additional evidence for asynchronous development comes from the laboratory rearing of *C. alternans* by M. Lund at Murdoch University. A single egg mass collected from Lake Monger was allowed to develop for 11 days in the laboratory. An analysis of the head width measurements of 48 larvae showed that different rates of development had occurred, resulting in five 2nd instar, 29 3rd instar and 14 4th instar larvae.

The spraying of Abate at North Lake did not appear to have any marked effect on the population structure of the midge species investigated. The only change worth noting was the lack of small individuals of *C. alternans* on 24 December 1987. However, the sample size for this date was small (n=9) and also, it may only reflect the overall decrease in larval abundance at North Lake after the 21 December application of Abate.

Chironomid Production and Environmental Parameters

The results obtained in this study support previous suggestions (Ali, 1980) that high midge densities occur as a response to nutrient enrichment. A definite cause and effect relationship has not been established by this study, but the lakes at which midge problems occurred, North Lake and Forrestdale Lake, were the two most enriched lakes. In addition, the peak in abundance of larvae of *P. nubifer* that occurred in North Lake in early December may have been a response to the algal bloom that had occurred at the lake in late October. The subsequent breakdown of this bloom would have provided a large food source to the larval midges inhabiting the lake sediments. Similarly, the peak in abundance of larvae of *P. nubifer* at Forrestdale Lake in early January may have been a response to the algal bloom that occurred at the lake in late November. The breakdown of the second algal bloom which occurred at the lake in January would have been unavailable to larval midges because the lake dried completely within the following month. Presumably if the lake had not dried until April, a second peak in larval abundance may have occurred.

The lack of a midge problem at Booragoon Lake, where nutrients levels were high but algal growth was low, indicates that it is the occurrence of algal blooms, not high nutrient levels per se, that enhances chironomid production. Algal blooms however, are a direct consequence of high nutrient levels.

Physico-chemical conditions in the three permanent lakes were relatively constant during the course of the study whilst greater variability occurred at Forrestdale Lake, particularly with regard to conductivity and temperature. The salinity of the lake rose to approximately 10 ppt (seawater is 35ppt) as the lake dried. The higher species diversity recorded at Forrestdale Lake and the changes in species abundance that occurred over time may have been partly in response to the changing physico-chemical conditions. *C. australis* which was dominant at the start of the study is favoured by cooler (and deeper) waters, *P. nubifer* is favoured by shallow warm waters (Maher and Carpenter, 1984), whilst *T. fuscithorax* is more tolerant of saline conditions.

PRELIMINARY INVESTIGATIONS INTO LONGER-TERM CONTROL OPTIONS

Chironomid Production Model

Because of the short term nature of this study, which was conducted over nine months, insufficient data is presently available to enable a water temperature/depth/nutrients/chironomid production model to be constructed. However the data collected in this study represents a "first step" towards that model and a second and third years data is now required.

Nutrient Enrichment and Chironomid Production

Sufficient relationship has been established between nutrient enrichment, algal blooms and the occurrence of nuisance midge swarms at North Lake and Forrestdale Lake to indicate that eutrophication control must be seriously considered as a longer-term strategy towards the control of nuisance midges. Eutrophication control options worthy of consideration include the reduction or treatment of enriched drainage waters, changes in land use activities in lake catchments (agricultural, horticultural and parks and gardens fertiliser practices may need to be modified), the planting of fringing rushes to act as natural nutrient filters and the planting of species such as *Melaleuca* to increase the tannin content of lake waters, and within-lake manipulation, such as the removal of enriched sediments or sediment capping.

Light Traps

Promising results have been obtained with a light trap built by the Cockburn Council using a design drawn up by one of the Murdoch study team, Adrian Pinder (see Figs 1 and 4). Further work is required to refine the design and to properly test the effectiveness of the trap in midge control. The use of light traps to capture adult midges at a lake represents one of the most environmentally 'safe' methods of control because it should not affect water quality . This approach is also attractive because it is unlikely that resistance would develop against this form of control.

Buffer Zones of Vegetation

No work has been undertaken on this topic as part of the present study due to lack of time but studies are needed to assess the density of understorey and canopy required to prevent midge swarms reaching nearby suburbs. Midges are passive fliers and the capacity of fringing vegetation to act as a physical barrier to prevent the passage of adult midges from the immediate lake environs to nearby housing appears to be considerable. A well developed band of fringing vegetation may also serve to keep lakes cooler (the growth of the pest species *P. nubifer* is favoured by warmer water temperatures).