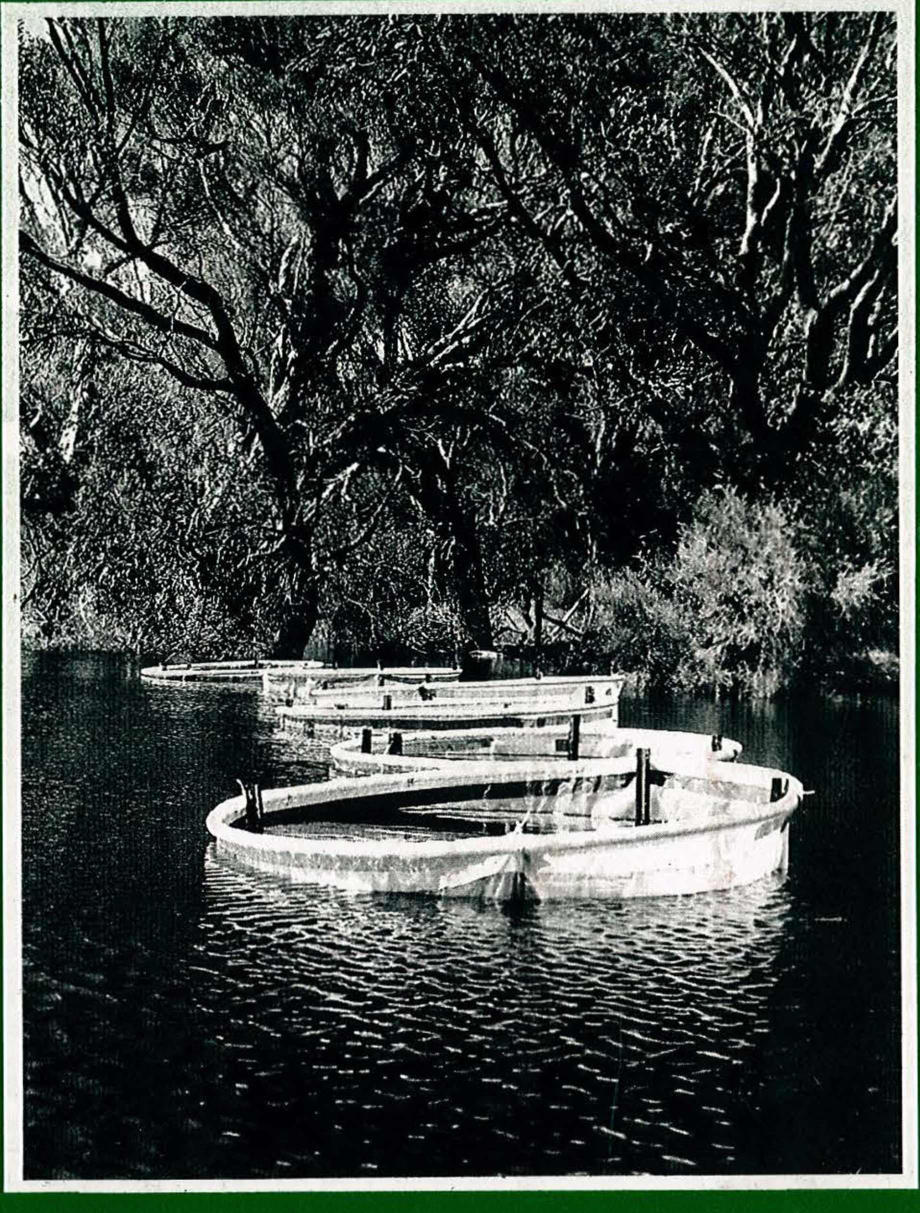
FURTHER INVESTIGATIONS INTO THE CONTROL OF NUISANCE CHIRONOMIDS (MIDGES) IN METROPOLITAN WETLANDS, PERTH, WESTERN AUSTRALIA



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MURDOCH UNIVERSITY

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

A Report on Studies from June 1988 to May 1989

Prepared for The Midge Research Steering Committee

By

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ACKNOWLEDGEMENTS

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 residents living near urban wetlands. This report is the second report to be prepared for the Committee and describes the results of the research programme undertaken over the period June 1988 to May 1989.

This research has been funded jointly by the following State Government departments and Local Authorities; the Department of Conservation and Land Management, the Environmental Protection Authority, the State Planning Commission, and the Cities of Armadale, Cockburn, Melville, Perth, Stirling and Wanneroo.

The members of the steering committee, who are listed below, are thanked for their interest, constructive comments and assistance during the preceding year.

Midge Research Steering Committee

Mr J. Lane	CALM (Chairperson)
Dr R. Humphries	EPA (Co-chairperson)
Mr A. Moore/Mr C. Spasesk	SPC
Mr J. Stubbs/ Mr N. Hume	City of Armadale
Mr D. Ashby/Mr P. Oorjitham	City of Cockburn
Mr G. Dunn	City of Melville
Mr A. Van Leeuwen	City of Perth
Mr J. Sutton/Mr D. Rajah	City of Stirling
Mr R. West	City of Wanneroo
Dr D. Edward	University of W.A.

The chairpersons of the Steering Committee, Mr Jim Lane (CALM) and Dr Bob Humphries (EPA), are especially thanked for their enthusiasm and guidance with the study.

Members of each of the six local authorities assisted the Murdoch research team in many ways. The collection of adult midge samples from residents living near the study lakes was carried out by the Armadale, Cockburn and Wanneroo City Councils. Perth and Wanneroo City Councils continued their existing larval sampling programmes and supplied us with samples of their collections for identification. Cockburn, Perth and Wanneroo Councils provided updated information on the histories of pesticide applications at North Lake, Lake Monger and Lake Goollelal respectively. Cockburn and Melville City Councils coordinated their first pesticide application at North Lake with our field enclosure experiment and provided the Abate used in our laboratory trials. The subsequent applications of Abate to North Lake using a boat and blower were carried out with the expertise of staff and equipment from Perth City Council and with the assistance of Cockburn and Melville City Council staff. Stirling City Council helped coordinate the alum experiment at Jackadder Lake, financed and built the enclosure and provided and applied the alum to the lake. Wanneroo City Council provided the photograph used in this report of the aerial application of Abate.

We are grateful to several companies and to local residents who provided information and helped in a variety of ways. Mr S. Broadbent (Wellcome Australia) and Robert Linton Pty Ltd provided information and samples of pesticides for laboratory use. Many residents living adjacent to the study lakes participated in the adult nuisance assessment programme and allowed us to hang light traps and thermometers on their properties.

Nutrient analyses of water samples were undertaken by the Centre for Water Research Nutrient Laboratory at the University of Western Australia and by Mr M. Lund and Mr D. Plaskett at Murdoch University. Analyses of water samples for pesticide levels were carried out by the Chemistry Centre of W.A. Scientific light traps were constructed by the central workshop at Murdoch University and meteorological data were obtained from the Bureau of Meteorology.

We thank Ms B. Robson for her conscientious involvement in the project for three months over summer. Mr M. Lund helped coordinate the Jackadder alum experiment and facilitated our participation in measuring the effect on midge populations. Mr E. Chester undertook the initial sampling of midges at Jackadder Lake as a Murdoch University undergraduate student project, under our supervision, and subsequently allowed us to use his data in this report. Ms F. Christidis, Mr I. Growns and Ms F. Whittles ably assisted with field work when extra help was required. The design of the field enclosures used in this study is a modification of those designed by Ms N. Hill for use during her honours project in 1988.

We gratefully acknowledge the provision of laboratory space, vehicles and other logistical support by the School of Biological and Environmental Sciences at Murdoch University.

SUMMARY

1. This report describes the results of the second year (1988/89) of a research programme undertaken to determine more effective and environmentally acceptable methods for control of nuisance midges near urban wetlands.

2. Laboratory trials undertaken to determine the susceptibility of larvae of the major pest species, *P. nubifer*, to Abate (temephos) revealed that 37.5 to 75gAI/ha (0.75 to 1.5 kg Abate 50SG/ha) produced between 70% and 85% mortality. Very high rates (500 gAI/ha or 10 kg Abate 50SG/ha) were needed to achieve 95% mortality. This latter result suggests that some resistance to Abate is present in the *P. nubifer* gene pool.

3. Laboratory trials of a granular formulation of Bti (provided by S. Broadbent of Wellcome) indicated that between 20 and 50 kg/ha would be required to cause mortality sufficiently high to be useful for midge control. This is 10 to 25 times higher than the 2 kg/ha recommended for mosquito control. Communication with S. Broadbent has indicated that a field trial of granular Bti may be possible as part of the 1989/90 research programme. The problem remains however, that the present strains and formulations of Bti were mainly designed for use against mosquitoes and that a new strain of Bti may be required for midge control.

4. Laboratory trials of Perigen 500EC (a liquid formulation of permethrin; a synthetic pyrethroid) indicated that this compound may be extremely effective against *P. nubifer*. 75% mortality was achieved with 200 to 250 gAI/ha (0.4 to 0.5 litres product/ha) and 95% mortality was achieved with 600 gAI/ha (1.2 litres of product/ha). At a cost of $100.00 per litre (April 1989 price) Perigen 500EC is an economically suitable alternative to Abate for midge control in the urban wetlands. Ecologically this compound may be less desirable because it may be more toxic to non-target invertebrates and fish than Abate.

5. Limited laboratory trials of Sumilarv 0.5G, an insect growth regulator (IGR), indicated that this compound may also be effective against *P. nubifer*, however further laboratory trials and field trials are required to verify this result.

6. The effectiveness of Abate under field conditions was investigated at North Lake by comparing the density of midge larvae in treated and untreated (control) areas (plastic enclosures) before and after the aerial application of Abate made to the lake on 15 November 1988 by the Cockburn and Melville City Councils. An extremely high mortality (92%) of *P. nubifer* occurred in the treated enclosures (when compared with larval density in the control enclosures) which had received Abate 50SG at a rate of

approximately 5kg/ha. The mean rate applied to the entire lake however was 1.1 kg/ha of Abate 50SG and the results of the routine larval monitoring programme indicated that this treatment appeared to have little effect in reducing the overall abundance of *P. nubifer*.

7. The "evenness" of the aerial application of granular Abate was also investigated during the 15 November treatment of North Lake. Aluminium trays were placed in both the central and littoral regions of the lake and on adjacent dry land to catch the Abate as it was applied. The influence of tree cover was also assessed by placing trays in the littoral and dry land areas in pairs, one of each pair in the open and the other beneath vegetation.

The aerial application was found to be extremely patchy. Less Abate was received in the littoral region than in the central region of the lake. This was not ideal because the littoral region of North Lake supports the greatest densities of larvae. Tree cover did not appear to influence the application rate to any great extent. The results of this investigation indicated that the broad scale application of Abate by fixed wing aircraft may not be appropriate for the control of midges in urban wetlands. Areas known to contain high densities of midge larvae (e.g. the littoral region of permanent lakes) need to be specifically targetted for a pesticide treatment to be most effective.

8. The results of the field evaluation of Abate at North Lake were used as a basis for planning subsequent pesticide treatments at both North Lake and Forrestdale Lake. The three treatments undertaken at North Lake between January and March 1989 were made at a rate of 25 kg/ha of Abate 10SG in water of a mean depth of one metre (this rate was equivalent to 5 kg/ha of Abate 50SG in a depth of one metre). Application was made by boat to the littoral region of the lake only.

The treatment of Forrestdale Lake undertaken on 21 February 1989 was made at a rate of 2.5 kg/ha of Abate 50SG in water of approximately 70 cm. A helicopter was used to apply Abate to the entire lake.

The routine larval monitoring undertaken at both lakes indicated that the January treatment of North Lake and the February treatment of Forrestdale Lake both appeared to be very effective in reducing densities of *P. nubifer*.

9. The regular (fortnightly) larval monitoring programme started by the Murdoch research team in 1987 was continued at two lakes, North Lake and Forrestdale Lake, in 1988/89. Physico-chemical and nutrient data were also recorded for each sampling occasion at each lake. The qualitative adult sampling programme and assessment of midge nuisance levels by householders was continued by the Cockburn and Armadale City Councils respectively.

Regular larval sampling programmes were continued at Lake Goollelal and Lake Monger by the Wanneroo and Perth City Councils respectively, and samples of larvae from these lakes were identified to species level by the

Murdoch research team.

Quantitative data on adult midge nuisance and species composition were collected using light traps placed near four residences at North Lake. Data on adult emergence were collected at Forrestdale and North Lakes during the summer months using four submerged emergence traps.

10. The pattern of change, peaks in larval density and species composition of the larval populations were quite different at North Lake and Forrestdale Lake. Adult species composition and nuisance levels also varied between the two lakes. To some extent these differences could reflect the fact that Forrestdale Lake is currently a seasonal lake which dries out in late summer whilst North Lake contains permanent water over the summer months.

11. The consistent recurrence of a single peak in the density of *P. nubifer* at Forrestdale Lake in both the summers of 1987/88 and 1988/89 indicates that a single well-timed application of an effective pesticide may be sufficient to control midge problems at the lake. Treatment when the density of *P. nubifer* reaches 500 larvae/m^2 or the total number of larvae of all species reaches 2 000 larvae/m^2 appears to be appropriate on the basis of data obtained so far. Weekly rather than fortnightly sampling in January and February is needed to detect the time at which the density of *P. nubifer* first reaches the nuisance threshold.

12. Extremely high densities of larvae of *P. nubifer* were recorded at North Lake throughout summer from December 1988 to March 1989. The consistently high level of midge production at the lake is probably very much a result of the enriched state of the lake and indicates the urgent need for nutrient inputs to be reduced. In the short term, continued applications of pesticide are likely to be needed over the summer months to control midge problems at the lake. It is both economically and ecologically desirable that each treatment is as effective as possible. Ideally the lake should be treated as soon as the threshold of 2 000 larvae of *P. nubifer*/m^2 is reached and on subsequent occasions when this threshold is reached thereafter to ensure that midge densities remain below nuisance levels. For maximum effectiveness the littoral region, which supports the greatest densities of *P. nubifer*, should be targetted for treatment. The relatively small area of the littoral region at North Lake (5 ha) indicates that this may be a suitable site for the trialling of alternative larvicides to Abate.

13. The abundance of larval midges at both North Lake and Forrestdale Lake was much higher in the summer of 1988/89 than that of 1987/88. The observed increase may have been related to the higher annual rainfall that occurred in 1988 (912.4 mm) compared with 1987 (786.6 mm). However further environmental data are needed to support this suggestion.

During the 1988/89 summer information on larval densities as well as emergence rates of adults were collected at North Lake. These data, along with longer-term environmental data, are neccesary to fulfil the aim of formulating a chironomid production model.

14. The emergence rates of adult midges were measured using submerged emergence traps. Peaks in emergence at North Lake corresponded to the peaks in larval abundance, with emergence rates per square metre being approximately 3% of the larval densities per square metre. Species composition of larvae and emerging adults were not always equivalent, but the patchiness of larvae and the small number of emergence traps used may have contributed to this discrepancy.

15. Light traps placed at four residences adjacent to North Lake indicated the extreme daily variation in the nuisance levels at each house. Neighbouring residences attracted different numbers of midges, although *P. nubifer* was the major species collected by all four traps. Nuisance midges collected by residents using aspirators showed a much more diverse species composition, suggesting that such collections may be species-biased.

16. A standard method for monitoring larval densities in Perth wetlands has been developed for use by local government authorities. Use of this method will enable more accurate predictions of impending midge problems to be made. As an approximate guide, a density of 2 000 larvae/m^2 or greater is considered to be the level at which a pesticide treatment is warranted if midge problems in adjacent urban areas are to be avoided.

17. Several alternatives to the chemical control of midges were investigated during 1988/89. The use of alum to reduce algal blooms (an important food source for larval midges) at Jackadder Lake appeared to result in a short term improvement in water quality and a reduction in the abundance of larval midges. However further work is required to conclusively demonstrate the effectiveness of alum as an indirect method of midge control.

18. The effectiveness of a light trap placed on the western side of Bibra Lake by Cockburn City Council was monitored between October and December 1988. The number of adult midges caught ranged from 0 to 51 072. This result indicated that light traps may have some potential as part of an integrated midge control programme. However the number of midges collected by a single light trap will probably only be a very small proportion of the total number emerging from the whole lake. Data obtained from emergence traps placed in North Lake indicated that approximately 41 million adults could emerge from this lake over a 24 hour period. The maximum number of adults collected at the Bibra Lake light trap (51 072) over 24 hours represented only 0.12% of this total.

19. To determine the variability in midge problems experienced within a single suburb, and the possible influence individual householders may exert on the problem, residents living near Lake Goollelal were asked to respond to a questionnaire regarding the degree of midge nuisance that they experienced and the location and physical appearance of their houses. The results of the questionnaire indicated that different levels of nuisance were experienced by householders living within close geographical proximity. However these differences could not be attributed to any obvious differences between houses.

20. There is no single "best" technique for the control of midges associated with urban wetlands. The use of pesticides, either Abate or a suitable alternative will continue to be an important and usually "quick" means of short term control. However pesticide treatment must be made at the right time. This requires that larval densities are monitored and the pesticide applied when a nuisance threshold is reached. It is very important that the pesticide used is effective, and that larval densities are reduced to below the nuisance threshold and then are kept below this threshold, if midge problems are to be prevented.

21. The problems of resistance, biomagnification, residues and harmful effects on non-target or beneficial predatory organisms mean that total reliance on broad spectrum pesticides is neither ecologically nor economically desirable. The modern concept of pest control is integrated pest management in which several control techniques are used simultaneously to provide the best possible control.

In addition to the short term use of pesticides in Perth wetlands some form of nutrient reduction is urgently required if a longer term solution to the midge problem is to be achieved. Ultimately this requires a change in land management practices in the catchment so that nutrient inputs from surface flows are reduced. More immediate solutions to the problem of excess nutrients entering a wetland may include the use of alum, the diversion or treatment of water in stormwater drains, and the capping or removal of nutrient-rich sediments. Additional control methods that may lessen the need for pesticide use include the use of light traps, reduction or changes in outdoor lighting of houses and the replanting of buffer zones of vegetation.

22. Proposed research to be undertaken during the final year of the study (1989/90) includes:

a) Continuation of the larval and adult monitoring programmes at North Lake and Forrestdale Lake with an emphasis on the treatment of lakes when nuisance threshold levels of larvae are reached. This will require close coordination with Cockburn, Melville and Armadale City Councils and CALM if treatments are to be made at the most appropriate times.

b) Field trials of alternatives to Abate - one or more of granular Bti, Perigen 500 and Sumilarv are to be tested in enclosures at North Lake or as whole lake treatments if sufficient pesticide is available.

c) Experimental investigations into the role of nutrients in midge production. Nitrogen and phosphorus, separately and in combination, will be added to small ponds (hopefully making use of small ponds with high midge densities, such as those on the South Perth foreshore) and the changes in environmental parameters and larval abundance will be monitored.

INTRODUCTION

This report describes the results obtained from the second year of a research programme undertaken to investigate more effective and environmentally acceptable methods of controlling midges near some of Perth's major wetlands. The results of the first year of study were reported previously (Davis, Harrington and Pinder, 1988) and readers are asked to consult that report to obtain a more comprehensive background to the work reported here. In particular, the review of the literature and appraisal of control options are still extremely relevant to this study.

The objectives for the second year of study were as follows:

1. To undertake laboratory trials to determine the susceptibility of *Polypedilum nubifer* to Abate and other potential larvicides (granular Bti, Perigen and Sumilarv).

- Results obtained in the first year of the study indicated that Abate was not effective against larvae of *Chironomus australis* (a minor pest species) at the recommended rates but insufficient data had been obtained to determine the effectiveness of Abate against the major pest species, *P. nubifer.* It was particularly important to obtain this information because Abate is currently the only pesticide registered for use against midges in Western Australia. The very real possibility that resistance to Abate may have developed in midge populations in the urban wetlands indicated that potential alternatives to this pesticide also needed to be tested. These laboratory trials would act as a baseline against which the future development of resistance could be assessed.

2. To determine the effectiveness of Abate under field conditions.

- Laboratory trials provide baselines on susceptibility to insecticides but they do not necessarily indicate the effectiveness of the pesticide in the field. For this reason the use of field trials is very important but they are much more time-consuming and expensive (in terms of materials) than laboratory trials. To properly determine the effectiveness of an application of Abate to a wetland it was important that a control area remain untreated. Plastic enclosures were used at North Lake to determine the effectiveness of an aerial application of Abate to the lake at the rate of 1.5 kg/ha. Treatment and control areas were used so that the effects of the pesticide on larval densities could be separated from any natural fluctuations that may have occurred. The "evenness" or "patchiness" of an aerial application of Abate was also investigated as part of the field experiment.

3. To continue larval and adult monitoring programmes at North Lake and Forrestdale Lake.

Our objectives in monitoring the abundance of larval and adult midges at North Lake and Forrestdale Lake were twofold. Firstly, at the conclusion of the first year of study we had suggested a density of 2 000 larvae of *P. nubifer* per square metre as the threshold which signalled the onset of nuisance swarms of adults. Larval densities at the lakes needed to be monitored so that the occurrence of this threshold could be detected. The relevant local authorities would be provided with the monitoring data so that treatment with Abate could be undertaken at the most appropriate times. Further data relating larval densities and adult nuisance levels were also required to enable better estimation of the threshold levels.

In addition, we needed to obtain reliable estimates of population densities to provide a basis for determing the factors which influence the distribution and abundance of the pest species. We needed to determine, if possible, the environmental conditions which resulted in an increase in the pest species to unacceptable levels. This may mean that the occurrence of midge problems could be predicted in advance from the fairly simple monitoring of environmental parameters.

4. To design a simple standard method for monitoring larval midge densities.

- The importance of monitoring larval densities so that larvicides can be applied at the most appropriate time is well recognised, however the success of this approach depends upon the implementation of a suitable sampling programme. One of the tasks of this study was to design a simple but accurate standard method for monitoring larval densities that could be used by the staff of local authorities.

5. To investigate alternatives (both short term and long term) to the chemical control of midges.

- There is no longer a single "best" technique in insect pest control. The problems of resistance, biomagnification, residues and harmful effects on non-target or beneficial predatory organisms mean that total reliance on broad spectrum organochlorine or organophosphate pesticides for pest control is neither ecologically nor economically desirable. The modern concept of pest management is that of integrated control (integrated pest management) in which several control techniques are used simultaneously to provide the best possible control. In practice this is often difficult to achieve particularly because more long term integrated strategies are often neglected in favour of short term methods (Stiling, 1985). A combination of control techniques however, can often have multiplicative rather than additive effects (Stiling, 1985). In an attempt to adopt a more holistic approach to midge control several alternatives to chemical control were considered in this study. These included the use of alum to reduce algal blooms (an important food source for larval midges) at Jackadder Lake, a light trap at Bibra Lake and the use of a questionnaire to identify human influences on, and perceptions of, nuisance midge swarms at Lake Goollelal.

PESTICIDE SUSCEPTIBILITY TESTS

INTRODUCTION

During the first nine months of research (1987/88) three larvicides (temephos, chlorpyrifos and Bti) were tested for their effectiveness against the larvae of several chironomid species (Davis, Harrington and Pinder 1988). Several priorities for future laboratory trials arose from these initial experiments. These included further tests of temephos and Bti on the main nuisance species, *Polypedilum nubifer.*

The initial experimental work undertaken between November 1987 and February 1988 showed that susceptibility to pesticides varied between species, and even between populations of the same species from different lakes. In an attempt to make the 1988/89 pesticide trials as comparable as possible they were all carried out against *P. nubifer* from North Lake. *P.nubifer* was chosen because it has been identified as the major nuisance species in the Perth region. North Lake was used as the source of larvae because it was the focus of the 1988/89 field studies and was known to support large numbers of *P. nubifer.*

As part of the 1987/88 research the efficacy of the current control agent, temephos (Abate), was investigated. These experiments demonstrated that at least one species with nuisance potential (*Chironomus australis*) was not susceptible to Abate 50SG at recommended concentrations (refer to the 1988 report). Other *Chironomus* species appeared to be more susceptible. A single experiment suggested that *P. nubifer* was susceptible to Abate at the recommended concentration (1.5 kg/ha). However, this result conflicted with the results of preliminary testing performed by Grant Pearson of C.A.L.M., which suggested that Abate 50SG was not effective against *P. nubifer* from Forrestdale Lake at similar concentrations. An important aspect of the 1988/89 research was to determine whether Abate is an effective larvicide for midges in Perth wetlands.

Laboratory tests of Bti (*Bacillus thuringiensis* var. *israelensis*) as a liquid formulation (Teknar) were carried out against three *Chironomus* species during the first series of laboratory trials (1987/88). The results of these trials suggested that Bti may have some potential as a midge larvicide, however it was concluded that further testing was required. In November 1988 a batch of granular Bti (made from a new Bti wettable powder) was received from Wellcome Australia. This wettable powder is more potent (35 000 Iu/mg) than the Teknar (600 Iu/mg), although the granules are made up so as to have approximately the same potency as Teknar. The granules are sand based and so transport the Bti to the sediment where it is most available to the midge larvae. The wettable powder is produced commercially overseas, but is not as yet marketed commercially by Wellcome in Australia. Another source of granular Bti that appears more promising in terms of availability is being investigated. The results of tests of granular Bti against P.nubifer are presented in this report.

The remaining two larvicides that were tested this year were an insect growth regulator (Sumilarv 0.5G) and a synthetic pyrethroid (Perigen 500EC).

Sumilarv is a 0.5% granular formulation of a new insect growth regulator (JHM S-31183) developed by Sumitomo Chemical Co. of Japan. This chemical, along with methoprene (Altosid), belongs to a group of insect growth regulators (IGR's) known as juvenile hormone analogues (Sumitomo, technical report), which generally only affect the metamorphosing last instar larvae and pupae (Mian and Mulla, 1982). Urea type IGR's, such as diflubenzuron (Dimilin) affect the moulting of all larval instars and pupae (Mian and Mulla, 1982). Consequently, given equal residual effects, the juvenile hormone analogues will control midge emergence for a shorter time than will a urea type IGR (Busvine, 1978). The product is at least two years away from commercial availability due to toxicity testing being carried out by Sumitomo. Federal registration of this product could take at least a further two years (S. Broadbent, Wellcome, pers. comm.). Sumilarv is reportedly much more potent than either diflubenzuron (Dimilin) or methoprene (Altosid), although no previous tests have been carried out on chironomid larvae. No cost information is available at present.

Perigen 500EC is an emulsifiable concentrate formulation (500g/l) of permethrin. Steve Broadbent of Wellcome Australia suggests a mosquito control rate of 25gAI/ha (50ml product/ha). Although this product is commercially available for control of other insects (cost approximately $100/litre) it is not registered for use in midge control in W.A.

METHODS

General

The pesticide trials reported here were carried out between October 1988 and March 1989. Most of the methods employed during these trials were described in the May 1988 report, and therefore are not given here in detail. In general the methods are based on those recommended for mosquito susceptibility tests by the World Health Organization (Russell, 1986). This year the trials of Abate and Perigen were run for three days rather than one, to allow for a greater time for the pesticide to act, and for moribund animals to die. Bti and Sumilarv take a longer time to affect the larvae and so trials of these chemicals were run for seven days. The concentrations used are calculated from equivalent amounts per hectare (assuming 0.5m depth to arrive at a volume)

Abate 50SG (Granular Temephos)

Three 72 hour trials of Abate 50SG were carried out against *P. nubifer* from North Lake. All trials were carried out using eight litres of filtered lake water in plastic buckets with a thin layer of sand as substrate. Seven concentrations (Table 1), ranging from 37.5 gAI/ha (0.75kg product/ha) to 100 000gAI/ha (200 kg product/ha), assuming 0.5m depth, were tested. Ten larvae (late 2nd to early 4th instar) were used for each replicate. After identification some of these were found to be species other than *P. nubifer* or had pupated and so were not counted in the analyses. The larvae were acclimated at 18 ± 4°C for one day, and the experiments were run for 72 hours at 19 ± 6 °C.

Granular Bti

Granular Bti was tested against *P. nubifer* from North Lake on three occasions between November 1988 and January 1989. Plastic buckets, filled with eight litres of filtered lake water, were used as test containers. One litre glass beakers were used in the second and third trials in addition to the plastic buckets, to determine the effects (if any) of the plastic upon the efficacy of the pesticide. Washed sand was used as a substrate in all containers. Five concentrations (ranging from 2kg/ha to 200kg/ha, assuming 0.5m water depth) were tested in the first trial, and in the glass beakers in the other two trials. Only three and two concentrations were tested in buckets in trials two and three respectively. The bucket trials were allowed to run for seven days. High control mortality was encountered for the tests in glass beakers after five days and so only the five day data could be used. Between 12 and 15 larvae (mainly 2nd and 3rd instar) were used for each replicate. A small proportion of these either pupated or were not *P. nubifer* and so were not used in the analyses. Larvae were acclimated at 26 ± 6 °C for one day, and the trials were run for seven days at 24 ± 8 °C.

Perigen 500EC (Liquid Permethrin)

One litre glass beakers were used to test the toxicity of Perigen 500 to *P. nubifer* from North Lake on three occasions during February and March 1989. Five concentrations were tested, ranging from the suggested mosquito rate of 25 gAI/ha (S. Broadbent pers. comm.) to 2500 gAI/ha, assuming a 0.5m water depth. About ten larvae (2nd and 3rd instar) were added to each beaker along with washed sand as substrate. Larvae were acclimated at temperatures between 17.0 and 19.5°C for one day in trial one and for three days in trials two and three. The temperature during the three trials ranged from 17.0 to 20.0°C. The three trials were terminated after 72 hours.

Sumilarv 0.5G

Sumilarv, being an insect growth regulator, interferes with the growth and development of insects. Chironomid larvae may be prevented from pupating properly or the pupae may fail to emerge as viable adults (Mian and Mulla, 1982). Although these chemicals are known to have some larvicidal activity, the larvae may not necessarily die during the trial. For this reason larval mortality is not a good indicator of IGR efficacy. A more accurate assessment of the effectiveness of IGR's can be made by monitoring adult emergence.

Three Sumilarv trials were carried out in glass beakers which were covered by wire mesh (1.5mm) to prevent the emerged adults from escaping (Fig. 1A). The five concentrations tested were between 5 and 500gAI/ha (assuming 0.5m depth). Ten 3rd and 4th instar *P. nubifer* larvae were added to each container and washed sand was added as substrate. The Sumilarv trials were performed concurrently with the Perigen trials and so the same temperatures and acclimitization times apply. The three trials were stopped after seven days.

The small number of larvae added to each beaker resulted in few larvae reaching pupation even in the controls. This made it difficult to examine the

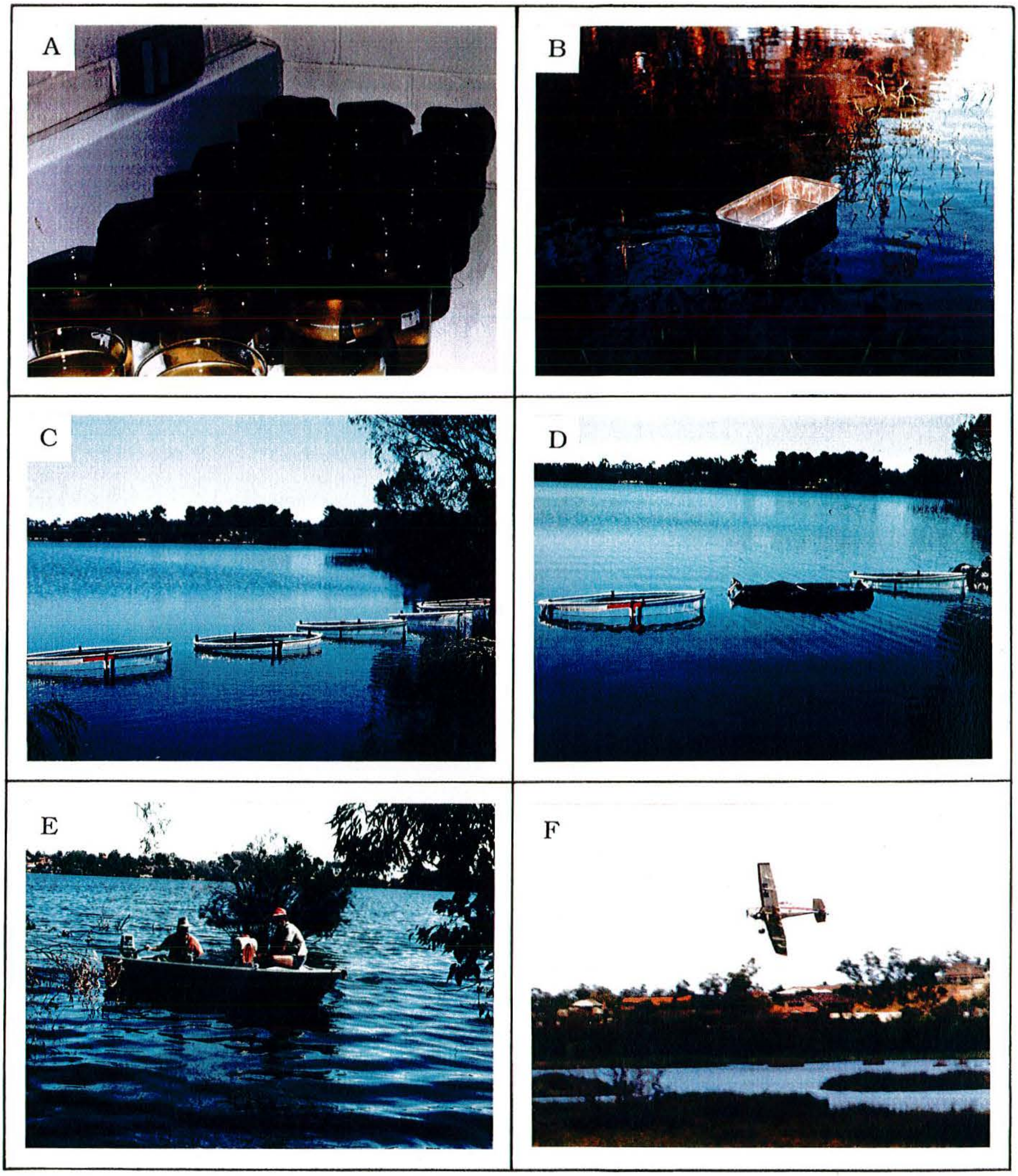


Figure 1. Photographs showing pesticide testing procedures.
A: Test beakers with wire mesh covers during a laboratory test of Sumilarv 0.5G, B: Aluminium tray used to catch Abate 50SG granules during the aerial treatment of North Lake on 15 November 1988, C: North Lake, showing the six field enclosures in position, D: Enclosures at North Lake with covers on the controls, E: Boat and blower used to treat the littoral region of North Lake with Abate 10SG, F: Aircraft used to treat Lake Goollelal with Abate 50SG.

effect of the pesticide upon the rate of pupation and emergence. To overcome this a trial was run using six 356mm x 254mm x 203mm glass aquaria as test containers. Each tank contained eight litres of filtered North Lake water, and washed sand substrate to a depth of two centimetres. Fifty *P. nubifer* larvae (3rd and 4th instar) from North Lake were added to each aquarium. One tank was used as a control and the other five were used to test five concentrations (between 5 and 500gAI/ha). The tanks were covered by 1.5mm wire mesh to prevent emerging adults from escaping. As this was considered a preliminary trial to test the methods, no replication was used. The emergence of adults was recorded daily for 22 days, after which emergence in the control tank ceased. Inhibition of emergence was calculated by comparing the total emergence after 22 days in the treated aquaria to that of the control aquarium.

Data Analysis
All dead and live larvae were identified after the trials were terminated (except for the Sumilarv aquarium experiment). Only *P. nubifer* larvae were included in the analyses, and pupae were only included for the Sumilarv beaker trials.

Where possible probit analysis was used to analyse the data. The probit computer program generates a table of lethal doses from a regression line calculated from transformed data. The 1988 midge research report or Finney (1971) should be consulted for a more thorough explanation of this procedure.

RESULTS

Tables 1 and 2 contain the results of each pesticide trial expressed as mean percentage mortalities of *P. nubifer* for the various concentrations (i.e. a mean of the three replicates of each concentration). The last line of each table contains the mean percent mortalities calculated from all three trials (i.e. the mean of nine replicates). The percent mortalities in this last line of each table are plotted against log concentration in Figures 2 to 5. The regression lines generated by the probit analyses are presented graphically in Figures 2 to 5; the associated LD75 and 95 values are also given for each pesticide.

Abate 50SG (Granular Temephos)
Rates of Abate normally used for midge control in the field range from 50 to 100gAI/ha (1.0 to 2.0 kg Abate 50SG/ha). At 75gAI/ha a mean mortality of 83.3 ± 9.0 % was achieved in the laboratory after three days (Table 1 and Fig. 2). For two of these trials 100% mortality was recorded at this concentration. Even at half this rate (37.5gAI/ha) a mean of 70.5 ± 13.4 % mortality was recorded. Doses higher than 75gAI/ha resulted in increased mortality, to a maximum of 98.3 ±1.7 % at 1 000gAI/ha.

Probit analysis of the Abate data resulted in an LD75 of 6.8gAI/ha (0.13 kg Abate 50SG/ha) and an LD95 of 47 000 gAI/ha (958 kg Abate 50SG/ha). The high mean mortalities recorded for the top four concentrations resulted in a very shallowly sloped line of best fit being calculated by the probit analysis

Table 1. Results of laboratory susceptibility tests of Abate 50SG (granular temephos) and granular Bti against *Poypedilum nubifer* from North Lake, showing mean % mortality ± standard error, after 72 hours (Abate) and seven days (Bti).

ABATE 50SG

	Concentration (gAI/ha)							
	Control	37.5	75	250	500	1000	10000	100000
Date	Mean % Mortality of Larvae ± S.E. (sample size)							
24 - 28 Oct 1988	10.0±10.0 (26)	18.1±7.6(28)	50.0±11.5(30)	61.1±11.1(20)	-	100.0±0.0(17)	75.4±12.3(27)	76.7±6.7(30)
14 -18 Nov 1988	13.9±3.2 (29)	93.3±6.7(29)	100.0±0.0(28)	100.0±0.0(29)	92.6±7.4(28)	96.7+3.3(30)	100.0±0.0(29)	100.0±0.0(29
20 - 23 Mar 1989	6.0±6.0 (31)	100.0±0.0(30)	100.0±0.0(27)	100.0±0.0(27)	100.0±0.0 30)	100.0±0.0(26)	100.0±0.0(27)	100.0±0.0(30)
Mean of all trials	**11.9±4.8**	**70.5±13.4**	**83.3±9.0**	**87.0±7.2**	**96.3±2.9**	**98.3±1.7**	**87.7±7.8**	**88.3±6.0**

GRANULAR Bti

	Concentration (kg/ha)					
	Control	2	10	50	100	200
Date	Mean % Mortality of Larvae ± S.E. (sample size)					
29 Nov - 6 Dec 1988	0.0±0.0 (17)	31.0±21.2 (13)	64.3±22.0 (14)	78.7±3.8 (27)	100.0±0.0 (39)	100.0±0.0 (43)
14 - 22 Dec 1988	4.2±3.4 (20)	15.9±0.7 (19)	-	95.8±3.4 (31)	-	100.0±0.0 (23)
19 - 26 Jan 1989	9.4±2.4 (42)	-	-	100.0±0.0 (45)	-	100.0±0.0 (45)
Mean of all trials	**4.5±1.9**	**23.5±8.5**	**64.3±22.0**	**91.5±3.6**	**100.0±0.0**	**100.0±0.0**

Table 2. Results of laboratory susceptibility tests of Perigen 500EC (liquid permethrin) and Sumilarv 0.5G against *Poypedilum nubifer* from North Lake, showing mean % mortality ± standard error, after 72 hours (Perigen) and seven days (Sumilarv).

PERIGEN 500EC

	Concentration (gAI/ha)					
	Control	25	250	500	1250	2500
Date	Mean % Mortality of Larvae ± S.E. (sample size)					
3 - 6 Feb 1989	20.0±10.8(30)	13.3±8.8(30)	83.3±3.3(31)	86.7±3.3(30)	100.0±0.0(30)	100.0±0.0(31)
20 - 23 Feb 1989	3.3±4.1(30)	6.7±8.2(29)	100.0±0.0(29)	100.0±0.0(29)	100.0±0.0(29)	100.0±0.0(28)
6 - 9 Mar 1989	0.0±0.0(28)	6.1±7.4(31)	100.0±0.0(29)	100.0±0.0(29)	100.0±0.0(30)	100.0±0.0(31)
Mean of all trials	**6.8±±4.4**	**7.7±3.6**	**89.5±3.2**	**92.1±2.8**	**100.0±0.0**	**100.0±0.0**

SUMILARV 0.5G

	Concentration (gAI/ha)					
	Control	5	50	100	250	500
Date	Mean % Mortality of Larvae and Pupae ± S.E. (sample size)					
3 - 6 Feb 1989	17.0±8.0(29)	18.8±10.8(31)	10.4±0.5(29)	16.7±10.8(30)	43.3±17.8(30)	70.0±14.1(30)
20 - 23 Feb 1989	20.0±12.2(30)	13.7±3.9(29)	28.2±16.5(31)	20.7±0.9(29)	40.0±18.7(30)	80.0±14.1(29)
6 - 9 Mar 1989	16.4±8.3(31)	21.1±6.7(28)	22.2±4.9(22)	26.7±16.3(30)	21.8±8.2(28)	74.2±10.7(31)
Mean of all trials	**17.8±4.0**	**17.9±3.3**	**20.6±4.8**	**21.3±4.8**	**35.2±5.5**	**74.7±5.5**

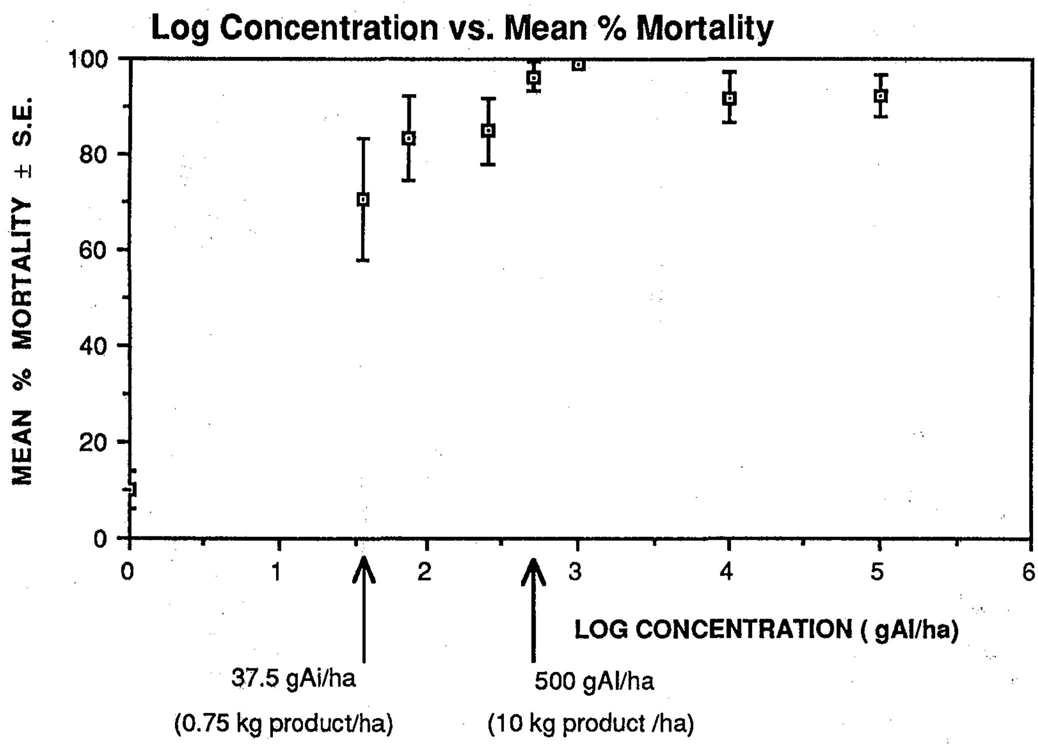


Figure 2. Results of 72 hour laboratory susceptibility tests, showing log concentration of Abate 50SG (granular temephos) vs. mean % mortality ± standard error of *Polypedilum nubifer* from North Lake.

program. This has resulted in unrealistic estimates of the LD75 and LD95 values and these should be used with caution.

Granular Bti
High control mortality in the glass beakers after five days precluded the use of the data from these containers for assessing Bti potency. In general the mortality observed in the beakers was lower than that observed in the plastic buckets for the same exposure time. The following results refer to trials carried out in the buckets.

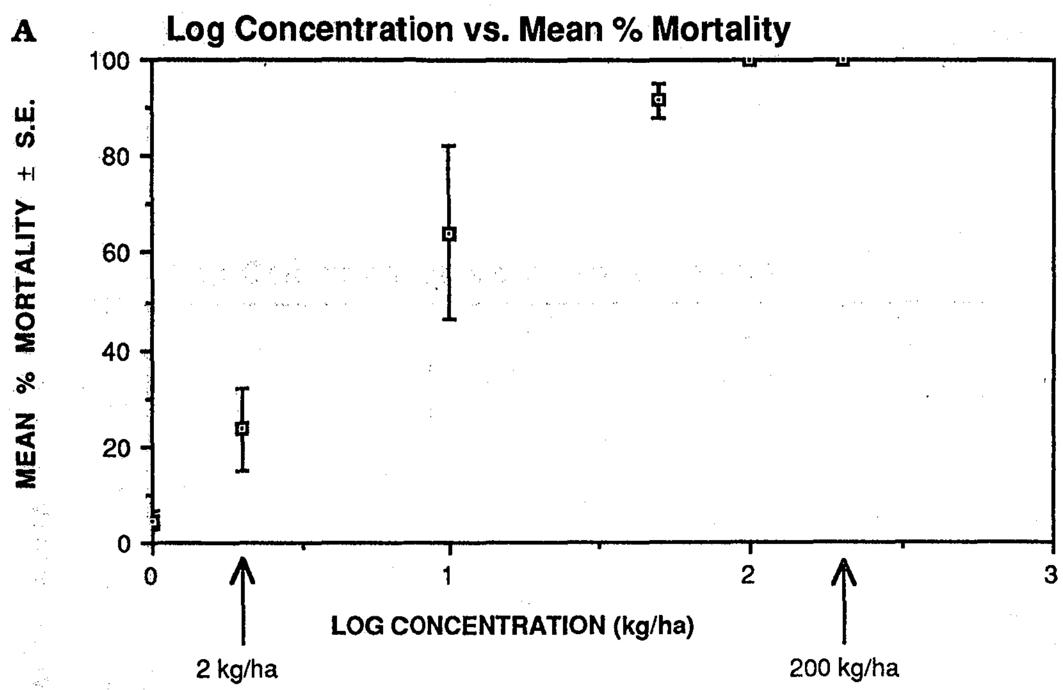
Greater than 75% mortality was recorded on all three occasions when *P.nubifer* was exposed to 50kg/ha of Bti granules for seven days (Table 1). The mean mortality of all nine replicates at this concentration is 91.5 ±3.6 % (Fig 3A). Mortality of 64.3 ± 22.0 % was recorded when *P. nubifer* was exposed to 10 kg/ha, however this concentration was tested on only one occasion.

These results suggest that between 10 and 50 kg/ha is required to cause mortality that is sufficiently high to be of use in midge control. This conclusion is supported by probit analysis of the seven day data from the bucket trials, which suggests an LD75 of 20.3 kg/ha, and an LD95 of 56.2 kg/ha (Fig 3B).

Perigen 500EC (Liquid Permethrin)
The results of the Perigen trials are presented in Table 2. All concentrations exceeding 25gAI/ha (50ml product/ha) resulted in high mortality of *P. nubifer* after three days. The mean mortality of *P.nubifer* was 89.5 ±3.2 % when exposed to 250gAI/ha (Fig. 4A), this is approximately ten times the rate suggested for mosquito control. The application of probit analysis to this data set (Fig. 4B) resulted in an LD75 of 224gAI/ha (0.45 litres product/ha) and an LD95 of 602gAI/ha (1.2 litres product/ha)

Sumilarv 0.5G
Table 2 contains the combined larval and pupal mortalities for the three Sumilarv beaker trials. Adult emergence was not high enough in the control beakers to draw conclusions about inhibition of emergence and a separate trial was carried out to assess this (see below). Only at 500gAI/ha was high mortality (74.7 ± 5.5) achieved (Fig. 5A). This rate is approximately ten times the rates that have been tested against mosquitoes by Sumitomo (20.8 to 83.3gAI/ha). At lower rates (5 to 250gAI/ha) mortality never exceeded 45%. Probit analysis (Fig. 5B) suggests that 614gAI/ha (122.8kg product /ha) would result in 75% mortality of larvae and pupae combined, and that 95% mortality could be achieved in the laboratory using 1363gAI/ha (273kg product /ha).

The trial carried out in the aquarium tanks was designed to determine the effects of Sumilarv upon adult emergence. Adult emergence was inhibited by 100% at concentrations of 50gAI/ha (10kg product/ha) and higher (Fig. 6). Exposure of the midge larvae to 5gAI/ha caused only 24% inhibition of emergence.



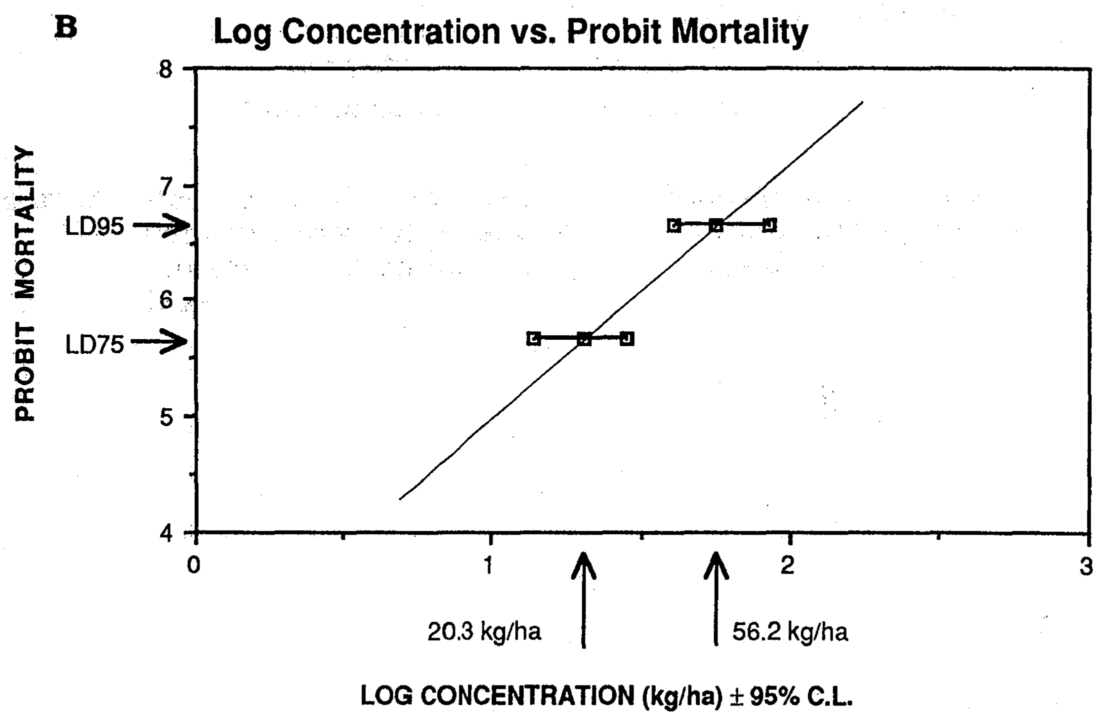
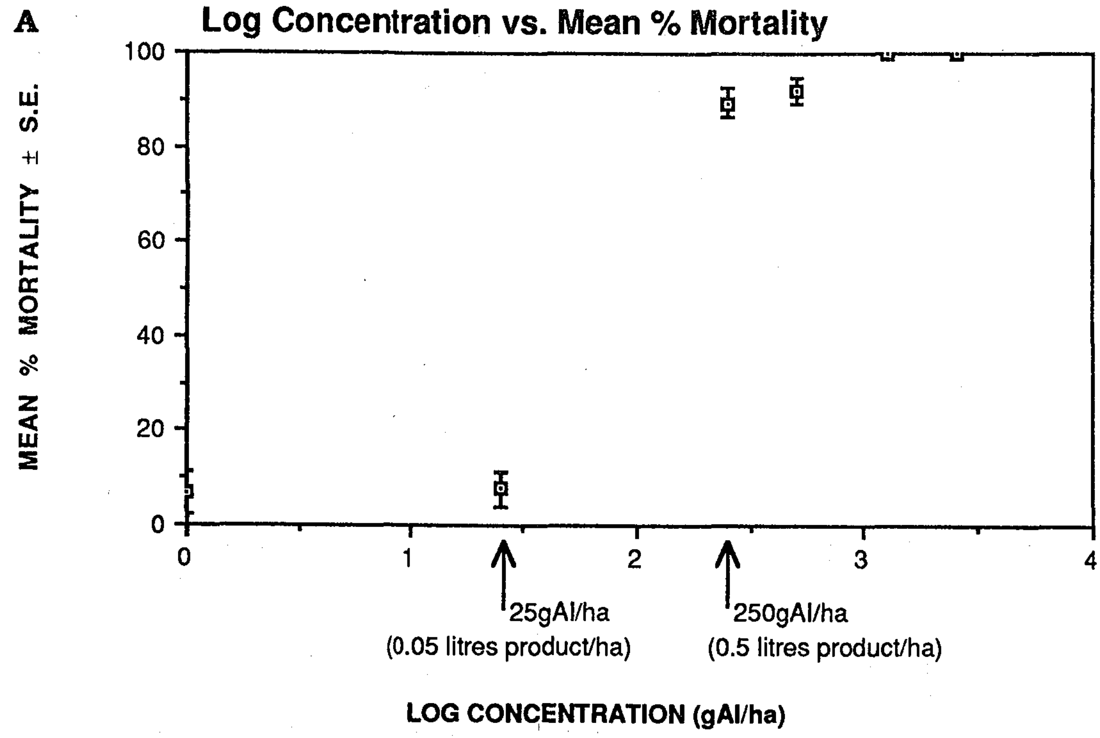


Figure 3. Results of 72 hour laboratory susceptibility tests, showing **A**: log concentration of granular Bti vs. mean % mortality ± standard error and **B**: log concentration of granular Bti vs. probit mortality of *Polypedilum nubifer* from North Lake.



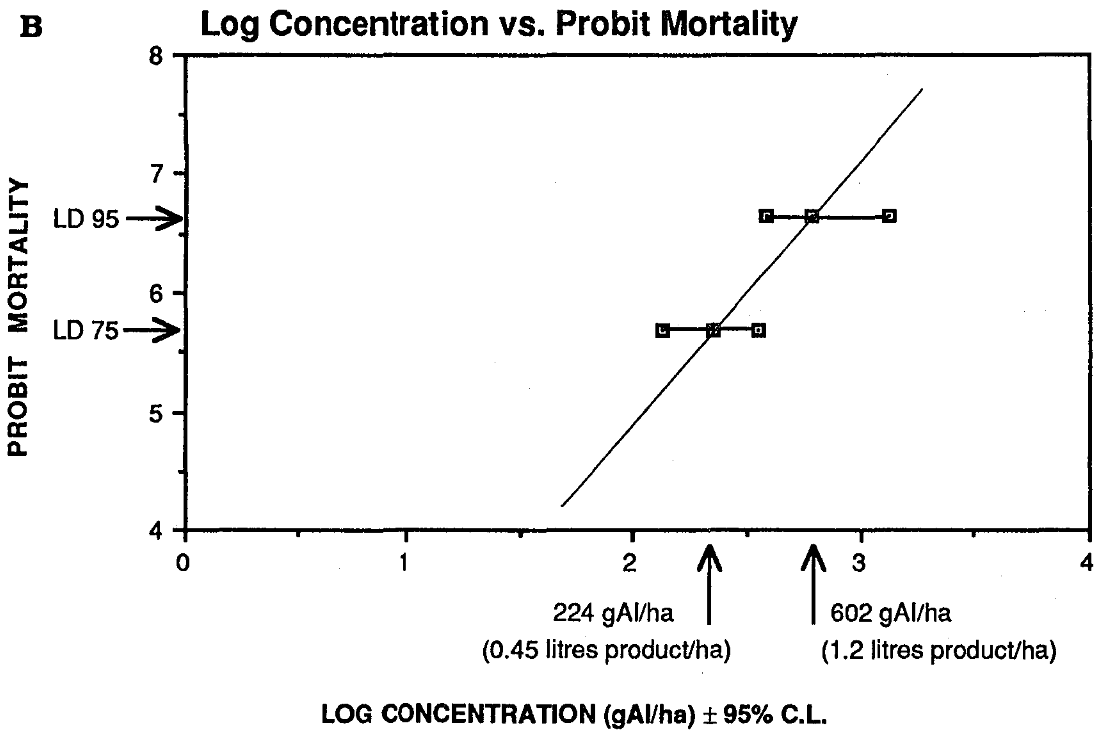


Figure 4. Results of 72 hour laboratory susceptibility tests, showing **A**: log concentration of Perigen 500EC (liquid permethrin) vs. mean % mortality ± standard error and **B**: log concentration of Perigen 500EC vs. probit mortality, of *Polypedilum nubifer* from North Lake.

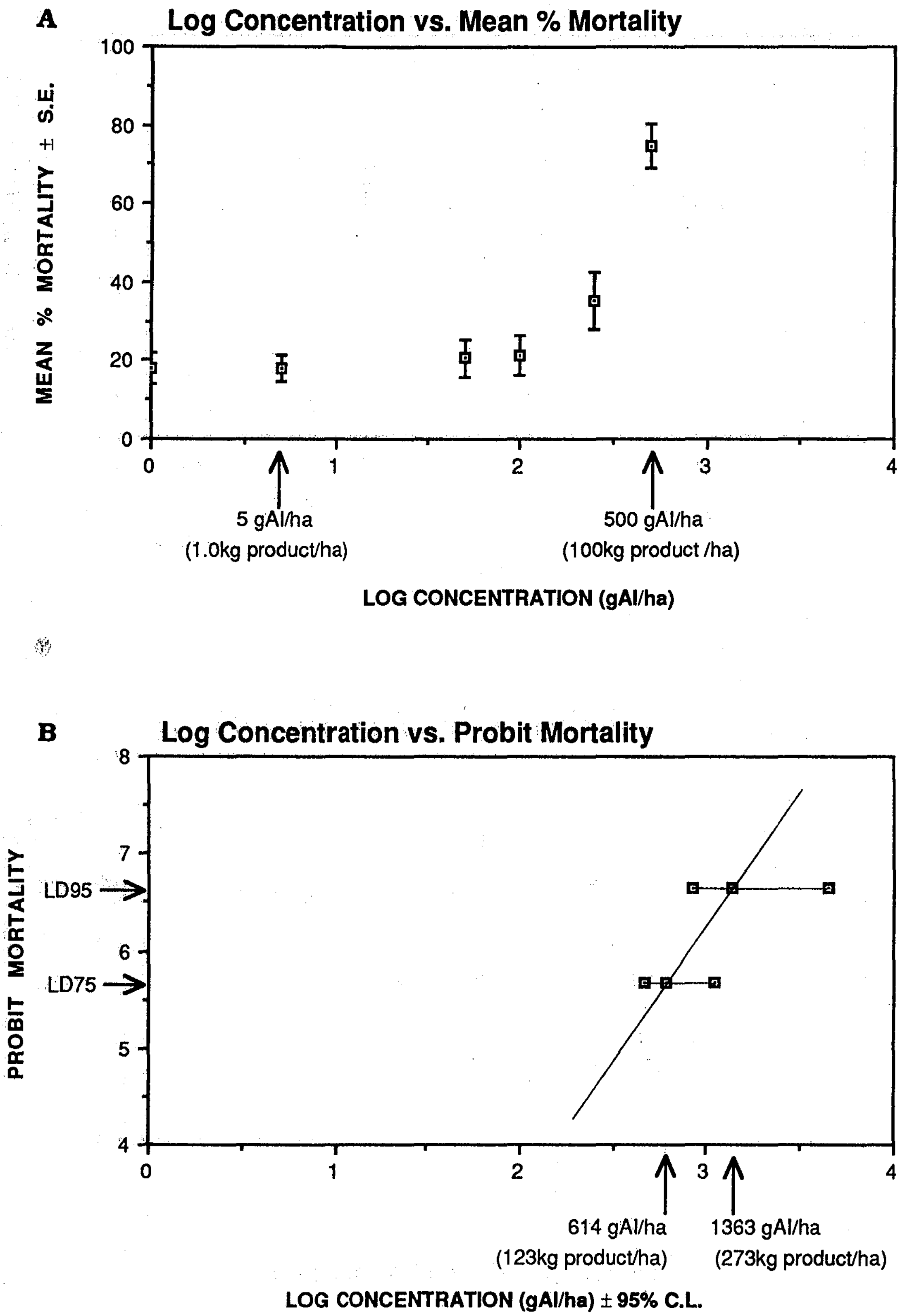


Figure 5. Results of 72 hour laboratory susceptibility tests, showing **A**: log concentration of Sumilarv 0.5G vs. mean % mortality ± standard error and **B**: log concentration of Sumilarv 0.5G vs. probit mortality, of *Polypedilum nubifer* from North Lake.

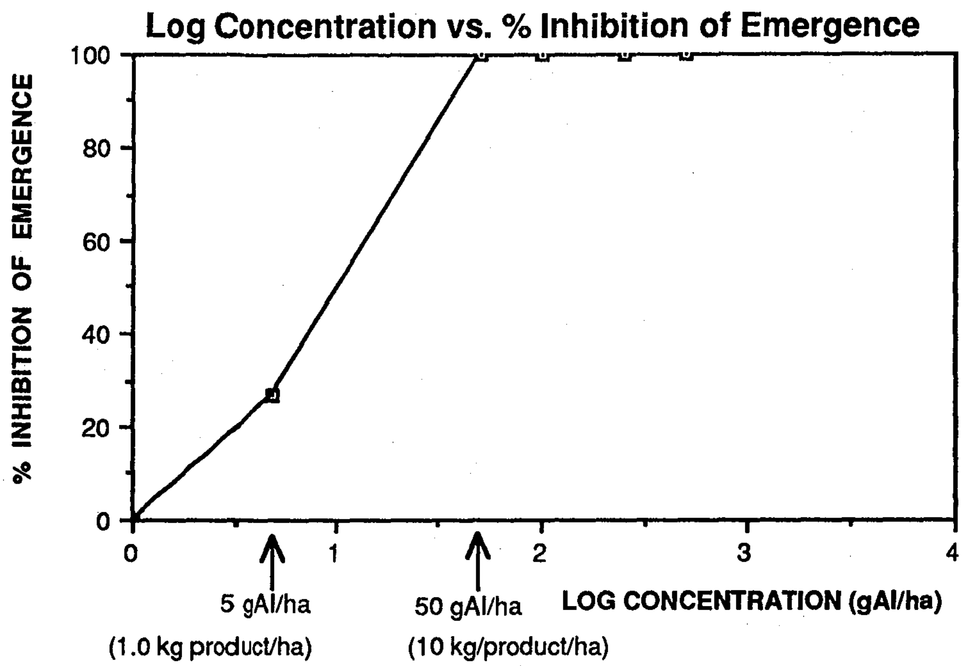


Figure 6. Results of laboratory susceptibility test showing log concentration of Sumilarv 0.5G vs. % inhibition of emergence after 22 days, of *Polypedilum nubifer* from North Lake.

DISCUSSION

Abate 50SG (Granular Temephos)

Probit analysis is most accurate when concentrations are used so as to give an even spread of mortalities between 0 and 100% (Finney, 1971). For the Abate trials this was not the case; all mean mortalities exceeded 70%, consequently the resulting regression line is believed to be overly horizontal, thus underestimating the LD75 and overestimating the LD95. The testing of lower concentrations may have resulted in mortalities lower than 70% and the probit analysis would have been more reliable. For these trials the actual data (Fig. 2) may be a better indication of Abate efficacy than the probit analysis.

The graph of mean percent mortalities (Fig. 2) shows that at concentrations of Abate within the usual range of field rates (50 to 100gAI/ha or 1.0 to 2.0 kg product/ha) mortality of 70% or higher is likely to occur. Ninety five percent mortality may be a more realistic aim when larval densities are high, however very high rates of around 500gAI/ha (10kg product/ha) may be required to achieve this. Laboratory trials of pesticides give an indication of the rates at which larvae are susceptible under controlled conditions. However environmental conditions in wetlands are much more variable and field trials are required to determine the rates needed to achieve control in the natural habitat of the larvae.

The high concentration of Abate required to achieve 95% mortality of *P. nubifer* indicates that some resistance is present in the *P. nubifer* gene pool. Tests comparing the susceptibility of larvae from a population that has not been exposed to Abate, to those from treated urban wetlands are required to investigate resistance. This has not yet been attempted due to the problems experienced in obtaining sufficient numbers of larvae from an untreated area.

The results of Abate laboratory trials undertaken during the 1987/88 research were taken into account, in conjunction with the results from routine field monitoring and the enclosure experiment, when decisions regarding the treatment of lakes were being made. The effectiveness of lake treatments carried out during the 1988/89 spring and summer are discussed in chapter four.

Granular Bti

This formulation of Bti may have some potential as a midge larvicide, although at least 20 to 50kg/ha may need to be used, compared to the 2kg/ha recommended for mosquito control. These results are similar to those found during the 1987/88 trials of liquid Bti (Teknar) in which 30 to 60 litres/ha were required to cause high midge larval mortality, compared to the 2 litres/ha recommended for mosquito control. Trials against mosquitoes in Queensland using the same batch of Bti granules were not as successful as expected (S. Broadbent, pers. comm.). It is therefore suspected that the Bti granules were not fully active, and so the actual potency of these granules may be higher than the results suggest. A field trial of this larvicide using enclosures may be possible as part of the 1989/90 research programme. The wettable powder (from which the granules are formulated) is produced overseas, however Wellcome Australia is not marketing this product commercially at present. Other sources of granular Bti that appear more promising in terms of availability, are being investigated.

Very little work has been carried out elsewhere on the efficacy of Bti against chironomid larvae. A wettable powder formulation of Bti achieved mediocre control of Chiromini and no control of Tanytarsini midges when tested in ponds by Ali (1981). The present strains and formulations are mainly designed for use against mosquitoes. Ali *et al.* (1981) suggest that new strains of Bti may be required for use in midge control.

There is some evidence to suggest that the type of substrate may have some effect upon the activity of the bacterial toxin. The toxin produced by the *Bacillus* has been found to adsorb to sediment particles, interfering with its larvicidal activity. The efficacy of Bti has been found to decrease as sediment particle size decreases and organic matter content increases (Margalit and Bobroglo, 1984), hence clay particles are particularly inhibitive of Bti efficacy (Ramoska *et al.*, 1982). Consequently it would be advisable to take lake sediment type into consideration when making decisions about the use of Bti for midge control. Another consideration is that of the stage of larval development. Since the toxin produced by the *Bacillus* acts upon the gut wall of the larvae, non feeding 4th instar larvae will not be affected and this may result in a delay in the control of adult midge emergence.

Of all the alternatives to Abate Bti is the most environmentally desirable. It is harmless to vertebrates (Biever, 1975) and research by many authors, (e.g. Sinegre *et al.* 1980, Miura *et al.*, 1980 and Ghareb and Hilsenhoff, 1988), has shown no adverse effects on a wide range of non-dipteran aquatic invertebrates and fish.

Perigen 500EC (Liquid Permethrin)
This liquid formulation of permethrin appears to be extremely effective against *P. nubifer* from North Lake and it is likely that other chironomid species will also be susceptible. The results of laboratory trials suggest that between 200 and 250gAI/ha (0.4 to 0.5 litres product/ha) is required to achieve 75% mortality. For practical midge larval control 95% mortality may be more desirable and up to 600gAI/ha (1.2 litres of product/ha) may be required for this. The cost of Perigen 500EC was $100.00 per litre at April 1989 prices.

One problem with the use of synthetic pyrethroids is their toxicity to non-target aquatic fauna. Although these chemicals are generally fairly harmful to fish (Miyamoto, 1976), the degree of toxicity is dependent upon the type of pyrethroid and species tested. Several pyrethroids were shown by Mulla *et al.* (1978) to have only slight toxicity to a variety of fish species. Permethrin was found to be fairly toxic to some species but not others, infering that at larvicidal rates fish kills may result. *Gambusia affinis* had low susceptibility to permethrin. Compared to other synthetic pyrethroids, Perigen is reportedly less toxic to fish because of its chemical structure (cis/trans isomers in a ratio of 25/75). In addition the chemical binds to the sediment, theoretically making it unavailable to fish (S. Broadbent pers.

comm.). However many fish, such as gobies and carp, feed by filtering the sediment and so may be exposed to the chemical in this way.

Many non-target insect and crustacean species have been shown to be highly susceptible to permethrin (Jolly *et al.* 1978; Anderson, 1982). Of the insects those which emerge from the water as adults tend to be most susceptible (Mulla *et al.*, 1979). Mammalian toxicity of pyrethroids is low (Herzberg, 1988), the gap between insect and mammalian toxicity being wider than that found for organophosphates (Elliot and Janes, 1978).

As with other chemical pesticides resistance may arise with long term use, as has been reported for several applications of pyrethroids (Miller, 1988 and Elliot, *et al.* 1978).

Sumilarv 0.5G
Larval mortality, as measured in the beaker experiments, obviously is not a useful indicator of the efficacy of insect growth regulators when considered alone. The trial carried out in aquaria demonstrated that monitoring of adult emergence is an essential aspect of IGR testing. This experiment showed that between 5 and 50 gAI/ha (1.0 to 10.0kg product/ha) effectively inhibited adult emergence. Further laboratory trials during the 1989/90 spring and summer are needed to verify this result. In addition it may be possible to obtain sufficient quantities of Sumilarv to carry out a field trial during the 1989/90 research programme.

In Tanzania Hemingway *et al.* (1985) achieved almost complete inhibition of mosquito emergence in pit latrines using 27.5 and 55 gAI/ha (5.5 to 11.0kg product/ha) of Sumilarv 0.5G. Results of field tests of other IGR's have produced variable results that are highly dependent upon species and type of IGR. In general where control was achieved it usually lasted for two to four weeks, although up to eight weeks control has been recorded (Mulla *et al.* 1976).

Resistance to IGR's is a potential problem with intensive and persistent use (Busvine, 1978) as with all chemical insecticides. Mosquito resistance to IGR's is not uncommon, and cross resistance to IGR's has been recorded for species already resistant to organophosphates (Mian and Mulla, 1982).

Insect growth regulators are considered to be relatively environmentally safe chemicals, although no non-target information is available as yet for Sumilarv. Methoprene (Altosid), like Sumilarv, is a juvenile hormone analogue type IGR (though reportedly 1000 times less potent than Sumilarv) and its non-target toxicity may be similar. Mulla *et al.* (1979) considered that at practical rates methoprene would not be expected to have any direct acute effects on most aquatic organisms. Breud *et al.* (1977) however, found populations of a variety of aquatic invertebrates to be adversely affected by methoprene. The insects whose adults emerge from the lake and zooplankton appear to be particularly sensitive to IGR,s, though population effects are usually short lived (Ali and Stanley, 1981). IGR's in general have little toxicity to fish and amphibians, although bio-accumulation (without toxic effects) is a common observation (Mian and Mulla, 1982). The more extensively tested IGR's such as methoprene and diflubenzuron have extremely low mammalian toxicity (Mian and Mulla, 1982).

Sumilarv is not likely to be available for some time due to toxicity testing currently being completed by Sumitomo Chemical Co. in Japan, which is expected to take about two years. Federal registration for its use in Australia also usually takes about two years and so it may not be commercially available until 1994 (S. Broadbent, pers. comm.).

FIELD TESTING OF THE EFFECTIVENESS OF ABATE USING ENCLOSURES AT NORTH LAKE

INTRODUCTION

A laboratory trial carried out during the 1987/88 midge research programme suggested that Abate caused high mortality of *P. nubifer* at normal field rates (Davis Harrington and Pinder, 1988). However, routine larval sampling revealed that the Abate treatments at North Lake during the 1987/88 spring and summer had variable effectiveness (from zero to 80% reductions in larval density were recorded). Two aspects of this years research were aimed at resolving this anomaly; these were further laboratory trials of Abate, and monitoring of a field Abate treatment at North Lake. The results of the laboratory trials of Abate are discussed in the previous chapter, and the results of the monitoring of the Abate application to North Lake are presented here.

The first treatment of North Lake took place on 15 November 1988, using a fixed wing aircraft to apply Abate 50SG at 1.5kg/ha. To ensure that the effects of the pesticide on larval densities could be separated from any natural variation in densities that may have occurred it was important that areas of the lake remained untreated. To achieve this, areas of the water column and sediment were isolated using plastic enclosures (Fig. 1C). Three of these enclosures were covered prior to treatment (Fig. 1D) to ensure that they did not receive any Abate, and so acted as controls. The remaining three enclosures received pesticide from the aerial application. Larval density and environmental parameters, both within and external to the enclosures, were measured before and after the Abate application.

The "evenness" or "patchiness" of the distribution of granular Abate, and the rate at which it was actually applied, were measured using aluminium trays to catch the Abate as it fell.

METHODS

Measurement of Abate Distribution
The evenness of the aerial Abate application and the influence of tree cover on the rate of application were measured by placing catch trays on and around the lake. Thirty six aluminium baking trays (0.1m deep x $0.25m^2$, Fig. 1B) were used to catch the granular Abate as it was applied. The trays were either floated on the water surface and anchored in place, or placed on the land. Eighteen trays were floated in the littoral zone, six trays were placed in the central area of the lake and the remaining twelve trays were placed on land 3 to 12 metres from the waters edge. The trays in the littoral zone and on the land were placed in pairs, one of each pair was placed in the open and the other tray was placed under nearby tree cover. The granules recovered from each tray were counted and weighed and the equivalent mean application rate per hectare was calculated.

Enclosure Experiment
The six enclosures were cylinders (height=1.5m, diameter = 2m) constructed from clear polyurethane plastic (200mm thick). Heat sealing was used to join the edges of the cylinders and to form hems at the top and bottom of the cylinders. PVC pipes (20mm diameter) were inserted into these hems to form rigid hoops that held the enclosures open.

Aerial treatment of the lake at 1.5kg/ha took place in the late afternoon of 15 November 1988. On the day before treatment the enclosures were placed in 1.0m deep water on the south eastern side of North Lake (Fig. 1C), over a substrate of sand with some organic matter and roots. The tops of the enclosures were tied up above the water surface to metal star pickets, and the bottom edges were weighed down with bricks tied around the PVC pipes. After the relevant samples had been collected three of the enclosures were chosen at random and covered with black plastic sheeting to prevent them from receiving pesticide, and thus acted as controls. The covers were removed immediately after the aerial application had been completed. Larval samples (sediment cores), oxygen and temperature profiles, and water samples were taken on three occasions; one day prior to treatment, and two days and seven days after treatment.

On each sampling occasion three sediment cores were collected from each enclosure using a corer of 9.8cm diameter. The locations of these were determined randomly, and in such a way that an area was cored only once. In addition nine cores were taken from the sediment outside the enclosures on each occasion. The sediment samples were preserved and sorted at a later date using the calcium chloride differential flotation method.

A water sample and an oxygen and temperature profile were taken from each enclosure and from three locations in adjacent open water on each sampling occasion. The water samples were taken back to the laboratory for measurement of pH and conductivity. The nitrogen, phosphorus chlorophyll-a and phaeophytin concentrations of these water samples were determined by the Nutrient Analysis Laboratory of the Centre for Water Research, at the University of Western Australia.

To determine the concentration of temephos in the water column after treatment, water samples were collected in acid-washed bottles for analysis by the Environmental Chemistry Laboratory of the Chemistry Centre of W.A. One sample was taken from each of three evenly spaced locations in the littoral area of the lake (in one metre deep water) prior to treatment in order to establish a baseline level of temephos. One day after treatment three more water samples were collected from the same locations as before, and in addition one sample was taken from each of the enclosures. The water samples were taken at approximately 30cm below the water surface.

RESULTS

Distribution of the Abate
The mean application rate calculated from all 36 trays was 1.17 ± 0.22kg/ha (Table 3). The mean amount that fell on the trays placed on the water

REGION OF LAKE	Number of Trays	ABATE CONCENTRATION(kg/ha)		
		Mean	S.E.	Range
Central	6	1.93	0.58	0.67 - 3.39
Littoral (open + shaded)	18	1.18	0.34	0.04 - 4.88
Land (open + shaded)	12	0.77	0.28	0 - 2.36
Littoral (open)	9	1.17	0.63	0.04 - 4.88
Littoral (shaded)	9	1.19	0.35	0.08 - 2.85
Land (open)	6	0.75	0.39	0 - 2.19
Land (shaded)	6	0.78	0.47	0 - 2.36
OVERALL	36	1.17	0.22	0 - 4.88

Table 3. Mean application rates of Abate 50SG for various regions of North Lake (based on tray catches) recorded during the aerial application on 15 November 1988.

surface (central and littoral regions combined) was equivalent to a rate of 1.37 ± 0.28kg/ha, and the trays placed on land received a mean of 0.77 ± 0.28kg/ha. The mean rates are all below the desired application rate of 1.5kg/ha, and the range of tray catches (0.04 to 4.88kg/ha) show that the Abate was very unevenly distributed on the lake surface and surrounding land. On average the central region of the lake received more Abate per hectare (1.93 ± 0.58kg/ha) than did the littoral regions (1.18 ± 0.34kg/ha). There was very little difference in mean tray catch between the trays in the shade and those in the open for the littoral and land trays (Table 3). The Abate granules that fell on the cover of one control enclosure were collected and weighed. The application, which was found to correspond to a rate of 5.11kg/ha, was much higher than desired application rate. It was assumed that since the enclosures were so close together, this was the rate received by the treated enclosures and adjacent lake area.

Concentration of Temephos in the Water Column

The three water samples collected one day prior to treatment indicated that there was no detectable temephos in the water of North Lake. Analysis of three samples from the same locations one day after treatment showed the mean temephos levels to be 0.07 ± 0.01μg/l. Assuming that the average depth of the entire lake was one metre, this concentration of temephos represents approximately 0.01 ± 0.002kg Abate 50SG/ha. The average concentration of temephos in water samples from the treated enclosures was 0.21 ± 0.03μg/l, this represents 0.04 ± 0.01kg Abate 50SG/ha given that the water in the enclosures was approximately 1.0m deep. By contrast the average concentration in the water samples from the control enclosures was 0.09 ± 0.046μg/l (or 0.02 ± 0.01kg Abate 50SG/ha).

Changes in the Density of Larvae in the Enclosures

P. nubifer accounted for 98% of the total larval density on all three sampling occasions, and so the following analysis is restricted to this species. The changes in *P. nubifer* larval density in the treated and control enclosures and in the area immediately surrounding them are shown in Figure 7. On each sampling occasion samples of sediment were taken from the treated enclosures, control enclosures and from the area immediately surrounding the enclosures (referred to in the figures as "external"). On the day prior to treatment there were no significant differences (d.f.= 2,24, F=1.135) in *P. nubifer* density between the three sample types (Table 4). The actual densities recorded in the treated and control enclosures and from outside the enclosures were 11 493 ± 790/m^2, 12 300 ± 1 720, and 15 584 ± 2 511/m^2 respectively. In the control enclosures there was no statistically significant change in *P. nubifer* density over the nine day monitoring period (d.f.=2,24, F=0.611). By contrast the changes in *P. nubifer* density over time in samples from the treated enclosures and from outside the enclosures were significant (d.f.=1,16, F=17.398 and 9.167 respectively). Two days after treatment the mean *P. nubifer* density had fallen to 6 015 ± 1 242/m^2 in the treated enclosures and 11 946 ± 1 972/m^2 outside the enclosures. The mean *P. nubifer* density in the treated enclosures seven days after treatment was 920 ± 283/m^2, a reduction of 92% from the density before treatment. Outside the enclosures the *P. nubifer* density had fallen by 72.3% to 4 289 ± 868/m^2 after seven days. The larval densities in the three sample

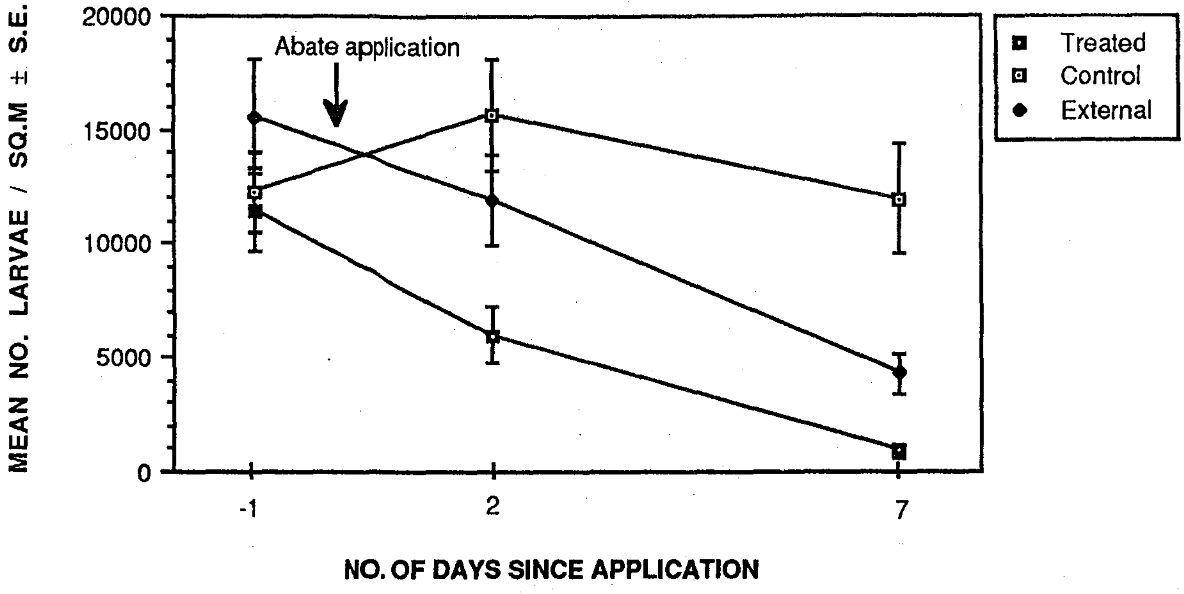


Figure 7. Changes in the density of *Polypedilum nubifer* larvae within the treated and control enclosures and outside the enclosures, during the field testing of Abate at North Lake, November 1988.

Table 4. Results of one-way analyses of variance comparing the density of *Polypedilum nubifer* larvae in the treated and control enclosures and outside the enclosures, on the day prior to the Abate application (day -1), and two and seven days afterwards, and comparing densities between dates for each group.

Between all three groups on each day

Time of sampling	degrees of freedom	F value	Significance
DAY -1	2, 24	1.135	N.S.
DAY 2	2, 24	6.234	**
DAY 7	2, 24	14.675	***

Between pairs of groups on day 2

Groups	degrees of freedom	F value	Significance
Treated vs. control	1, 16	12.38	**
Treated vs. external	1, 16	6.464	*
Control vs. external	1, 16	1.409	N.S.

Between pairs of groups on day 7

Groups	degrees of freedom	F value	Significance
Treated vs. control	1, 16	20.4	***
Treated vs. external	1, 16	13.532	**
Control vs. external	1, 16	9.564	**

Changes in larval density over time (day -1 to day 7)

Group	degrees of freedom	F value	Significance
Treated	2, 24	17.398	***
Control	2, 24	0.611	N.S.
External	2, 24	9.167	**

types (control, treated and external) were significantly different on day seven (Table 4).

Changes in the Density of Larvae in the Whole Lake

As part of the routine larval monitoring programme, larval density was measured each week for three weeks after treatment. Sampling on the day following treatment revealed a 20% increase in total larval density from 4 826 ± 1 735/m^2 (seven days before treatment) to 5 796 ± 1 215/m^2 after treatment. It is suspected that this value also included dead and dying larvae. These larvae could not be separated from live larvae by the sampling techniques employed, and the density is believed to be unrealistically high. A reduction in the density of *P. nubifer* of 4.6% was recorded for the same period. Eight days after treatment the density of *P. nubifer* larvae had risen by 53%, from 2 968 ± 1 335/m^2 seven days before treatment to 4 541 ± 1 834/m^2 eight days after treatment.

Environmental Parameters

An increase in the oxygen concentration (of water outside and within enclosures) of approximately 2-3 mg/l was observed at all depths between one day prior to treatment and two days afterwards (Fig. 8). The resulting oxygen concentrations were between 8.0 and 10.3 mg/l on day 2. Little change was recorded in oxygen profiles between day 2 and day 7, except for a small decrease on the lake bed (Fig. 8). On days -1 and 2 the oxygen levels were similar within the enclosures and externally, however between days 2 and 7 oxygen concentrations increased outside the enclosures at all depths to be 1 mg/l to 2mg/l higher than in the enclosures. In general the oxygen concentration at depth was slightly higher than at the surface (Fig. 9).

Water temperatures were similar in both the treated and control enclosures and in water external to the enclosures (Fig. 9). In general temperatures increased by several degrees between day -1 and day 2 to be approximately 24°C, but then dropped back to 21-22°C. Only on day -1 were there apparent decreases with depth.

The concentration of total phosphorus in all water samples ranged from 256 to 389µg/l on day -1, after which an overall decrease to 220 to 239 µg/l by day 7 was recorded (Fig. 10). The total phosphorus concentration in the treated enclosures was initially lower on day -1 than in the control enclosures or the surrounding water. By day 2 the total phosphorus levels in the treated enclosures had risen to the external and control enclosure concentrations.

Within the enclosures the concentration of chlorophyll-a remained fairly constant at 41 to 53 mg/l between day -1 and day 2, while outside the enclosures an increase from 44 to 71 mg/l was observed (Fig. 10). From day 2 to day 7 the chlorophyll-a concentration increased both within the enclosures and outside the enclosures to between 93 and 107 mg/l. The concentration of phaeophytin changed slightly over time within and outside the enclosures (Fig. 10), however the standard errors indicate that these changes were not significant.

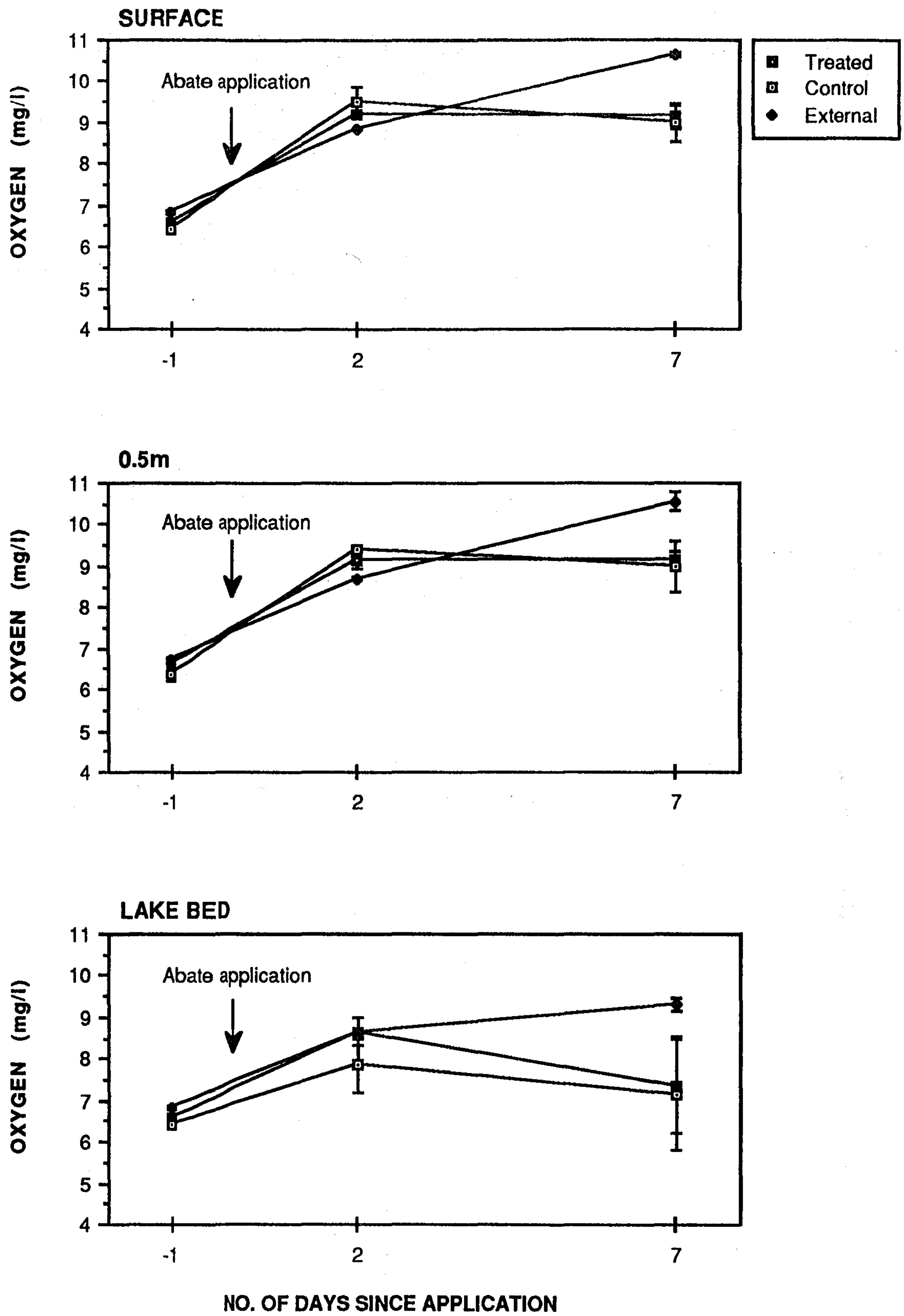


Figure 8. Changes in dissolved oxygen concentration within the treated and control enclosures and outside the enclosures, at the water surface, 0.5m and at the lake bed, during the field testing of Abate at North Lake, November 1988.

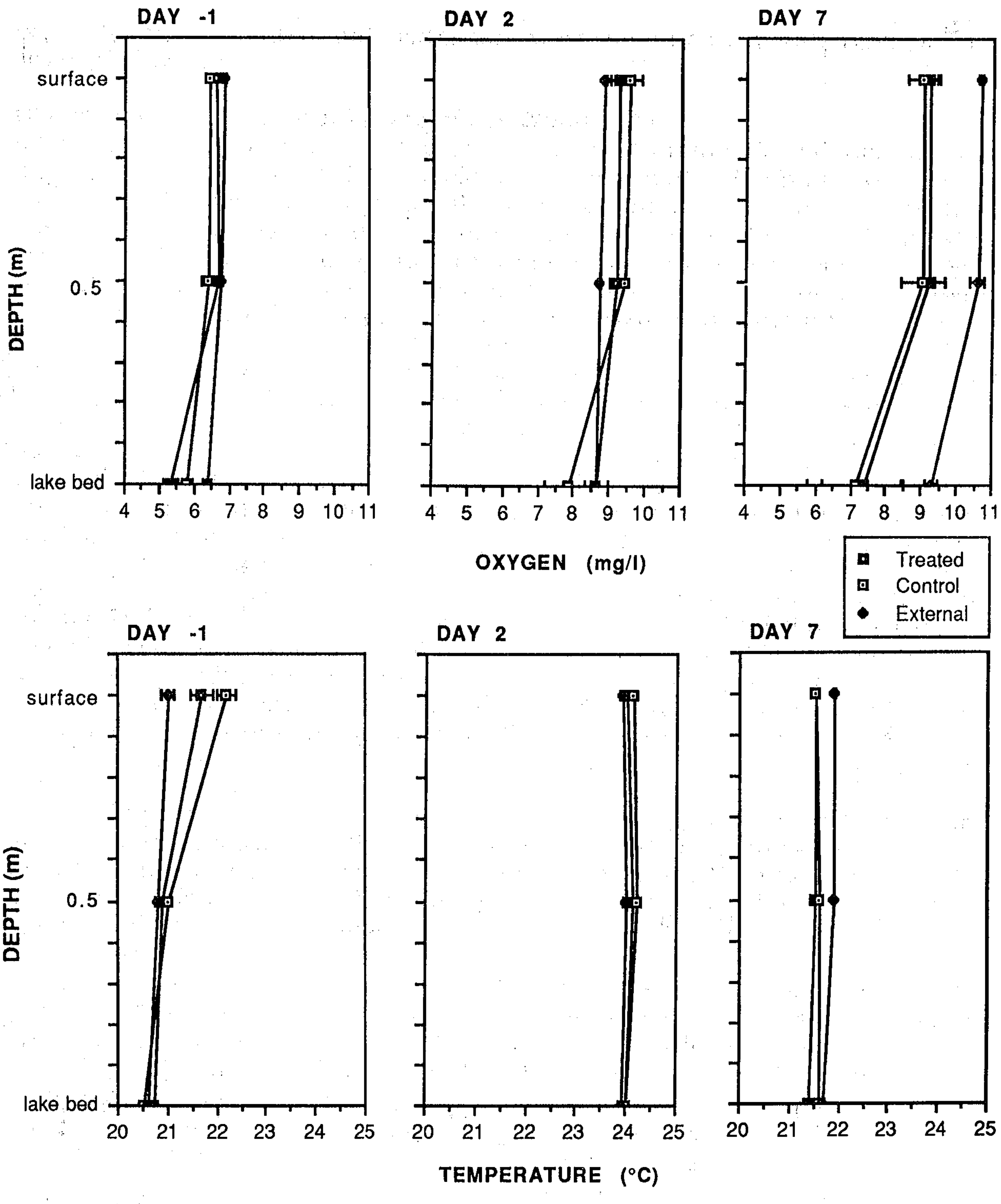


Figure 9. Depth profiles of dissolved oxygen concentration and temperature within the treated and control enclosures and outside the enclosures, on the day prior to the Abate application (day -1) and two and seven days afterwards, during the field testing of Abate at North Lake, November 1988.

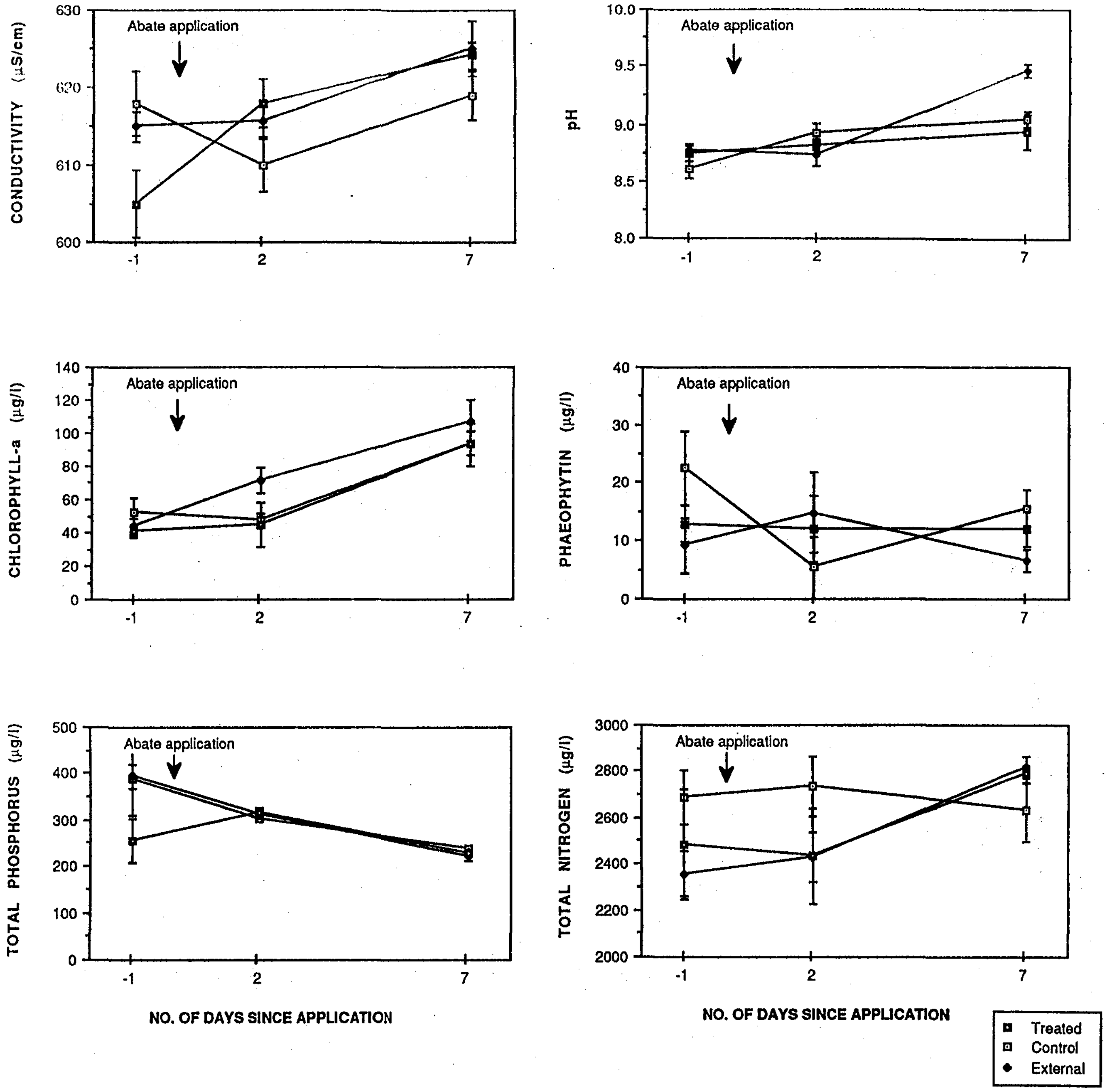


Figure 10. Changes in conductivity, pH, concentrations of chlorophyll-a, phaeophytin, total phosphorus and total nitrogen within the treated and control enclosures and outside the enclosures, during the field testing of Abate at North Lake, November 1988.

The range of conductivity observed was 605 to 625 µS/cm (Fig. 10), with no meaningful trends apparent from the data. Measurements of pH ranged from 8.60 to 8.93 on days -1 and 2. On day 7 the pH of the treated and control enclosures were 8.94 and 9.05 respectively, whereas the pH of the water outside the enclosures was slightly higher at 9.46.

DISCUSSION

Distribution of the Abate

In order to effectively reduce the density of larval midges at North Lake it was imperative that sufficient larvicide reached the littoral regions of the lake, because it is this area that supports the largest larval populations. The tray catches revealed that this region received less (1.37 ± 0.28kg/ha) than the desired application rate of 1.5kg/ha. The central region received 1.93 ± 0.58 kg/ha and the adjacent dry land area also received a substantial amount of insecticide, leaving less to be applied to the littoral area. The tray catch data show that tree cover had very little influence on the rate of Abate applied to a particular region. The amount of Abate that fell on the cover of one control enclosure corresponded to an application rate of 5.11 kg/ha.

By contrast, the concentration of temephos measured in samples of water from the treated enclosures corresponded to an application rate of only 0.041 kg/ha. This difference may have been due to a combination of factors. The granules are sand-based and so sink to the sediment where the bulk of the Abate is slowly released. Thus it is possible that at the time when the water samples were taken (one day after the treatment) all of the Abate had not been released from the granules, and/or the chemical was not evenly distributed throughout the water column. The samples were taken at approximately 30cm below the water surface. At the time this depth was considered appropriate, but samples of water closer to the sediment may have revealed higher concentrations. Alternatively the temephos may have been released rapidly and broken down in the 24 hours since treatment and so was not detectable in high concentrations. The organophosphate pesticides are known to break down rapidly under alkaline conditions (Nicholson, 1984).

Changes in the Density of Larvae in the Enclosures

While the density of *P. nubifer* did not change significantly over time in the control enclosures, a 92% reduction in *P. nubifer* occurred in the treated enclosures. A lesser reduction (73%) occurred immediately outside the enclosures. These results suggest that a proportion of the mortality in the treated enclosures was due to some enclosure effect, or that the Abate was less concentrated (or became diluted), outside the enclosures. The latter explanation is more likely as no significant reduction in larval density occurred in the control enclosures. The amount of Abate that was applied to the enclosures (assumed to be approximately 5.11kg/ha) certainly appears to have been sufficient to cause very high larval mortality.

Changes in the Density of Larvae in the Whole Lake

It appears that the rate of Abate applied to the lake as a whole was not sufficient to cause high larval mortality. Those individuals that survived may have been able to emerge and produce the next generation of larvae, such emergences immediately following treatment are a common observation. Eight days after treatment the density of *P. nubifer* larvae had increased by 53% to over 4 500/m^2. The patchiness of the application, as evidenced by the range of tray catches (Table 3), suggests that some areas of the littoral region received very little Abate. It is possible that such areas became refuges from which larvae were able to recolonize other areas after the breakdown of the Abate. Both early and late instar chironomid larvae may leave an area of sediment and colonize new areas, especially if conditions are unfavourable (Davies, 1976). Also, it is generally recognised that Abate breaks down rapidly in water (Nicholson, 1984), especially in alkaline water such as that of North Lake.

Environmental Parameters

Variations in weather conditions occurred during the period that the enclosures were being monitored. On the day prior to treatment there was little wind and the water was calm, whereas on the second day after treatment the wind was stronger and the water surface choppy. This alone may have been sufficient to explain the increase in oxygen concentration in the water after treatment. As this change occurred in both the enclosures and the water outside the enclosures, and was an increase rather than a decrease, the oxygen concentration of the water probably did not have any major effect on larval mortality. Similarly, changes in water temperature should not influence the analysis, as the same conditions occurred both within the enclosures and outside the enclosures. Also, the observed changes in nutrient and chlorophyll-a concentration, pH and conductivity are within the normal ranges recorded for North Lake. Most of the changes in these parameters were only minor and similar patterns of change occurred both external to, and within, the enclosures. The alkalinity of the water may have caused a more rapid break down of the temephos.

Conclusions

The high rate of Abate received in the vicinity of the enclosures (5.11kg/ha) appears to have been sufficient to significantly reduce *P. nubifer* larval density in this region. By contrast the larval monitoring programme indicated that the mean rate applied to the littoral region of the lake (1.37 ± 0.28 kg/ha) appeared to have very little effect on the overall abundance of *P. nubifer* larvae. The aerial application was found to be extremely patchy, and the area that supported high larval populations (the littoral region) was not specifically targeted and received less Abate than the central regions and the desired application rate. Considering these results the use of fixed-winged aircraft to apply pesticide may need to be reviewed for certain lakes.

LARVAL AND ADULT MONITORING PROGRAMMES

INTRODUCTION

During the second year of research, the abundance and species composition of larval midge populations were monitored by regular sampling programmes at Forrestdale Lake and North Lake. The larval monitoring programmes at Lake Goollelal and Lake Monger were continued by the Wanneroo and Perth City Councils respectively, and samples of larvae from these lakes were identified to species level by the Murdoch research team. The data collected by the larval monitoring programmes were used in making decisions about the timing of larvicidal treatments and also to assess the general effectiveness of Abate treatments at the lakes.

Residents living adjacent to Forrestdale Lake, North Lake and Lake Goollelal continued to collect adult midges from their houses and scored the level of midge nuisance that they had experienced on a fortnightly basis. In addition, quantitative data on adult midge nuisance and species composition were collected using four light traps placed at residences near North Lake.

Data on adult emergence were collected at Forrestdale and North Lakes during the summer months using four submerged emergence traps.

DESCRIPTIONS OF STUDY SITES

Descriptions of Forrestdale Lake, North Lake, Lake Goollelal and Lake Monger, including lake area, depth and lake vegetation are given in the previous year's report (Davis, Harrington and Pinder, 1988).

PESTICIDE APPLICATION HISTORIES

The histories of the application of Abate pesticide to the four lakes under study were given in our previous report. Table 5 brings this information up to date, by giving details of Abate treatments during the 1987/88 and 1988/98 summers. During the 1987/88 summer North Lake received Abate treatments on four occasions, whereas none of the other three lakes was treated. By contrast, all four lakes were treated with Abate during the 1988/89 summer, with Forrestdale Lake receiving one treatment, North Lake five treatments, Lake Goollelal one treatment and Lake Monger two treatments. In addition, adult fogging was used extensively at Lake Monger.

METHODS

General

Two lakes, Forrestdale Lake and North Lake, were monitored by the Murdoch University study team. At these lakes the lake substrates were sampled for chironomid larvae using a corer and the water column was sampled with a plankton net. Sampling frequency was monthly during winter (May to September 1988) except that sampling did not begin at

Table 5. Pesticide application histories for Forrestdale Lake, North Lake, Lake Goollelal and Lake Monger, 1987/88 and 1988/89. This table brings up to date the information given in our previous report.

LAKE	DATE	AREA TREATED (ha)	RATE APPLIED (kg/ha)	ABATE FORMULATION	COST OF ABATE	APPLICATION METHOD	COST OF APPLICATION	EFFECTIVENESS OF APPLICATION
FORRESTDALE LAKE	1987/88	-	-	-	-	-	-	-
	21 FEB 89	200	2.5	50SG	$6,750	Helicopter	$3,437	Very effective
NORTH LAKE	21 DEC 87	25	1.5	50SG	$456	Fixed wing plane	$194	Good
	18 JAN 88	25	1.5	50SG	$456	Fixed wing plane	$194	Satisfactory
	8 FEB 88	25	1.5	50SG	$456	Fixed wing plane	$194	Good
	14 MAR 88	25	1.5	50SG	$456	Fixed wing plane	$194	Good
	15 NOV 88	25	1.5	50SG	$456	Fixed wing plane	$350	Satisfactory
	20 DEC 88	25	2.0	50SG	$608	Fixed wing plane	$350	Satisfactory
	19 JAN 89	5	25.0	10SG	$875	Boat	-	Satisfactory
	3 FEB 89	5	25.0	10SG	$875	Boat	-	Satisfactory
	23 MAR 89	5	25.0	10SG	$875	Boat	-	Satisfactory
LAKE GOOLLELAL	1987/88	-	-	-	-	-	-	-
	10-12 DEC 88	75	2.4	50SG	$2,257	Fixed wing plane	$1,616	Extremely good
LAKE MONGER	1987/88	-	-	-	-	-	-	-
	10-11 JAN 89	65	0.46 litres	100E	$623	Boat	$578	Poor
	9-10 MAR 89	65	2.0	10SG	$768	Boat	$577	Variable but poor

Forrestdale Lake until July 1988. During the summer months (September 1988 to March 1989) larval sampling was undertaken on a fortnightly basis except at North Lake during November 1988, when sampling was carried out every week. Environmental parameters including water depth, water and air temperature were recorded on each sampling occasion. Water samples were collected for the analysis of pH, conductivity, total phosphorus, total nitrogen and chlorophyll-a.

The larval sampling programmes being undertaken by the Wanneroo and Perth City Councils at Lake Goollelal and Lake Monger, respectively, were continued as in previous years. The councils provided samples of their collections to the Murdoch research team for identification.

Estimates of adult midge emergence were made at Forrestdale Lake and North Lake using submerged emergence traps. This information was collected with the aim of determining the relationship between larval abundance and daily emergence of adult midges.

A quantitative assessment of the nuisance caused by adult midges was made at North Lake using four light traps placed at residences adjacent to the lake. The light traps were monitored over a period of nine weeks and were run for three nights each week. In addition a small number of residents at North Lake, Forrestdale Lake and Lake Goollelal were asked to comment on the extent of the nuisance caused by adult midges each fortnight and to collect adult midges from their houses with an aspirator for later species identification by the Murdoch research team.

Meteorological data for Perth were obtained from the Bureau of Meteorology. Air temperature, rainfall and wind strength and direction are shown in Figure 21.

The methods used in the field monitoring programme are outlined below.

Larval Sampling
This section briefly describes the methods used in the larval monitoring programme that was undertaken from early March 1988 until late March 1989. The methods that were used were the same as those described in our previous report (Davis, Harrington and Pinder, 1988) and that report should be consulted for detailed information.

Forrestdale Lake

Quantitative samples of the lake substrate were collected from Forrestdale Lake every month during winter (July and August 1988) and fortnightly during spring and summer (September 1988 to March 1989). Only the northern half of the lake was sampled because of its large size. On each sampling occasion twenty cores (9.8 cm diameter) were taken from the lake sediment and these were located using random number pairs. An additional six core samples were taken from the submerged *Typha* reeds around the perimeter of the lake. A plankton net (34 cm diameter, 76 μm mesh size) was used to sample the water column for planktonic 1st instar larvae. Two plankton tows each covering a distance of four metres, were made on each sampling occasion between September 1988 and March 1989.

North Lake

Larval sampling at North Lake was carried out on a monthly basis during winter (March to late August 1988) and a fortnightly basis during spring and summer (September 1988 to March 1989). During November 1988 the lake was treated with Abate and weekly sampling was carried out for a period of four weeks after the application. On each sampling occasion 20 cores (9.8 cm diameter) were taken from the littoral zone, each located using a random degree-coordinate. Ten cores were taken from the deeper middle section of the lake using a long-handled corer (10.9 cm diameter). The water column was sampled for planktonic larvae using a plankton net. Two plankton tows were made on each sampling occasion between September 1988 and March 1989. The net used was the same as that described for Forrestdale Lake.

Sorting by Differential Flotation

Core samples from Forrestdale and North Lakes were placed in plastic bags for storage prior to sorting in the laboratory. If lengthy storage was necessary then 100% ethanol was added to the samples as a preservative. Larvae were separated from the core substrate material by differential flotation using saturated calcium chloride solution. The sorting and identification methods used are described in detail in the previous report.

The effectiveness of the calcium chloride flotation method for removing midge larvae from the substrate material was determined by the following procedure. Twenty littoral cores from North Lake were sorted just using the flotation method and the sediments were sorted again by eye. The sediment was sieved through four sieves (mesh sizes 2mm, 500µm, 250µm and 180µm) and examined under a dissecting microscope. For seven of the cores, all larvae had been found using the flotation method and on average (20 cores) 70.46% ± 7.20 of the larvae were found from each core.

The calcium chloride flotation method of sorting substrate samples does not provide absolute counts of the abundance of midge larvae. However, the method is quicker than other comparable methods and finds a high proportion of the larvae occurring in each core. In any monitoring programme it is important to use the same field and laboratory methods throughout the programme and a consistent amount of effort should be put into sorting samples from different dates. Once the methods to be used have been determined, several collections will need to be made during the peak nuisance period for midges. It should be possible to determine the "threshold level"; the number of midge larvae per square metre at which adult midges cause a nuisance to nearby residents. Even though the threshold level being used for the monitoring programme may not correspond to the absolute number of larvae (because some larvae will have been missed during sorting), it is the **relative** change in abundances that are important.

Lake Goollelal

Lake Goollelal was sampled every three weeks between July 1988 and late January 1989 by the Wanneroo City Council. After treatment of the lake with Abate in early December 1988 the lake was sampled on a weekly basis for a period of three weeks. The same ten sites were sampled on each occasion by using an 800 ml scoop attached to a long handle. Larvae were sorted from the substrate by sieving (mesh size 1.25 mm). Samples of larvae from each site were identified by the Murdoch research team.

Lake Monger

Lake Monger was sampled approximately every three weeks from March 1988 to January 1989 by the Perth City Council. The substrate at each of the eight sites was sampled using a bucket thrown from a boat. The samples were sorted in the field by sieving (mesh size 1.2 mm). Larvae from the samples were identified by the Murdoch research team.

Perth City Council has recently changed its sampling method from using a bucket sampler to using a corer. However, results of this single collection (15 March 1989) are not included here because of the difficulty of relating the two methods.

Larval Population Dynamics
Information on the life history of *P. nubifer* at North Lake was collected over a four week period during November 1988. Field sampling was carried out each week for four weeks from 2 November 1988 and the head capsules widths of approximately 100 larvae (chosen at random) from each sampling occasion were measured. These data were intended to complement the data collected during the previous year of study to further address the question of sychrony in the emergence of adult chironomids. By spacing the sampling dates more closely (weekly) rather than the usual fortnightly sampling, it was hoped that any mass development of cohorts within the population of *P. nubifer* would be apparent. The methods used were the same as those described in the previous report.

Adult Emergence
During the second year of the study emergence traps were used at Forrestdale and North Lakes to gain an idea of the relationship between larval abundance and emergence rates of adult midges. Cone-shaped emergence traps were constructed from a wire frame covered with fine-meshed terylene curtain fabric (Fig. 11A). The base of the cone (in contact with the lake substrate) was 34 cm in diameter. A glass jar was attached to the top of the trap funnel with its opening facing downwards. The trap was held beneath the water and in contact with the substrate by weights tied on to the base of the trap frame. When submerged the upper half of the collecting jar contained air; the air-water interface thus created trapping midges in the jar. A table-tennis ball attached to the trap served as a position-marker for each submerged trap.

Four emergence traps were placed at each of the two lakes. Emergence rates were calculated from the number of midges caught in each trap over

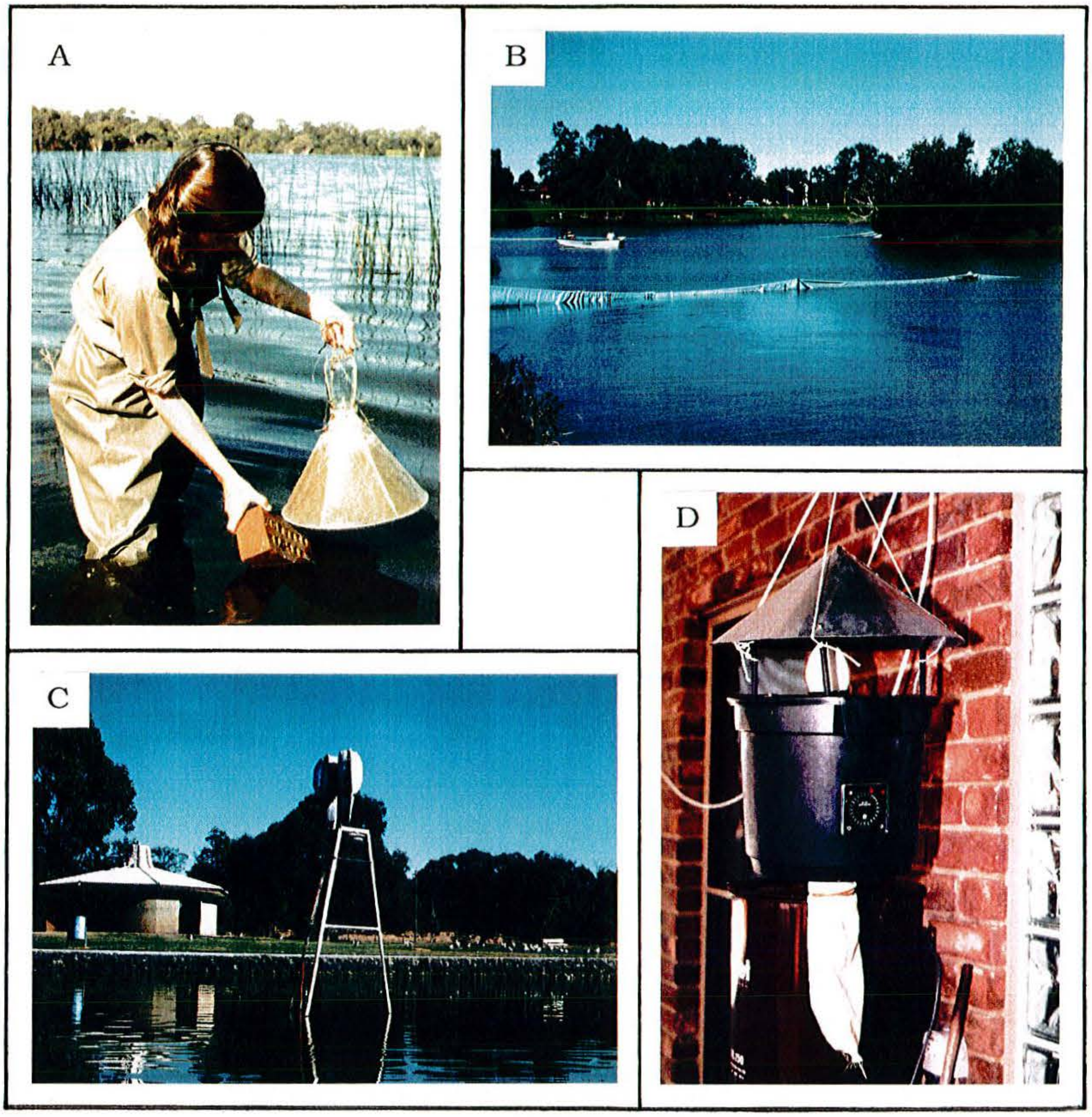


Figure 11. Photographs showing equipment used in field research.
A: Emergence trap with attached weights, B: Jackadder Lake, showing the control enclosure, C: Bibra Lake light trap, D: Light trap placed at residences near North Lake.

one 24 hour period each fortnight. The traps were run during the period between September 1988 and January 1989 at Forrestdale Lake and between September 1988 and February 1989 at North Lake. Several traps were lost or destroyed due to vandalism, but where possible these were replaced to maintain a total of four traps at each lake.

Adult Nuisance Assessment
An assessment of the numbers of adult midges reaching residences adjacent to North Lake was made using four light traps. The light traps were designed by one of the Murdoch team (Adrian Pinder) and constructed by the Murdoch University workshop. The design is similar to the design described by Upton and Norris (1980).

Briefly, the design uses ultra violet light from a mercury vapour lamp to attract the adult midges and does not include a fan. Figure 11D shows the light trap consisting of a plastic plant pot (30 cm diameter) with a metal funnel insert. Above the funnel a 100 W mercury vapour lamp is supported by four brackets. The lamp is sheltered by a metal cowl lid. The funnel opens into a short piece of PVC pipe to which is attached a removable cloth bag. Each light trap is fitted with an automatic timer switch. When the light is turned on, adult midges (and some other flying insects) are attracted to the UV light. They are stunned on impact with the light and fall into the funnel and through to the catch bag beneath.

The four light traps were hung at houses adjacent to North Lake to reduce the possibility of vandalism and to provide a power source. The four traps were placed at two pairs of houses; two houses on the west side of the lake (Trap 1: 23 DuMaurier Road and Trap 2: 165 Progress Drive, Kardinya) and two houses on the north side (Trap 3: 2 Stone Court and Trap 4: 41 Windelya Road, Kardinya). In this way, obvious house-to-house variations in midge nuisance levels would be apparent.

All four light traps were hung at positions convenient to the residents concerned. In each case this was beneath an external pergola. The traps were run on three nights per week for a period of nine weeks (13 December 1988 to 23 February 1989). The light was switched on automatically at 7.00 pm and off at 4.30 am. The catch bags were collected each morning at 9.00 am. The adult midges from each trap were counted (often by subsampling) and identified in the laboratory.

At Forrestdale Lake, North Lake and Lake Goollelal the assessment of adult nuisance continued using the methods described in the previous report. Local council staff coordinated the fortnightly collection of adult midges by residents living near the lakes. Approximately six residents at each lake were asked to collect midges from their houses using the aspirator provided and to preserve them in vials of ethanol. In addition, the resident was given a nuisance score sheet and asked to assess the degree of nuisance caused by midges during that fortnight as "low", "moderate", "high" or "extreme".

The resulting samples of midges were identified by the Murdoch research team and the information recorded on the score sheets was summarized as a mean nuisance score for each fortnight.

Environmental Parameters
Information on water depth, water and air temperature and water quality was collected each fortnight from Forrestdale Lake and North Lake.

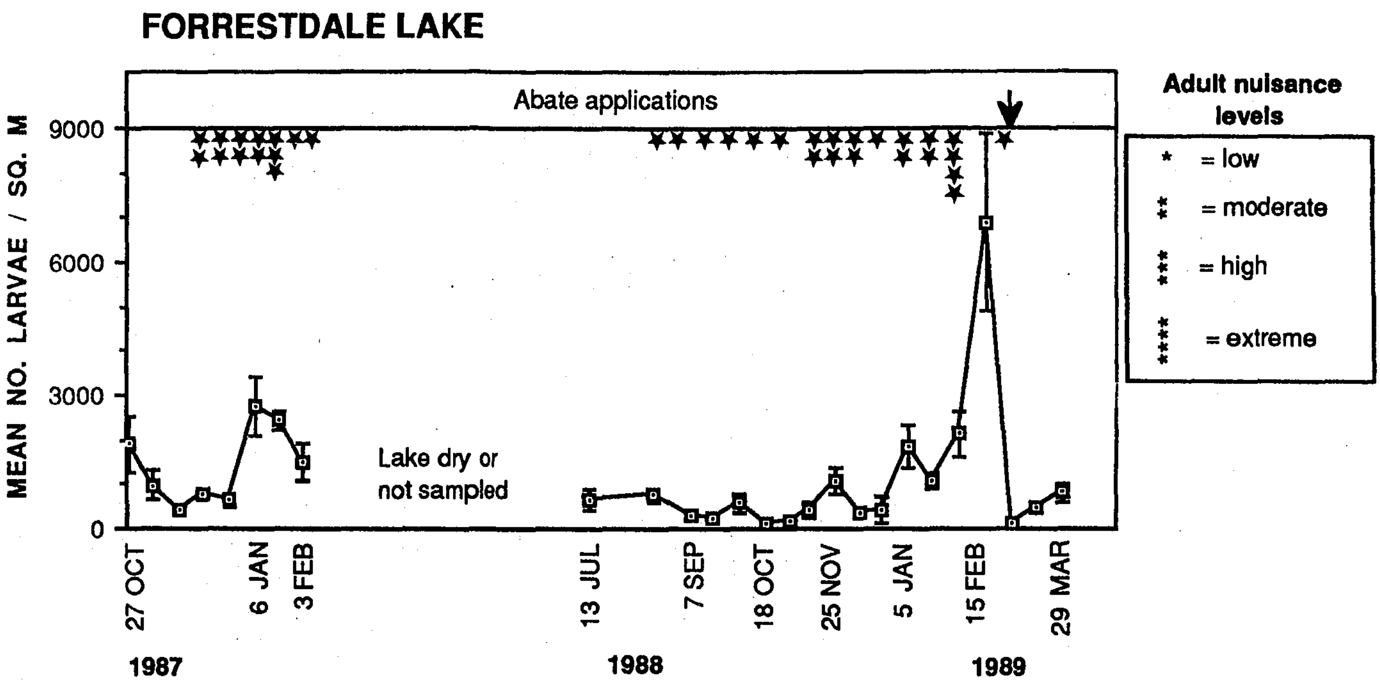
Lake depths were read from staff gauges and water and air temperatures were recorded by maximum-minimum thermometers at each lake. For the analyses of water quality, five small water samples were collected at evenly-distributed points around each lake. These were mixed together in the laboratory and pH and conductivity were measured. A sample of water was filtered for chlorophyll-a analysis and samples of water (100 ml) were frozen for analyses of total nitrogen and total phosphorus. Water quality analyses were carried out by the Centre for Water Research Nutrient Laboratory at the University of Western Australia and by Derek Plaskett and Mark Lund at Murdoch University (some chlorophyll-a determinations). Data for air temperature, rainfall and wind strength and direction for Perth City were obtained from the Bureau of Meteorology.

RESULTS

Larval and Adult Monitoring Programmes
Changes in the larval densities for the two lakes sampled by the Murdoch study team (Forrestdale and North Lakes) over the entire study period, late October 1987 to late March 1989, are shown in Fig. 12. The levels of adult nuisance experienced by local residents are given at the top of each graph to indicate the relationship between these scores and the corresponding larval abundances. The dates on which the lakes were treated with Abate are also indicated. Forrestdale Lake was not treated during the 1987/88 summer and only once during the 1988/89 summer (21 February, 1989). North Lake received four applications of Abate during the 1987/88 summer (21 December 1987, 18 January, 8 February and 14 March 1988) and five applications during 1988/89 (15 November and 20 December 1988, and 19 January, 3 February and 23 March 1989).

The species composition of larval and adult populations sampled at Forrestdale Lake, North Lake and Lake Goollelal are given in Figures 13 to 15. Separate plots of larval densities for the lake (open water), the *Typha* reeds and for the plankton tows are given for Forrestdale Lake (Fig. 13). Data for all the samples taken from the open water have been combined because figures for the previous year indicated that the the larval collections made in the littoral and central regions of Forrestdale Lake were not significantly different. Larval densities for North Lake are presented separately for the littoral and middle regions of the lake (Fig. 14). Species composition at Lake Monger is presented for larval populations only (Fig. 16).

The pattern of change in larval density that occurred at Forrestdale Lake during the 1988/89 summer was similar to that which occurred during the 1987/88 summer. In general larval densities were less than 2 000 larvae/m^2, but a major peak in abundance occurred in both years. The peak was higher in 1988/89, with densities reaching 6 905 ± 1 962 larvae/m^2 compared to 2 783 ± 666 larvae/m^2 in 1987/88. Larval densities at North



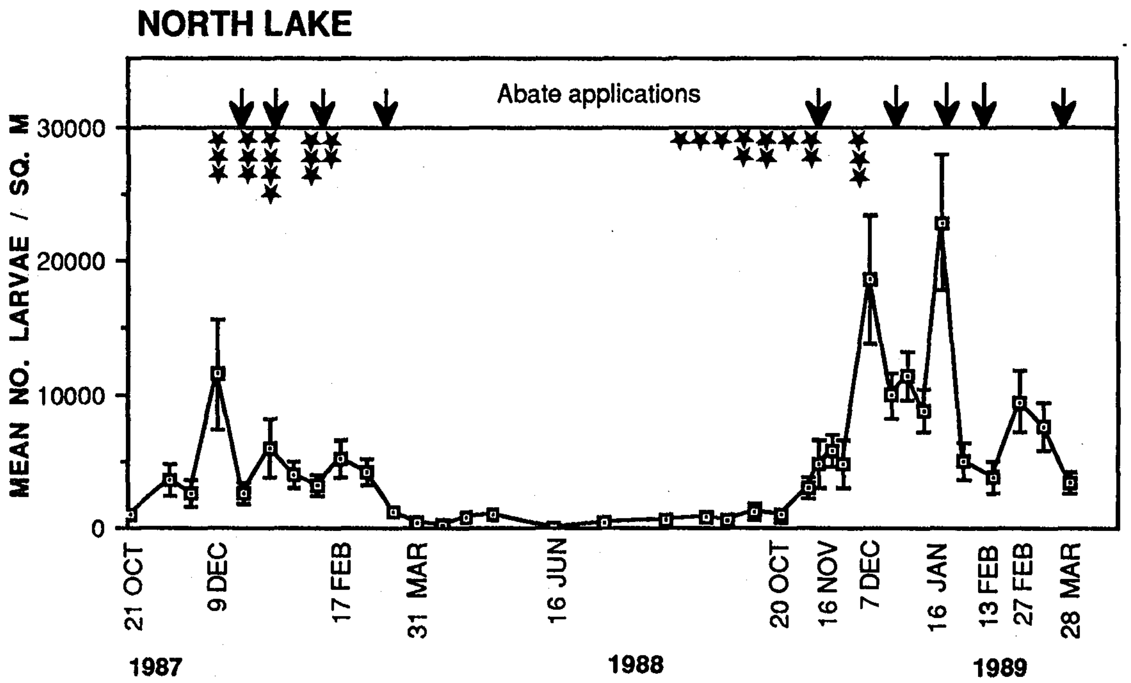


Figure 12. Changes in the mean number of chironomid larvae per square metre at Forrestdale and North Lakes, October 1987 to March 1989. Data for Forrestdale Lake are for the entire open water region, whereas North Lake data represent the littoral region only. Means and standard errors are shown. Adult nuisance levels and the dates on which Abate was applied to the lakes are indicated.

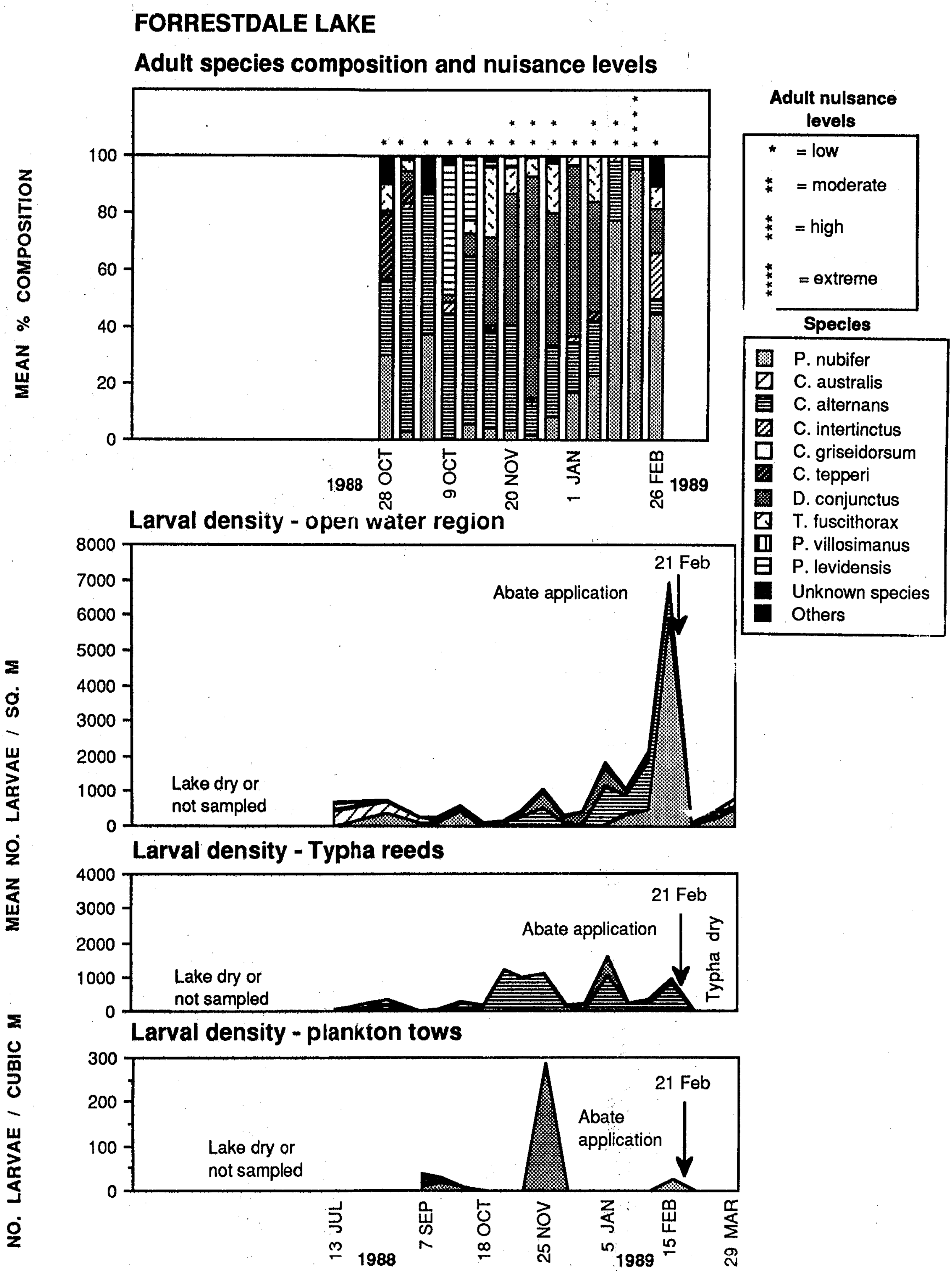


Figure 13. Changes in species composition and nuisance levels for adult chironomids, cumulative numbers of larvae per square metre for the open water region and the *Typha* reeds and cumulative numbers per cubic metre for plankton tows at Forrestdale Lake, July 1988 to March 1989. Collections of planktonic larvae began in September and collections of adults began in October 1988. Note the different Y-axis scales.

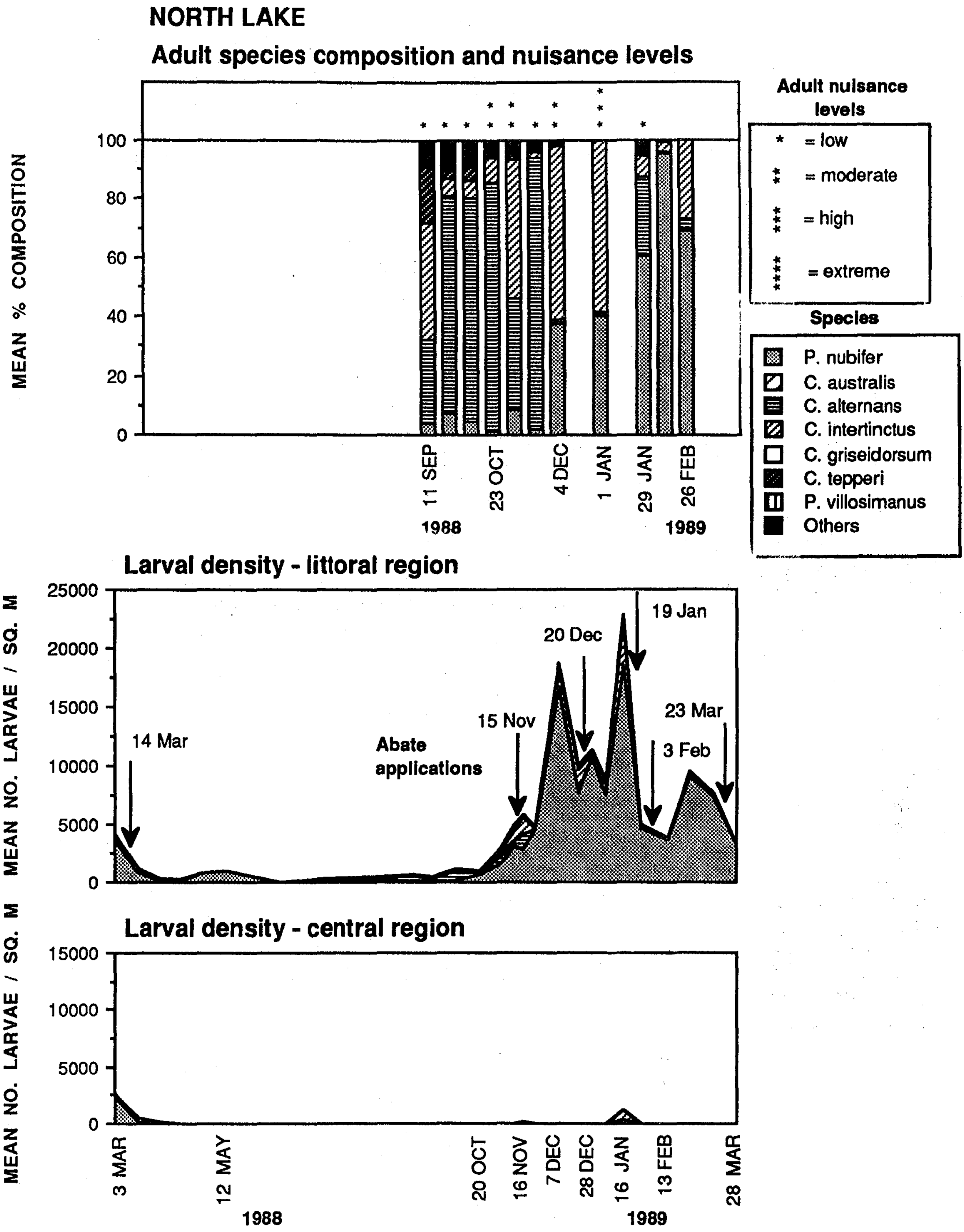


Figure 14. Changes in species composition (aspirator collections) and nuisance levels for adult chironomids and cumulative numbers of larvae per square metre for the littoral and central regions of North Lake, March 1988 to March 1989. Collections of adults began in September 1988.

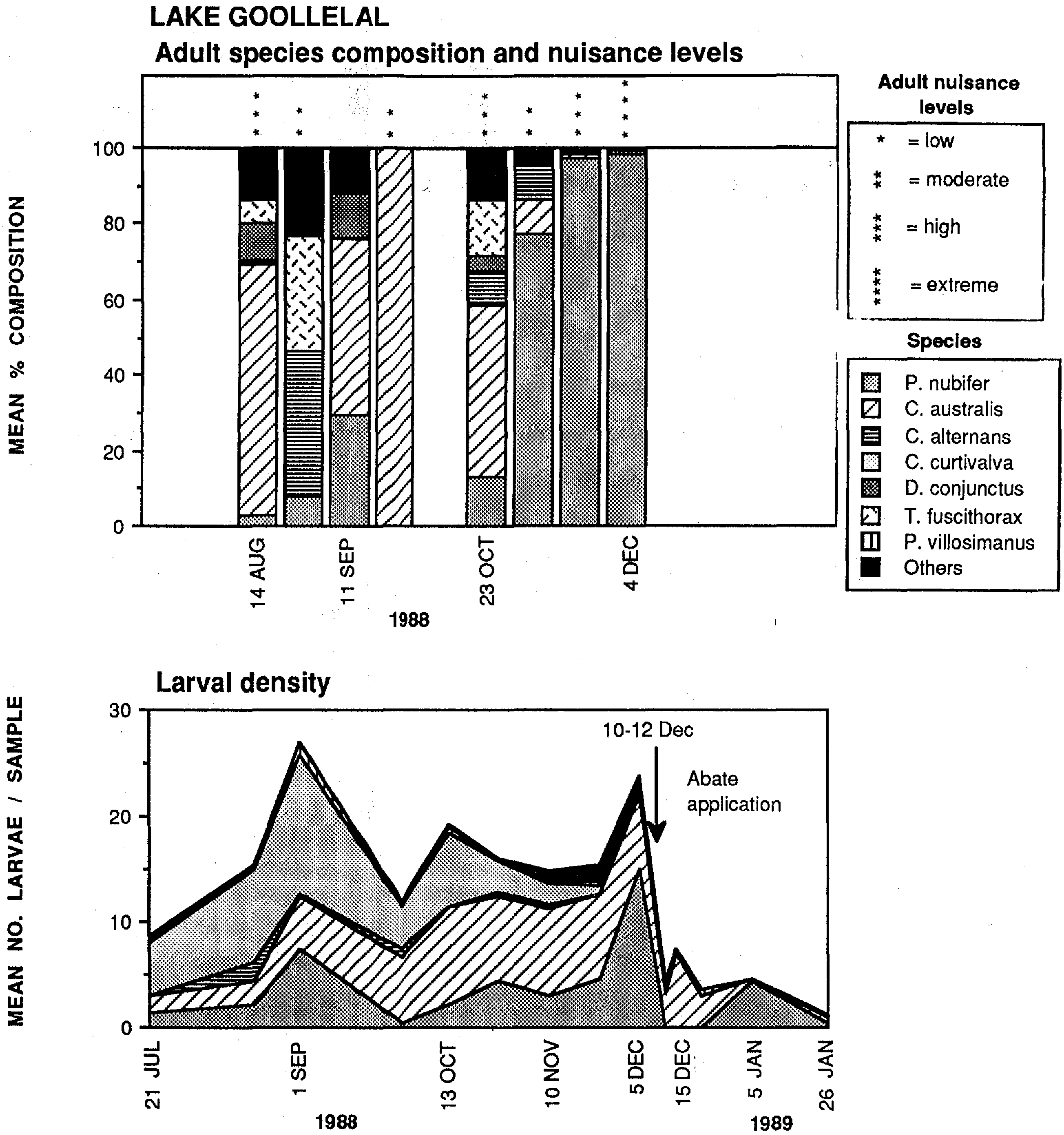


Figure 15. Changes in species composition and nuisance leveas for adult chironomids and cumulative numbers of larvae per sample for Lake Goollelal, July 1988 to January 1989. Collections of adults were made from August to December 1988.

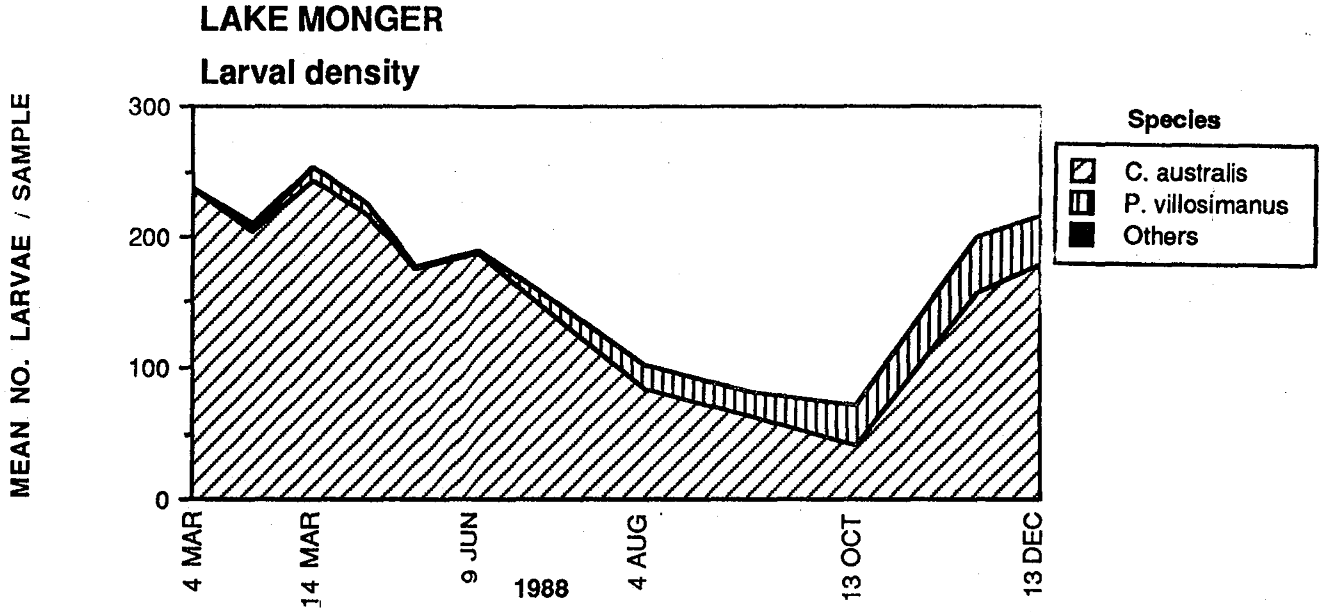


Figure 16. Cumulative numbers of chironomid larvae per sample for Lake Monger, March to December 1988.

Lake during the 1988/89 summer were generally higher than during the 1987/88 summer. During the period 20 October 1987 to 31 March 1988 larval densities exceeded 4 000 larvae/m^2 on four of the twelve sampling occasions. During the corresponding period in 1988/89, larval densities exceeded 4 000 larvae/m^2 on eleven of the fifteen sampling occasions.

The patterns of change and the peaks of larval density differed at all of the lakes studied, as did the species composition of the larval populations (Figs 13 to 16). Adult species composition and nuisance levels also differed between lakes.

Larval densities were lower at Forrestdale Lake than at North Lake during the summer period, September 1988 to March 1989. However, the large size and shallow nature of Forrestdale Lake mean that the overall production of adult midges from this lake is likely to be much higher for a given larval density than for the same larval density at North Lake. Adult nuisance levels in the vicinities of the two lakes were similar, reflecting the total production of adult midges.

Forrestdale Lake dried out in February 1988, but sampling recommenced on 13 July 1988, some months after the lake began to fill with water. Larval densities in the lake exceeded 2 000 larvae/m^2 on only two sampling occasions (1 February and 15 February 1989). Following the application of Abate on 21 February 1989 at 2.5 kg/hectare there was a 98.5% reduction in larval density (6 905 ±1 962 larvae/m^2 on 15 February to 102 ±36 larvae/m^2 on 1 March 1989). Larval densities in the *Typha* reeds encircling the lake were generally lower than those in the open water with densities exceeding 1 000 larvae/m^2 on only three sampling occasions (31 October and 25 November 1988 and 5 January 1989). Plankton tows of the water column collected chironomid larvae on nine of 16 sampling occasions. However, high numbers of larvae were found on only one occasion (25 November 1988, 289 *D. conjunctus* larvae/m^3). Levels of adult nuisance were recorded as low to moderate from September 1988 until the beginning of February 1989. During the first half of February residents reported the nuisance levels as extreme and an Abate treatment was carried out at the request of the majority of Forrestdale residents. Immediately after the lake treatment low nuisance levels were noted.

Larval densities in the littoral region of North Lake were very high compared to those at Forrestdale Lake. Larval abundance remained low (less than 1 000 larvae/m^2) between 31 March 1988 and 21 September 1988 and began to increase almost constantly until 7 December 1988, when a peak of 18 605 ± 4 810 larvae/m^2 was reached. Two further distinct peaks in larval density occurred during the summer (16 January and 27 February 1989 when 22 828 ± 5 116 larvae/m^2 and 9 459 ± 2 344 larvae/m^2 respectively, were recorded). Larval densities in the central region of North Lake were very low (less than 400 larvae/m^2) except for the first sampling occasion on 3 March 1989 (2 530 ± 2 208 larvae/m^2). Plankton tows of the water column collected larvae on only three occasions (4.1 *D. conjunctus* larvae/m^3 on 6 January, 4.1 *P. nubifer* larvae/m^3 on 27 January and 8.3 *P. nubifer* larvae/m^3 on 27 February 1989). Adult nuisance levels were scored by local residents as low to moderate except for the period between late December

1988 to mid January 1989, when levels of nuisance were scored as high.

The application of Abate to North Lake varied markedly in effectiveness between March 1988 and March 1989. Larval numbers fell by 70% (from 4 178 ± 997 larvae/m^2 to 1 235 ± 261 larvae/m^2) three days after the final Abate treatment (14 March 1988, 1.5 kg/hectare, aerial application) during the 1987/88 summer. The first Abate application during the 1988/89 summer was carried out on 15 November 1988 (1.5 kg/hectare, aerial application) and a 20% increase in larval numbers (4 826 ± 1 735 larvae/m^2 to 5 796 ± 1 215 larvae/m^2) was recorded one day after the treatment. However, large numbers of dead and dying larvae were observed floating on the surface of the lake on the sampling occasion the day after the treatment and their presence in samples may have influenced the result. Larval numbers increased by 14% (9 949 ± 1 731 larvae/m^2 to 11 374 ± 1 759 larvae/m^2) eight days after the second Abate application (2.0 kg/hectare, aerial application). The third, fourth and fifth Abate treatments were applied by boat to the littoral area of the lake (Fig. 1E) at approximately 25 kg/hectare of Abate 10SG (equivalent to 5 kg/hectare Abate 50SG). Reductions in larval numbers of 78% (22 828 ± 5 116 larvae/m^2 to 4 981 ± 1 415 larvae/m^2), 22% (4 981 ± 1 415 larvae/m^2 to 3 847 ± 1 169 larvae/m^2) and 55% (7 611 ± 1 790 larvae/m^2 to 3 414 ± 722 larvae/m^2) occurred in the littoral region eight days, ten days and five days respectively, after each Abate application by boat.

The species composition of larval populations from the open water region at Forrestdale Lake changed markedly over the period July 1988 to March 1989. *C. australis* was the dominant species in July, but became less important during August, September and October, when *P. nubifer* increased in abundance. From late October, *C. alternans* and *D. conjunctus* were dominant with either species predominating. In February, *P. nubifer* once again dominated, with *P. villosimanus* also being important. In the *Typha* reeds *C. alternans* was the dominant species throughout the sampling period. Collections of adult midges made in the suburb of Forrestdale were seldom dominated by one species, although high numbers of *C. alternans* adults occurred for much of the period between August and November 1988. *D. conjunctus* became important between October 1988 and January 1989, with *P. nubifer* being clearly dominant during February. Adult nuisance levels were scored as low or moderate from August 1988 until February 1989, except for a two week period in February when *P. nubifer* predominated and levels were recorded as extreme.

At North Lake in the littoral region *P. nubifer* was by far the major larval species, dominating from March until July 1988 and returning in importance from October 1988 until March 1989. *C. alternans* replaced *P. nubifer* as the dominant larval species from July until October 1988. The central region of North Lake was dominated by *P. nubifer* and *C. australis* but numbers were very low for almost the entire study period. Abate applications during the study period did not appear to influence larval species composition. Adult midge collections were dominated by *C. alternans* and *C. intertinctus* between September 1988 and January 1989, with *P. nubifer* becoming more important from December 1988 until reaching dominance in late January and February 1989. Adult nuisance levels were scored by residents as low to moderate between September and late February except for the period from late December 1988 to mid January 1989, when *C. intertinctus* and *P. nubifer* were the main species present and levels of nuisance were recorded as high.

At Lake Goollelal larval species composition was dominated by three species, *C. curtivalva, C. australis* and *P. nubifer. C. curtivalva* dominated from July to September 1988, with *C. australis* becoming more important at the end of September and *P. nubifer* peaking in dominance in early September, early December 1988 and early January 1989. A reduction in larval density occurred after the aerial Abate treatment (Fig. 1F) on 10-12 December 1988, with *P. nubifer* disappearing from larval collections made between 12 December 1988 and 5 January 1989. Collections of adults were dominated by *C. australis* from August to October, and *P. nubifer* was most commonly collected in November and early December 1988. Adult nuisance levels were recorded by residents as moderate to high between mid August and late November 1988. During early December levels were scored as extreme and *P. nubifer* dominated the collections.

C. australis was the dominant larval species in Lake Monger throughout the study period, March to mid December 1988, although *P. nubifer* was considered to be the major species of adult midge causing nuisance (A. Van Leeuwen, pers. comm.). Recent changes to the sampling programme being undertaken by Perth City Council include taking samples from the littoral region, where high densities of *P. nubifer* have been found to occur. Larval density results presented in Fig. 16 reflect the sampling programme being used up until January 1989, where most samples were taken from relatively deep water.

Larval Population Dynamics

Head capsule width was measured for 398 *P. nubifer* larvae collected at North Lake during four weekly sampling occasions in November 1988. Results are presented as width-frequency graphs in Fig. 17. Three size classes are apparent, with the majority of larvae having head capsule widths of 0.30 - 0.38 mm and 0.18 - 0.26 mm.

The width-frequency graphs for head capsules of *P. nubifer* from North Lake in November 1988 suggest the presence of two distinct groups of larvae. In addition there were a few smaller larvae. These groups can be interpreted as larval instars (Oliver, 1971) and are taken to represent 3rd and 4th instar larvae. Second instar larvae were not well represented, probably because they were too small to be detected by the calcium chloride sorting method used. The 1st instar larvae of most species of chironomids are planktonic (Oliver, 1971) and would not have been sampled in cores taken from the substrate.

Relatively large numbers of 4th instar larvae were present on each of the weekly sampling occasions. This may be the consequence of an unequal development rate, where more than half the life of some chironomids is spent in the 4th instar (Butler, 1987). The Abate application at North Lake on 15 November 1988 did not appear to affect the structure of the *P. nubifer* population.

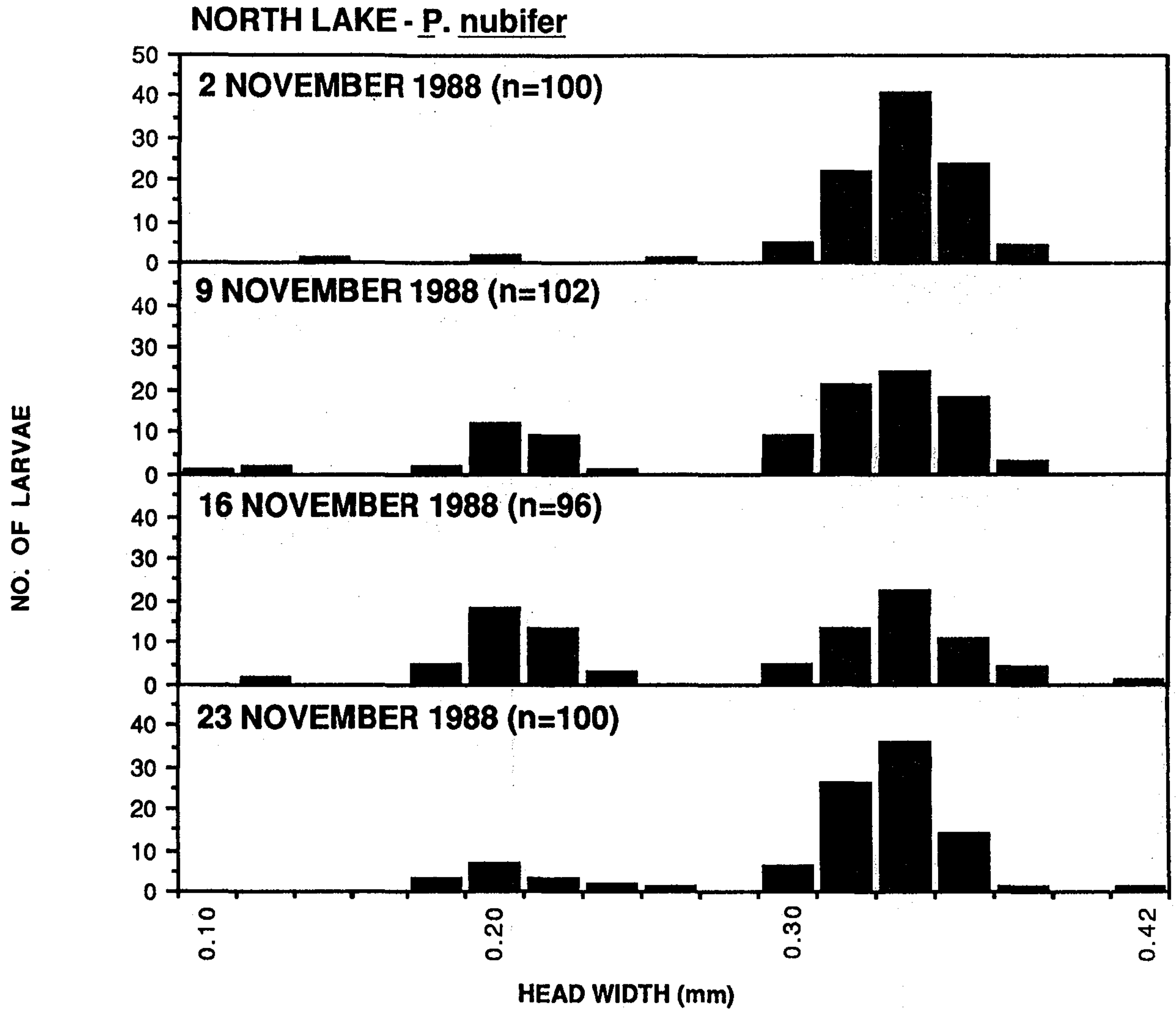


Figure 17. Changes in the size-frequency distribution of larvae of *Polypedilum nubifer* at North Lake, November 1988.

The collection of width-frequency information on a weekly basis during 1988 was intended to address the question of synchrony in the development of *P. nubifer* larvae in Perth wetlands. However, the weekly sampling regime gave a very similar picture of the development of larvae within the North Lake *P. nubifer* population to that shown by fortnightly sampling during the previous study year (Fig. 18). There is no evidence of a well-defined pulse through time that would be evident in the graphical representation of a sychronous population (Omori and Ikeda, 1984). Hence, these new data support our previous conclusion that *P. nubifer* does not show synchrony in the development of larvae and is unlikely to have synchronous adult emergence or egg laying.

Chironomid Production

In addition to information on larval densities, data on emergence rates were collected at Forrestdale Lake between 19 September 1988 and 17 January 1989 and at North Lake between 20 September 1988 and 28 February 1989. At North Lake four light traps were used to gain quantitative information about the changing numbers and species composition of adult midges reaching nearby residences. These were run during the period 13 December 1988 to 23 February 1989.

Adult emergence rates at Forrestdale Lake were very low during the period studied, with emergence occurring on only two of the ten sampling days. Emergence occurred on 3 October (11.01 adults/m^2) and 8 December 1988 (2.75 adults/m^2). The species that emerged were *C. alternans*, *D. conjunctus* and *T. fuscithorax*.

Information on chironomid production at North Lake is given in Fig. 19. Graphs relating to larval density, adult emergence and adult abundance at light traps are drawn to the same time scale (X-axis) and cover the period during which the emergence traps were in place. The pattern of adult emergence follows the pattern of larval density fairly closely, although the major peak in emergence on 5 January 1989 preceeds the peak in larval density on 16 January 1989. The other major peaks on 16 November and 7 December 1988 occur in both larval density and adult emergence.

Changes in the peaks in abundance of larvae and emerging adults of individual species did not always correspond in timing or magnitude. Particularly apparent are the peaks in emergence of *C. intertinctus* that occurred on 8 November, 16 November 1988 and 5 January 1989. These peaks are considerably smaller in the larval collections. Conversely, peaks in larval densities of *P. nubifer* recorded on 28 December 1988, 16 January and 27 February 1989 did not produce correspondingly large peaks in the emergence collections. There are several possible explanations for the discrepancies between the larval density and adult emergence values. The larval monitoring programme provides good evidence for the existence of patchy distributions of chironomid larvae in the lake substrate. The relatively small area of lake substrate that was sampled for adult emergence by the four traps may have resulted in the species composition results not being totally representative of the lake as a whole. The placement of the emergence traps was in a relatively deep part of the littoral region to reduce

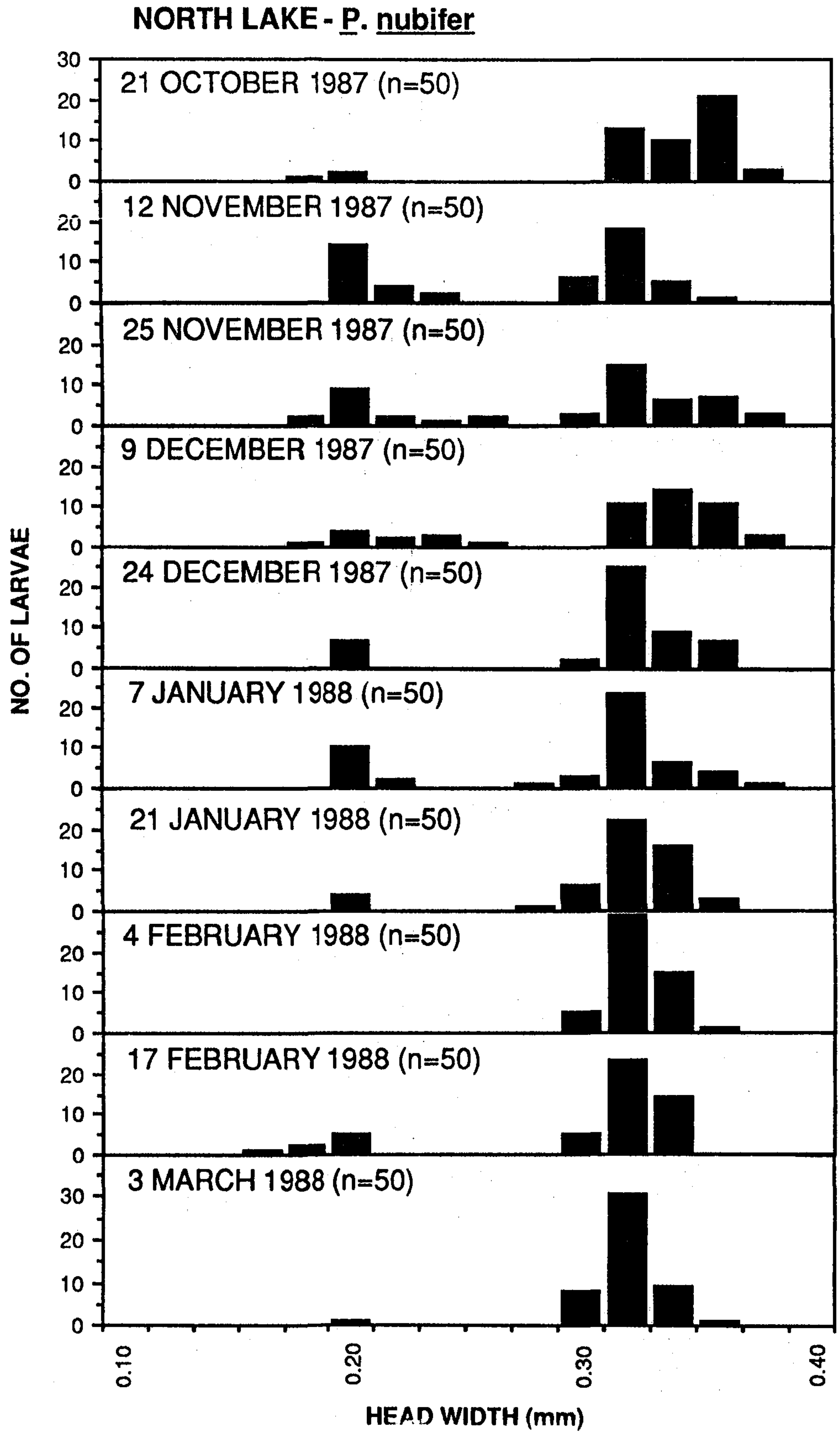


Figure 18. Changes in the size-frequency distribution of larvae of *Polypedilum nubifer* at North Lake, October 1987 to March 1988.

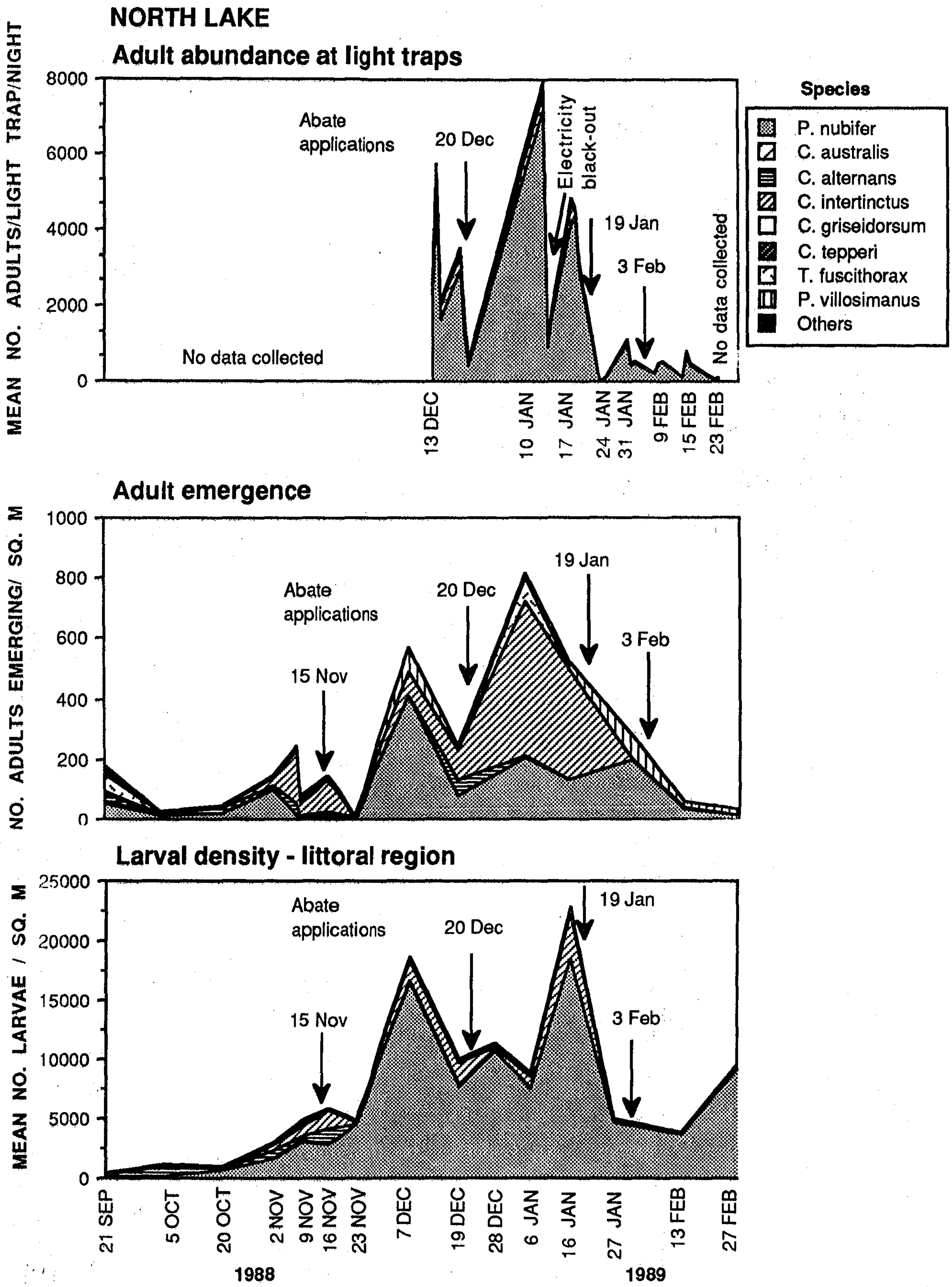


Figure 19. Changes in the cumulative numbers of adult chironomids at light traps per night, adults emerging per square metre over 24 hours and larvae per square metre for the littoral region of North Lake, September 1988 to February 1989. Light trap collections began in December 1988. The dates on which Abate was applied to the lake are indicated. Note the different Y-axis scales.

the chance of vandalism of the traps and this may have favoured the collection of *C. intertinctus* over *P. nubifer*. Alternatively, emerging *P. nubifer* may have avoided the emergence traps, thereby reducing their representation in the collections. The general agreement between the peaks in abundance of larvae and of adult midges at the light traps, as well as the *P. nubifer*-dominated species composition in both collections lends support to the idea that the emergence traps were biased in their collection of particular species of emerging adults.

Emergence rates are approximately 3% of the larval density figures. Given that the life cycle of *P. nubifer* is known to take three to five weeks during the summer period (Edward, 1964), then allowing for mortality in pre-emergence stages (larvae and pupae), this ratio of emerging adults to larval density seems reasonable.

The abundance of adult chironomids at light traps follows a similar pattern to the pattern of adult emergence, although the peaks in abundance at the light traps occurred slightly later. Two major peaks occurred on 13 December 1988 and 10 January 1989. The sudden reduction in attendance at the light traps on 11 January 1989 may have been the result of an electricity black-out that occurred on that night.

Four Abate treatments carried out at North Lake while the emergence traps were in place resulted in varied emergence responses. The application of Abate on 15 November 1988 was followed by a small peak in emergence (primarily of *C. intertinctus*) the following day. Emergence continued to increase following the Abate application on 20 December 1988, although emergence of *C. intertinctus* was responsible for much of the peak (around 5 January 1989) recorded after the treatment. After the two following Abate applications (19 January and 3 February 1989), both at a higher application rate, numbers of emerging adults, particularly *C. intertinctus*, decreased.

Adult abundance at the light traps peaked on the night of 20 December 1988, after the application of Abate to the lake during the same day. Numbers of adults caught by the light traps fell after pesticide applications to the lake on 19 January and 3 February 1989.

Midge Nuisance and House-to-House Variation
Changes in the abundance of adult midges at the four light traps located at residences near North Lake during the period from 13 December 1988 to 23 February 1989 are shown in Fig. 20. Light traps 1 and 2 were at neighbouring residences on the western side of North Lake and facing the lake across a road and lakeside vegetation. Both light traps were hung in comparable positions, on the northern side of the house under an overhanging pergola, but in sight of the lake. Light traps 3 and 4 were placed at neighbouring residences to the north of North Lake and separated form the lake by two roads and lakeside vegetation. Light trap 3 hung beneath an overhanging pergola at the front (southern side) of the house, whereas light trap 4 hung at the back (northern side) of the house. The positioning of light traps 3 and 4 was not ideal in that they were not strictly comparable, however the wishes of the residents concerned had to be respected.

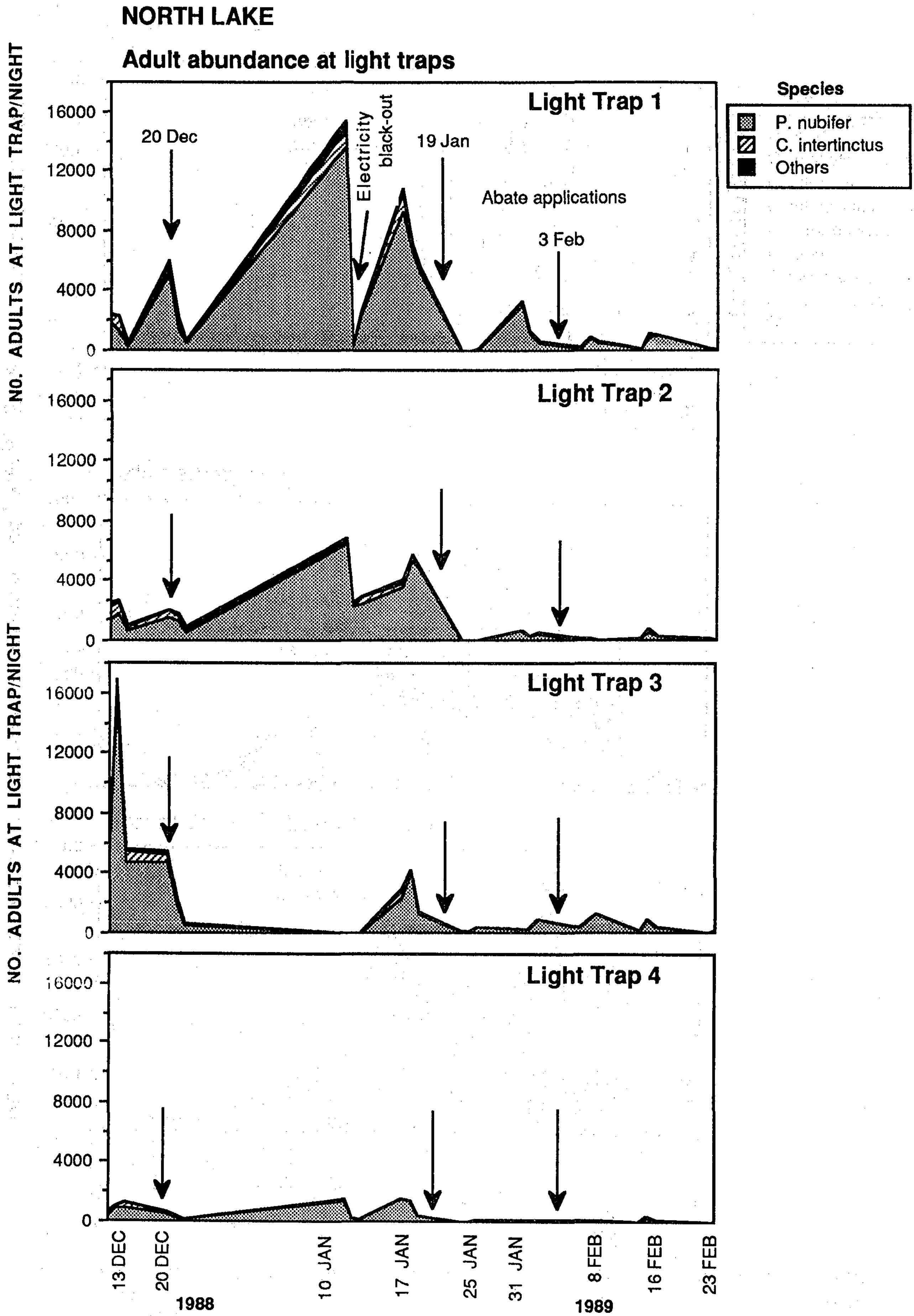


Figure 20. Changes in the cumulative numbers of adult chironomids at light traps per night at four residences near North Lake, December 1988 to February 1989. The dates on which Abate was applied to the lake are indicated.

Light traps 1 and 2 caught considerably more adult midges than traps 3 and 4, except for the very high number caught by trap 3 on 14 December 1988. This cannot be explained by the records for wind direction for Perth City, however local wind conditions may have been predominantly easterly during the evening when midges were being caught by the light traps. In general, the same peaks in abundance occurred at all light traps. Major peaks occurred on the nights of 20 December 1988, 10 January and 17 January 1989. The sudden drop in the number of adults caught on 11 January 1989 occurred in all three light traps (light trap 3 was temporarily removed from 10 - 12 January) and was probably due to an electricity blackout on that night. Other peaks in abundance occurred on 31 January, 8 February and 16 February 1989, although these are less apparent at light traps 2 and 4 than at traps 1 and 3.

Applications of Abate pesticide to North Lake are indicated on Fig 20. The application that took place during the day of 20 December was followed by a peak in adult abundance that night. Adult abundance at the light traps fell after the application of Abate to the lake on 19 January and 3 February 1989.

Species composition at all four light traps over the entire study period was dominated by *P. nubifer*. *C. intertinctus* was the only other species that accounted for greater than 10% of the adult midges caught on any night.

Environmental Parameters
Weather data for Perth city, comprising fortnightly maximum and minimum air temperatures, fortnightly rainfall totals and maximum wind gusts are given in Fig. 21. Changes in lake depths, water temperatures, conductivity and pH for Forrestdale and North Lakes are given in Figures 22 and 23 and changes in chlorophyll-a, total phosphorus and total nitrogen are given in Figures 24 and 25.

The weather data recorded over the study period indicate the general environmental regimes present in the Perth area. More detailed information is necessary to elucidate the relationships between environmental factors and chironomid production, but collection of such data was beyond the resources of this study.

Water levels at Forrestdale Lake increased from mid July to a peak of 1.45 mAHD in mid November 1988 and then decreased due to evaporation over the summer period, reaching 0.48 m in late March 1989. At North Lake water levels decreased initially, reaching their lowest level (1.6 mAHD) in late April 1988, increased to a peak of 3.18 m in October and decreased again over the summer period.

Water temperatures at the two lakes were very similar even though Forrestdale Lake became much shallower than North Lake late in the summer. Conductivity however, reflected the change in water depth at Forrestdale Lake, with salinities reaching five times the levels recorded at North Lake. The pH of both lakes was approximately neutral during the winter months, but alkaline during spring and summer. North Lake was more alkaline, with pH values near 10, compared to pH values near 9 at

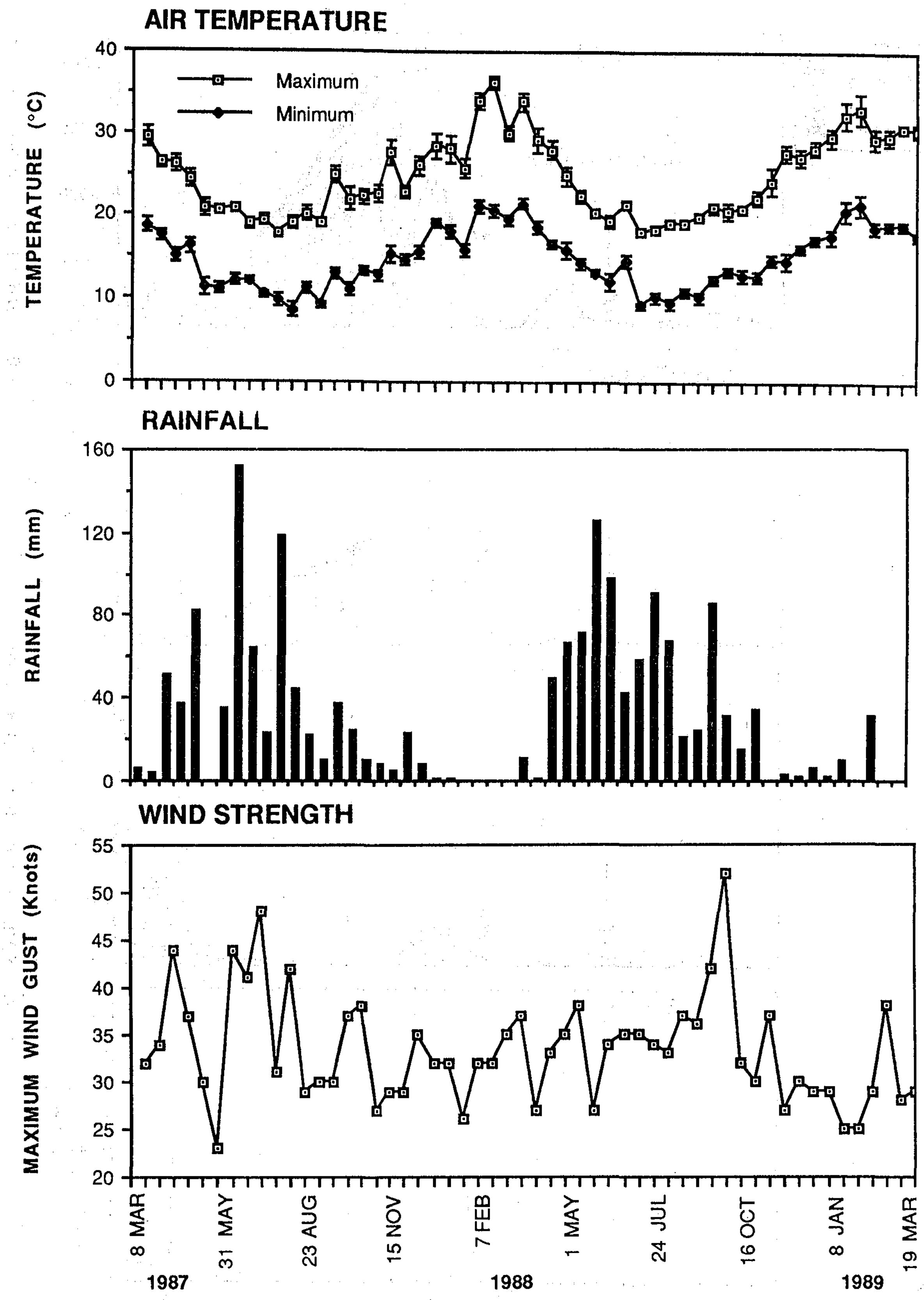


Figure 21. Weather data for Perth City for March 1987 to March 1989. Fortnightly maximum and minimum temperatures, fortnightly rainfall totals and the maximum wind gust for the fortnight are shown.

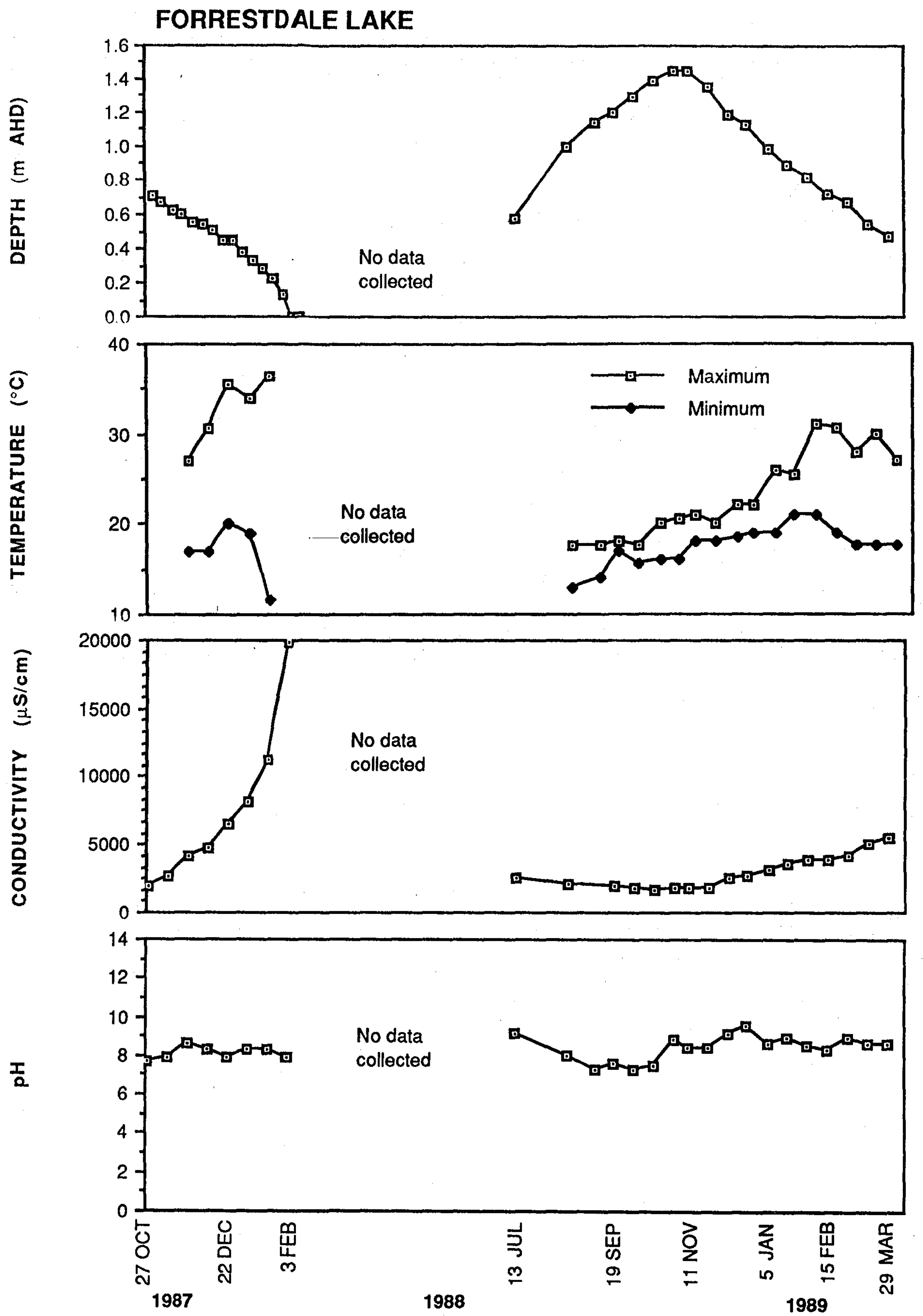


Figure 22. Changes in lake depth, temperature, conductivity and pH at Forrestdale Lake, September 1987 to March 1989.

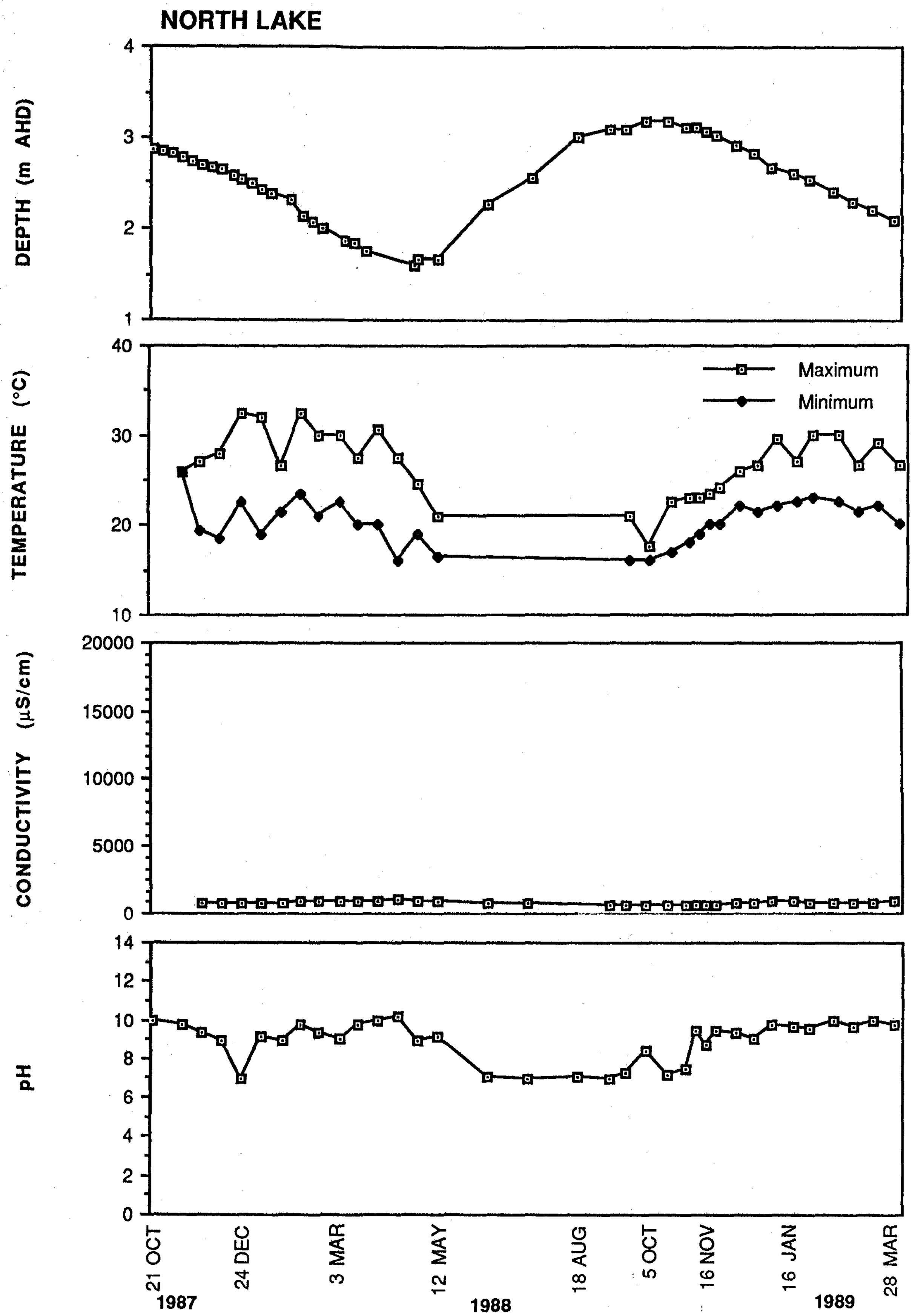


Figure 23. Changes in lake depth, temperature, conductivity and pH at North Lake, September 1987 to March 1989.

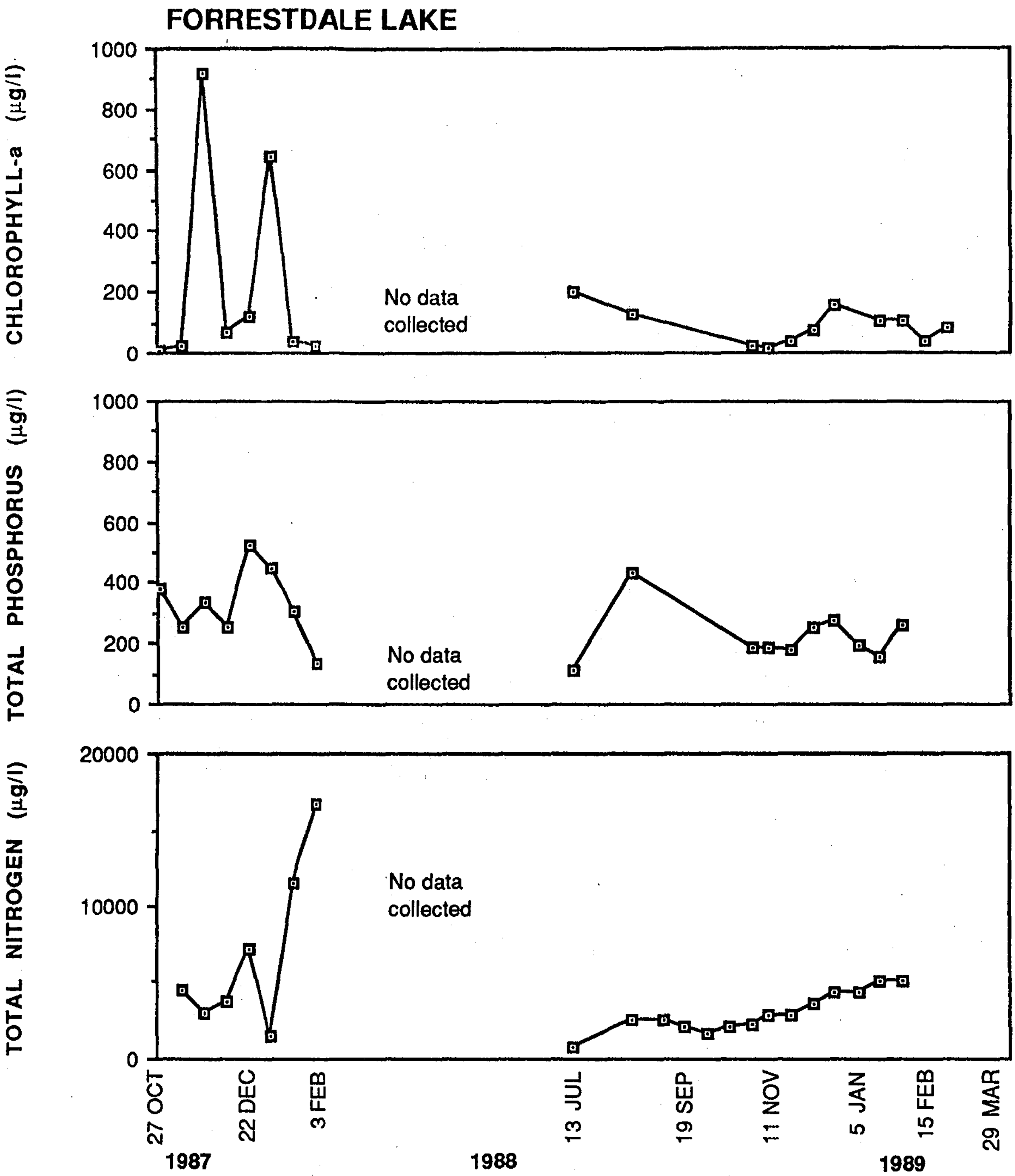


Figure 24. Changes in concentrations of chlorophyll-a, total phosphorus and total nitrogen at Forrestdale Lake, September 1987 to March 1989.

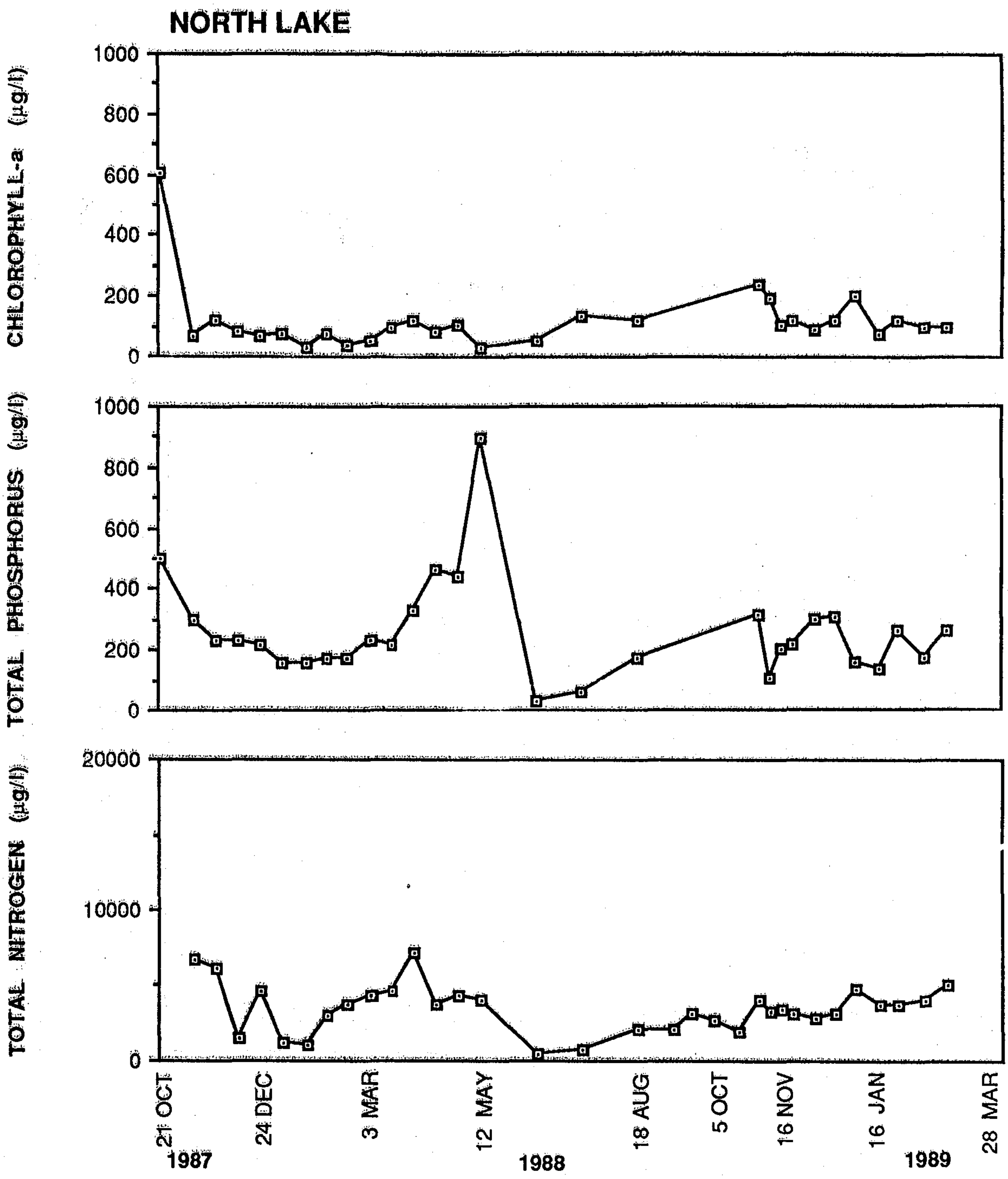


Figure 25. Changes in concentrations of chlorophyll-a, total phosphorus and total nitrogen at North Lake, September 1987 to March 1989.

Forrestdale Lake.

Chlorophyll-a concentrations at Forrestdale and North Lakes fluctuated widely over the study period, but both can be classified as eutrophic lakes. High concentrations of chlorophyll-a at both lakes during spring (October and November) resulted from algal blooms present at that time. Concentrations of total phosphorus varied over the study period but were at comparable levels at the two lakes except for a single high value recorded in May at North Lake. Levels of total nitrogen were of similar levels, and in the case of both lakes, total nitrogen values were lower in winter than in spring and summer.

DISCUSSION

The first critical step in modern agricultural or horticultural pest management is to determine the densities at which a species reaches damaging levels; this is known as the economic injury level or EIL (Horn, 1988). The aim is then to ensure that population densities do not exceed this EIL by the use of control measures, many of which involve the use of pesticides. It is extremely ecologically desirable that pesticides are only used when needed so that effects on non-target organisms and beneficial predatory species are kept to a minimum. In addition, the problem of insect resistance means that they must only be used on an "as-needed " basis to maximise the time period for which they will remain effective. Use on an "as-needed" basis is also the most economic approach (Horn, 1988). Setting nuisance levels for midges is more difficult than setting EIL's for many agricultural pest species because it is not economic damage as such that is important, but rather the much more subjective level of people's tolerances to midges. We are dealing with so called aesthetic injury levels or AIL (Horn, 1988) which may vary over an extremely wide range. In addition, although high densities of larval midges will provide a warning of impending swarms of adults, other factors may affect whether or not nuisance swarms actually occur. In particular, weather conditions at the time of adult emergence will ultimately influence whether or not problems occur.

The results of the first year of study indicated that the threshold for nuisance levels of *P. nubifer* was approximately 2 000 larvae/m^2 or greater. Levels of adult nuisance at North Lake were recorded as high throughout December 1987, January and February 1988 and densities of *P. nubifer* exceeded 2 000 larvae/m^2 for virtually all of this period. This summer (1988/89) larval densities of *P. nubifer* exceeded 2 000/m^2 from November 1988 until the end of March 1989 but the levels of adult nuisance were only scored as high for the period between late December 1988 to mid January 1989. These later results suggest that the threshold or AIL for larval densities at North Lake could possibly be raised. However a decision to change the threshold is probably best left until further monitoring data have been obtained over the summer of 1989/90.

The nuisance threshold for larval *P. nubifer* at Forrestdale Lake appears to be much lower than that at North Lake. Levels of adult nuisance were scored as high or extreme following an increase in larval densities to approximately

1 000 larvae/m^2 in January 1988 and 500 larvae/m^2 in February 1989. A nuisance threshold for *P. nubifer* of 500 larvae/m^2 may be appropriate for Forrestdale Lake. The difference in thresholds between the two lakes highlights the need to set nuisance thresholds on a lake-by-lake basis. A lower density of larvae appears to result in a greater nuisance at Forrestdale Lake than at North Lake because midge emergence takes place over a much larger area at the former lake than at the latter.

The consistent occurrence of a single peak in the density of *P. nubifer* that occurred at Forrestdale Lake in the summer of 1987/88 and 1988/89 indicates that the onset of midge problems at this lake may be fairly accurately predicted by a larval monitoring programme. Weekly rather than fortnightly sampling in January and February may be more appropriate to detect the point at which the density of *P. nubifer* first reaches the nuisance threshold.

The peak in the density of larval *C. australis* that occurred at Forrestdale Lake in late spring in 1987 did not occur in 1988. Previous sampling at the lake in 1985 and 1986 indicated that a spring peak in *C. australis* is probably fairly common and could result in sufficient numbers of adults to cause a problem to Forrestdale residents. The lower densities of *C. australis* recorded in the spring of 1988 may have been a result of the lake being more than 50 cm deeper at this time than in preceding years and, as a consequence, water temperatures were probably cooler.

The spring peak in *C. australis* and the late summer or pre-drying peak in *P. nubifer* at Forrestdale indicate that either one or two well-timed applications of an effective pesticide may be sufficient to control midge problems at the lake. In contrast, the sustained high level of production of *P. nubifer* at North Lake from December 1988 through until March 1989 indicates that more frequent pesticide treatments are likely to be needed at this lake. The extremely high level of midge production at this lake also indicates the urgent need for longer term control measures such as the reduction of nutrient inputs. The apparent effectiveness of the Abate treatment undertaken in January 1989 which involved the use of a much higher application rate (5kg/ha) by boat to the specific area (the littoral region) where larval midges were known to occur demonstrates the advantages of selectivity in pesticide use. In this case the application of pesticide directly to the littoral region by boat rather than widespread application to the whole lake by plane was both ecologically and economically more desirable. This kind of treatment however could only be made after the sampling programme had determined where the larval midges were most abundant and the field trial of Abate had determined the most effective concentration.

It is tempting to speculate that the increase in abundance of larval midges at both North Lake and Forrestdale Lake in the summer of 1988/89 compared with that of 1987/88 was in some way a consequence of the higher rainfall in 1988. The total rainfall for 1988 was 912.4 mm compared with 768.6 mm in 1987. An increase in surface runoff may have resulted in a greater flushing of nutrients into the lakes from their surrounding catchments. This in turn would have resulted in a greater production of algae and so a more abundant food source for larval midges. However, this suggestion does not appear to be supported by either the chlorophyll-a or total phosphorus data sets.

A STANDARD METHOD FOR MONITORING LARVAL MIDGE DENSITIES IN PERTH LAKES

INTRODUCTION

An important aspect of the 1988/89 research programme was to develop simple monitoring methods that would allow local government authorities to monitor the density of midge larvae in lakes in the Perth region. A workshop was held at Murdoch University in March 1989 to demonstrate techniques that the midge research group felt were most appropriate. The information in this chapter was presented at that workshop. The techniques described are designed to be flexible, and should be useful for a wide variety of lake types, although they may need to be modified for particular situations. These methods ensure that data obtained on different sampling occasions are comparable and so enabling more accurate predictions of impending midge problems to be made. In addition the larval midge abundance at different lakes can be compared when the same field and laboratory methods have been used.

FIELD SAMPLING FOR MIDGE LARVAE

General

It is recommended that a corer (Fig. 26) is used to take samples of the lake substrate because this type of sampling device collects a known area of the lake bed. This allows the data to be converted to the number of larvae per square metre and consequently, the abundance of larvae on different dates or at different lakes can be meaningfully compared.

The lakes in the Perth area are of two major types, some are relatively flat-bottomed and generally less than one metre deep across the entire lake (e.g. Forrestdale Lake). Others have a shallow edge area and a deep central region, up to 4m deep (e.g. North, Booragoon and Jackadder Lakes). In general, the shallow regions of the lake contain the highest concentrations of larvae (especially of the nuisance species *Polypedilum nubifer*), and most samples should be taken here. However, it should be stressed that each lake is different and an initial thorough survey (this should be undertaken in summer) should indicate where the major problem areas occur (shallow water, deep water or both, in reeds etc.).

Shallow lakes

A minimum of ten cores should be taken on each monitoring occasion. Locate these evenly over the area of the lake. Extra cores may need to be taken in any particular areas where you suspect numbers of larvae may be unusually high, and these should be analysed separately.

Deeper lakes

A minimum of ten cores should be taken around the edge of the lake on each monitoring occasion. These should be approximately evenly spaced around the perimeter of the lake. Take each core 5 paces in from the edge of the lake. In addition, once a month take 4 cores from the middle of the lake (these may require the use of a long-handled corer) to check the abundance of larvae in the deeper water. If larvae become abundant in the central region then more frequent sampling may be required here.

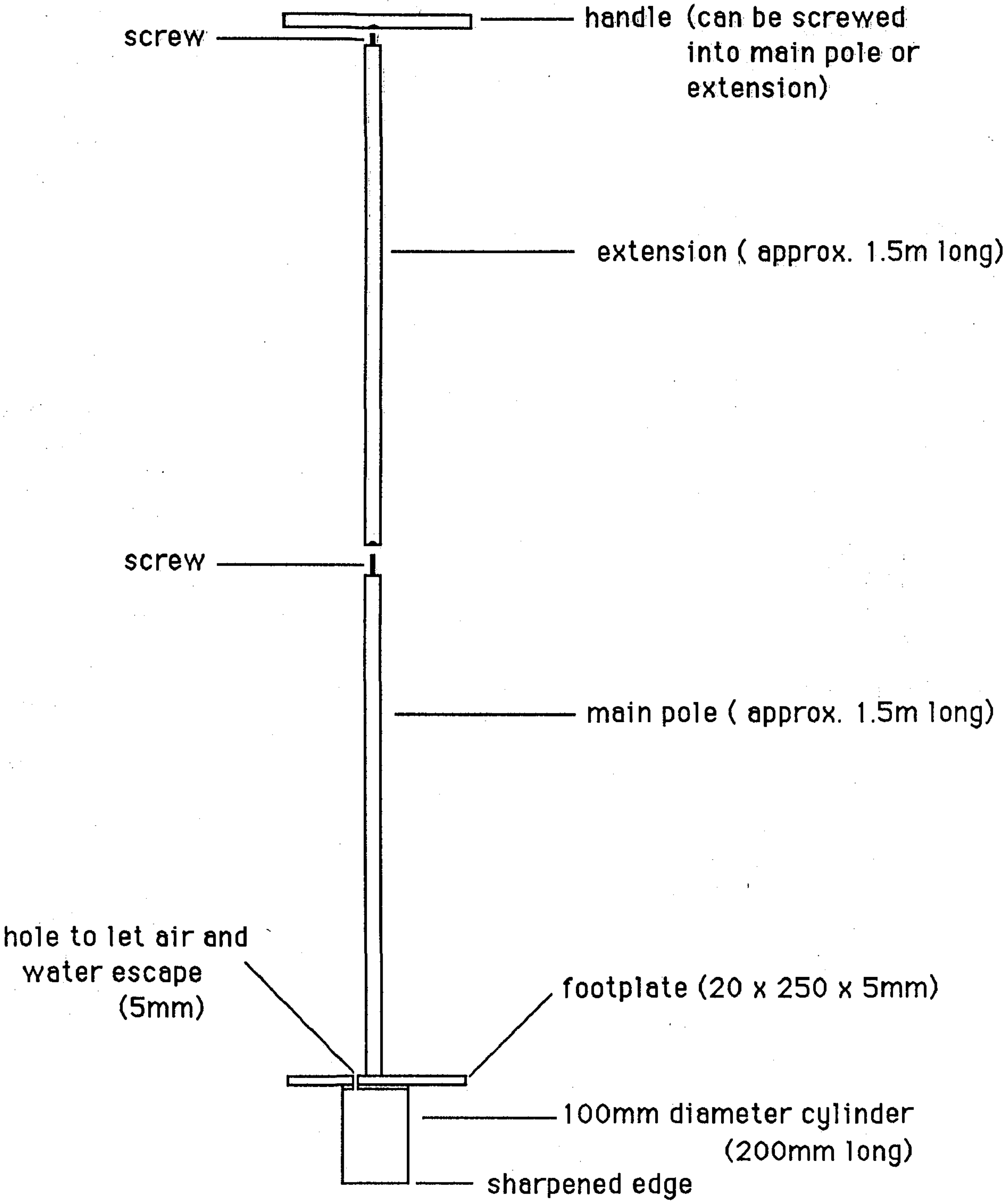


Figure 26. Design of corer for sampling lake sediments. Construction from stainless steel is preferable allowing the cutting edge to be sharpened, however aluminium will suffice.

Sampling Frequency
The rate of development (from egg to adult) of midges and other insects depends on the temperature of the surrounding environment (the lake water). Hence, in high summer temperatures, development can be very fast and larval numbers in the lake can increase to problem levels over a period of only one or two weeks. Consequently, a larval monitoring programme should sample the lake at least every fortnight during the summer months (November - February), and weekly when numbers begin to rise quickly. If the programme is to be continued through the winter, then monthly sampling should be adequate.

Sampling Procedure
Tip the core into a tray and if possible, retain only the top half. This can be sorted in the field or placed in a plastic bag (with preservative if necessary) to be sorted in the laboratory at a later time. It is important to keep a record of the location of each sample (perhaps on a rough sketch map of the lake) so that particular problem areas can be located for treatment. To facilitate this, each sample should be labelled with a number. Water-proof paper written on with pencil makes good permanent labels and field sheets.

SEPARATION OF MIDGE LARVAE FROM SEDIMENT SAMPLES

Outlined below are the methods recommended for separating midge larvae from samples of the lake substrate. At Murdoch University we have found the flotation technique to be the quickest and most efficient method. An alternative is to pass the samples through one or more sieves, however, due to sediment retention in the sieves and/or the loss of small larvae, this tends to be a more time consuming and less efficient method than flotation.

Calcium Chloride Flotation
When sufficient calcium chloride is dissolved in water a saturated salt solution is formed. Midge larvae contain relatively fresh water within their bodies and hence have a lower specific gravity than the calcium chloride solution. This causes the larvae (and often other organic matter) to float to the water surface. Calcium chloride can be very irritating to the skin and so rubber gloves should be worn when sorting.

<u>Materials</u>

- two plastic buckets
- calcium chloride flakes
- one sieve (mesh size no larger than 0.25mm)
- tweezers
- a rag
- rubber gloves
- plastic apron
- preservative and containers for larvae

<u>Methods</u>

1) To make five litres of solution add 3.5kg of calcium chloride flakes to 4.0 litres of water in a bucket and stir until completely dissolved. If a scum forms on the surface then it can be removed with a folded rag.

2) Place the entire sample (this may or may not have been preserved) in the sieve to drain off excess water (and hence avoid diluting the solution). Empty the contents of the sieve into the solution and break up any lumps in the sample, stir thoroughly.

3) Using tweezers pick off the midge larvae from the water surface and place them in a labelled container. The contents of the bucket may need to be stirred a few times for all of the larvae to come to the surface. A desk lamp is useful to improve visibility (ensure the wiring and switches do not get wet).

4) When no more larvae can be found the contents of the bucket should be passed through a sieve into a second bucket and the sediment disposed of. The calcium chloride solution in the second bucket can now be reused for the next sample. This solution may be reused up for up to ten samples, but additions of small amounts of calcium chloride may be required to maintain a saturation.

5) This method can be employed in the field or workshop (a sink or shaded outdoor area is useful for workshop sorting). If sorting is to be carried out in the field then a sealable bucket of calcium chloride may be made and carried from site to site by boat or vehicle.

6) This flotation method is useful for most types of sediment, although large amounts of organic matter may make the larvae difficult to see. The time required to sort a sample depends upon the density of the larvae, type of substrate and experience of the operator. We have found that a sample can take between five minutes and one hour to sort.

Counting and Identification of the Larvae
The larvae should be counted during or after sorting and the number obtained in each sample recorded on a data sheet such as Table 6. For the identification of larvae a simple guide ("A Guide to the Common Midges (Chironomidae) of the Perth Metropolitan Area") was produced for an earlier workshop. Copies of this guide are available from the midge research group at Murdoch University.

If you are using a corer to take sediment samples then it is possible to convert the **number of larvae per core** to the **number of larvae per square metre** using the method shown below.

step 1 - Work out how many times the corer fits into a square metre (**C**)

$$\mathbf{C} = \frac{1}{3.14 \times \text{radius} \times \text{radius}}$$

(radius = the radius of the corer base in metres)

Table 6. Sample data sheet for use in recording information on larval density.

LAKE : DATE :

SAMPLE TYPE : EDGE CORES

	NO.	1	2	3	4	5	6	7	8	9	1 0	AVERAGE	AVERAGE	%
SPECIES												PER CORE	PER SQ. M	COMPOSITION
TOTAL														

SAMPLE TYPE : MIDDLE CORES

	NO.	1	2	3	4	5	6	7	8	9	1 0	AVERAGE	AVERAGE	%
SPECIES												PER CORE	PER SQ. M	COMPOSITION
TOTAL														

step 2 - Calculate the average number of larvae per core (**X**). If there are major differences between the edge cores and middle cores then they should be worked out separately.

$$\mathbf{X} = \frac{\text{total number of larvae in all cores}}{\text{number of cores}}$$

step 3 - Number of larvae per square metre = **X** x **C**

Example

The corer used had a diameter of 10cm, thus the radius is 5cm (or 0.05m).

Core no.	No. larvae per core
1	15
2	20
3	5
4	35
5	0

step 1 Radius of corer is 5cm, i.e. 0.05m.

$$\mathbf{C} = \frac{1}{3.14 \times 0.05 \times 0.05} = 127.4$$

step 2 Average number of larvae per core (**X**) = $\frac{15 + 20 + 5 + 35 + 0}{5} = 15$

step 3 Number of larvae per m^2 = **X** x **C** = 1 911 / m^2

<u>JACKADDER LAKE ALUM EXPERIMENT</u>

INTRODUCTION

There is increasing evidence to suggest that algal blooms and their decomposition products provide the major source of food for chironomid larvae in Perth metropolitan lakes. Algal blooms are the direct result of excessive nutrient loading in the lakes and a high internal nutrient load within a lake may remain a problem for many years even if measures are taken to control further nutrient additions.

A method for controlling excessive algal blooms is to limit one of the nutrients required by the algae for growth. This can be achieved most easily by adding aluminium to bind with phosphorus in the water column and the sediment (Cooke et al., 1986). The resulting insoluble forms of phosphorus are then no longer available for plant growth.

In an effort to improve the water quality of Jackadder Lake, alum (aluminium sulphate) was added to the lake during January 1989. The experiment was coordinated by Mark Lund (Murdoch University) and John Sutton (Stirling City Council). The building of an enclosure, to act as a control area, and the addition of the alum were carried out and financed by the Stirling City Council.

The proposed water quality improvements and reduced algal production resulting from the addition of alum to Jackadder Lake were expected to affect the herbivorous invertebrates living in the lake. As part of our aim to find longer-term control measures for chironomids in Perth wetlands, the changes in larval chironomid abundance were investigated over several months by the Murdoch research team.

METHODS

General

Jackadder Lake is located 8km northwest of the Perth City centre in the City of Stirling. The lake is 7.18 ha in area with a small island on the eastern side. For most of its area the lake is less than 2m deep, but a deeper channel (> 4m deep) runs across the northwestern part of the lake. The lake surrounds are dominated by lawns and parkland and little fringing vegetation remains.

A small part of the lake (approximately 0.25 ha) was established as a control area, using the island as one end of the enclosure. Two curtains made of PVC plastic were suspended from chains attached to support poles placed on the island and the shore (Fig. 11B). Heavy chains held the curtains in contact with the sediment on the lake bed. The enclosure was established during the week of 15 December, approximately one week before the initial sampling on 23 December 1988.

Liquid alum was added to the treated area (the area of the lake not included in the control enclosure) on 4 and 5 January 1989. A total of 33.5 tonnes of liquid alum (equivalent to 14.6 tonnes of crystalline commercial alum ($Al_2(SO_4)_3.14H_2O$) was applied to the lake surface through a hose connected to a tanker. The amount of alum added to the lake was determined using guidelines from Cooke and Kennedy (1981) and was calculated to reduce the initial pH of the lake water from 8.5 to an optimum pH of 6.0.

The monitoring of larval abundance and the measurement of environmental parameters was carried out on the following dates: 23 December 1988 (12 days before the alum treatment), 9 January (5 days after treatment), 23 January (19 days after treatment), 14 February (41 days after treatment) and 14 March 1989 (69 days after treatment).

Abundance of Chironomid Larvae

Quantitative samples of the lake substrate were collected from the treated and control areas. A 9.8cm corer was used to sample the sediments in the littoral region of lake as well as the central region of the control area. A long-handled (10.9cm diameter) corer was used to sample the deep central region of the treated area. The top 5cm of each core was retained and preserved with 100% ethanol until sorting was 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 core substrate by differential flotation using saturated calcium chloride solution. The sorting and identification methods used are described in detail in the previous report. Larval abundance information on the first three sampling occasions was collected by Edwin Chester, the remaining data were collected by the Murdoch research team.

On each sampling occasion 30 core samples were collected, nine from the control area and 21 from the larger treated area. The nine cores from the control area comprised six from the littoral region and three from the central area of the enclosure. The 21 cores from the treated area comprised 15 from the littoral region and six from the deeper central region. The littoral cores were located approximately evenly around the littoral band and five paces into the lake from the shore. The central cores were located evenly over the surface of the area to be sampled.

The initial aim of the experiment was to examine the effect of alum on littoral and central populations of chironomid larvae by comparison with the corresponding populations in the untreated (control) enclosure. Previous studies at Jackadder Lake found that the central region of the lake supported much lower densities of larvae than the littoral region and that the species composition of the two zones differed. After perusal of the results from the initial sampling occasion it became clear that the entire area included in the control enclosure was "littoral" in terms of water depth and the abundance of larvae in the substrate. Consequently, because of the lack of a deep central region in the control enclosure, only the effect of the alum application on larvae in the littoral region could be properly investigated.

Abundance of Other Invertebrates

On each sampling occasion the lake was sampled for macroinvertebrates by taking three sweep net samples in each of the treated and control areas.

This part of the experiment was carried out by Mark Lund. However, not all of the samples have been sorted and consequently these collections will not be referred to further.

Environmental Parameters
Information on the changing physical environment was collected on several occasions before and after the addition of alum to Jackadder Lake. This part of the study was undertaken by Mark Lund.

On each sampling occasion a number of environmental parameters were measured in the treated and control areas of the lake; these comprised oxygen and temperature profiles, pH, conductivity and Secchi depth (a measure of lake turbidity). Lake water was collected from the treated and control areas and was filtered in the field for chloropyll-a and ortho-phosphorus analyses. Samples of water were frozen for analyses of total phosphorus, ortho-phosphorus, total nitrogen and ammonia. The analyses of the water samples, except for chlorophyll-a, are incomplete and these results will not be discussed further here.

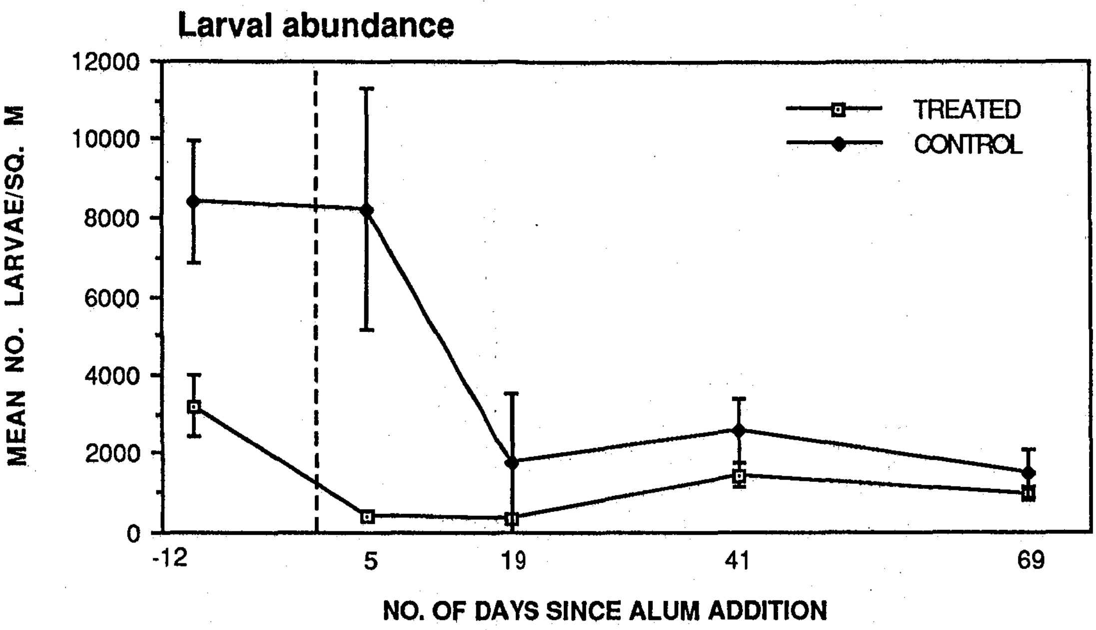
RESULTS

Abundance of Chironomid Larvae
Changes in the densities and species composition of larvae in the treated and control areas of Jackadder Lake during the period from 23 December 1988 to 14 March 1989 are given in Fig. 27. Separate plots of the changes in larval densities of *P. nubifer, C. griseidorsum* and *P. villosimanus* are given in Fig. 28.

The abundance of larvae in the treated area (3 217 ± 789 larvae/m^2) was 38.3% of the larval abundance in the control enclosure (8 408 ± 1 555 larvae/m^2) on the first sampling occasion, 12 days before the addition of alum to the lake. Larval numbers fell by 88.1% (to 382 ± 94 larvae/m^2) in the treated area five days after the alum treatment and then remained consistently lower than the initial larval abundance. The highest density reached after treatment was 1 439 ± 315 larvae/m^2 (44.7% of the initial density) on 23 December 1988 (day -12).

By contrast, in the control area larval numbers remained almost constant (8 408 ± 1 555 larvae/m^2 to 8 222 ± 3 101 larvae/m^2) between day -12 and day 5. By day 19 (23 January 1989) there was a 79% reduction in larval abundance in the control area, but thereafter larval densities remained low and approximately constant.

P. nubifer was the most abundant larval species in both the treated (84.9%) and control (91.4%) areas at the beginning of the experiment. It remained the dominant species in both areas with one exception, on day 19 in the treated area, when *P. nubifer* fell to 30.6% and *C. griseidorsum* increased to 44.4% of the total larval abundance. *C. griseidorsum* and *P. villosimanus* became relatively more important in both the treated and control areas by day 19 and declined again by day 41 (Fig. 27). In general the changes in percentage composition that occurred in the treated area occurred in the



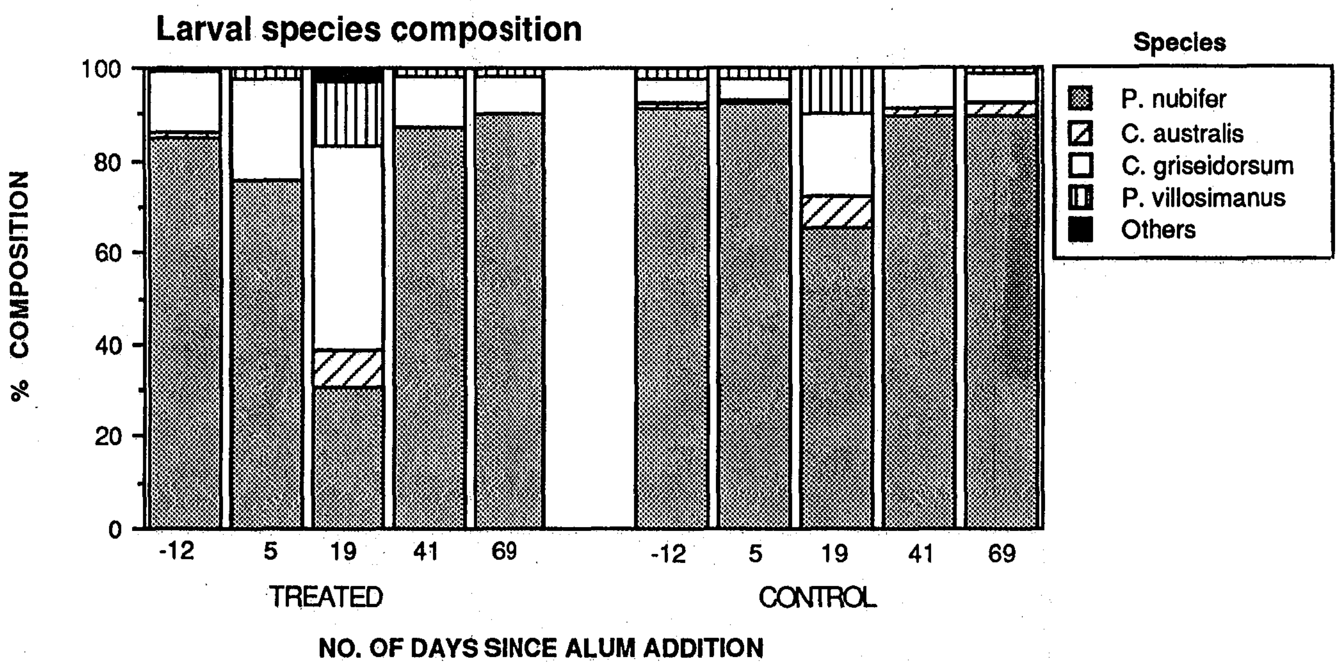


Figure 27. Changes in the mean number of chironomid larvae per square metre and the species composition of larvae within the treated and control areas at Jackadder Lake, December 1988 to March 1989. Means and standard errors are shown in the graph of larval abundance.

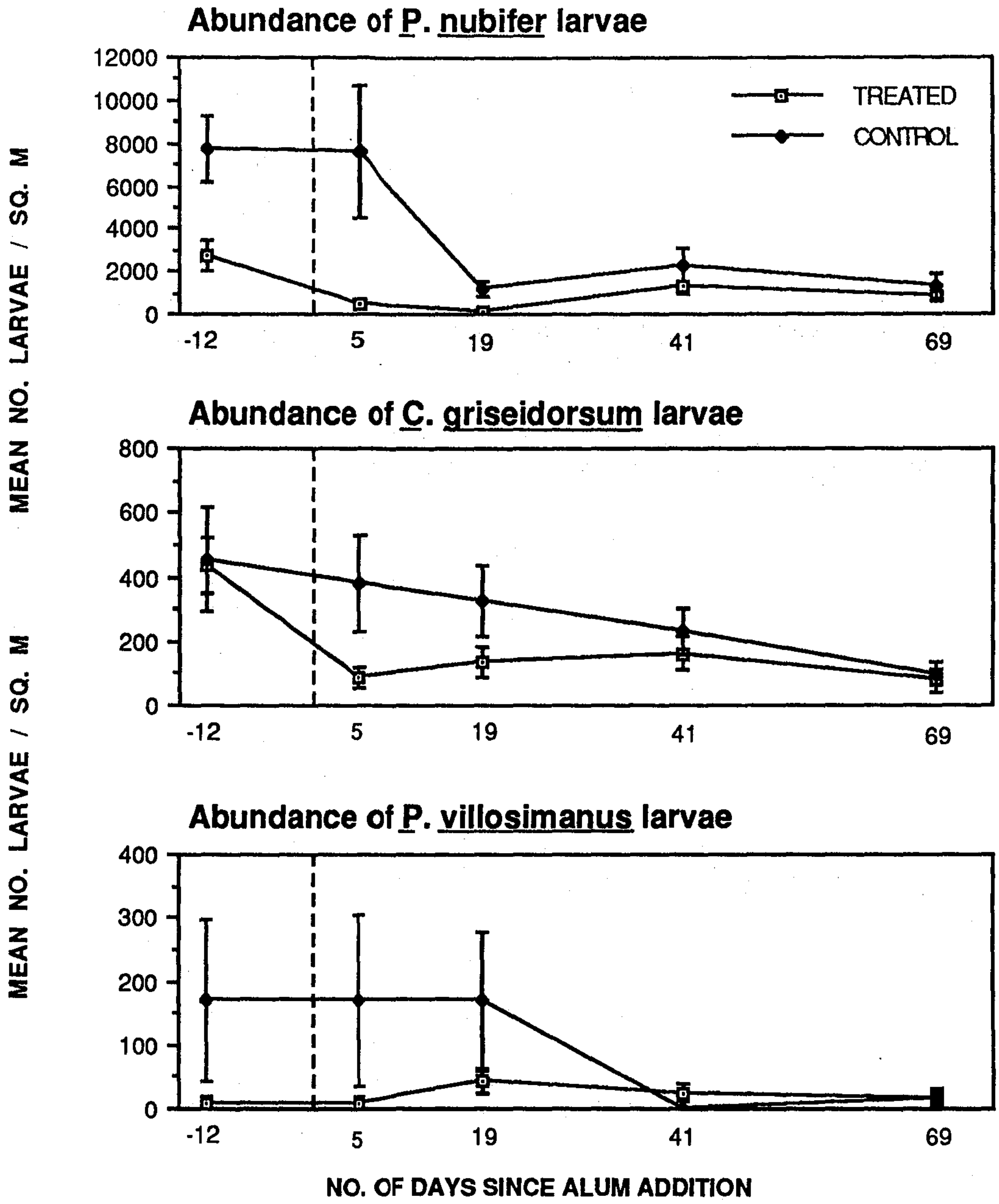


Figure 28. Changes in the mean number of *P. nubifer*, *C. griseidorsum* and *P. villosimanus* larvae per square metre within the treated and control areas at Jackadder Lake, December 1988 to March 1989. Means and standard errors are shown.

control area but to a lesser degree.

The patterns of change in the densities of *P. nubifer* in the treated and control areas are shown in Fig. 28. The agreement between the changing densities of *P. nubifer* and the total larval abundances (Fig. 27) are apparent. In the treated area the greatest reduction in abundance of *P. nubifer* occurred between day -12 and day 5, whereas in the control *P. nubifer* abundance fell between day 5 and day 19. Larval populations of *C. griseidorsum* and *P. villosimanus* decreased in abundance over the period of the experiment (Fig. 28).

Environmental Parameters
Concentrations of dissolved oxygen were higher in the treated area than in the control enclosure, except on the last sampling occasion, day 69. There was a general increase in the oxygen concentration over time, with surface concentrations increasing between day -12 and day 69 from 7.64 mg/l to 9.44 mg/l in the treated area and from 6.32 mg/l to 9.87 mg/l in the control area. The lowest oxygen concentrations were recorded at the lake bed, but these were extremely variable over time and no consistent trend was found between the treated and control areas.

Water temperatures were consistently higher at the surface than at depth, and in general they were similar in the treated and control areas. During December 1988 surface temperature was 25°C ± 1°C but fell to 21°C ± 1°C by March 1989.

Lake water was moderately alkaline before the addition of alum (treated pH: 8.35, control pH: 8.27 on day -12), but fell to approximately neutral levels on day 2 (treated: 6.83, control: 7.13). By day 69 pH in both areas had increased to above the pre-treatment levels (treated: 8.76, control: 8.78).

Over the period of the experiment conductivity of the treated and control areas was very similar. Conductivity rose steadily from 797 µS/cm (0.40 ppt) on day -12 to 948 µS/cm(0.47 ppt) on day 13 and then fell again to initial levels.

Changes in Secchi depth recorded during the study indicated a minor improvement in water clarity in both the treated and control areas between day -12 and day -6 prior to the application of alum (Fig. 29). However, water clarity continued to improve in the treated area until day 2, whereas no further improvement occurred in the control area. By day 69 Secchi depth values had returned to the initial levels.

Chlorophyll-a concentrations fell dramatically in both the treated and control areas during the study period. Initial concentrations (treated: 42.3 µg/l, control: 30.0 µg/l on day -12) decreased by day 2 (treated: 9.0 µg/l, control: 13.7 µg/l) and then increased in both areas to approximately 70 µg/l on day 69 (Fig. 29). Although the final chlorophyll-a concentrations in both areas were similar, levels increased much more rapidly after day 2 in the control area than in the treated area.

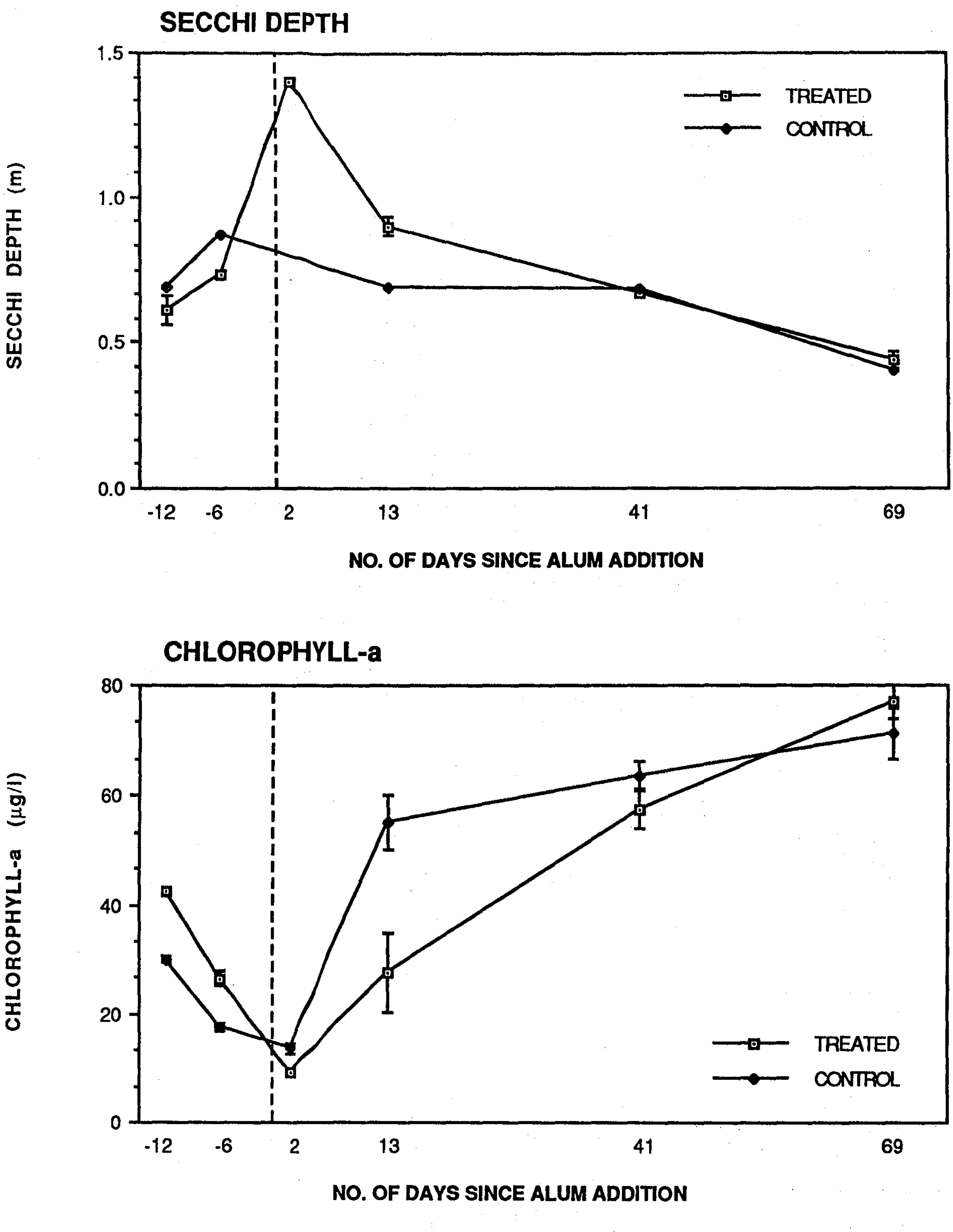


Figure 29. Changes in Secchi depth and concentrations of chlorophyll-a within the treated and control areas at Jackadder Lake, December 1988 to March 1989. Means and standard errors are shown.

DISCUSSION

Larval abundance decreased in the treated area of Jackadder Lake after the addition of alum. Species composition changed from a *P. nubifer*- dominated population to a more diverse population 9 days after the treatment and then returned to the original composition 41 days after treatment. Lake water became more neutral, conductivity increased, Secchi depth improved and chlorophyll-a concentrations fell temporarily to meso-eutrophic levels before returning to their initial eutrophic levels. However since these changes also occurred in the control area, but mostly to a lesser extent, the cause(s) of the changes must be examined.

It may be that at least part of the post-treatment change can be explained as a natural fluctuation in larval midge populations and physical parameters. Information on larval abundance and chlorophyll-a levels that was collected over the 1987/88 summer at Jackadder Lake (see our previous report) suggests that changes of these magnitudes occur naturally. Between 23 December 1987 and 2 February 1988 there was a 78% reduction in larval abundance at Jackadder Lake (1 820 ± 385 larvae/m^2 to 401 ± 99 larvae/m^2) and this followed a marked decrease in chlorophyll-a concentration from 89.7 µg/l to 6.4 µg/l (5 January to 19 January 1988). The decrease in larval abundance in the treatment area of the lake that occurred after the addition of alum (90.5% by day 19) followed a less drastic decrease in chlorophyll-a than that measured in January 1988.

There were however, differences between the environmental parameters measured in the treated and control areas of the lake, suggesting that the alum may have been partially responsible for the decrease in larval abundance. In the treated area chlorophyll-a concentrations fell further and stayed low for longer than in the control enclosure. There was considerably more improvement in Secchi depth in the treated area than the control area and although the intended decrease in pH (to 6.0) did not eventuate, pH decreased further in the treated area than in the control area.

An alternative explanation for the similarity in the changes that occurred in the treated and control areas of the lake is that the control was contaminated by alum from the treated area. This possibility cannot be discounted because some leakage into the control enclosure over the barriers was observed. In addition, alum may have moved through the continuous layer of sediment on the lake bed, although this would have been a very slow process.

A number of problems were encountered throughout the duration of the experiment. The addition of such a large amount of alum to the lake was a difficult procedure and it is likely that it was not evenly distributed over the entire area. This may have resulted in a reduction in the binding of the alum with phosphorus and algal cells. Ideally the experiment should have been carried out during spring, when algal concentrations are usually lower and consequently more controllable. However, difficulties in building the enclosure and obtaining large amounts of alum made this logistically impossible.

The relatively small size of Jackadder Lake may have influenced the extent of the control of phosphorus and algal growth by the alum addition. In small lakes a relatively large proportion of the lake area comprises the littoral region and phosphorus release in this region may be significant (Cooke and Kennedy, 1978). Also, the addition of alum may not have been sufficiently large because the planned reduction in pH (to 6.0) was not achieved and consequently the removal of phosphorus compounds may not have been efficient (Cooke *et al.*, 1986).

The placement of the control enclosure was not ideal in that the area enclosed and the treatment area did not contain similar densities of midge larvae prior to the addition of the alum. Unfortunately there was no alternative because of the physical difficulty of constructing such a large enclosure elsewhere in the lake. The position of the island in the lake provided a barrier on one side as well as support for relatively short supporting chains and curtains.

Although the experiment has not, as yet, provided indisputable evidence for the effectiveness of alum in improving the water quality at Jackadder Lake, there is some suggestion that short term improvements in water quality and larval abundance did occur. The aim of the experiment was to limit phosphorus availability for algal growth within the water column. Analyses of phosphorus levels in the water samples collected on each sampling occasion are not complete and until these data are available it is premature to judge the effectiveness of the alum treatment. Ideally, phosphorus reduction should provide a long-term control of algal growth within a lake and further monitoring of larval abundance and physical parameters is planned.

Additional benefits have been achieved by undertaking this experiment. Large control enclosures are seldom used in lake experiments and much has been learnt about the choosing of control sites and construction of such enclosures. No less important is the fact that this study is the first of its type that has been carried out in Australia and the data collected during the experiment should provide the basis for comparison with lakes elsewhere.

BIBRA LAKE LIGHT TRAP - AN INVESTIGATION INTO THE EFFECTIVENESS OF A LIGHT TRAP FOR MIDGE CONTROL

INTRODUCTION

Many night flying insects are attracted to light and, as a consequence, light traps can provide a very effective non-chemical means of trapping large numbers of insects. Ultra violet (UV) and mercury vapour discharge ('black') lights are generally used in light traps because these are the most attractive lights to insects (Stiling, 1985).

The large numbers of adult midges that collect in well lit areas adjacent to wetlands (street lamps, toilet blocks and nearby houses) indicate the potential of light traps for midge control. To investigate this form of control further, Cockburn City Council organized the construction of a large light trap on the western side of Bibra Lake in October 1988. The light trap was attached to the top of a metal tripod located in the lake, 15 m from shore. A bright light, consisting of two 400W mercury vapour street lights positioned back-to-back, and an electric insect killer (45 cm diameter) located just below the light, were supported at a height of 2m above the water surface (Fig. 11C). The light and insect killer were connected to the all-night electricity circuit at the lakeside toilet block and were switched on during the hours of darkness.

METHODS

The Murdoch research team monitored the effectiveness of the light trap on five occasions during October, November and December 1988. On each occasion a cloth bag was hung beneath the light and insect killer at approximately 1500 hours and was collected 24 hours later. The midges collected were counted (by sub-sampling if very large numbers of midges had been collected) and identified.

RESULTS AND DISCUSSION

The number of adult midges collected ranged from 0 to 51 072 (mean 13 306 ± 10 945). The major species present were *C. australis*, *C. alternans*, *P. nubifer* and *P. villosimanus*, although *C. intertinctus*, *C. tepperi* and *D. conjunctus* occurred in small numbers. *C. australis* dominated the collections made on 26 October and 9 November, whereas *P. nubifer* was the dominant species in the 7 December and 20 December 1988 collections.

Other flying insects were attracted by the light trap. Of these, moths were the most numerous, with elaterid beetles, ichneumonid wasps and several families of flies being represented.

The light trap shows some potential as being part of an integrated programme of control for chironomid midges, although the number of adult midges collected (maximum 51 072) would probably have represented a very small proportion of those emerging. Information on emergence rates at Bibra Lake is not available, however at nearby North Lake the maximum rate of emergence recorded was 818 adults/m^2. Assuming a similar rate of emergence through- out the 5 ha littoral area of North Lake, then approximately 41 million adults would emerge in 24 hours. Consequently the effectiveness of a single light trap must be seen to be limited.

The ecological desirability of using non-chemical control methods, means that it is important to pursue the use of light traps in the future, by using more traps and by comparing the attractiveness of traps of different designs. To further this avenue of research, a number of light traps are to be constructed by Perth City Council at Lake Monger before next summer and their effectiveness will be monitored. As a note of caution however, Stiling (1985) states that insect traps alone are rarely sufficient to provide adequate control of insect pests. They are generally used in conjunction with other methods of control and may well mean that fewer applications of pesticides are needed. In one example, black lights mounted around a tobacco crop in Florida reduced the annual number of insecticide sprays from 17 to two.

LAKE GOOLLELAL RESIDENTS SURVEY - HUMAN PERCEPTIONS OF, AND INFLUENCES ON, NUISANCE MIDGE SWARMS

INTRODUCTION

Much anecdotal information was obtained during the first year of our study to indicate that the severity of midge swarms appeared to vary over quite small spatial scales. In some instances, neighbouring households appeared to experience quite different levels of nuisance and it was not clear whether this was the result of different levels of tolerance on behalf of the householders, the different physical features of their dwellings (e.g. brighter outdoor lights etc.) or micro-meteorological effects (i.e. differences in local wind patterns).

In an attempt to research this area further, and to arrive at control measures which could be implemented by individual householders, residents living adjacent to Lake Goollelal were asked to respond to a questionnaire regarding the degree of midge nuisance that they experienced and the location and physical appearance of their houses.

METHODS

After consultation between the Murdoch research team and members of the Midge Research Steering Committee, agreement was reached on the details of the questionnaire to be sent to residents living near Lake Goollelal. The questions to be asked of residents related to the degree of nuisance that midges caused, to the physical characteristics of the house and surrounding garden and to the use of external lights. Figure 30 shows the questionnaire sent to residents included in the survey. Ray West of the Wanneroo City Council organized the distribution and collection of the completed questionnaires during August and September 1988.

Of the 95 questionnaires sent out to residents, 44 (or 46%) were returned. Eight of these were not used in the analysis of the results because the householders had resided at their present addresses for only a few months and as a result, were unable to answer some questions.

RESULTS AND DISCUSSION

Table 7 gives a summary of the results of the survey. The residences have been grouped on the basis of the general level of midge nuisance that was experienced: "low", "moderate", "high" or "extreme". There are few trends apparent from the answers to the questionnaire. The "general" level of nuisance experienced by residents corresponded closely to the levels experienced "last year" and "this year so far". Apart from the greater number of outside lights at those houses experiencing extreme midge nuisance, there were no clear differences between the groups. Residents in the "extreme" group had a mean of 13 outside lights, though the large number of

QUESTIONNAIRE

Name ______________________________

Address ______________________________

____

Date ____________________

How many years have you resided at the above address? ____________________

How would you describe the problem caused to you by midges (please use low, moderate, high, extreme)?

Generally? ________________________

Last Year? ________________________

This Year So far? ________________________

Are midges a nuisance inside or outside you house? ________________________

Can you see a lake or waterbody from your property? ________________________

What colour is the exterior of your house? ______________________________

How many outside lights (patio, front door, car port)

do you have? ________________________

do you use often? ________________________

Are the outside lights ordinary incandescent bulbs or fluorescent tubes? ______

____

Are your inside lights shielded form the street by curtains? ________________

by trees and shrubs? ________________

Do you have insect screens on your windows and doors? ________________

Do you take any control measures against midges on your property e.g.

sprays? ____

Figure 30. The questionnaire sent to residents living near Lake Goollelal.

LEVEL OF MIDGE NUISANCE GENERALLY	Distance from Lake (m)	No. Years at Address	Problem Last Year	Problem this Year	Problem Inside or Outside	See Lake from House?
LOW (n=12)	281±32	12±0.8	Generally Low	Generally Low	Most none Some outside	9 Yes 3 No
MODERATE (n=13)	298±35	5±0.8	4 High 8 Mod 1 Low	1 Extreme 1 High 6 Mod 5 Low	6 Outside 5 Both 2 -	10 Yes 3 No
HIGH (n=8)	238±36	6±2.0	1 Extreme 5 High 2 Mod	4 High 2 Mod 2 Low	3 Outside 5 Both	7 Yes 1 No
EXTREME (n=3)	223±48	15±10.8	2 Extreme 1 High	2 Mod 1 Low	2 Outside 1 Both	3 Yes

LEVEL OF MIDGE NUISANCE GENERALLY	No. of Outside Lights	O'side Lts Used Often	Bulbs or Fluoros	Curtains	Trees or Shrubs	Insect Screens
LOW (n=12)	5.9	6 Yes 5 No	Mainly bulbs	10 Yes 1 No	6 Yes 5 No	10 Yes 1 No
MODERATE (n=13)	6.4	Mixture	Mainly bulbs	13 Yes	6 Yes 6 No	12 Yes 1 No
HIGH (n=8)	3.9	4 Yes 4 No	5 Bulbs 1 Fluoro 1 Both 1 Halogen	6 Yes 1 No 1 Some	3 Yes 5 No	7 Yes 1 No
EXTREME (n=3)	13	3 Yes	3 Bulbs	3 Yes	2 No 1 -	3 Yes

Table 7. Summary of results from 36 questionnaires completed by residents living near Lake Goollelal. The column headings relate to questions asked in the questionnaire (Fig. 30) (- = no answer).

lights at one house (33, presumably mostly comprising a string of decorative lights) biases this figure markedly. Factors such as distance from the lake, house colour, types of outside light, presence of curtains, trees or insect screens did not appear to influence the severity of the nuisance caused by midges. Many residents attempted their own control measures using insecticide sprays, insect coils and electric insect killers.

The approximate locations of the residences concerned in relation to the lake are shown in Fig. 31. Apart from the occurrence of high and extreme nuisance experienced by a number of residents on the western side of the lake, there was no apparent trend in the level of nuisance at any direction from the lake.

These results support the initial belief that different levels of nuisance are experienced by householders living within close geographical proximity. The reasons as to why this should occur are not clear but it appears it is not the result of obvious differences between houses.

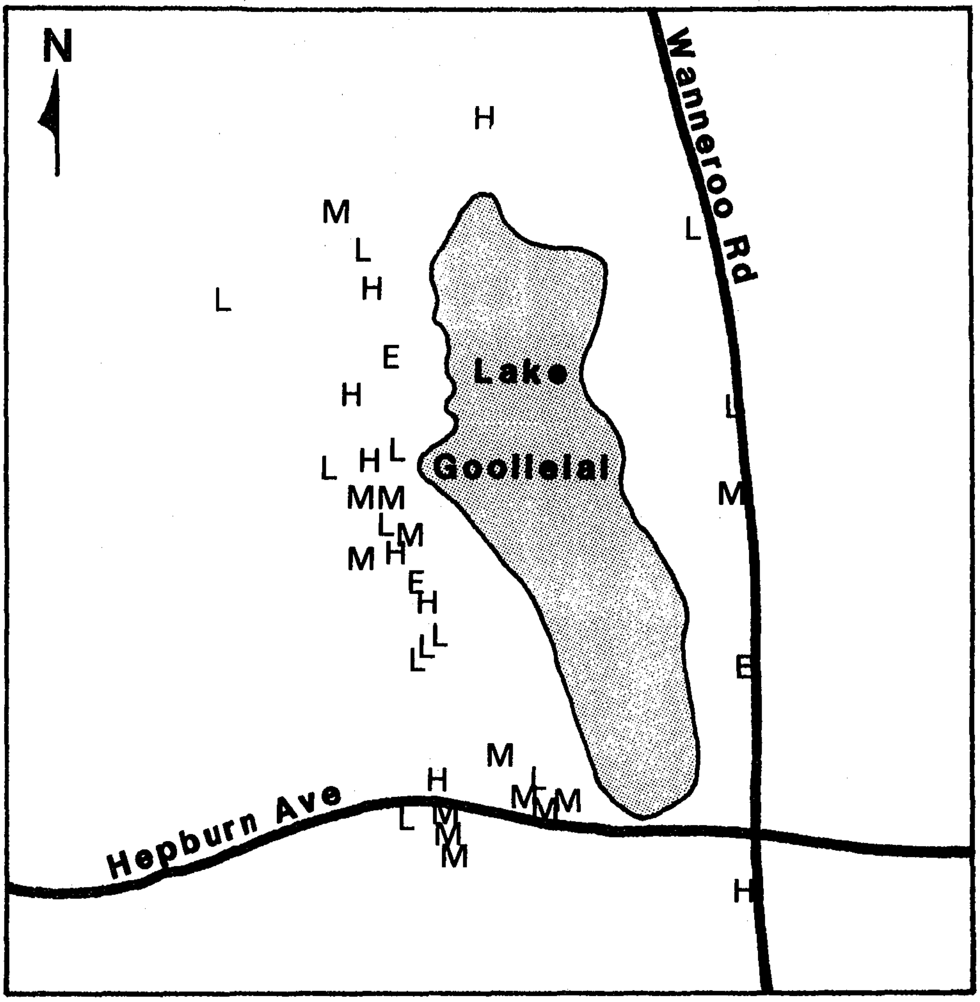


Figure 31. Map showing the locations of residences included in the Lake Goollelal survey indicated by the level of nuisance generally experienced. (L = low, M = medium, H = high, E = extreme).

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

Data obtained in the second year of research into Perth's midge problems will contribute to the better management of the problem in several ways.

Perhaps one of the most important pieces of information to be obtained this year was the data on the effectiveness of Abate in the field which was gained by the use of enclosures during the 15 November 1988 treatment of North Lake by Cockburn and Melville City Councils. Firstly, an increase in application rate of Abate (to approximately 5 kg/ha of 50SG in one metre of water) appears to be needed for treatment with this pesticide to be effective. The results of monitoring the treatment at North Lake also indicated that the application of Abate by the fixed wing aircraft was very patchy. Alternative methods of application are needed (e.g. by boat or helicopter) to target the areas where larval midges are most abundant.

The usefulness of the data obtained from evaluating the effectiveness of Abate in the field indicates the value of undertaking this type of work. For this reason field testing of one or more alternatives to Abate (granular Bti, Perigen 500 and Sumilarv) will be given major priority in 1989/90.

The high rates of Abate needed to achieve 95% mortality of *P. nubifer* under controlled conditions in the laboratory suggest that some resistance to Abate is present in the gene pool of this species. As a consequence, the effective use of Abate in the wetlands in future years will become increasingly limited and alternatives to this pesticide must be found.

The laboratory trials of granular Bti, Perigen and Sumilarv which were undertaken this year indicated that all three compounds are potentially useful (although none are ideal). Field trials are now needed to determine their effectiveness under field conditions.

Continuation of the larval and adult monitoring programmes at Forrestdale and North Lakes revealed major differences in the nature of midge populations and problems at the two lakes. The consistent recurrence of a single peak in the density of *P. nubifer* at Forrestdale Lake in the summers of 1987/88 and 1988/89 indicates that a single well-timed application of an effective pesticide may be sufficient to control midge problems at this lake. The need for treatment of the lake in spring to control *C. australis* may need to be considered in 1989/90; densities were not high enough to cause problems or warrant treatment in 1988.

The extremely high and sustained production of midges at North Lake between December 1988 and March 1989 indicated that, in the short term, continued applications of pesticides are likely to be needed at this lake during summer, to control midge problems. In the longer term however, the problem of excessive nutrient inputs to the lake must be tackled, and the nutrient status of the lake reduced if any lasting reduction in midge densities is to occur.

When pesticide treatments are used they must be effective. For control to be achieved larval densities must be reduced to below the threshold considered to cause midge problems in nearby urban areas. Even a mortality rate of 60% to 80% is not sufficient if the pool of larvae which survive the treatment is large enough to result in a continuation of the midge problem. Only the January treatment of North Lake reduced larval densities to anywhere near the threshold level.

The accurate prediction of impending midge problems is an important feature of any midge control programme and to facilitate this a standard method for monitoring larval densities in Perth wetlands has been developed for use by Local Government. The method uses a corer to sample a known area of the lake substrate for midge larvae, thus allowing comparisons of larval densities on different dates and even at different lakes. In general, a density of 2 000 larvae/m^2 or greater is considered to be the level at which a pesticide treatment is warranted if midge problems in adjacent urban areas are to be avoided.

Several alternatives to the chemical control of midges were investigated during the 1988/89 research programme. The use of alum to reduce algal blooms (an important food source for larval midges) at Jackadder Lake appeared to result in a short term improvement in water quality and a reduction in the abundance of larval midges. However further work is required to conclusively demonstrate the effectiveness of alum as an indirect method of midge control.

In a second study the effectiveness of a light trap at Bibra Lake in controlling adult midges was investigated. The number of adult midges caught over 24 hours ranged from 0 to 51 072, indicating that light traps may have some potential as part of an integrated midge control programme. However the number of midges collected by a single light trap will probably be only a very small proportion of the total number emerging from the whole lake.

The variability in midge problems experienced within a single suburb, and the possible influence that individual householders may exert on the problem was investigated. Residents living near Lake Goollelal were asked to respond to a questionnaire regarding the degree of midge nuisance that they experienced and the location and physical appearance of their houses. The results of the questionnaire indicated that different levels of nuisance were experienced by householders living within close geographical proximity, but that these differences could not be attributed to any obvious differences between houses.

There is no single "best" technique for controlling midges associated with urban wetlands. The use of Abate or suitable alternative pesticides will continue to be an important means of short term control. The problems of resistance, biomagnification, residues and harmful effects on non-target or beneficial predatory organisms mean that total reliance on broad spectrum pesticides is neither ecologically nor economically desirable. The modern concept of pest control is integrated pest management in which several control techniques are used simultaneously to provide the best possible control.

In addition to the short term use of pesticides in Perth wetlands some form of nutrient reduction is urgently required if a longer term solution to the midge problem is to be achieved. Ultimately this requires a change in land management practices in the catchment so that nutrient inputs from surface flows are reduced. More immediate solutions to the problem of excess nutrients entering a wetland may include the use of alum, the diversion or treatment of water in stormwater drains, and the capping or removal of nutrient-rich sediments. Additional control methods that may lessen the need for pesticide use include the use of light traps, reduction or changes in outdoor lighting of houses, and the replanting of buffer zones of vegetation.

Results of the previous two year's research have prompted a number of questions relating to the better control and management of nuisance midges in Perth wetlands. Suggested priorities for research to be undertaken during the final year of the study (1989/90) include firstly, the continuation of the larval and adult monitoring programmes at North Lake and Forrestdale Lake with an emphasis on the treatment of lakes when nuisance threshold levels of larvae are reached. This will require close coordination with Cockburn, Melville and Armadale City Councils and CALM if treatments are to be made at the most appropriate times. Secondly, field trials of alternatives to Abate should be carried out. Ideally one or more of granular Bti, Perigen 500 and Sumilarv should be tested in enclosures at North Lake or as whole lake treatments if sufficient pesticide is available. The third proposed research priority is to undertake experimental investigations into the role of nutrients in midge production. Small ponds (perhaps those on the South Perth foreshore) could be used to test the influence of nitrogen and phosphorus, separately and in combination, in a controlled experiment. The changes in environmental parameters and larval abundance would be monitored over a period of several months.

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