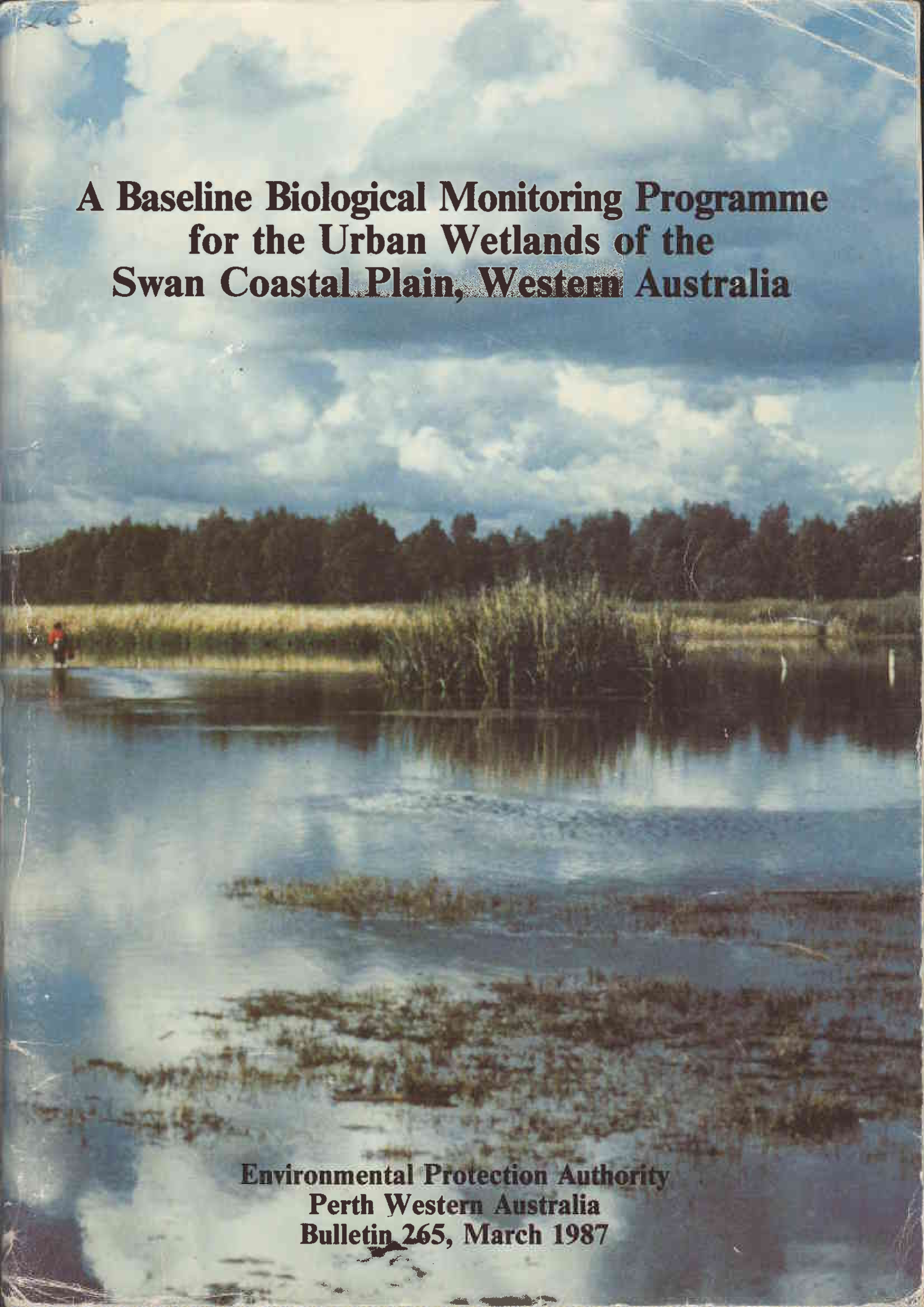
A Baseline Biological Monitoring Programme for the Urban Wetlands of the Swan Coastal Plain, Western Australia



Environmental Protection Authority
Perth Western Australia
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Cover Photograph : Thomsons Lake, July 1985. (Photograph by S W Rolls).

BACK COVER

Water Boatman (*Agraptocorixa hirtifrons*)
Caddisfly larva (*Notalina fulva*)
Midge larva (*Chironomus australis*)
Caddisfly larva (*Oecetis sp.*)
Water mite (Hydracarina *sp.*)
Dragonfly nymph (*Hemianax papuensis*)
Freshwater isopod (*Paramphisopus palustris*)
Ostracod (*Mytilocypris ambiguosa*)
Backswimmer (*Anisops hyperion*)
Caddisfly larva (*Triplectides australis*)

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ACKNOWLEDGEMENTS

Recognising that Perth's wetlands are an important part of the regions groundwater resource, the work reported here was undertaken in conjunction with the **Perth Urban Water Balance Study** as a contribution to the understanding of the wetlands, and as an aid to the management of this facet of the regions groundwater resource. The Perth Urban Water Balance Study was undertaken by the Water Authority of Western Australia in collaboration with the Centre for Water Research at the University of Western Australia, the Geological Survey section of the Mines Department, the Department of Conservation and Environment (now the Environmental Protection Authority), and Murdoch University.

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1. **SUMMARY**

1.The macroinvertebrate fauna and water chemistry of five Perth lakes - Jandabup Lake, Lake Joondalup, Lake Monger, North Lake and Thomsons Lake - were sampled on a three monthly and monthly basis respectively from April 1985 to April 1986, to determine spatial and seasonal variability and to provide a baseline against which future changes in the wetlands could be assessed. Both Jandabup Lake and Thomsons Lake were dry during the summer months whilst Lake Joondalup, Lake Monger and North Lake contained permanent water.

2. Seasonal variation occurred in conductivity, and the concentrations of Na, Cl, K, Ca, Mg, total P and total N in three lakes - Jandabup, Joondalup and Thomsons - but was less evident in North Lake and Lake Monger. Concentrations appeared to increase as a result of concentration by evaporation in summer and to decrease as a result of dilution in winter. North Lake and Lake Monger appeared to be the only lakes with a significant groundwater inflow during summer.

3. Jandabup Lake differed from the other four lakes, being the only acidic and the least enriched waterbody studied. Lake Joondalup, Lake Monger, and Thomsons Lake were all hypereutrophic with respect to ortho-P during summer, and meso-eutrophic or eutrophic during winter. North Lake was hypereutrophic throughout the year. The effects of nutrient enrichment were evident in the four lakes that exceeded the criteria for hypereutrophy; increased primary productivity occurred in Thomsons Lake in the form of extensive submerged macrophyte growth; in Joondalup in the form of an algal/sediment ooze known as metaphyton; and in Monger and North Lakes as algal blooms.

4. Comparison of the results of this study with that of the study of Gordon *et al.* (1981) conducted on Lake Monger and Lake Joondalup ten years earlier (in 1975/76) revealed two to fourteen fold increases in the concentrations of total P and ortho P and three to five fold increases in the concentrations of total N recorded in the two lakes. The comparison suggests that increasing urbanisation has resulted in increased nutrient enrichment of the urban lakes. Concentrations of NH_4 and NO_2/NO_3 have decreased since the earlier study and this result may reflect an increase in nitrogen uptake due to the presence of metaphyton in Lake Joondalup and extensive algal blooms in Lake Monger.

Comparison of the results of this study with those obtained ten years earlier by the Cockburn Wetlands Study (Newman *et al* , 1976) for Thomsons Lake and North Lake indicate that water quality in Thomsons Lake has improved in the last decade, whilst North Lake has remained hypereutrophic. The mean concentration of total P recorded at Thomsons Lake was 4 times lower in this study than the value recorded 10 years earlier, whilst the mean concentration of total P recorded at North Lake was virtually the same in both studies. The concentration of total nitrogen at both lakes has increased since the Cockburn Wetlands Study. The apparent improvement in water quality at Thomsons Lake may be due to the fact that the lake was seasonal for the 10 years prior to this study, whereas it was a permanent lake for the 10 years prior to the Cockburn Wetlands Study.

5. The water chemistry data indicated that lowered water levels alone may not adversely affect water quality in the urban wetlands, but rather the effects of evaporative concentration coupled with low water levels may result in unacceptably high concentrations of salt and nutrients in some permanent wetlands. The implication for the management of the urban lakes are that the hydrogeology of each lake must be known, and ion and nutrient concentrations monitored to determine how serious evaporative concentration effects may be. Summer drying of some lakes may be beneficial because it removes the stresses posed to aquatic life by the high salinities and nutrient levels at this time. Seasonal drying also reduces nutrient cycling within wetlands, and provides peaks of organic matter after re-flooding which enhances both invertebrate and waterfowl productivity. However, the need to retain some permanent water bodies as drought refuges and faunal reservoirs is recognised.

6. A total of 87 invertebrate taxa were recorded from the five lakes, and this is amongst the highest number of taxa recorded from Australian lakes. A total of 62 taxa recorded from Thomsons Lake represents the highest number recorded from a wetland on the Swan Coastal Plain. Seasonal variation in species richness occurred in the two seasonally dry lakes, Thomsons and Jandabup,

but numbers remained fairly constant in Joondalup, Monger and North Lake. Faunal abundances in the lakes peaked in late summer as water levels fell, and this may be an important feature for the waterfowl which arrive at the lakes at this time as the waterbodies further east dry out. The macroinvertebrate fauna of the urban lakes appeared to be well adapted to a cycle of summer drying and winter filling.

7. The wetlands contain elements of both an ancient Gondwanaland fauna and more recently arrived species that may still be undergoing active dispersal betweeen Australia and the Northern Hemisphere. The possibilty that ostracods are being transferred between wetlands in Perth and Russia and Japan each year by migratory waders is of zoogeographic and ecological interest, and warrants further investigation.

Whilst individual elements of the invertebrate fauna are not rare or unique, the association of species that occur in some wetlands may be considered unique.

8. Reduced species richness and the absence of almost an entire macroinvertebrate trophic group, the second order consumers, or predators, in both Lake Joondalup and Lake Monger, and to a lesser extent in North Lake, indicates a serious deterioration in the food chains of these lakes and, as a consequence, the environmental quality of these lakes. Loss of faunal diversity and invertebrate predators in Lake Joondalup may be attributed to high summer salinities and nutrient enrichment, and in Lake Monger to nutrient enrichment alone. However, the effects of pesticides, heavy metals and predation by the native and introduced fish fauna on the structure and function of the wetland macroinvertebrate communities also needs to be determined before the observed reduction in faunal diversity and trophic structure can be conclusively regarded as a consequence of wetland eutrophication.

9. The assessment of water quality is dependent upon what use is to be made of the water. Because no criteria have yet been set by the State Government for the urban wetlands, the assumption was made in this study that water quality must be sufficient to maintain viable or "healthy" freshwater ecosystems for the preservation of aesthetic values, waterbird habitat and scientific and educational resources.

10. Combined chemical and biological monitoring appears to be a suitable method for assessing water quality in the urban wetlands. Using chemical monitoring alone, the high conductivities and nutrient concentrations recorded in Lake Joondalup and Lake Monger showed that water quality problems may be present, but gave no indication as to how severely they may effect the biota. This gap in understanding was reduced by sampling the macroinvertebrate fauna. The macroinvertebrate fauna of Lake Joondalup and Lake Monger had low species richness, and an almost complete absence of one trophic group, the invertebrate predators. This indicated that, compared with Jandabup Lake and Thomsons Lake, the composition and structure of the invertebrate food chains has deteriorated. Thus, the poor water quality revealed by the chemical monitoring programme was reflected in the reduced environmental quality of the aquatic ecosystem. On the basis of the results of the combined monitoring programme, the water quality in the two wetlands appeared to be unsatisfactory for the maintenance of the scientific and educational values of the waterbodies. The observed deterioration in invertebrate food chains should also be regarded as an indicator that both the aesthetic values of the two wetlands and their values as waterbird habitat are at risk. Active management, particularly with regard to decreasing nutrient inflows, should be undertaken immediately if further serious degradation of food chains and consequent loss of the social values of the lakes is to be avoided.

High nutrient concentrations, the occurrence of nuisance blue-green algal blooms during spring, and the absence of some invertebrate predators from North Lake indicate that the environmental quality of this lake is also reduced compared to that of Thomsons Lake and Jandabup Lake. Nutrient inflows into the lake need to be reduced to prevent a further deterioration in the lake's environmental quality.

11. Although conductivities and concentrations of nutrients in Thomsons Lake and Jandabup Lake were high before the lakes dried in late summer, the macroinvertebrate faunas of these two lakes had complete trophic structure and high species richness in all seasons except autumn (before the start of the winter rains). The combined monitoring programmes indicated that water quality within the two lakes in 1985/1986 was sufficient for the maintenance of the aesthetic, scientific and educational values of the wetlands. Both wetlands are Nature Reserves. Thomsons Lake has an extensive zone of fringing vegetation within its' reserve, but the reserve on Jandabup Lake does not include the entire area of emergent vegetation. The importance of the emergent and fringing vegetation, which acts as a buffer between the lakes and nearby urban and rural activities, is immense. Every effort should be made to ensure that the protection that Thomsons Lake has recieved in the past is continued in the future, and that efforts are made to prevent more intensive use of the unreserved reed beds in Jandabup Lake.

12. Perth's wetlands are of enormous social and wildlife conservation value, and a water quality management programme for the urban wetlands must be designed and implemented to ensure that these values are retained. Water quality criteria should be established, and a monitoring programme undertaken to ensure that the criteria are being met. A combined biological and chemical monitoring programme incorporating both an assessment of the richness and trophic structure of the macroinvertebrate fauna (or the presence / absence of selected indicator groups such as the Odonata and Coleoptera) and measurements of conductivity and nutrient concentrations on a seasonal or twice yearly (summer and winter) basis, would provide an effective and cost efficient wetland monitoring programme.

The fact that the urban wetlands appear to be quite resilient systems (probably because much of the flora and fauna is adapted to withstand the stresses of seasonal drying and filling), and the effects of poor water quality appear to be reversible, suggests that it is not too late to design and implement water quality management programmes for many of the urban wetlands already experiencing water quality problems.

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2. INTRODUCTION

The wetlands of the Swan Coastal Plain are a dominant feature of the Perth environs, and their presence within an urban setting may be considered unique, certainly within Australia and probably worldwide.

The importance of the urban wetlands, both for wildlife conservation and for their social values as areas of open space within the city, are described by Arnold and Wallis (1986). The wetlands are areas of high biological productivity and directly or indirectly support most of the wildlife of the Swan Coastal Plain (Seddon, 1972). Their importance for wildlife conservation however, extends beyond the south west of Western Australia because they are visited each summer by migratory wading birds from the Northern Hemisphere, and Australia is signatory to international treaties which oblige it to protect the habitats of many of these species (Arnold and Wallis, 1986).

The lakes and swamps of Perth's wetlands are connected via an unconfined aquifer, and water levels will vary accordingly with the height of the water table (Allen, 1976). Urbanisation has resulted in an increasing demand for water from the unconfined aquifer. With increased groundwater extraction, water levels in wetlands will drop and shallow lakes may dry completely . Conversely, increasing urbanisation has also resulted in an increase in water levels in some lakes because urban development has resulted in increased run off. Local wetlands often act as compensating basins for storm water, and most lakes have at least one, and often several, drains discharging into them. The urban wetlands are shallow waterbodies (maximum depth < 3 m), and water level changes of greater magnitude or duration than the normal seasonal variations may present a serious stress to wetland ecosystems.

Urbanisation has also led to elevated nutrient levels in many of the urban lakes. Nutrient enrichment often results in the occurrence of algal blooms in nuisance proportions. Whilst wetlands do have the capacity to act as nutrient filters, overloading of this capacity results in poor water quality and a rapidly deteriorating wetland environment. The use of pesticides to control water-breeding insect pests (mosquitoes and midges) must also be regarded as a serious stressor in some urban wetlands. Wetlands are often treated as "black boxes" with "inputs" of nutrient rich waste waters and "outputs" of decaying and toxic algal blooms and nuisance swarms of insects. In reality they are complex ecosystems about which too little is known for effective management.

The study described here was undertaken to obtain ecological data from selected urban wetlands as part of the wetland evaluation and management contribution to the Perth Urban Water Balance Study. Faced with the need to consider various options for wetland management, the Perth Urban Water Balance Study required information on;

1. the relative values of the wetlands of the Perth region; and
2. the water levels and water level fluctuations required to sustain the wetlands.

This study sought to provide information pertaining to both points by focussing on an important but largely unseen and poorly described component of Perth's wetland ecosystems : the macroinvertebrate fauna.

2.1 WHY STUDY MACROINVERTEBRATES ?

Macroinvertebrates are an essential component of wetland food webs, are responsible for a significant proportion of the secondary production occurring in wetlands, and form two interconnected wetland food chains; a grazing food chain and a detrital food chain (Figures 1 and 2). Within wetland food webs macroinvertebrates comprise much of the diet of waterbirds and waders, but whilst considerable attention has been directed to the waterfowl populations of the urban wetlands (Riggert 1966, 1976; Newman *et al.* 1976; Bekle 1982a, b) and much of the documented waterfowl diversity and abundance is likely to be a direct consequence of the macroinvertebrate food supply, few studies have considered the latter fauna. Unpublished studies by Ayre *et al* (1977), Hembree and George (1978) and van Alphen (1983) are the only studies which have described the macroinvertebrate communities of some of Perth's wetlands.

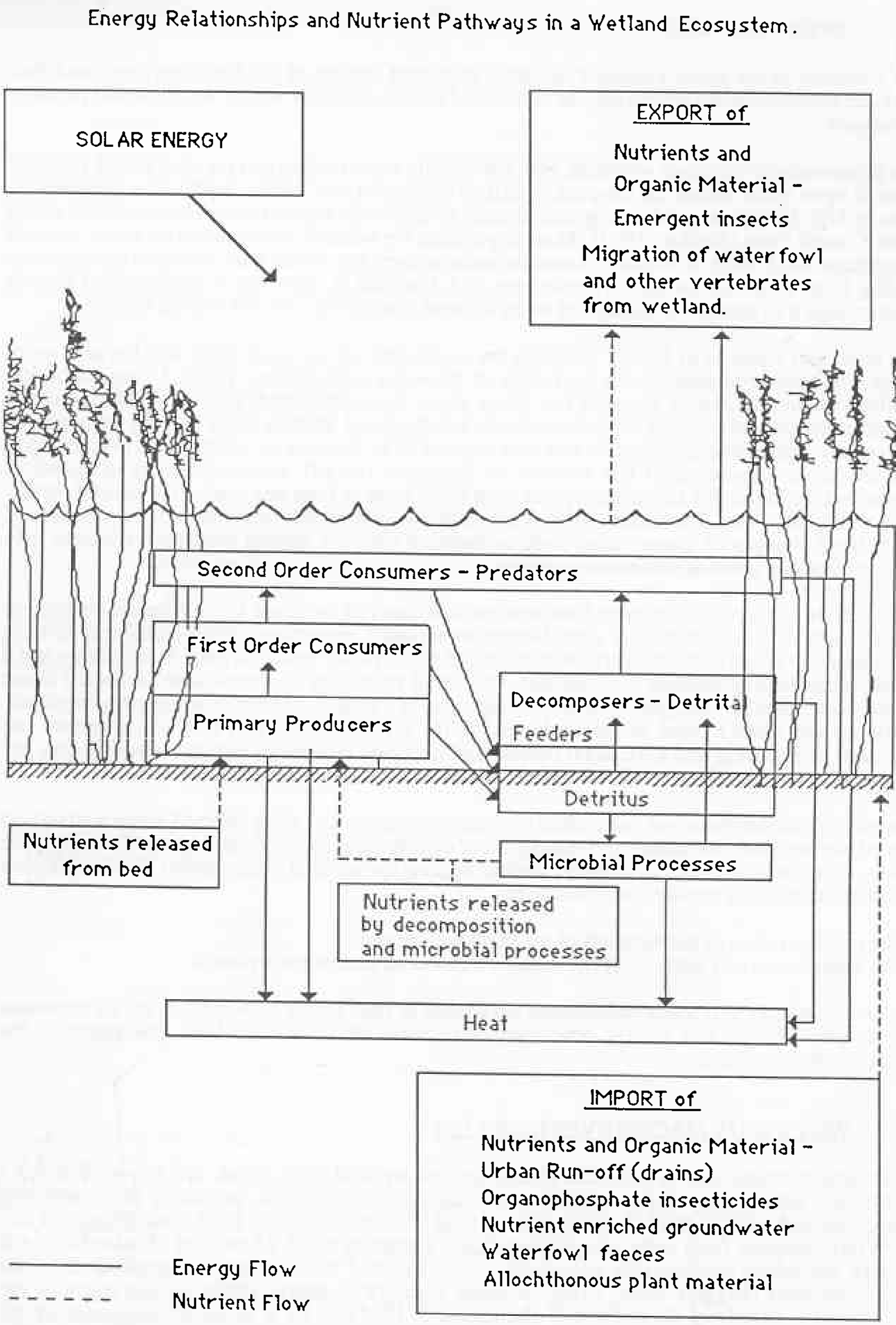
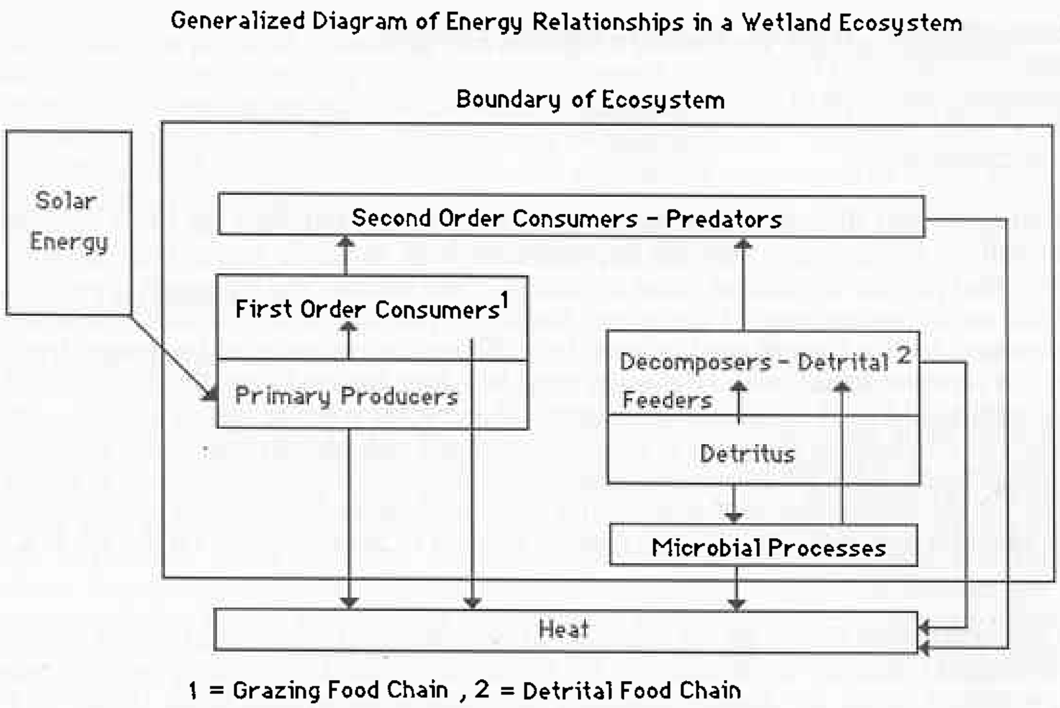


Figure 1: Energy relationships and nutrient pathways in a wetland ecosystem.



Primary Producers : Macrophytes (fringing reeds and submerged plants)
: Periphyton / Metaphyton
: Phytoplankton , Algae

Invertebrate members of grazing and detrital food chains

First Order Consumers :	Zooplankton Gastropods	Chironomid larvae (in part)
Second Order Consumers :	Dragonfly nymphs Damselfly nymphs Megalopterans Water Mites Chironomid larvae (in part)	Dysticid larvae Hydrophilid larvae Corixid bugs (water boatmen) Notonectid bugs (backswimmers)
Decomposers :	Oligochaetes Amphipods Freshwater shrimps Mayfly larvae Beetle larvae Caddisfly larvae	Chironomid larvae (in part) Phreatiocids Ostracods Corixid bugs (in part)

Figure 2: Generalized diagram of energy pathways and trophic structures in a wetland ecosystem.

In addition to their importance within wetland food webs, macroinvertebrates may act as biological indicators for the assessment of water quality. Management of the urban wetlands must incorporate a water quality management programme, and water quality monitoring is an essential part of such a programme (Campbell, 1982). Water quality monitoring involves the measurement of various physical, chemical and biological factors, and the type of monitoring needed is dependent upon what uses are to be made of the water in question.

Campbell (1982) listed the following major uses for inland waters in Australia :

1. Water supply : domestic use, agriculture, industry
2. Recreational use : swimming, boating, fishing, aesthetic appreciation, waterfowl habitat, nature studies

3. Science and education : scientific research, teaching resource
4. Food source : commercial fishing
5. Waste disposal : discharge of effluents
6. Drainage
7. Energy : hydroelectricity.

Perth's wetlands do not directly serve water supply purposes, but they do have considerable recreational values; in particular they are important for both aesthetic reasons and as waterfowl habitats. They also possess significant value as scientific and educational resources. In addition, the wetlands form an important part of the urban drainage system. For recreational, scientific and teaching purposes, wetland water quality must be sufficient to maintain and preserve freshwater ecosystems. To preserve social values the water must be odour free and visually pleasant, and must maintain the habitat and food supply for the waterfowl and other wildlife that inhabit the wetlands. For scientific and educational purposes it is important that a rich and diverse fauna is maintained, and that some pristine areas are preserved. The quality of urban drainage may be far poorer than that required for the maintenance of aquatic life, and the potential for conflict between uses of wetlands is apparent and indeed conflict is already evident in many regions on the Swan Coastal Plain.

Because of the importance placed on the recreational, scientific and educational values of the urban wetlands, biological monitoring appears to be a suitable method of water quality monitoring because it provides a means for directly assessing the status of the aquatic biota. Hellawell (1978) noted that changes in physical and chemical characteristics of a waterbody due to management practices, catchment influences or pollutants are of little practical value unless they can be related to their effect upon the biota. Ultimately water quality is related to human activities and the maintenance of biota, and so water quality monitoring should utilise biological data directly. Measurement of physical and chemical parameters gives instantaneous information on water quality whilst macroinvertebrate communities can act as integrators of the water quality history of each wetland.

The use of biological data, in any form, as an indicator of water quality, is known as biological monitoring (Arthington *et al,* 1982). Biological monitoring techniques are well established in Britain, Europe and the USA, and recent reviews of various methods are given by Hellawell (1978) and James and Evison (1979). However, the application of biological monitoring in Australia, until very recently, was limited, and some of the reasons for this are discussed in reviews by Bayly and Lake (1978), Williams (1980), Davey (1980), Arthington *et al* (1982) and Campbell (1982). Macroinvertebrates are the organisms most widely used in biological monitoring studies (Arthington *et al* , 1982), and five approaches using single species or entire communities have been listed by Jones and Walker (1979). These are :

1. Toxicity tolerances
2. Bioassays
3. Indicator organisms
4. Bioaccumulation
5. Community approaches

1 to 4 are best employed where the effects of specific pollutants are being studied and so were not appropriate to this study. The use of community data employs the concept that the structure and composition of whole communities can change as a consequence of poor water quality (Bayly and Lake, 1979). Hellawell (1978) suggested that community data is "probably the most informative for general management purposes" and this approach (5) appeared to be the most suitable for Perth's wetlands.

2.2 OBJECTIVES

The objectives of the study were :

1. to describe the macroinvertebrate communities of selected urban wetlands, and to determine variations within and between wetlands and between seasons;

2. to determine the physical, chemical, and biological parameters that may influence macroinvertebrate community structure in the selected wetlands;
3. to provide baseline information on the macroinvertebrate fauna and various physico-chemical parameters against which future changes may be assessed; and
4. to determine the feasibility of using biological monitoring techniques to assess the water quality of Perth's wetlands.

3. METHODS

3.1 OVERVIEW

To achieve the objectives, five wetlands were chosen for study, two sites were selected per wetland, and monthly water samples and three-monthly faunal samples were collected from each site. Because the life cycles of many macroinvertebrates may span from several months to several years, the interval between sampling occasions was set at three months to ensure that as many species as possible were collected. Monthly collection of water samples was undertaken to determine large-scale seasonal changes in water chemistry. Manpower and budget constraints prevented sampling on the finer spatial and temporal scales which are required for the analysis of non-conservative or biologically mediated ions, particularly nutrients, which may vary on daily or hourly timescales or less.

The physico-chemical environment of each wetland was assessed by measuring the following parameters : depth, light transparency, pH, conductivity, cation and anion concentrations (Na^+, K^+, Ca^{++}, Mg^{++}, Cl^-, HCO_3^{--} and SO_4^{--}), nutrient concentrations (total P, PO_4^{--}, organic P - by difference, total N, NH_4^+, NO_2^{--}/NO_3^-, and organic N-by difference), and the organic content of the lake sediments. Measurement of nutrients, organic content of lake sediments and chlorophyll-*a* concentrations (see below) also enabled each lake to be classified on the basis of trophic structure.

The macroinvertebrate fauna was sampled both quantitatively and qualitatively to enable the determination of the following community parameters: species richness (S), abundance (mean number of individuals /m^3), Shannon - Wiener diversity (H), evenness or equitability (E), and percentage species composition. Other biotic factors measured included chlorophyll-*a* concentration (as an indicator of algal abundance) and qualitative assessment of the dominant form of primary production in each lake. Primary analysis of the data collected is presented in this report but further analysis is proposed, using multivariate statistical techniques, and will be published later.

3.2 CHOICE OF WETLANDS AND SAMPLING SITES

Five urban wetlands, Jandabup Lake, Lake Joondalup, Lake Monger, North Lake and Thomsons Lake were chosen for study following discussions with Dr J Arnold (DCE), Dr T Allen (Geol. Survey) and members of the Perth Urban Water Balance Study team (Cargeeg et al, 1987). The location of the five wetlands on the Swan Coastal Plain and their relationship to the water table is given in Figure 3.

Lakes Jandabup and Joondalup were chosen as being representative of lakes on the Gnangara Groundwater Mound, and North and Thomsons Lakes of lakes on the Jandakot Mound. Jandabup Lake (C class reserve), Thomsons Lake (A class reserve), and Lake Joondalup (A class reserve) are of considerable ecological interest because they represent important waterfowl habitats. Sampling permits for these lakes were obtained from the Department of Conservation and Land Management, and permission to sample in Lake Monger and North Lake was obtained from the Perth City Council and the Cockburn City Council respectively .

Initially a pristine or undisturbed wetland was to be included within the study to act as a "control " site. However no wetlands that were entirely free of human influences or urban pressures could be found within the urban region. Disturbances have included the removal of fringing vegetation,

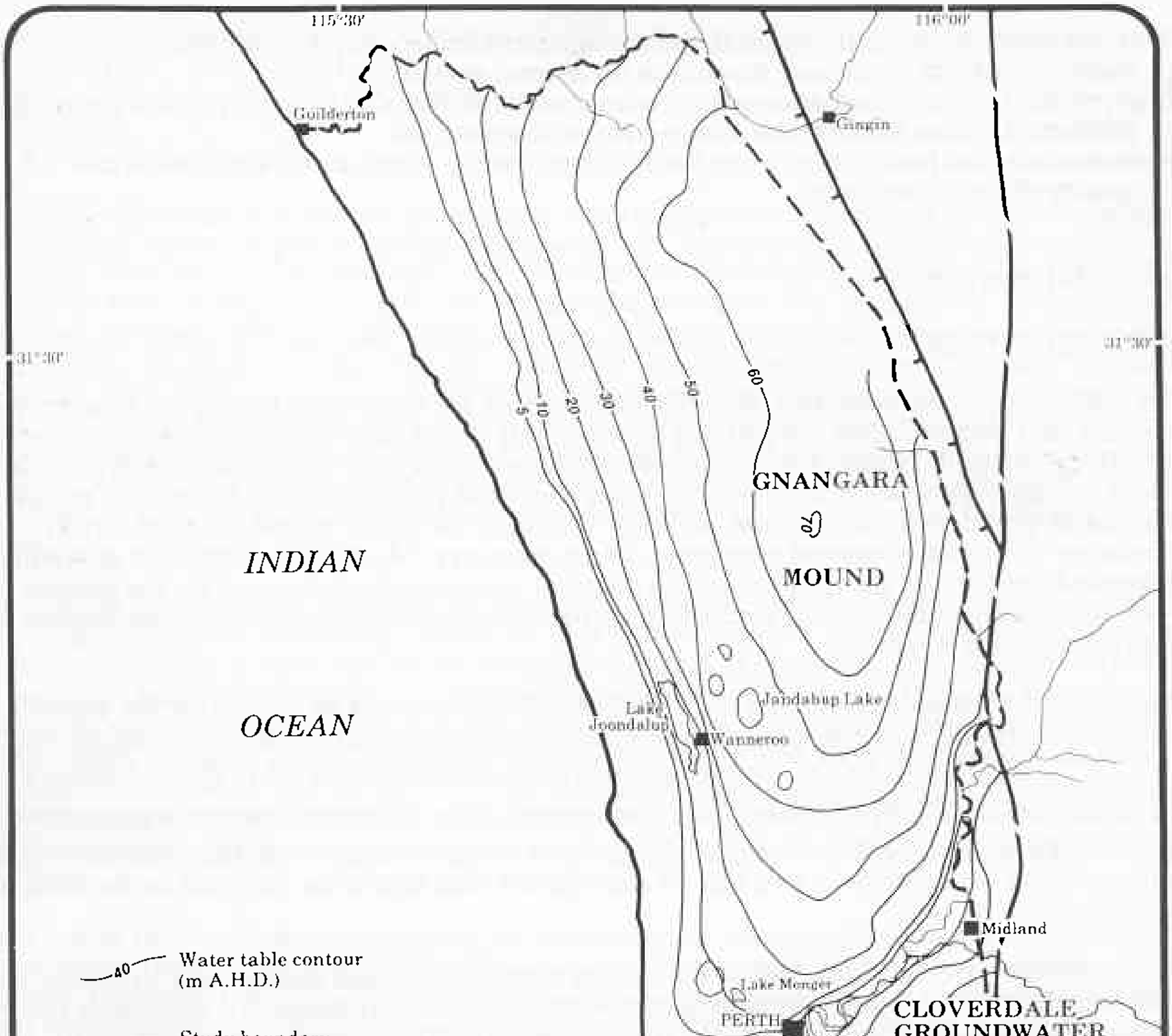


Figure 3: Location of the five wetlands studied on the Swan Coastal Plain, W.A., and their relationship to the water table. Map provided by the Water Authority of Western Australia.

pesticide applications, encroaching land uses (eg nearby urban development, market gardens and rubbish tips), and the use of wetlands as compensating basins and associated drains. Lake Monger represented the most altered lake within the urban wetland system. Little natural fringing vegetation remains around Lake Monger, water levels are regulated and stay artificially high during summer, pesticides are applied regularly during the summer months for the control of midges, and a rubbish tip was previously located on the north eastern edge. Knowledge of the structure and function of the faunal communities present within this system, and the extent of their similarity or dissimilarity to the other apparently less degraded lakes, could provide valuable information on the responses of wetlands to urban pressures.

A previous study of some of the lakes of the northern Swan Coastal Plain (Hembree and George, 1978) had identified the littoral zone as being the most productive region within urban wetlands, and a decision to sample only within the littoral zone was made on the basis of this information (the term "littoral" is generally considered to refer to the section of the lake lying closest to the margin or edge). Two sites were chosen per wetland to enable variations within each lake to be identified. The location of sampling sites within each wetland is shown in Figure 4. Each site was designated by a single letter allocated in alphabetical order from A to J. The final choice of sites was determined by the homogeneity and representativeness of areas within the littoral zone, and by the ease of access to them.

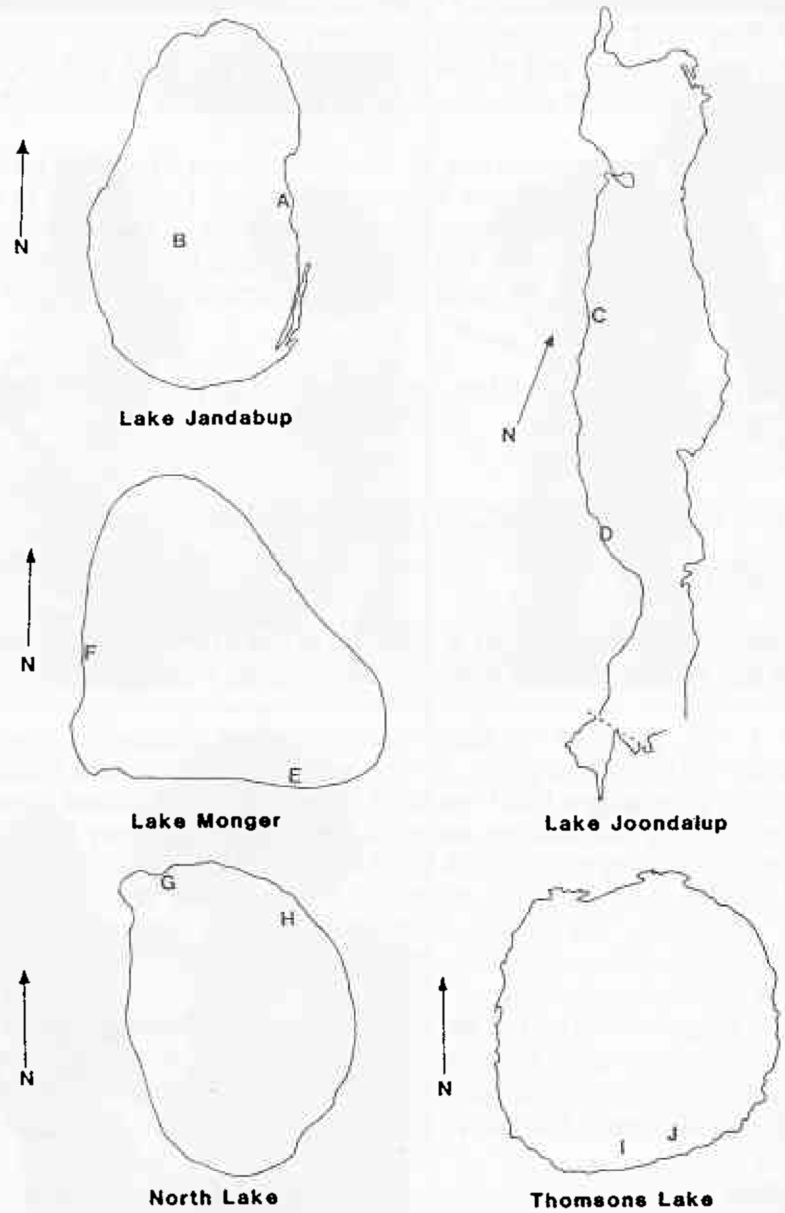


Figure 4: Location of sampling sites in the five wetlands studied. Each site is indicated by a single letter allocated in alphabetical order from A to J. The lakes are not drawn to the same scale.

3.3 VEGETATION AND LAND-USE STUDY

A consultant botanist, Mr Mark Burgman, was employed in May 1985 to compile vegetation maps and field herbariums for the five wetlands. This work was completed on June 30, 1985. Mr Burgman also provided maps showing changes in vegetation and land use in the vicinity of the five lakes, compiled from an examination of aerial photographs taken in 1958, 1963, 1968, 1978, 1981, 1983 and 1984 .

3.4 WATER CHEMISTRY AND NUTRIENTS

Water samples were collected from the two sites at each lake on a monthly basis. Two 500 ml samples were collected for the analysis of the ions: Na^+, K^+, Mg^{++}, Ca^{++}, Cl^-, HCO_3^{--} and SO_4^{--}. Six water samples were collected and stored in 200 ml Whirlpaks for the following nutrient analyses: soluble reactive phosphate (PO_4^{--}), nitrite/nitrate (NO_2^{--}/NO_3^-) ammonium (NH_4^+), total phosphorus and total nitrogen. Three samples (PO_4^{--} , NO_2^{--}/NO_3^-, NH_4^+) were filtered in the field using a 50 ml syringe and 0.45 micron filter, as illustrated in Photograph 1. The Whirlpaks were placed in an insulated container in the field, and later frozen and stored until analysis. The filter papers were later used for chlorophyll-*a* determinations. Water depth, air and water temperatures, Secchi disc turbidity and pH were measured in the field, and 100 ml water samples were collected for later measurement of conductivity in the laboratory at Murdoch University.

Analyses for the major ions were carried out by the Government Chemical Laboratories, and the nutrient analyses by the Centre for Water Research Nutrient Laboratory at the University of Western Australia. Nutrient analyses were carried out with a Technicon autoanalyser and spectrophotometer. Samples analysed for total phosphorus and total nitrogen were digested first before analysis with a block digester. Organic phosphorus and organic nitrogen were obtained by difference calculations.

Chlorophyll-*a* analyses were undertaken by one of the authors (S W Rolls) at the Water Authority's Chemistry Laboratory.

3.5 MACROINVERTEBRATE SAMPLING PROGRAMME

3.5.1 FIELD COLLECTION

The aquatic invertebrate fauna was sampled at each site at three monthly intervals : April 1985, July 1985, October 1985 and January 1986. Two sampling methods were used :

1. Pump samples - A PVC pipe (15 cm diam) was pushed or hammered into the substrate to a depth of approximately 10 cm (Photograph 2). The water, sediments, and fauna enclosed within, were pumped out of the pipe with a hand operated bilge pump and passed through a 250 micron mesh net (Photograph 3). The net contents were shaken onto a white tray for brief examination in the field and then preserved in ethanol (100%) and stored in labelled plastic bags (Photograph 4). With this method the fauna in both the water column and the sediments could be sampled quantitatively at the same time. The density of invertebrates was measured by recording the depth of water in the pipe and calculating the volume of water filtered through the net. Six pump samples were taken at random locations at each site.
2. Sweep samples - A long handled sweep net was used to sample the species in the water column (Photograph 5). Two sweep samples were collected per site: one in the open water and one from amongst the fringing reeds. This method may be regarded as semi-quantitative because the net was swept vigorously through the water for a fixed period (one minute) for all samples.

Photographs of sampling techniques used in the wetlands study.

1: Selected water samples were filtered in the field using a 50ml syringe and 0.45 micron filter paper for later chlorophyll-*a* determination.

2: Quantitative samples of aquatic macroinvertebrates were collected using a PVC pipe (15cm diameter).

3: The pipe was pushed into the substrate to a depth of approximately 10cm, and the water, sediments, and fauna were pumped out of the pipe with a hand operated bilge pump into a 250 micron mesh net.

4: The contents of the net were transferred to labelled plastic bags and preserved with 100% ethanol.

5: Semi-quantitative samples were collected by sweeping a long-handled net through the water for a fixed period of time (one minute).

(Photographs by D. Birt, Water Authority).

3.5.2 SORTING

Pump samples - In the laboratory all samples were washed through a set of three sieves (2 mm, 600 micron and 180 micron). The choice of sieves was made on the basis of those required for the sediment analysis which was undertaken on the samples at the same time. The material retained on each sieve was placed onto a separate white tray, and all invertebrates that could be detected by the naked eye were removed, sorted into taxa, and preserved in $^1/_4$ oz Macartney vials in 70% ethanol.

Material in the 600 and 180 micron trays was subsampled (by volume) and examined at 10x magnification under the binocular dissecting microscope. All invertebrates were removed and stored as described above. All sediments and organic material were retained for further analysis (see section 3.6).

Sweep samples - All samples were processed in the laboratory by the method described above, but only a representative sample from each taxon present was kept. All sediments and remaining organic material were discarded.

3.5.3 IDENTIFICATION

The contents of all vials were re-examined following initial sorting, and identifications were made to species level where possible or otherwise to the lowest taxonomic grouping possible. The following keys and taxonomic papers were consulted: CSIRO (1970), Edward (1964), Knowles (1974), Lansbury (1970), Mathews (1982), Morrissy (1977), Smith and Kershaw (1979), Watson (1962), Watts (1963, 1978), Williams (1962, 1980), and Wroblewski (1970). Specialist taxonomists were contacted to provide help with the identification of material in the following groups; Dytiscidae and Hydrophilidae (Dr C H S Watts, Institute of Medical and Veterinary Science), Hydracarina (Dr M Harvey, Museum of Victoria), Hydroptilidae (Dr A Wells, Adelaide Univ), Leptoceridae (Ms R St Clair, Monash Univ), Ecnomidae (Mr J Dean, Melbourne and Metropolitan Board of Works) and Ostracoda (Dr P De Deckker, Monash Univ).

3.6 ORGANIC CONTENT AND SEDIMENT ANALYSIS

All material collected by the pump sampler, minus the invertebrate component, was analysed for grain size and organic content. Grain size was determined by the sieving method (2 mm, 600 micron, and 180 micron mesh sizes) described above. Sediment passing through the 180 micron sieve was collected in a 10 litre container, allowed to settle, and the bulk of the water decanted off. Dry weights for all the material in each of the four size classes were obtained after samples had been dried overnight at 110°C. Samples were then ashed at 600°C for two hours to enable calculation of organic content. Only the results of the organic content analysis are presented in this study. The sediment results will be reported at a later date.

3.7 VALIDITY OF SAMPLING METHODS

Although the validity of collecting water samples for chemical analysis (particularly of non conservative and biologically mediated ions) on only one occasion per month and at only two sites per lake may be questioned because these parameters may vary on daily or hourly timescales, the results obtained in this study were generally very consistent between the two sites in each lake and over the winter months (section 5.1). More variability was evident during the summer months, probably because the higher summer temperatures result in increased biological activity.

Replicate samples were collected for six of the 12 sampling occasions and processed separately by the Water Authority Chemical Laboratory. In all cases the results obtained by the Centre for Water Research and the Government Chemical Laboratories varied by no more than 10% from the Water Authority results.

Species-samples curves, similar to the species-area curves employed in botanical studies, were plotted after the first sampling session to determine the validity of taking six pump samples per site.

At almost all sites no new species were recorded after five samples had been sorted, which indicated that six samples were sufficient to detect all common taxa. Sweep samples were taken to ensure that rarer taxa were also sampled, and between two and five extra taxa were generally collected from each site by this method.

4. PHYSICAL CHARACTERISTICS OF THE STUDY AREA

4.1 THE SWAN COASTAL PLAIN

4.1.1 CLIMATE

The Swan Coastal Plain has a mediterranean climate with a cool wet winter and hot dry summer. The rainfall is highly seasonal and about 90% of the annual rainfall occurs within the period April to October. The annual average rainfall for Perth is 870 mm and Class A pan evaporation is 1819 mm. Evaporation exceeds precipitation in all months except the period between May and August. The annual rainfall is highly variable from year to year, and the period 1975-1984 was the driest ten year period on record.

Monthly rainfall totals for the period April 1985 to April 1986 are given in Figure 5 (Bureau of Meterology, pers comm, 1986). The maximum monthly total of 190.6 mm was recorded in July 1985, and a summer storm in February 1986 resulted in an unseasonally high monthly total of 80.6 mm. The total rainfall recorded for the twelve month period April 1985 to March 1986 of 806.2 mm was 60 mm below the annual average.

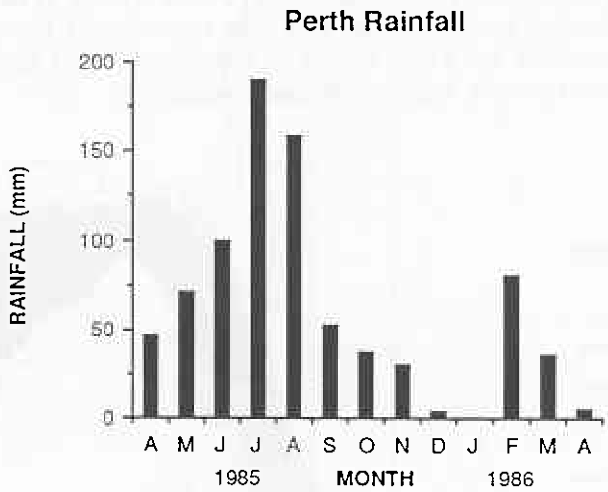


Figure 5: Total monthly rainfalls (mm) for Perth from April 1985 to April 1986.
Data provided by The Bureau of Meteorology, Perth, W.A., 1986.

4.1.2 GEOMORPHOLOGY AND GEOLOGY

The Swan Coastal Plain consists of a series of distinct landforms running in an approximately north-south direction and extending from the coast to the Darling and Gingin Scarps. The Quindalup and Spearwood Dune systems lie closest to the coast, with the Bassendean Dune system further east. Wetlands occur within interdunal depressions in these three systems and lie along the boundaries between adjacent systems (Cargeeg *et al*, 1987).

The Swan Coastal Plain is on the eastern, onshore edge of the Perth basin. In this region the basin contains about 13 000 m of Permian to Quaternary aged sedimentary rock. The uppermost plain formations are late Tertiary and Quaternary, comprising sand, limestone and interbedded silt and clay, up to 100 m thick.

The Quaternary sediments form a heterogenous unconfined aquifer which varies in composition both vertically and laterally. The aquifer is recharged from rainfall and this leads to a build-up of water, forming mounds of groundwater in the sediments. Two large mounds, the Gnangara Mound and the Jandakot Mound, are present within the urban region (Figure 3). Because the water table is higher than sea level, the groundwater drains towards the boundaries of the water table under the action of gravity. The rate of groundwater movement is in the order of 50 to 100 metres per year.

4.2 DESCRIPTION OF STUDY SITES

4.2.1 JANDABUP LAKE

Jandabup Lake is a shallow (<1.5m deep), oval-shaped lake lying within a Crown reserve of 232.3 ha, situated approximately 22 km north of Perth city and 9 km east of the Indian 0cean. The open water area of the lake comprises 110 ha and is surrounded by a zone of sedges 134 ha in area. The lake lies in an interbarrier depression between the Bassendean and Spearwood Dune systems. The lake is a surface expression of the Gnangara Mound groundwater flow system (Allen, 1976) and the hydrogeology of the lake has been described by Allen (1979). An inflow of groundwater occurs on the eastern side of the lake and this together with rainfall maintains the water level. Allen (1979) noted that the lake behaves as an evaporative basin : outflow is impeded by organic lake deposits and about 90% of the groundwater inflow and rainfall is lost by evaporation.The lake was virtually dry by late summer in both 1985 and 1986, however, complete drying of the lake is a fairly recent phenomenon (J Arnold, pers comm, 1986).

The bed of the eastern half of the lake comprises fine sands (Photograph 26) and the western half (55% of the total lake area) is diatomite (Photograph 27) (Allen, 1979). A map of the vegetation of the lake (Figure 6) was compiled by Marchant and was reproduced from Ayre *et al* (1977). *Baumea articulata* is the dominant rush and forms an extensive stand across much of the lake, whilst a narrow band of *Baumea juncea* borders the open water.

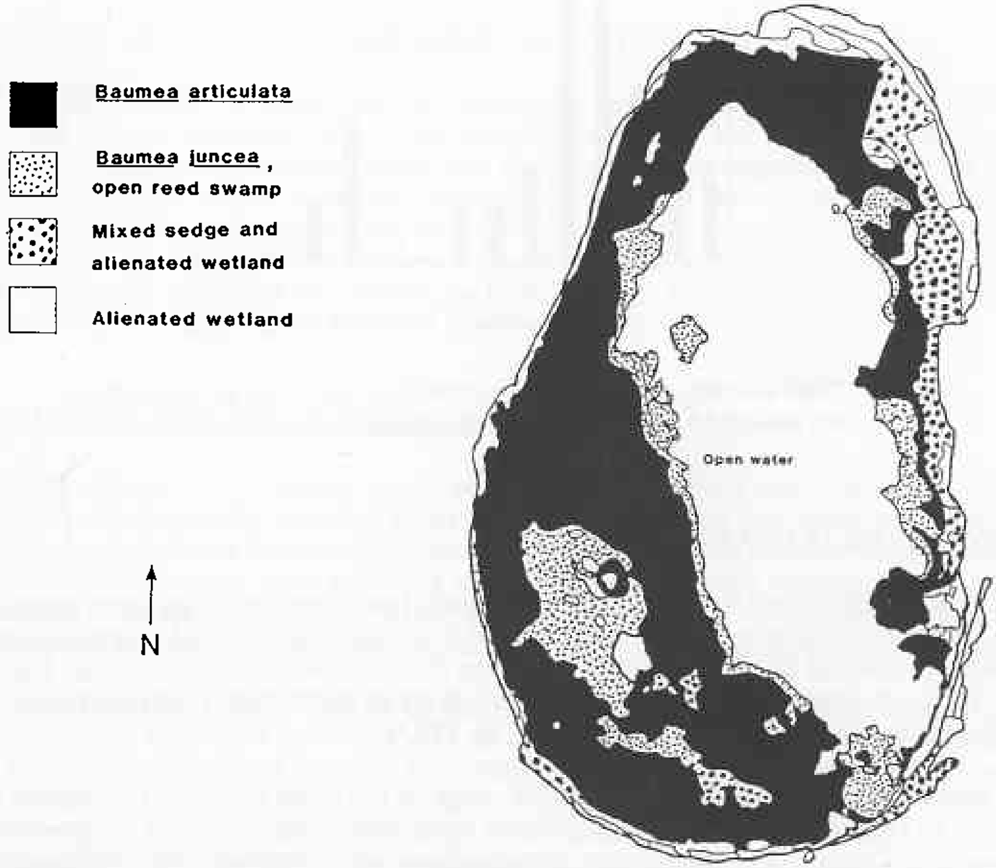


Figure 6: Map of the vegetation of Jandabup Lake after Marchant, in Ayre *et. al* (1977). Checked by Burgman, 1985.

Although the central area of the lake is a C - class reserve for the conservation of flora and fauna, almost a third of the lake and most of the surrounding land is freehold (Allen, 1979). Increasing land use around the lake (Figure 7) has resulted in increasing alienation of the wetland vegetation as indicated by comparing the land-use maps compiled from aerial photographs taken in 1968, 1981, 1983 and 1984, respectively. The form of land use has remain unchanged, however, and may be classified as rural or semi-urban.

Site A (Photographs 6 and 7) is situated on the eastern edge of the open water on sand, and Site B (Photograph 8 and 9) is at the western edge on a diatomite bed. Both sites were completely dry at the start of the study in April 1985, and from January through to April in 1986. During these times monthly water samples and one set of faunal samples (April, 1985) were taken from the water (which was only a few centimetres deep) remaining in the centre of the lake at a point approximately midway between sites A and B.

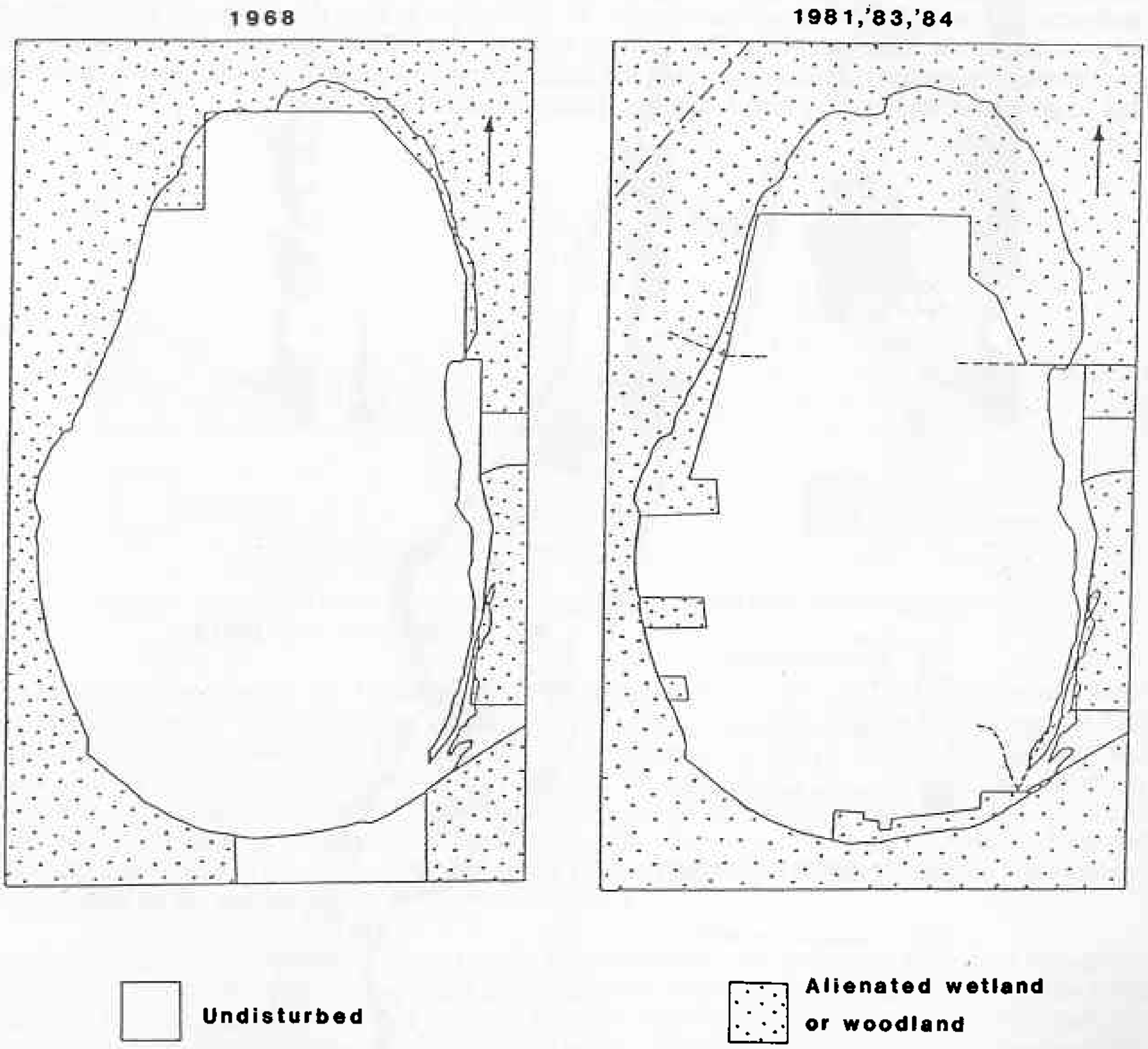


Figure 7: Changes in land-use around Jandabup Lake compiled from aerial photographs taken in 1968, 1981, 1983, and 1984.

4.2.2 LAKE JOONDALUP

Lake Joondalup is a shallow, linear lake situated approximately 20 km north of Perth and 6 km east of the Indian Ocean. The lake has a total area of 593 ha comprising 449 ha of open water, 79 ha of sedgeland and 64 ha of paperbark woodland (Arnold, 1987), and is an A - class reserve for the conservation of flora and fauna. The lake is a surface expression of the Gnangara Mound flow system and is one of a series of lakes within the Spearwood Dune system forming a chain of wetlands parallel to the coast. Congdon (1985) described the water balance of the lake and concluded that evaporation is the largest contributor to the water balance, followed by precipitation. Surface water flows into the lake from the south, coming from the Wallubuenup-Beenyup swamp system, and there is some seepage of groundwater into the lake on the eastern and western sides (Congdon, 1985).

A map of the vegetation of the lake (Figure 8) was compiled by Marchant and is reproduced here from Ayre *et al* (1977). The lake contains large expanses of open water plus many small islands and emergent stands of *Baumea articulata*. *B. articulata* is also the dominant rush within the vegetation of the lake margins. The western edge of the lake still contains fine stands of the paperbark, *Melaleuca rhaphiophylla* , but the natural fringing vegetation of the eastern lake margin has largely been replaced by lawns, playing fields and other urban features.

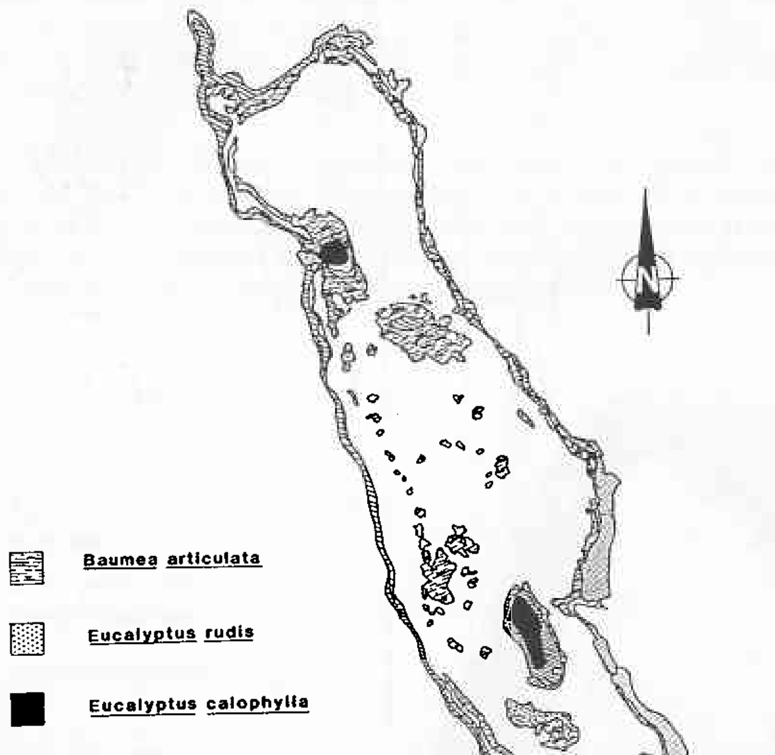


Figure 8: Map of the vegetation of Lake Joondalup after Marchant, in Ayre *et. al.* (1977). Checked by Burgman, 1985.

The increasing urbanization of the land surrounding Lake Joondalup is evident from a comparison of the three maps given in Figure 9. The maps show the land use changes around the lake as determined from aerial photographs taken in 1963, 1968, 1981, 1983 and 1984. The almost complete urbanization of the area east of the lake and the increasing urbanization of the western region of the lake are clearly shown.

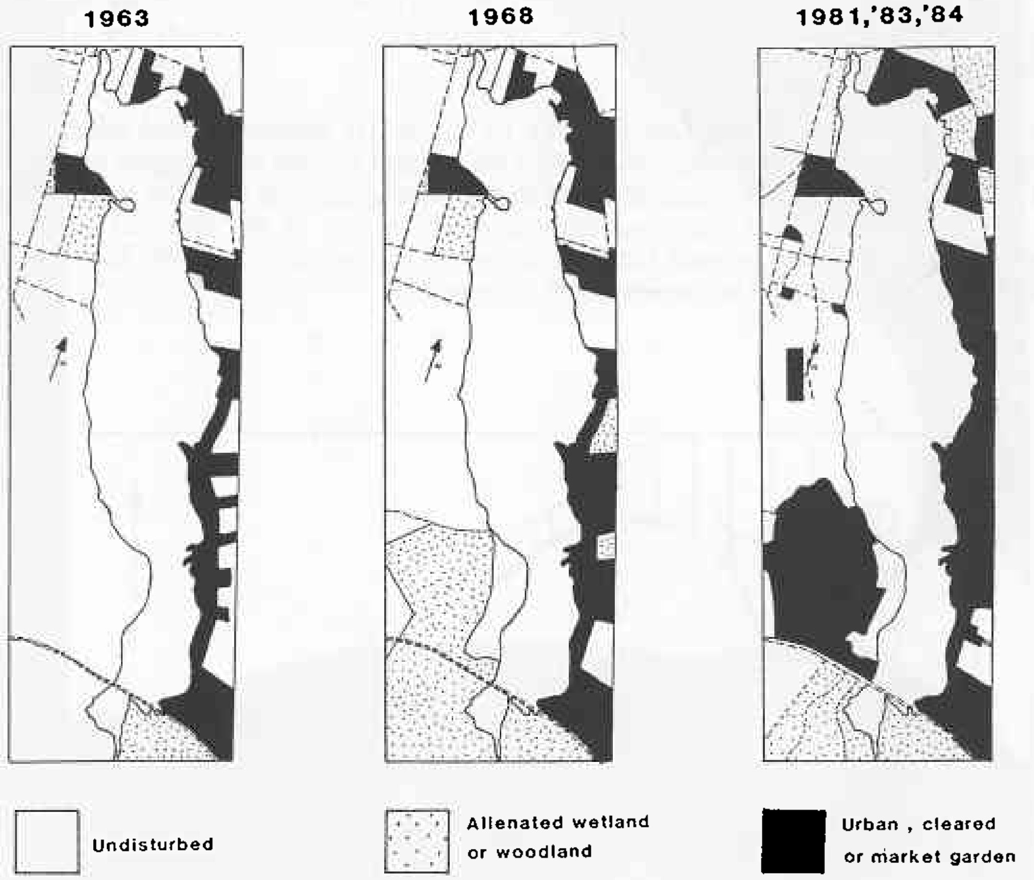


Figure 9: Changes in land-use around Lake Joondalup compiled from aerial photographs taken in 1963, 1968, 1981, 1983, and 1984.

The two sampling sites on the lake, sites C (Photographs 10 and 11) and D (Photographs 12 and 13), are both on the western margin and are sites of permanent water, although the depth at each varies from 100 cm in winter to 10 cm or less in late summer (section 5.1). Site C is adjacent to a stand of *B. articulata* and fringing woodland of *M. rhaphiophylla* just south of Neil Hawkins Park; Site D is adjacent to similar vegetation on the edge of a small park within the suburb of Edgewater. The lake is shallower on the eastern side, and large expanses of soft mud created difficulties of access to the open water during the summer months. This precluded the possibility of placing sites on the eastern shore.

An algal /sediment suspension or ooze, known as metaphyton, was present at both sites throughout the study. The occurrence of metaphyton in the lake was first recorded by Rose in 1979 who noted that very little is known about this form of benthic micro-algae. During the present study the metaphyton comprised the lower half of the total water column at both sites on all but one sampling occasion. Light penetration within the metaphyton (as revealed by Secchi disc) was less than 5 cm, and experiments by Rose (1979) revealed that light penetration in metaphyton held in the laboratory was less than 0.5 cm. During late summer (March and April, 1986), much of the metaphyton appeared to die as water levels decreased, exposing the upper layers to air. The dead algal cells first formed a distinctive pink mat, which later turned white upon further drying. Near the centre of the lake the dried metaphyton formed large banks (Photograph 28) firm enough to support the weight of waterfowl. The lake is sprayed regularly during the summer months with the organophosphate pesticide Temephos (Abate), for the control of chironomids (the larval stage in the life-cycle of the midge).

4.2.3 LAKE MONGER

Lake Monger is a shallow lake with 70 ha of open water. The lake is close to the centre of Perth, and completely surrounded by urban development. A rubbish tip was present on the north-eastern shore of the lake from 1950 to 1964, and approximately 100 ha of wetland area was reclaimed by landfill during this time. The lake is sprayed regularly during the summer months with the organophosphate pesticide Temephos (Abate), for the control of chironomids (the larval stage in the life-cycle of the midge).

A map of the vegetation of the lake is given in Figure 10. Some residual stands of reeds and bulrushes (*B. articulata* and *Typha orientalis*) are present around the margins of the lake, but no original woodland remains. A comparison of aerial photographs of the lake taken in 1963, 1968, 1981, 1983 and 1984 reveal that considerable modification of the wetland environment had occurred by 1963, and that general land-use activities in the vicinity of the lake have remained essentially the same over the last twenty years (Figure 11).

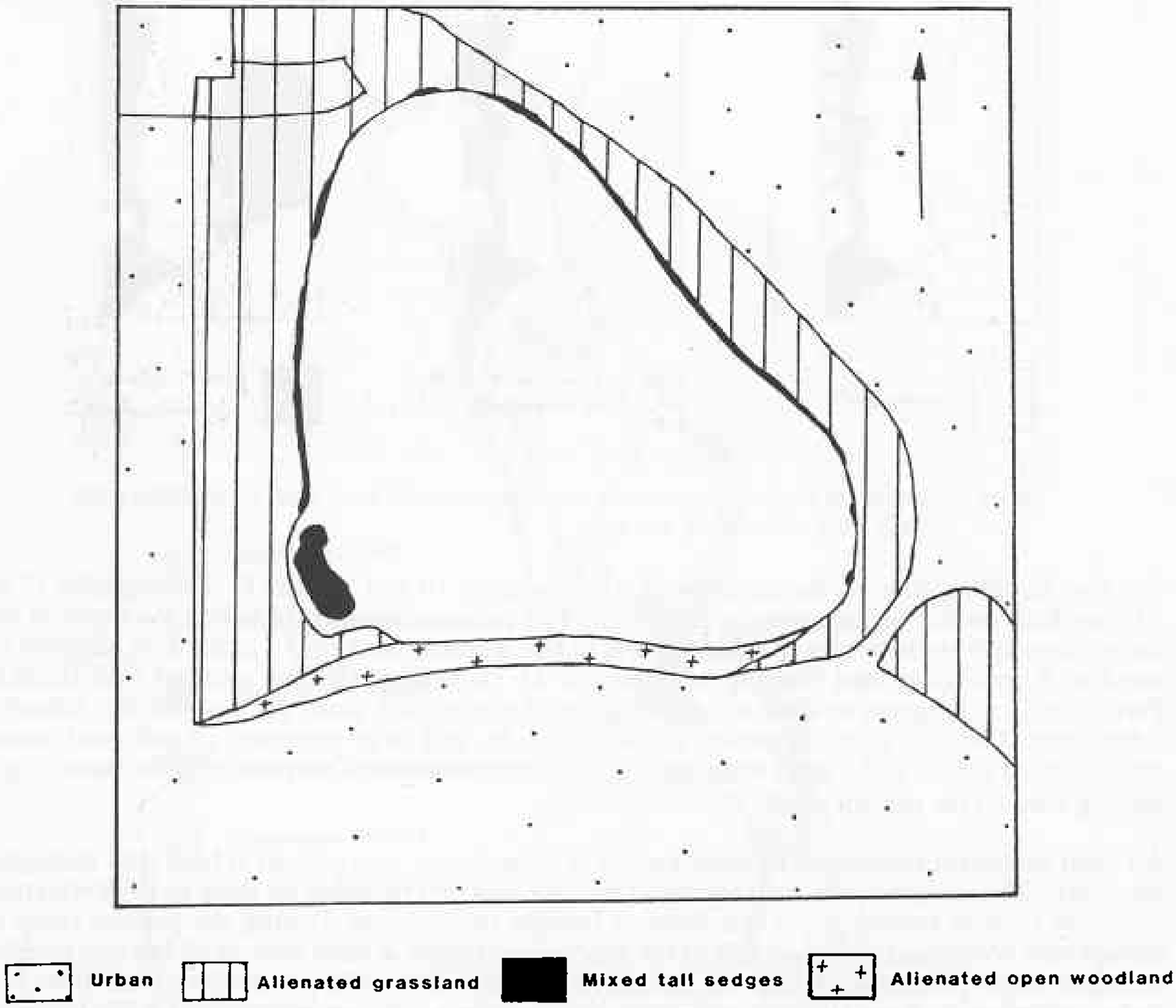


Figure 10: Map of the vegetation of Lake Monger, reproduced from maps drawn by M. Burgman, 1985.

1963,'68,'81,'83,'84

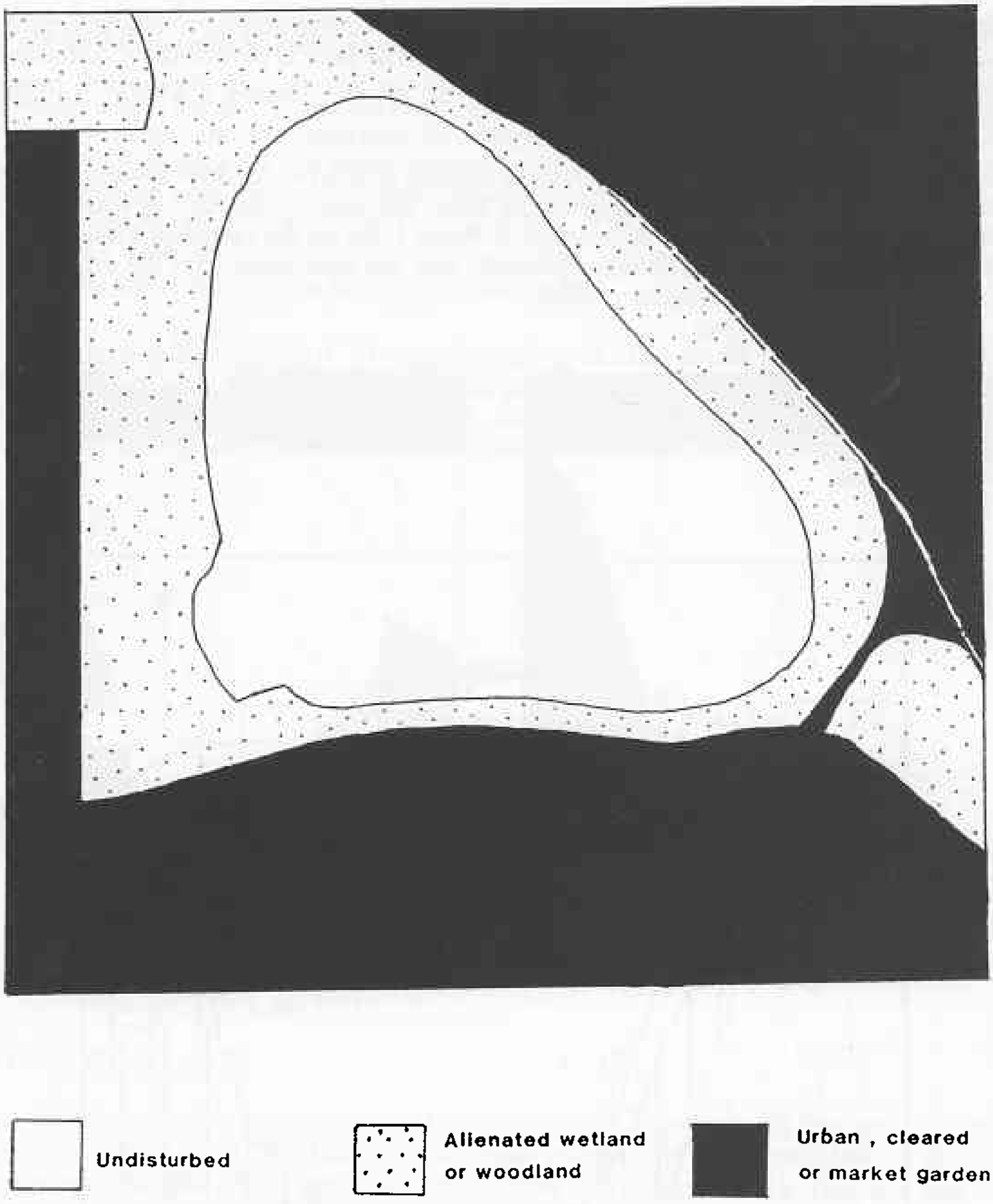


Figure 11: Land-use around Lake Monger compiled from aerial photographs taken in 1963, 1968, 1981, 1983, and 1984. Land-use in the vicinity of the lake has remained virtually unchanged over the period 1963 to the present.

Site E (Photographs 14 and 15) is located at the south-eastern edge of the lake adjacent to the lawns and a cycleway which encircles the lake. Site F (Photographs 16 and 17) is on the western margin of the lake, and is adjacent to a small stand of sedges, lawns, and an inflowing stormwater drain. Both sites had permanent water, and the depth increased from late summer to winter by approximately 60 cm (section 5.1). Several drains carry stormwater into the lake, and an outflow drain at the south-eastern corner carries overflow, during winter, to the Swan estuary. Water levels are regulated by the Perth City Council during summer, and water is pumped into the lake from nearby bores to prevent the lake drying out.

4.2.4 NORTH LAKE

North Lake is a small, shallow lake of approximately 29 ha in area and up to 2 m in depth, situated 14 km south of Perth and 7 km from the Indian Ocean. The lake is part of the Cockburn chain of wetlands which lie parallel to the coast and within an interbarrier depression between the Bassendean and Spearwood Dune systems.

The lake is a surface expression of the Jandakot Mound groundwater flow system, and receives some inflow from stormwater drains entering from the nearby suburb of Kardinya and the Murdoch Veterinary School farm. The position of North Lake on the Jandakot Mound is similar to that of Jandabup Lake on the Gnangara Mound, and the two lakes may be considered to be hydrogeologically equivalent (Megirian, 1982).

A map of the vegetation of North Lake is given in Figure 12. Remnants of natural vegetation are present at the north-eastern end of the lake, comprising mainly a narrow strip of *M. rhaphiophylla* woodland and some small stands of *B. articulata* . A Community Employment Programme (CEP) funded planting programme was carried out at the lake in 1985 and 1986, primarily to re-establish the native vegetation.

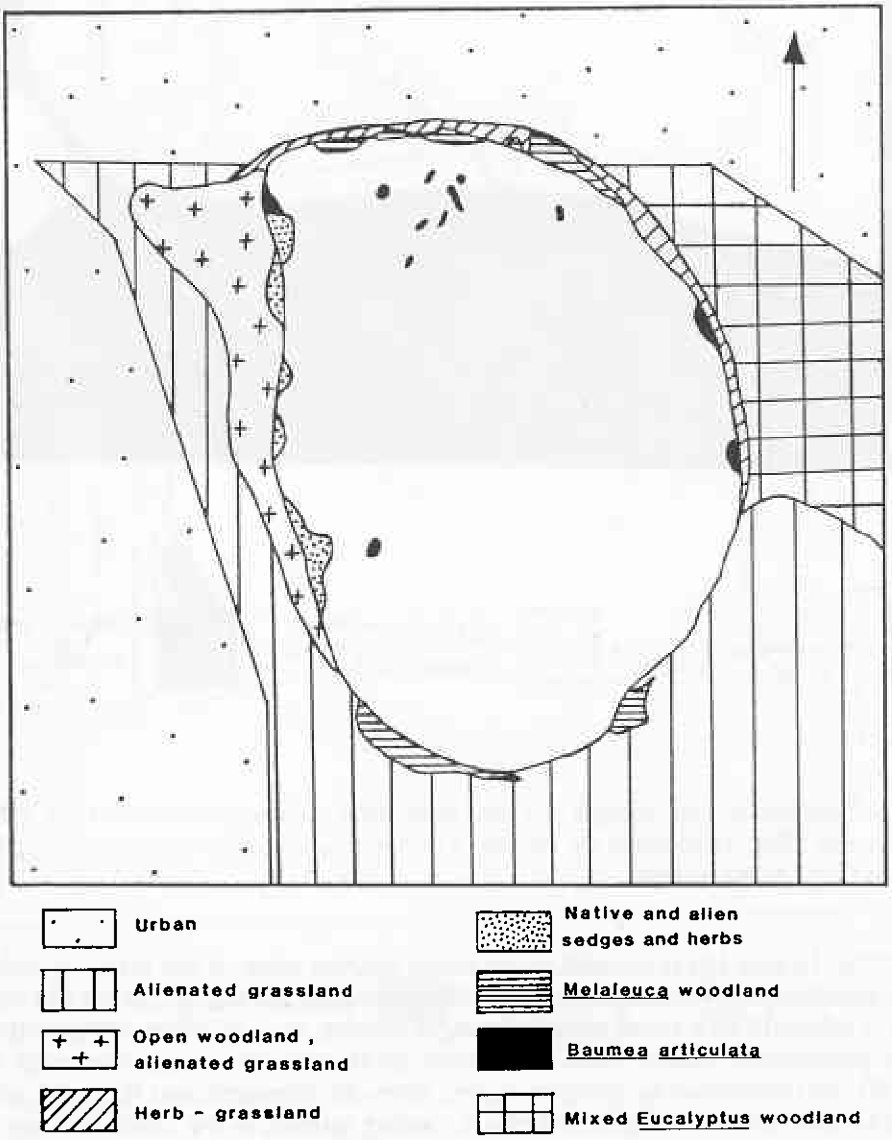


Figure 12: Map of the vegetation of North Lake, reproduced from maps drawn by M. Burgman, 1985.

Comparison of aerial photographs of the lake taken in 1958, 1981, 1983 and 1984 (Figure 13) reveal an increase in suburban development on the western side of the lake, but the return of a cleared portion of land to woodland at the south-eastern corner of the lake. A stand of *Eucalyptus* and *Banksia* woodland on the north-eastern edge of the lake has remained undisturbed.

Site G (Photographs 18 and 19) is at the north-western edge of the lake adjacent to a small stand of the rush *B. articulata,* and the paperbark, *M. rhaphiophylla.* Site H (Photographs 20 and 21) is next to similar vegetation at the north-eastern edge of the lake and also lies adjacent to the undisturbed *Banksia* woodland. Both sites possess permanent water although water levels may drop to as low as 20 cm in late summer (section 5.1). The lake is sprayed regularly during the summer months with the organophosphate pesticide Temephos (Abate), for the control of chironomids (the larval stage in the life-cycle of the midge).

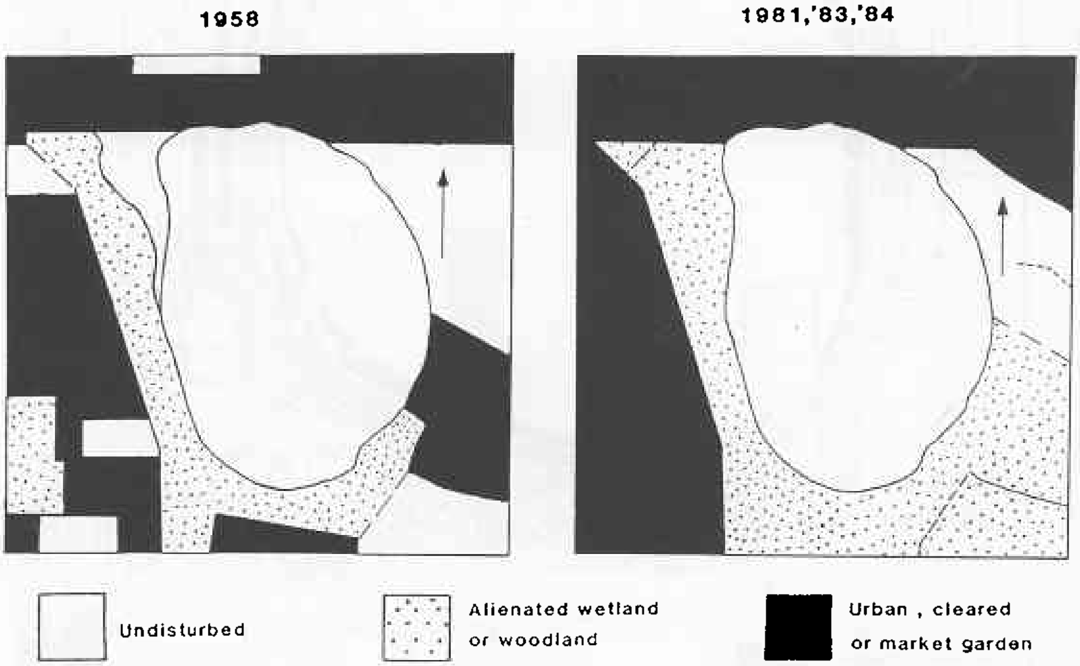


Figure 13: Changes in land-use around North Lake compiled from aerial photographs taken in 1958, 1981, 1983, and 1984.

4.2.5 THOMSONS LAKE

Thomsons Lake is a shallow almost circular lake situated approximately 22 km south of Perth and 4 km east of the Indian Ocean. The lake is an A - class reserve and is the only lake in this study for which a management plan has been published (Crook and Evans, 1981). The lake lies centrally within a reserve area totalling 509 ha, and comprises approximately 151 ha of open water and 101 ha of sedges. Although a maximum depth of 3.3 m has previously been recorded (Crook and Evans, 1981), depths recorded during this study were less than 1 m. Thomsons Lake is the largest lake within the Cockburn wetlands chain, and similarly to all lakes within the chain, is a surface expression of the Jandakot flow system. The lake also experiences some inflow from a drain from Lake Kogolup to the north, and agricultural land to the east (Crook and Evans, 1981).

A map of the vegetation of Thomsons Lake (Figure 14) was given by Crook and Evans (1981). An extensive stand of *B. articulata* and *T. orientalis* occurs around the entire margin of the lake, preventing easy public access to the open water. A significant expanse of the bulrush, *T. orientalis*, appears to have occurred since the area was mapped by Crook and Evans (1981), but the extent of the expansion has not been measured. During the winter of 1985 the entire southern half of the lake supported a dense stand of *Myriophyllum salsugineum* (Identification by N Marchant, WA Herbarium, 1986). The leafy macrophyte formed a submerged meadow which extended throughout the water column and persisted within the lake until its complete drying in January 1986. The collapsed *Myriophyllum* formed a dry mat across the peat bed (Photograph 31) until the lake re-filled. No mention is made of the presence of *Myriophyllum* in the management plan (Crook and Evans, 1981), which suggests that the macrophyte may be a recent coloniser of the lake.

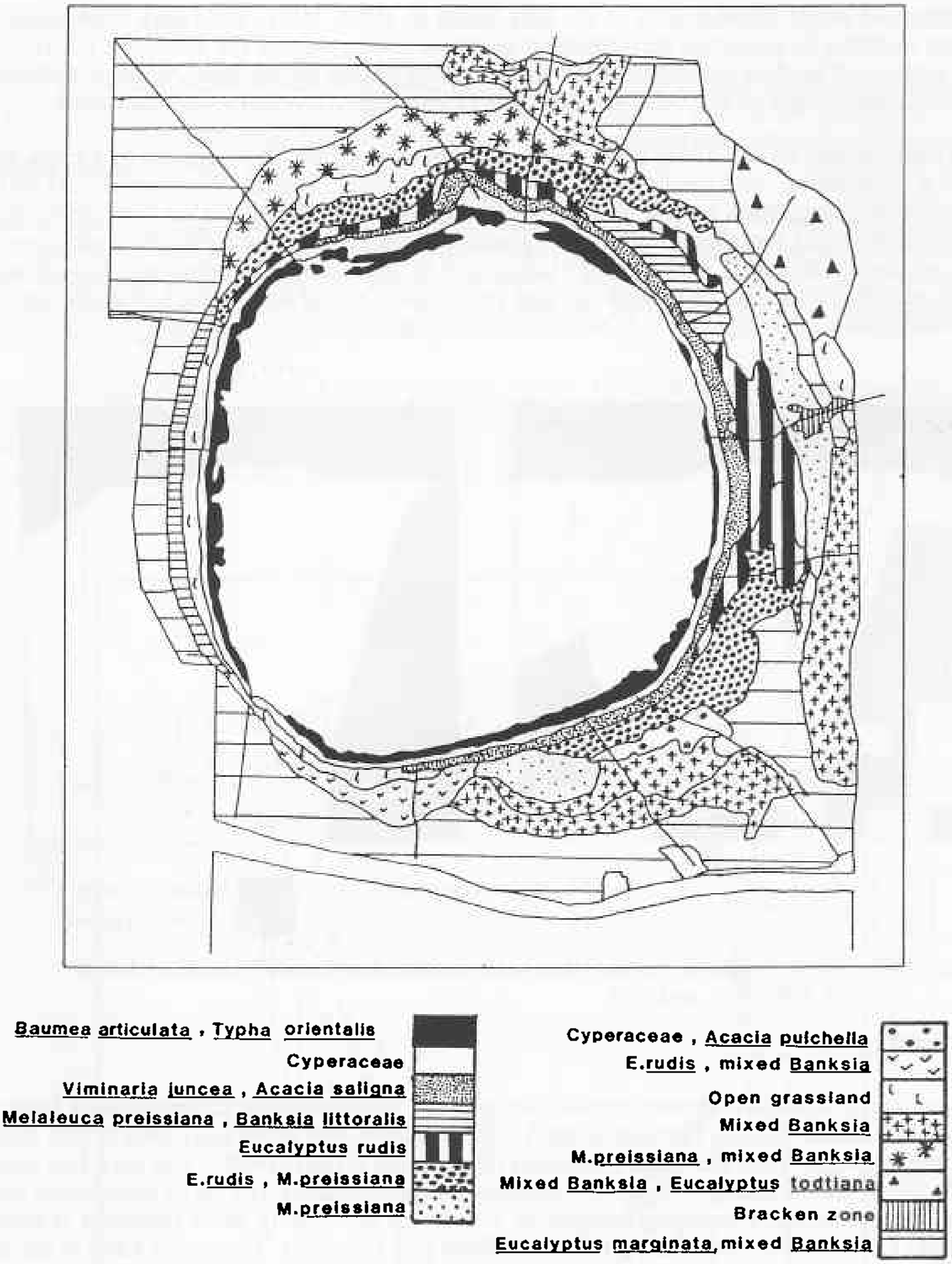


Figure 14: Map of the vegetation of Thomsons Lake, after Crook and Evans (1981).
Checked by Burgman, 1985.

A comparison of aerial photographs of the lake taken in 1956, 1963, 1968, 1981, 1983 and 1984 reveals increasing rural development on the land adjacent to the Reserve (Figure 15), and also indicates the extent of the buffer zone around the lake. Study sites I and J were situated at the southern end of the lake within the bed of *Myriophyllum* . Site I (Photographs 22 and 23) was next to a stand of *B. articulata* , and Site J (Photographs 24 and 25) was adjacent to a stand of *T. orientalis.*

Both sites were completely dry at the start of the study in April 1985, and from January through to April in 1986. During these times monthly water samples and two sets of faunal samples (April 1985 and January 1986) were taken from the water (only a few centimetres deep but still supporting *Myriophyllum*) in the centre of the lake.

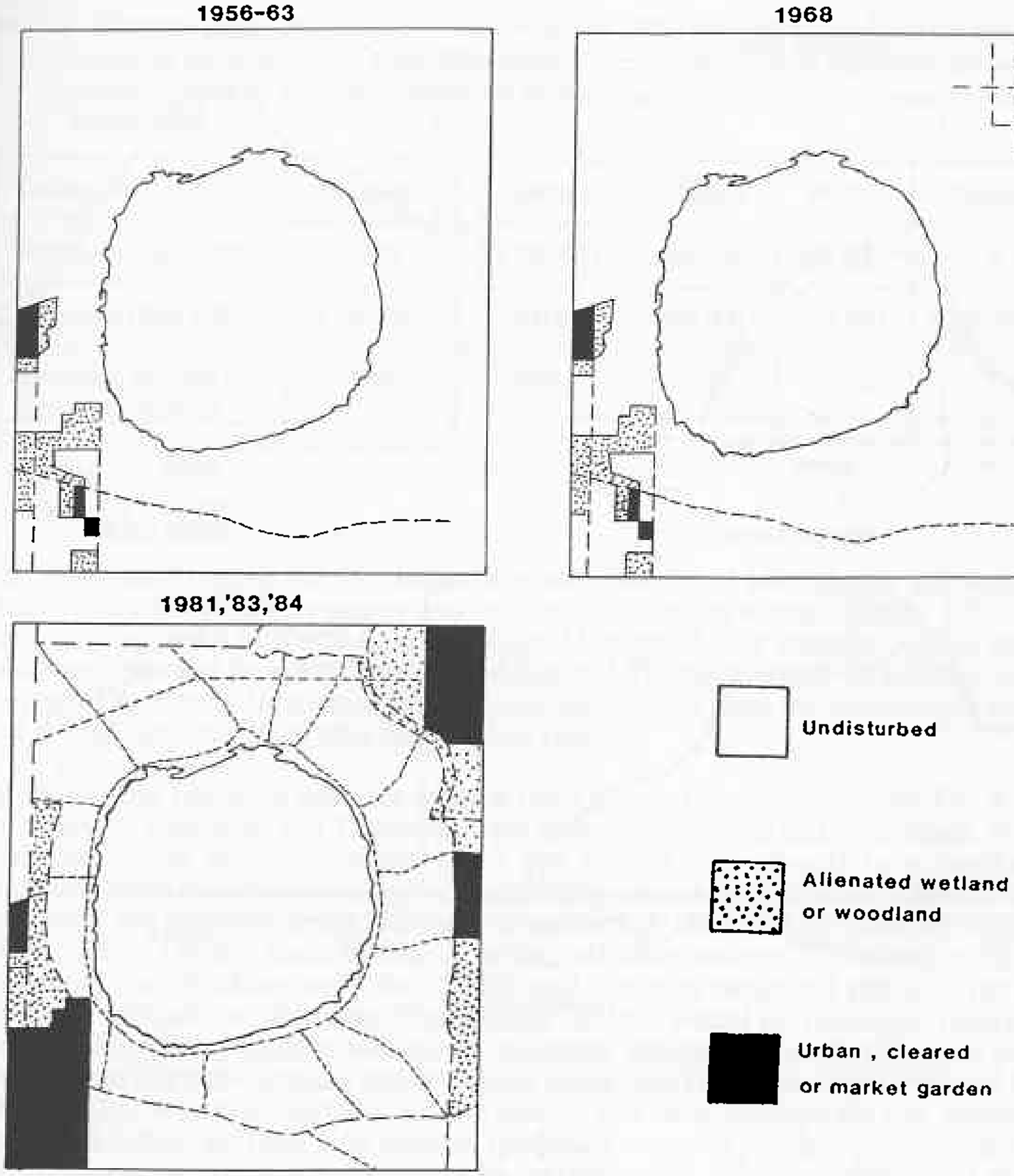


Figure 15: Changes in land-use around Thomsons Lake compiled from aerial photographs taken in 1956, 1963, 1968, 1981, 1983, and 1984.

5. RESULTS

5.1 PHYSICO-CHEMICAL PARAMETERS

5.1.1 WATER DEPTH

Changes in water depth at the study sites (Figure 16) generally followed the changes in rainfall over the same period (Figure 5), but with an approximate lag of two months between the maximum rainfall recorded in July and the maximum depth recorded in September. Maximum depths were recorded at all sites, except those in Lake Monger, in September. Maximum depths were recorded in Lake Monger in August. Water levels in Lake Monger are artificially maintained and during winter the lake overflows into a drain discharging to the Swan River.

The unseasonal rainfall event in February appeared to slightly reduce the rate of decrease of lake water levels in Lakes Joondalup, Monger and North. No change was observed at the sites in Jandabup and Thomsons Lake, but the littoral regions of these lakes were already completely dry by January. However, a considerable increase in the amount of water lying in the central regions of both lakes was observed at this time.

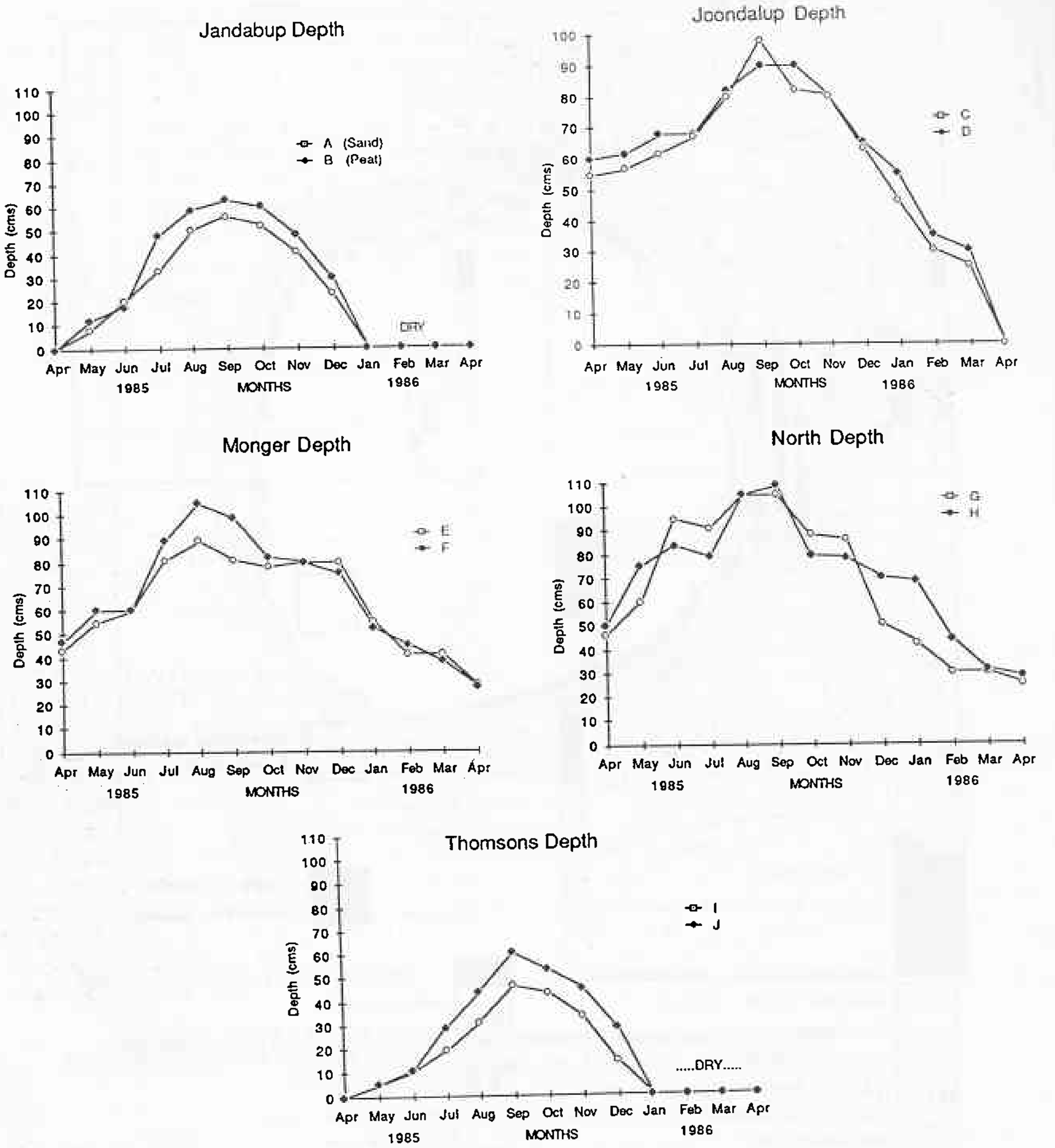


Figure 16: Monthly changes in water depth (cm) at each site in the five lakes studied from April 1985 to April 1986.

Both Jandabup and Thomsons Lakes have been temporary water bodies of recent years, and depths ranging from 0 to 63 cm were recorded during this study. Joondalup, Monger and North are relatively deeper and more permanent water bodies: maximum depths at the littoral study sites were between 98 and 109 cm, and minimum depths between 0 and 28cm.

Because all the study lakes are shallow, small changes in depth represent large changes in volume. Lake volumes were calculated for the periods of minimum (April 1985) and maximum (September 1985) depths, from depth/area graphs and area/volume graphs provided by the Water Authority.

Maximum and minimum lake volumes and the percentage change in volume between the two are given in Table1.

Table 1. Minimum (April 1985) and maximum (September 1985) lake volumes (m^3) for the five lakes studied on the Swan Coastal Plain. Lake volumes were calculated from depth/area and area/volume graphs provided by the Water Authority of Western Australia, for the period January 1985 to January1986.

Volume (m^3)	Jandabup	Joondalup	Monger	North	Thomsons
Minimum (April 1985)	6 300	1 550 000	390 000	200 000	0
Maximum (Sept 1985)	1 000 000	3 700 000	869 000	555 000	1 057 000
Percentage decrease by the end of summer	99%	58%	55%	64%	100%

5.1.2 CONDUCTIVITY

Changes in conductivity in the five lakes reflected changes in lake depths and volumes with maximum values recorded in summer and minimum values in winter (Figure 17). Only small increases were recorded in North Lake and Lake Monger during summer, whilst much larger increases were recorded from Jandabup, Joondalup and Thomsons Lake. In addition, the dilution effect afforded by a small increase in lake volume was evident from the decreases in conductivity recorded in the latter three lakes after the February rainfall.

Monger, North and Jandabup were the freshest lakes during the winter months. The mean winter conductivities for Joondalup and Thomsons were approximately two and three times, respectively, those of the former three. A salinity of 3 ppt (which corresponds to a conductivity of approximately 6000 microSiemens/cm) was arbitrarily chosen by Williams (1964) to distinguish between fresh and saline systems, and this criterion has been widely used by other workers (Buckney, 1980). On the basis of this criterion, all lakes except Thomsons remained fresh throughout the year. Buckney and Tyler (1976) used a salinity range of 1 ppt to 10 ppt chosen on stoichiometric grounds, to delineate "fresh" from "saline" waters in Tasmania. Buckney (1980) suggests that this salinity range is also one of important ecological and physiological changes and therefore in both physico-chemical and biological terms may represent a more realistic delineation of fresh and saline waters in Australia. On the basis of this latter criterion the five wetlands studied here may be classified as "fresh". As many of the inland waters of Western Australia are saline, the relative freshness of the urban lakes must be considered to be one of their most ecologically important features.

5.1.3 pH

Four of the five lakes, Joondalup, Monger, North and Thomsons were alkaline (Figure 18), although pH values in North Lake (yearly mean pH +/- SE of 7.07 +/- 0.13) tended to be lower than those recorded in Joondalup, Monger and Thomsons (8.53 +/- 0.12, 7.91 +/- 0.19 and 8.47 +/- 0.16 respectively). Jandabup Lake was acidic (yearly mean pH of 5.6 +/- 0.27) on all but one sampling occasion (June 1985). A minimum pH of 3.3 was recorded at the lake in February, 1986. No distinct seasonal changes in pH were evident in any lake, and values recorded from Joondalup were the most constant.

Congdon and McComb (1976) suggested that leaching of calcareous deposits may be the main factor determing the high pH in Lake Joondalup. They attributed the constancy in pH, at least in part, to the buffering effect of carbonate and bicarbonate ions which were expected to be high because of high recorded levels of Ca^{++} and Mg^{++}. Both Joondalup and Monger lie within the Spearwood dune system in which calcareous sands overlie aeolianite. The mean yearly pH values recorded for Joondalup (8.53 +/- 0.12) and Monger (7.91 +/- 0.19) were slightly different from those recorded for the two lakes (9.10 +/- 0.10 for both lakes) by Gordon *et al* (1981) ten years earlier in their 1975 /76 study. Lower pH values in Jandabup, and to some extent North Lake, may reflect the siliceous nature of the sands of the Bassendean dune system in which they lie.

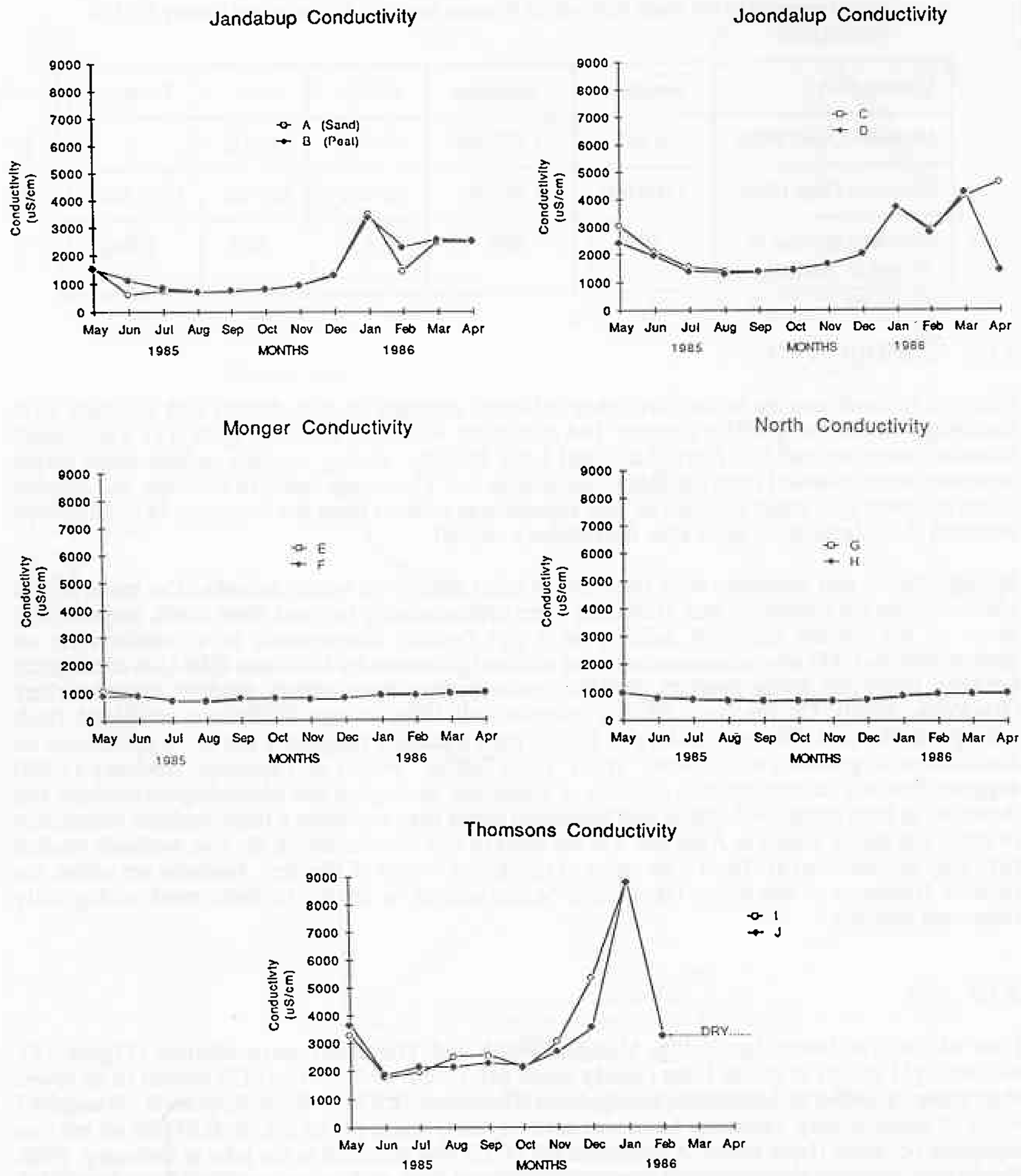


Figure 17: Monthly changes in conductivity (microSiemens/cm) at each site in the five lakes studied from April 1985 to April 1986.

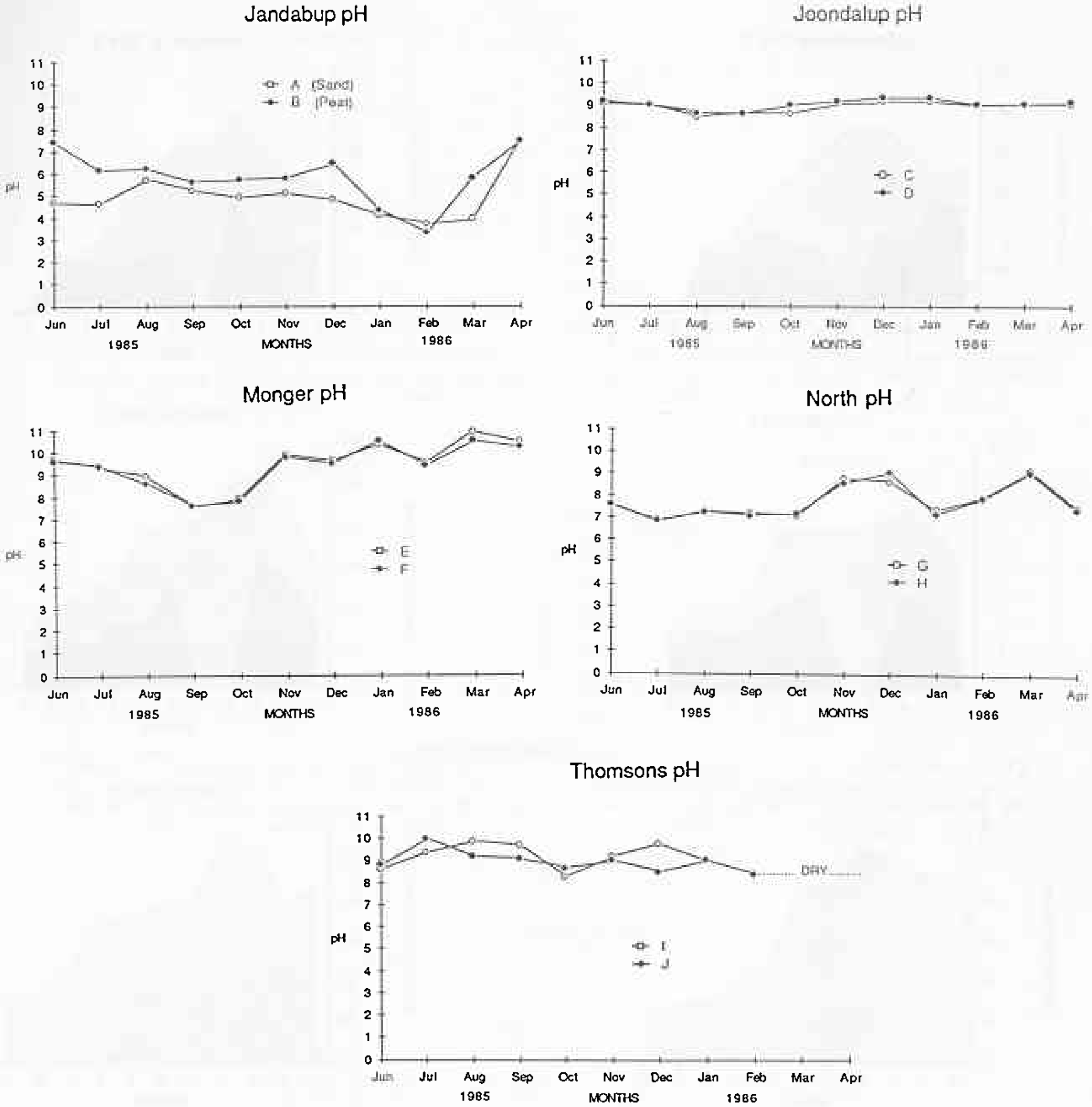


Figure 18: Monthly changes in pH at each site in the five lakes studied from April 1985 to April 1986.

5.1.4 SECCHI DEPTH AND LIGHT PENETRATION

Three of the lakes, Jandabup, North and Thomsons, contained waters that were coloured, probably with humic and fulvic acids, during the winter months. The waters were darkest when the lakes first started to fill at the beginning of winter. Despite some colouration, light penetration was high in Jandabup Lake and Lake Thomson, and the Secchi disc was visible on the lake bed on all sampling occasions. Secchi disc readings were recorded at Lake Joondalup, Lake Monger and North Lake (Figure 19). Light penetration in North Lake was restricted at Site H in December and Site G in March by the presence of algal blooms. The differences between sites were probably caused by different prevailing winds concentrating algae in different areas of the lake. Light penetration in Lake Monger was restricted by the dense algal blooms that were present at the lake on all occasions except September and October, 1985. Light penetration was least in Joondalup because of the presence of metaphyton. The metaphyton restricted light penetration in the lower 50% of the water column on all sampling occasions except October,1985.

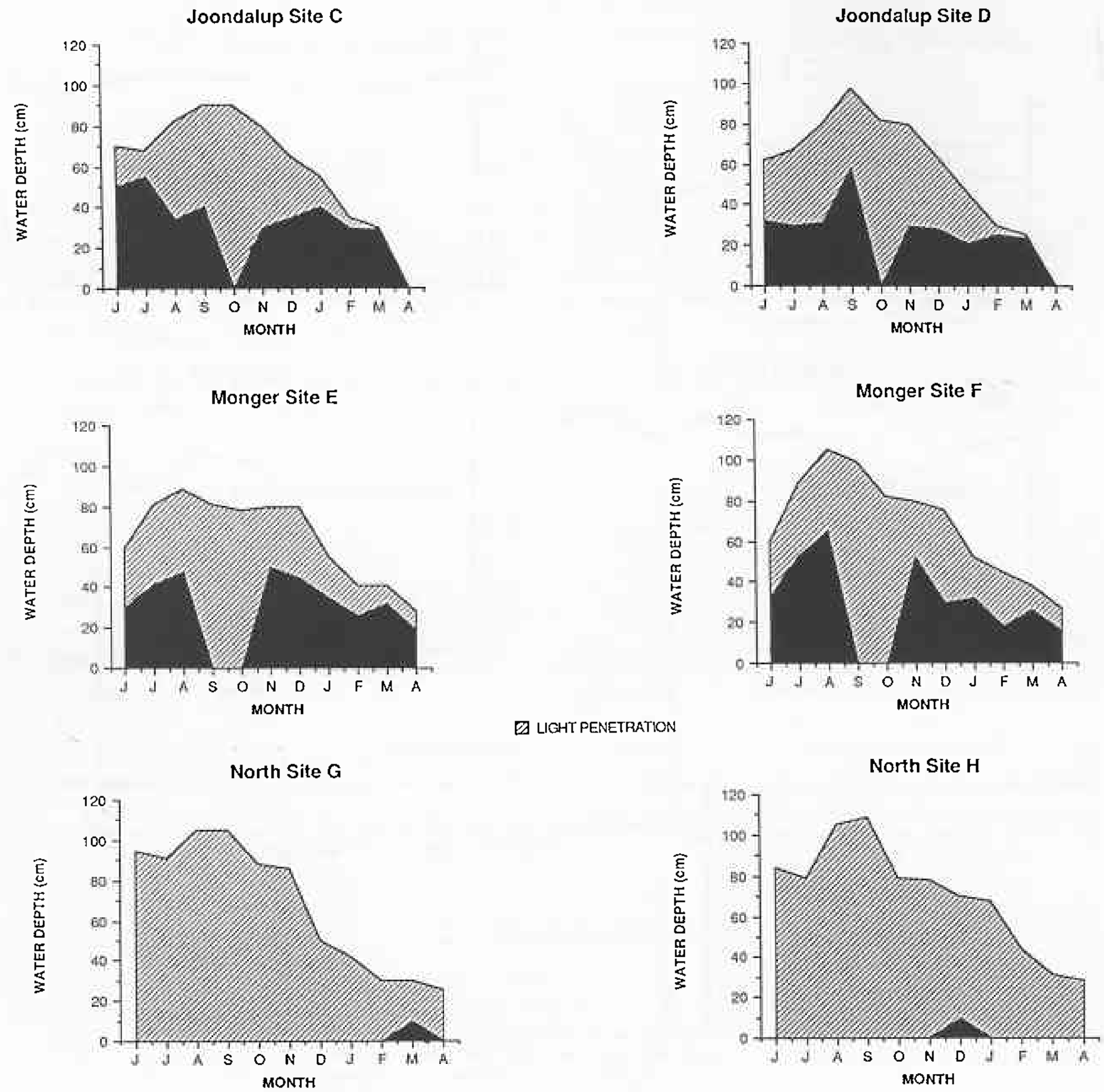


Figure 19: Monthly changes in light penetration as measured by Secchi disc at each of the two study sites in Lake Joondalup, Lake Monger, and North Lake for the period April 1985 to April 1986. The shaded regions represent the depth to which light was transmitted in the water column. The lower region within the water column not receiving any light is given in black.

5.1.5 IONIC CONCENTRATIONS

Similar to conductivity, the ionic concentrations in lakes Jandabup, Joondalup and Thomsons displayed considerable seasonal variation in levels (Figures 20-26), with maximum concentrations occurring during late summer at the time of lowest lake volumes, and minimum concentrations during winter when lake volumes were high. Less seasonal variation is evident in Monger and North Lake. To facilitate lake comparisons, mean ionic concentrations and ionic equivalents for both winter/high water and summer/low water periods are given in Table 2. On the basis of milliequivalents per litre, the order of ionic dominance in each lake for each period is given in Table 3.

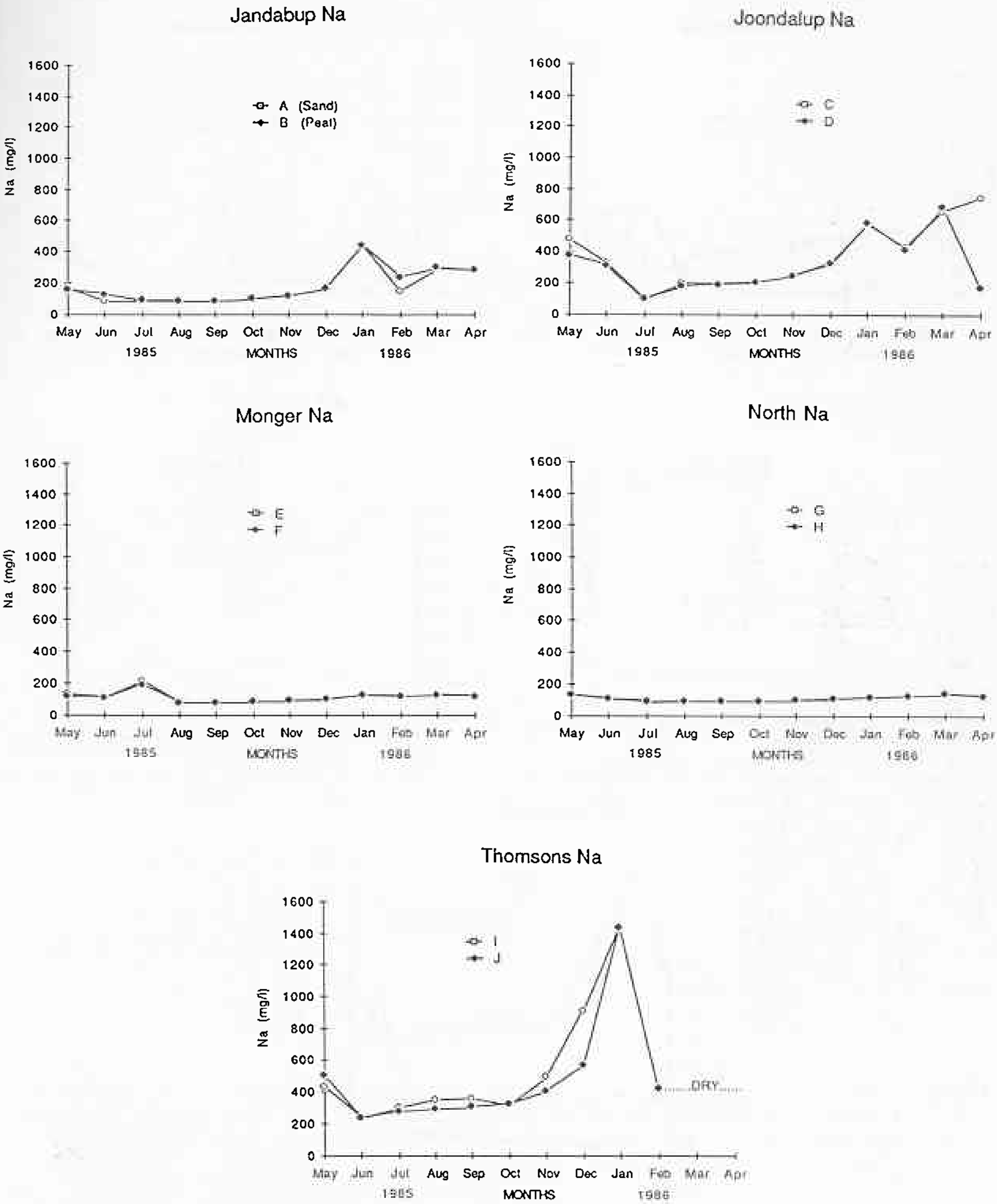


Figure 20: Monthly changes in the concentration of sodium ions (Na^+) in milligrams/litre at each site in the five lakes studied from April 1985 to April 1986.

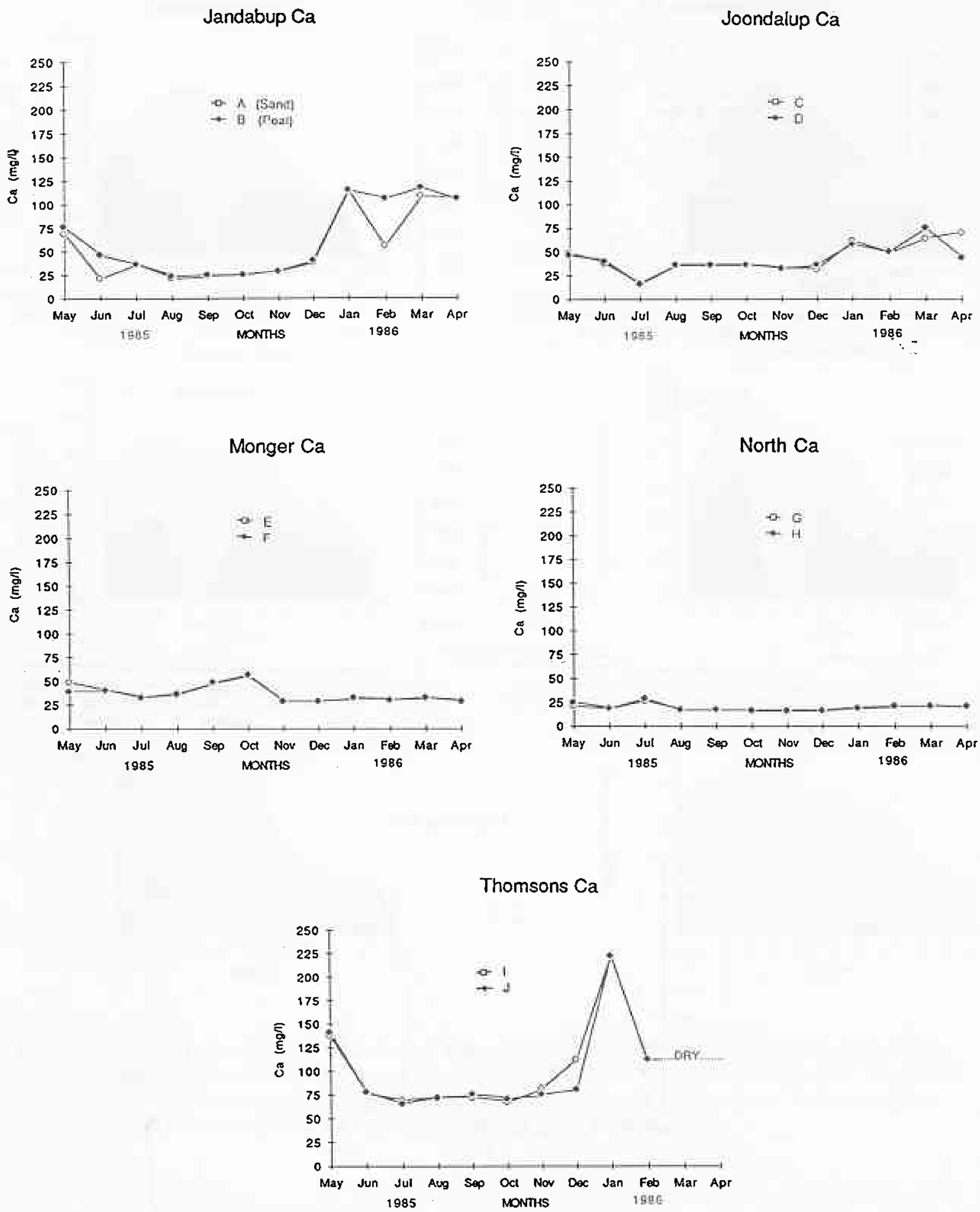


Figure 21: Monthly changes in the concentration of calcium ions (Ca^{++}) in milligrams/litre at each site in the five lakes studied from April 1985 to April 1986.

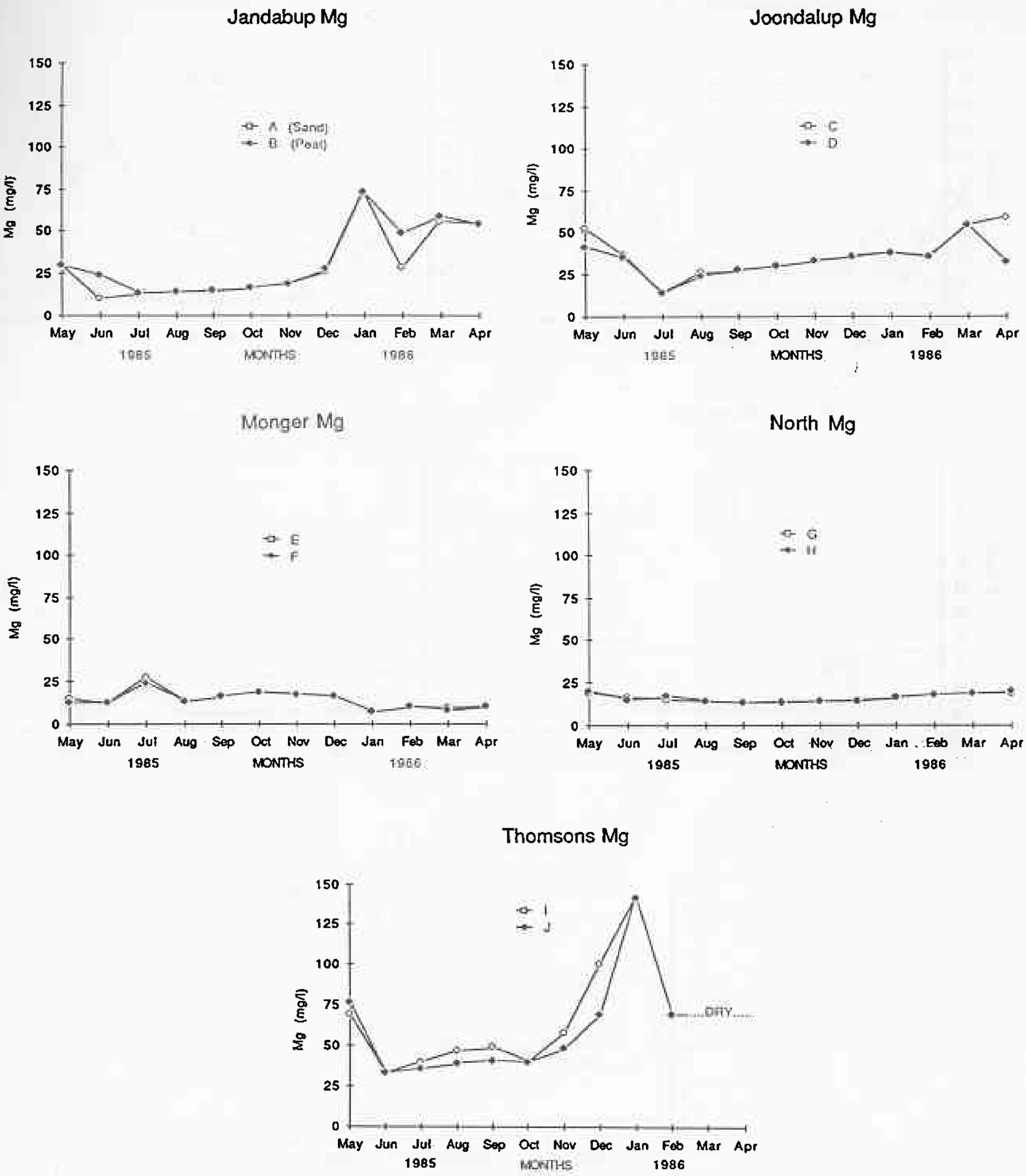


Figure 22: Monthly changes in the concentration of magnesium ions (Mg^{++}) in milligrams/litre at each site in the five lakes studied from April 1985 to April 1986.

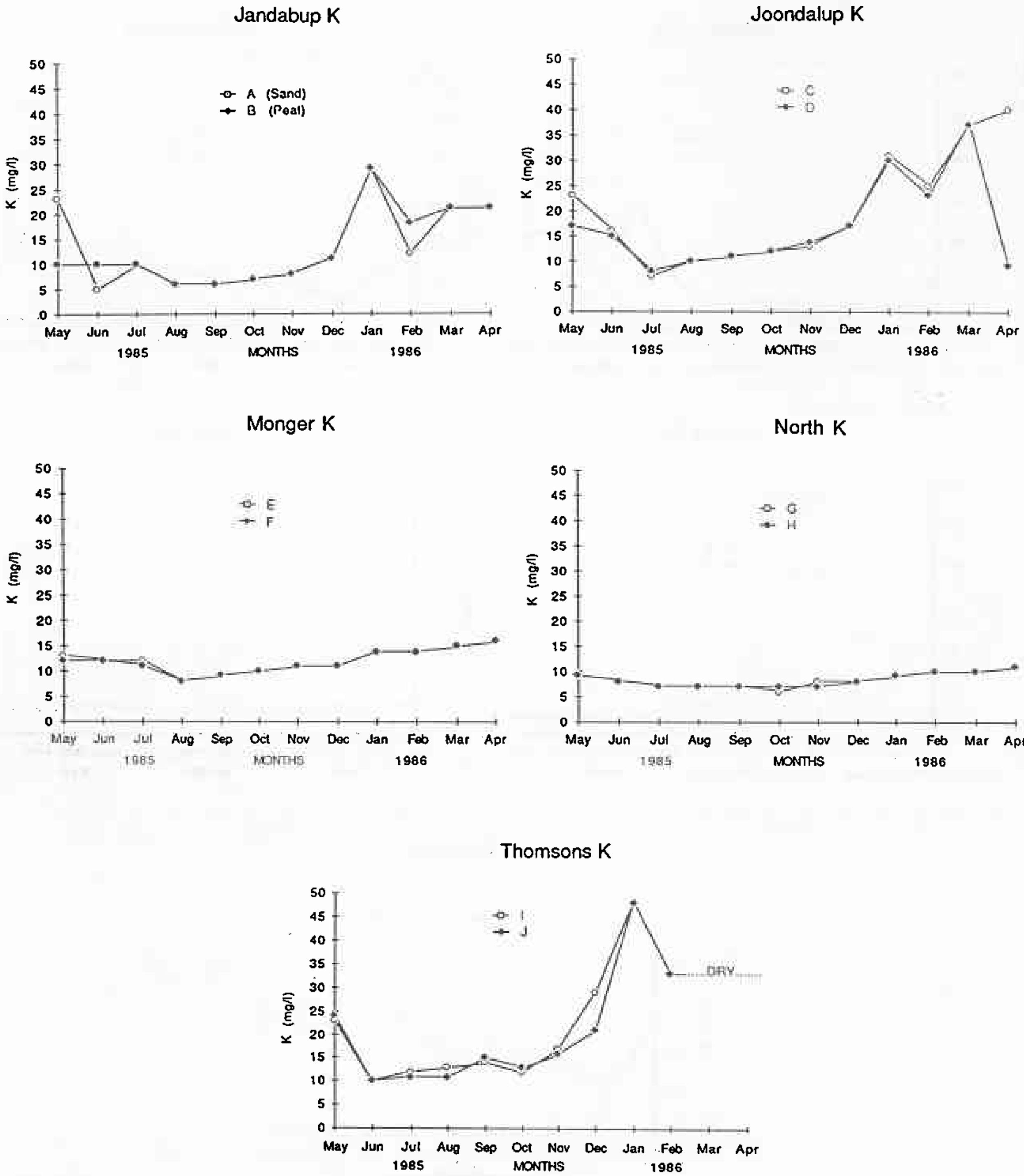


Figure 23: Monthly changes in the concentration of potassium ions (K^+) in milligrams/litre at each site in the five lakes studied from April 1985 to April 1986.

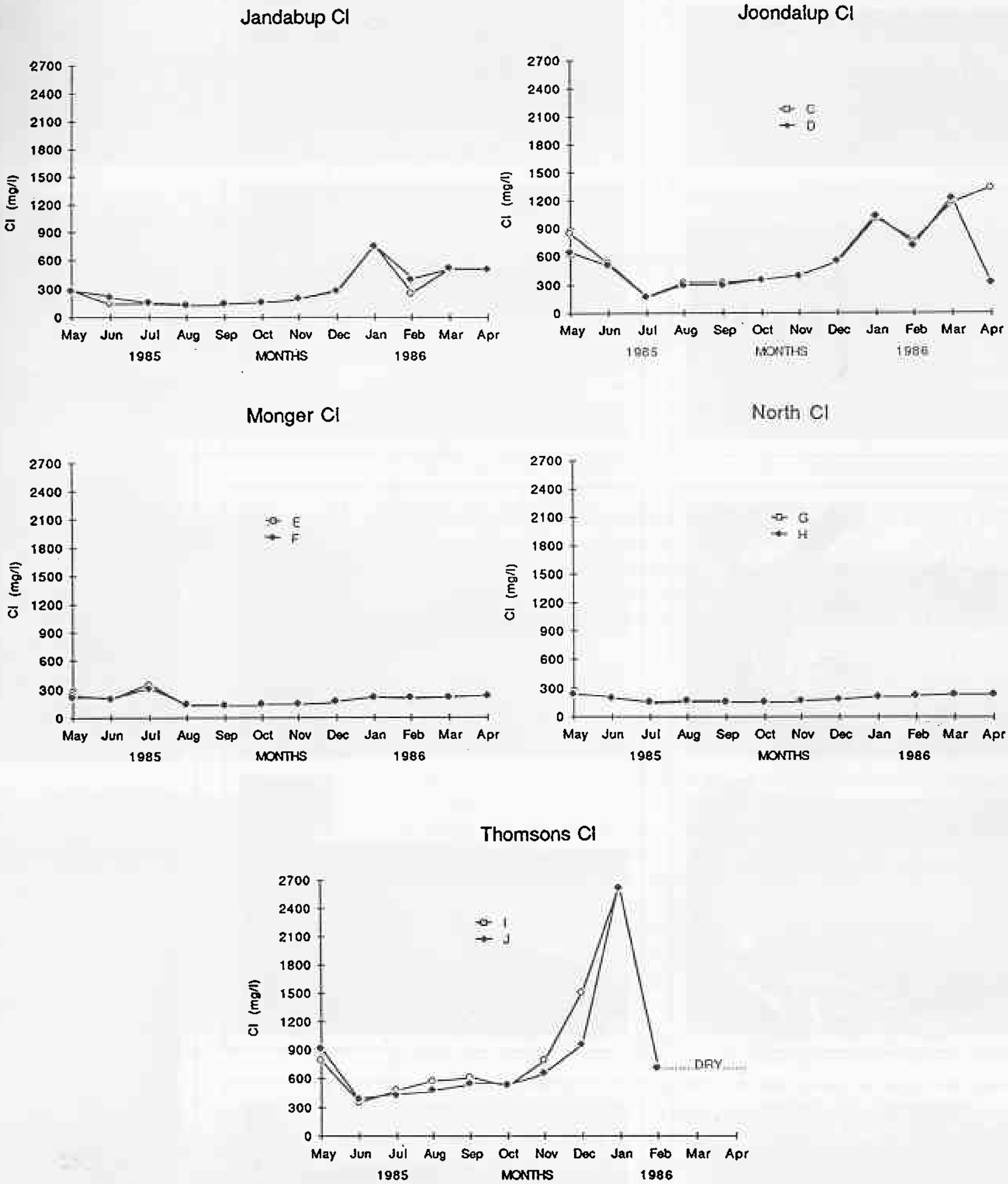


Figure 24: Monthly changes in the concentration of chloride ions (Cl^-) in milligrams/litre at each site in the five lakes studied from April 1985 to April 1986.

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Photographs of the study sites.

6: Site A, on the eastern side of Jandabup Lake, winter 1985. The reed in the foreground is *Baumea articulata* .

7: Site A and the eastern margin of Jandabup Lake were completely dry in the summer of 1985/86.

8: Site B on the western margin of Jandabup Lake in winter 1985. The dominant reed at the site is *B. articulata*..

9: Site B and the western margin of Jandabup Lake were completely dry in the summer of 1985/86.

10: Site C, on the western margin of Lake Joondalup in winter 1985. The reed in the foreground is *B. articulata* .

11: Site C at Lake Joondalup in summer 1985/86.

12: Site D, on the western margin of Lake Joondalup in winter 1985. Vegetation in the foreground includes the reed *B. articulata* and the paperbark, *Melaleuca rhaphiophylla* .

13: Site D at Lake Joondalup in the summer of 1985/86.

14: Site E, on the south-eastern margin of Lake Monger, in winter 1985.

15: Site E at Lake Monger in the summer of 1985/86.

16: Site F, on the north-western margin of Lake Monger, in winter 1985. Fringing vegetation in the foreground includes *Typha orientalis* and *B. articulata* (behind).

17: Site F at Lake Monger in summer 1985/86.

18: Site G, on the northern margin of North Lake, in winter 1985. Submerged branches of the paperbark *M. rhaphiophylla* and the sedge *B. articulata* are visible in the foreground.

19: Site G at North Lake summer 1985/86.

20: Site H, on the eastern margin of North Lake, in winter 1985.

21: Site H (with sandy beach exposed) at North Lake in the summer of 1985/86.

22: Site I on the southern margin of Thomsons Lake in winter 1985. The aquatic macrophyte *Myriophyllum salsugineum* was in flower and covered the southern half of the lake. The sedge *B. articulata* is present at this site.

23: Site I at Thomsons Lake in summer 1985/86. Much of the lake was dry and covered with dead *M.salsugineum.*

24: Site J on the southern margin of Thomsons Lake in winter 1985. The dominant aquatic macrophyte is *M. salsugineum* and the fringing vegetation is *T. orientalis* .

25: Site J at Thomsons Lake in summer 1985/86. Comparison of the position of the stand of *T. orientalis* relative to the site marker in photographs 24 and 25 reveals that the bullrush has penetrated further into the lake in the six month interval between the two photographs.

(Photographs: S W Rolls)

26: The lake bed is comprised of fine sands at site A, on the eastern margin of Jandabup Lake; **27**: In contrast to site A, the lake bed at site B on the western margin of Jandabup Lake is composed of diatomite; **28**: A white bank of dried metaphyton at Lake Joondalup in late summer (March), 1986; **29**: Clumps of algae on the water surface at the northern margin North Lake in spring (October), 1985; **30**: Algal bloom in Lake Monger in summer (January), 1986; **31**: Drying mat of *Myriophyllum salsugineum* on the bed of Thomsons Lake in summer (January), 1986.

(Photographs: S.W.Rolls, J.A.Davis)

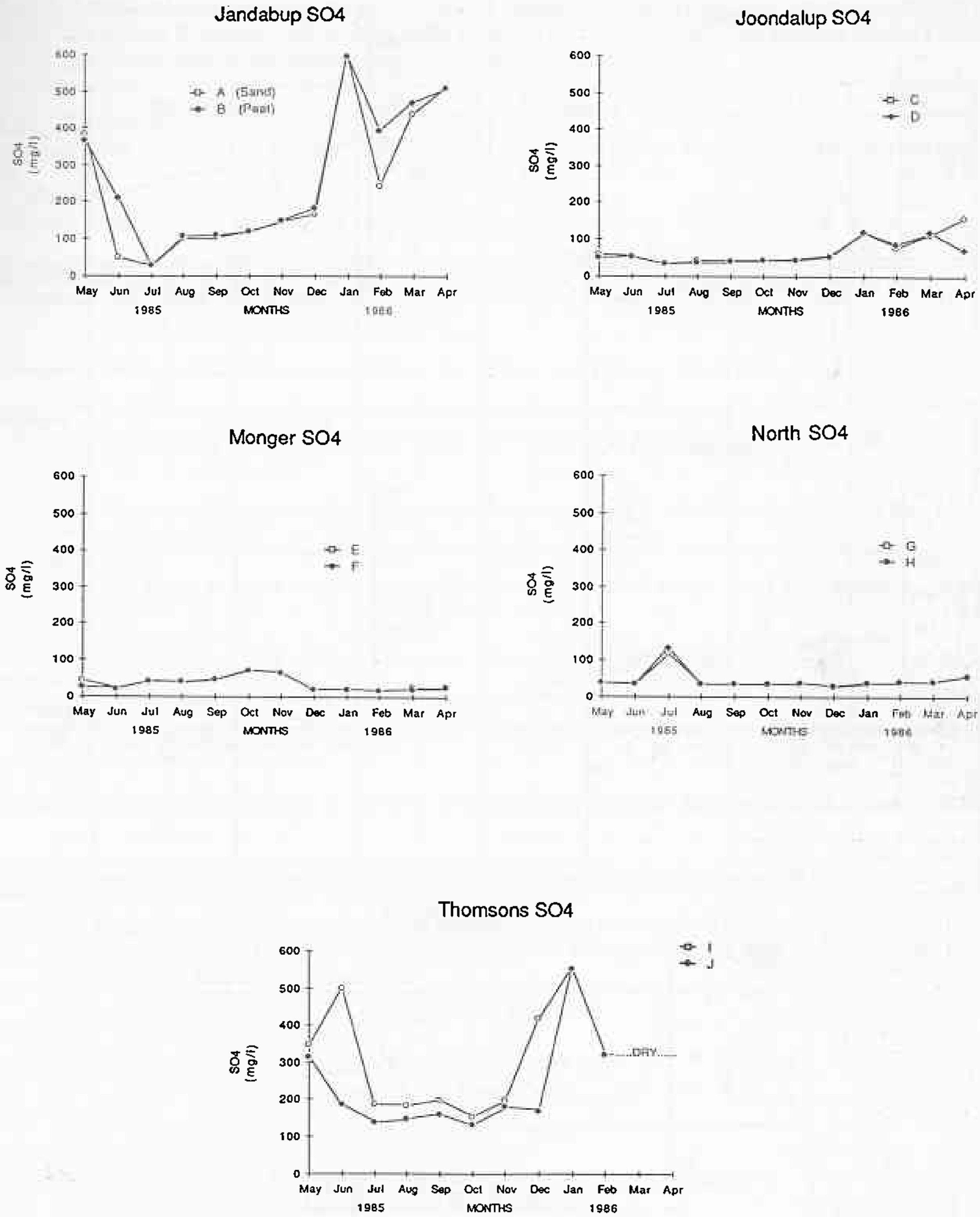

Figure 25: Monthly changes in the concentration of sulphate ions (SO_4^{--}) in milligrams/litre at each site in the five lakes studied from April 1985 to April 1986.

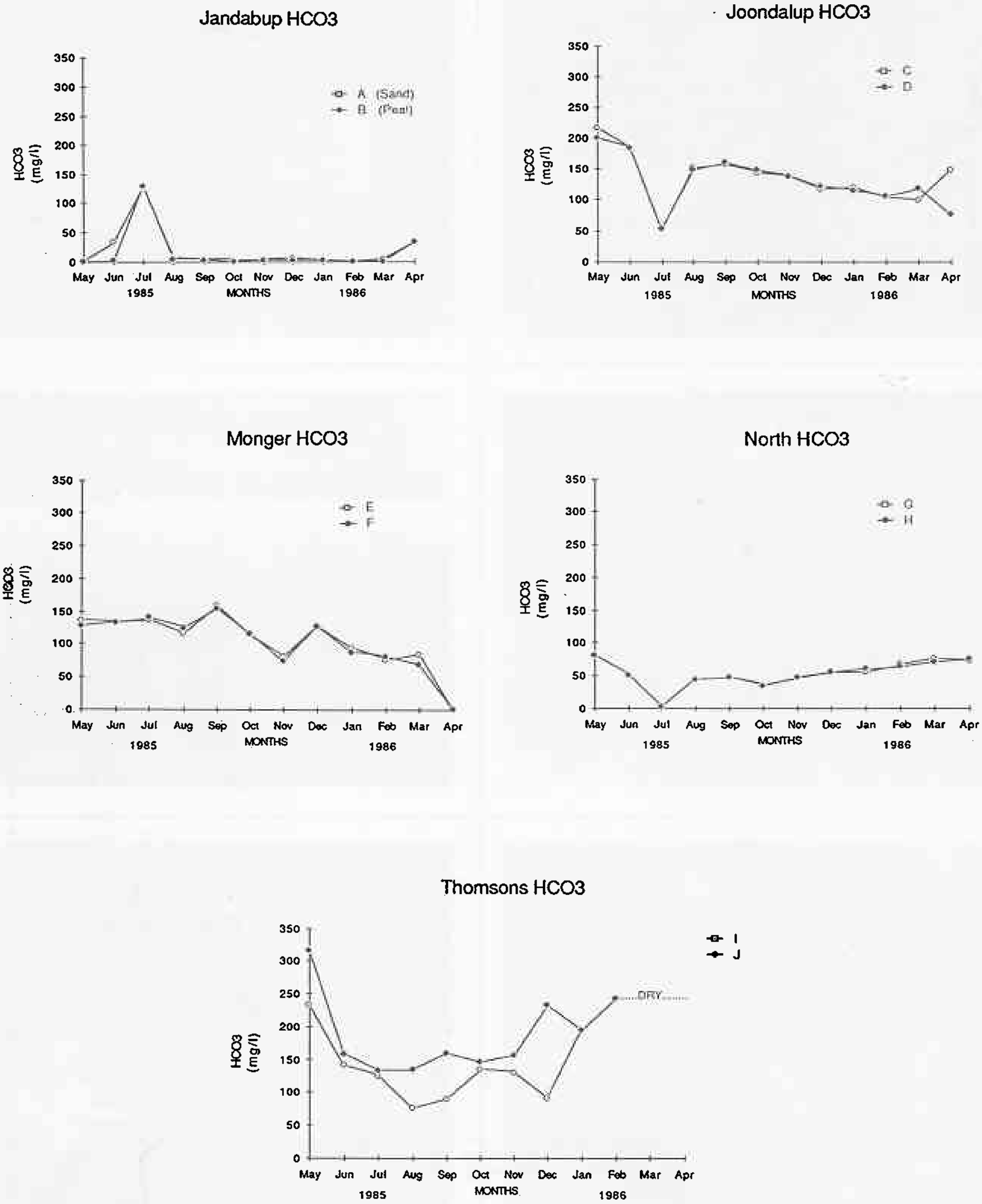

Figure 26: Monthly changes in the concentration of bicarbonate ions (HCO_3^{-}) in milligrams/litre at each site in the five lakes studied from April 1985 to April 1986.

Table 2: Mean ionic concentrations (milligrams/litre) and standard errors for winter (June 1985 to November 1985) and summer (December 1985 to April 1986) periods in the five lakes studied on the Swan Coastal Plain. The second value in each case is expressed in milliequivelants/litre.

	Na	Ca	Mg	K	Cl	HCO3	SO4
Jandabup							
Winter	94.1 +/- 4.9 4	28.3 +/- 2.2 1	15.6 +/- 1.1 1	7.4 +/- 0.5 0	154.5 +/- 8.1 4	27.7 +/- 14.0 1	105.8 +/- 15.3 2
Summer	276.5 +/- 32.7 12	90.0 +/- 10.2 5	49.9 +/- 5.6 4	19.4 +/- 2.1 1	478.3 +/- 57.9 13	9.2 +/- 4.2 0	410.0 +/- 50.6 9
Joondalup							
Winter	209.3 +/- 19.9 9	32.4 + /- 2.4 2	27.5 +/- 2.13 2	11.6 +/- 0.8 0	341.3 +/- 32.2 10	139.3 +/- 12.4 5	42.7 +/- 1.8 1
Summer	494.5 +/- 59.2 21	53.5 +/- 4.6 3	41.7 +/- 3.1 4	26.6 +/- 3.2 1	865.1 +/- 105.8 24	113.3 +/- 6.0 4	97.8 +/- 10.7 2
Monger							
Winter	104.9 +/- 13.9 5	39.9 +/- 2.8 2	17.2 +/- 1.4 1	10.3 +/- 4.3 0	175.6 +/- 22.4 5	124.0 +/- 7.5 4	47.5 +/- 5.1 1
Summer	116.0 +/- 3.5 5	30.4 +/- 0.5 2	10.3 +/- 1.0 1	14.0 +/- 5.6 0	204.0 +/- 7.4 6	75.8 +/- 13.8 2	21.2 +/- 0.9 0
North							
Winter	94.2 +/- 1.8 4	18.2 +/- 1.3 1	14.3 +/- 3.6 1	7.2 +/- 1.7 0	161.2 +/- 4.4 5	38.8 +/- 5.0 1	49.8 +/- 10.1 1
Summer	121.7 +/- 3.4 5	19.1 +/- 7.1 1	17.4 +/- 6.4 1	9.6 +/-3.4 0	216.9 +/- 6.5 6	65.5 +/- 2.7 2	40.4 +/- 3.1 1
Thomsons							
Winter	325.3 +/- 20.8 14	72.5 +/- 1.3 4	42.0 +/- 2.1 4	12.8 +/- 6.6 0	533.3 +/- 34.9 15	132.3 +/- 7.5 4	196.3 +/- 28.2 4
Summer	835.5 +/- 225.3 36	131.3 +/- 31.1 7	95.3 +/- 17.3 8	32.8 +/- 5.7 1	1447.3 +/- 420.4 41	191.0 +/- 34.6 6	364.0 +/- 80.3 8

Winter means for the period June to November 1985, and summer means from December 1985 to April 1986.

Table 3: Comparison of the ionic composition of seawater (average world values) and freshwater in northern hemisphere temperate zone lakes (after Wetzel, 1975), and the five study wetlands on the Swan Coastal Plain, Western Australia.

Average World Seawater Cations : $Na^{+} > Mg^{++} > Ca^{++} > K^{+}$ Anions : $Cl^{-} > SO_4^{--} > HCO_3^{-}$
Freshwater Northern Hemisphere -Temperate Zone Open Lakes (Wetzel,1975) Cations : $Ca^{+} > Mg^{++} > Na^{+} > K^{+}$ Anions : $CO_3^{-} > SO_4^{--} > Cl^{-}$ Urban Wetlands, WA Cations : $Na^{+} > Ca^{++} > Mg^{++} > K^{+}$ Anions : $Cl^{-} > HCO_3^{-} > SO_4^{--}$
Exceptions Lake Joondalup (summer), Thomsons Lake (summer) Cations : $Na^{+} > Mg^{++} > Ca^{++} > K^{+}$ Jandabup Lake (summer and winter) , Thomsons Lake (summer) Anions : $Cl^{-} > SO_4^{--} > HCO_3^{-}$

All five lakes are dominated by sodium chloride, as is the case for many Australian lakes (Williams, 1967; Buckney, 1980; Hart and McKelvie, 1986) but not so for most Northern Hemisphere waters which are dominated by calcium bicarbonate (Table 2, Wetzel, 1975). Bayly and Williams (1973) suggested that NaCl dominance is a result of the overriding importance of the atmospheric supply of oceanic salts to inland waters. Certainly the proximity of the urban wetlands to the coast suggests that rainfall, with dissolved salts derived from the ocean, is the main determinant of the ionic composition of the urban wetlands. In contrast, the ionic composition of Northern Hemisphere waters is considered to be rock dominated, that is, primarily influenced by composition of rock material in the drainage basin.

The greater dominance of calcium ions in most of the wetlands compared to that of seawater, may be due to the leaching of calcium from limestone. The increased importance of SO_4^{--} compared with HCO_3^- in Jandabup Lake, in both winter and summer, may be attributed to groundwater input to the lake or to the geology of the lake basin.

The proportions and concentrations of major ions in shallow lakes can be changed by evaporation and precipitation of less soluble salts, such as $CaCO_3$ and $MgSO_4$ for example (Hart and McKelvie, 1986). This may be the explanation for the increase in concentration of Mg and SO_4 in Lake Joondalup and Thomsons Lake during summer. Alternatively, a sea breeze laden with sulphur dioxide emissions from the Kwinana industrial area may also be responsible for high sulphate levels in Thomsons Lake in the summer period.

Na^+, Mg^{++}, K^+ and Cl^- are conservative ions which undergo minor spatial and temporal changes within a lake as a result of biotic utilisation (Wetzel, 1975), therefore concentrations of these ions may be expected to reflect changes in lake depths and volumes. Ca^{++}, inorganic C and SO_4^{--} are dynamic ions, and their concentrations may be strongly influenced by plant growth and microbial metabolism (Wetzel, 1975). Seasonal changes in Ca^{++} and SO_4^{--} are evident in three lakes, Jandabup, Joondalup and Thomsons, and HCO_3^- alone in Thomsons Lake. Large but generally non-seasonal fluctuations in HCO_3^- (and to a lesser extent Ca^{++} and SO_4^{--}) in the other lakes, may be attributed to plant and microbial action.

5.1.6 PHOSPHORUS

Large increases in total phosphorus concentrations occurred in Lake Monger and Thomsons Lake during the summer months, smaller increases were recorded in Joondalup and Jandabup, whilst concentrations in North Lake were highest during winter (Figure 27). Concentrations in Jandabup were usually the lowest recorded in the five lakes, whilst concentrations in Monger were usually the highest, with a maximum value of 964 ug/L being recorded in April 1985. Comparison of the range of concentrations recorded in the urban wetlands (Table 4) with Wetzel's (1975) classification of lake productivity (after Vollenweider, 1968), reveals that peak levels in four of the lakes; Joondalup, Monger, North and Thomsons exceeded the criterion for hypereutrophy by two to nine times. Only Jandabup remained below the hypereutrophic level and for much of the year could be classed as oligo-mesotrophic. North lake was the only lake that remained hypereutrophic during the winter months.

Table 4. Classification of Lake Trophic Status Based on Nutrient Concentration. (After Wetzel 1975, modified from Vollenweider, 1968)

(ug/l)			
Category	**Total P** (and Ortho P)	**Total N**	**Inorganic N**
Ultra-oligotrophic	0 - 5	0 - 250	0 - 200
Oligo-mesotrophic	5 - 10	250 - 600	200 - 400
Meso-eutrophic	10 - 30	300 - 1100	300 - 650
Eutrophic	30 - 100	500 - 15 000	500 - 1500
Hyper Eutrophic	> 100	> 15 000	> 1500

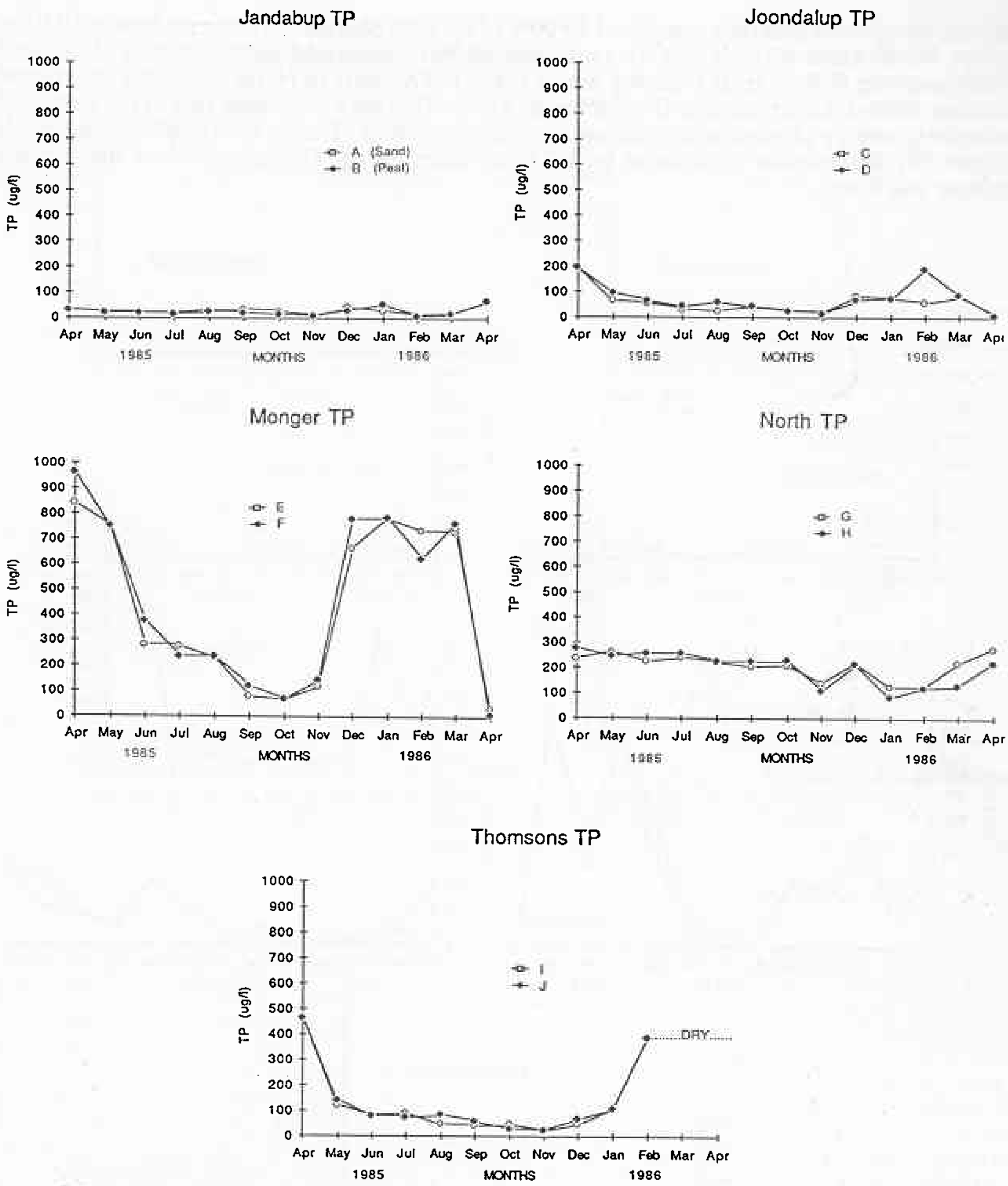

Figure 27: Monthly changes in the concentration of total phosphorus in micrograms/litre at each site in the five lakes studied from April 1985 to April 1986.

Organic phosphorus generally comprised 50-90% of the total phosphorus concentration in all lakes except North Lake (Figure 28). Organic phosphorus comprised approximately 20%, and orthophosphate 80% of total P during winter (May to October) in North Lake, but the reverse situation existed during summer (December to April). This may have been due to the uptake of orthophosphate by phytoplankton during the warmer months. Trends in orthophosphate levels (Figure 29) were similar to those of total P in all lakes except Thomsons, where the summer increase was lower.

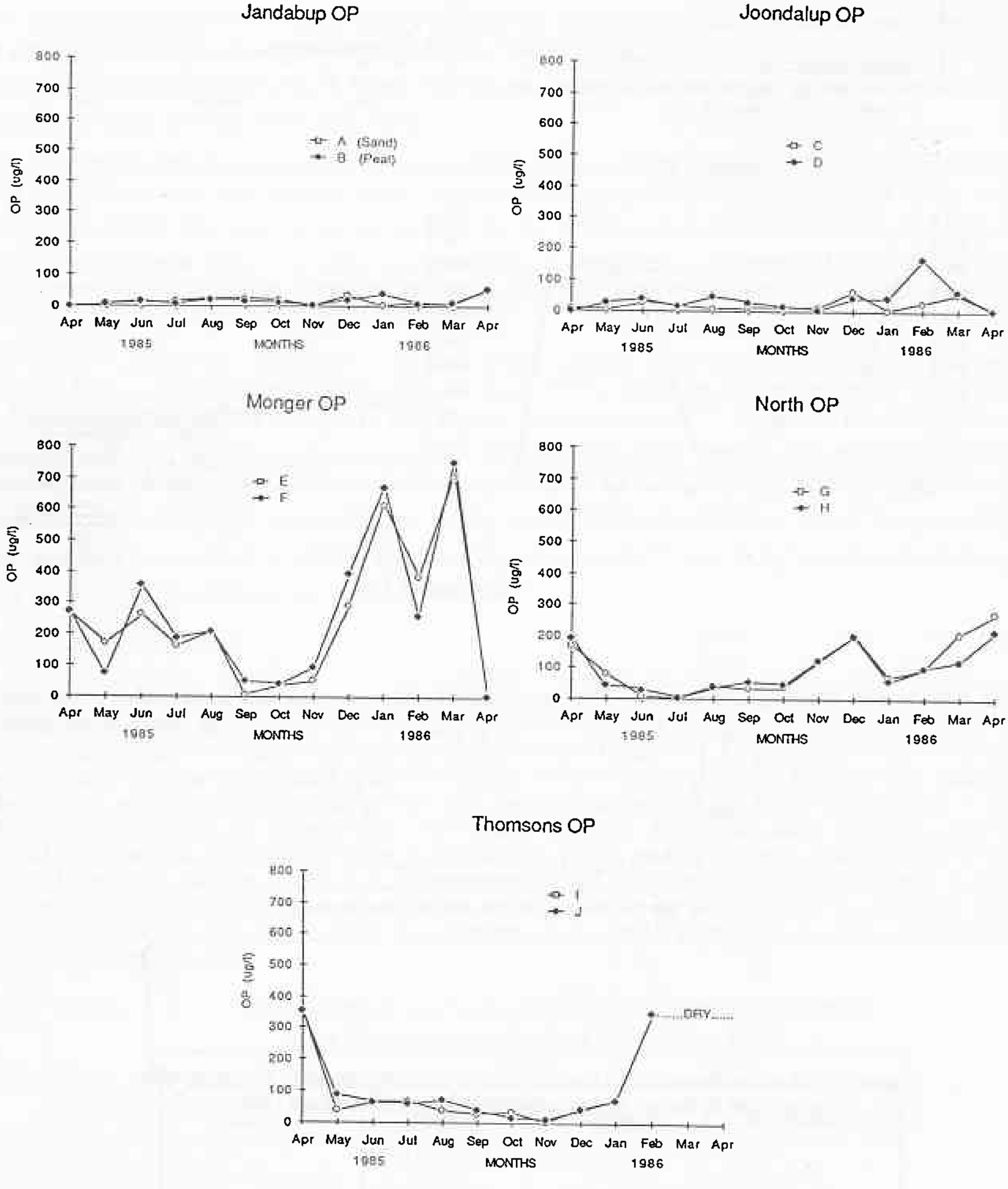

Figure 28: Monthly changes in the concentration of organic phosphorus in micrograms/litre at each site in the five lakes studied from April 1985 to April 1986.

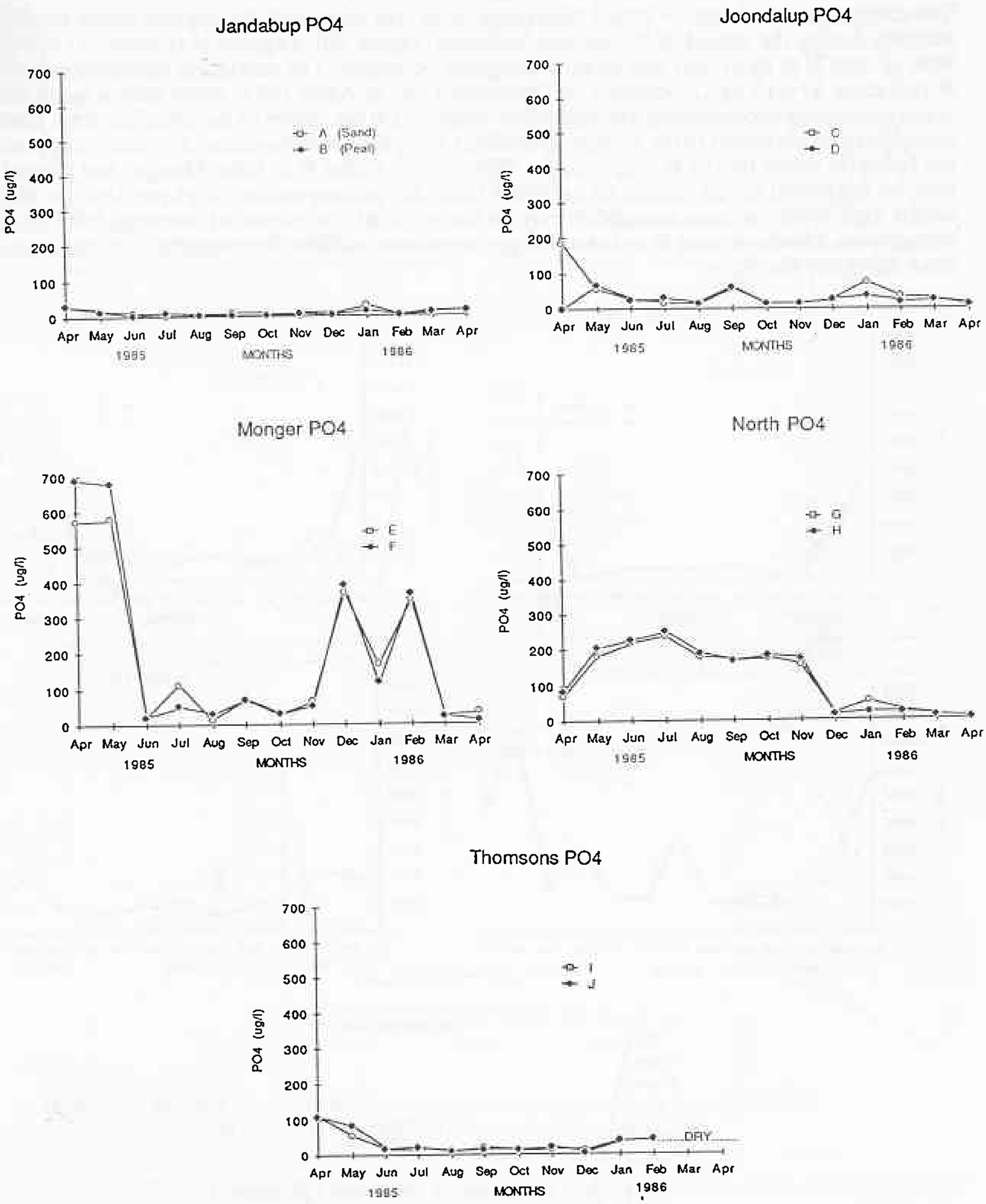

Figure 29: Monthly changes in the concentration of orthophosphate ($PO_4^{-\,-}$) in micrograms/litre at each site in the five lakes studied from April 1985 to April 1986.

The February rain event may have been the cause of the sudden decrease in organic P in Lake Monger in that month, but the cause of a similar decrease in orthophosphate in the lake during January is not known.

5.1.7 NITROGEN

The concentration of total N varied seasonally in all five lakes with the highest levels recorded in summer during the period of lowest lake volumes (Figure 30). Organic N (Figure 31) comprised 90% of total N at most sites and on most sampling occasions. The maximum concentration of total N recorded, 17 215 ug/L, occurred in Thomsons Lake in April 1985, when only a small pool of water containing decomposing *Myriophyllum* remained at the centre of the lake.This high level can most likely be attributed to the release of nutrients from the decomposition of organic material from the formerly dense bed of *Myriophyllum* . High levels of total N in Lake Monger and North Lake may be attributed to the release of nutrients from the decomposition of phytoplankton blooms, whilst high levels in Lake Joondalup may be the result of the release of nutrients from decaying metaphyton. Levels of total N in Lake Monger were more variable in comparison to those recorded from the other four lakes.

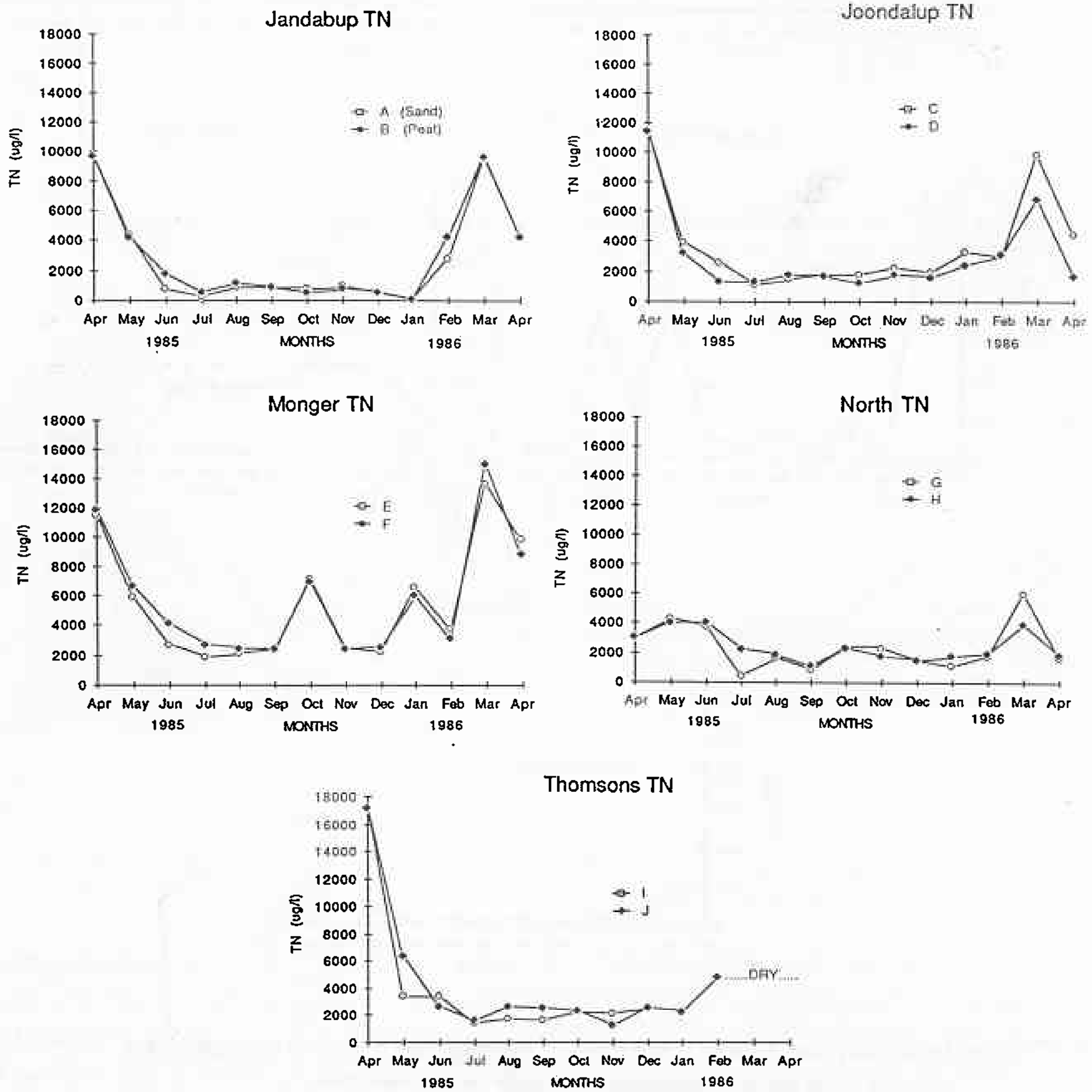

Figure 30: Monthly changes in the concentration of total nitrogen in micrograms/litre at each site in the five lakes studied from April 1985 to April 1986.

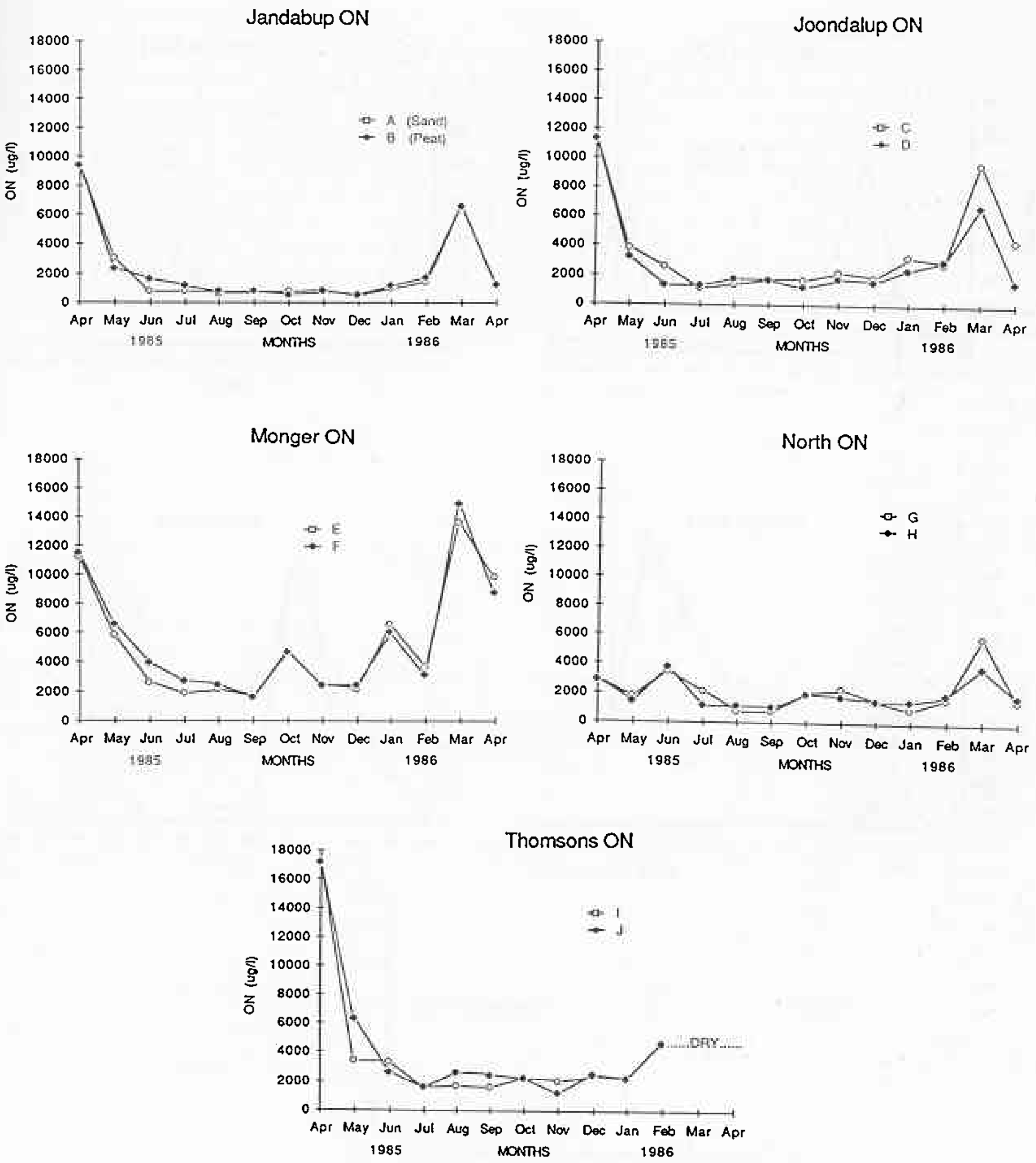

Figure 31: Monthly changes in the concentration of organic nitrogen in micrograms/litre at each site in the five lakes studied from April 1985 to April 1986.

Levels of NO_2/NO_3 (Figure 32) and NH_4 (Figure 33) did not increase with decreasing lake volumes, and NH_4 was generally present at higher concentrations than NO_2/NO_3 in all lakes. Two peaks in NH_4, 1856 ug/L and 3040 ug/L, occurred in Jandabup Lake in May 1985 and March and April 1986, whilst two peaks in NO_2/NO_3, 530 ug/l and 492 ug/l, occurred in July 1985 and February 1986. Maximum concentrations of NH_4 occurred in Lake Monger in October 1985, and in North Lake in May 1985. Maximum concentrations of NO_2/NO_3 occurred in Lake Monger in June and October 1985, and in North Lake in August 1985. Concentrations of NH_4 and NO_2/NO_3 were very low (<15 ug/L) in Lake Joondalup and Thomsons Lake throughout the entire sampling period.

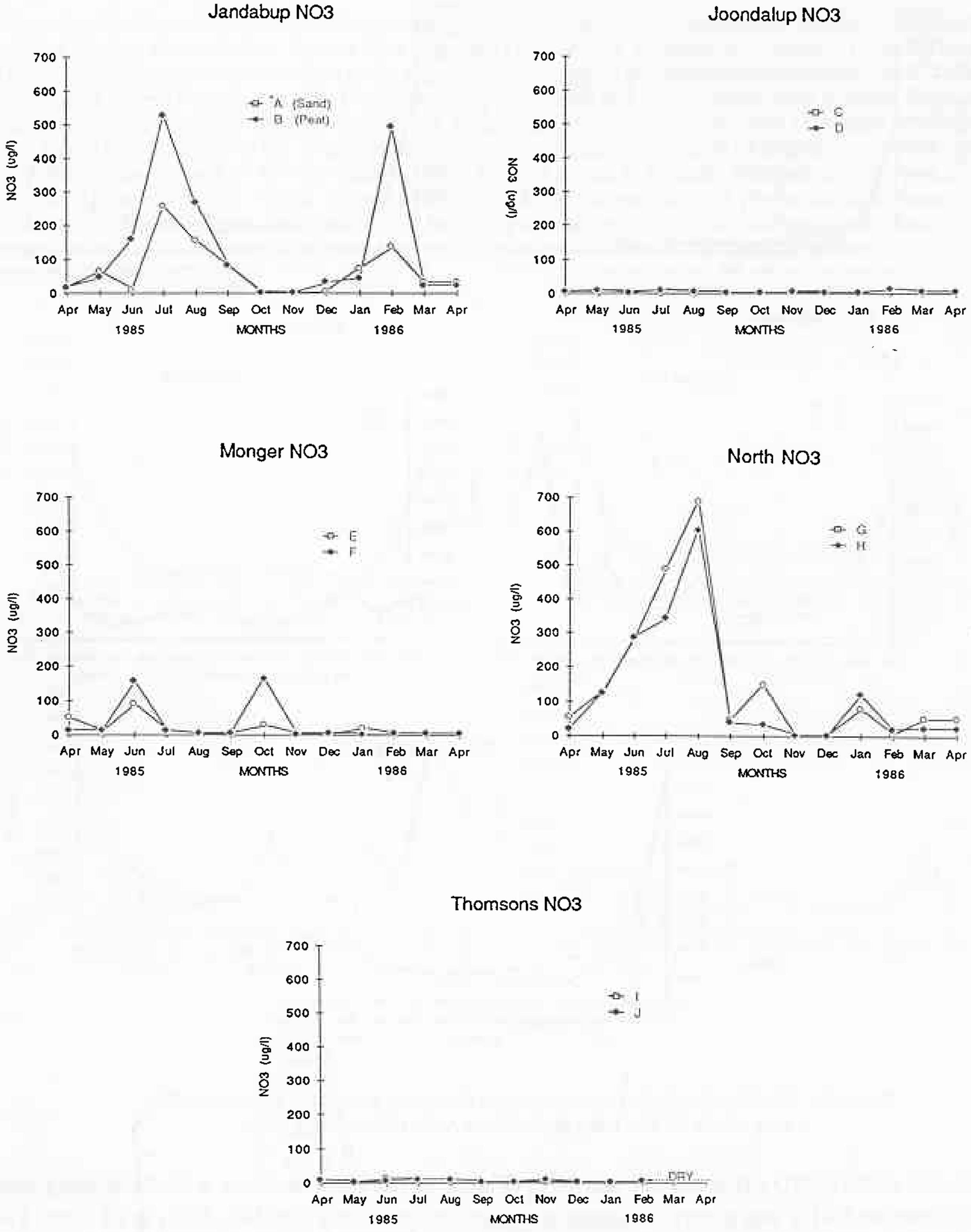

Figure 32: Monthly changes in the concentration of nitrate (NO_2^{-} $^{-}$/NO_3^{-}) in micrograms/litre at each site in the five lakes studied from April 1985 to April 1986.

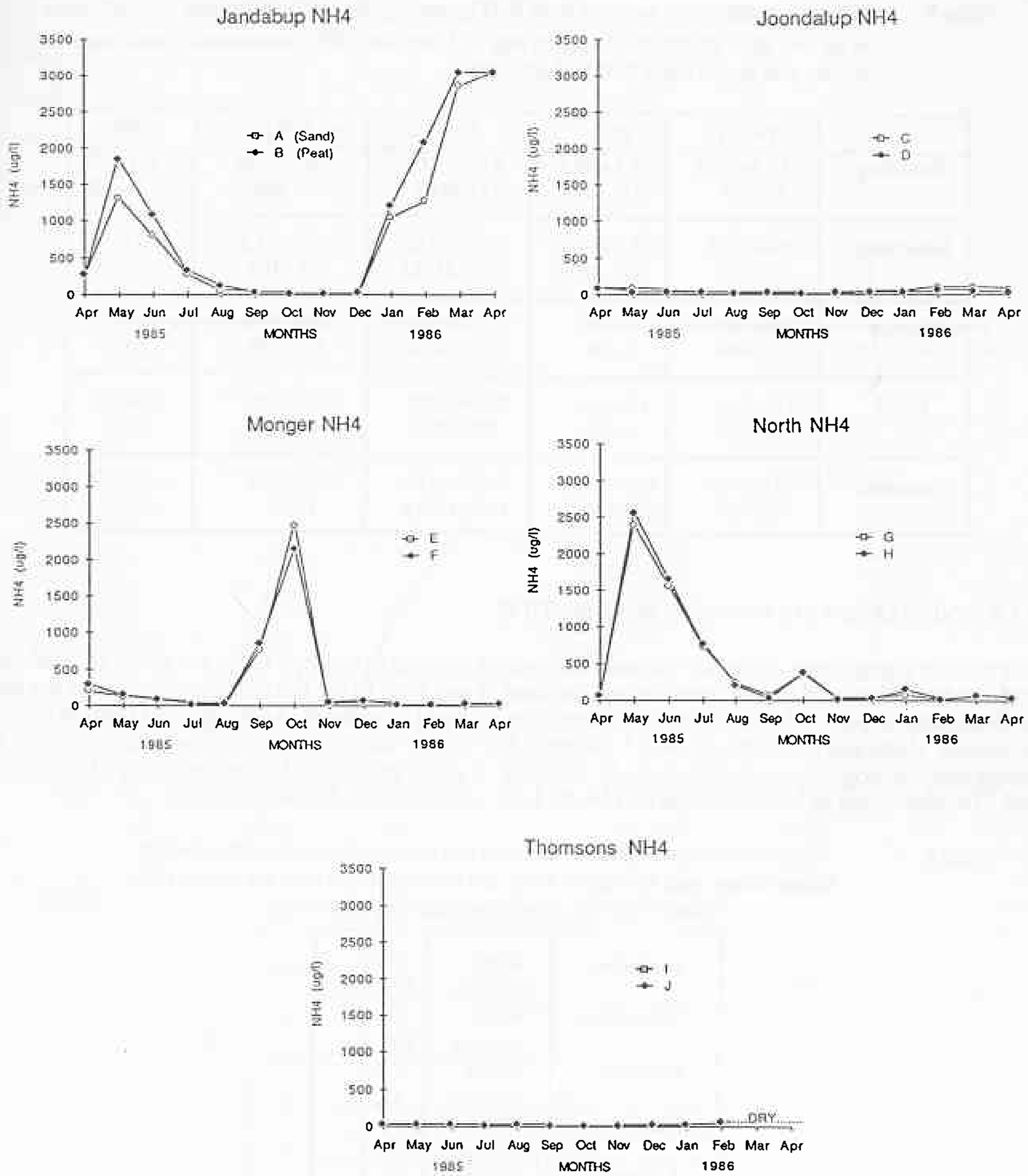

Figure 33: Monthly changes in the concentration of ammonium (NH_4^+) in micrograms/litre at each site in the five lakes studied from April 1985 to April 1986.

Comparison of the values of total N recorded in this study (Table 5) with Wetzel's (1975) classification of lake productivity (after Vollenweider, 1968), reveals that all lakes were hypereutrophic at the time of maximum concentration during summer, and that all except Jandabup Lake remained hypereutrophic or eutrophic throughout the remainder of the year despite fairly large decreases in concentration due to dilution during winter. Jandabup Lake may generally be classified as meso-eutrophic during the winter months. On the basis of concentrations of inorganic N, Lakes Jandabup, Monger and North may also be classified as hypereutrophic during periods of peak concentrations. Concentrations of inorganic N were so low in Lake Joondalup and Thomsons Lake, that both lakes must be classed as ultra-oligotrophic with respect to this nutrient.

Table 5. Mean concentrations of nutrients (total P, PO_4, total N, NH_4, NO_2/NO_3) and standard errors in the five lakes studied for the period June to November 1985 (winter/spring), and range for the one year period April 1985 to April 1986.

	Total P	PO_4	TN	NH_4	$N0_3$
Jandabup	19.8+/-2.2 10 - 67	5.8+/-0.7 11 - 28	870+/-77.9 14 - 9716	230.4+/-98 17 - 3040	131+/-44 2 - 530
Joondalup	36+/-38.9 13 -195	24.7+/-4.9 12 - 187	1675+/-122 1231-11482	23.3+/-3.2 12 - 101	13.4+/-2.9 2 - 13
Monger	186+/-39 36-964	46+/-8 8-690	3321+/-510 1569-14939	546+/-242 10-2460	41+/-17 2-157
North	211+/-12 123-280	194+/-9 4-239	2069+/-295 712-6007	501+/-159 14-2556	259+/-65 1-690
Thomsons	54.4+/-6.8 20-460	14.5+/-1.2 3-118	2103+/-173 1168-17215	21.2+/-0.8 17-61	6.1+/-1.2 1-11

5.1.8 NITROGEN TO PHOSPHORUS RATIOS

Nitrogen to phosphorus ratios for summer and winter periods in the five lakes are given in Table 6. Ratios were calculated on the mean values for total N and total P, for the two sites combined for the periods June to November (winter) and December to April (summer). As the typical ratio in tissue of aquatic algae and macrophytes is 7:1 (Wetzel, 1975, after Vallentyne, 1974), it is probable that P rather than N would be more likely to be limiting to plant growth in Lakes Jandabup, Joondalup and Thomsons, but in Lake Monger and North Lake nitrogen may become limiting.

Table 6. Nitrogen to phosphorus ratios in winter and summer for the five lakes studied. Winter values were for August 1985, and summer values were for March 1986. Values from both sites in each lake were combined.

Jandabup	Winter Summer	35 : 1 479: 1
Joondalup	Winter Summer	39 : 1 100: 1
Monger	Winter Summer	10: 1 19: 1
North	Winter Summer	8: 1 29 : 1
Thomsons	Winter Summer	35 : 1 Dry

5.2 CHLOROPHYLL - *a*

Chlorophyll-*a* concentrations were recorded at the two sites in each lake from October 1985 to April 1986 (Figure 34), as a means of assessing the occurrence and abundance of phytoplankton in the waterbodies. The low concentrations recorded in Lakes Jandabup, Joondalup and Thomsons suggest that little phytoplankton growth occurred in these lakes, whilst the higher levels in North Lake and Lake Monger indicate the presence of fairly large algal blooms. Evidence of phytoplankton blooms were visible to the naked eye in both lakes (Photographs 29 and 30). As spring and summer progressed, the waters of Lake Monger became progressively greener as a result of the phytoplankton blooms. The sudden decrease in chlorophyll-*a* concentration in Lake Monger in February may have been a consequence of the rainfall event, either as a direct result of the dilution of lake waters or from associated changes in water chemistry.

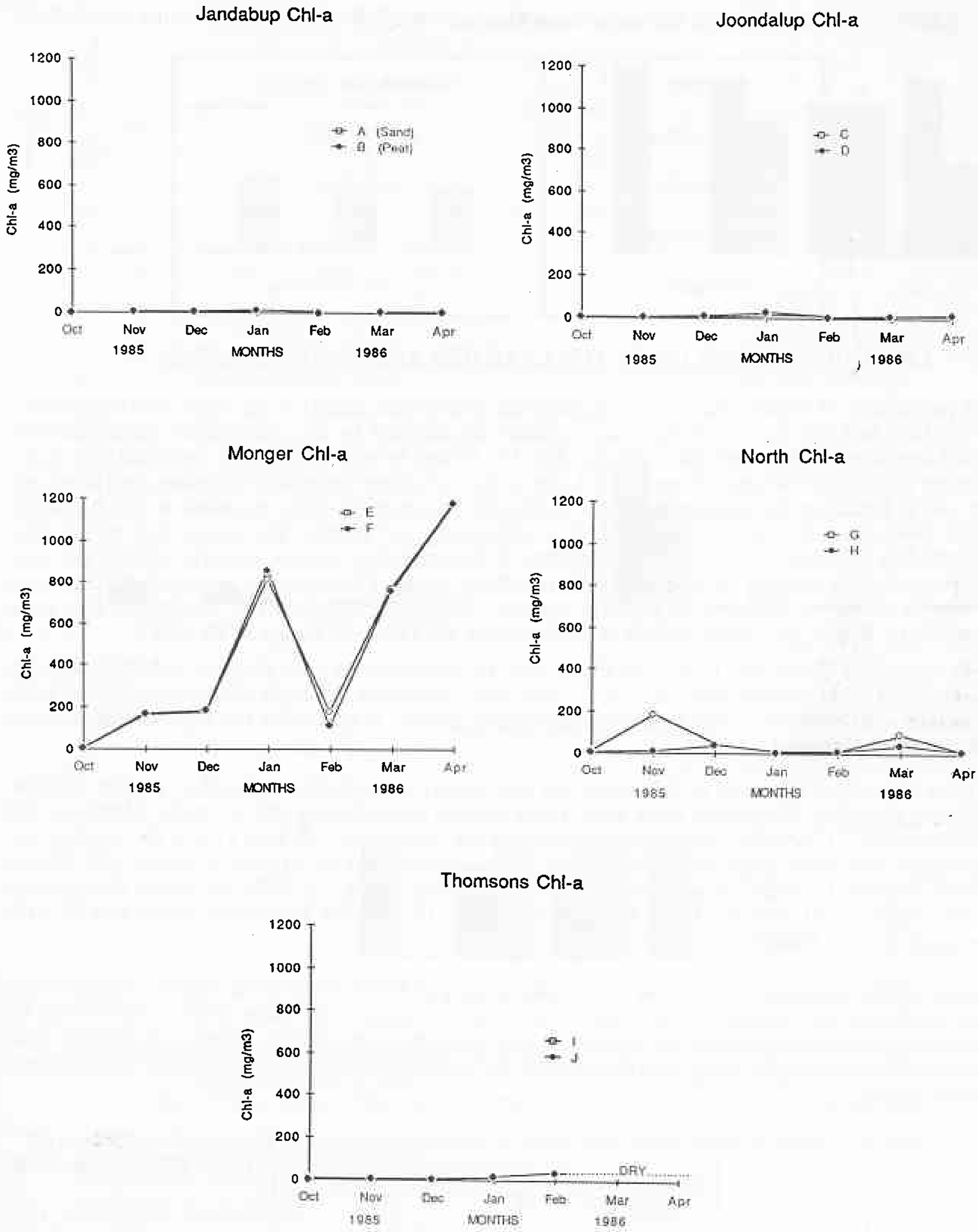

Figure 34: Monthly changes in the concentration of chlorophyll-a (mg/m^3) at each site in the five lakes studied from October 1985 to April 1986.

Comparison of chlorophyll-*a* concentrations given in Figure 34 with Wetzel's (1975) classification of lake trophic status (Table 7), indicates that all lakes were oligotrophic in winter, and with the exception of Jandabup which was mesotrophic, all were eutrophic in summer.

Table 7. Classification of lake trophic status based on chlorophyll-*a* concentration. (After Wetzel, 1975)

Category	Chlorophyll-*a* (mg/m3)
Ultra-oligotrophic	0.01 - 0.05
Oligotrophic	0.3 - 3.0
Meso - eutrophic	2 - 15
Eutrophic	10 - 500

5.3 ORGANIC CONTENT (%) OF THE LAKE BED AND WATER COLUMN

The percentage of organic material (excluding the invertebrate fauna) in the upper five centimetres of the lake bed and the overlying water column, as sampled by the quantitative pump method, varied considerably between lakes (Figure 35). The lowest levels, <10%, were recorded from Lake Monger throughout the year, from North Lake on the later three sampling occasions, and from one site (A) at Jandabup throughout the year. The higher values of 40-60% recorded at North Lake in April 1985, may be the consequence of a collapsed algal bloom. The sandy bed of the lake appeared to be covered by several millimetres of decomposing organic material during the later summer months, but was clear again by the middle of winter.The two sites at Jandabup Lake were distinctly different in terms of organic content. Values recorded at the sandy site (A) were consistently low, < 5%, whilst values at the diatomite site (B) were higher at 25-30% .

High values in Thomsons Lake (40-55%), may be attributed to both the peat substrate and the dense stand of *Myriophyllum* present at both sites. Similarly the high values recorded at Lake Joondalup (40-80%) may also be attributed to plant growth, in particular the algal /sediment ooze known as metaphyton.

Whilst the values recorded in this study are not strictly comparable with other studies because different sampling techniques were used, some general comparisons can be made. Marchant and Williams (1977) recorded percentage organic matter values of 9.7% and 11.8% for washed and unwashed sediments respectively from Pink Lake, a saline lake in western Victoria, and Timms (1980) recorded values ranging from 24-94% for dune lakes, 12-13% for North Queensland coastal lagoons, 31-79% for North Queensland maars, 13-28% for Tasmanian lakes, and 32-51% for south-eastern Australian volcanic lakes.

Rybak (1969) attempted to relate the degree of eutrophy of Polish lakes to the organic content of the bed, and found that organic matter content could vary for lakes of the same trophic type (Table 8). Despite considerable variation, he concluded that an increase in organic content was evident from oligotrophic to eutrophic lakes, and considered the following levels to be associated with different trophic stages.

Table 8. Content of organic matter (percentage) in the bottom sediments of lakes of various trophic types. (After Rybak, 1969)

Trophic Status	Organic Content
Oligotrophic	11 - 20%
Mesotrophic	17 - 30%
Eutrophic	18 - 61%
Dystrophic	77 - 83%

Jandabup Lake, which has been classed as mesotrophic (this study), and Lake Joondalup, North Lake and Thomsons Lake, which have been classed as eutrophic (this study) on the basis of nutrient levels, appear to fit within this scheme, whilst Lake Monger (which has also been classed as eutrophic) contains levels of organic matter which lie below that of oligotrophy in Rybak's (1969) classification. The reasons for this are not known, but this result suggests that other factors apart from the degree of nutrient enrichment, such as the geology of the lake basin, may determine the organic content of a lake bed.

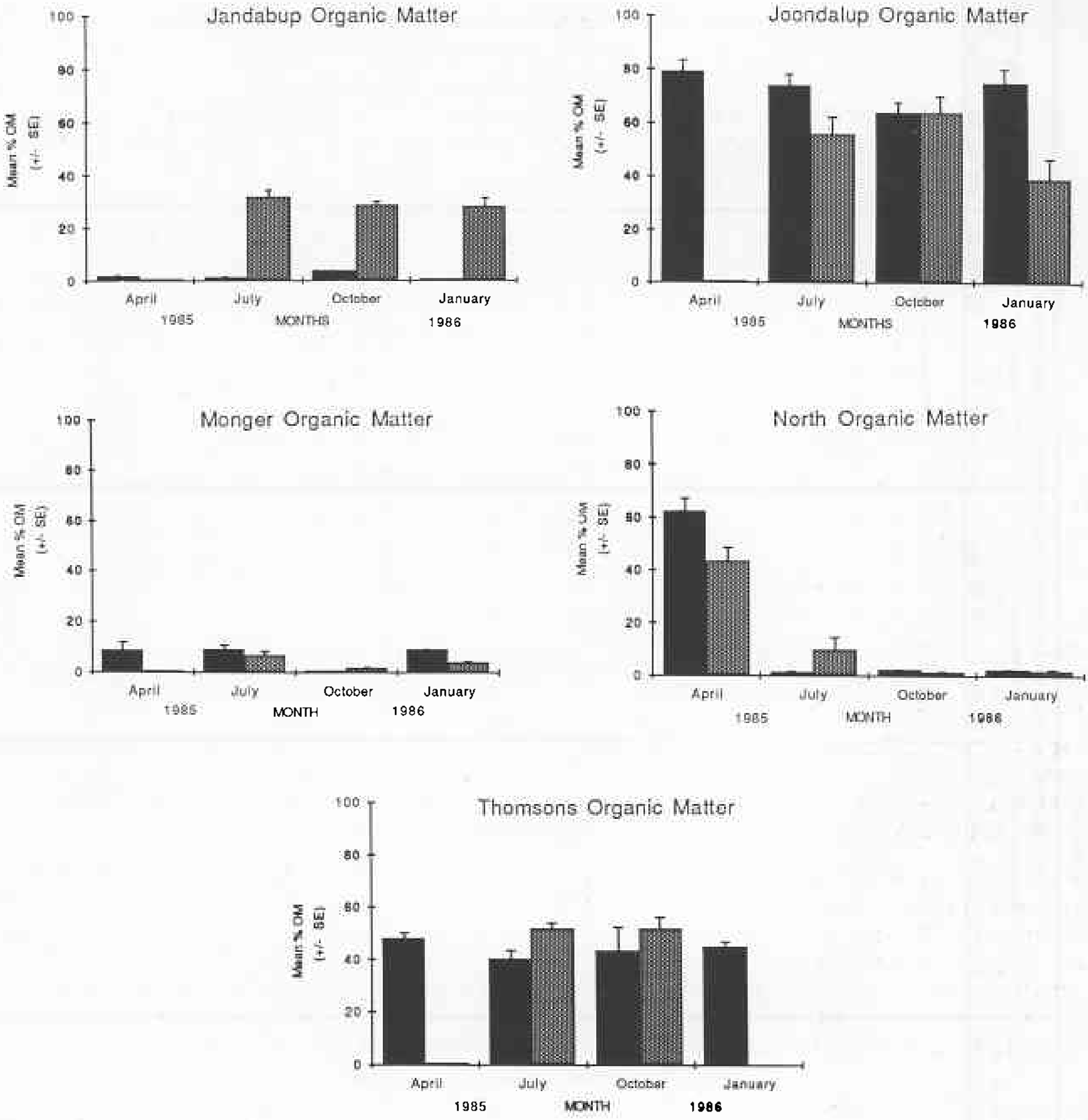

Figure 35: Seasonal changes in mean content (%) of organic matter of the lake bed and water column at two sites (represented by black and cross-hatched shading) in each of the lakes studied, from April 1985 to January 1986. Vertical bars show the standard error associated with the mean.

5.4 <u>MACROINVERTEBRATE FAUNA</u>

5.4.1 SPECIES RICHNESS

All taxa recorded from the five wetlands during the study and the presence/absence of each taxon at each site on each sampling occasion are listed in Table 9. A total of 87 taxa were recorded from the five urban wetlands, and this number may be expected to increase because several taxa including the Nematoda, Oligochaeta, Cladocera and Copepoda were not identified to species level. The term taxon rather than species is the correct way to refer to these faunal groupings, however the term "species" is more commonly used and as it applies to the major proportion of the fauna considered in this study, it will be used from this point onward.

The total number of species collected from each lake from seasonal sampling (conducted from April 1985 to January 1986) is given in Table 10.

Table 9: List of taxa occuring in the five wetlands. The symbol + indicates the presence of a taxon at a site, a blank space indicates that the taxon was absent. Each site was sampled on a seasonal (three monthly) basis from April 1985 to January 1986.

LIST of TAXA

TAXON	COMMON NAME	Jandabup							Joondalup								Monger							North								Thomsons					
		X Apr	A Jul	B Jul	A Oct	B Oct	A Jan	B Jan	C Apr	D Apr	C Jul	D Jul	C Oct	D Oct	C Jan	D Jan	E Apr	E Jul	F Jul	E Oct	F Oct	E Jan	F Jan	G Apr	H Apr	G Jul	H Jul	G Oct	H Oct	G Jan	H Jan	X Apr	I Jul	J Jul	I Oct	J Oct	X Jan
PORIFERA	Sponge																								+												
PLATYHELMINTHES																																					
Tricladida sp.A	Flatworm		+	+																					+		+				+						
Nematoda	Roundworm	+					+							+				+	+	+	+	+	+				+			+			+				
ANNELIDA																																					
Oligochaeta spp.	Aquatic earthworm	+			+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+		+			+
Hirudinea																																					
Glossiphonidae sp.A	Leech									+				+							+				+		+	+				+					+
MOLLUSCA																																					
Gastropoda																																					
Planorbarius corneus	Aquatic snail																+		+						+				+		+						
Physastra gibbosa	Aquatic snail		+	+					+	+	+		+	+	+	+			+					+								+	+	+	+		+
Physa acuta	Aquatic snail																+	+	+		+				+	+	+	+	+	+	+	+	+	+	+	+	+
Pseudosuccinea columella	Aquatic snail																		+																		
Plotiopsis balonnensis	Aquatic snail																+	+																			
Bivalvia																																					
Sphaeruim castertanum	Pea Clam																+																				
ARTHROPODA																																					
Crustacea																																					
Cladocera	Water Flea					+	+	+				+								+	+			+	+	+	+	+	+	+		+	+	+	+		+
Copepoda					+	+	+	+			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Ostracoda																																					
Mytilocypris ambiguosa			+	+				+						+	+																			+	+	+	
Sarscypridopsis aculeata			+	+	+		+	+						+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Candonocypris novaezelandiae					+	+								+			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Alboa woorca			+		+						+		+	+							+											+	+	+	+	+	+
Bennelongia australis			+	+				+																									+	+	+	+	
Cypretta baylyi								+																							+				+	+	
Eucypris virens																																	+				
Ostracoda sp.A																																+	+		+	+	+
Amphipoda																																					
Austrochiltonia subtenuis		+			+	+	+	+	+	+	+	+	+	+	+	+				+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Isopoda																																					
Paramphisopus palustris		+		+	+	+	+	+					+								+		+	+		+	+	+	+	+	+			+	+	+	+
Decapoda																																					
Palaemonetes australis	Freshwater Shrimp								+	+	+	+	+	+	+	+																					
Cherax quinquecarinatus	Gilgie					+																															
Arachnida																																					
Limnochares australica	Water mite			+																													+	+			
Hydracarina sp.A	Water mite		+	+	+			+																									+				
Hydracarina sp.B	Water mite																						+				+			+							
Hydracarina sp.C	Water mite																												+		+		+	+			
Hydracarina sp.D	Water mite																							+				+	+		+						
Hydracarina sp.E	Water mite																													+	+						
Hydracarina sp.F	Water mite																														+					+	
Collembola	Springtail																										+										
Insecta																																					
Ephemeroptera (nymphs)																																					
Tasmanocoenis sp.	Mayfly nymph																						+	+	+	+		+	+	+	+						
Odonata																																					
Austrolestes annulosus	Damselfly nymph		+	+	+	+													+									+	+						+	+	+
Austrolestes analis	Damselfly nymph			+																																	
Austrolestes io	Damselfly nymph																																			+	
Xanthagrion erythroneurum	Damselfly nymph																							+	+	+	+	+	+	+	+		+	+	+	+	+
Aeshna brevistyla	Dragonfly nymph																																	+			
Hemianax papuensis	Dragonfly nymph					+																				+								+	+	+	
Hemicordulia tau	Dragonfly nymph		+	+	+	+	+	+																													
Ischnura aurora																																					
Hemiptera																																					

Hemiptera																																					
Micronecta robusta	Waterboatman				+	+	+	+			+	+	+	+			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+
Agraptocorixa hirtifrons	Waterboatman	+		+	+	+		+	+					+			+	+	+	+	+	+	+	+	+	+						+					+
Sigara mullaka	Waterboatman							+																							+						
Anisops hyperion	Backswimmer		+	+	+			+									+					+						+		+	+	+	+	+	+	+	+
Anisops doris	Backswimmer																																				+
Notonecta handlirschi	Backswimmer			+	+	+		+																	+										+	+	
Mesovelia sp.A	Aquatic bug																								+	+											+
Coleoptera																																					
Sternopriscus multimaculatus (adults)	Diving beetle				+	+	+	+															+														
Macroporus gardneri (larvae)	Diving beetle																																		+	+	
Antiporus femoralis (larvae)	Diving beetle		+	+			+	+																											+		
Hyphydrus sp. (larvae)	Diving beetle														+						+		+					+	+								
Hydaticus sp.	Diving beetle		+																																		
Platynectes ? (larvae)	Diving beetle			+																													+				
Haliplus fuscatus/gibbus (adults)	Aquatic beetle		+		+																												+	+			
Berosus discolor (adults)	Aquatic beetle		+	+	+	+																										+					
Hydrovatus opacus (adult)	Aquatic beetle																													+							+
Helochares sp. (adults)	Aquatic beetle																																+				
Berosus australiae (adults)	Aquatic beetle																				+																
Hydrophilidae (adults)	Aquatic beetle												+																	+							+
Berosus sp. (larvae)	Aquatic beetle			+	+	+	+	+													+			+								+	+	+			
Hydrophilidae sp.A (larvae)	Aquatic beetle																																			+	
Helochares sp. (larvae)	Aquatic beetle																											+									
Curculionidae (adults)	Weevil		+																																+		
Diptera																																					
Chironomus australis (pupa)	Midge pupa							+										+	+		+	+	+		+							+	+	+			
Chironomus australis (larva)	Midge larva			+				+						+			+	+	+	+	+	+	+		+			+				+		+			+
Chironomus alternans (pupa)	Midge pupa																				+							+					+				
Chironomus alternans (larva)	Midge larva													+						+	+				+		+	+	+			+	+	+			
Chironomus intertinctus (pupa)	Midge pupa																								+												
Chironomus intertinctus (larva)	Midge larva																+		+					+			+	+									
Cladopelma curtivalva (larva)	Midge larva					+		+							+																						
Cryptochironomus griseidorsum (pupa)	Midge pupa																					+															
Cryptochironomus griseidorsum (larva)	Midge larva			+			+	+															+			+	+	+	+	+	+						
Dicrotendipes conjunctus (pupa)	Midge pupa																																+				+
Dicrotendipes conjunctus (larva)	Midge larva		+	+	+	+	+	+						+								+	+					+	+	+	+	+	+	+			+
Polypedilum nubifer (pupa)	Midge pupa		+														+					+	+	+	+							+					+
Polypedilum nubifer (larva)	Midge larva	+					+	+	+			+	+	+		+	+	+	+	+	+	+	+	+	+			+	+	+	+	+	+	+			+
Procladius villosimanus (pupa)	Midge pupa					+														+	+			+	+	+	+		+			+	+				
Procladius villosimanus (larva)	Midge larva	+	+	+		+		+	+		+			+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Tanytarsus fuscithorax (pupa)	Midge pupa		+																																		
Tanytarsus fuscithorax (larva)	Midge larva		+	+	+	+	+	+																										+	+		+
Pentaneura levidensis (larva)	Midge larva					+																															
Limnophyes pullulus (pupa)	Midge pupa																									+											
Limnophyes pullulus (larva)	Midge larva		+	+		+																				+	+			+			+				
Lundstroemia parthenogenetica	Midge larva				+																																
Ablabesmyia notabilis (larva)	Midge larva	+	+		+	+																													+	+	
Anopheles annulipes (pupa)	Mosquito pupa																																			+	
Anopheles annulipes (larva)	Mosquito larva																																			+	
Ceratopogonidae	Biting-midge larva	+	+	+	+																			+	+	+	+				+	+		+			+
Tabanidae	Marchfly larva																																+	+			
Stratiomyidae	Soldierfly larva																																	+			
Trichoptera																																					
Triplectides australis (pupa)	Caddisfly pupa																														+						
Triplectides australis	Caddisfly larva				+												+		+	+	+		+	+	+	+	+	+	+		+			+		+	
Notalina fulva	Caddisfly larva																							+				+									+
Oecetis sp.A	Caddisfly larva	+																				+					+	+		+							
Ecnomidae sp. A	Caddisfly larva																											+		+							
Hellyethira litua	Caddisfly larva											+	+																								

X denotes samples taken from the centre of the lake due to drying at sampling sites.

Table 10. Total number of species collected from the five urban wetlands between April 1985 and January 1986.

	Thomsons	North	Jandabup	Monger	Joondalup
Total number of species	62	55	49	40	24

Ten species were common to the five wetlands, and these are listed in Table 11. Further species common to the five lakes may be found when members of the Nematoda, Oligochaeta, Cladocera, and Copepoda are identified to species level. Twenty four species were unique, that is recorded from only one wetland, and these comprised eight species recorded only from Thomsons Lake, five from North Lake and Jandabup Lake, four from Lake Monger, and two from Lake Joondalup.

Table 11. Species common to the five lakes studied.

Candonocypris novaezelandiae	(Crustacea : Ostracoda)
Sarscypridopsis aculeata	(Crustacea : Ostracoda)
Austrochiltonia subtenuis	(Crustacea : Amphipoda)
Paramphisopus palustris	(Crustacea : Isopoda)
Micronecta robusta	(Hemiptera : Corixidae)
Anisops hyperion	(Hemiptera : Notonectidae)
Chironomus australis	(Diptera : Chironomidae)
Dicrotendipes conjunctus	(Diptera : Chironomidae)
Polypedilum nubifer	(Diptera : Chironomidae)
Procladius villosimanus	(Diptera : Chironomidae)

The Insecta were the dominant class in terms of species number; a total of 53 species were recorded compared with 14 species of Crustacea. However the Crustacea, and in particular the Ostracoda, were often the most abundant organisms in the quantitative samples. Species numbers within the Insecta were dominated by the Diptera (17 species) and the Coleoptera (16 species). Within the Diptera the Chironomidae (midges) was the most common family comprising 13 species, and often the most abundant (in terms of number of individuals) at each site.

The structure of the fauna of each lake was similar with respect to the Crustacea but differed for the Insecta. Twelve species of Crustacea were recorded in Thomsons Lake, 11 in Jandabup Lake, 9 in Lake Joondalup and 7 in both North and Monger. Thirty nine species of insects were recorded from Thomsons Lake, 31 from Jandabup and 29 from North, but only 18 from Lake Monger and 11 from Lake Joondalup.

Seasonal variation in species richness was evident in the two seasonally dry lakes, Jandabup and Thomsons, but not in the permanent waters, Joondalup, North and Monger (Figure 36). In the former two the lowest numbers of species, 10 and 24 respectively, were recorded in April 1985 when only a shallow pool of water remained in the centre of each lake. The higher number in Thomsons Lake was probably due to the presence of the dense mat of decaying *Myriophyllum* in the central pool, which provided both food and shelter for the invertebrate fauna. No submerged plant material was present in Jandabup. The number of species in both lakes rose quickly as the lakes filled with the winter rains, and the highest numbers of species per site, 31 in Thomsons Lake and 25 in Jandabup Lake were recorded in July. Numbers were still high in January prior to the complete drying of both lakes.

The maximum number of species per site in the three permanent lakes, 27 in North, 21 in Monger and 18 in Joondalup, were recorded in October. Apart from the 18 species recorded at site D in Lake Joondalup in October, species richness in Lake Joondalup was extremely low, with only 5 to 7 species being recorded from each site on each sampling occasion. Low species richness may be directly related to the presence of metaphyton in the lake. The dense turbid suspension of algal cells and sediment comprising the metaphyton must provide an inhospitable physical environment to most lentic organisms. The only occasion on which species numbers at Joondalup significantly increased, in October 1985, was also the only occasion on which no metaphyton was recorded at the two lake sites (Figures 19 and 36).

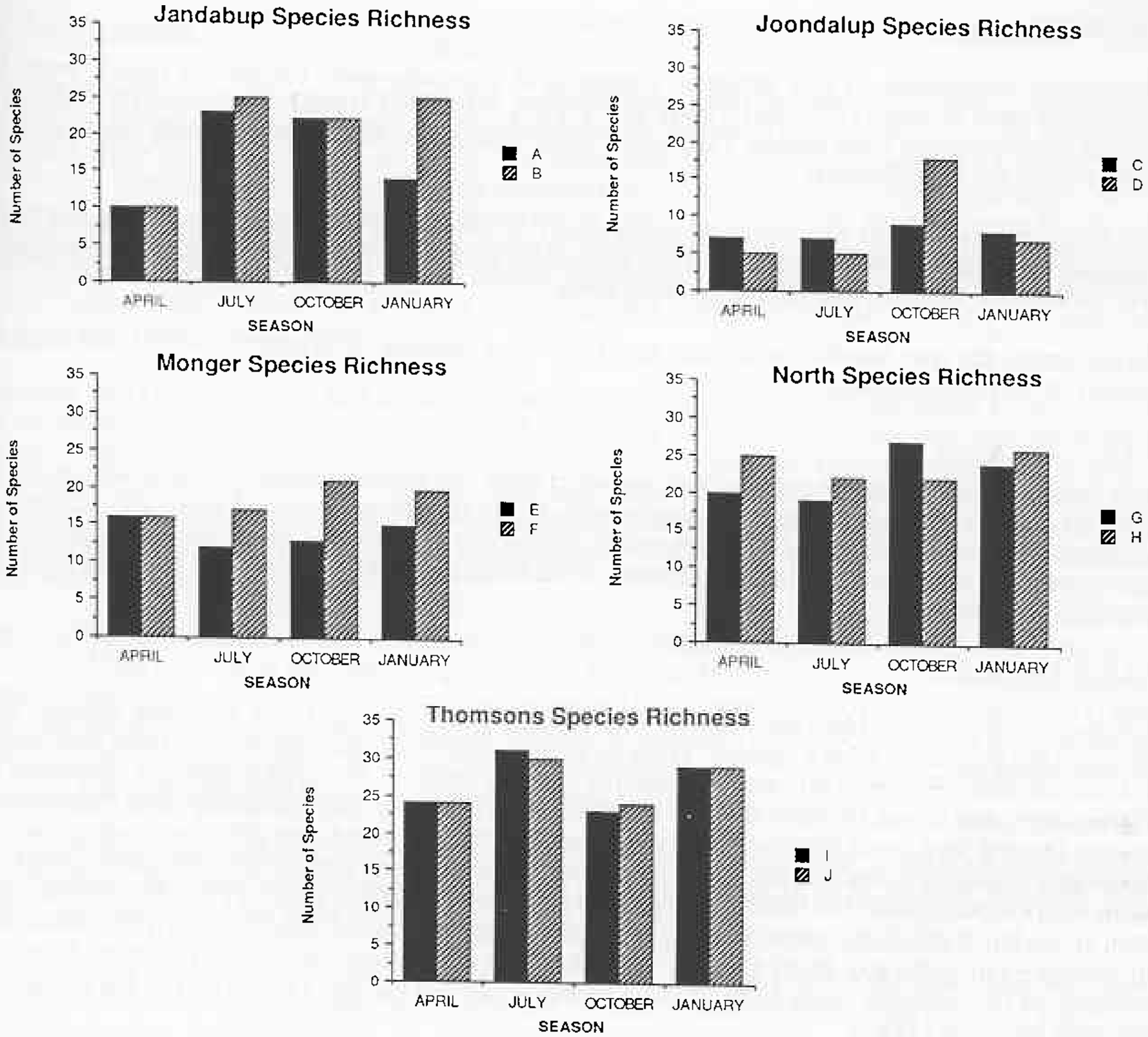

Figure 36: Seasonal changes in species richness at two sites (represented by black and cross-hatched shading) in each of the lakes studied, from April 1985 to January 1986. Species richness is defined here as the total number of species recorded in the six quantitative (pump) samples and two semi-quantitative (one minute sweep net) samples collected from each site on each sampling occasion.

5.4.2 SPECIES COMPOSITION

5.4.2.1 Porifera

Freshwater sponges were found (attached to submerged wood) only in North Lake and only on one sampling occasion, and therefore may be considered to be fairly rare within the urban wetland system.

5.4.2.2 Platyhelminthes

Triclads were recorded only from Jandabup Lake in July, and from North Lake in April, July and January. Triclads can occur in a wide range of inland waters but they are not normally found in saline lakes (Williams, 1980). They feed on both live and decaying animal matter.

5.4.2.3 Nematoda

Nematodes are amongst the most abundant organisms on earth (Williams, 1980), and the eggs of some species are resistant to dessication. They were recorded from every wetland but they did not occur in large numbers and could only be considered to be common in Lake Monger, where they were recorded on all but one sampling occasion.

5.4.2.4 Oligochaeta

Taxonomic knowledge of this group in Australia is generally poor except for recent work by Brinkhurst and Fulton (1979 and 1980) and Fulton (1983) in which 11 previously unknown species were recorded from central Tasmanian lakes. Material collected in this study has been sent to W. Fulton for identification .

The Oligochaeta formed an important component of the wetland fauna as they occurred in all wetlands on most sampling occasions. They were most abundant in Lake Joondalup and comprised over 50% of the fauna in that lake in January 1986.

Oligochaetes are true benthic organisms and their food consists of organic material and bacteria present in the sand and mud.

5.4.2.5 Hirudinea

Only one species, a Glossiphoniidae, was recorded from the urban wetlands and this was recorded from all lakes except Jandabup. Glossiphoniids have also been recorded from the Kemerton wetlands by Bunn (1983). The glossiphoniids commonly feed on the body fluids of freshwater gastropods and this may explain their absence from Jandabup Lake because that lake had the least abundant snail fauna.

5.4.2.6 Mollusca

Five species of gastropod and one bivalve were recorded from the five lakes, but Lake Monger was the only lake to contain all six species. Three of the six species are thought to have been introduced to Australia from Europe. Only one species, the native planorbid *Physastra gibbosa* , occurred in all five lakes, and it was the only mollusc recorded from Jandabup and Joondalup. The Planorbidae are the largest and most diverse family of freshwater snails and are the dominant group of freshwater molluscs in many areas. Shell form is often variable and species identification cannot be made with certainty until the family has been revised (Smith and Kershaw, 1979). *P. gibbosa* has been recorded throughout south eastern Australia in slow flowing freshwater rivers, lakes and billabongs, and generally from algae or weed habitats. *Physastra* has been recorded from the wetlands of the northern Swan Coastal Plain by Hembree and George (1978) and in the Kemerton wetlands by Bunn (1983).

A second planorbid, the planispiral *Planorbarius corneus* , was recorded from Lake Monger and North Lake. This species was introduced to Australia from Europe as an aquarium species, and presumably has been released from aquaria where it occurs.

A physid, *Physa acuta* , was recorded from Lake Monger, North Lake and Thomsons Lake. This species is very similar in appearance to *P. gibbosa* and can only be separated from it on the form of the radula. The species has previously been recorded from Adelaide, central Victoria and NSW, and Smith and Kershaw (1979) consider the species in south eastern Australian to be introduced, probably from western Europe. Hembree and George (1978) considered *Physa* to be a recent introduction to Western Australia, and a rapid coloniser because it has been recorded in waters from Perth to Gingin.

Plotopsis balonnensis, Pseudosuccinea columella and *Sphaerium castertanum* were recorded only from Lake Monger. The thiarid, *P. balonnensis* , has previously been recorded in the Murray - Darling system (Smith and Kershaw 1979). The lymnaeid, *P. columella,* is an introduced species to Australia and is known to be an intermediate host for the sheep liver fluke, *Fasciola hepatica.* This species has been recorded elsewhere in Western Australia by Bunn (1983) in the Kemerton wetlands, and in some streams on the Darling Scarp (Bunn, pers comm). The sphaeriid, *S. castertanum* , had previously been recorded by Hembree and George (1978) in Loch McNess and is generally associated with organic muddy substrates.

5.4.2.7 Cladocera and Copepoda

Cladocerans and copepods were present in all lakes but little comment can be made on the species composition of the zooplankton until species identifications have been made.

5.4.2.8 Ostracoda

Ostracods were important members of the wetland fauna both in terms of species richness and abundance with a total of eight species recorded from the wetlands during the study. All eight were recorded from Thomsons Lake, six from Jandabup, four from Joondalup and two from Monger and North. Two species, *Sarscypridopsis aculeata* and *Candonocypris novaezelandiae* , were present in all five wetlands and were recorded on all sampling occassions from Monger, North and Thomsons. Bunn (1983) recorded eight species of ostracod from the Kemerton wetlands, Hembree and George (1978) recorded two to four species in each of the lakes they studied on the northern Swan Coastal Plain, whilst van Alphen (1983) recorded at total of 10 species from four lakes on the southern Swan Coastal Plain.

Hembree and George (1978) had noted that the Ostracoda were the dominant fauna of the lakes of the northern Swan Coastal Plain, and referred to Barclay's (1966) comments that their preference for well weeded, richly organic habitats, and their ability to produce resistant eggs ideally suited them to life in temporary waterbodies. However despite the fact that ostracods are widely distributed and common throughout Australia, in both fresh and saline and permanent and temporary waters, little is known of the ecological requirements of the freshwater ostracods (Williams, 1980).

Candonocypris novaezelandiae is a freshwater species which is often associated with eutrophic waters and has even been recorded from sewerage lagoons. It is generally found in high numbers in the littoral region of lakes in decaying vegetation and black organic muds (DeDeckker, 1981) and often appeared to be the most abundant species within the urban wetlands. The species is cosmopolitan, being recorded from Japan, New Caledonia and New Zealand, and elsewhere in Australia from Victoria and South Australia (DeDeckker, 1981).

The other most common and abundant species, *Sarscypridosa aculeata* , is also a cosmopolitan species which has previously been recorded from temporary pools in WA, SA and Victoria. This species has been recorded from waters of salinities up to 21.3 ppt .

Alboa wooroa was recorded from all lakes except North, and has previously been recorded from permanent and temporary waterbodies in WA and SA and in waters of salinities up to 3.5 ppt.

Mytilocypris ambiguosa was recorded from Jandabup, Joondalup and Thomsons Lake and was the largest and one of the most easily recognised ostracod species in the lakes because of its size. It is a salt tolerant species and is endemic to Australia.

Cypretta baylyi occurred in Jandabup, North and Thomsons Lakes. It is a common inhabitant of freshwater and temporary waterbodies in WA, and has also been recorded from the Northern Territory. *Bennelongia australis* occurred only in Jandabup Lake and Thomsons Lake. It has previously been recorded from mainly temporary waters in WA and SA, and in waters with salinities up to 4.4 ppt. In Thomsons Lake it occurred in waters up to 6 ppt. *Eucypris virens* was only recorded from Thomsons Lake in this study, but it is a cosmopolitan species which also occurs in North Africa, the USSR and New Zealand. In Australia it has previously been recorded from WA, SA and Victoria. It usually occurs in fresh and temporary waters but previously has been recorded in waters up to 4.4 ppt. In Thomsons Lake it also occurred in waters up to 6 ppt.

The occurrence of three cosmopolitan species, *C. novaezeladiae, S.aculeata* and *E.virens* in Perth wetlands may be a consequence of the useage of these wetlands by migratory waders which travel each year between USSR and Japan and Australia and New Zealand. It is entirely feasible that the resistant eggs of these ostracods would enable them to survive being carried over very large distances by waterbirds.

5.4.2.9 Amphipoda

Only one species, a member of the Ceinidae, *Austrochiltonia subtenuis* was recorded from the urban wetlands, but this species was a common and abundant member of the fauna. It occurred in all lakes, and in three of the lakes, Joondalup, North and Thomsons it occurred at all sites in all seasons. *Austrochiltonia* is widely dispersed throughout southern Australia and is a euryhaline genus that can tolerate a wide range of environmental conditions (Bayly and Williams, 1973). It has previously been recorded from the Kemerton wetlands by Bunn (1983), and from all the lakes studied by Hembree and George (1978) except Lake Bambun. Amphipods are detritivores, feeding on the decaying plant and animal material of the lake bed. They do not possess resistant eggs and their mode of survival in Perth's temporary waters may be to burrow into the moist lake bed. Alternatively they may be transferred from permanent to temporary waters by waterfowl. Their occurrence in the wetlands in large numbers suggests that they are successful by whatever means.

5.4.2.10 Isopoda

Paramphisopus palustris , a member of the Phreatoicidea, was recorded from all five lakes but it was only abundant (comprising more than 5% of the total fauna at a site) in Jandabup Lake. The Phreatoicidea have a southern distribution, occurring in New Zealand, Australia, India and South Africa. Similar to *A. subtenuis*, *P. palustris* is a detrital feeder and does not possess resistant eggs, but its mode of survival or recolonisation of the temporary wetlands is probaly similar to that proposed above for *A. subtenuis* . Previously Hembree and George (1978) had only recorded *P. palustris* from Jandabup Lake. They suggested that it may be more sensitive to increased salinity than *A. subtenuis* .

5.4.2.11 Decapoda

The shrimp *Palaemonetes australis* was only recorded from Lake Joondalup, but it was the most abundant member of the fauna of this lake in both April and July. *P. australis* is a detrital feeder and inhabits both lentic and lotic environments in south-west WA. It is a euryhaline species and able to tolerate salinities from 0-35 ppt (Bray, 1976). The extremely high salinity tolerance of this species suggests that it may act as an indicator species for high salinity. In particular, the dominance of *P.australis* in apparently fresh water bodies may reflect high salinities at some time in the past, most probably during times of low summer water levels. It does not possess a drought resistant life history phase, which may explain its absence from Jandabup and Thomsons Lake, although *A. subtenuis* and *P. palustris* , which also lack drought resistant stages, are quite common in these two lakes.

The gilgie, *Cherax quinquecarinatus* , was only collected from Jandabup Lake during this study, but signs of its presence including claws and parts of the carapace and burrows were observed on many occasions at Thomsons Lake. This species is probably present in many of the wetlands of the Swan Coastal Plain, but it was not readily collected by the sampling methods used in this study.

5.4.2.12 Hydracarina

Seven species of water mite were collected in this study of which only one has been identified so far. This species, *Limnochares australica* , being relatively large and bright orange in colour, was a conspicuous member of the fauna at Jandabup Lake and Thomsons Lake during the winter months. Four was the maximum number of species recorded per lake in both North Lake and Thomsons Lake, with two species present in Jandabup Lake, one in Lake Monger and none recorded from Lake Joondalup.

Hydrachnids are most abundant in heavily vegetated, shallow, sheltered, and fresh standing waters (Williams, 1980), and most are predatory. Parasitic hydrachnids were observed attached to the head and pronotal areas of notonectids collected during this study, but only free-living species have been recorded in Table 9. The larval stage of many hydrachnids are ecto-parasitic upon aquatic insects and such a strategy, where mobile hosts such as notonectids are involved, would ensure the dispersal of hydrachnids to new waterbodies and re-colonisation of temporary ones.

5.4.2.13 Collembola

This is not a fully aquatic group but rather members are often found attached to the surface film of water (Williams, 1980). Only one species, from North Lake, was collected during this study.

5.4.2.14 Ephemeroptera

Only one species, *Tasmanocoenis* sp., a member of the Caenidae, was collected, and this species was common in North Lake but was absent from all other lakes except for one record from Lake Monger. The reason as to why the distribution of this species was so restricted is not clear although the fact that ephemeropterans have never been recorded from even slightly saline waters, and only a few species can breed in temporary waters (Williams, 1980), may explain its absence from Jandabup, Joondalup and Thomsons Lake. *Tasmanocoenis tilyardi* was recorded from streams in the jarrah forest by Bunn *et al* (1986) but we will not know if this species is the same until nymphs have been reared through to adults.

5.4.2.15 Odonata

Eight species, four zygopterans (damselflies) and four anisopterans (dragonflies), were recorded from the wetlands. Six species were present in Thomsons Lake, four in North Lake and Jandabup Lake, and one in Lake Monger. No odonatans were recorded from Lake Joondalup. The damselfly *Austrolestes annulosus* was the most common species, occurring in all lakes except Joondalup, and the dragonflies *Hemianax papuensis* and *Hemicordulia tau*, occurred in all lakes except Joondalup and Monger. All species have fairly wide ecological tolerances in the larval phase, they are all carnivorous and are generally associated with weed or decomposing plant material (Watson, 1962). Odonata are rarely found in polluted waters (Watson, 1962), and the results of this study suggest that they may also be absent from highly eutrophic waters.

5.4.2.16 Hemiptera

Six species of Hemiptera were recorded from Thomsons Lake, five from both North Lake and Jandabup Lake, three from Lake Monger and two from Lake Joondalup. Waterboatmen or corixids were the most common hemipterans in the lakes. Two species, *Micronecta robusta* and *Agraptrocorixa hirtifrons*, occurred in all five lakes and were most common in Lake Monger and North Lake. A third corixid, *Sigara mullaka*, was only recorded from Jandabup Lake and from North Lake in January. *M. robusta* has previously been recorded from SA, WA, NSW and Victoria. *A. hirtifrons* has been recorded from SA, NSW, Victoria, Queensland and the Northern Territory, whilst *S. mullaka* appears to be endemic to Western Australia.

The backswimmer, *Anisops hyperion*, occurred in all lakes except Joondalup, and was most common in Thomsons Lake were it was recorded at all sites in all seasons. A second species, *Anisops doris*, was only recorded from Thomsons Lake. *Notonecta handlirschi* occurred in Jandabup Lake, North Lake and Thomsons Lake. *Anisops* is the dominant genus of the Notonectidae in Australia, and 25 species have been described. *A. hyperion* has been recorded from SA, NSW, Victoria and Queensland, and *A. doris* has been recorded from NSW and Queensland. *Notonecta handlirschi* is the only member of the genus *Notonecta* in Australia and has only been recorded from Western Australia.

One species of *Mesovelia* was recorded from North Lake and Thomsons Lake. These bugs inhabit the upper surface of the water film rather than the water proper.

Most aquatic hemipterans are carnivorous and feed by sucking the body fluids from their prey (Williams, 1980). All species collected during this study appeared to be carnivorous except *M. robusta* which may be classed as a detrital feeder. Both the Corixidae and the Notonectidae are strong fliers and can readily colonize both permanent and temporary waterbodies.

5.4.2.17 Coleoptera

The Coleoptera was the second most dominant order of insects present in the lakes. A total of 16 species were collected, with 11 recorded from Thomsons Lake, eight from Jandabup Lake, five from North Lake, four from Lake Monger and two from Lake Joondalup. The Hydrophilidae and the Dytiscidae were the two most common families, comprising seven and six species respectively. No species was common to all five lakes, and only one species, a larval hydrophilid, occurred in four of the five lakes. Both adults and larvae of the Dytiscidae and larvae of the Hydrophilidae are usually voracious predators, whilst the adults of the Hydrophilidae, Haliplidae, Hydrochidae and Curculionidae are usually herbivores. Despite their importance in terms of species richness, little is known of the life cycles of virtually all the species recorded here, and lack of taxonomic studies meant that only the dytiscids and adult hydrophilids could readily be identified.

5.4.2.18 Diptera

The Diptera was the dominant order of insects in the urban wetlands, and a total of 17 species were recorded from the five lakes: 14 from Thomsons Lake, 12 from Jandabup Lake, nine from North Lake, seven from Lake Monger and six from Lake Joondalup. The most diverse and abundant family was the Chironomidae: 11 species were recorded from Jandabup Lake, eight from both Thomsons Lake and North Lake, seven from Lake Monger and six from Lake Joondalup. Four species were common to all five wetlands: *Chironomus australis, Dicrotendipes conjunctus, Polypedilum nubifer* and *Procladius villosimanus*. One species, *Lundstroemia parthenogenetica*, occurred only in Jandabup Lake. Species diversity in North Lake and Lake Monger may be lower because they are regularly sprayed with a pesticide (Abate) for the purpose of midge control. Low species diversity in Lake Joondalup may be due to a combination of reasons; the presence of metaphyton and regular spraying of portions of the lake with Abate for the control of midges.

The number of species of chironomids recorded from the urban wetlands (13) is amongst the highest recorded in Australia so far. Previously Bunn (1983) recorded 19 species in the Kemerton wetlands; Maher and Carpenter (1984) recorded 12 species from two wetlands in NSW; Timms (1980) recorded 5 to 7 in eastern Australian lakes; and Fulton (1983) recorded 20 species from lakes on Tasmania's Central Plateau.

All species collected during this study may be classed as detrital or algal feeders except *P.villosimanus* which is predatory.

Ceratopogonids, which are the predatory larva of a biting midge or sandfly, were fairly common in Jandabup Lake, North Lake and Thomsons Lake, but were absent from Joondalup and Monger. The other dipterans, a tabanid (March fly larva), a stratiomyid and a culicid (mosquito larva and pupa) were only found in Thomsons Lake.

5.4.2.19 Trichoptera

Five trichopteran or caddisfly species were recorded in this study. North Lake contained the most diverse caddis fauna with four species, two species were present in Thomsons Lake, Lake Monger, and Jandabup Lake, and one species in Lake Joondalup. Three of the five species; *Triplectides australis, Notalina fulva* and *Oecetis* sp. belong to the Leptoceridae which is one of the largest trichopteran families in Australia. *T. australis* is a widespread species which occurs in slow flowing rivers and lentic waters throughout Australia (Morse and Neboiss, 1982), and has previously been recorded in WA by Bunn (1983). Ecnomids and hydroptilids have also been recorded in WA by Bunn (1983).

5.4.3 MACROINVERTEBRATE ABUNDANCE

Considerable variation in the abundance of the macroinvertebrate fauna was evident both between lakes and between seasons (Figure 37). The relative lack of fauna in Lake Joondalup may be explained by the reason already suggested for the reduced species richness, the presence of metaphyton. Low numbers in Jandabup Lake compared to Monger, North and Thomsons may reflect the lower nutrient status of the former.

Abundances in all lakes were generally lowest in autumn when water levels had been low for several months. This may be due to the stresses posed to aquatic life by lowered lake volumes and the associated features of elevated ion and nutrient levels and high summer water temperatures. Higher densities in one of the temporary lakes, Thomsons, compared with the other, Jandabup, were probably due to the presence of aquatic weed (*Myriophyllum salsugineum*), which provided both food and shelter in the former. Numbers increased as the lakes filled, and the maximum number of individuals were recorded from Jandabup, North and Monger in January, and from Thomsons in both July and January. The maximum density (mean number of individuals/m^3) recorded at each site is given in Table 12.

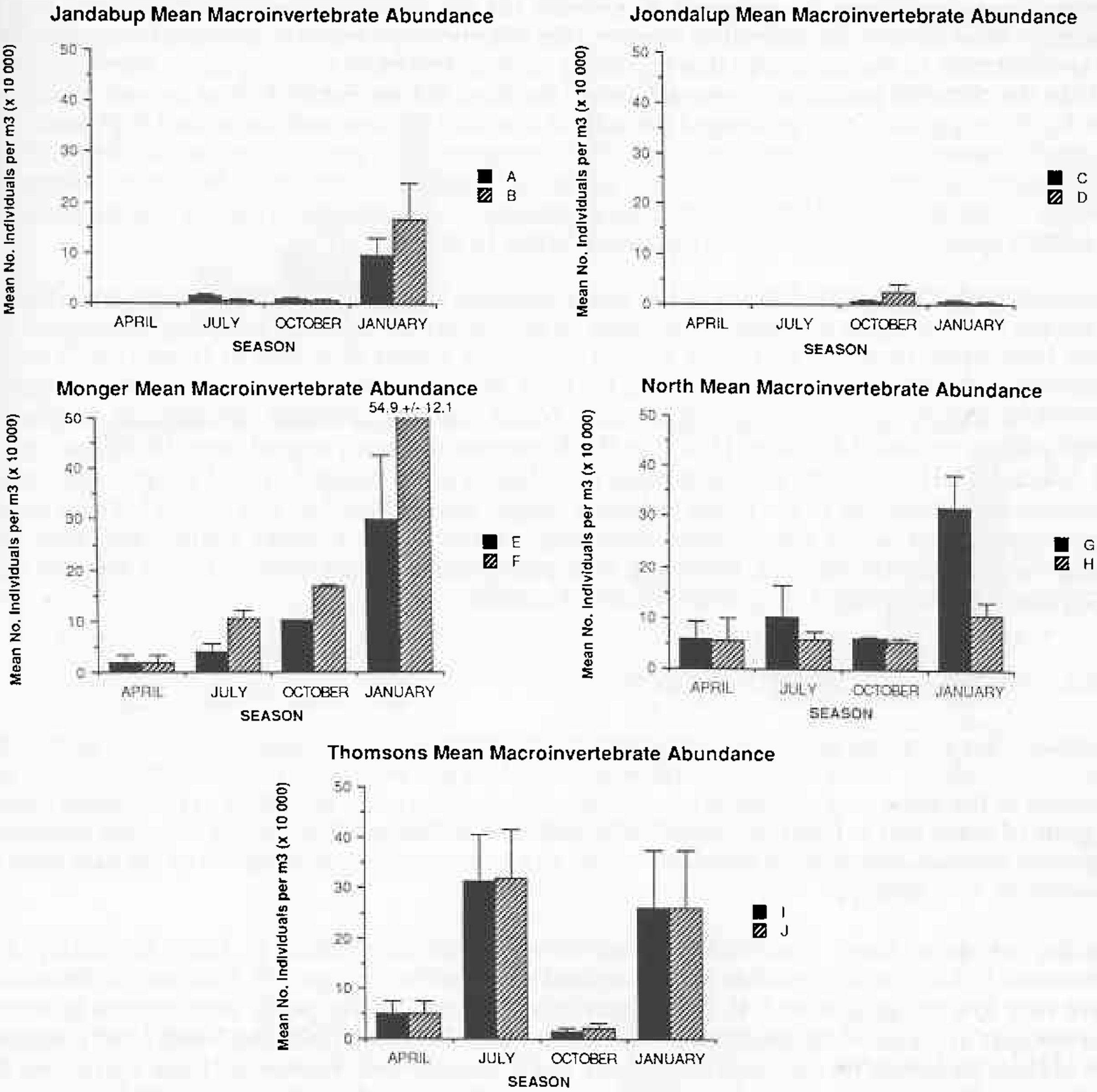

Figure 37: Seasonal changes in mean macroinvertebrate abundance at two sites (represented by black and cross-hatched shading) in each of the lakes studied, from April 1985 to January 1986. Vertical bars show the standard error associated with the mean.

Table 12. Maximum macroinvertebrate abundance (mean number of individuals per m^3) recorded per site in the five wetlands studied from April 1985 to January 1986.

Maximum mean number of individuals/m^3 +/- one standard error.	Monger	Thomsons	North	Jandabup	Joondalup
	549 501 +/- 121 252	321 784 +/- 93 777	320 329 +/- 65 190	168 677 +/- 70 959	25 643 +/- 16 173

Different patterns of change in faunal abundance were observed within each lake. In Joondalup densities were highest in spring and summer and lowest in autumn and winter, although it may not be valid to interpret data from a system where densities overall were very low. In both Jandabup and North Lake densities in summer (January) were markedly higher than densities on the three other sampling occasions. Densities in Lake Monger steadily increased from a minimum in autumn (April) through winter and spring to a maximum in summer (January). A bimodal distribution was present in Thomsons Lake with peaks in the fauna occurring in winter and summer, and lower numbers in autumn and spring.

Several hypotheses can be proposed to account for the large increases in faunal densities in summer. Most simply, the decreased summer lake volumes may result in increased concentrations of invertebrates in the same way that increased ionic and nutrient concentrations were observed. Unlike the chemical parameters however, faunal densities did not remain high at the end of summer (in April), suggesting that prolonged periods of low lake volume and associated high ionic and nutrient concentrations combined with high temperatures, are deleterious to invertebrate populations. Alternatively or in addition, peaks in faunal abundance may be due to changes in species composition within the invertebrate communities and changes in the life history phases of dominant species. These factors are discussed further in the section 5.4.5.

Comparisons of faunal abundance in the urban wetlands with those in lake systems elsewhere in Australia or overseas is not possible because of the variety of different sampling techniques that have been used. However two other studies conducted within WA, that of Bunn (1983) on the Kemerton wetlands and DeHaan (1986) on the Lake Muir wetlands, did employ the same sampling procedure and so some comparison is valid. Mean macroinvertebrate abundances (excluding zooplankton) recorded by Bunn (1983) in the Kemerton wetlands ranged from 18 200/m^3 to 81 300/m^3. DeHaan (1986) recorded mean abundances of 54 000/m^3 to 235 000/m^3 (excluding zooplankton). Densities in the urban wetlands ranged from 300/m^3 to 549 500/m^3. These results demonstrate that while some urban wetlands on the Swan Coastal Plain have very low macroinvertebrate abundances, reflecting their poor environmental quality, others are very high compared to other wetland systems in Western Australia.

5.4.4 ZOOPLANKTON ABUNDANCE

Although the sampling techniques employed in this study were primarily designed to sample the macroinvertebrate fauna of the littoral zone, zooplankton were also caught and so sorted and counted in the same way. However, zooplankton tend to be more abundant in the deeper central regions of lakes and at night, so the material collected in this study probably does not accurately represent wetland zooplankton populations, and as a consequence interpretation of the data must be undertaken with caution.

Similar trends to those observed for macroinvertebrate abundance in Lake Joondalup and Thomsons Lake were also evident in the zooplankton densities (Figure 38). Numbers in Joondalup were very low (ranging from 0 to 7 646 individuals/m^3) whilst two peaks were present in winter and summer in zooplankton densities in Thomsons Lake. Jandabup Lake and North Lake contained the highest densities of zooplankton, whilst Lake Monger and Thomsons Lake contained the highest numbers of macroinvertebrates. Zooplankton densities in Jandabup and North Lake steadily increased as the lakes filled from autumn to summer, whilst densities in Monger and Thomsons remained fairly constant after an initial rise in winter.

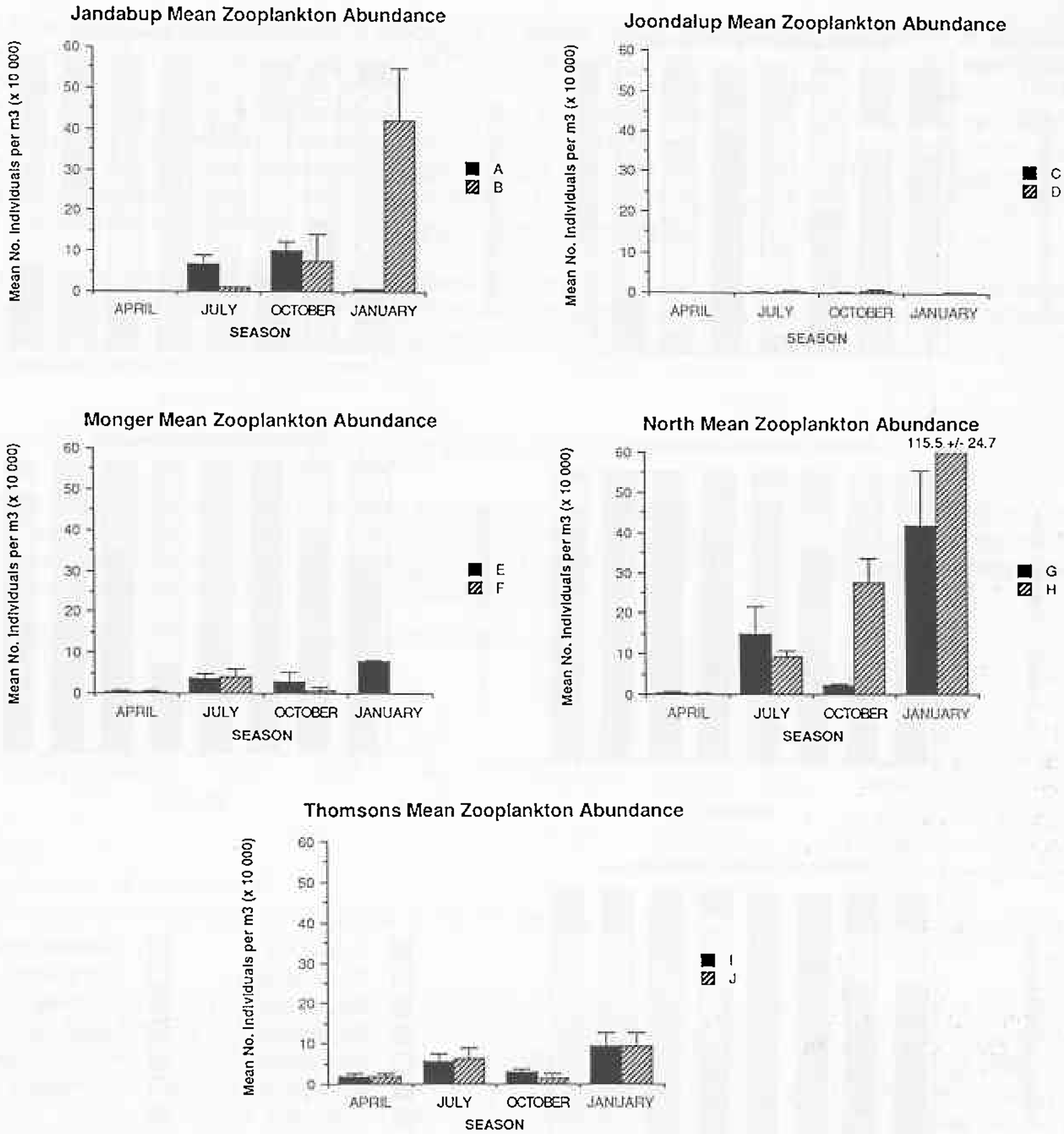

Figure 38: Seasonal changes in mean zooplankton abundance at two sites in each of the lakes studied (represented by black and cross-hatched shading), from April 1985 to January 1986. Vertical bars show the standard error associated with the mean.

5.4.5 MACROINVERTEBRATE COMMUNITY STRUCTURE

Ostracods, chironomids and amphipods were generally the most abundant members of the macroinvertebrate fauna in all lakes except in Joondalup and Jandabup at some sites and in some seasons, but the percentage species composition varied considerably between the five lakes and between seasons (Figure 39). Ostracods were absent from Jandabup in April and within the low numbers of animals that were present at this time, the Chironomidae and the Oligochaeta were the dominant taxa. Site differences were evident at Jandabup with ostracods being the dominant taxon at the sandy site (A) in winter and spring, and chironomids being the dominant taxon at the diatomite site (B) in winter, spring and summer. Jandabup was the only lake at which the Coleoptera comprised a major component of the fauna, and this was at site B in January.

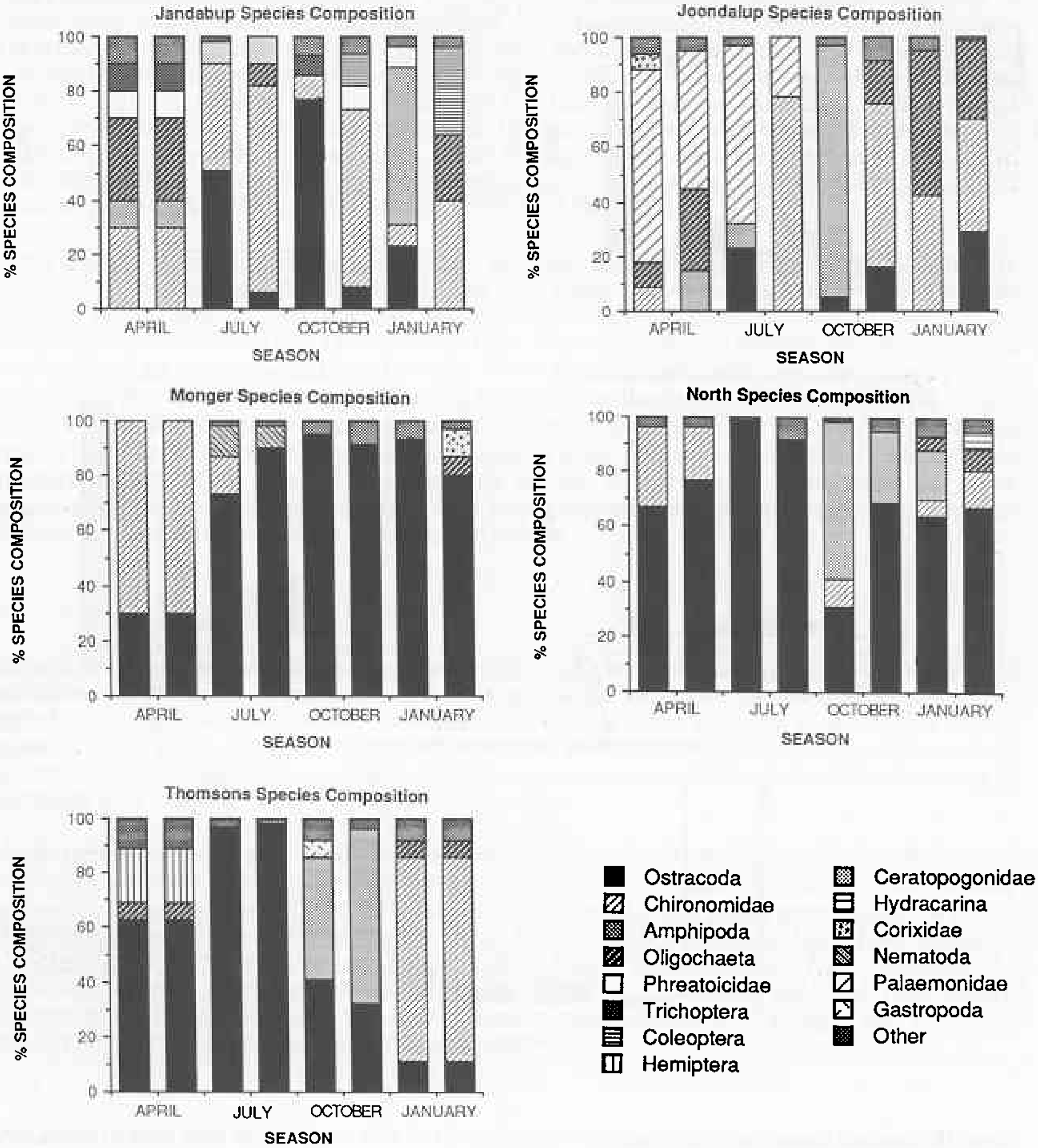

Figure 39: Seasonal changes in species composition based on faunal abundance at two sites (represented by adjoining columns) in each of the lakes studied, from April 1985 to January 1986. Groups comprising less than 5% of the total faunal abundance at each site were placed in the "other" category.

A decapod, the shrimp *Palaemonetes australis*, was the dominant member of the fauna at Joondalup in autumn and at one site in winter but was completely absent from the other four lakes. Chironomids, amphipods, oligochaetes and ostracods comprised the dominant fauna at Joondalup in spring and summer.

The faunas of both Lake Monger and North Lake were almost totally dominated by ostracods throughout the year. Chironomids were present in higher proportions in autumn, but their absence in spring and summer may be a result of the pesticide spraying programmes that were carried out at both lakes during these seasons specifically for midge control.

In Thomsons Lake ostracods were dominant in winter whilst chironomids dominated in summer. Previously Hembree and George (1978) had noted that ostracod numbers reached maximum densities in the wetlands of the northern Swan Coastal Plain during winter, and Edward's (1964) study of chironomids in Lake Monger revealed that most chironomid species reach maximum densities during summer. The two separate peaks in ostracod and chironomid abundance may explain the two peaks in faunal abundance recorded in Figure 37. A similar shift in dominance from ostracods to chironomids may have been observed in Lake Monger and North Lake if the numbers of chironomids had not been artificially suppressed by the application of Abate.

As a general trend, the relative proportions of ostracods appeared to be inversely related to the relative proportions of chironomids, and to a lesser extent amphipods, in all five lakes. Whether this is a result of temporal separation of dominant life history phases or some form of competitive interaction remains to be determined.

5.4.6 SHANNON-WIENER DIVERSITY AND EVENNESS

Diversity indices represent a combined measurement of both species richness and the abundance of individuals of each species, but whether such indices are a valid means of assessing community structure remains an issue of some debate (Peet, 1974; Green, 1979). Certainly the interpretation of diversity indices should be treated with caution.

Shannon-Wiener diversity (H) was calculated for each site at each season, by the formula:

$$H = - \sum_{i=1}^{S} Pi\ (\log_2 Pi)$$

where
S = number of species and
Pi = the proportion of the total sample in the i^{th} species (after Krebs, 1985)

Seasonal changes in H were evident in each lake but the pattern of change for each was different (Figure 40). The highest diversities were recorded from Jandabup Lake, and a site difference was present with a more diverse community present on the peat than on the sand. The inherent association of oligotrophy and high species diversity claimed by Margalef (1964) was used by Fulton (1983) to explain the high diversity observed in oligotrophic Tasmanian lakes, and may equally well be invoked to explain the high diversity in Jandabup Lake. Jandabup Lake was the only urban wetland which approached oligotrophy with respect to the concentration of ortho P.

Diversity in Thomsons Lake steadily increased from autumn to summer with some differences between sites. Diversity in Lake Monger decreased from autumn to spring and increased slightly in summer, whilst diversity in North Lake decreased from autumn to winter and increased from winter to summer. Lake Joondalup may have displayed a similar pattern of change to Monger except for the large increase in diversity at one site at the spring sampling session.

Evenness or equitability (E) was calculated for each site, at each season, by the formula:

$$E = \frac{H}{H_{max}}$$

where H = Shannon Wiener diversity and
H_{max} = the maximum possible diversity = $\log_2 S$
S = number of species

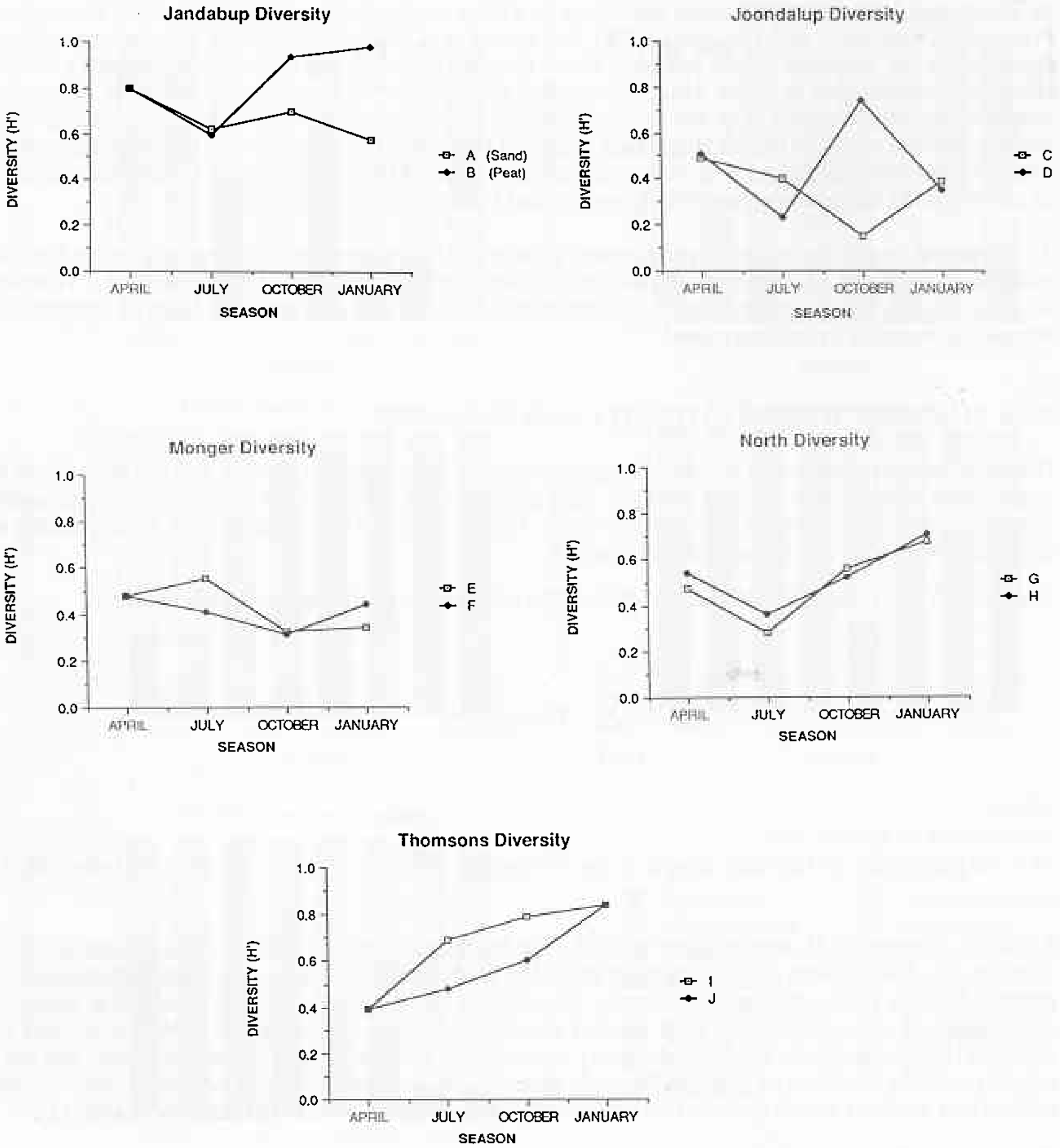

Figure 40: Seasonal changes in Shannon-Wiener diversity (H') at two sites in each of the lakes studied (represented by open and shaded symbols), from April 1985 to January 1986. The diversity index (H') was calculated from the combined results of the six quantitative samples collected at each site.

Evenness in all lakes was low (Figure 41), suggesting that a small number of taxa occurred in very high numbers. The data presented in Figure 39, the percentage species composition for each site at each season, indicates that this is the case with the fauna being dominated by ostracods, chironomids and amphipods.

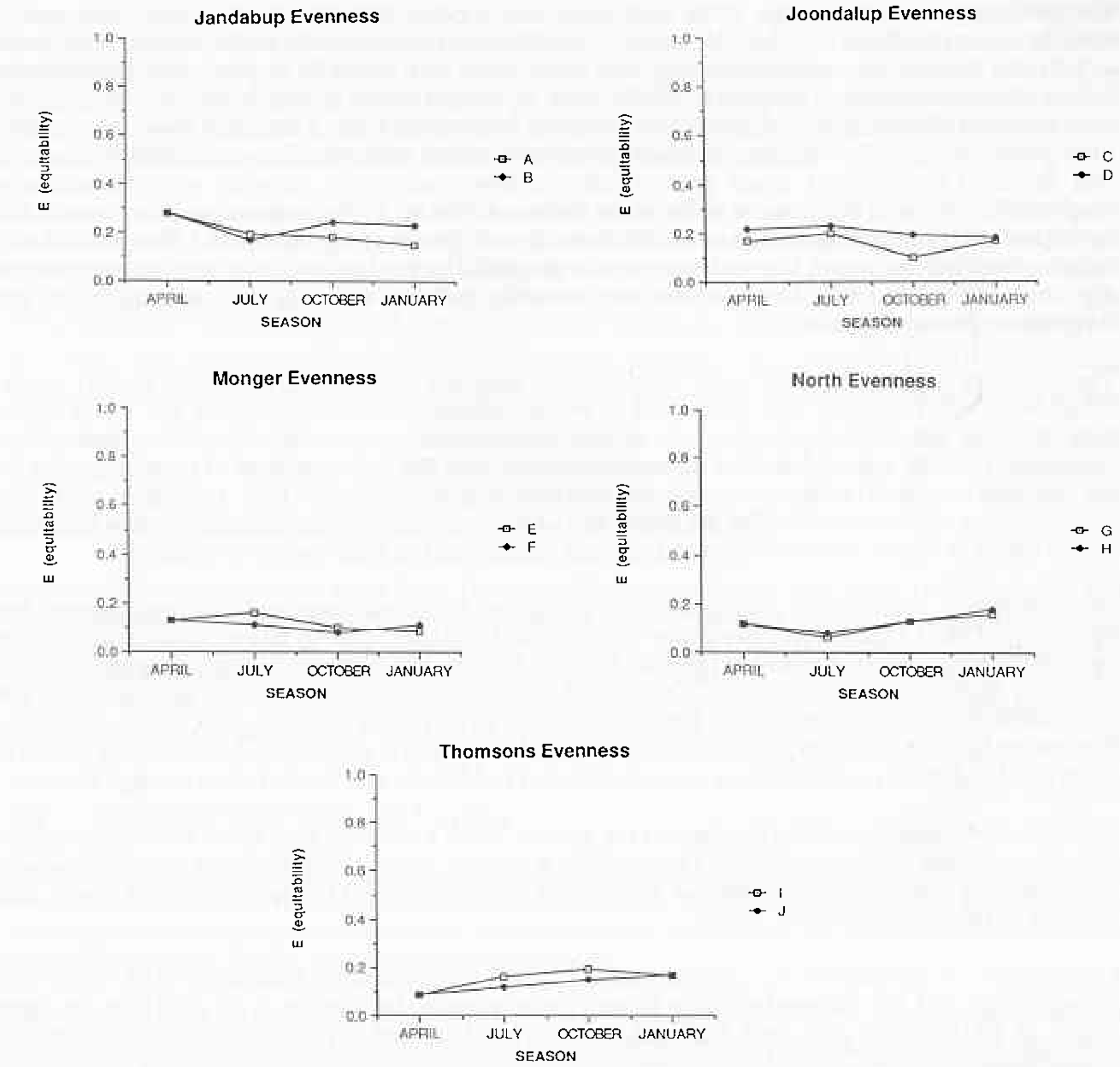

Figure 41: Seasonal changes in species evenness (E) at two sites (represented by open and shaded symbols) in each of the lakes studied, from April 1985 to January 1986. Evenness (E) was calculated from the combined results of the six quantitative samples collected at each site.

6. DISCUSSION

6.1 WATER CHEMISTRY

Seasonal variation in conductivity and the concentrations of Na, Cl, Mg, K, Ca, SO_4, total P and total N was clearly evident in three wetlands ; Jandabup, Joondalup and Thomsons, but less apparent in North Lake and Lake Monger. Concentrations appeared to increase as a result of concentration by evaporation in summer, and decrease as a result of dilution in winter. Seasonality in water chemistry has commonly been observed in wetland studies conducted in Australia and South Africa (Howard-Williams, 1972 ; Congdon and McComb, 1976; Briggs, 1980; Gordon *et al*, 1981; and Briggs *et al* , 1985). The seasonal changes in the two temporary wetlands, Jandabup and Thomsons, seem clearly related to changes in water level, but the reason as to why one permanent wetland (Lake Joondalup) displayed seasonal changes but the two other permanent wetlands (Lake Monger and North Lake) did not, needs further consideration.

The percentage volume change in the three lakes was similar, 55-64% (Table 1), and evaporation must be occurring from all lakes. However, Lake Monger receives extra water from nearby bores as part of a Council management strategy, and North Lake may naturally receive some groundwater inflow through summer (Megirian, 1982), both of which serve to counteract the evaporative concentration effects of high summer temperatures. In contrast, Lake Joondalup appears to receive little groundwater inflow during the summer months, which supports Congdon's (1985) findings that the lake experiences a net groundwater outflow during the summer months, and that evaporation is a major component of the water balance of the lake. The stresses posed to aquatic life by higher salinities and nutrients concentrations do not persist in Jandabup and Thomsons Lake because both lakes dry out, but such stresses do persist in Joondalup, a deeper lake which does not dry completely, and this may explain the severely reduced richness and abundance of the invertebrate fauna of that lake.

These results suggest that low water levels *per se* may not adversely affect water quality in the urban wetlands, but rather that the effects of evapo-concentration coupled with low water levels may result in unacceptably high levels of salt and nutrients in some permanent wetlands. The implication for the management of the urban lakes are that the hydrogeology of each lake must be known, and ion and nutrient concentrations monitored to determine how serious evaporative concentration effects may be. The situation will vary from year to year, because hot dry summers would result in higher conductivities and nutrient concentrations than cooler or wetter ones.

Nutrient levels, in particular orthophosphate levels, are high in the wetlands during summer, but Williams (1980) notes that phosphate and nitrate levels exceed so-called critical levels for eutrophication in many Australian lakes and wetlands, and that Northern Hemisphere criteria may not apply to Australian waterbodies. Certainly the effects of nutrient enrichment are evident in the four lakes that exceed the criteria for hypereutrophy; increased primary production occurs in Thomsons Lake in the form of extensive submerged macrophyte growth; in Joondalup in the form of an algal/sediment ooze known as metaphyton; and in Monger and North Lakes as algal blooms.

High levels of orthophosphate throughout the year in North Lake may be a result of nutrient inflow from the adjacent Veterinary School farm and the Kardinya drain, whilst high and variable levels in Lake Monger may reflect the extensive amounts of fertiliser applied to the surrounding lawns, and the lack of fringing vegetation.

Comparison of the maximum concentrations of total P recorded in Joondalup (195 ug/L) and Monger (964 ug/L) in this study (Table 5) with those recorded by Gordon *et al* (1981) in the same lakes in 1975/76 (70 ug/L and 110 ug/L respectively), reveal twofold and ninefold increases respectively in the two lakes. Comparison of the maximum concentrations of ortho P recorded in this study, 187 ug/L in Lake Joondalup and 690 ug/L in Lake Monger, and those recorded by Gordon *et al* (1981) in 1975/76 (of 40 ug/L in Lake Joondalup and 50 ug/L in Lake Monger) reveal fourfold and fourteenfold increases respectively in the two lakes. These results probably reflect the increasing urbanization of both lake catchments, with an attendant increase in the amounts of garden fertilisers and detergents in the surface run-off, and in the groundwater, entering both lakes.

The mean concentration of total P recorded in Thomsons Lake during winter and spring in this study (54 ug/L) was lower than the winter mean (220 ug/L) recorded by the Cockburn Wetlands Study (Newman *et al*, 1976) for the years 1971-1978. The maximum concentration of 460 ug/L recorded at Thomsons Lake was also lower than the maximum (700 ug/L) recorded by the Cockburn Wetlands Study. The apparent improvement in water quality at the lake may be due to the lake being seasonal for the 10 years preceding this study, whilst it was a permanent lake for the 10 years prior to the Cockburn Wetlands Study. The seasonal drying of the lake bed and oxidation of surface sediments may have resulted in reduction in nutrient cycling in the lake. In addition, the lower mean water levels associated with the seasonal lake appears to have favoured the occurrence of the aquatic macrophyte *Myriophyllum salsugineum*, and an increase in the density of *Typha* at the lake, both of which result in removal of nutrients from the water column. The root system of *M. salsugineum* could increase aeration within the lake sediments, and lead to a reduction in phosphorus exchange between the sediments and overlying water (R. Lukatelich, pers comm).

Mean total phosphorus concentrations recorded in this study (211 ug/L) and the Cockburn Wetlands Study (220 ug/L) for North Lake were similar, whilst the maximum concentration recorded for this study (280 ug/L) was much lower than the maximum concentration recorded in the Cockburn Wetlands Study (700 ug/L). High concentrations recorded in the Cockburn Wetlands Study may have been due to the clearing and fertilising of land to the north of the lake, as part of a project to establish a veterinary farm on the Murdoch University campus.

The maximum concentrations of total N recorded by Gordon *et al.* (1981) in 1975/76 in Lake Joondalup and Lake Monger were 3500 ug/L and 3000 ug/L respectively. The maximum concentrations recorded in this study (Table 4) were approximately three and five times higher respectively. Gordon *et al* recorded maximum concentrations of 1900 and 1100 ug/L for NO_3/NO_2 and 1500 and 2600 ug/L for NH_4 in Lake Joondalup and Lake Monger respectively. In this study only the value recorded for NH_4 in Lake Monger was similar to the 1975/76 value. Values of NO_3/NO_2 in both lakes, and NH_4 in Lake Joondalup, were many times lower in this study than in 1975/76. These results may reflect an increase in nitrogen uptake due to the presence of metaphyton in Lake Joondalup, and extensive algal blooms in Lake Monger. The very low levels of these nutrients in Lake Joondalup and Thomsons Lake suggest that metaphyton and *Myriophyllum* effectively remove NH_4 or NO_2/NO_3 from the water column.

Maximum concentration of total N in Thomsons Lake recorded in this study (17 215 ug/L) was higher than that recorded in the Cockburn Wetlands Study (Newman *et al*, 1976) (15 450 ug/L). Conversely, the maximum concentration of total N in North Lake recorded in this study (6007 ug/L) was lower than the maximum recorded by the Cockburn Wetlands Study (8400 ug/L). Increases in total N in Thomsons Lake during summer may be partially due to nitrogen release from decomposing *M.salsugineum*, the cause of the decrease in North Lake is not known.

6.2 MACROINVERTEBRATE FAUNA

Murkin and Kadlec (1986) recently stated that while there have been numerous studies of invertebrates in lakes (Wetzel, 1975) and streams (Hynes, 1970), little information is available on the nature of invertebrate communities within wetlands, and so few published studies exist with which the study of Perths' wetlands can be compared.

The total of 87 taxa recorded from the urban wetlands is close to the highest number of taxa recorded from Australian lakes, and the total of 62 taxa recorded from Thomsons Lake represents the highest number recorded from a single water body. This may be a consequence of the use of a smaller mesh size for sampling nets and more intensive sampling effort however it does suggest that Timms (1980) claim that the species richness in Australian lakes is lower than species richness of Northern Hemisphere lakes needs to be re-examined for Australian wetlands.The maximum number of species recorded by Timms (1980) was 38 from Lake Purrumbete in Victoria, and 45 from Lake St Clair in Tasmania. Fulton (1983) recorded 48 to 55 taxa in three Tasmanian lakes, but both Fulton's study (1983) and Timms earlier studies (1973, 1974, 1978, 1980a and 1980b) were conducted in much deeper lakes than Perths wetlands (species richness decreases with depth), and sampling was from the profundal zone, not the littoral zone.

Marchant (1982) sampled the littoral zone of five permanent billabongs along Magela Creek (Northern Territory) at monthly intervals for one year. The greatest number of taxa recorded from a billabong was 45 during the late wet season and early dry season, and 18 taxa were recorded at the end of the dry season. A total of 92 taxa were recorded from the billabong system, the oligochaetes were the most abundant fauna but chironomids and ostracods were also dominant. Species numbers in the urban wetlands were slightly lower than those recorded by Marchant (1982), and the importance of the oligochaetes was reduced with ostracods, chironomids and amphipods comprising the dominant fauna. In Western Australia, Bunn (1983) recorded 72 taxa from the Kemerton wetlands. Studies by Ayre *et al* (1977) and Hembree and George (1978) could not be used for the comparison of species richness because identifications had not been made to species level in the former, and species of insects had not been identified in the latter.

Individual elements of the macroinvertebrate fauna of the urban wetlands do not appear to be rare or unique, a conclusion reached earlier by Hembree and George (1978) in their study of the lakes of the northern Swan Coastal Plain. However the associations of species that occur in the wetlands may be considered to be unique. In particular, the wetlands contain elements of a Gondwanaland fauna together with species that may be still undergoing active dispersal between Australia and the Northern Hemisphere. The possibility that the ostracods are still being transferred between wetlands in Perth and in Russia and Japan by migratory waterbirds needs further investigation and suggests an intercontinental link in the ecology of the wetlands previously recognised for migratory waders but not for invertebrates.

The macroinvertebrate fauna of the urban wetlands appears to be well adapted to a cycle of lakes drying and filling. Species richness was highest in Thomsons Lake, a temporary waterbody, and faunal abundances in the lakes peaked in summer as water levels fell. Summer maxima in invertebrate densities may well be an important feature for the waterfowl which arrive at the urban lakes during this time as wetlands further east dry out. An obvious management implication is that seasonal changes in water level and the complete drying of some lakes, is preferable to the maintenance of artificially full lakes in summer if the lakes are to be managed for the aquatic fauna particularly the waterfowl. Briggs and Maher (1985) emphasised the importance of drying and reflooding of waterbodies to invertebrates and waterfowl (this has been stressed by many authors) and suggested that permanent inundation reduces long term plant productivity and prevents the peaks in organic matter availability that occur after flooding, and which enhance invertebrate productivity.

Permanent lakes within the urban region are also needed however, to provide drought refuges for the waterfowl and to act as reservoirs of invertebrates to ensure recolonisation of seasonal waterbodies when they refill following the winter rains.

6.3 TROPHIC STRUCTURE

Wetland ecosystems typically comprise both grazing and detrital food chains (Figures 1 and 2), and knowledge of the relative proportions of the invertebrate fauna which comprise the different trophic levels provides insight into the functioning of a wetland. The dominant fauna of the urban wetlands were detritivores; the ostracods, chironomids and amphipods, and the detrital food chain appears to be the largest and most important pathway for the processing of matter and cycling of energy within Perth's wetlands.

The apparent absence of many of the second order consumers (predators) from Lake Joondalup and Lake Monger, and to a lesser extent North Lake (Table 13), suggests some deterioration of invertebrate food webs within these systems and may be a consequence of the increased nutrient status of these waters.

Table 13. Total number of species of predatory invertebrates recorded from the five wetlands studied between April 1985 and January 1986.

	Thomsons	Jandabup	North	Monger	Joondalup
Number of predatory species	23	17	14	9	5

Dragonflies and damselflies and most water mites, beetle larvae and predatory hemipterans are absent from Joondalup and Monger (Table 9), and occur in reduced species numbers in North Lake. Invertebrate predators represent an important internal means of control of invertebrate numbers within a wetland, and an absence of invertebrate predators suggests that control of populations of nuisance species (such as larval chironomids) by invertebrate predation, must be almost entirely lacking. The absence of most second order consumers may be a direct result of a reduction in light penetration in lakes due to algal blooms associated with eutrophication. Almost all missing species were visual predators and decreased light penetration in Lake Joondalup due to the presence of metaphyton and in Lake Monger because of dense algal blooms (Figure 19), may effectively exclude these species from the two lakes. Alternatively, a large biomass of metaphyton or large algal blooms may severely reduce dissolved oxygen concentrations in wetlands during summer and invertebrate predators with high oxygen requirements may be excluded from such lakes.The fact that all three lakes are treated with the organophosphate pesticide Abate for midge control may also be a cause of the reduction in invertebrate predators, and the exact role of this pesticide on non-target species needs to be elucidated. There is some evidence from a study of Forrestdale Lake that Abate caused a reduction in larval damselfly numbers in that lake (Davis *et al*, 1987).

6.4 HOW USEFUL ARE COMMUNITY DATA FOR THE BIOLOGICAL MONITORING OF PERTH'S WETLANDS ?

While there is much agreement that the use of community data is the best approach to take to the biological monitoring of aquatic systems where a general assessment of environmental quality is required, the actual methods or means of describing community composition and structure and changes thereof are still under debate. Many studies have assessed changes in community structure by the use of diversity indices, but Bayly and Lake (1979) suggest that species diversity is a confusing concept that refers to two different categories : heterogeneity and heterogeneity indices and species richness and richness indices (after Peet 1974), and that the term species diversity should not be used. Stable and mature ecosystems were considered to display high heterogeneity and high species richness, and pollution was a pertubation that decreased both and resulted in a less stable ecosystem (Bayly and Lake, 1979). However the values of these parameters may change for reasons other than pollution or poor water quality. Community structure is controlled by the physical nature of the habitat as well as by water quality and, for example, the more heterogeneous the habitat the higher the number of species that may be present per given area (Campbell, 1982).

Although the Shannon-Wiener index has been widely used, Goodman (1975) suggested that it has no clear biological meaning and that there are no available criteria for precisely measuring community diversity under natural conditions. Bayly and Lake (1979) concluded that species richness and heterogeneity are often reduced by pollution, and so may be used as indicators of environmental quality. However, they recommended that monitoring programmes should include more than one index and present as much of the primary data as possible.

In this study the low values for species richness recorded from Lake Joondalup and Lake Monger compared to those recorded from Thomsons Lake, Jandabup Lake, and North Lake (Table 10) are considered to indicate that the environmental quality of these two lakes is poor. Species richness appears to be a useful means for assessing environmental quality in the urban wetlands. The highest values for the Shannon-Wiener index were recorded from the lakes with the highest species richness, but variability in this index both between sites and between seasons indicate that it may not be a useful as a consistent measure of wetland environmental quality.

Determination of trophic structure and comparison of the number of species of predatory invertebrates within each wetland (Table 13) also appears to be a useful means of assessing environmental quality. Loss of predatory species at the top of the invertebrate food chain reflects a major deterioration in these chains. Some index of trophic structure other than the total numbers of species in each trophic group is desirable. The ratio of the total numbers of species of herbivores to detritivores to predators in each lake is given in Table 14. This may be a suitable index but further work is required to determine the robustness of these ratios. Changes in the abundance of organisms in each trophic group is not a useful parameter because all the lakes were dominated by detritivores, which generally comprised more than 90% of the total fauna on all sampling occasions.

Table 14. Ratio of the total number of species of herbivores to detritivores to predators recorded in the five urban wetlands studied from April 1985 to January 1986.

	Thomsons	Jandabup	North	Monger	Joondalup
Ratio of H:D:P	1:6:6	1:5:5	1:4:4	1:3:2	1:6:2

Both species richness and trophic structure can be costly parameters to measure because of the need to identify large numbers of invertebrates.The use of only one invertebrate order or family would be less time consuming, and so less costly, because a fewer number of specimens would be involved. This approach would be similar to that of the use of "indicator organisms". Jones and Walker (1979) defined an indicator organism as one whose tolerance to a particular pollutant is known, and whose distribution and abundance indicates the extent of contamination by that pollutant. They also noted that the mere presence of an organism is an indicator that certain environmental conditions exist, because it implies that at least the minimal requirements for the species are met. The absence of a species is a less useful criterion because it may reflect one or more of a number of factors, and so cannot be attributed to a specific pollutant (Jones and Walker, 1979). The concept of indicator organisms, *per se* , was not a relevant one to this study because the presence of specific pollutants was not assessed. However, the idea that the presence of species belonging to certain groups may be used as a general indicator of the environmental quality of a wetland is one which warrants further attention.

Watson (1962) noted that larval Odonata (dragonflies and damselflies) are rarely found in polluted waters, and the results of this study suggest that larval Odonatans are absent from wetlands with the combined factors of high nutrient levels and reduced light penetration. The numbers of species of larval Odonata recorded from each lake between April 1985 and January 1986 are given in Table 15. The virtual absence of Odonata from Lake Joondalup (0 species) and Lake Monger (1 species) supports other data, including low species richness and reduced numbers of predatory invertebrates, which indicates that the environmental quality of these two lakes is poor. The highest number of Odonata were recorded from Thomsons lake (6 species), and this result reflects both the high species richness and complex trophic structure recorded at that lake. Whether the presence of high numbers of Odonata within wetlands may be considered to be indicative of good environmental quality, and absence or low numbers indicative of poor environmental quality, needs further investigation.

Table 15. The number of species of Odonata recorded from the five urban wetlands studied from April 1985 to January 1986.

	Thomsons	Jandabup	North	Monger	Joondalup
Number of species	6	4	4	1	0

Similarly to the Odonata, the presence of high numbers of species of Coleoptera may be potential indicators of good environmental quality in Perth's wetlands. The total number of species of Coleoptera recorded from the five lakes studied are listed in Table 16. High numbers of coleopteran species occurred in lakes with a high species richness and complex trophic structure, and lakes with low species richness and reduced numbers of predatory invertebrates also possessed low numbers of coleopterans.

Table 16. The number of species of Coleoptera recorded from the five urban wetlands studied from April 1985 to January 1986.

	Thomsons	Jandabup	North	Monger	Joondalup
Number of species	11	8	5	4	2

The Odonata would be an ideal group to use as environmental indicators because their taxonomy is well known, and keys exist to identify virtually all species that may be found in the urban wetlands. In addition, the Odonata have wide ecological tolerances, and so the potential exists for them to occur in all wetlands. The Coleoptera would be less suitable because many species remain undescribed. Further work is needed to determine the exact ecological requirements of each species within each order before a final decision on their suitability as environmental indicators can be made.

The factors most likely to affect the composition and abundance of the macroinvertebrate fauna in the urban wetlands are summarised in Table 17.

Table 17. Possible factors affecting the composition and abundance of the macroinvertebrate fauna of the urban wetlands and their occurrence at each of the wetlands studied.

	Thomsons	Jandabup	North	Monger	Joondalup
Physical disturbance (removal of wetland habitat and fringing vegetation)	-	-	x	xxx	x
Seasonality	x	x	-	-	-
Nutrient enrichment	x	-	x	x	x
Decreased light transparency (as a consequence of nutrient enrichment)	-	-	x	xxx	xxx
Pesticides (and other pollutants)	-	-	x	x	x
Fish predation	-	-	x	x	x

The low species richness and absence of invertebrate predators (including members of the Odonata and Coleoptera) recorded for Lake Monger and Lake Joondalup appears to reflect the various impacts that urbanisation has had on these two lakes (given in Table 17). Experimental work is now required to determine the exact effects that physical disturbance, nutrient enrichment and decreased light transparency, pesticides and predation by native and introduced fish may have on the structure and function of wetland macroinvertebrate communities.

6.5 THE ENVIRONMENTAL QUALITY OF PERTH'S WETLANDS: THE COMBINED RESULTS OF THE CHEMICAL AND BIOLOGICAL SAMPLING PROGRAMMES

The assessment of water quality is dependent upon what the water in question is to be used for, and because no criteria have yet been set for the urban wetlands, the assumption was made in this study that water quality must be sufficient to maintain viable or "healthy" freshwater ecosystems for the preservation of aesthetic values, waterbird habitat, and scientific and educational resources. The chemical and biological parameters measured in each lake between April 1985 and April 1986 are summarised in Table 18.

The results of the chemical monitoring indicate that elevated levels of nutrients (in particular orthophosphate) are present in all lakes, with the exception of Jandabup Lake, and water quality problems associated with eutrophication would be expected to occur in these lakes. Light penetration was reduced in Lake Joondalup due to the presence of metaphyton (an algal/sediment ooze), and in Lake Monger and North Lake as a result of large algal blooms. Nuisance blooms of blue-green algae which resulted in the death of resident ducks and unsightly banks of dead and decomposing algae occurred at North Lake during September and October 1985. Elevated salinities occurred at Thomsons Lake, Jandabup Lake, and Lake Joondalup in summer (January) 1986.

Water quality parameters for the five urban wetlands.

PARAMETER	JANDABUP LAKE	LAKE JOONDALUP	LAKE MONGER	NORTH LAKE	THOMSONS LAKE
Lake Type	Seasonal	Permanent	Permanent	Permanent	Seasonal
pH	Acidic	Alkaline	Alkaline	Neutral-Alkaline	Alkaline
Salinity (winter)	Fresh	Fresh	Fresh	Fresh	Fresh
(summer)	Fresh	Fresh	Fresh	Fresh	Saline
Ortho - P (winter)	O-mesotrophic	M-eutrophic	Eutrophic	H-eutrophic	M-eutrophic
(summer)	M-eutrophic	H-eutrophic	H-eutrophic	H-eutrophic	H-eutrophic
Nitrate/nitrite (winter)	U - oligotrophic	U-oligotrophic	U-oligotrophic	O-mesotrophic	O-mesotrophic
(summer)	Eutrophic	U-oligotrophic	U-oligotrophic	Eutrophic	U-oligotrophic
Chlorophyll a (spring)	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic
(summer)	M-eutrophic	Eutrophic	Eutrophic	Eutrophic	Eutrophic
Light Transparency	100%	Reduced	Reduced	Slightly Reduced	100%
Primary Production	Algae	Metaphyton	Algae	Algae	Sub. Macrophytes
Organic content (bed)	< 5%-35%	40%-80%	<10%	< 5%-60%	40%-55%
Species richness (min/site)	10	5	12	19	23
(max/site)	25	18	21	27	31
(total/lake	49	24	40	55	62
Macro. Abund (autumn)	Low	Low	Medium	Medium	Medium
(summer)	Medium	Low	High	High	High
Zoo. Abund (autumn)	Low	Low	Low	Low	Low
(summer)	High	Low	Low	High	Medium
Diversity H (autumn)	High	Medium	Medium	Medium	Low
(summer)	High	Medium	Low	Medium	High
Evenness (a & s)	Low	Low	Low	Low	Low
Trophic Structure	Complete	(-) Predators	(-) Predators	Red. Predators	Complete
Dominant Trophic Group	Detritivores	Detritivores	Detritivores	Detritivores	Detritivores

Table 18: Summary of the physico-chemical and biological water quality parameters measured at the lakes studied in 1985/1986. Minimum (winter or autumn) and maximum (spring or summer) values are given where determined. Categories of macroinvertebrate and zooplankton abundances are defined as follows:

Low = < 5 000 individuals/m^3

Medium = 10 000 - 25 000 individuals/m^3

High = > 25 000 individuals/m^3

O - mesotrophic = oligomesotrophic, M - eutrophic = mesoeutrophic, H - eutrophic = hypereutrophic

U - oligotrophic = ultraoligotrophic

The results of the faunal (biological monitoring) component of the study indicate that environmental quality of Jandabup Lake and Thomsons Lake is high, moderate in North Lake, and poor in Lake Joondalup and Lake Monger. Low species richness in Lake Joondalup and Lake Monger compared with the numbers of species recorded in Thomsons, Jandabup, and North Lakes, suggests that the poor water quality (as revealed by chemical monitoring) in these two lakes has resulted in a reduction in the invertebrate fauna. The almost total absence of one of the trophic groups (the invertebrate predators) from both lakes, indicates that food chains within the lakes are disrupted, and as a consequence the freshwater ecosystems of both lakes must be classified as degraded, with an attendant loss of some of the lakes aesthetic, scientific, and educational values.

The extremely low species richness and abundance in Joondalup indicate that the environmental quality of the lake is very poor despite the fact that conductivities and ionic and nutrient concentrations are not very different to those recorded in other lakes. Lake Joondalup experiences summer peaks in ionic and nutrient concentrations but, because of greater depth does not dry out, and this appears to result in conditions that are unfavourable to all but the most tolerant of organisms, for example the shrimp *Palaemonetes australis* . The presence of large amounts of metaphyton and the lack of predatory invertebrates also indicate water quality problems at the lake, which if left unmanaged may result in further deterioration of the lake ecosystem and complete loss of the lake's social values.

Lower species richness and a reduced number of predatory invertebrates, massive algal blooms and very high nutrient levels, all indicate that water quality in Lake Monger is poor. The reduced number of predatory invertebrates, consistently high phosphorus levels, and nuisance blooms of blue-green algae in North Lake indicate some problems with water quality, but the higher species richness suggests that these problems have not reached the magnitude of those in Lake Joondalup or Lake Monger.

High species richness during winter, spring and summer and complete invertebrate grazing and detrital food chains in Jandabup Lake and Thomsons Lake indicate that the environmental quality of both lakes is high. Both are nature reserves and have extensive zones of fringing vegetation. The importance of the fringing vegetation, which acts as a buffer between the lakes and the nearby urban and rural developments, and creates considerable diversity within the lake ecosystem, is immense.

The results of this study indicate that a knowledge of macroinvertebrate species richness alone, if measured on a seasonal basis will provide a means for assessing environmental quality within urban wetlands. In addition, knowledge of the composition and trophic structure of the macroinvertebrate community will provide important information on the state of wetland food chains. The possibility of using the presence/absence of members of single macroinvertebrate orders (such as the Odonata and the Coleoptera) as environmental indicators needs further investigation, because such methods may provide a means of simplifying biological monitoring programmes.

Neither biological nor chemical monitoring should be conducted in isolation, but rather both methods need to be incorporated into a single programme for the assessment of the environmental quality of wetland ecosystems. The information provided by the measurement of a range of physical, chemical, and biological parameters, such as those listed in Table 18, provides both a comprehensive evaluation of water quality and some knowledge of the type of processes that may be occurring within each wetland ecosystem. It is an understanding of wetland processes rather than monitoring alone which will ultimately lead to better wetland management.

7. IMPLICATIONS FOR MANAGEMENT

A set of water quality criteria must be established for the urban wetlands and a water quality management programme set up to ensure that the aesthetic, wildlife conservation, environmental, scientific, and educational values of wetlands are maintained. A monitoring programme should be undertaken to ensure that the criteria are being met, if not for all wetlands in the metropolitan region, at least for those considered to be most important or most under threat.

A combined chemical and biological monitoring programme incorporating the measurement of conductivity and nutrient concentrations and an assesment of macroinvertebrate species richness, community composition and trophic structure, or the presence or absence of certain environmental indicator groups, at regular seasonal, or twice yearly (summer and winter) intervals would provide the basis for an effective and cost efficient wetland water quality monitoring programme.

To determine the likely effects of decreased water levels the hydrogeology of each lake must be known, and conductivy and nutrient concentrations monitored (as suggested above) to determine how important evapo-concentrative effects may be.

Summer drying of some lakes may be beneficial because it removes the stresses posed to aquatic life by the high salinities and nutrient levels at that time, it may also reduce nutrient cycling within a wetland and provide the peaks in organic matter, after reflooding, which enhances both invertebrate and waterfowl productivity. However, some permanent water bodies must be retained as drought refuges and faunal reservoirs.

Eutrophication (or nutrient enrichment) is a problem in urban wetlands and the sources of nutrients need to be identified and reduced where possible. The effect of inflow from stormwater and other drains on wetland water quality needs to be assessed.The effects of pesticides on wetland ecosystems, whether applied directly to a wetland for midge control or indirectly received from areas where pesticides are applied to homes for termite control and to household gardens or to market gardens, is an issue of concern that needs more investigation. The fact that activities in the catchment as a whole and not just the immediate wetland environs may have an enormous affect on wetland water quality must be recognised by all agencies involved in wetland management.

The presence of a buffer zone of fringing sedges on the margins of a lake appears to be of considerable value in the maintenance of good environmental quality in wetland ecosystems and the preservation of such zones and replanting (where needed and where feasible) is urged.

Jandabup Lake and Thomsons Lake have high scientific value and every effort should be made to ensure that the protection they have received as Nature Reserves is not reversed by the increasing pressures of urban development in the northern and southern metropolitan regions. Lake Joondalup, Lake Monger and North Lake all have water quality problems and need active management, in particular a reduction of nutrient inputs, to prevent loss of the lakes' aesthetic and wildlife conservation values.

The fact that the urban wetlands are largely resilient systems (probably because much of the flora and fauna is adapted to withstand the stresses of seasonal drying and filling), and the effects of poor water quality appear to be reversible, suggests that it is not too late to design and implement water quality management programmes for many of the urban wetlands already experiencing water quality problems.

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