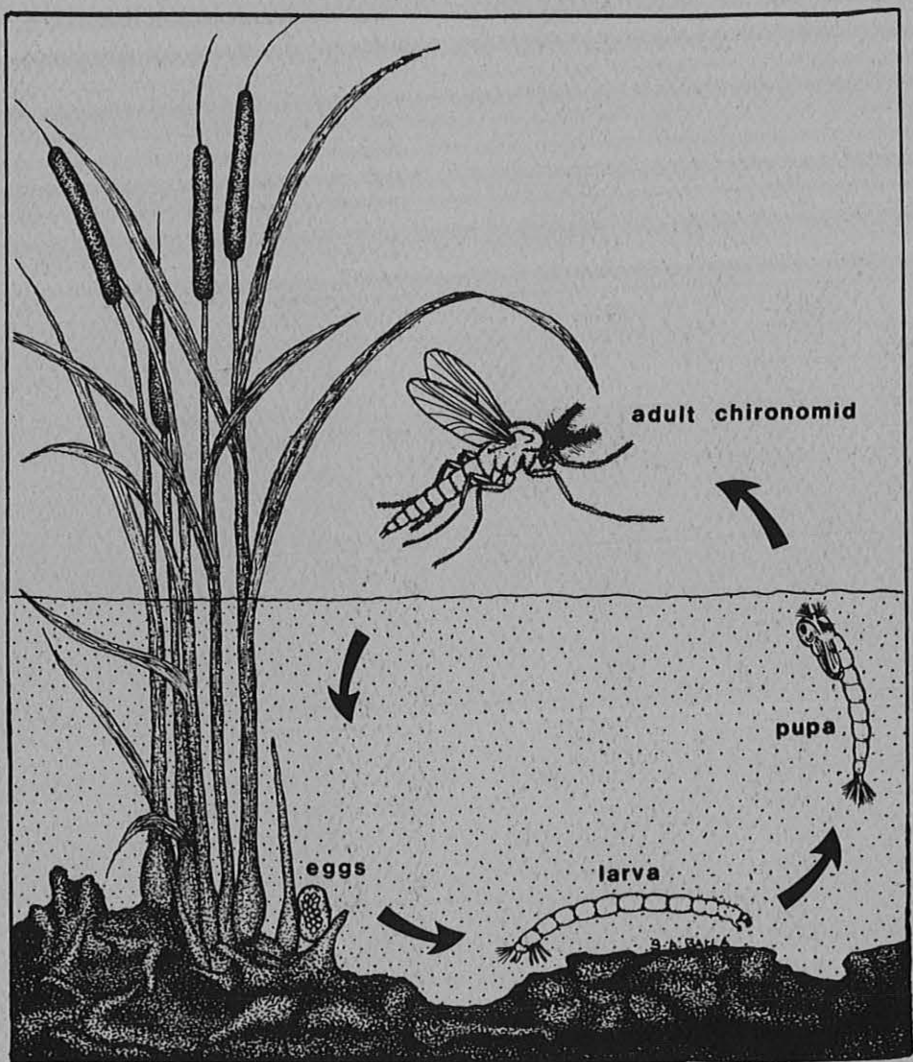
FORRESTDALE LAKE CHIRONOMID STUDY



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Forrestdale Lake Chironomid Study

A study of the larval chironomids in Forrestdale Lake W.A. and the effects of the pesticide Abate.

Prepared for: The Department of Conservation and Land Management

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ACKNOWLEDGMENTS

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Mr Grant Pearson of CALM provided considerable assistance with all aspects of the fieldwork, and made our study much easier to carry out than it may have been.

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Contents

SUMMARY

1. Nine species of larval chironomids were recorded from Forrestdale Lake between September 1985 and January 1986. Three species; *Dicrotendipes conjunctus, Polypedilum nubifer* and *Procladius villosimanus* were common on most sampling occasions, a fourth species, *Chironomus australis*, was common at the start of the study but not in the later stages.

2. *D. conjunctus* and *P. nubifer* were abundant on a submerged alga, *Chara* sp., which was widespread throughout the lake. Both species plus *P. villosimanus* were also abundant in the sediments of the lake bed. Forrestdale Lake appeared to be unique amongst the urban wetlands of the Swan Coastal Plain in 1985, having a dense lake-wide bed of *Chara* . The alga, which has a macrophyte-like growth form, appears to provide an extensive substrate and food source for larval chironomids and other macroinvertebrates.

3. Only one species, *P. nubifer,* had been reported to cause nuisance swarms at the lake, but larval densities of *D. conjunctus* and *P. villosimanus* were high enough to suggest that these species may also contribute to the midge problem. Life cycles of six to eight weeks duration were recorded for both *D. conjunctus* and *P. nubifer,* the life cycle of *P. villosimanus* could not determined but is known to be considerably longer. Chironomids with shorter life cycles are able to produce a greater number of individuals in a given time than those with longer life cycles, and as a consequence, they can recover from a spraying event more quickly and their potential to produce a series of nuisance swarms during summer is greater.

4. The pesticide Abate (temephos) was found to be effective in reducing the numbers of *D. conjunctus* and *P.nubifer* but not effective against *P. villosimanus.* Densities of *P. villosimanus* actually increased after the Abate treatments. If *P. villosimanus* is found to be a nuisance species the usefulness of Abate for the reduction of midges at Forrestdale would appear to be reduced and alternative means of control must be considered. If *P. villosimanus* is not a nuisance species, Abate remains an effective treatment, at least against *D. conjunctus* and *P. nubifer,* and will provide approximately six to eight weeks control at the lake temperatures and water levels recorded in this study.

5. Larvae were distributed evenly throughout the lake while water levels were high, but densities at the edge of the lake became lower when the water level at the shore fell to 10cm or less. Larval densities within the *Typha* were consistently low throughout the study period, probably because the lake bed within the *Typha* was dry by mid-December.

6. Forrestdale Lake has a rich and diverse macroinvertebrate fauna and invertebrate species richness is one of the highest recorded from the urban wetlands. Some members of the non-target fauna appear to be affected by the Abate treatments. Densities of two of the most abundant groups, the Amphipoda and the Ostracoda, were reduced after the first spraying. Numbers of the Notonectidae and the Odonata were also reduced. These latter two groups constitute part of the higher-order trophic structure of the lake and therefore, as predators, exert some degree of natural control on larval chironomid populations. This control would be lost when their numbers fell after spraying.

7. Short-term and long-term proposals for the management of the midge problem at the lake are suggested. The use of pesticides is not a long-term solution to the nuisance swarms of midges because of the development of resistance to pesticides which progressively reduces their effectiveness. In addition, the chironomid fauna is an important component of both the detrital and grazing food chains within the lake and undoubtedly forms part of the diets of resident waterbirds. The lake is valued as a waterbird habitat, and because of its status as a wetland Nature Reserve the use of a pesticide such as Abate, which effectively destroys an important portion of the wetland's food chains each spring and summer, must in principle be considered undesirable.

In the short term, spraying with Abate should continue in conjunction with a simple monitoring programme carried out to detect increases in larval numbers. No application of Abate or any other pesticide should be permitted unless their effects are monitored, preferably on both target and non-target organisms.

In the longer term a greater understanding of wetland processes and chironomid ecology must be developed and alternative forms of control investigated. The structure of the chironomid community at the lake is not a simple one, at least four major species are responding in different ways to pesticide application, changing physico-chemical parameters and increasing nutrient concentrations. As a result more information is required on the ecology of the most abundant species and the factors driving the lake's primary and secondary production .

8. Greater public awareness of wetland processes needs to be developed by appropriate educational means. In particular, the importance of maintaining wetland food chains for wetland conservation and the possibility that nuisance swarms of insects such as midges are often made worse by human-initiated factors, such as the clearing of fringing vegetation, and the problem of increased nutrient inputs needs to be addressed. The ongoing problems caused by permitting surburban development immediately adjacent to wetlands also needs to be clearly communicated to government planning agencies and private developers alike.

RECOMMENDATIONS

The use of pesticides is not a long-term solution to the nuisance swarms of midges because of the development of resistance to pesticides which progressively reduces their effectiveness. It is already evident that the swarming is becoming worse; perhaps an indication that Abate's effectiveness is waning.

Pesticides also affect non-target organisms and hence unbalance the lake ecosystem. This might result in undesirable effects such as other species becoming a nuisance to local residents.

The chironomid fauna is an important component of both the detrital and grazing food chains within the lake and undoubtedly forms part of the diets of resident waterbirds. Anything affecting the chironomids must have an impact on the food chains within the lake. The lake is valued as a waterbird habitat, and because of its status as a wetland Nature Reserve the use of a pesticide such as Abate, which effectively destroys an important portion of the wetland's food chains each spring and summer, must in principle be considered undesirable.

Ultimately, some other form of control must be found. However, this requires much more information than this preliminary study could gather. In the short term spraying with Abate will probably need to continue because no socially, politically, or ecologically suitable alternatives have, as yet, been devised.

Short- Term Management Proposals

1. The proximity of the suburb of Forrestdale to the lake suggests that some form of midge control will be required each summer. As long as spraying with Abate continues a simple monitoring programme must be carried out to detect increases in larval numbers. No application of Abate or any other pesticide should be permitted unless their effects are monitored preferably on both target and non-target organisms. If swarms are to be avoided the lake should be sprayed as soon as an increase in larval numbers is observed in spring, and thereafter when further larval increases are recorded, probably six to eight weeks after the initial treatment.

2. Fortnightly samples taken at several different sites should provide enough information on which to base a spraying programme. Sweep samples can be taken if a bed of *Chara* is still present within the lake, otherwise core samples of the lake sediments should be obtained. Larval numbers can be estimated in the field if necessary.

3. Ideally, a biologist should be employed to undertake such a monitoring programme, in which case more thorough sampling methods and the identification of species should be carried out. If funding does not permit the employment of specialized personnel, then a simple monitoring programme could be carried out by any motivated person provided some initial training in techniques and identification is given.

4. If swarms do occur, the adults forming the swarms should be identified immediately to determine which of the nine or more possible chironomid species are occurring in pest proportions. If *P. villosimanus* is found to form nuisance swarms, the use of Abate is ineffective and an alternative means of control must be considered. If *P. nubifer* and/or *D. conjunctus* are the major nuisance species, then Abate will continue to be an effective pesticide (until resistance is developed). For maximum economy spraying should only be carried out when the numbers of larvae are high.

Long-Term Management Proposals

Longer-term and ecologically sensitive management of the lake requires that the following problems be addressed:

1. The structure of the chironomid community at the lake is not a simple one, at least four major species are responding in different ways to pesticide application, changing physico-chemical parameters and increasing nutrient concentrations. As a result more information is required on the ecology of the most abundant species. Such information needs to be acquired over several years, because year to year variations are likely to occur in wetland ecosystems such as Forrestdale Lake, which are very much influenced by fluctuations in annual rainfall.

2. The microdistribution of larval chironomids within the lake, particularly with regard to the occurrence of submerged macrophytes and algae, needs to be determined to enable the choice of the most appropriate sampling sites.

3. The effects of Abate on the chironomids and other fauna needs to be examined. One way of doing this is to set up enclosures within the lake and ensure Abate is excluded. Comparison of faunal richness and abundance in treated and untreated areas would provde information on the effectiveness of Abate on different chironomid species, the possible development of resistance and the effects of the pesticide on the non-target invertebrates.

4. The role of the chironomids in the wetlands needs to be established. This entails an examination of their predators, prey and their role in the detrital and grazing food chains within the lake. They undoubtedly form part of the diets of waterbirds and it is the waterbirds which make this wetland so valuable for conservation and scientific and educational purposes.

5. The role of nutrients in the ecology of the lake must also be investigated as increasing midge populations and the presence of extensive beds of *Chara* reflect an overall increase in nutrients entering the lake. The potential for Abate, an organophosphate, to further increase nutrient levels needs to be assessed.

6. Greater public awareness of wetland processes needs to be developed by appropriate educational means, with particular regard to the importance of maintaining wetland food chains for wetland conservation, and the possibility that nuisance swarms of insects such as midges are often made worse by human initiated factors such as the clearing of fringing vegetation and increased nutrient inputs to the lake.

The ongoing problems caused by permitting surburban development immediately adjacent to wetlands needs to be clearly communicated to government planning agencies and private developers alike. The large expense associated with the control of midges at Forrestdale Lake may have been avoided if the suburb had been sited further from the lake and particularly if placed to the south or west rather than on the downwind side of the summer seabreeze.

INTRODUCTION

Forrestdale Lake is a large (area = 244 hectares) but shallow and temporary waterbody on the Swan Coastal Plain lying within the Shire of Armadale. In recent years swarms of midges (adult chironomids) have reached nuisance proportions in the lake environs, particularly within the adjacent suburb of Forrestdale, between the months of September and January (the latter date being dependant upon the lake drying out). Several applications of the larval pesticide Abate 5SG are made to the lake by aerial spraying during these months.

There is some suggestion that the effectiveness of pesticide applications, which have been made two or three times each year since 1975, may be decreasing. In 1984-85 adult midge numbers appeared to be little affected by spraying of the lake. Reasons for increasing midge numbers are not clear. It is possible that the midge populations within the lake have developed higher tolerances as a result of repeated pesticide applications. Abate might also destroy the natural predators of midges and thus intensify the problem. The widening belt of *Typha* around the margins of the lake have been implicated in providing shelter from aerial spraying to the midge larvae living within it.

Initially, nothing was known about the species which constituted the swarms or the species of larvae present in the lake.

A biological sampling programme was undertaken to determine the densities, species composition and distribution of the larval chironomid communities within the lake and to monitor the effects of Abate treatments on these communities. The major objective of the study was to provide baseline information which would be of use in formulating a management policy for the control of nuisance midge swarms at Forrestdale Lake.

METHODS

Study Sites and Sampling Frequency

Permanent sampling sites, marked by jarrah stakes, were set up along two transects, north to south (to middle of lake) and east to west (across the lake) as indicated in Fig. 1. Sites within the *Typha* were included on each transect.

The lake was sampled at fortnightly intervals ; a preliminary sampling was undertaken on September 29, 1985 (along the east-west transect only) and the first proper and subsequent samplings were conducted on October 10 and 21, November 6 and 20, December 4, 16 and 30 and January 13, 1986.

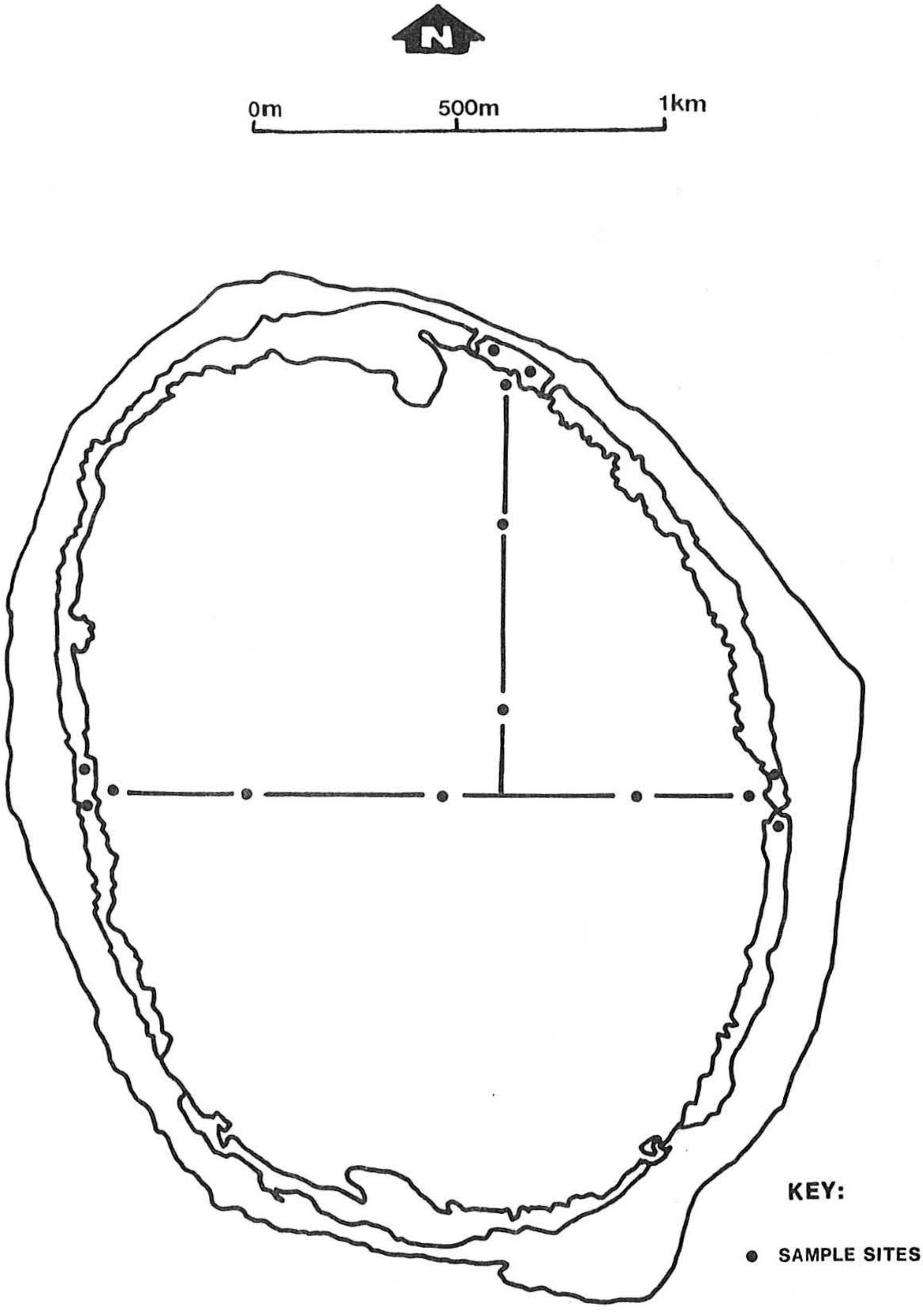


Fig. 1. Location of transects and sampling sites in Forrestdale Lake.

The sampling programme was discontinued when the water level had fallen to less than 10 cm and much of the lake bed was dry. Aerial applications of Abate, in granular form, were made to the lake on October 18 and December 20, 1985.

Depth, Temperature and Salinity

Water depths at each site and the temperature of the water and lake bed were recorded on each sampling occasion. Water samples (500 ml) were collected for the measurement of conductivity / salinity on October 13, November 6 and December 16. Samples were stored at $4^{o}C$ prior to measurement with an Activon conductivity meter.

Invertebrate Sampling Methods

Core samples only were taken at a preliminary sampling session, as previous work undertaken by Edward (1964) in Lake Monger, and ourselves in North Lake and Lake Monger (as part of a different study conducted in 1985), suggested that the chironomid fauna would be a predominantly benthic one. However, observations made at the preliminary sampling session revealed that Forrestdale Lake differed from the former two lakes in that a very dense stand of submerged vegetation covered almost the entire bed of the lake. The vegetation consisted mainly of *Chara* sp., an alga with a macrophytic type of growth form, and the macrophyte *Ruppia polycarpa* . Because larval chironomids were observed freely swimming within the vegetation, three different invertebrate sampling techniques were employed at each site to ensure that all habitats (the benthos, the open water and the submerged vegetation) were adequately sampled. The techniques employed were as follows :

Core samples - quantitative samples of the surface of the lake bed were taken using a 10 cm diameter stainless steel corer. The upper 5 cms only of each core were kept.

Pump samples - quantitative samples of the lake bed and water column (comprising both open water and submerged vegetation) were taken using a 15 cm diameter PVC pipe and a hand operated bilge pump. The pipe was pushed or hammered into the bed to a depth of approximately 10 cms, and the water, sediments, vegetation and fauna enclosed within were pumped out of the pipe into a 250 micron mesh net.

Sweep samples - a long handled sweep net was used to sample larvae in the water column and within the submerged vegetation. This method may be regarded as semi-quantitative because the net was swept vigorously through the water for a fixed period of time (one minute) for all samples. Two core samples, two pump samples and two sweep samples were taken at each site. All samples were placed in labelled plastic bags and preserved with 100% ethanol. Samples were transported back to Murdoch University for sorting and identification.

Sorting and Identification of Larval Chironomids

Because the sorting and identification of invertebrates takes a considerably longer period of time to complete than the amount of time spent on collection, only samples from the north-south transect (the two sites within the northern stand of *Typha* and at 0m, 200m and 600m from the lake margin - Fig. 1) were sorted for this study. The remaining samples, from the east-west transect, have been stored and will be processed at a later date if any additional information is required.
In the laboratory the core and pump samples were individually washed through 1mm and 500 micron sieves, the material retained on each sieve was placed onto white trays and all larval and pupal chironomids visible to the naked eye were removed and stored in 1/4 oz Macartney bottles in 70% ethanol. The contents of the trays were then subsampled (by volume) and examined at 10x magnification under a Wild M6 dissecting microscope. All chironomids were removed and stored as above.
The sweep samples usually contained large amounts of *Chara* and the dense matted strands effectively hid most larvae. The *Chara* was first subsampled, the algal strands in the subsample were then pulled apart and larvae and pupae were removed and stored as above.
The contents of all vials were examined following initial sorting and larvae and pupae were identified to species level using Edward's (1964) and Martin's (1986) unpublished keys.

Size-Frequency Analysis

To obtain life history information larval head capsule diameters were measured for the three most abundant species, *D. conjunctus, P. nubifer* and *P. villosimanus* collected in pump samples.

Sorting and Identification of Non-Target Macroinvertebrates

A study of the effects of Abate on non-target invertebrates was carried out by Ms Barbara Wienecke as an Independant Study Contract; this project formed part of her B.Sc. studies at Murdoch.
Due to time constraints her study was restricted to samples taken at one site only; the 200m site on the north-south transect.
All macroinvertebrates in the samples (cores, pumps and sweeps) taken at the 200m site on all sampling occasions were sorted and identified by the same procedures as described above for larval chironomids. Specimens were identified to species level where possible, using the following keys to the Australian fauna : general, Williams (1980); Odonata, Watson (1962); Mollusca, Smith and Kershaw (1979); and Coleoptera, Matthews (1982).

RESULTS

Depth, Temperature and Salinity

The annual changes in depth of Forrestdale Lake over the period July 1982 to January 1986 are given in Fig. 2a. The change in depth at three sites in the lake and one in the *Typha*, over the study period October 1985 - January 1986, are given in Fig. 2b. Water levels in the lakes of the Swan Coastal Plain generally reach a maximum in October and fall to a minimum in April (Seddon, 1972).
The maximum depth of 65cm recorded at the centre of the lake at the start of this study was the lowest maximum recorded at the lake in the period 1982 to 1985 (Fig.2a). The sites within the *Typha* and at the edge of the lake (0m site) were completely dry on December 16, 1985 . Some water remained at the centre of the lake at the last sampling session, on January 13, 1986, but the lake was completely dry during February, March and April, 1986. In the preceding three years the lake had not dried completely until March.
Temperatures of the lake water and the bed, at the 200m site, are given in Fig. 3. It should be noted that by coincidence all sampling was conducted on days that were relatively cool and the temperature of the shallow lake may have been considerably higher at other times. Both water and bed temperatures varied little over the study period, water temperatures were consistently high; between 23^{o}C and 26 ^{o}C, whilst temperatures in the bed were 2-3 ^{o}C lower.

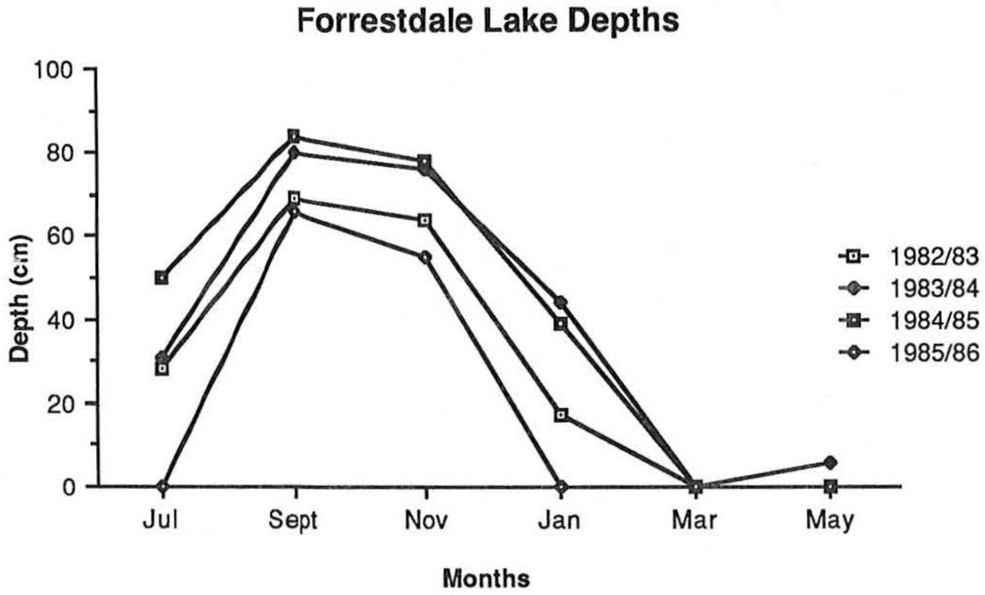


Fig. 2a. Changes in water depth at Forrestdale Lake from July 1982 to May 1986. (Data from CALM)

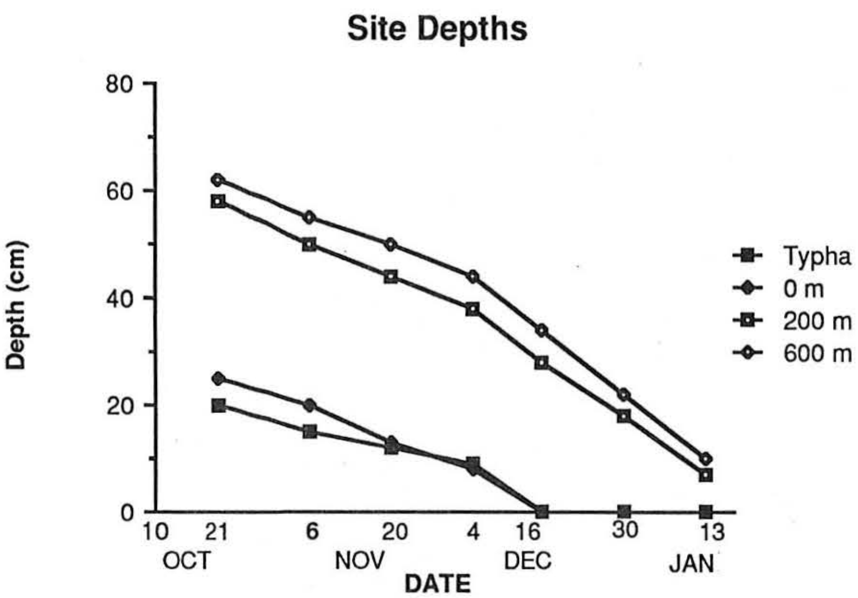


Fig. 2b. Changes in depth (cm) at the four sampling sites in Forrestdale Lake between October 1985 and January 1986.

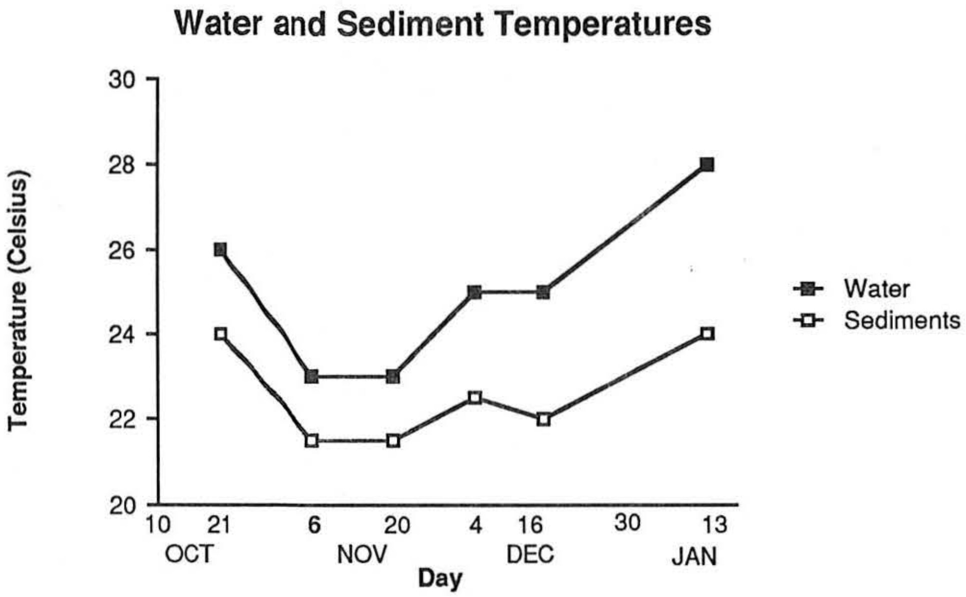


Fig. 3. Variation in water and bed temperature at the 200m site in Forrestdale Lake between October 1985 and January 1986.

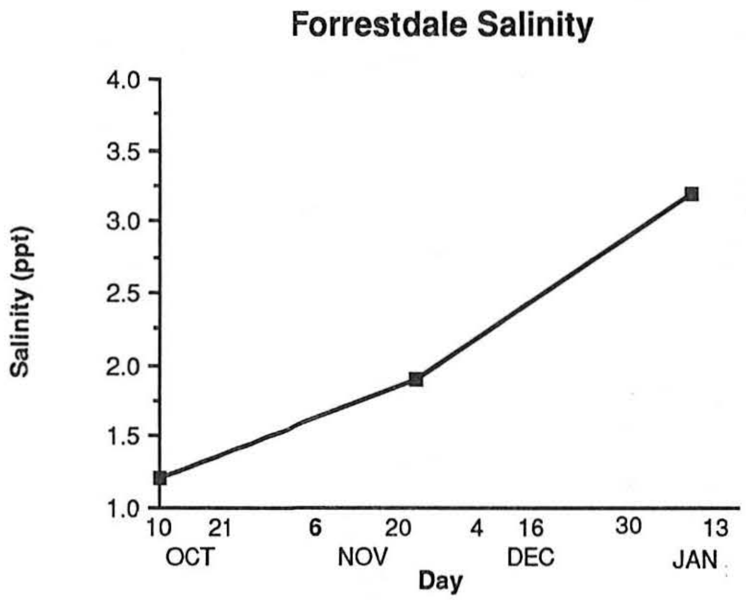


Fig.4. Changes in salinity (p.p.t.) at Forrestdale Lake between October 1985 and January 1986.

Changes in the salinity of the lake water are given in Fig. 4. Using a salinity of 3 p.p.t (after Williams, 1981) as the boundary between fresh and saline systems, Forrestdale Lake can be classified as fresh at the start of the study in October, and brackish near the end of the project in January. Salinity increased as the lake volume decreased and the maximum value of 3.1 p.p.t was recorded from the last sample taken in December.

Species Composition and Abundance of the Larval Chironomid Fauna

Larvae of nine species of chironomid were recorded from Forrestdale Lake between September 1985 and January 1986. Of these only three species; *Dicrotendipes conjunctus, Procladius villosimanus* and *Polypedilum nubifer,* were common throughout the study. A fourth species, *Chironomus australis,* was common at the start of the study but not thereafter. The total numbers of larvae obtained at all sites, by all sampling methods, is given in Fig. 5. Mean larval densities plus or minus standard errors and the changes in relative abundance of each species over the study period, as revealed by each sampling method, are given in Figs 6 (a and b), 7(a and b), and 8 (a and b).

Size-Frequency Analysis

The cumulative number of larvae occurring in 2mm size classes, based on head capsule width, in the three most abundant species; *D. conjunctus, P. nubifer* and *P. villosimanus* is given in Figs. 9 a, b and c respectively. Distinct peaks on each graph indicate the presence of three instars in *D. conjunctus* and *P. villosimanus* and two instars in *P. nubifer.* Probably all three species also possessed an earlier instar too small to be detected in this study (that is, larvae which would pass through a 250 micron mesh net).

The actual number of larvae in each size class, based on head capsule width in each species, is given in Figs. 10, 11 and 12. Although distinct peaks were evident in the cumulative frequency plots, changes in the peaks cannot be traced on the size frequency histograms. This may be a result of too long an interval between sampling (that is, weekly rather than two weekly samples were needed) or that sample sizes were too small. However the effects of the first Abate treatment are evident, with numbers of *D. conjunctus* being reduced, whilst numbers of *P. villosimanus* increased. Numbers of *P. nubifer* were too low to detect any change.

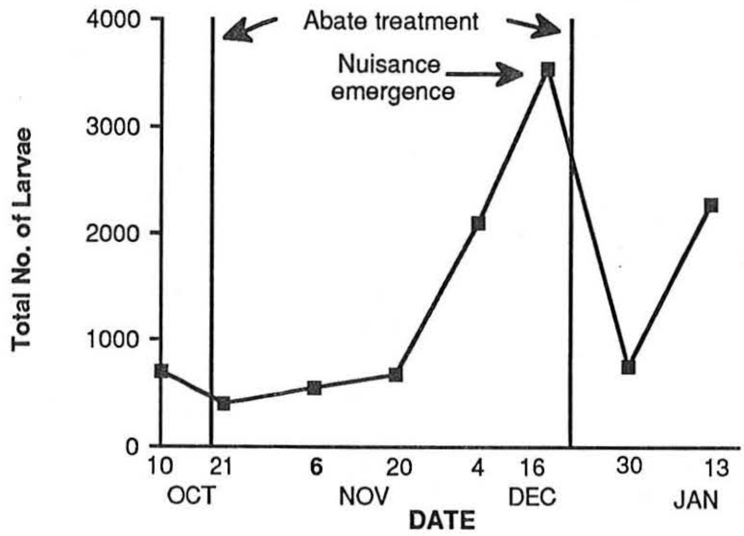


Fig. 5. Changes in the total number of chironomid larvae sampled at Forrestdale Lake between October 1985 and January 1986.

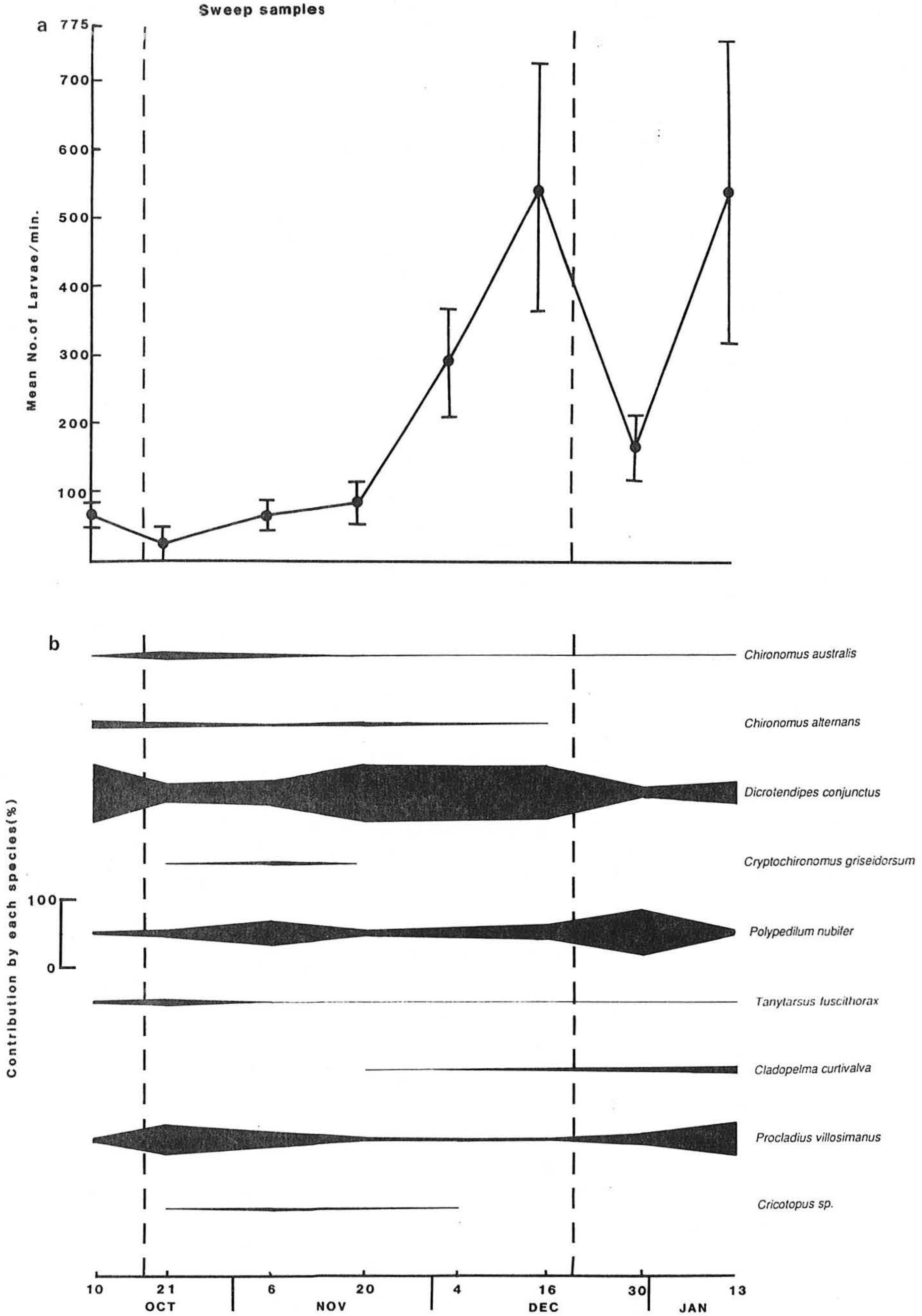


Fig. 6. Chironomid density and percentage contribution by each species in sweeps from Forrestdale Lake. Vertical lines indicate the days on which the lake was sprayed with Abate.

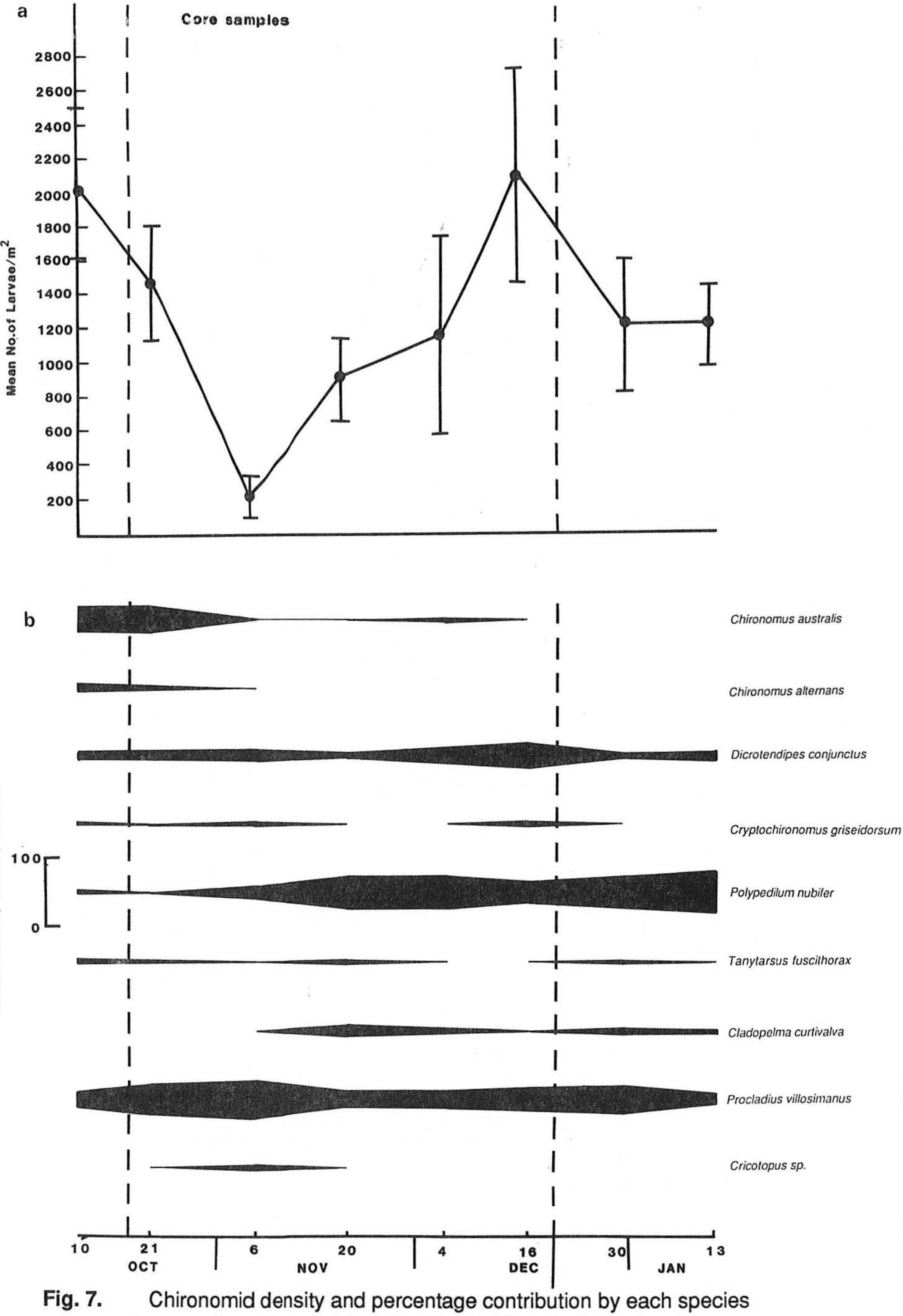


Fig. 7. Chironomid density and percentage contribution by each species in cores from Forrestdale Lake. Vertical lines indicate the days on which the lake was sprayed with Abate.

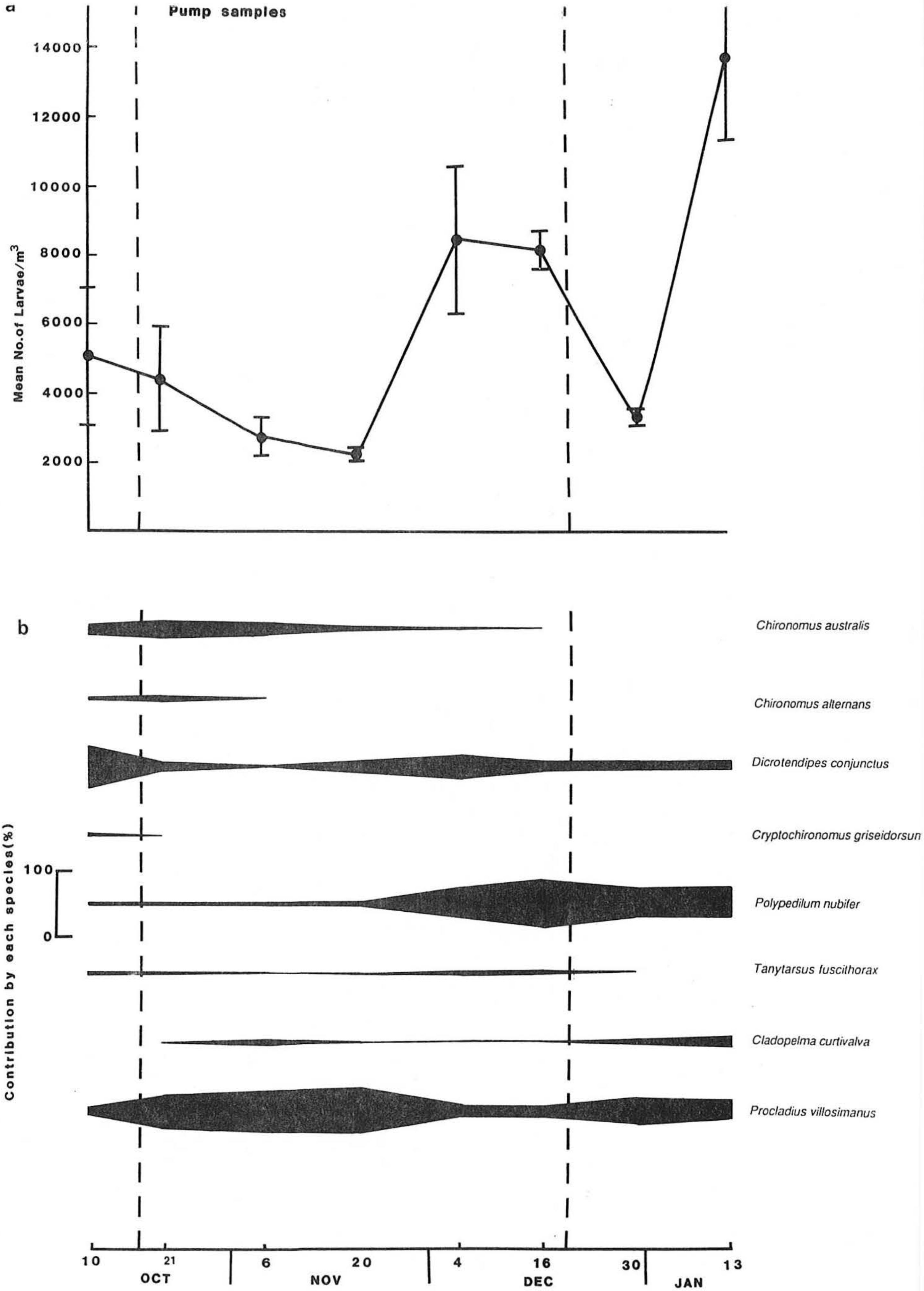


Fig. 8. Chironomid density and percentage contribution by each species in pumps from Forrestdale Lake. Vertical lines indicate the days on which the lake was sprayed with Abate.

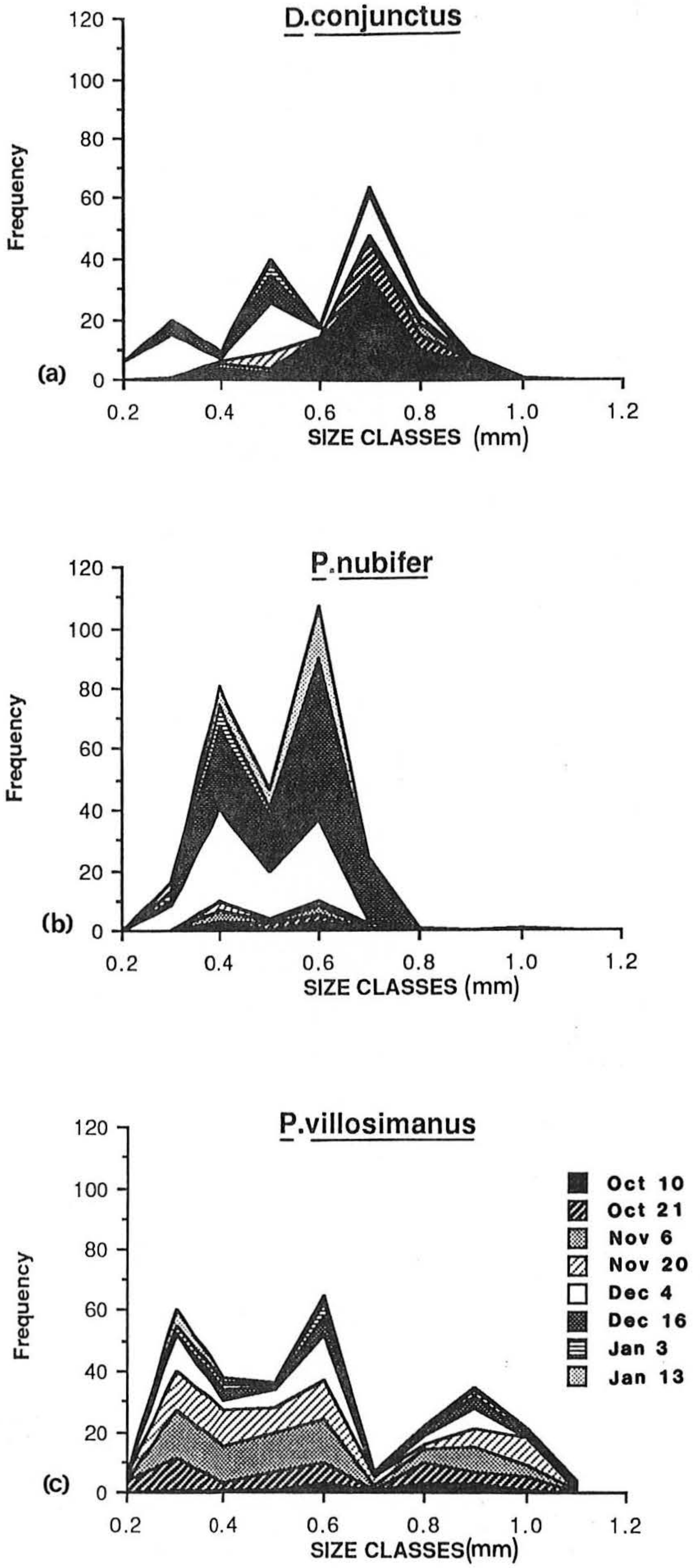


Fig. 9. Cummulative frequency of larvae occuring in 0.2 mm size classes, based on head capsule width, for the three most abundant chironomid species.

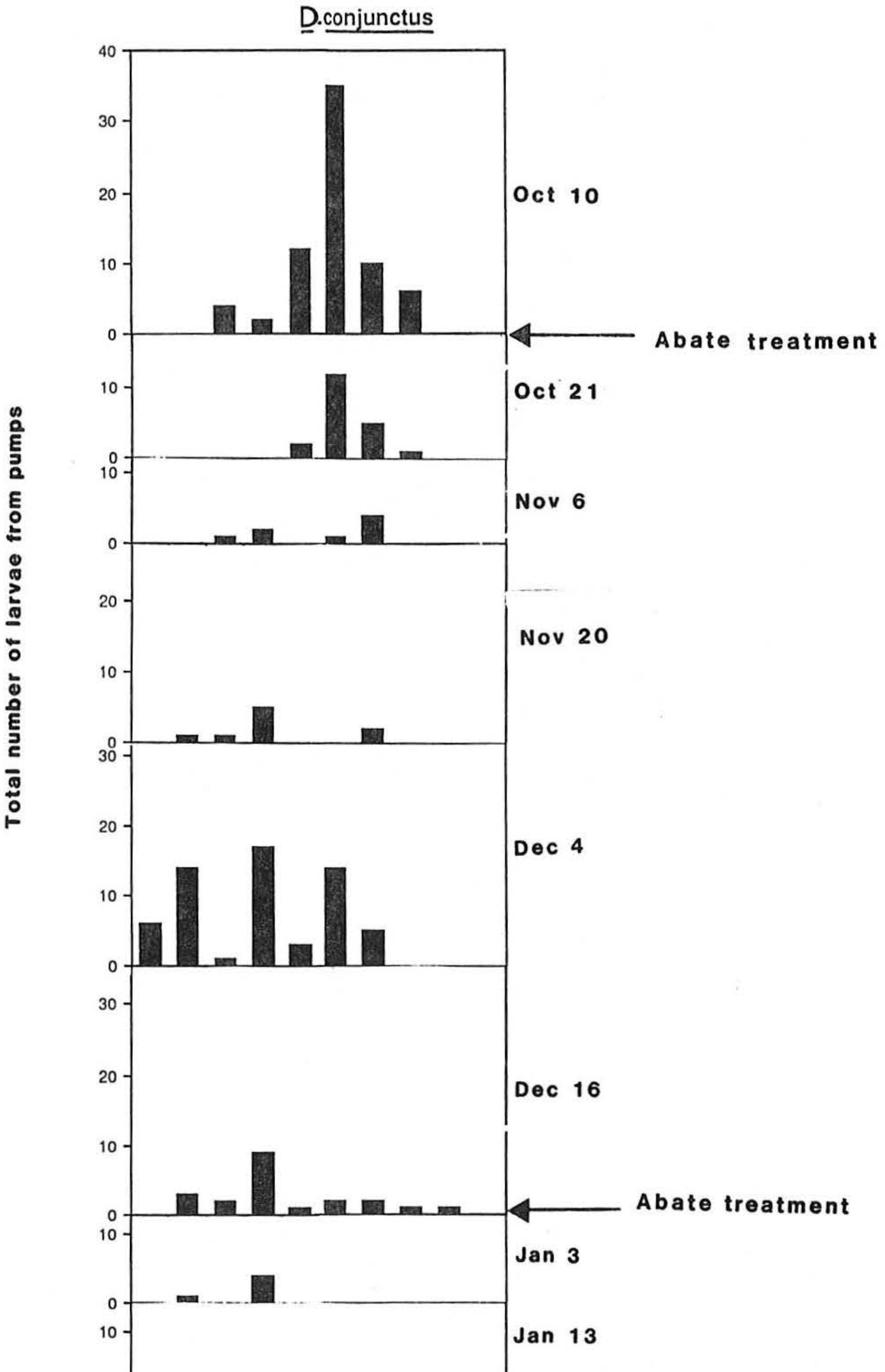


Fig. 10. Total number of larval *D. conjunctus* in 0.2 mm size classes, as measured from head capsule width, collected in pump samples on each sampling occasion.

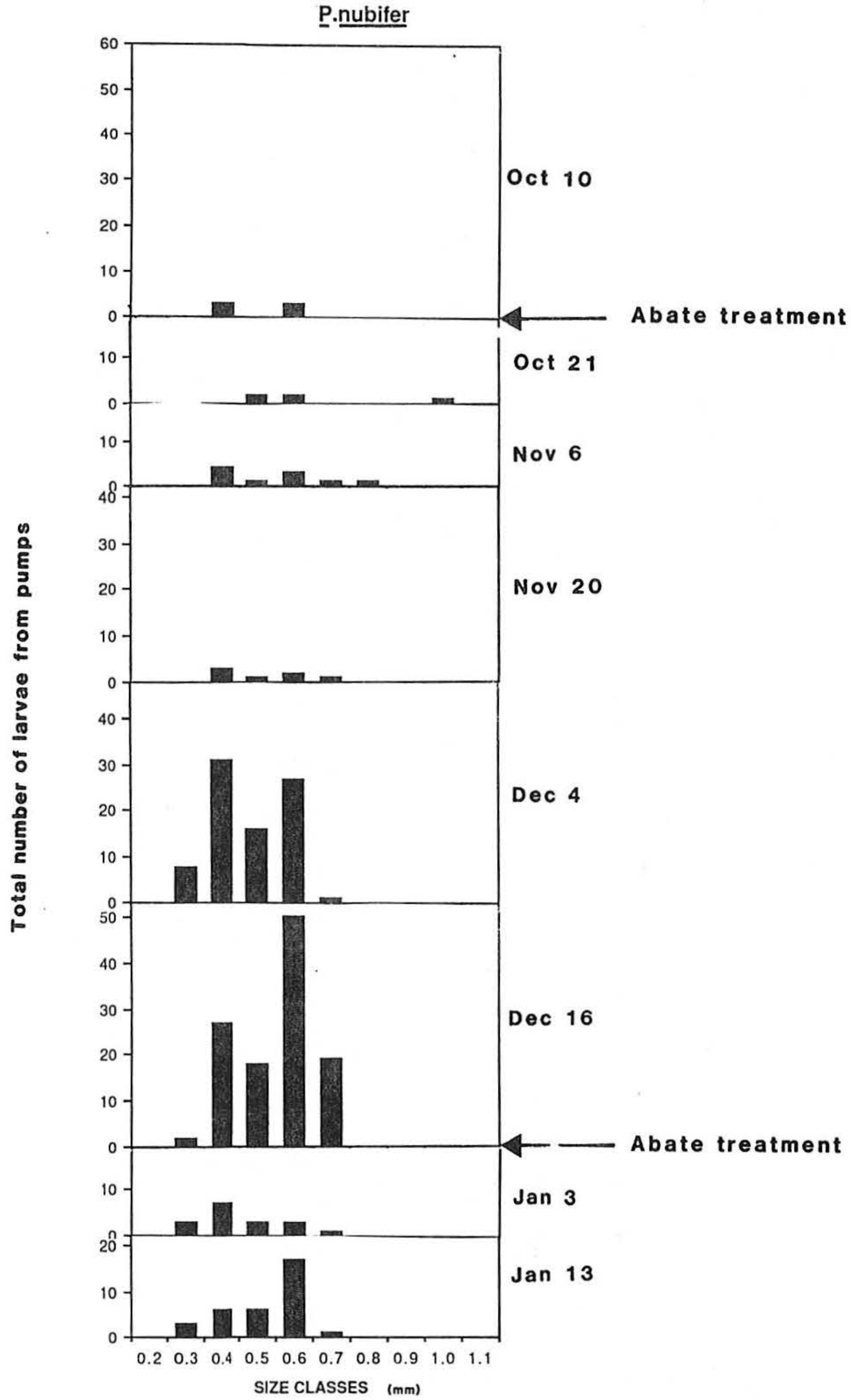


Fig. 11. Total number of larval *P. nubifer* in 0.2 mm size classes, as measured from head capsule width, collected in pump samples on each sampling occasion.

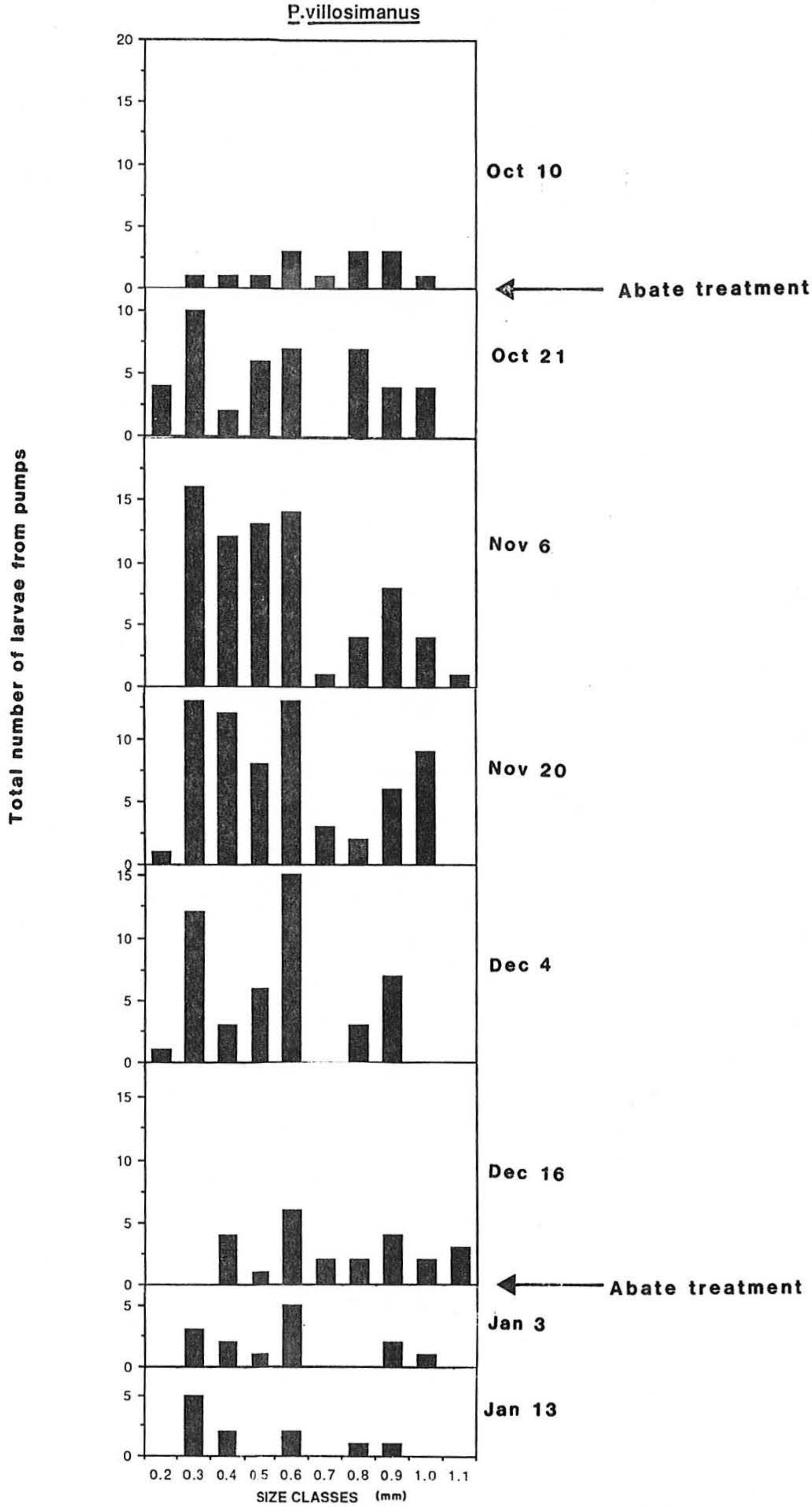


Fig. 12. Total number of larval *P. villosimanus* in 0.2 mm size classes, as measured from head capsule width, collected in pump samples on each sampling occasion.

The presence of large numbers of last instar *D. conjunctus* six weeks after spraying suggests that the larval life cycle of this species was six weeks in duration. Similarly the presence of large numbers of *P. nubifer* six and eight weeks after spraying suggests a larval life cycle of six to eight weeks in this species. The length of the life cycle of *P. villosimanus* could not be determined.

Comparison of Sampling Methods

Much larger numbers of larvae and pupae were obtained in the sweep samples than the core or pump samples. This was a consequence of the sweep net technique sampling a greater volume of water than the cores and pumps, although the actual volume was difficult to assess and hence this technique can only be regarded as semi-quantitative.
Mean larval densities (and associated standard errors) obtained by each sampling method on each sampling occasion are given in Figs 6a, 7a and 8a. Large standard errors suggest differences in larval distributions either within or between sites, as means were calculated on data combined from all sites.
The standard errors associated with each type of sampling method were variable (Figs 6a, 7a and 8a) and no single method was more consistent or reliable on the basis of low variation between replicate samples. The pump method is a means by which both the lake bed and the water column can be sampled quantitatively at the same instant, and as such probably represents the best method for quantitative studies. Core samples and sweep samples are easier to collect and allow for easier separation of the fauna into benthic and water column components. These latter two sampling methods would be the easiest methods to use if a larval monitoring programme is to be conducted by inexperienced personnel.

Differences Between Sites

Mean numbers of larvae in the core and pump samples at each site (*Typha* x2, 0m, 200m and 600m) plus standard errors are given in Fig. 13. The results from the core and pump samples for each site were combined to enable mean site densities and standard errors to be calculated. Mean numbers of larvae per sweep for each of three sites; 0m, 200m and 600m (sweeps were not collected in the *Typha*) are given in Fig.14.
Chironomid distribution within the lake may be patchy as differences in larval densities between sites were evident (Figs 13 and 14). These differences may well account for the large standard errors associated with the combined sites data set (Figs 6a, 7a and 8a) .

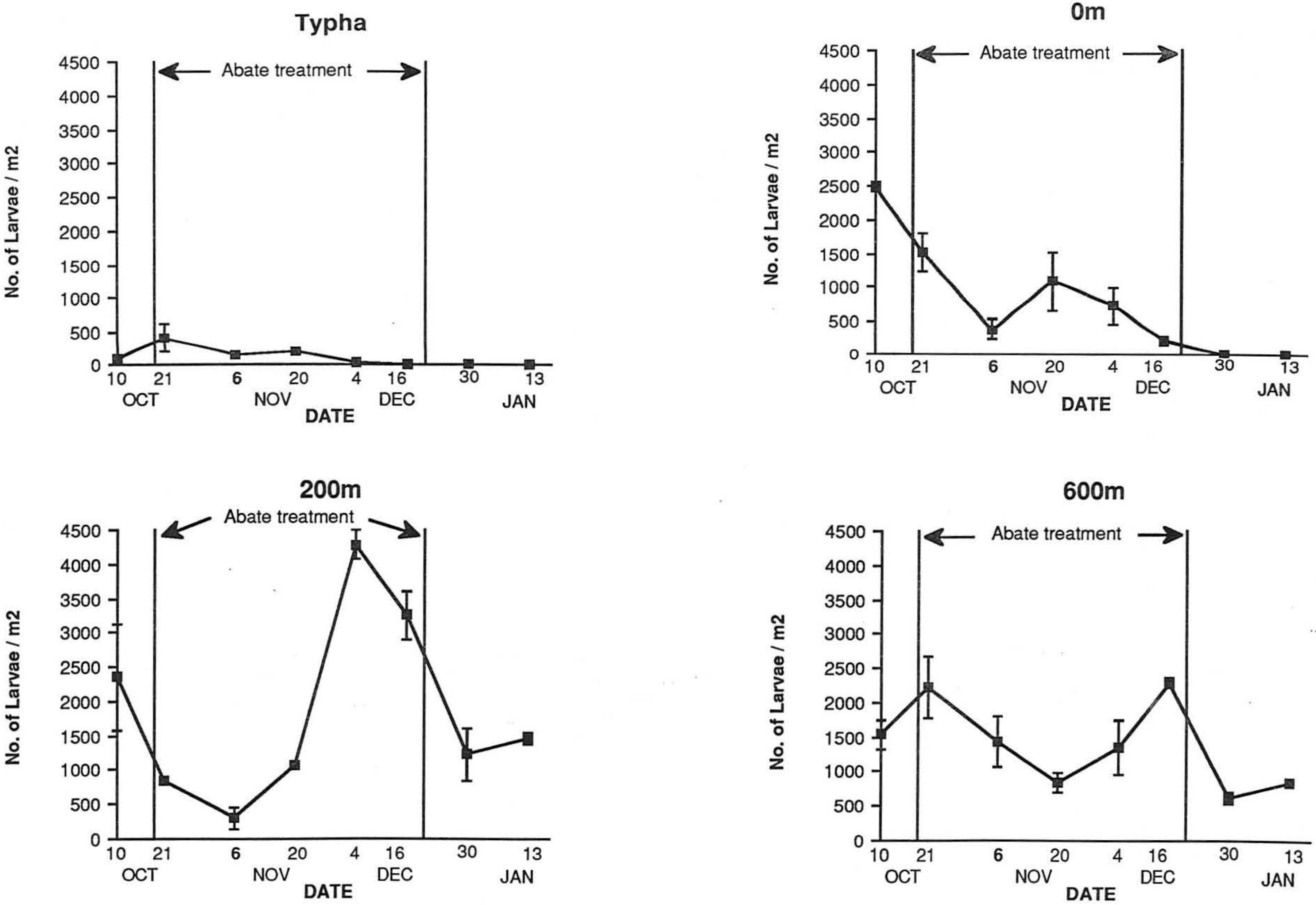


Fig. 13. Mean number of chironomid larvae plus or minus one standard error in the core and pump samples taken at each site on each sampling occasion.

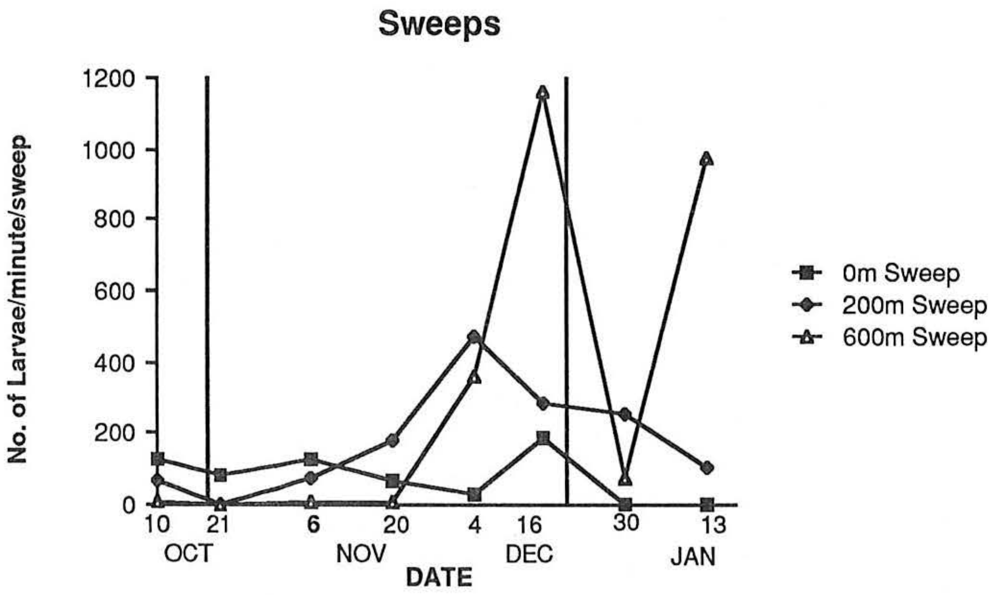


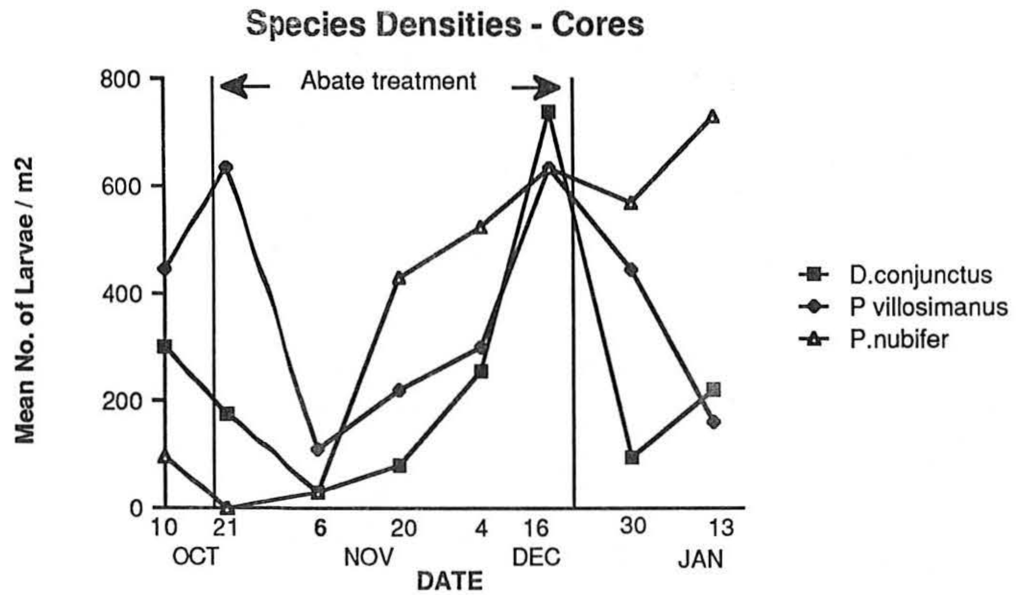
Fig. 14. Mean number of chironomid larvae per sweep at each site (0m, 200m and 600m) on each sampling occasion.

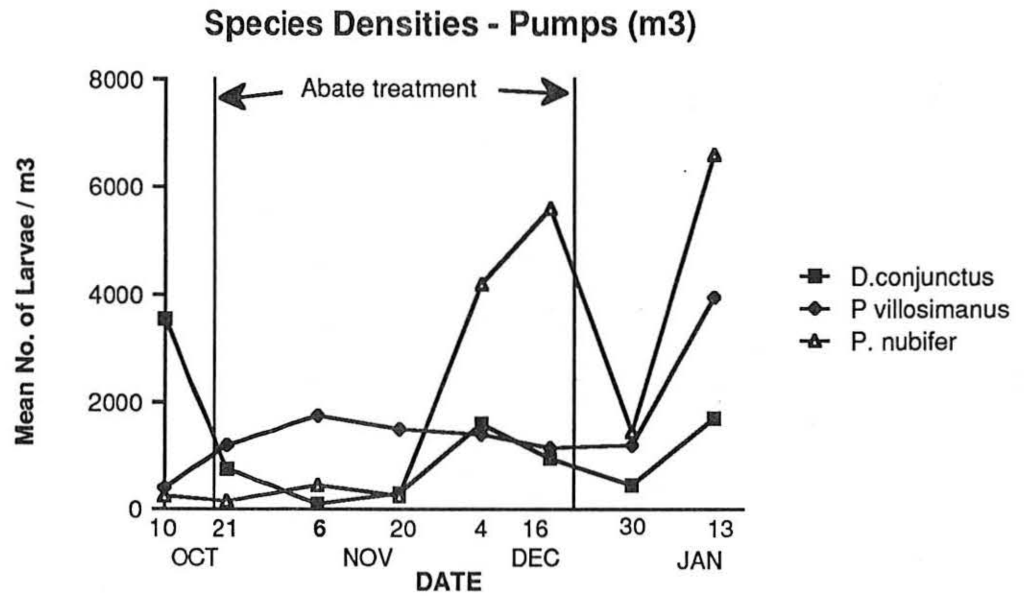
The standard errors associated with the larval densities at each site were considerably smaller than those for the combined site data indicating that the within site variation was less than the variation between sites.

The Apparent Effects of Abate on the Chironomid Fauna

Figures 5 - 11 indicate that total numbers were reduced, and changes in the relative abundance of each species occurred after both Abate treatments. Changes in the total numbers of the three most common species and the densities of each obtained by the three different sampling methods are given in Fig. 15. The three species responded differently to the Abate treatments. *P. villosimanus* appeared to increase in abundance (possibly due to reduced competition), whilst *D. conjunctus* and *P. nubifer* decreased after the first treatment, although *P. nubifer* was present only in low numbers prior to the first treatment. *P. nubifer* displayed a dramatic decrease in numbers after the second treatment, whilst decreases in the abundance of *D. conjunctus* and *P. villosimanus* had already occurred prior to the second spraying. A further decrease in *D. conjunctus* occurred after the second spraying but again *P. villosimanus* showed a slight increase.
In the cores *P. villosimanus* peaked immediately after the first Abate treatment reaching 635 larvae/m^2 on October 21, followed by a peak in *P. nubifer* of 635 larvae/m^2 on December 16 and in *D. conjunctus* of 741 larvae/m^2 on December 16. In the pump samples *D. conjunctus* peaked before the first spraying with 3572 larvae/m^3 on October 10, *P. villosimanus* reached a maximum of 1756 larvae/m^3 on November 6 and *P. nubifer* reached a maximum of 6593 larvae/m^3 on December 16. *D. conjunctus* was the most abundant species in the sweep samples and a maximum of 409 larvae was recorded in the sweep samples taken on December 16.

Chironomid larvae are usually regarded as benthic animals, however their collection in sweep samples supports visual observations made at Forrestdale Lake of the larvae swimming in the water column amongst the *Chara* strands. Densities of *D. conjunctus* were highest in the sweep samples indicating that this species occurred predominantly in the water column and the submerged vegetation rather than in the lake bed. *P. nubifer* was the most abundant species in both the pump and the sweep samples, indicating that this species was probably widespread throughout the water column, submerged vegetation and lake bed. *P. villosimanus* appeared to be a predominantly bottom-dwelling species, because the numbers of larvae collected in the sweeps were much lower than those in the pumps or cores.





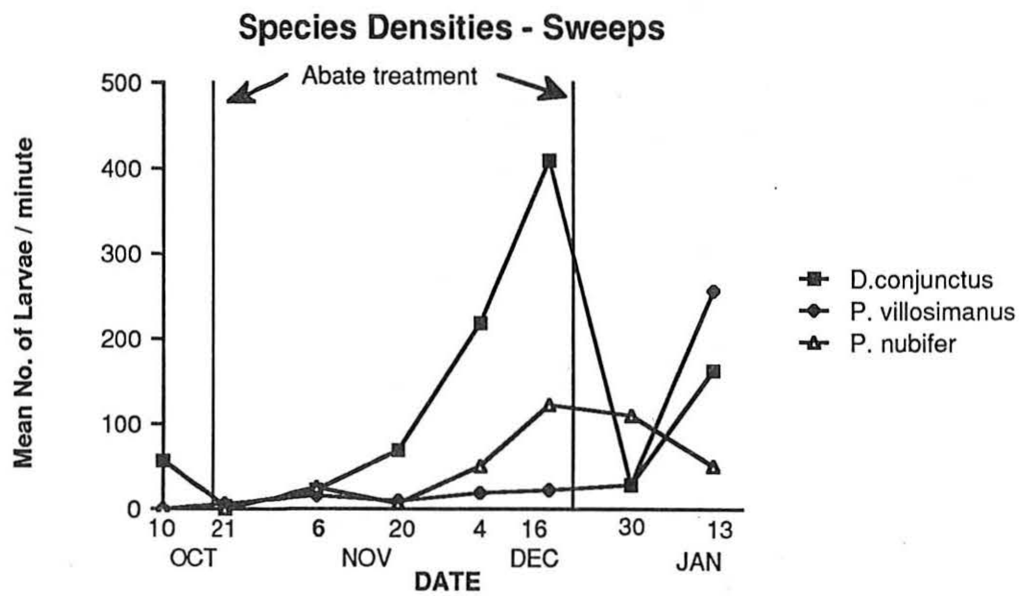


Fig. 15. Changes in the numbers of larvae of the three most common chironomid species obtained by the three different sampling methods.

The results given in Figs. 6b, 7b, 8b and 15 reveal that Abate is more effective aginst the two species that occur in the water column, *D. conjunctus* and *P. nubifer*, than against *P. villosimanus* which occurs predominantly in the bed.

The Composition and Abundance of the Macroinvertebrate Fauna

All the invertebrate taxa recorded at the 200m site are listed in Table1. The relative abundance of each taxa and total densities of all macroinvertebrates collected by both sweep samples and core samples are given in Figs 16 and 17 respectively.

DISCUSSION

Species Composition and Abundance of Larval Chironomids

Nine species of chironomids were recorded from Forrestdale Lake during the study. In 1980 these numbers would have been considered to be higher than those recorded from most other Australian waterbodies (Timms, 1980), however since Timms's review Fulton (1983) reported 12-15 species from three Tasmanian lakes, and Maher and Carpenter (1984) recorded 10 and 11 species from two wetlands in south-western New South Wales. Edward (1964) recorded seven species in Lake Monger in a study undertaken in the early 1960's.

However of the nine species recorded in Forrestdale Lake, only three or four (*Dicrotendipes conjunctus*, *Procladius villosimanus*, *Chironomus australis* and *Polypedilum nubifer*) were present in large numbers (comprising approximately 90% of the chironomid fauna) on any one sampling occasion (Figs 6b, 7b and 8b).

The fact that eight of the nine species were collected by all three sampling methods (cores, pumps and sweeps) suggests that the chironomid fauna was not restricted to the benthic region (that is, the lake bed), the region with which larval chironomids are most commonly associated. Only *Cricotopus* sp. did not occur in samples taken from the water column (pumps and sweeps) indicating that it may be a species which lives fairly deep within the lake bed.

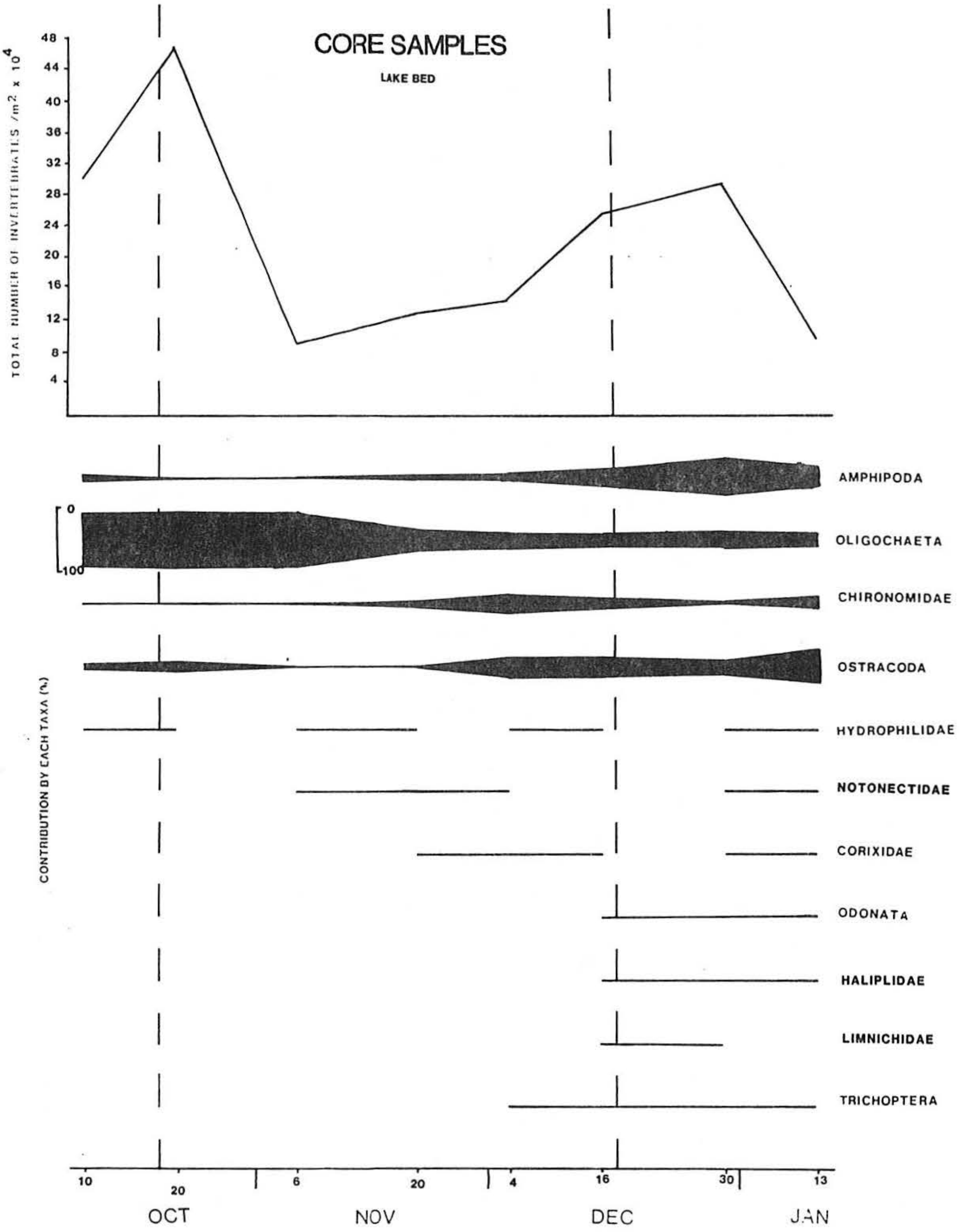


Fig. 17. Total density and percentage contribution by each taxa to the macro-invertebrate fauna of the bed at Forrestdale Lake. Vertical lines indicate the days on which the lake was sprayed with Abate.

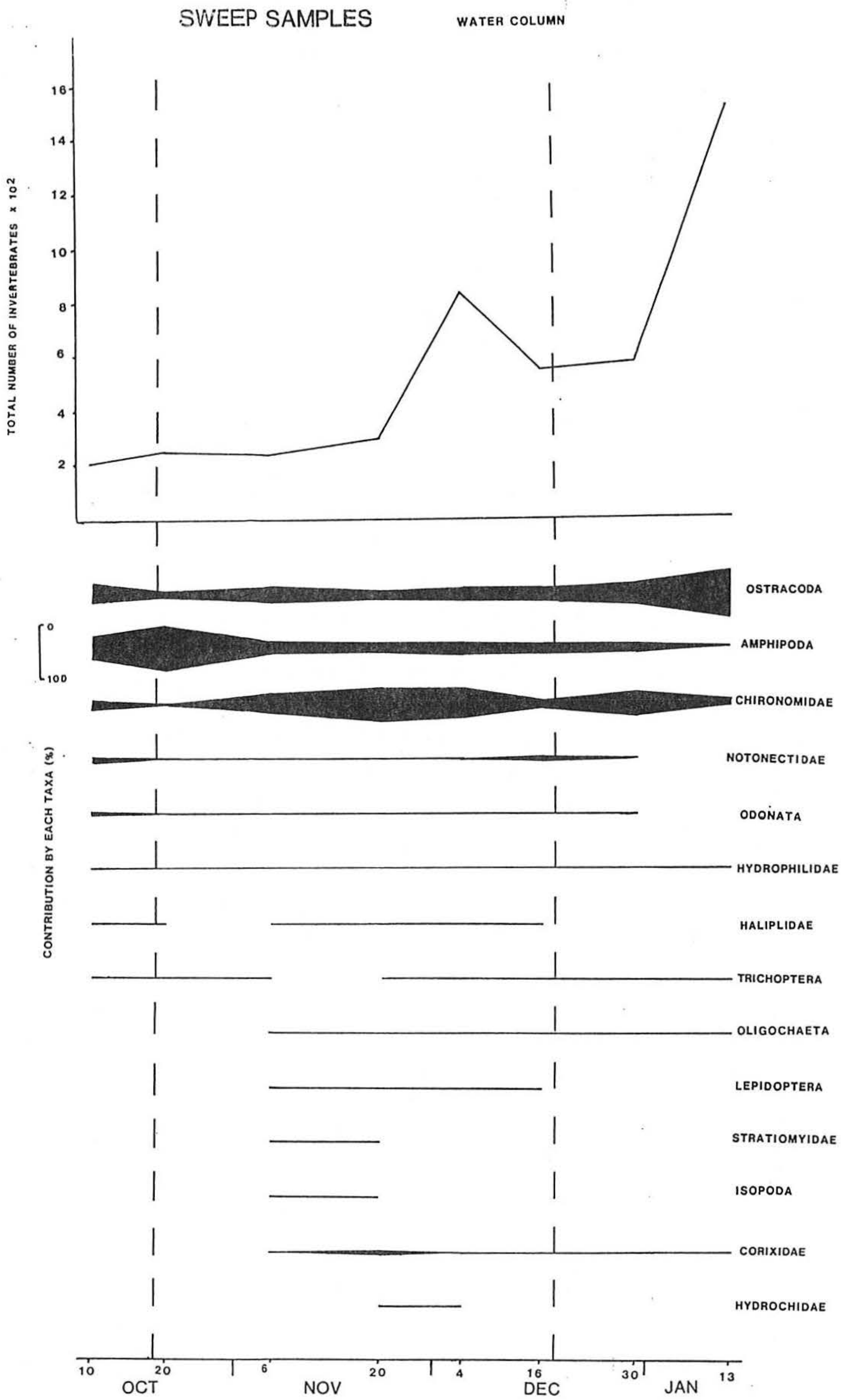


Fig. 16. Total density and percentage contribution by each taxa to the macroinvertebrate fauna of the water column and submerged vegetation at Forrestdale Lake. Vertical lines indicate the days on which the lake was sprayed with Abate.

The three different sampling methods give some indication of substrate preferences amongst the chironomid species. Larvae of *D. conjunctus* were more abundant amongst the vegetation in the water column than in the sediments of the lake bed, *P. nubifer* appeared equally abundant in both microhabitats, whilst *P. villosimanus* and *C. australis* were more abundant in the bed than in the water column (Figs 6, 7 and 8). Published ecological information on Australian chironomids is scarce (Maher and Carpenter,1984), however similar observations regarding the association of *D. conjunctus* with aquatic vegetation and *P. villosimanus* with the sediments of the bed, and the ability of *P. nubifer* to occur in large numbers in both habitats, were made by Maher and Carpenter in their 1984 study in NSW.

D. conjunctus is an algal feeder and appeared to be feeding on the extensive beds of *Chara* present in the lake, *P. nubifer* and *C. australis* may be regarded as opportunistic and capable of feeding on both the *Chara* and the detritus of the lake bed. *P. villosimanus* is normally regarded as a predaceous species which feeds on larval chironomids and other aquatic insect larvae, however this species has also been observed feeding on algae when algal material is in plentiful supply (Edward, 1964).

The presence of larval chironomids living within the *Chara* and feeding on it suggests that larval densities may well be a function of the amount of submerged vegetation in the lake. As a consequence, chironomid densities must be far higher than those that would occur if the chironomid fauna comprised solely of bottom dwellers. There is some suggestion that *Chara* has only colonised the lake in recent years, and if so, the recent increase in midge numbers reported by Forrestdale residents may well be a consequence of this. The stands of *Chara* would provide a more extensive substrate and food source for the larvae than would previously have been available.

The recent and widespread occurrence of *Chara* within the lake appears to reflect the increasing nutrient status of the lake. Whilst mechanical removal of the *Chara* bed may be an option to decrease midge numbers this action is not recommended. The alga may be capable of removing large amounts of nutrient from the water column and prevent the widespread occurrence of toxic or nuisance blooms of blue-green algae. Poor water quality, smelly and decaying algal blooms, oxygen depletion and bird deaths may result if primary production within the lake changes to a phytoplankton dominated system rather than the present *Chara* / *Ruppia* association. A decrease in primary production within the lake, and a resulting decrease in chironomid numbers may possibly be achieved, if nutrient inputs to the lake are lowered.

The Apparent Effects of Abate on the Chironomid Fauna

Decreases in the total number of larval chironomids were observed after both the first and second applications of Abate (Fig.5). Numbers increased to near pre-spray levels 33 days (4.7 weeks) after the first application and reached a maximum 47 days (6.7 weeks) after spraying. At this time larval numbers were more than three times those recorded at the start of the study and prior to the first application of Abate. At this stage no midge swarms of nuisance proportions had been reported by local residents, but the increase in larval numbers indicated that a mass emergence of adults was probably imminent. To determine whether or not larval numbers could increase even further the Armadale Shire was asked to delay their intended second spraying until after the next sampling session a fortnight hence. The Shire agreed to this and large numbers of adults emerged several days later. A decrease in numbers was subsequently observed after the second application of Abate on December 20th.

Comparison of the changes in the relative abundance of larval species (Figs 6b, 7b and 8b) and total numbers of the three dominant species (Fig.15) in the water column and the lake bed, reveals that the situation is far more complex than may be assumed from an examination of changes in total numbers alone.

C. australis, a predominantly sediment-dwelling species, decreased to very low levels after the first application of Abate and numbers remained low for the remainder of the study (Figs 6b, 7b and 8b). *C. australis* had previously only been recorded from permanent waters and in temperature tolerance tests had displayed some degree of susceptibility to high water temperatures (Edward,1964). Sustained high temperatures and decreasing water levels throughout the study are more likely to account for the disappearance of this species than any prolonged effects of the Abate treatment. Because the lake is shallow it follows air temperature closely and has pronounced diurnal variation. By coincidence, the sampling days were relatively cool and did not reflect the increased temperatures over summer.

In contrast, the relative abundance of *P. nubifer* was low during the first half of the study, but increased to the point where it was the most abundant species in both the bed and the water column immediately prior to the complete drying of the lake at the end of the study. Maher and Carpenter (1984) reported that densities of *P. nubifer* in Lake Merrimajeel and Murrumbidgil Swamp (NSW) generally increased with falling water levels, and the same interpretation may be drawn from our study.

Larval numbers rose from virtually zero after the first application of Abate to 620/m^2 (in cores taken 47 days after spraying) and 5,790/ m^2 (in pumps taken 59 days after spraying). A decrease in numbers was observed in all samples after the second application of Abate.
P. nubifer is known to have a life cycle of three to four weeks at summer temperatures and eight to eleven weeks at winter temperatures (Edward, 1964). A life cycle of six to eight weeks was observed in our study.
Numbers of *D. conjunctus* decreased after both the first and second applications of Abate but numbers had already dropped dramatically prior to the second spraying as a result of a synchronous adult emergence. Edward (1964) recorded the length of larval life in the laboratory for *D. conjunctus* as seven to nine weeks at spring temperatures and nine to eleven weeks at winter temperatures. The length of the larval life span recorded in this study was approximately six weeks.

The relative abundance of *P. villosimanus* actually increased after both the first and second applications of Abate and this species appeared to be little affected by spraying. *Procladius* is known to be the most resistant genus of the Chironomidae to Abate (Blair, 1979), however its ability to form nuisance swarms is not known. If *P. villosimanus* does form nuisance swarms then the application of Abate to the lake is unlikely to reduce these. Edward (1964) observed only light aggregations of adults at Lake Monger, but there is a suggestion (Maher and Carpenter,1984) that *P. villosimanus* exhibits swarming behaviour similar to that of *P. nubifer* (a common nuisance species). Regardless of whether or not it is a nuisance species, *P. villosimanus* may play a positive role in the reduction of midge numbers because of its predatory nature.
An inverse relationship appeared to exist between the abundance of *P. villosimanus* (high numbers) and *D. conjunctus* (low numbers) in the first half of the study, and between *P. nubifer* (high numbers) and *P. villosimanus* (low numbers) in the later stages of the study. If *P. villosimanus* does form nuisance swarms the overall effectiveness of Abate treatments to the lake may be minimal, because the reduction in one species may, through the removal of competition, allow another species to dominate. The monitoring of densities of chironomid adults should be undertaken next spring and summer to enable positive identification of nuisance species. The overall effectiveness or otherwise of an Abate treatment programme at the lake may well be determined on the basis of this information.

Treatment with Abate may have had the the effect of synchronising the development and emergence of *D. conjunctus* and *P. nubifer* respectively, although previously Edward (1964) had noted the highly synchronous development of *P. nubifer* in Lake Monger under natural conditions. If the use of Abate does synchronise adult emergence this would suggest that one treatment must be followed by subsequent treatments if large scale emergences are to be avoided.

The Distribution of Chironomidae within Forrestdale Lake

Larval chironomids appeared to be fairly evenly distributed throughout the lake proper at the start of the study, but densities within the *Typha* were low and remained low throughout the study (Fig.13). The two northern sampling sites were situated within very dense stands of *Typha*, the bed within the *Typha* was compacted, and neither the bed nor the denseness of the stems at these sites appeared to provide a suitable substrate for the larvae.

Larval densities were highest near the edges of the lake amongst filamentous algae (at the 0m and 200m sites) prior to the first application of Abate (2,479 and 2,352 /m^2 respectively) and fell at all sites, albeit more slowly at the deepest site (600m), after spraying. Larval densites at the very edge of the lake (the *Typha* and 0m sites, the two shallowest sites), continued to decrease for the remainder of the study, probably as a result of decreasing water levels at the two sites.

Quite distinct differences in the changes in larval densities occurred at the two deeper sites and the reasons for this are not clear. However, both sites displayed the same general trends with minima after the first Abate treatment followed by maxima prior to the second Abate treatment, and finally minima again after the second spraying. Further data analysis is required to determine the distribution of individual species within the lake.

These results suggest that the application of Abate to the lake may be more easily made by liquid application from a boat than by aerial spraying once the water level starts to drop and the edges start to dry. At this time the greatest number of larvae occurred within the *Chara* in the deeper central region of the lake.

The Effect of Abate on Non - Target Organisms

Twenty five macroinvertebrate taxa were recorded from Forrestdale Lake in the course of this study (Table 1), and this number will increase when groups such as the Oligochaeta and Ostracoda are fully identified to species level. This number compares favourably with the maximum numbers recorded from a study of five other lakes on the Swan Coastal Plain; 25 taxa have been recorded from Thomsons Lake, 24 from Jandabup and 23 from North Lake. Lake Monger and Lake Joondalup are somewhat poorer with maximum richness of 18 and 13 taxa respectively. These figures were produced from similar sampling techniques and identification effort so comparisons are valid.

The fauna of the lake bed was dominated by oligochaetes, amphipods, ostracods and chironomids, and the same groups minus the oligochaetes were also the most abundant fauna of the open water/submerged vegetation (Figs 14 and 15).

The effects of the Abate treatments were most evident in the water column / vegetation samples. As already discussed, decreases in the abundance of the Chironomidae were evident after both treatments. In the Ostracoda numbers decreased after the first application of Abate but not the second. Large numbers of very small ostracods appeared in the last samples but the reason as to why such a large recruitment of new individuals should occur immediately prior to the lake drying up is not known.

A decrease in the abundance of two members of the Insecta; the Notonectids (backswimmers) and the Odonatans (damselflies) also occurred. The Notonectids slowly recovered after the first treatment but numbers decreased again after the second. The Odonata decreased after the first treatment and numbers remained low for the rest of the study. This result must be regarded with some concern because both the Notonectidae and the Odonata are predators (second order consumers) and form part of the higher trophic levels of the lake. Both species would be responsible for some degree of predation on the chironomid fauna, and their decrease in numbers represents a loss of some form of "internal" or natural control on chironomids within the lake.

The fauna of the lake bed seems little affected by the Abate treatments, the greatest reduction in relative abundance occurred in the Chironomidae after the second spraying. Reductions in the abundance of the Amphipoda and Ostracoda occurred after the first spraying but not after the second. The greater effectiveness of Abate on the fauna of the water column compared to that on the fauna of the bed may merely reflect the greater abundance of individuals in the water and submerged vegetation.

Miles and Woehst (1967, cited by Blair, 1979) found that temephos (the chemical component of Abate) tends to deposit onto solid surfaces such as the walls of experimental containers, organic material and debris so that less of the toxicant remains in aqueous solution. Blair (1979) suggests that the residual effectiveness of the pesticide would be reduced as a result, particularly in habitats well covered with vegetation. However our results suggest that the larvicide is more effective on the animals living within the *Chara* than those on the bed. A possible explanation for this apparently conflicting information is that the temephos does attach to the strands of *Chara* , and in doing so is rendered more effective against the animals that live and feed within this plant material, and less effective against the animals living in the bed of the lake.

PHYLUM	CLASS	ORDER	FAMILY	GENUS AND SPECIES
ANNELIDA	Oligochaeta			spp.
	Hirudinea			sp.
MOLLUSCA				
	Gastropoda			
			Planorbidae	
				Physa acuta
			Hydrobiidae	
				Coxiella sp .
ARTHROPODA	Crustacea			
		Ostracoda		spp.
		(subclass)		
		Amphipoda		
			Ceiinidae	
				Austrochiltonia subtenius
		Isopoda		
			Phreatoicidea	
				Paramphisopus palustris
	Insecta			
		Odonata		
		Zygoptera		
		(suborder)	Lestidae	
				Austrolestes annulosus
		Hemiptera		
			Corixidae	
				Agraptocorixa hirtifrons
			Notonectidae	
				Anisops hyperion
		Coleoptera		
			Haliplidae	
				Haliplus sp.
			Hydrochidae	sp.
			Dysticidae	sp.
			Limnichidae	sp.
		Diptera		
			Chironomidae	
				Chironomus australis
				Chironomus alternans
				Dicrotendipes conjunctus
				Cryptochironomus griseidorsum
				Procladius villosimanus
				Polypedilum nubifer
				Cladopelma curtivalva
				Cricotopus sp.
				Tanytarsus fuscithorax
			Stratiomyidae	sp.
			Ceratopogonidae	sp.
		Lepidoptera		sp.
		Trichoptera		sp.

TABLE 1. Macroinvertebrate taxa recorded from Forrestdale Lake (October 1985 - January 1986)

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