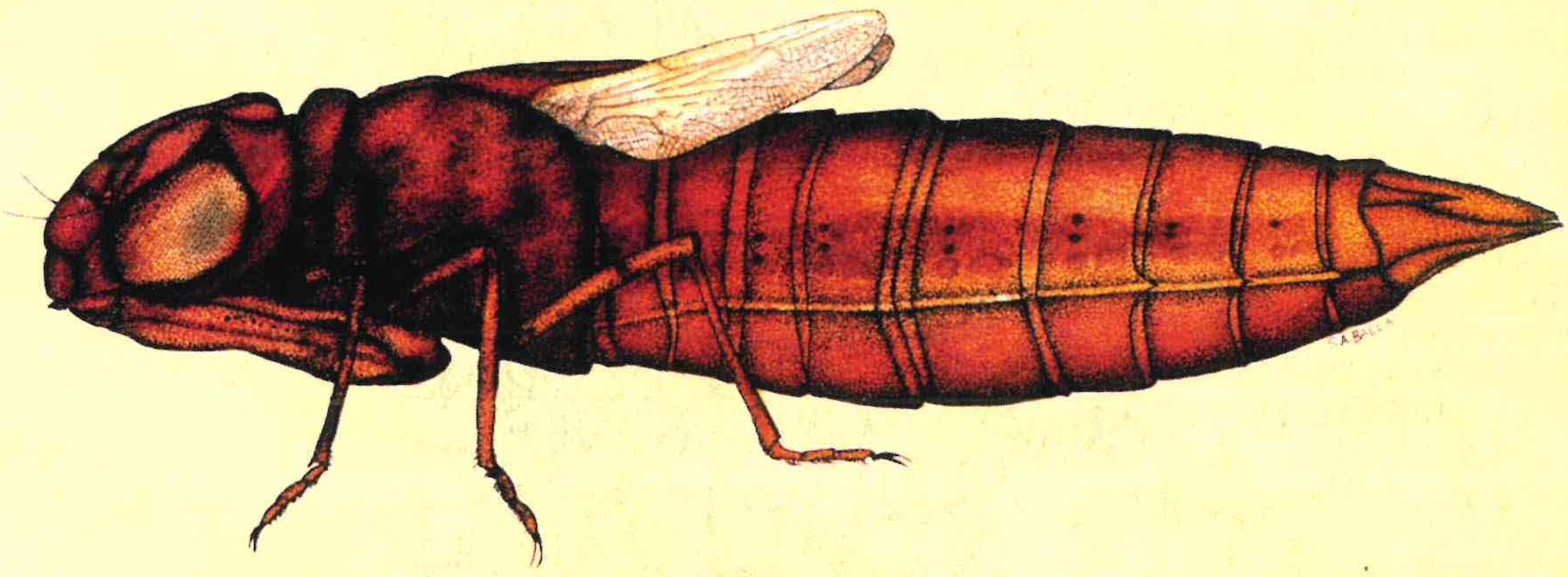
WETLANDS OF THE SWAN COASTAL PLAIN

Volume 5



Managing Perth's wetlands to conserve the aquatic fauna.

S A Balla and J A Davis

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Water Authority of Western Australia

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AN ENVIRONMENT WORTH PROTECTION

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Contents

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Executive summary

Aquatic invertebrates were collected from six wetlands on the Swan Coastal Plain near Perth, Western Australia, every three weeks between August 1988 and September 1989. The aim was to obtain information on the impact of changing wetland water levels, nutrient enrichment and the presence of fish on the aquatic invertebrate communities.

The wetlands are surface expressions of a superficial unconfined aquifer and receive inputs from the groundwater and runoff from surface catchments. The mediterranean-type climate, in concert with the existence of the unconfined aquifer, profoundly shapes the character of these wetlands. The seasonal changes from winter wet to summer drought affords a predictable annual cycle; only the length of the wet and dry seasons varies. Water levels peak in spring (September–October) and are lowest in autumn (March–April).

The seasonal wetlands near Perth are dry for four or five months each year when rainfall is average, and up to six or eight months from December to August when rainfall is below average. Water is only consistently present in the seasonal wetlands from August to the end of November; a period of about 120 days. None of the invertebrates were found to have larval phases that were longer than this and most were less than half this period. The timing of drying is determined by the level of the groundwater which is dependent on the quantity of the previous years rainfall. The rate of drying is relatively slow compared to the rate of refill, and drying can occur between December and April. The timing of refill is determined by the beginning of the winter rains. Refill is rapid and can occur between April and July.

The six wetlands represented a small subset of the numerous wetlands on the Swan Coastal Plain and encompassed a range of depths, pH, conductivities, nutrient levels and water colours. As the physical and chemical characteristics of the wetlands changed through the seasons, so did the invertebrate communities. The fauna in the less enriched wetlands differed between wetlands, while the communities in the hypertrophic wetlands were more similar to eachother. A total of 176 taxa, over 5.9 million individuals weighing more than 240kg were collected from these wetlands. High species richness was associated with seasonal drying either of the entire wetland or over a substantial portion. In addition, the well vegetated wetlands had a higher species richness. Invertebrate abundance was highest in the presence of either green algae or cyanobacteria. Higher invertebrate biomass appeared to be associated with nutrient enrichment, however, the larger, heavier invertebrates may require the presence of aquatic macrophytes, since the highest biomass occurred in wetlands with both cyanobacterial blooms and abundant macrophytes.

The information gathered in this study was insufficient to properly ascertain the impact of fish on the invertebrate communities. Field experiments are recommended to further assess the influence of fish.

Only a few (about 3%) taxa require permanent wetlands, and all of these are non-mobile. However, over 27% of the taxa require water when the seasonal wetlands are dry, and these are mobile animals with short-lived non-aquatic adults, or have aquatic adults with no desiccation

resistant stage. Therefore, some permanent wetlands need to be conserved for these taxa. Many of the permanent wetlands in Perth were once seasonal wetlands that have become overfilled and hypertrophic due to urbanization. Rehabilitation of these hypertrophic wetlands would render them more suitable as a habitat for a greater number of species.

Reduction of nutrient inputs from drains and revegetation is likely to increase species richness. The high mobility of many species of macroinvertebrates will ensure that they recolonize suitable habitats. About 70% of the fauna has no requirement for water throughout the year because they have either long-lived non-aquatic adults or a desiccation resistant stage. Almost 80% of the taxa are mobile and most of these animals have to ability to disperse to the wetter south-west, or aestivate until the rains begin, because they were not found in the permanent wetlands when the seasonal wetlands were dry.

Fringing terrestrial vegetation around wetlands should be conserved as habitat for animals with non-aquatic adults (e.g. dragonflies) to use for feeding, breeding and shelter. In addition, avian and mammalian fauna are often associated with bush surrounding wetlands.

The primary impact on wetland water levels is rainfall, but groundwater extraction reduces wetland water levels and urbanization increases water levels (and incidentally nutrient levels). In addition to lowering maximum and minimum water levels, extraction also has the potential to reduce the time water is present in the seasonal wetlands and accelerate the rate of drying. The impact of extraction is presently being moderated by reducing extraction near wetlands or by pumping water into wetlands. To conserve the aquatic fauna groundwater extraction should be managed to ensure that drying of seasonal wetlands does not occur before December and the rate of drying should not exceed 2cm/day. Pumping water into wetlands to compensate for extraction should occur in spring if peak water levels have not flooded the fringing vegetation, rather than maintaining a shallow pool in autumn.

The major environmental cost of groundwater extraction and urbanization is loss of wetland habitat. Since approximately 70% of the original wetlands on the Swan Coastal Plain have been lost, it is likely that some species of invertebrates that occur today are remnants of much larger populations. For the larger, predatory taxa where only a few individuals occur in each wetland, the number of wetlands inhabited often determines the size of the population. Further loss of wetlands is likely to reduce population sizes, and may already have led to the loss of species. In addition to conserving the remaining wetlands generally, attention to conserving a mosaic of wetland types is essential to maintenance of species diversity. The less obvious swamps and damplands probably support more aquatic flora and fauna than the lakes and are extremely valuable wetland habitats and should be the focus of future research. While information is being gathered on the range of wetland types in relation to vegetation and aquatic fauna existing on the Swan Coastal Plain, the best medium term approach is to conserve as much wetland habitat as possible. In the long term, conservation of Swan Coastal Plain wetlands requires that limits to population growth in Perth be addressed.

1 Introduction

The subject of this report is the effects of changing water levels and nutrient enrichment on the aquatic invertebrates communities that inhabit the wetlands of the Perth metropolitan area. Like many urban wetlands throughout the world, the wetlands of the Perth metropolitan area are a focus of conflict. The management of these wetlands for the purposes of conservation, water supply, drainage and recreation, has created problems of sufficient magnitude to require information on their ecology. The purpose of this research is to provide information that will contribute to the management of these wetlands to conserve species diversity.

Climate and geology

The wetlands studied in this project lie on the Swan Coastal Plain in the south-west of Western Australia, and are a result of a fortuitous combination of climate and geology. The Swan Coastal Plain extends from Geraldton, southwards for 550km to Dunsborough.

The climate of south-western Western Australia is loosely equivalent to that of the Mediterranean Basin with a hot, dry summer and a cool, moist winter (Dell *et al.* 1986). As described by Main (1986), the seasons represent:

1. a long decline in the quality of the environment through summer,
2. an abrupt transition from summer drought to winter wet and cold,
3. a relatively short (shorter than summer decline) improvement in the environmental quality culminating in spring,
4. a gradual turn-over from spring to summer.

Rainfall is highly seasonal with 90% occurring between April and October. The average annual rainfall for Perth is 870mm and Class A pan evaporation is 1819mm. Evaporation exceeds precipitation in all months except the period between May and August. Rainfall is variable from year to year with a maximum of 1339mm and a minimum of 507mm recorded in 1945 and 1940 respectively (Ventriss 1989).

Below the Swan Coastal Plain is a heterogenous, unconfined aquifer which varies in composition vertically and laterally. The aquifer is recharged from rainfall which 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. Wetlands occur in interdunal depressions within these three dune systems and along the boundaries between adjacent dune systems (Cargeeg *et al.* 1987) and are surface expressions of this unconfined aquifer.

Groundwater and wetlands

The groundwater originates from rainfall and seawater trapped during former high sea levels. Rain falling on the land surface infiltrates the soil. When the amount of rain exceeds attractive forces in the soil, water moves under gravity from the partially saturated zone to a saturated zone in the formation underlying the soil. The upper surface of the zone of saturation is the water table and water in the zone of saturation is referred to as unconfined groundwater (Allen 1981).

Infiltration occurs over most of the Coastal Plain. It is depleted by vegetation which utilizes water from both the unsaturated and saturated zones. Where the water table is deep, 30% of the rainfall may reach and remain as groundwater; in areas where the water table is shallow, most of the rainfall which reaches the water table may be used by the vegetation (Allen 1981).

The groundwater moves under gravity down a gradient toward discharge areas around the coast and in low-lying areas occupied by wetlands and rivers. In coastal areas the outflowing groundwater overlies a wedge of saltwater which tapers inland (Allen 1981). The rate of groundwater movement in the flow system is controlled by the gradient of the water table and by the size and degree of interconnection of void spaces in the water bearing formation. Flow varies from about 0.01 to 100m/year (Allen 1981).

As groundwater moves through the saturated zone beneath the Coastal Plain it is depleted by evapotranspiration from the water table and from wetlands. In the northern Perth area the water table forms a mound reaching an elevation of about 70m above sea level beneath the Bassendean Dunes. This is referred to as the Gnangara Mound. In the southern Perth area a mound about 25m above sea level occurs beneath the Bassendean Dunes near Jandakot and is called the Jandakot Mound. Other minor groundwater mounds occur within the coastal strip at Cottesloe, Bicton, Rockingham and Baldivis. Elsewhere, the water table has a general slope to the west toward the sea or major rivers (Allen 1981).

The wetlands of the coastal plain can be divided into two broad categories; those which contain water permanently and those which are seasonally dry. The Coastal Plain loses two thirds of its wetlands in summer, autumn and early winter as a result of evaporation (Seddon 1972), while the remaining third must support those animals that require a permanent source of water for survival.

The importance of the urban wetlands for both wildlife conservation and for their social values as areas of open space within the city is significant (Arnold and Wallis 1987). The wetlands are the most biologically productive areas of the Swan Coastal Plain and directly or indirectly support most of the wildlife (Seddon 1972). For brevity, the time when water is not present in the wetlands will be called the "drought period". The length of this drought period varies from year to year.

Impacts on wetlands

1. Wetland loss

Since European settlement, more than 200,000ha of wetland have been destroyed (Seddon 1972). In 1955 there was 7879ha of seasonal wetlands and 6155ha of permanent wetlands. In 1966 there remained only 2806ha of seasonal and 1449ha of permanent wetland (Seddon 1972). Arnold and Sanders (1981) concluded that over 50% of wetlands had been lost to landfill or drainage. In an earlier, formal study of wetland loss Riggert (1966) calculated that by 1966, 49% of wetlands on the Coastal Plain between Yanchep and Rockingham had been drained, filled or cleared, 31% between Rockingham and Harvey had been lost and 96% had been lost between Harvey and Busselton. Riggert's figures included areas like the Swan River and Peel–Harvey Estuary that contain a lot of open water so that theoretically at least, he probably underestimated loss of small wetlands. On the basis of a recent aerial survey Halse (1988) concluded that 70% of wetlands have either been lost or drastically modified by clearing of vegetation. The process is continuing despite the increasing biological importance of these wetlands as inland areas become saline (Halse 1987), with the most recent estimate of 80% loss of wetlands by Godfrey (1989).

2. Urbanization

Although the urban wetlands are usually connected to the water table, surface run–off provides a substantial contribution of water (e.g. Congdon 1985). The overfilling of wetlands following urbanization and clearing for agriculture have both resulted in a rise in the water table and increased surface run–off into wetlands. Urbanization disturbs the long term equilibrium achieved by the unconfined aquifer. Following clearing and urbanization, three factors contribute to a rise in the water table; decreased transpiration and interception of rainfall by vegetation, the addition of imported waters by septic systems and irrigation, and increased recharge from shedding areas (roads, roofs and paths). The last factor is the most significant (MacFarlane 1981). Williamson and Cole (1976) have estimated that recharge under a typical urban block is almost 4 times as great as that for Bassendean sands in the Gnangara area. Of this recharge, septic tanks contributed 21%, excess irrigation 15% and enhanced recharge from shedding areas 27%. The remaining 37% resulted from rainfall. The final water level equilibrium will depend upon a number of factors, particularly housing density, the quantity of water extracted by bores and the type of sewerage and drainage system adopted (MacFarlane 1981). Changes in wetland water levels have significant environmental consequences. Wetland ecosystems are particularly sensitive to water level changes. The result has been the destruction of wetland vegetation such as paperbarks and native rushes as well as the introduction of exotic weed species. Many wetlands are now deeper and contain water for a longer period than in their natural state prior to urbanization. Dead trees in wetlands such as Blue Gum Swamp and Lake Claremont are evidence that these permanent swamps previously dried or had lower water levels.

3. Pollution

Pollution of groundwater from septic tanks is a significant problem. Currently, 45% of Perth's households have septic tanks and the sands which underlie Perth do little to prevent the septic effluent from leaching into the groundwater (Atwood & Barber 1988). Nitrates enter the groundwater as they are not attenuated by any of the soils. Phosphates are fixed in Spearwood and Quindalup sands, but there capacity is finite, and once this is exceeded, they also reach the groundwater (Whelan *et al.* 1979). Bacteria and viruses have been shown to be capable of travelling at least 0.8m in Perth sands (Parker *et al.* 1979), and could enter the superficial groundwater. An estimated $25x10^6m^3$ of effluent is discharged annually into the Perth sands, contributing 2200 tonnes of nitrogen and 440 tonnes of phosphorus to the groundwater each year (Whelan 1987). Cleaning solvents used in septic systems may also cause significant contamination although they are not monitored Atwood & Barber (1988). Over fertilized domestic gardens can have a nutrient input to the groundwater as well. Atwood & Barber (1988) estimated that 5000 tonnes of fertilizer is applied annually to Perth gardens. Of that, 250 tonnes of nitrogen and 100 tonnes of phosphorus infiltrate into the groundwater (Whelan 1987). One hectare of vegetables in leaching sands could contribute more than 500kg of phosphorus and 2,000kg of nitrogen per year to the groundwater (Luke 1987).

Stormwater from urban runoff also presents a threat to the groundwater from nutrients, heavy metals, oil and polycyclic aromatics (Bliss *et al.* 1979). Some recent urban developments are using local wetlands as sumps for stormwater, which are connected to the groundwater, ensuring further inputs of nutrients, oils and greases to the groundwater from runoff (Bishaw 1980). The quality of water from the initial storm flushes can be worse than raw sewage (Sartor & Boyd 1972). For example, 80% of phosphorus load entering North Lake came from stormwater washing in fertilizers Bayley *et al.* (1989).

Excessive pumping from bores may cause intrusion of saline or contaminated water into useful aquifers as been observed in some riverside areas after several dry years (LaBrooy 1981).

Chemical spills from vehicles using residential streets, and leachates from waste disposal sites (including ammonia, heavy metals and salts are also entering the groundwater and wetlands (Hedgcock & Moritz 1989). All of these potential pollution sources can be individually significant and collectively cause considerable stress to the groundwater resource. Polluted groundwater can cause wide-ranging degradation to wetlands as well as terrestrial ecosystems (Hedgcock & Moritz 1989).

4. Groundwater extraction

The unconfined aquifer also supplies water to the city of Perth in conjunction with streams flowing from the Darling Scarp. The growth of Perth has resulted in an increasing demand for water from these streams and the unconfined aquifer. Many streams have been extensively dammed to supply Perth's increasing population because they are relatively inexpensive sources of water and further dams are planned (e.g. Davis *et al.* 1988a,b). Currently, groundwater supplies 60-70% of the total domestic and industrial water for Perth.

Management of Perth's groundwater resources is undertaken in accordance with the concept of sustainable yield (Webster 1989) as defined under the State Conservation Strategy (Department of Conservation and Environment 1987). Groundwater currently contributes 1/3 of the total water supply and is expected to continue to produce 1/3 of public supply over the next 25 years (Webster 1989). By the year 2000, based on current trends, it is estimated that total water consumption in the Perth metropolitan region could be close to $550x10^6m^3$/annum of which $350x10^6m^3$ could come from groundwater resources. Water levels of the wetlands vary seasonally with the height of the water table (Allen 1981). As groundwater is increasingly extracted, the level of the water table will drop and wetlands would become increasingly shallow and eventually dry completely unless rainfall increases substantially.

Climatic change due to the Greenhouse Effect

Due to climatic changes induced by the Greenhouse Effect it is possible that Perth will experience hotter conditions during summer for longer periods, accompanied by dry easterly winds. With diminishing water resources, lowered groundwater levels and much increased costs of available water, large reticulated gardens would eventually become unaffordable for many. Additional use of private bores would further contribute to local drawdown eventually rendering many too shallow, and therefore, obsolete. Public agencies and local authorities would be under pressure to continue pumping to maintain parks, sports grounds and landscaped areas thereby placing additional pressure on available supplies. In addition, saline intrusion might be expected in coastal and estuarine locations and the wetlands would be severely stressed or disappear altogether. Massive dieback of large trees and both native and exotic vegetation could be expected (Singleton 1989).

Research needs

The problem of limited water availability has already produced a situation of competition for water between people and wetlands. Responsibility for management of this limited groundwater resource lies with the Water Authority. The Water Authority supplies water for public consumption, actively encourages water conservation and is responsible for drainage and groundwater extraction. Both drainage and groundwater extraction have impacts on wetland ecosystems. The responsibility for protection of the wetlands mainly lies with the Environmental Protection Authority, although specific wetlands are the responsibility of the Department of Planning and Urban Development, Local Government Authorities and the Department of Conservation and Land Management. Even if the population of Perth increased no further and drawdown of the groundwater was not necessary, current theory concerning the greenhouse effect suggests that the climate of the Perth region will become drier and this will have consequences for Perth's wetlands.

If wetland water levels are to be artificially maintained, a thorough knowledge of the biological requirements of the flora and fauna of these wetlands is needed. Water requirements for ecosystem maintenance often relate to timing, duration and quality of water rather than to quantity alone (Western Australian Water Resources Council 1987). To ensure the survival of healthy and diverse invertebrate communities, information on species utilization of the permanent and seasonal wetlands is needed along with information about the requirements of inhabitants of seasonal wetlands. Perth's urban wetlands are shallow waterbodies (generally 1–2m deep) and water level changes of greater magnitude or duration than the normal seasonal variations may present a serious stress to wetland ecosystems.

This research is part of a suite of five projects examining various aspects of groundwater levels in wetland ecosystems (see Volumes 2–7 in this series). This study and that on the wetland vegetation will provide guidelines for managing water levels to maximize species diversity. The wetland classification and waterbird use studies will allow identification of wetland types, while the groundwater study will provide information on the movement of water and nutrients and ultimately assist in catchment management. Environmental management criteria are needed along with a better understanding of wetland ecosystems so that accurate predictions of the impacts of water level variations can be determined and appropriate groundwater management strategies may be developed (Sinclair *et al.* 1981). Ultimately, the information obtained in this and the other four studies will be used to define environmental critera and develop strategies for managing Perth's wetlands.

Objectives

The purpose of this study was to gather information to aid in the management of wetland water levels. Particular attention was focused on the role of permanent and seasonal wetlands in supporting different invertebrate species. The underlying assumption was that the goal of managing the wetlands is to conserve the maximum species diversity. Aside from wetland loss, the problems for the wetlands are either that the water levels have been lowered by extraction and may become lower due to the greenhouse effect, or they are unnaturally high because of urbanization and land clearing. Unnaturally high water levels are almost always associated with nutrient enrichment and other pollution (e.g. pesticides). Very few wetlands in metropolitan Perth, seasonal or permanent, do not experience some nutrient enrichment. It was unrealistic to consider the impact of altered water levels without addressing the role of nutrient enrichment. Therefore, in addition to considering the quantity and duration of water in these wetlands, it was also important to investigate the role of water quality in maintaining healthy invertebrate communities.

Another incidental factor associated with urbanization is the introduction of the exotic mosquitofish which has the potential to significantly modify invertebrate communities (see Lloyd *et al.* 1986). Other factors were recognized as possibly influencing invertebrate communities such as the colour of the water, wetland size and salinity. However, these factors are less amenable to manipulation for the purpose of management and were not included in the design of the project.

The project aims were:

1. To compare invertebrate species richness and community composition in
    a. seasonal and permanent wetlands
    b. nutrient enriched and less enriched wetlands
    c. wetlands with and without fish
2. To obtain life history information on individual species:
    a. How long are the aquatic stages of the life cycles of the invertebrates
    b. When are the invertebrates present in the wetlands?
    c. How do species in seasonal wetlands survive the dry period?

Six wetlands were chosen for investigation. Four of these wetlands were of particular interest to the Water Authority of Western Australia and the Environmental Protection Authority. These four wetlands are designated as reserves for conservation; Thomsons Lake, North Lake, Jandabup Lake and Nowergup Lake. Based on information obtained by Davis & Rolls (1987) and Rolls *et al.* (1990), it was anticipated that two of these wetlands (Thomsons Lake and Jandabup Lake) would dry, while the other two were permanent wetlands. Wetlands that have been given the status of reserves are management priority areas and this reflects their high biological value. Bird counts have been the basis for their classification as reserves. While all of these wetlands are affected by groundwater extraction, Jandabup Lake and Nowergup Lake receive groundwater inputs from specially constructed bores to maintain water levels during the drought period. Water levels in North Lake are unnaturally high due to urbanization (specifically, vegetation clearing and stormwater drains). In addition to these four wetlands, another two were chosen; Bartram Swamp which was expected to dry because of a track which passed through it, and Murdoch Swamp which was permanent.

North Lake and Nowergup Lake were frequently observed with cyanobacterial blooms (blue-green algae), and were previously found to be nutrient enriched (Rolls *et al.* 1990). Thomsons Lake had high levels of nutrients, and Jandabup Lake low levels of nutrients when sampled by Davis & Rolls (1987) and Rolls *et al.* (1990). Bartram Swamp and Murdoch Swamp had not been studied previously, but showed no signs of nutrient enrichment, and were considered to be likely to have low nutrient levels. Together, the six wetlands provided a design for comparisons of the impact of seasonal drying, nutrient enrichment and the presence of fish on invertebrate communities.

3 seasonal wetlands (Jandabup, Bartram, Thomsons)	3 permanent wetlands (Murdoch, Nowergup, North)
3 nutrient enriched (Nowergup, North, Thomsons)	3 less enriched (Jandabup, Bartram, Murdoch)
3 with fish (Jandabup, North, Nowergup)	3 without fish (Bartram, Murdoch, Thomsons)

The location of these wetlands is shown in Figure 1.1. Comparison between groups was planned with nested analyses of variance, with samples replicated within seasons. In addition, fish were to be removed from Jandabup Lake by allowing the wetland to dry in a second year of sampling as a field experiment. Bartram Swamp was to be used as a control in this second year, and also for examining interannual variation in the timing and abundance of individual species.

Unfortunately the project design was thwarted by unforseen human and climatic intervention. Although Jandabup Lake became very shallow, the water level was artificially maintained by the Water Authority and the wetland did not dry. Thomsons Lake had dried each year for the previous decade, but did not dry in the year of invertebrate sampling (1988–89) or the following year. In addition, the nutrient levels in Bartram Swamp and Murdoch Swamp were higher than expected. Finally, public opposition to the drying of Jandabup Lake eliminated the possibility of examining the impact of fish on the invertebrate community in this wetland. Consequently, this study became primarily descriptive rather than experimental, relying on life history information obtained on the macroinvertebrates. The data was analysed with classification and ordination techniques and comparisons between wetlands were made with Scheffe's multiple contrasts. These results were then used to formulate environmental criteria and management strategies.

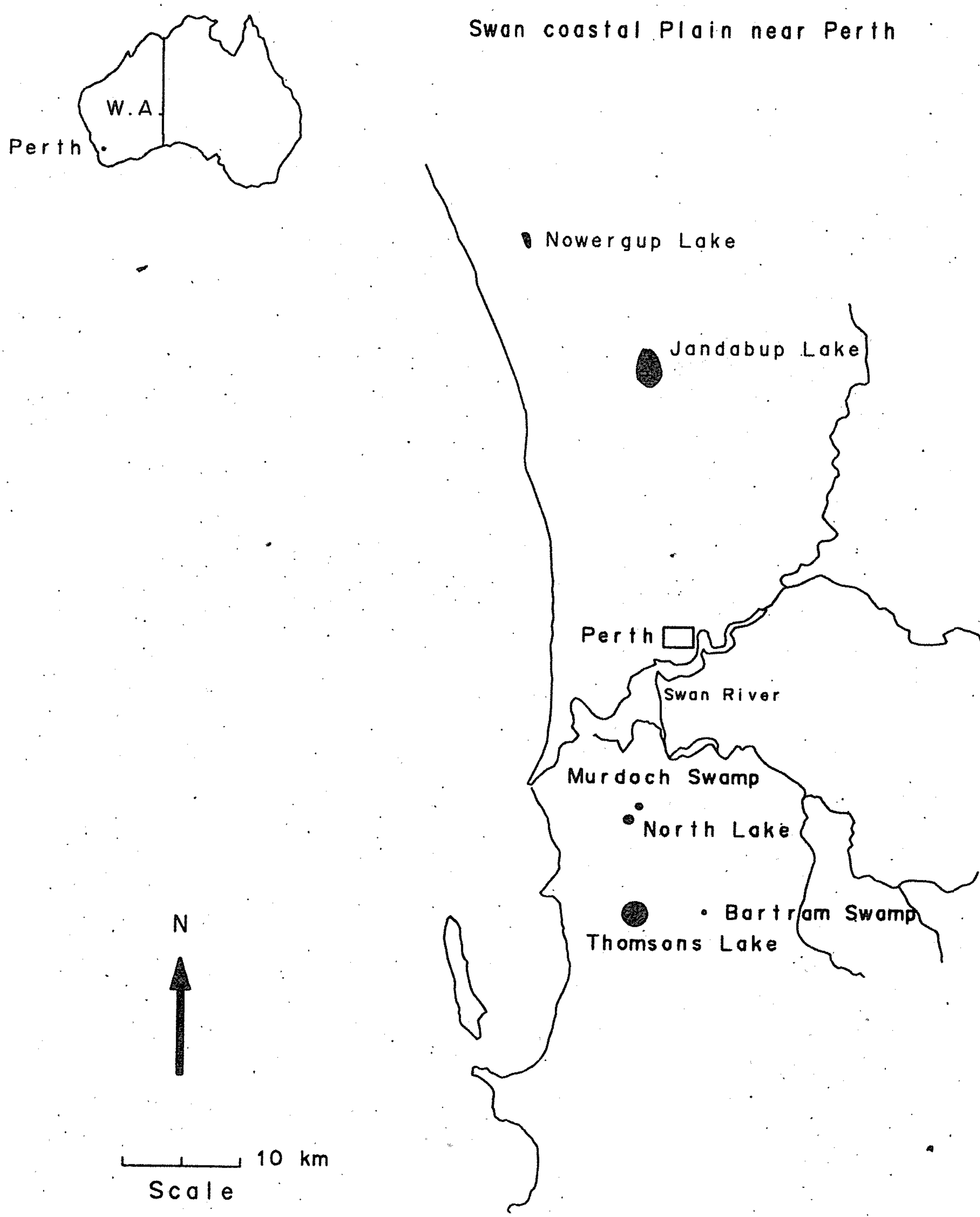

Figure 1.1 Location of the six wetlands

2 Literature review

Introduction

This chapter reviews the literature pertinent to this research. The groundwater resources of the Swan Coastal Plain near Perth are evaluated, and the likely extent of future water shortages is defined. Since the most economical solutions to water shortages entail wetland loss, the current mechanisms operating to conserve the wetlands are explored. Many of the wetlands are naturally seasonal, but if groundwater extraction increases these wetlands are likely to contain water for shorter periods of time. The impact of seasonal drying on invertebrate community structure is reviewed and evidence of adaptations of macroinvertebrates to seasonal drying is documented. However, increased drying is not the only problem created by the increasing population of Perth. The use of the urban wetlands as a sump for stormwater and urban run-off has led to overfilling of wetlands and nutrient enrichment. The impact of eutrophication on macro-invertebrate community structure is also addressed. Since fish occur in most of the permanent wetlands the impact of fish on macroinvertebrate communities, and in particular the introduced mosquitofish *Gambusia holbrooki* (Girard), is also reviewed.

The water resource

Between 1829 and 1890 water supplies for Perth were drawn mainly from springs and wells, but pollution from nearby septic tanks was a serious and often deadly problem. The construction of the first artesian well for public water supply was completed in 1897 and subsequent artesian wells were added to meet the needs of the expanding population. The shallow groundwater remained an unattractive source because of its earlier association with disease. Between 1954 and 1973 eight additional deep artesian wells were drilled close to service reservoirs to provide an economical means of meeting the high summer water demands (Caldwell 1981).

Systematic investigations of the aquifers of the Swan Coastal Plain commenced in the early 1960's (Caldwell 1981). The first development of the extensive shallow groundwater resources by the Metropolitan Water Board (now the Water Authority of Western Australia) was Stage 1 of the Mirrabooka Scheme, commissioned in 1970 and further schemes have been constructed at Gwelup, Wanneroo and Jandakot (Stage 1) (Caldwell 1981).

The shallow groundwater system at Jandakot (see Figure 2.1) is characterized by a small water table mound, with groundwater flowing radially outwards to discharge boundaries. Horizontal permeabilities range from 15 to 40m/day while vertical permeabilities are much lower. Recharge is wholly from rainfall. There is a small vertical head gradient through the aquifer which is responsible for a downward flow component (Pollett 1981). The Water Authority's wells and those of many Jandakot landowners draw from the lower part of the shallow aquifer system. This mound has a form of leaky artesian aquifer behaviour. In this case, leakage is sufficiently slow and distributed over such a wide area that no effect has so far been measured at the water table. The significance of the leaky artesian response observed at Jandakot is that land or water "users" (e.g. flora, fauna, wetlands, summer pasture, shallow wells, pits or soaks) which rely on groundwater at shallow depth are likely to be less affected by groundwater abstraction than predicted by groundwater models (Pollett 1981).

Groundwater abstraction from the Jandakot Mound began with the eastern Stage 1 chain of wells commissioned in 1979. In 1989 the Water Authority abstracted $4.0x10^6m^3$/annum from the Stage 1 bores and plans to abstract approximately $4.0x10^6m^3$/annum from a second line of bores. The location of the Stage 1 and 2 abstraction wells on the Jandakot mound are shown in Figure 2.2. About $9x10^6m^3$/annum was consumed by public and private abstraction in 1988. Evapotranspiration from wetlands and vegetation accounts for $25x10^6m^3$ per annum and the Water Authority estimates that $16x10^6m^3$/annum may be abstracted privately without unacceptible detriment to the environment (Water Authority of Western Australia 1991).

The larger Gnangara Mound (Figure 2.1) is a major water resource for Perth. It extends over an area of $2091km^2$ and is estimated to contain $195,000x10^6m^3$ of water. Annual input via rainfall ($1675x10^6m^3$) and water imported from surface sources through the public water supply system ($80x10^6m^3$) is $1755x10^6m^3$. Annual output via evapotranspiration ($1165x10^6m^3$), leakage to underlying aquifers ($107x10^6m^3$), outflow to ocean and rivers ($372x10^6m^3$) and abstraction from wells ($111x10^6m^3$) is $1755x10^6m^3$ (Environmental Protection Authority 1987). Evapotranspiration accounts for 70% of rainfall and consists of a diffuse, widespread loss from plants (57%) and intensive direct evaporation from open water and fringing vegetation of the relatively small areas of

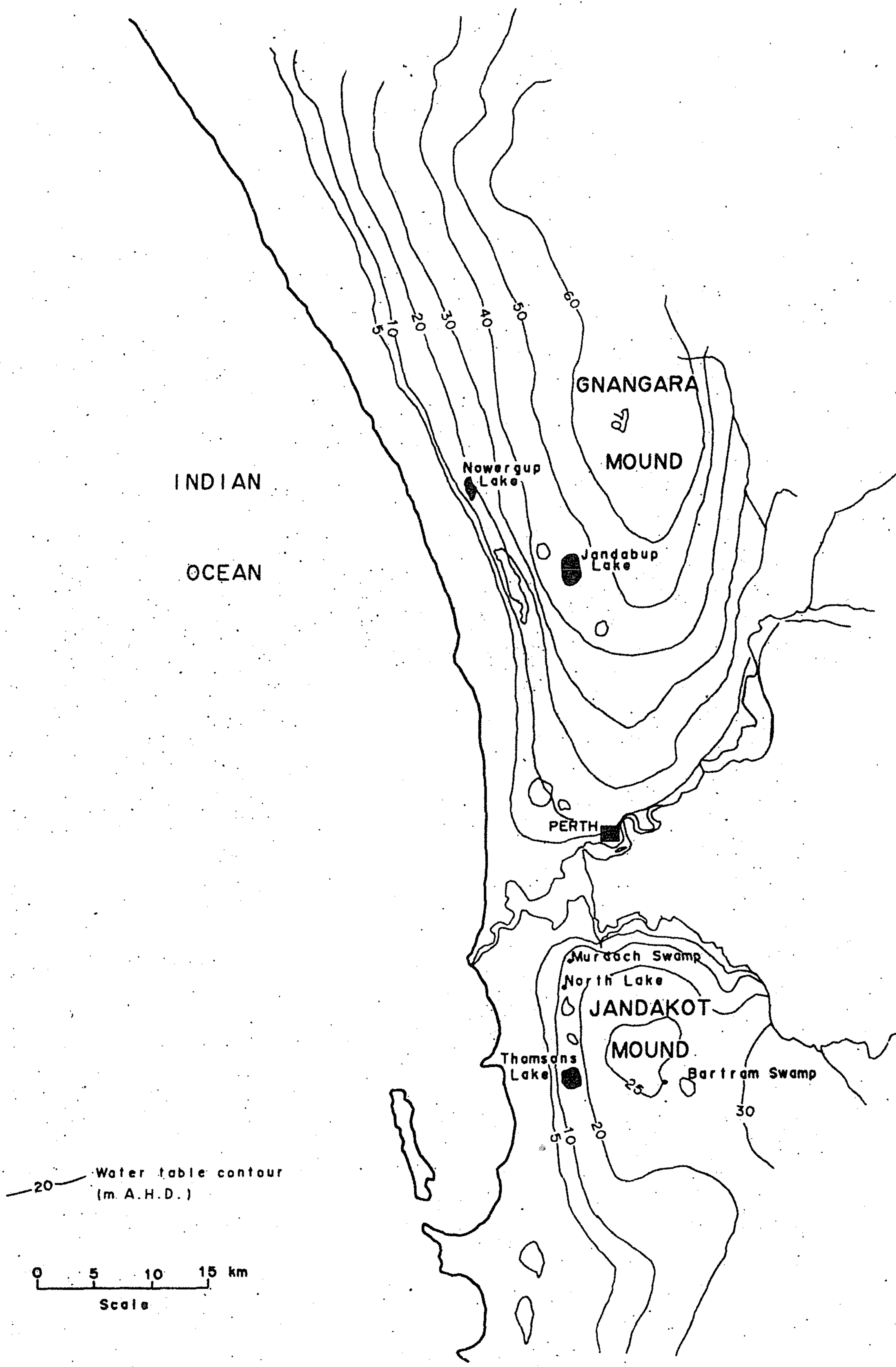

Figure 2.1 Location of the Jandakot and Gnangara Mounds with the six wetlands indicated in black.

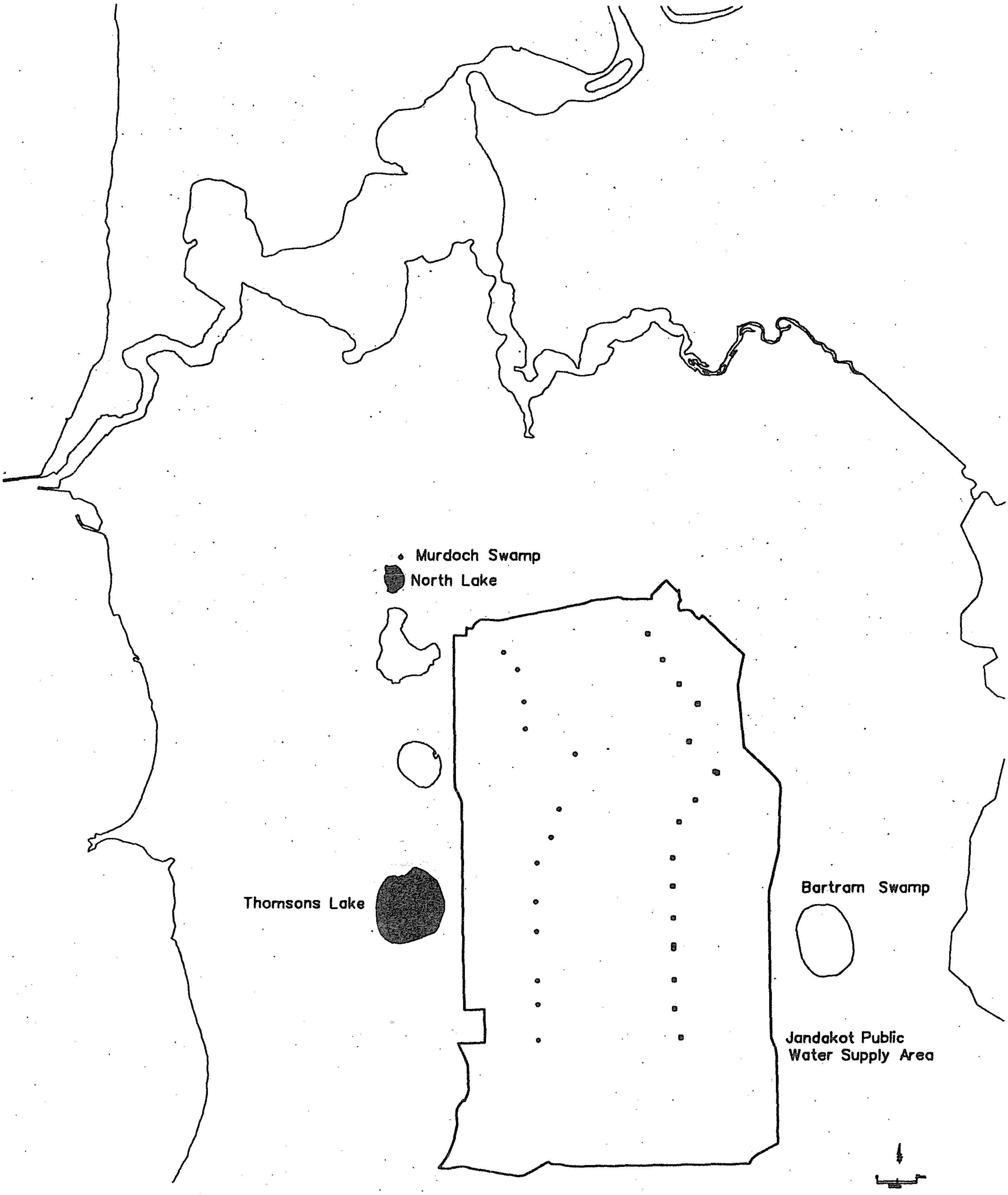

Figure 2.2 Location of Jandakot Stage 1 bores and the proposed Stage 2 and South Jandakot bores.

wetlands (13%) (Environmental Protection Authority 1987).

The groundwater resources of the mound are to be developed further for public water supply as the population of Perth increases. The amount of water that can be obtained from the mound is determined by the desire to limit the impact on the environment, particularly the wetlands (Environmental Protection Authority 1987). Retention of wetlands is the major constraint in managing the groundwater resources of the mound. Without this constraint much more water could be developed for public and private supplies (Environmental Protection Authority 1987). Within the Wanneroo Groundwater Area, quotas take into account the proximity to wetlands and the relationship between groundwater flow and wetlands. On the eastern margin of Lake Jandabup the full quota has now been allocated and in other parts of the Area allocations are approaching their quota (Environmental Protection Authority 1987). Development of water supply schemes on the mound commenced in 1971 when the Mirrabooka Groundwater Scheme began production (production quota: $16x10^6m^3$/annum). This was followed by the Gwelup Scheme in 1974 ($7x10^6m^3$/annum), the Wanneroo Scheme in 1976 ($12.2x10^6m^3$/annum) and the Pinjar Stage 1 scheme in 1989 ($3.2x10^6m^3$/annum) (Environmental Protection Authority 1987 and Water Authority of Western Australia 1989) (see Figure 2.3). Other groundwater schemes which are planned are further Stages of Pinjar ($10.8x10^6m^3$/annum), Lexia ($6.5x10^6m^3$/annum), Yeal ($9.6x10^6m^3$/annum), and Barragoon ($3.5x10^6m^3$/annum). The Water Authority is currently investigating a number of new groundwater schemes in the North West Corridor between Whitfords and Two Rocks. These could provide a further $45x10^6m^3$/annum. Quotas are intended to reflect the sustainable yield of the aquifer within the environmental constraints.

Models of the groundwater have been developed for the Jandakot and Gnangara Mounds. A review of the impact of Jandakot Stage 1 concluded that abstraction had less impact than rainfall on groundwater levels and did not significantly affect groundwater levels in the area (Water Authority of Western Australia 1987). Implementation of Jandakot Stage 2 abstraction and increased urban development over the mound led to a revision of estimates (Water Authority of Western Australia 1991). Estimates of the effect of low rainfall for the years 1977–87, urbanization and groundwater abstraction Stage 1 and 2 are shown in Table 2.1. As a result of the expanding population public water supply extraction should rise from 4 to $8x10^6m^3$/annum, and private extraction should rise from 9 to $16x10^6m^3$/annum (Water Authority of Western Australia 1991). While land clearing and urbanization produces higher water levels (by reducing evapotranspiration and increasing groundwater recharge via increased runoff), groundwater extraction opposes this trend and the result is a mitigation of both effects. Nevertheless, the overall impact of these developments is a predicted decrease in the water table in autumn on the Jandakot Mound wetlands of 0.10m (e.g. North Lake, Forrestdale Lake) to a drop of 0.9m in Twin Bartram Swamp and 1.10m in Solomon Rd Swamp (Water Authority of Western Australia 1991). The size of the decrease is positively

Table 2.1 The impact of Jandakot Mound Groundwater Scheme Stage 1, Stage 2, rainfall and urban development on groundwater levels of the Jandakot Mound.

Wetland	Rainfall	Urbanization	Stage 1 Extraction	Sub-Total	Stage 2 & Urbananization
North Lake	0	+0.6m	-0.35m	+0.25m	-0.10
Thomsons Lake	-0.5m	0	-0.25m	-0.75m	-0.50
Bartram Swamp	?	0	-0.40m	-0.60m?	<-0.15?
Murdoch Swamp	?	0	-0.60m	-0.60m	?

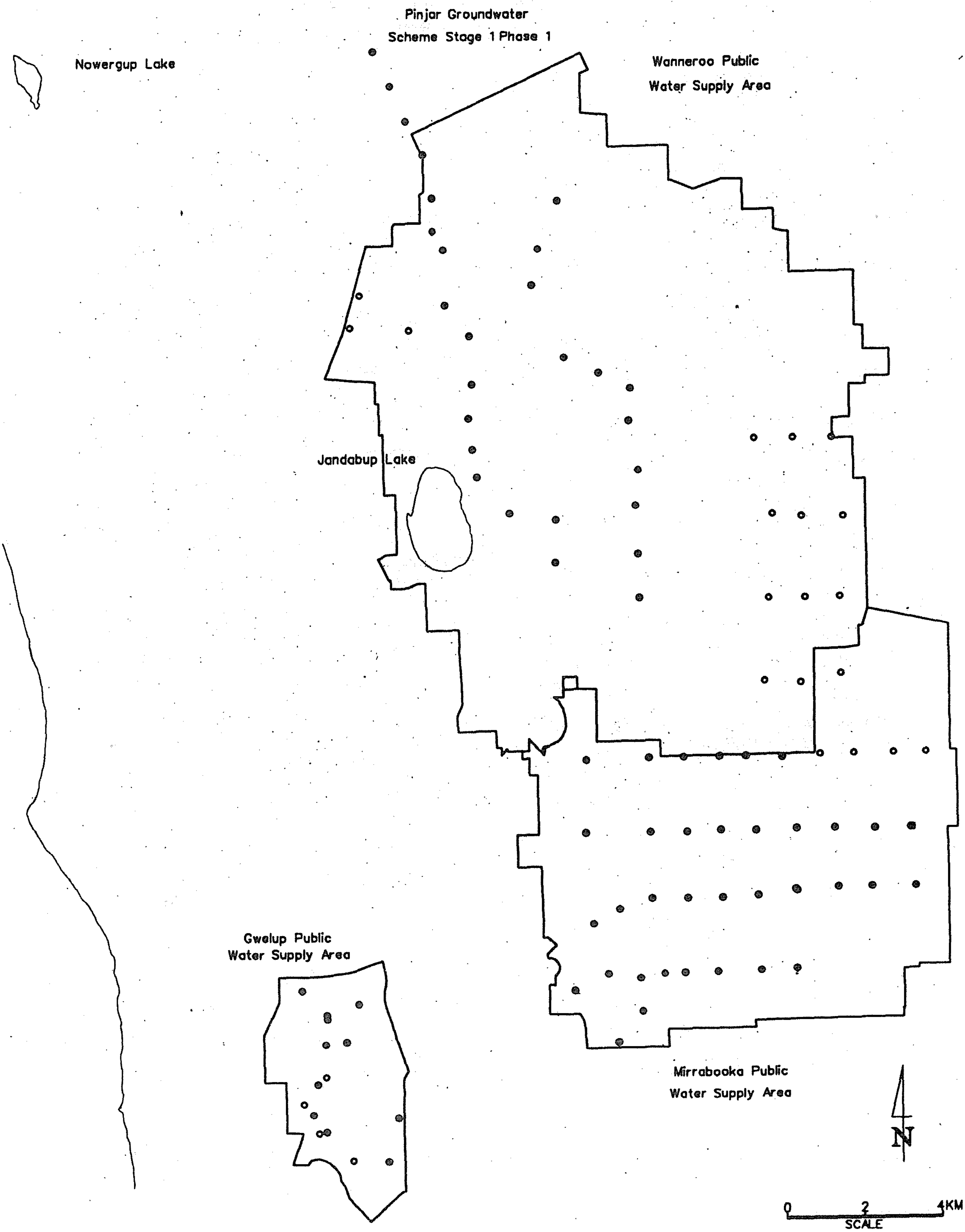

Figure 2.3 Location of groundwater abstraction schemes on the Gnangara Mound.

correlated with the proximity of the borefield.

The Gnangara Mound has suffered water table decline since commencement of Water Authority Scheme production in 1976. The most significant declines have occurred beneath the Wanneroo Wellfield (up to 2m) and Mirrabooka Wellfield (up to 1m). These declines have been accentuated by the below average rainfall during the previous two decades and reduced recharge of the aquifer resulting from unthinned pine forest on the Mound (Water Authority of Western Australia 1989). Computer modelling successfully predicted up to 2.5m declines in the centre of the Wanneroo Wellfield and for the Mirrabooka Wellfield, decline between 1-1.5m.

The Gnangara Mound water level was modelled by the Water Authority for 10 wet years with 934mm rainfall per annum (142mm higher than average). Water levels in the region rose by 1.0-1.5m. The effect of the Pinjar Stage 1 public water supply scheme and private development was largely mitigated. There was less than 0.50m rise in the water levels of Nowergup Lake and Jandabup Lake because evapotranspiration reduced the effect (Water Authority of Western Australia 1986).

A series of 10 dry years were simulated with a rainfall of 675mm (126mm below average). Water levels in the region fell between 1-3m. Water level decline in the western chain of wetlands (including Nowergup Lake) was 1m, while in the eastern group (including Jandabup Lake) declines were 3.0m (Water Authority of Western Australia 1986). The difference in water levels between above and below average rainfall periods with current urban development could be up to 4m (Sinclair *et al.* 1981).

Abstraction has a significant effect on Gnangara Mound groundwater levels. In addition to pumping, rainfall variations can strongly influence water level trends. Water level records generally indicate that the below average rainfall period from 1969 to 1988 had a profound impact on water level trends in this period. These records and groundwater modelling suggest that recharge events such as above-average winter rainfall are important for replenishing aquifers. The addition to water storage in wet winters appears to be of such sigificance that even where a sequence of average rainfall years follows, groundwater level trends will exhibit only a gradual decline accompanying discharge of excess stored water. This effect appears to have occurred following the wet winters of 1963-1965. The subsequent occurence of a prolonged series of dry years appears to have exacerbated and prolonged declining water levels (Pollett 1981). Assuming the population increases as predicted, urban expansion occurs in the region and all proposed groundwater schemes are developed, then groundwater resources of the mound will be largely committed within 25 years (Environmental Protection Authority 1987).

The use of groundwater to meet future needs has certain advantages over surface water sources. Groundwater exploitation has a low capital cost compared with dams because construction can be staged more easily and requires no long and expensive transmission pipelines. It is a more reliable source than surface water in times of prolonged drought and losses from groundwater storage are less than from surface reservoirs. The main disadvantage is that operating costs are relatively high (Caldwell 1981).

Total water consumption in Perth is now close to $400x10^6m^3$ annually of which approximately half is supplied by the Water Authority and the rest is abstracted by private users (Webster 1989). In addition to large commercial operations, many urban gardens have their own bores. While the volume of water abstracted from these bores is difficult to control, it lowers the overall cost to the Water Authority of providing water. In 1985 $262x10^6m^3$ were obtained from groundwater sources of which $206x10^6m^3$ were abstracted privately and the remainder pumped by the Water Authority. Of the $262x10^6m^3$, $223x10^6m^3$ came from the shallow unconfined aquifer, the rest was artesian (Webster 1989).

Strategic water resource studies for the Perth-Bunbury region indicate that potable resources are likely to be fully committed within 50 years at the latest (Western Australian Water Resources Council 1987) and studies of water supplies for the 21st century suggest that there may be a shortfall of potable resources in the Perth-Mandurah region of $300x10^6m^3$/year by the year 2050 (Hollick 1989). The exact date at which regional resources will be fully committed depends on the population growth rate, the extent of recycling, future water consumption per capita and the effects of climate change (Hollick 1989). However, water resources are limited and given the high rate of population growth in Perth at present, demand for water is increasing.

These projections are based on the assumption that use of shallow groundwater will continue to be restricted in order to protect the wetlands. If this constraint were removed, the water table could be drawn down to reduce losses through evaporation, evapotranspiration and outflows to rivers and the ocean. Hollick (1989) calculated that halving these losses for the Gnangara Mound as a whole would make an additional $750x10^6m^3$/year available for extraction compared to current and planned extraction of about $150x10^6m^3$/year and total projected demand for the Perth-Mandurah region of $700x10^6m^3$/year in 2050. Similarly, drawdown of the water table on the Jandakot Mound could make a smaller but major contribution to supplying Perth's future water needs.

It is possible to conserve the metropolitan wetlands by artificially maintaining wetland water levels with groundwater. There are still significant gains in available water since the evaporation from 10,000ha of wetland is approximately 200 million kL/year (Hollick 1989). There are a number of secondary benefits of artificially maintaining wetlands. First, the risk of pollution of groundwater from overlying land uses would be reduced by increasing the depth of soil between the groundwater and the surface. Second, land drainage problems would be reduced by making infiltration of stormwater in low-lying areas possible, incidentally increasing net groundwater recharge. Third, the feasibility of artificial recharge of the aquifer with effluent would be increased because of more extensive areas with adequate depth of soil above the water table (Hollick 1989).

One of the statutory conditions arising from the environmental impact assessement for development of the Pinjar Stage 1 groundwater scheme and subsequent schemes, is statutory minimum and preferred minimum water levels for many wetlands on the Gnangara Mound. The Water Authority is obliged to manage public and private extraction in accordance with these water level criteria (Water Authority of Western Australia 1989). The preferred minimum water level reflects the level at which maintenance of social and environmental values of the wetlands would be ensured. A maximum period permitted below the preferred minimum water level is specified for each wetland; usually two or three months. Below the absolute minimum water level, social and environmental values of the wetland were regarded as "significantly threatened" by the Environmental Protection Authority (Water Authority of Western Australia 1989). Generally, these minimums ensure that these wetlands do not dry.

It is most economical to supply the greatest quantites of water when demand is at a maximum. Because about 80% of the demand for water occurs in the 6-7 months of summer and autumn, it is desirable to have most of the annual draw in this period (Water Authority of Western Australia 1991). It is not economically feasible to transfer groundwater elsewhere for storage because of the costs associated with pumping. Therefore, groundwater extraction is likely to accentuate the annual drought. Extraction of groundwater would be expected to lower the water table and therefore, reduce the amount of time water is present in the wetlands and also lower maximum and minimum water levels. Extraction may also affect the rate of drying.

Conservation of wetlands

The World Conservation Strategy was launched in 1980 and resulted from the combined efforts of the International Union for Conservation of Nature and Natural Resources, the World Wildlife Fund, the United Nations Environment Program and 700 scientists worldwide. The World Conservation Strategy maintains that sustainable development can only be achieved by the conservation of living resources. A principle recommendation was that every country should prepare a National Conservation Strategy.

The World Conservation Strategy objectives of living resource conservation are:

1. to maintain essential ecological processes and life-support systems,
2. to preserve genetic diversity and
3. to ensure sustainable utilization of species and ecosystems.

In 1976 the Australian Water Resources Council adopted a statement of water resource development and management goals, regarding the need to integrate development and conservation. It was asserted that a balanced approach to water resources management would include the maintenance of adequate undisturbed aquatic environments as reference areas and the preservation of appropriate wetlands for the benefit of fish and native wildlife. This was adopted in principle by the Commonwealth and by all Australian States (Department of Home Affairs and Environment 1982a).

The water allocation principles detailed by the Western Australian Water Resources Council (1987) are to provide for essential needs of the individual and society for water, support economic development of the state and be consistent with the three principles of the World, National and State conservation strategies. All wetlands of state, national or international environmental significance have been allocated a management priority of ecosystem maintenance. For these wetlands, management of the groundwater resource should be undertaken to protect this use in accordance with appropriate objectives. This particularly applies in relation to land use and groundwater extraction for both urban/industrial and irrigation/rural supply adjacent to and upstream of wetlands. The major objective of groundwater management is to ensure that long term ecosystem viability is "reasonably" protected (Western Australian Water Resources Council 1987).

The availability of adequate water supplies is a limiting factor on both the size of Australian cities and total population and also on the development of irrigation and industry (Department of Home Affairs and Environment 1982b). Present management policies in groundwater control areas are designed by the Water Authority and the Environmental Protection Authority to preserve and conserve wetlands (eg. Environmental Protection Authority 1987). While this places stringent constraints on abstraction (Hollick 1983), the maintenance of water levels in wetlands is the most significant consideration in the regional development of the groundwater resource (Sinclair *et al.* 1981).

Sinclair *et al.* (1981) found that concern for groundwater supplies was justified and practical management of the groundwater was feasible. As Perth grows it is proposed to further develop these resources to maintain the groundwater component of public water supplies at about 35% (Sinclair *et al.* 1981). However, higher levels may be used in drought years when reservoir levels are low. For example, in 1979/80 groundwater constituted 42% of total supplies and 49% in 1977–78 (Research Group on Groundwater Management 1989). In 1988 groundwater contributed 66% of public water supplies.

Environmental values have been used to develop management objectives for individual wetlands (Water Authority of Western Australia 1991). For example, Thomsons Lake has a high diversity of bird species and is important for breeding. Migratory waders are regularly recorded. It is also a remnant breeding area for marsh harriers (*Circus aeruginosus*) and Australian bitterns (*Botaurus poiciboptilus*) in the metropolitan area (Water Authority of Western Australia 1991). Thomsons Lake is regarded as a high priority conservation area which possesses a high degree of naturalness. The Department of Conservation and Land Management objectives for the wetland are that water levels must reflect rainfall, and follow natural seasonal fluctuations, and to minimize sudden rises in level due to artificial sources of water (arising from urban development), to prevent excess nutrient input and if possible to reduce current levels of nutrient input (Water Authority of Western Australia 1991).

The importance of wetlands for wildlife conservation extends beyond the south–west of Western Australia because loss of wetlands is not restricted to Western Australia; it is a worldwide problem. Conservation of the more mobile species presents particular problems (Morgan 1972). The south–west of Western Australia is visited each summer by migratory wading birds for the Northern Hemisphere (Arnold & Wallis 1986) and Australia is signatory to international treaties which entail an obligation to protect the habitats of many of these species. In 1974 Australia signed the Ramsar Convention which required contracting parties to designate wetlands within their territory of international significance in terms of ecology, botany, zoology, limnology or hydrology. Moreover, under the terms of an agreement with Japan, Australia is obliged to protect migratory birds and their habitats. This includes over 20 species of birds that depend on wetlands for their survival and thus, Australia has an international responsibility (Department of Conservation and Environment 1980).

Whether the invertebrates are regarded as bird food or as valuable in their own right, their high diversity and abundance of invertebrates indicates that they play a central role in wetland ecosystems. Despite widespread public perceptions of insects as pests, their importance results largely from their enormous numbers and diversity, giving them substantial roles in material recycling and ecosystem maintenance (New 1984). A basic tenet of insect conservation is that preservation of habitat is of prime importance. A change in the condition of habitat almost invariably means a change in the associated insect community (New 1984). Habitat management, rather than just preservation may be necessary, but this can usually be done only from a detailed knowledge of the requirements of particular insect species (New 1984). The initial step of protecting land from gross human change or destruction of natural vegetation is imperative (New 1984). Groundwater abstraction and urbanization have the potential to significantly alter nutrient levels, water levels and the fringing vegetation. However, this can be minimized by management of the volume and rates of extraction and the design of urban drainage systems to exclude wetlands as endpoints for stormwater input.

The impact of seasonal drying on macroinvertebrate communities

It is through life history traits intrinsic to resident organisms that both habitat features and food availablitily influence the distribution and abundance of wetland invertebrates (Robert & Matta 1984, Reid 1985 and Neckles *et al.* 1990). Because hydrologic regime is a major influence on wetland systems, many life history traits governing an organism's distribution and abundance should be a direct response to wetland hydrodynamics (Murkin & Wrubleski 1988). Each species has a unique set of eco-physiological adaptations that underlie its seasonal cycle (Tauber & Tauber 1981), and alterations to the hydrological regime such as prolonged flooding may eliminate environmental stimuli necessary for development, egg hatching or feeding (Maher & Carpenter 1984 and Neckles *et al.* 1990).

Temporary wetlands flooded for days or weeks are characterized by very high abundance of aquatic invertebrates and low taxonomic diversities (e.g. Stout 1964, Barclay 1966, Hartland-Rowe 1966, McLachlan 1985, Sklar 1985, Williams 1985, Wylie & Jones 1986 and Ebert & Balko 1987). However, semipermanent or prolonged flooding may reduce invertebrate abundance (Neckles *et al.* 1990 and Murkin & Kadlec 1986). The high abuandance of invertebrates in seasonal wetlands have been attributed to a variety of physical and biological habitat features.

Aerobic decomposition of soil organic matter is stimulated by alternate wetting and drying (Birch 1960, Reddy & Patrick 1975, Briggs & Maher 1985 and Briggs *et al.* 1985) and release of nutrients from dry soil following reflooding is common in wetlands (Cook & Powers 1958, Kadlec 1962, Howard-Williams 1972, McLachlan *et al.* 1972 and Dykjova & Kyet 1978). High soil organic matter levels in freshly inundated wetlands provide a large instantaneously available food source for detrital feeding invertebrates (Briggs & Maher 1985) which, in turn, form abundant prey for predators (Wiggins *et al.* 1980).

Terrestrial vegetation grows during the dry period and when flooded, decomposes and releases a pulse of plant nutrients (Odum 1969 and LeCren & Lowe-McConnell 1980). The decaying vegetation in a newly flooded wetland contains more protein than permanently submerged detritus (Barlocher *et al.* 1978 and Mackay 1985), and provides an abundant organic food resource (Hartland-Rowe 1972, Swanson *et al.* 1974, Sklar 1985 and Wylie & Jones 1986).

Nutrient release from soil and detritus leads to a greater net primary productivity in seasonal wetlands compared with permanent wetlands (Conner and Day 1976 and Conner *et al.* 1981). Temporary wetlands have large numbers of detritivores and filter feeders (Kulp and Rabe 1984) and the rest of the invertebrate community is directly linked to primary production through detrital food chains (Fenchell & Jorgensen 1977, Anderson & Sedell 1979 and Danell & Sjoberg 1979).

Maximum aquatic macrophyte productivity follows drying and reflooding (Kadlec 1962, Harris & Marshall 1963 and Briggs & Maher 1985). The importance of drying and reflooding, re-establishment of macrophytes and orderly successional stages of waterbodies to invertebrates and waterfowl has been stressed by many authors (e.g. Kadlec 1962, Lowe-McConnell 1975, Whitman 1976, McLachlan 1977, van der Valk & Davis 1978, Dannell and Sjoberg 1982, Smith & Kadlec 1983, Maher 1984 and Murkin & Batt 1987). Permanent or prolonged flooding results in the death of aquatic vegetation (Driver 1977 and Murkin *et al.* 1991), reduces long term plant productivity and prevents the peak in organic matter availablility which occurs after reflooding (Briggs & Maher 1985). It frequently results in a narrow band of emergent vegetation along the shorline, large expanses of open water and low macrophyte production (Weller & Spatcher 1965 and van der Valk & Davis 1978).

Increases in vegetation density and diversity subsequent to the dry period has been found to significantly increase invertebrate abundance (Wegener *et al.* 1974). Any factors that lower macrophyte production or cause macrophytes to be removed or redistributed will affect the invertebrate community (Rabe & Gibson 1984 and Murkin & Batt 1987). Invertebrate production rapidly diminishes following the loss of emergent vegetation on a seasonal basis (Marchant 1982b), and in the long-term (Voigts 1976, Murkin 1983 and Murkin & Batt 1987). Plant species composition can greatly influence the taxonomic composition and size structure of the littoral zone macroinvertebrate community (Hanson 1990). Additional invertebrate productivity may also occur due to litterfall (Maher 1984).

Physiological and behavioural adaptations to seasonal drying

A summary of information available on the adaptations of aquatic fauna to seasonal drying was necessary to evaluate the potential of the taxa collected during this study. A general summary was produced by Williams (1987), and the work of Wiggins *et al.* (1980) was especially helpful. However, information on the Australian fauna is scant, with the work of Boulton (1989) being most useful.

Cnidaria to Hydracarina

Cnidaria were not found in temporary ponds by Kenk (1949) and are not mentioned by Williams (1987), and presumably are not adapted to seasonal drying.

Turbellaria are frequently found in temporary habitats (Kenk 1949), and may have dessication resistant eggs, cysts enclosing the young, as adults or fragments of animals, and in cocoons (Castle 1928, Kenk 1944, Wiggins *et al.* 1980 and Ball *et al.* 1981). Turbellaria were collected from reflooded substrate from an intermittent stream in Victoria by Boulton (1989).

Nematoda are known to survive dessication as eggs, larvae and adults (Pennak 1953 and Williams 1985). Boulton (1989) found nematodes under dry leaf litter, and in reflooded substrate.

The Oligochaeta are able to withstand seasonal drying as adults or fragments of animals, cysts enclosing the young and eggs (Kenk 1949 and Wiggins *et al.* 1980). Oligochaetes have been found under dry leaf litter and in reflooded substrate in Victoria (Boulton 1989).

Hirudinea were collected from a temporary pond by Kenk (1949), and may survive in dry mud as adults where some species construct mucous lined cells (Hall 1922, Pennak 1953 and Wiggins *et al.* 1980).

Hydracarina may have resistant larvae but usually are parasitic on mobile aquatic taxa (Wiggins *et al.* 1980). Evidence for a dessication resistant stage was obtained by Boulton (1989) who collected mites from reflooded substrate from an intermittent stream in Victoria.

Gastropoda

Some species of gastropods may rely on passive dispersal to recolonize seaonal wetlands. Small snails (<3mm) have the potential to disperse distances of up to 10km by adhering to the feathers of birds (Boag 1986).

Ferrissia sp. was collected from permanent billabongs along the Magela Creek (Northern Territory) but only in the dry season (November–December) attached to plants (Marchant 1982b). *Ferrissia* spp. were found under dry leaf litter and in reflooded substrate by Boulton (1989).

Sphaerium spp. are often found in seasonal wetlands where they aestivate as adults or juveniles (see McKee & Mackie 1981).

Other aquatic molluscs aestivate as adults on plants and amongst leaf litter in dry wetlands (Strandine 1941 and Eckblad 1973).

Crustacea

Cladocera: Many species of cladocerans inhabit ephemeral and seasonal wetlands and have desiccation resistant epphipial eggs, or adults that survive in moist substrate (Elborn 1966, Chirkova 1973, DeDeckker & Geddes 1980, Wiggins *et al.* 1980 and Williams 1980, 1985).

Ostracoda: Many species have desication resistant eggs, and some species survive as adults in moist substrate (Pennak 1953, Williams & Hynes 1976, DeDeckker & Geddes 1980, Wiggins *et al.* 1980, Williams 1980, 1985 and Pinder 1986).

Conchostraca: Bishop (1967a,b, 1968) studied the biology of *Limnadia stanleyana* and found that this taxa has eggs which are extremely resistant to dessication, and mature rapidly when conditions are favourable. Not all the eggs hatch during a flood event to insure against the possibility that the wetland may dry before eggs can be produced. It is likely that most Conchostraca share these characteristics, and are therefore well adapted to ephemeral and seasonal wetlands.

Copepoda: Many species have eggs that are highly resistant to desication, while other species have diapausing copepodites, or survive as adults in cysts (Cole 1953, Yaron 1964, DeDeckker & Geddes 1980 and Williams 1980, 1985). Pinder (1986) found adult harpactacoid copepods in dry substrate in Thomsons Lake.

Amphipoda: Several species of amphipods are known to inhabit temporary ponds, retreating with the groundwater either by burrowing or by using crayfish burrows (Kenk 1949, Clifford 1966 and Williams & Hynes 1976). Williams (1985) notes that members of the genus *Austrochiltonia* migrate to permanent water during the dry period. Swanson (1984) recorded amphipods being transported between wetlands by water fowl. Boulton (1989) noted that *Austrochiltonia australis* over-summered in strips of *Eucalyptus* bark and leaf litter near the margins of dried pools in intermittent streams in central Victoria. Pinder (1986) found *A. subtenuis* in moist mud at Thomsons Lake.

Isopoda: Nicholls (1943) noted that *P. palustris* was collected from seasonal swamps and was believed to survive buried in the dry mud. Other isopods are also able to tolerate seasonal drying often via behavioural rather than physiological mechanisms (e.g. Koch 1989). The North American species *Asellus militaris* Ilay inhabits temporary wetlands and retreats to the groundwater during the dry period (Kenk 1949). The Australian isopod *Haloniscus searlei* Chilton survives the dry phase as an adult under stones and other refuges (Williams 1983).

Decapoda: Crayfish juveniles and adults in seasonal habitats are found in burrows at the water-table (Crocker & Barr 1968 and Williams *et al.* 1974).

Insecta

Many insects are adapted to seasonal or ephemeral environments by virtue of rapid life cycles. Hynes & Williams (1962) found many insect larvae in Uganda were fully grown in 1 month. Hynes (1975) concluded from a study of seasonal changes of the fauna of a stream in Ghana that the average life cycle was 2.5 months.

Ephemeroptera: Bunn (1988) found *Tasmanocoenis tillyardi* in jarrah forest streams near Perth to have a univoltine life cycle with small nymphs first appearing in late summer, inferring that egg laying must occur in early summer.

Marchant (1982a) estimated the life cycles of *Cloeon fluviatile* and *Tasmanocoenis* sp. from Magela Creek, Northern Territory to last one month. Growth, emergence and reproduction occurred continuously until the nymphs disappeared for the driest two months even though some water remained. Since nymphs close to emerging were found only two weeks after the billabongs started to refill, Marchant (1982a) surmized that these nymphs grew from diapausing eggs.

Several species of Ephemeroptera are known to have aestivating eggs, some of which apparantly survive summer drought (Lehmkuhl 1973 and Wiggins *et al.* 1980). *Nousia* spp. hatched from resting eggs in reflooded substrate from an intermittent stream in Victoria (Boulton 1989).

Odonata: Larvae of *Argiolestes pusillus* may be able to survive drying (Watson 1981). Other records of larvae surviving absence of water exist in Australia (Watson 1968) and elsewhere (Fischer 1961 and Daborn 1971). Results of this study suggests that *Aeshna brevistyla* may also be able to survive in moist substrate. None of the species found in this study are known to lay eggs that are resistant to dessication, however, members of the genus *Austrolestes* are known to oviposit in plants (see Watson 1958). Lake *et al.* (1989) found *A. analis* early in a refilling pond in Victoria and suggested the presence of drought resistant eggs in vegetation.

Hemiptera: Of the aquatic hemiptera collected here, none are known to have eggs that can withstand dessication, however, they are all good fliers (Lansbury 1981) and capable of flying great distances. Hynes (1955) observed that six species of Hemiptera survived the dry period in permanent pools until rains created temporary habitats, which were then colonized. The same behaviour was recorded for *Ranatra* and *Notonecta* by Cole (1968). Marchant (1982b) collected *P. brunni* from billabongs on Magela Creek (N.T.), in the dry season, and this species disappeared in the wet season. In contrast, *Ranatra* sp. were found in the dry season in the Magela Creek billabongs (Marchant 1982b).

Diptera: Chironomidae: The tropical African species *Polypedilum vanderplanki* Hinton is able to survive dehydration in sun-baked mud (Hinton 1951, 1960) in ephemeral pools which exist for one to eleven days (Cantrell & McLachlan 1982). There is no evidence that chironomids present in the Perth wetlands have adaptations to seasonal drying.

Ceratopogonidae: *Dasyhelea thompsoni* de Meillon larvae of tropical Africa seal themselves in water-tight capsules when emphemeral pools dry out and aestivate until the next rain (Cantrell & McLachlan 1982). Pinder (1986) recovered larval ceratopogonids from the dry bed of Thomsons Lake, and Williams (1980) notes that they are often associated with the moist mud at the margins of wetlands.

Coleoptera: The majority of North American Coleoptera that colonise seasonal wetlands are believed to migrate to permanent water during the dry phase (Fernando 1958, Southwood 1962, James 1969 and Wiggins *et al.* 1980). Most of the coleopterans collected from an intermittent stream in Victoria over-summered in permanent water (Boulton 1989). However, *Copelatus australiae*, *Hyderodes shuckhardi*, *Lancetes lanceolatus*, and *Platynectes decumpunctus* were found under dry leaf litter, and *Necterosoma penicilliatum*, and Helodidae larvae were recovered from reflooded substrate (Boulton 1989). McKaige (1980) observed live adults of *Hyderodes shuckhardi* in dry mud in western Victoria, and from mud flooded with water emerged *Encohrus* sp., *Hydrochus* sp., *Hydrobius* sp., *Helochares* sp. and *Liodessus shuckhardi* (Lake *et al.* 1989). Dytiscidae have also been found in dry wetlands overseas by Boumezzough (1983) and Williams (1983), (see also Jackson 1956, Young 1960, and James 1969). *Rhantus* sp. was recorded as overwintering in a dry pool basin as eggs, and in southern Ontario (North America), while adults either overwintered in dry substrate or in permanent wetlands (Wiggins *et al.* 1980). Barclay (1966) found that most coleopterans migrated away from a drying wetland in New Zealand (near Auckland), but *Rhantus pulverosus* remained in the last puddle and some individuals sought refuge under logs where they remained for many weeks. Species of *Haliplus* in North

America were found aestivating in dry soil in prairie wetlands by Wallis (1933 in Wiggins *et al.* 1980). The North American species *Hydrobius fuscipes* adults emerged from dry substrate (Wiggins *et al.* 1980). Hence it is likely that numerous Coleoptera can aestivate in dry mud.

Anura

Although little attention was given to the frogs in this study, there is good information on the biology of the taxa which occur on the Swan Coastal Plain (see Main 1965, 1968 and Littlejohn 1981). Main (1968) reviewed the breeding seasons of these species which are coincident with the period of wetland reflooding and maximum water levels. The following is a list of species which are associated with wetlands of the Coastal Plain near Perth derived from Littlejohn (1981), integrated with information on distributions from Tyler *et al.* 1984).

1. Species which oviposit without water, but the larvae require water:

Geocrinia leai (Fletcher) (breeding season; autumn–spring): Oviposits in litter and vegetation beside the wetland. Tadpoles take more than 120 days to complete metamorphosis.

H. eyrei (Gray) (breeding season; autumn): This species oviposit in burrows in or near swamps which are flooded by early winter rains to release the larvae.

Pseudophryne guentheri Boulenger (breeding season; autumn–early winter): Breeds in burrows which are flooded. The tadpoles are well developed before emerging (Tyler *et al.* 1984).

2. Species which inhabit seasonal wetlands:

Crinia georgiana Tschudi (breeding season; July to October (Main 1965)): Tadpoles complete metamorphosis in 35–45 days (Tyler *et al.* 1984).

Neobatrachus pelobatoides (Werner) (breeding season; May to July): This species was found in Bartram Swamp as an adult in a crayfish burrow 1.5m underground with no free water present on 28th April 1990 (Tyler *et al.* 1984).

Ranidella insignifera (Moore) (breeding season; winter–spring): Tadpoles take 150 days to mature (Tyler *et al.* 1984).

3. Species which inhabit semi-permanent and permanent wetlands:

Littoria adelaidensis (Gray) (breeding season; early spring),

L. moorei (Copland) (breeding season; spring–summer),

Limnodynastes dorsalis (Gray) (breeding season; winter–early summer): Inhabits a burrow during dry conditions (Tyler *et al.* 1984).

Ranidella glauerti (Loveridge) (Breeding season; autumn–spring): Tadpoles take more than three months to develop (Tyler *et al.* 1984).

The long-necked tortoise *Chelodina oblonga* lays up to three clutches of eggs between September and January (Kuchling 1988) and the young emerge from the nests about mid-August, with slight variations depending on seasonal conditions (Clay 1981).

Overall, many wetland inhabitants have the potential to survive the seasonal drying of wetlands either with desiccation resistant eggs, larvae or adults, by moving to permanent water or by having a terrestrial phase in the life cycle.

The impact of nutrient enrichment on macroinvertebrate communities

Nutrient enrichment or eutrophication results from the excessive accumulation of nutrients, particularly phosphorus and nitrogen (Hynes 1971 and Hellawell 1986). Eutrophication often results in the loss of macrophytes and their replacement with phytoplankton; first green algae, and finally cyanobacteria (e.g Mason 1977). High nutrient concentrations increase the growth of epiphytic algae on macrophytes and the growth of phytoplankton in the water column. This combination reduces the light available to submerged macrophytes until they are unable to germinate and grow. Nutrient enriched wetlands are dominated eventually by emergent macrophytes, benthic algae and phytoplankton rather than submerged macrophytes (Morgan 1970 and Hough *et al.* 1989). Blooms of algal and cyanobacterial species able to exploit the conditions occur, causing the water to become supersaturated with oxygen during the day and anoxic at night and during the decay of blooms (Jeffries & Mills 1990). Oxygen concentrations are further reduced by an increase in the biomass of material decaying in the wetland and the sediment often becomes unstable and anoxic. In hypertrophic wetlands, cyanobacterial blooms can be continuous (Jeffries & Mills 1990) and may have toxic effects on macroinvertebrates and fish (Larkin & Northcote 1969 and Penazola *et al.* 1990).

A moderate increase in nutrient levels initially leads to an increase in productivity of aquatic macrophytes and phytoplankton, which leads to an increase in abundance and biomass of grazing and predatory macroinvertebrates (Wood 1975, Pearson & Rosenberg 1978 and Hellawell 1986). With increasing eutrophication, there is a progressive disappearance of invertebrate species and macroinvertebrate diversity is usually low in eutrophic wetlands (Jonasson 1969, Wood 1975, Hellawell 1986 and George *et al.* 1990). In moderately eutrophic wetlands tolerant species are amphipods, some leeches and molluscs (Hellawell 1986). At subtle levels, eutrophication changes species composition within taxonomic groups (e.g. Chironomidae, Wiederholm 1984). Under the influence of severe eutrophication, a few species are represented by very large numbers of individuals able to take advantage of the changes which eutrophication induces and to exploit the increased food supply (Wood 1975, Hellawell 1986 and Rolls 1989). Elimination of sensitive oxygen dependent animals and an increase in some tolerant species results in a change in community structure (Hellawell 1986). Most Isopoda, Trichoptera, Ephemeroptera and Odonata are generally intolerant of organic pollution because of intolerance to low oxygen concentrations, or the increased access of predators due to loss of macrophyte cover (Carr & Hiltunen 1965, Morgan 1970, Wood 1973, Cook & Johnson 1974, Lang 1974, Hergenrader & Lessig 1980, Reavell & Frenzel 1981, Watson *et al.* 1982, Marchant *et al.* 1984 and Osborne & Davies 1987). Certain chironomid species and oligochaetes are tolerant of low oxygen concentrations and hence are often abundant in eutrophic wetlands (Grimas 1969, Howmiller & Beeton 1971, Peterka 1972 and Henderson-Sellers & Markland 1987). They live in the accumulated organic deposits feeding on bacteria-enriched material (Brinkhurst & Cook 1974 and Brinkhurst *et al.* 1972). In hypertrophic conditions new species only found under such conditions may appear, and often these are nuisance flies (e.g. Learner 1975, Wood 1975, Hellawell 1986 and Pinder *et al.* 1991). Numbers of oligochaetes can be high (up to 420,000m^{-2}) which may be attributed not only to the abundant food supply but also to the absence of predators (Wright 1955, Brinkhurst 1963 and Carr & Hiltunen 1965).

The impact of fish on macro-invertebrate communities

Two species of fish were found in this study. The native Swan River goby *Pseudogobius olorum* (Sauvage), and the introduced mosquitofish *Gambusia holbrooki* (Girard). *P. olorum* is found in estuaries, streams and wetlands in Western Australia and is considered to be derived from a marine ancestor. Information on estuarine populations is currently being gathered by Howard Gill (Murdoch University) but little is known of the distribution or life history of wetland populations. *G. holbrooki* is native to central America and has been distributed worldwide for mosquito control. It was introduced into Western Australia in 1934 (Lloyd *et al.* 1986) and occurs in most of the permanent wetlands on the Swan Coastal Plain.

The mosquitofish *Gambusia holbrooki* is an omnivore, consuming zooplankton and macroinvertebrates; mosquito larvae are only a minor part of the diet (Grubb 1972, Whitaker 1974, Farley 1980 and Walters & Legner 1980). While their effectiveness as a mosquito control agent is questionable (Lloyd *et al.* 1986), their environmental impact is the focus of concern. Detrimental effects of *G. holbrooki* on invertebrate populations was noted by Stephanides (1964) and Legner & Medved (1974). Experiments have demonstrated a substantial impact on beetles (Walters & Legner 1980), notonectids (Hurlbert & Mulla 1981), rotifers, crustaceans (Hurlbert *et al.* 1972) and molluscs (Rees 1979). Bence (1988) noted the impact of mosquitofish on cladocerans, ostracods, copepods, beetle larvae and zygopteran larvae. The effects of general fish predation on the Odonata affecting abundance and species composition is extensively documented (Wright 1946, Gerking 1962, Macan 1966, Hall *et al.* 1970, Benke 1972, Faragher 1980, Mittelbach 1981, Bohanan & Johnson 1983, Johnson *et al.* 1983, Morin 1984a,b, Pierce *et al.* 1985, Martin 1986 and Crowley *et al.* 1987).

In Australia the evidence for adverse impacts of *G. holbrooki* is patchy and mostly circumstantial, often relating to the decline of native fish (see Marshall 1966, Reynolds 1976, Cadwallader 1978, Lake 1978, Wharton 1979, McDowall 1980 and McKay 1984). *G. holbrooki* has been implicated in the decline of the purple-spotted gudgeon *Mogurnda adspersa* (Castelnau) (Hoese *et al.* 1980), and species of *Melanotaenia*, *Ambassis*, *Pseudomugil*, *Craterocephalus* and *Retropinna* in Queensland (Arthington *et al.* 1983) and elsewhere (Marshall 1966, Mees 1977 and Lloyd 1984). However, habitat destruction and water-quality degradation have also reduced native fish populations (Arthington *et al.* 1983).

The primary concern with *G. holbrooki* is the large population sizes that are attained. For example, Lloyd *et al.* (1986) notes that ten pregnant females can produce a population of five million in six months. Trendall (1982) collected *G. holbrooki* from several wetlands near Perth and found that females had two or three broods per year. This high fecundity indicates that *G. holbrooki* has the potential to have a considerable impact on the invertebrate communities in Perth's wetlands.

Overview

During the next ten to twenty years water consumption by the inhabitants of Perth will exceed the available resources. The future water supply options for Perth involve increasing costs, whether economic or environmental. The environmental costs entail the lowering of wetland water levels and the loss of wetland area. However, management of the wetlands by the Water Authority is to be done within the concept of sustainable yeild. Groundwater extraction is constrained by statutory minimum water levels in some wetlands, although at present these minimums have no scientific basis. As the city of Perth grows not only will more water be required, but so will land for housing. Many aspects of urban development are incompatible with wetland conservation. Urbanization increases water levels and nutrient enrichment in wetlands, with the result that most wetlands within the urban area are permanent and eutrophic. Seasonal drying, nutrient enrichment and the presence of fish have the potential to significantly affect the macroinvertebrate communities in the wetlands of the Swan Coastal Plain, and management of the wetlands to conserve species diversity requires knowledge of the way these factors affect the macroinvertebrate species in these wetlands.

3 Physical and chemical charateristics of the wetlands

Introduction

This chapter describes the six wetlands in terms of their physical and chemical characteristics based on the information collected during one year of field work. The invertebrates were collected simultaneously, but will be considered in later Chapters. In addition, information on groundwater and wetland water levels collected by the Water Authority of Western Australia, was used to determine when drying and refill of the seasonal wetlands near Perth occurs, what determines the timing of drying and refill and the impact of groundwater abstraction.

Site descriptions

Jandabup Lake

Jandabup Lake (see Plate 3.1) is a shallow (<1.5m deep) oval shaped wetland lying within a Crown reserve of 232.3ha, 22km north of Perth city. The open water occupies 110ha and is surrounded by a 134ha zone of sedges. The wetland lies in an interbarrier depression between the Bassendean and Spearwood Dune systems. The bed of the eastern half of the wetland is comprised of fine sands and the western half (55% of the total lake area) is diatomite.

Jandabup Lake lies on the Gnangara Mound and inflow of groundwater occurs on the eastern side of the wetland (Allen 1980). It behaves as an evaporation basin Allen (1980); outflow is impeded by organic lake deposits and about 90% of the groundwater inflow and rainfall is lost by evaporation. *Baumea* sp. is the dominant rush and the aquatic vegetation is relatively diverse. Although the central area of the wetland is a A-class reserve for the conservation of flora and fauna, almost a third and most of the surrounding land is freehold (Allen 1980). Increasing rural or semi-urban activity around the lake has resulted in alienation of the wetland vegetation.

Bartram Swamp

Bartram Swamp (see Plate 3.1) is on the Bassendean Dunes of the Jandakot Mound south of Perth. This wetland lies immediately west of the intersection of Bartram Road and Boronia Road along the boundary of the Locality of Banjup (City of Cockburn) and Forrestdale (City of Armadale). Nothing was known of this wetland prior to this study. More than two-thirds of the wetland is on privately owned land. On the western side is part of a semi-rural block which has a house situated on the edge of the wetland. As the wetland began to dry it became evident that the part of the wetland on this land had been excavated. Conversations with the owners revealed that the excavation had occurred within the last 5 years. This portion of the wetland is inhabited by a small number of goats. The eastern portion of the wetland lies over agricultural land which supports cattle. Only the central portion of the wetland was accessible for sampling. It has relatively natural vegetation with several rushes and reeds including *Baumea* sp., and submerged aquatic macrophytes including *Myriophyllum* sp. In winter the water overlies a track which is an extension of Bartram Road. As the water level subsides, the wetland becomes partitioned into unequal thirds by narrow sections of artificially raised ground along which fence lines run. The division between the eastern portion and the central portion also supports a raised track under which three large metal pipes lie to connect the eastern and central sections. At maximum water levels the lake occupies approximately 3ha, with a maximum depth of about one metre.

Murdoch Swamp

Murdoch Swamp (Plate 3.1) is the "Upper Swamp" on the campus of Murdoch University. It lies on the Jandakot Mound and is part of the Beeliar Chain of wetlands. According to Newman and Hart (1984), Murdoch Swamp occupies an area of 1.3 ha at the average winter water level. It was deepened by 2m in the late 1930's to serve as a permanent source of water for fire control in the surrounding pine plantations. Very little damage to the surrounding vegetation occurred as a consequence of this dredging, since mature *Melaleuca* sp. occur around the edge of the small, deep pool. The rest of the wetland dries seasonally, and supports mature trees (*Melaleuca* sp., *Banksia* sp.) shrubs and sedges which form a closed canopy wetland.

Apart from the work of Hart (1978) little information exists on Murdoch Swamp. It is sometimes used as a teaching resource, particularly as an example of a "healthy" wetland in comparison to nearby North Lake.

Nowergup Lake

Nowergup Lake (Plate 3.1) is located about 30km north of Perth on the steepest gradient of the Gnangara Mound groundwater flow system. It covers an area of 58.2ha with an area of open water of 34ha. The maximum water level recorded was

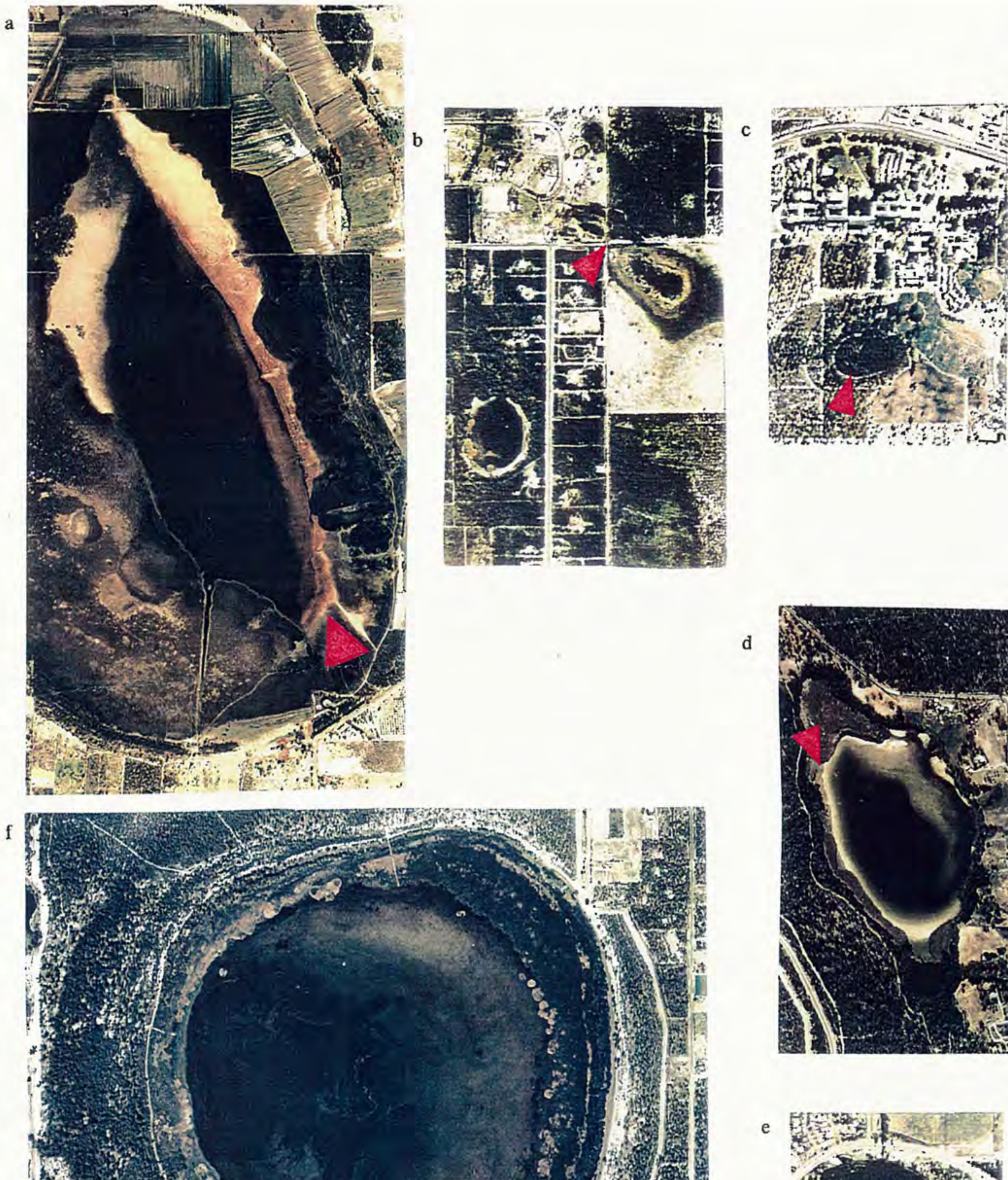

Plate 3.1 Aerial photographs of the six wetlands (Scale 1:20,000) with the sampling sites indicated with an arrow. a. Jandabup Lake, b. Bartram Swamp, c. Murdoch Swamp, d. Nowergup Lake, e. North Lake and f. Thomsons Lake.

17.72m AHD in 1974 and a minimum level of 16.31m AHD in 1980. The greatest depth of the lake is 4.0m (13.11m AHD). Therefore, the wetland has not dried completely since records began.

The western side is a woodland area reserved and vested in Department of Conservation and Land Management. On the eastern shore there is a free range piggery (with runoff directly into the wetland) and a number of small holdings. To the north is a large lucerne farm and to the south-east a large market garden.

Within the wetland *Typha orientalis* is increasing its area rapidly. Vegetation surrounding the lake consists of tuart (*Eucalyptus gomphocephala*), *Banksia* sp., *Melaleuca* sp., jarrah (*E. marginata*), and limestone heath. Arnold (1988) believed it would be a significant drought refuge and breeding area for birds. The invertebrates of Lake Nowergup were surveyed in 1986 and 1987 (see Rolls *et al.* 1990).

North Lake

North Lake (Plate 3.1) is approximately 29ha in area, situated 14km south of Perth in an interbarrier depression between the Bassendean and Spearwood Dune systems. It 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 Veterninary School farm (diverted elsewhere in 1990). 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 hydrologically equivalent (Megirian 1982). Small remnants of natural vegetation are present around the margin of the wetland, comprising mainly a narrow strip of *Melaleuca raphiophylla* woodland and some small stands of *Baumea articulata*.

North Lake is probably the most intensively studied wetland on the Swan Coastal Plain. Hart (1978) investigated the invertebrates and water chemistry as part of a comparison with other nearby wetlands. Murray *et al.* (1986) recorded water chemistry data as part of a Draft Management Plan for the wetland and its associated bushland. Davis and Rolls (1987) and Rolls *et al.* (1990) collected invertebrates from North Lake every two or three months from April 1985 until May 1987. McDougal & Ho (1991) intensively sampled the water in an attempt to track nutrient cycles within the wetland. Hill (1988) looked at the impact of the organophosphate pesticide Abate on the non-target invertebrates of North Lake. Monitoring of larval chironomids since 1987 has occurred over spring, summer and autumn (Davis *et al.* 1988, 1989, 1990 and Pinder *et al.* 1991). The nuisance chironomid problem has resulted in the application of pesticide (Abate) to North Lake since 1972, usually only in the summer months.

Thomsons Lake

Thomsons Lake (Plate 3.1) is a shallow, almost circular wetland situated approximately 22km south of Perth between the Bassendean and Spearwood dune systems. It lies within an A-class nature reserve with approximately 151ha of open water and 101ha of sedges. Thomsons Lake is the largest wetland within the Beeliar wetland chain on the Jandakot Mound. Crook and Evans (1981) found that in 1976 the wetland was approximately 1700m in diameter and one metre deep in winter 1976. The amount of water in the lake varies widely. Water Authority data show that the wetland dried in 1961, 1962, 1963 and every year between 1978 and 1988, and reached its greatest recorded depth of 3.6m in October 1968.

An extensive stand of *B. articulata* and *T. orientalis* occurs around the entire margin of the wetland preventing easy access to the open water. A significant expansion of the bulrush *T. orientalis* has occurred since the area was mapped by Crook and Evans (1981) but the extent of the expansion has not been measured. The macrophyte *Myriophyllum salsugineum* occurs in much of the wetland forming a dry mat across the peat bed when the wetland dries. It may be a recent colonizer of the lake since it is not mentioned by Crook and Evans (1981). Its presence probably reflects the lowered water table levels of the relatively dry period between 1978 and 1988. Collections of invertebrates from Thomsons Lake were made from 1985 to 1987 (e.g. Pinder 1986, Davis & Rolls 1987 and Rolls *et al.* 1990).

There continues to be an increase in rural and urban development around the wetland. Thomsons Lake lies between the smaller Kogolup Lake in the north and Bangapup Lake in the south. It is bounded to the east and west by rural small holdings, to the south by Russel Road and the University of Western Australia Marsupial Breeding Station, and to the north by uncleared bushland zoned Rural and owned by the State Housing Commission (Crook and Evans 1981). The Thomsons Lake Nature Reserve also includes some 300ha of mainly woodland and open forest in a buffer 100-400m in depth around the centrally placed wetland. This vegetation has developed on two dune systems of Pleistocene Age (Spearwood and Bassendean dune systems) and includes a variety of plant associations dominated by flooded gum (*Eucalyptus rudis*), jarrah (*E. marginata*), pricklybark (*E. todtiana*), swamp paperbark (*Melaeuca preissiana*) and various *Banksia* species.

Thomsons Lake forms part of the "Southern Lakes Drainage Scheme" and the purposes of the Reserve under the Land Act include "drainage". Under the existing drainage regime water drains into the wetland from the north, from Lake Kogolup, and from agricultural land to the east. Blooms of the cyanobacteria *Microcystis aeruginosa* occur periodically indicating that significant amounts of mineral nutrients, nitrogen and phosphorus many be entering the wetland. Newman (1976) found the lake to be increasingly enriched by nitrogen and phosphorous and noted that the impact of this human-induced eutrohpication on the wildlife of the reserve could be considerable.

Methods

Samples were collected at three weekly intervals between August 1988 and September 1989 from each of the six wetlands. Sampling at Murdoch Swamp, Bartram Swamp and Nowergup Lake was started slightly later than at the other wetlands. Water samples were taken on each occasion and spot measurements of temperature (using a glass alcohol thermometer accurate to 0.1°C) and water depth were recorded. Depth was measured relative to the deepest part of each wetland. Four of the six wetlands (North Lake, Nowergup Lake, Jandabup Lake and Thomsons Lake) had AHD (Australian Height Data) depth gauges which facilitated calculation of the actual depth of the water. In Bartram Swamp it was always possible to reach the deepest point, while at Murdoch Swamp a marker was used to measure changes in depth. It was not possible to accurately establish the depth at Murdoch Swamp because it was too deep to measure without a boat. In the absence of AHD information, the minimum depth was estimated relative to the marker. In the laboratory, the water samples were used to measure pH (using a glass electrode Hanna HI 8424 pH meter), conductivity (with a Hanna HI 8733 meter, automatically standardized to 25°C), chlorophyll *a*, and on selected occasions, total nitrogen and total phosphorus. The purpose of nutrient measurements was to establish the range of nutrient levels in the six wetlands, rather than to follow the changes between samples. The amount of chlorophyll *a* present in water samples was measured using a method adapted from Moran and Porath (1980) and Moran (1982). Total nitrogen and phosphorus were measured following perchloric acid digestion using the automated phenate method (American Public Health Association 1985), and the single solution method (Murphy and Riley 1962) respectively. Analyses were replicated three times for each sample. Total nitrogen analyses yielded lower than expected, but consistent, recoveries. To account for this, a correction factor (1.92) was determined (see Lund 1992), based on duplicate analyses by an independent laboratory. Determination of the trophic state of each wetland was based on criteria of OECD (1982) using total phosphorus, total nitrogen and chlorophyll a levels. An alternative described by Salas & Martino (1991) for warm tropical wetlands used by Davis *et al.* (1993) was not used because it relies only on total phosphorus, the temperatures reached at the bottom of wetlands in winter probably fall below 10°C and these are strictly in a temperate rather than a tropical climate.

The Water Authority provided information on groundwater levels for wetlands and monitoring bores on the Jandakot Mound and information on the timing of refill and drying in seasonal wetlands is based on this data. Records of water levels in Thomsons Lake have been kept by the Water Authortity since 1952. From 1971 onwards, the records are monthly, and despite missing records, it is possilbe to follow seasonal fluctuations in water levels.

Results

Graphs of depth, temperature, conductivity, pH, chlorophyll *a*, total phosphorus and total nitrogen are shown in Figures 3.1 to 3.7. Appendix 1 provides the raw data from which these figures were derived. Table 3.1 summarizes the range, mean and standard deviation for these parameters in each wetland.

Jandabup Lake

Between August 1988 and September 1989 Jandabup Lake was observed to have moderately coloured water, which was darker in spring and early summer when pH was low. There were no cyanobacterial blooms, although there were many rooted aquatic macrophytes with epiphytic algae attached.

Of the six wetlands, it was the second most shallow, and would have dried if the water levels had not been artificially maintained by the Water

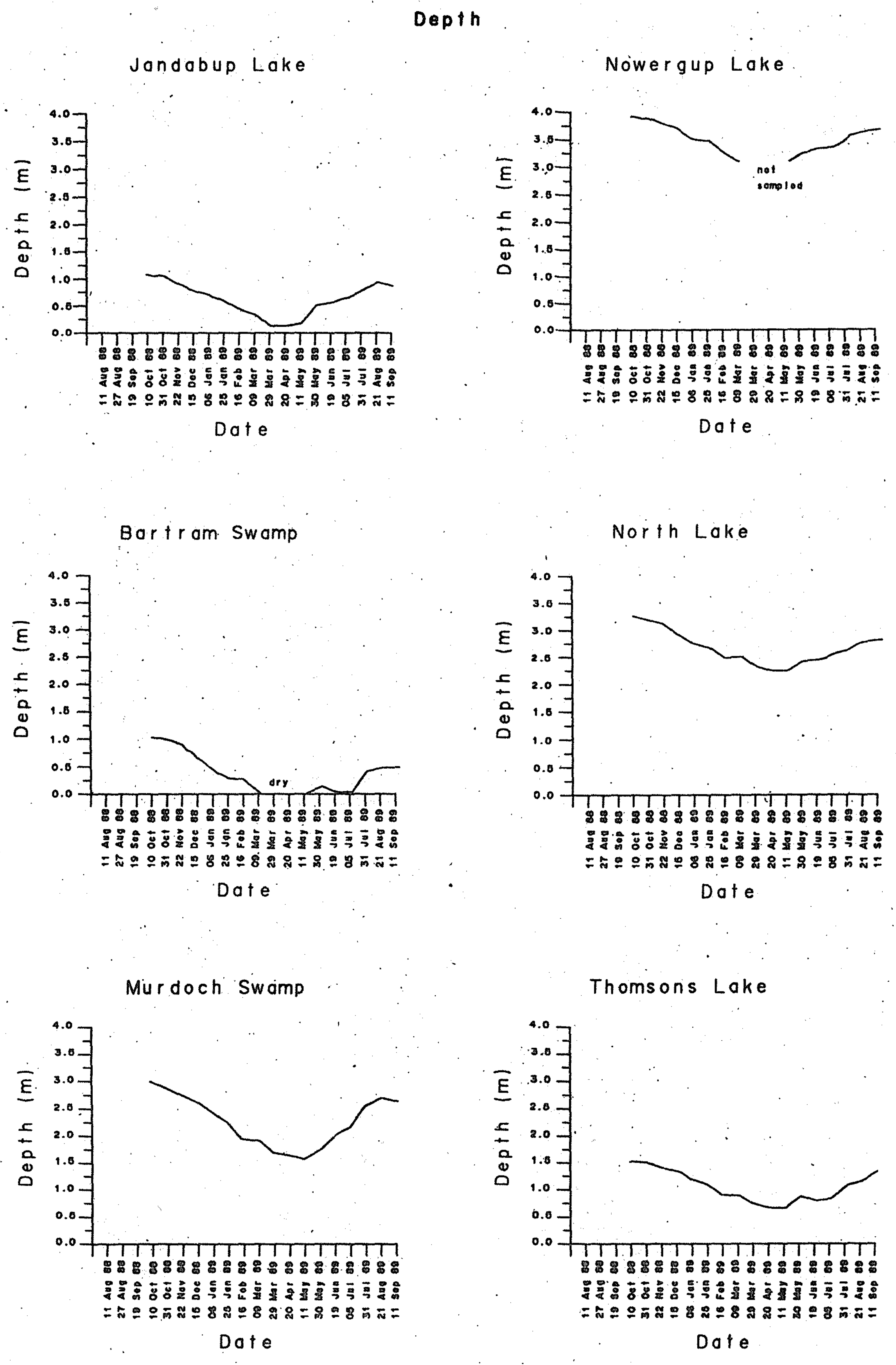

Figure 3.1 Depth (m) recorded at the six wetlands between August 1988 and September 1989.

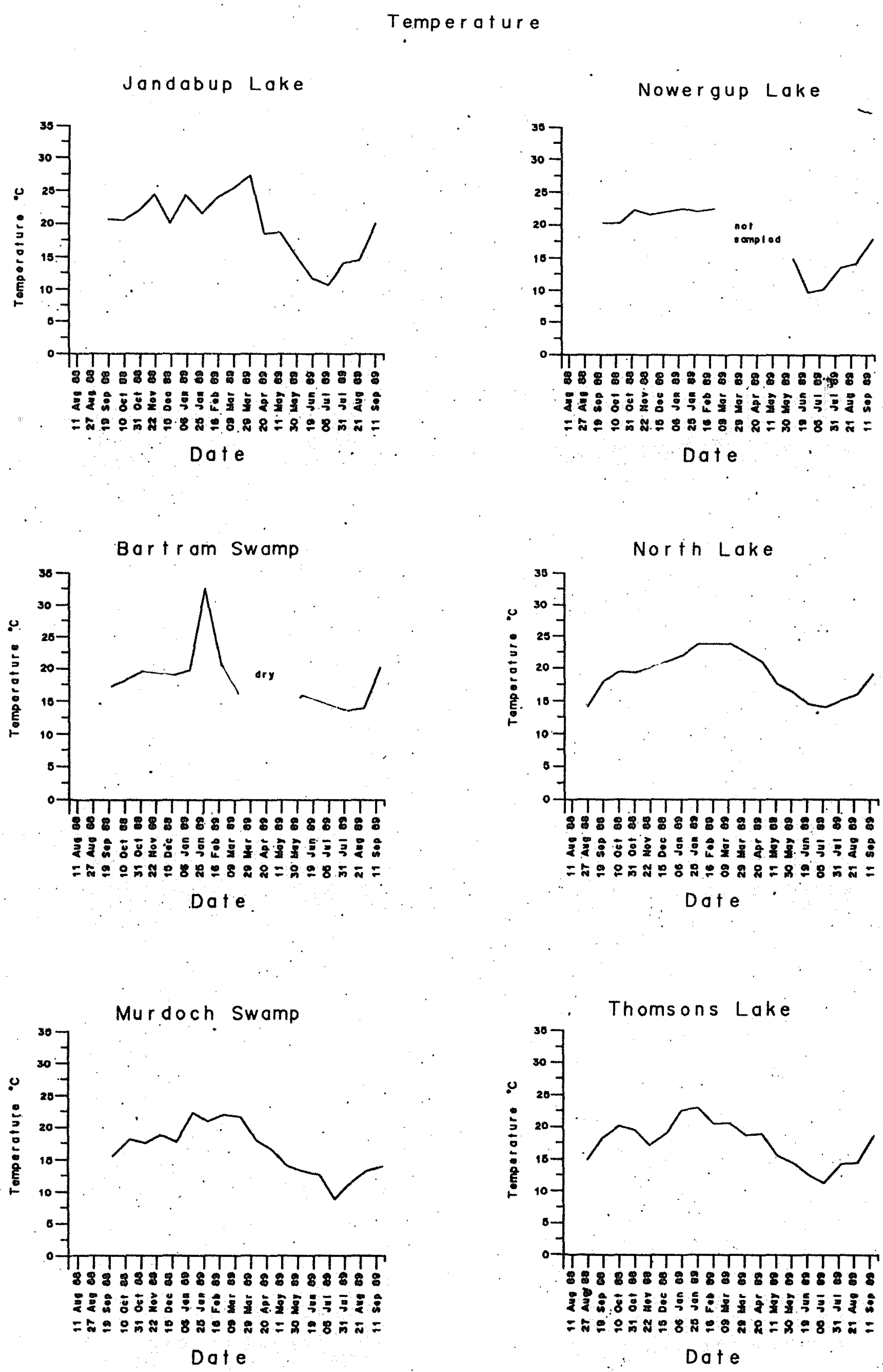

Figure 3.2 Temperature (°C) recorded at the six wetlands between August 1988 and September 1989.

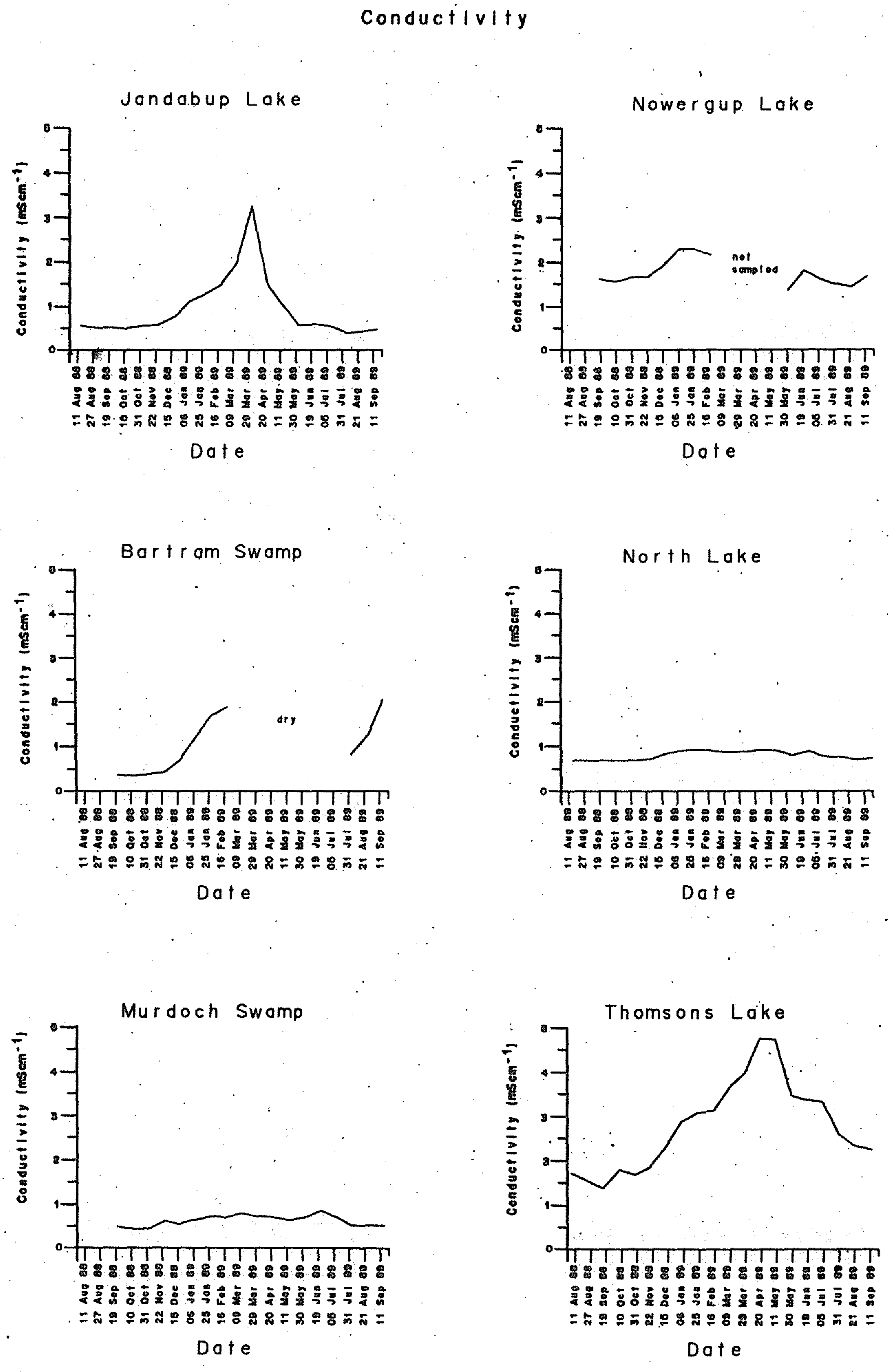

Figure 3.3 Conductivity ($mScm^{-1}$) recorded at the six wetlands between August 1988 and September 1989.

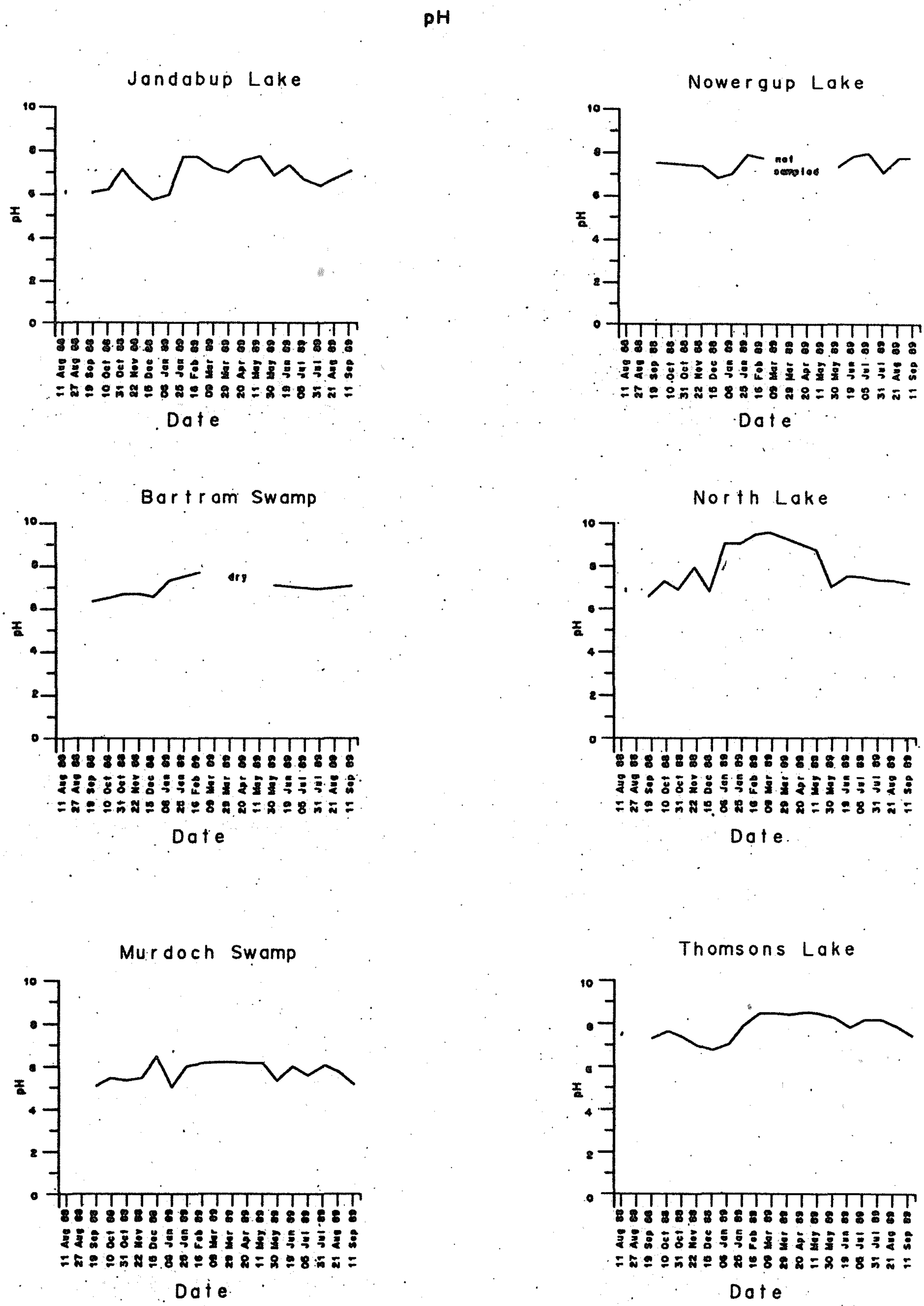

Figure 3.4 pH recorded at the six wetlands between August 1988 and September 1989.

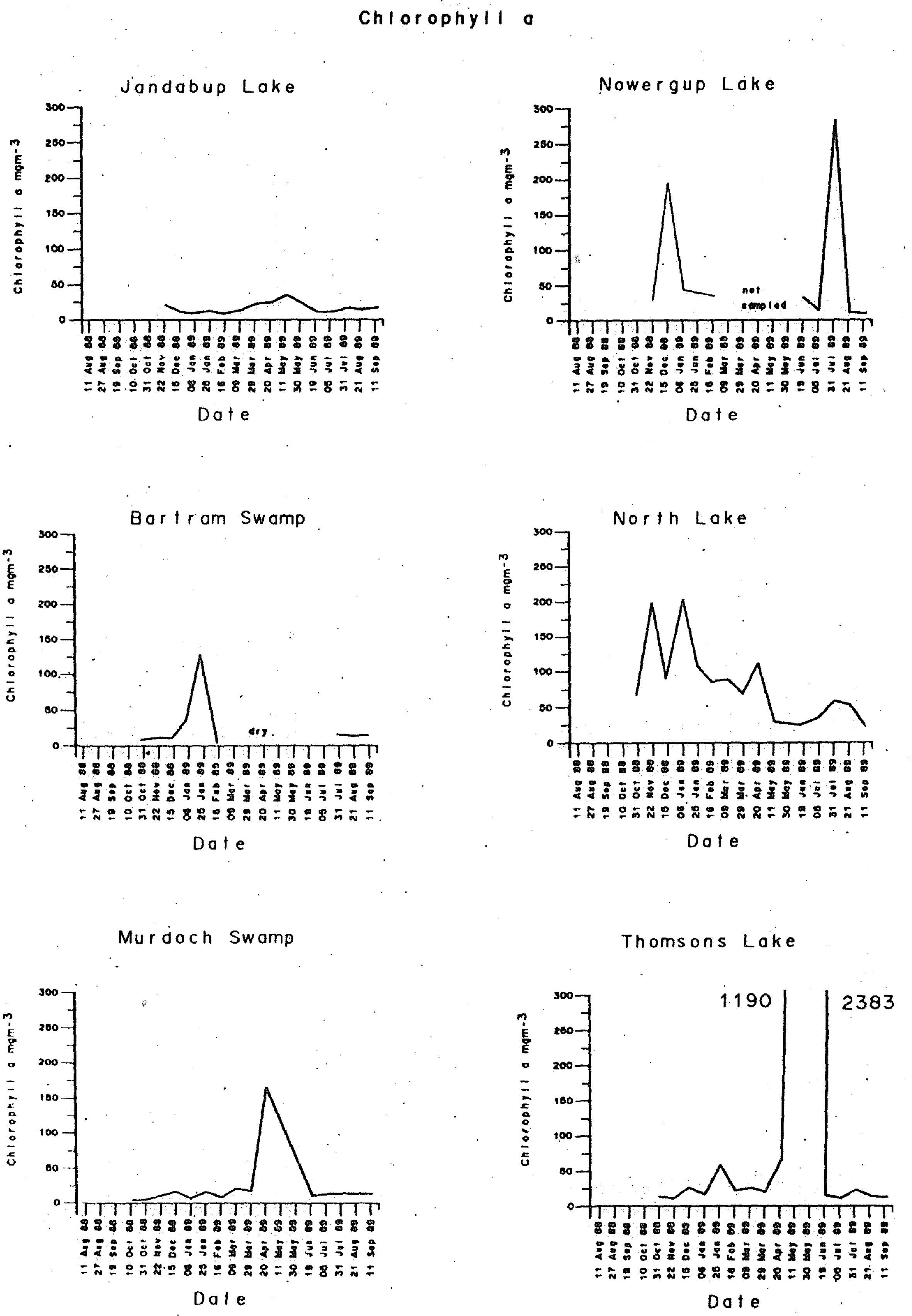

Figure 3.5 Chlorophyll a (mgm^{-3}) recorded at the six wetlands between August 1988 and September 1989.

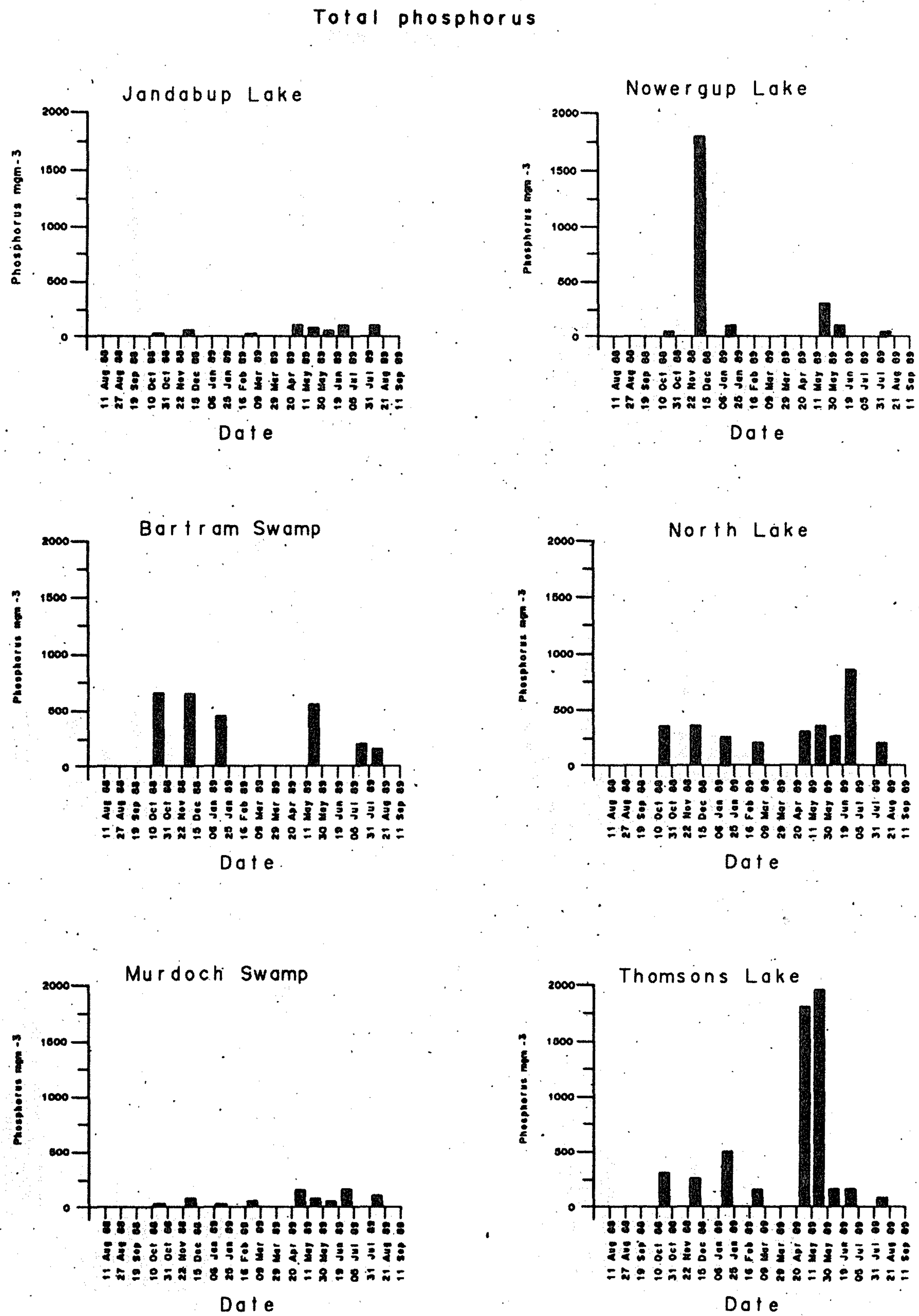

Figure 3.6 Total phosphorus (mgm^{-3}) recorded at the six wetlands between August 1988 and September 1989.

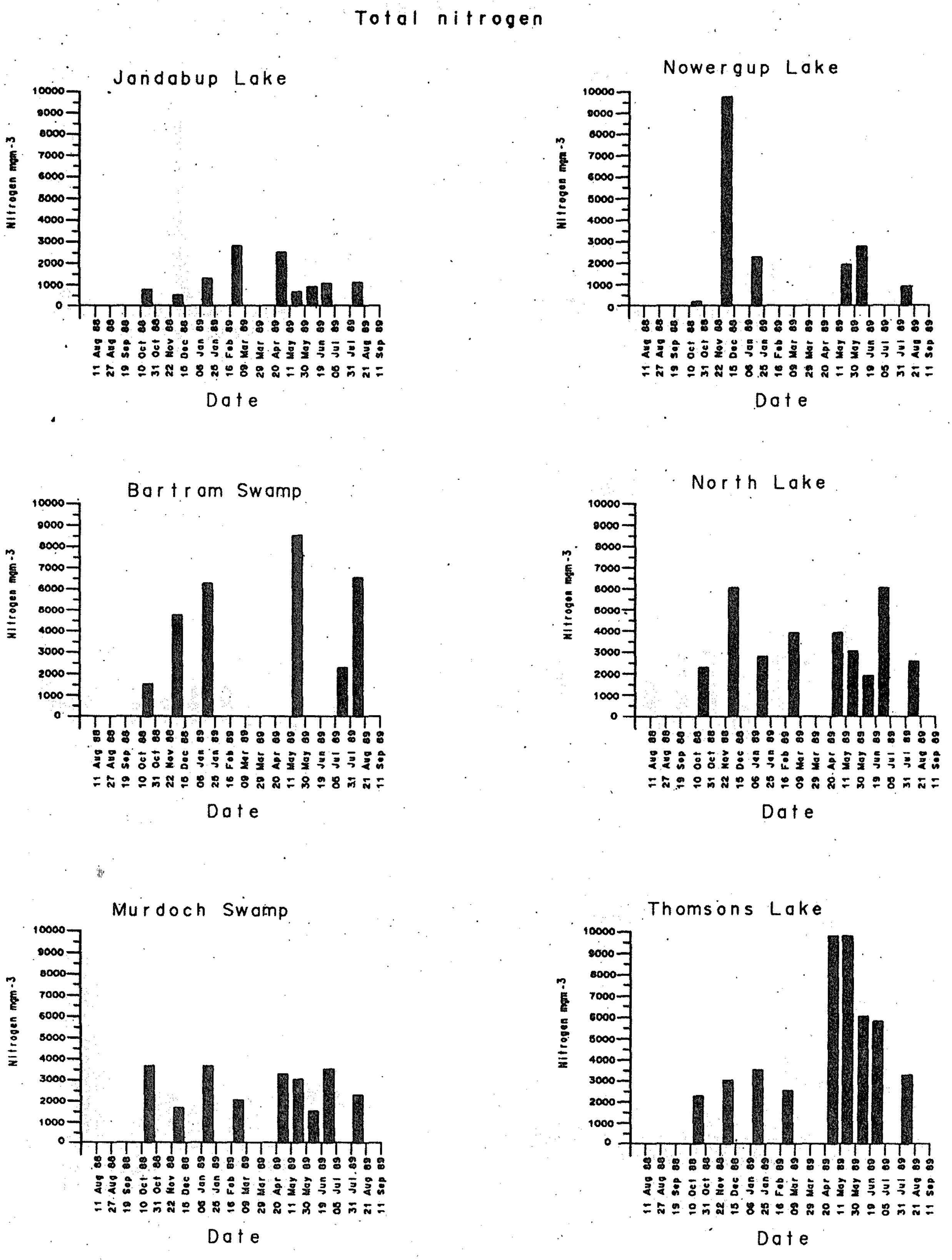

Figure 3.7 Total nitrogen (mgm^{-3}) recorded at the six wetlands between August 1988 and September 1989.

Table 3.1 Range, mean and standard deviation of the physicochemical parameters in the six wetlands between August 1988 and September 1989. Depth (m), Temp = temperature (°C), Cond = conductivity ($mScm^{-1}$), Chl a = chlorophyll a (mgm^{-3}), Phos = total phosphorus (mgm^{-3}) and Nitr = total nitrogen (mgm^{-3}). X = mean, SD = standard deviation.

	Jandabup	Bartram	Murdoch	Nowergup	North	Thomsons
Depth						
Range	0.13-1.11	0.00-1.05	1.58-3.08	3.35-4.01	2.33-3.37	0.66-1.55
X±SD	0.64±0.31	0.48±0.34	2.32±0.47	3.67±0.22	2.76±0.31	1.07±0.29
Temp						
Range	11.0-28.0	14.3-35.0	9.50-30.0	11.0-23.0	14.8-25.0	11.2-23.0
X±SD	19.9±4.7	19.9±5.2	16.9±3.9	18.7±4.4	19.9±3.5	17.5±3.3
Cond						
Range	0.48-3.31	0.33-1.97	0.35-0.72	1.47-2.32	0.57-0.83	1.29-4.74
X±SD	0.94±0.71	0.82±0.60	0.52±0.11	1.77±0.29	0.70±0.09	2.81±0.99
pH						
Range	5.69-7.86	6.51-7.82	5.01-6.61	6.83-7.93	6.81-9.74	6.56-8.32
X±SD	6.84±0.68	7.00±0.36	5.81±0.47	7.50±0.35	8.05±1.02	7.64±0.56
Chl a						
Range	5-31	5-122	2-158	10-283	24-202	5-2383
X±SD	11.3±7.2	26.0±37.2	23.7±40.0	70.0±87.7	82.3±53.0	287.1±707.9
Phos						
Range	1-107	111-688	24-148	34-1823	160-875	65-1945
X±SD	53±36	440±225	76±45	397±645	332±203	583±699
Nitr						
Range	611-2594	1482-8633	1363-3694	141-20634	1905-6156	2235-42812
X±SD	1341±811	5083±2501	2724±845	4784±7143	3644±1468	12576±16218

Authority. The wetland evaporates to a shallow pool in summer and autumn, however, complete drying of the lake has not occurred for at least 16 years (local resident Brian Smith, pers. comm. 1989). Conductivity was the second highest of the six wetlands, and the pH second lowest. Jandabup Lake could be classified as mesotrophic (c.f. OECD 1982) with the lowest levels of chlorophyll *a*, total phosphorus and total nitrogen.

Bartram Swamp
Of the six wetlands, this was the shallowest (maximum depth 105cm), and the only one that dried completely. It also reached the highest water temperature, but had the lowest minimum conductivity and a relatively neutral pH. The colour of the water was extremely dark. It can be classified as eutrophic (c.f. OECD 1982) with the third lowest chlorophyll *a* levels, and the second highest mean total phosphorus and nitrogen levels. There was no green algal or cyanobacterial blooms during the sampling period, but the floating aquatic macrophyte *Lemna* sp. was collected in summer.

Murdoch Swamp
Murdoch Swamp was very darkly coloured, similar to Bartram Swamp. It was the second deepest and had the coolest minimum and mean temperature in

winter, probably because of the shading afforded by the closed-canopy. Conductivity was lowest, and so was pH, and although chlorophyll *a*, total phosphorus and total nitrogen levels were second lowest, this wetland was classified as eutrophic (c.f. OECD 1982). The floating aquatic macrophyte *Azolla* sp. was present throughout the year in small quantities. In autumn a green algal scum formed in the excavated permanent portion.

Nowergup Lake
Nowergup Lake was not sampled from 9 March to 11 May 1989 when the open water was inaccessible due to the soft surrounding mud. Nowergup Lake was the least coloured of the six wetlands, and was also the deepest. It has the second highest mean conductivity and the highest minimum conductivity. The pH was relatively neutral, and the chlorophyll *a*, total phosphorus and total nitrogen levels were the third highest. This wetland can be classified as hypertrophic according to OECD (1982) recommendations. A cyanobacterial bloom occurred in December and early January, and the floating aquatic macrophyte *Lemna* sp. was present at the end of January 1989. Extensive beds of *Polygonum* sp., *Baumea* sp. and *T. orientalis* surround the wetland.

North Lake
Of the six wetlands, this was the second deepest. It also had the second lowest conductivity, and the highest mean and maximum pH. The chlorophyll *a* levels were the second highest, and the total phosphorus and nitrogen levels were the fourth highest. Using the OECD (1982) guidelines this wetland was classified as hypertrophic. The water was almost clear, and during the year sampled, there was a continuous cyanobacterial bloom.

Thomsons Lake
Although drying occurred in the 10 years prior to this study, the wetland did not dry during 1989. The water colour was relatively dark, although less so than Murdoch Swamp and Bartram Swamp. Of the six wetlands, the conductivity of Thomsons Lake was the highest. A cyanobacterial bloom occurred from January to June 1989. It was worst in May, with 30cm thick slurry of cells forming a gel on the surface of the water, extending for at least 200m from the fringing vegetation into the open water. Green algae was present in March and the floating macrophyte *Lemna* sp. was found in January. The pH was high during the algal bloom, but otherwise relatively neutral.

Levels of chlorophyll *a*, total phosphorus and total nitrogen found during the cyanobacterial bloom exceed all previous records for wetlands in metropolitan Perth. Predictably, this wetland was classified as hypertrophic according to the OECD (1982) categories.

The timing of drying and refill
The length of time that Thomsons Lake was dry, varies from not at all to 7 months. Between 1978 and 1988 the lake was usually dry for approximately 4 months each year (see Table 3.2). The months when water levels were lowest was variable; occasionally February or March, and often April or May. The timing of refill (in April, May or June), was less variable than the timing of drying (by December, through to April).

Bartram Swamp and most of the other wetlands on the Jandakot Mound that lie between Forrestdale Lake and Thomsons Lake (e.g. Gibbs/Bartram Swamp, Twin Bartram Swamps) were dry from mid-February to late July 1989; a period of 5.5 months. In 1990 Bartram Swamp dried from January until the end of July, and was dry again in December. Two monitoring bores JM26 and JM31 are close to Bartram Swamp and the period when Bartram Swamp was dry in 1989, 1990 and 1991 was related to AHD levels at these monitoring bores. If hypothetical wetlands existed at these bores they would reflect what was happening at Bartram Swamp in years prior to this study (when there are no records for Bartram Swamp). Table 3.3 and 3.4 show when these "wetlands" would have been dry. It is interesting to note that after 1986, there is good correspondence between the water levels in these two hypothetical wetlands, but prior to 1986, the "wetland" at JM26 dried for longer than JM31. This difference may be due to changes in local land-use. The length of time the "wetland" at JM31 was dry varied between 1–6.5 months, usually 4–5 months. At JM26 it was dry for 3 to 7 months, usually 5 months. The driest months were always April or May.

For Thomsons Lake there was a statistically significant correlation beteween the number of dry months and both the minimum groundwater levels ($r=0.777$, p0.05, $n=13$), and previous years maximum groundwater levels ($r=0.737$, p0.05, $n=13$) (Figure 3.8). However, the correlation between the previous years rainfall and groundwater levels was not significant. The relationship between rainfall and water levels in Thomsons Lake was probably confounded by drainage and land use activity in the catchment (e.g. clearing). The effect of drainage and evaporation from the wetland

Table 3.2 The number of months Thomsons Lake did not contain water for the years that records show that the lake dried.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Previous Years Rainfall	Water Level Minimum	Previous Years Maximum
1962		---	---	---	---	---							733mm	10.85	<12.30
1963		---	---	---	---	---							1040mm	10.97	<12.30
1978		---	---	---	---								600mm	10.93	12.37
1979			---	---	---	---						---	840mm	11.39	12.78
1980	---	---	---	---	---	---							645mm	10.75	12.18
1981		---	---	---	---	---							809mm	11.12	12.53
1982				---	---								785mm	11.43	12.56
1983		---	---	---	---	---							814mm	11.26	12.71
1984		---	---	---	---	---							762mm	11.51	12.76
1985				---	---								850mm	11.62	12.85
1986	---	---	---	---	---								693mm	11.44	12.66
1987				---									929mm	11.78	13.04
1988				---									769mm	11.74	12.88

Table 3.3 The number of months the hypothetical wetland at bore JM26 (and by inferance Bartram Swamp) did not contain water assuming that Bartram Swamp was dry when the level in this monitoring bore was below 26.6mAHD.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Previous Years Rainfall	Water Level Minimum	Previous Years Maximum
1976	---	---	---	---	---	---							725mm	26.25m	27.38m
1977		---	---	---	---	---	---						752mm	26.10m	27.17m
1978	---	---	---	---	---	---							600mm	26.04m	26.95m
1979			---	---	---	---							840mm	26.30m	27.51m
1980	---	---	---	---	---	---							645mm	25.88m	27.07m
1981		---	---	---	---	---							809mm	26.10m	27.18m
1982		---	---	---	---	---							785mm	26.26m	27.16m
1983		---	---	---	---	---							814mm	26.15m	27.30m
1984		---	---	---	---								762mm	26.25m	27.45m
1985		---	---	---	---	---							850mm	26.19m	27.56m
1986	---	---	---	---	---								693mm	26.12m	27.28m
1987		---	---	---	---	---							929mm	26.03m	27.51m
1988	---	---	---	---	---								769mm	26.09m	27.28m
1989		---	---	---	---	---							835mm	26.27m	27.49m
1990	---	---	---	---	---	---	---						741mm	25.96m	27.19m

Table 3.4 The number of months the hypothetical wetland at bore JM31 (and by inferance Bartram Swamp) did not contain water assuming that Bartram Swamp was dry when the level in this monitoring bore was below 25.6mAHD.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Previous Years Rainfall	Water Level Minimum	Previous Years Maximum
1976		---	---	---	---								725mm	25.28m	26.63m
1977				---	---	---							752mm	25.37m	26.19m
1978		---	---	---	---	---							600mm	25.24m	26.18m
1979			---	---	---								840mm	25.45m	26.73m
1980	---	---	---	---	---	---							645mm	25.16m	26.23m
1981		---	---	---	---								809mm	25.24m	26.46m
1982					---								785mm	25.54m	26.50m
1983		---	---	---	---	---							814mm	25.21m	26.74m
1984		---	---	---	---								762mm	25.29m	26.64m
1985		---	---	---	---	---							850mm	25.19m	26.53m
1986	---	---	---	---	---	---							693mm	25.10m	26.34m
1987		---	---	---	---	---							929mm	25.35m	26.57m
1988		---	---	---	---								769mm	25.05m	26.40m
1989		---	---	---	---	---							835mm	25.33m	26.69m
1990	---	---	---	---	---	---							741mm	25.15m	26.25m

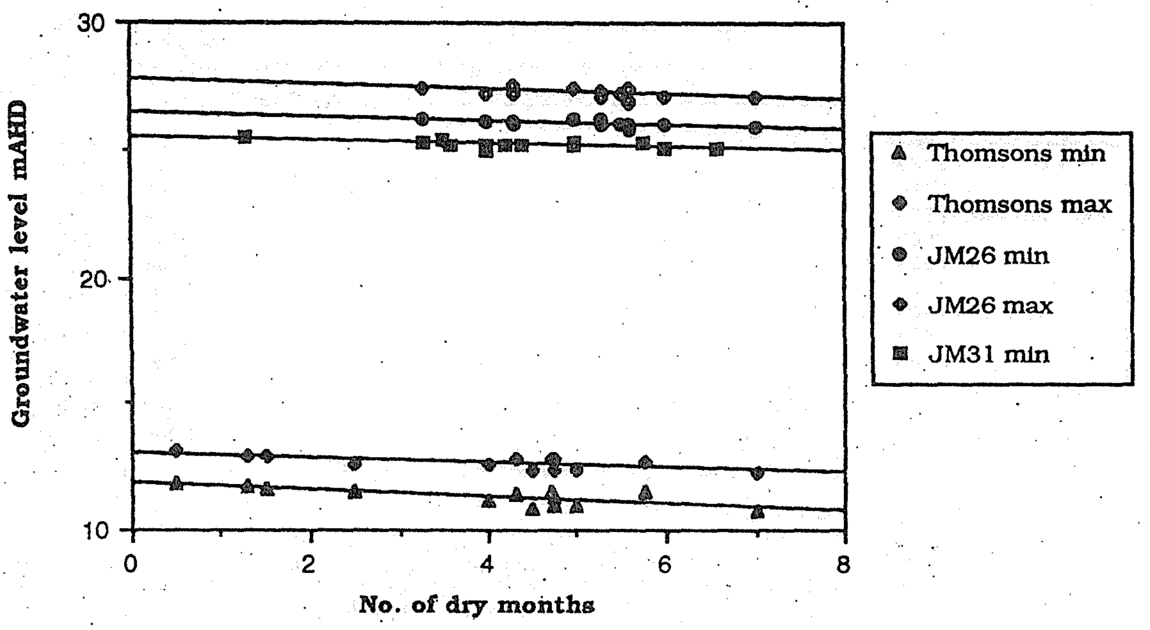

Figure 3.8 The relationship between groundwater levels and the number of months Thomsons Lake and the hypothetical wetlands at wells JM26 and JM31 were dry.

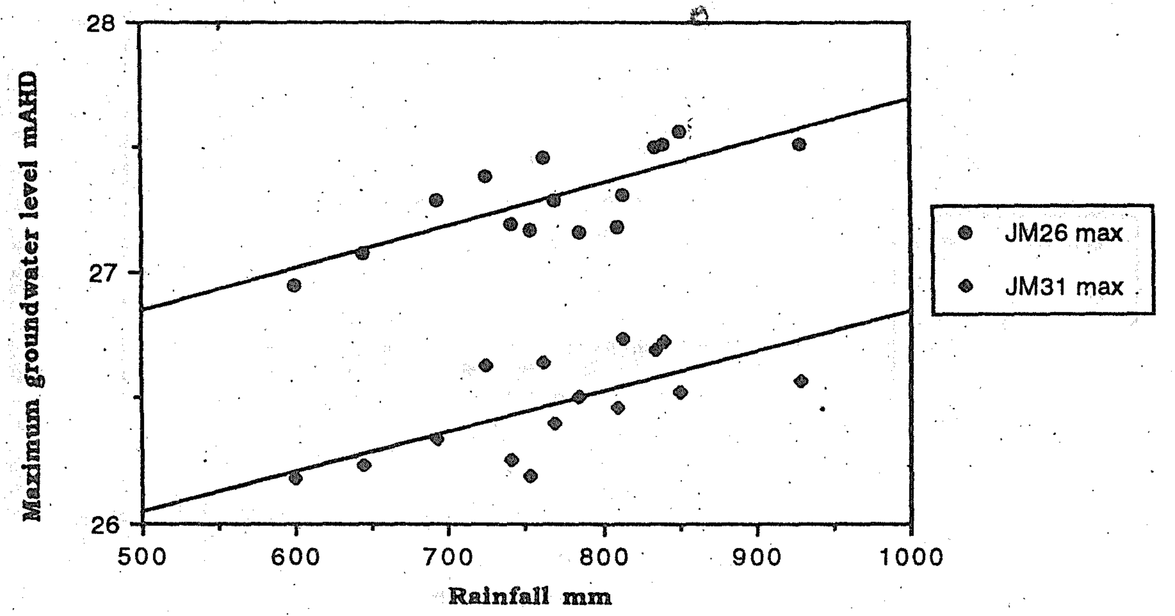

Figure 3.9 The relationship between rainfall and maximum groundwater levels at the wells JM26 and JM31.

surface can be circumvented to some degree by looking at sub-surface groundwater levels at the hypothetical wetlands at monitoring bores JM26 and JM31.

At the "wetland" at JM26 there was a significant correlation between the number of dry months and the minimum (r=0.633, p0.05, n=15) and the previous years maximum groundwater levels (r=0.551, p0.05, n=15) (see Figure 3.8). In addition there was a significant positive correlation between the previous years rainfall and the maximum groundwater levels (r=0.777, p0.05, n=15) (see Figure 3.9). At the "wetland" at JM31 there was a significant correlation between rainfall and the previous years maximum water level (r=0.678, p0.05, n=15) (Figure 3.9). There was also a significant correlation between the number of dry months and the minimum groundwater levels (r=0.654, p0.05, n=15) (Figure 3.8).

Water level data from Thomsons Lake showed a change in the rate of drying after groundwater extraction commenced in 1979 (Figure 3.10). Prior to 1979 the maximum rate of drop in water level was 1.48cm/day (30 Nov 1973–12 Feb 1974). After 1979, the rate of drop in water level exceeded the previous maximum: 1.66cm/day (15 Nov–17 Dec 1979), 2.36cm/day (15 Sep–18 Oct 1982), 1.83cm/day (16 Jan–15 Feb 1984), 2.03cm/day (31 Mar–29 Apr 1987) and 1.57cm/day (1 Feb– 1 Mar 1988). At bores JM26 and JM31, the rate of drop of groundwater may have increased slightly since pumping began (see Figures 3.11 and 3.12). However, these trends are tentative since there were only three years records before pumping started. The rate of drying for the six wetlands of this study (Table 3.5) did not exceed 2cm/day with maximum rates of decrease between 0.74 and 1.46cm/day.

Table 3.5 The increase or decrease in water level in the six wetlands in cm/day

Date	Jandabup	Bartram	Wetland Murdoch	Nowergup	North	Thomsons
31 Oct 88	-0.19	-0.20	-0.56	-0.14	-0.40	-0.08
22 Nov 88	-0.57	-0.53	-0.61	-0.39	-0.42	-0.38
15 Dec 88	-0.68	-1.04	-0.63	-0.41	-0.83	-0.48
06 Jan 89	-0.38	-1.10	-0.80	-0.86	-0.76	-0.60
25 Jan 89	-0.55	-0.95	-1.10	-0.20	-0.42	-0.74
16 Feb 89	-0.59	-1.32	-1.46	-1.05	-0.82	-0.74
09 Mar 89	-0.62		-0.14	-0.71	-0.05	-0.15
29 Mar 89	-1.00		-1.05		-0.81	-0.71
20 Apr 89	0.00		-0.35		-0.38	-0.36
11 May 89	+0.23		-0.36		+0.05	+0.05
30 May 89	+1.83	+0.68	+1.00		+0.89	+1.21
19 Jun 89	+0.34	-0.50	+1.35	+0.50	+0.20	+0.50
05 Jul 89	+0.50	0.00	+1.25	0.00	+0.50	+0.31
31 Jul 89	+0.58	+1.42	+1.46	+0.77	+0.42	+1.00
21 Aug 89	+0.73	+0.29	+0.76	+0.55	+0.55	+0.27
11 Sep 89	-0.48	-0.05	-0.29	+0.10	+0.19	+0.86
max dec	-1.00	-1.32	-1.46	-1.05	-0.83	-0.74
max inc	+1.83	+1.42	+1.46	+0.77	+0.89	+1.21

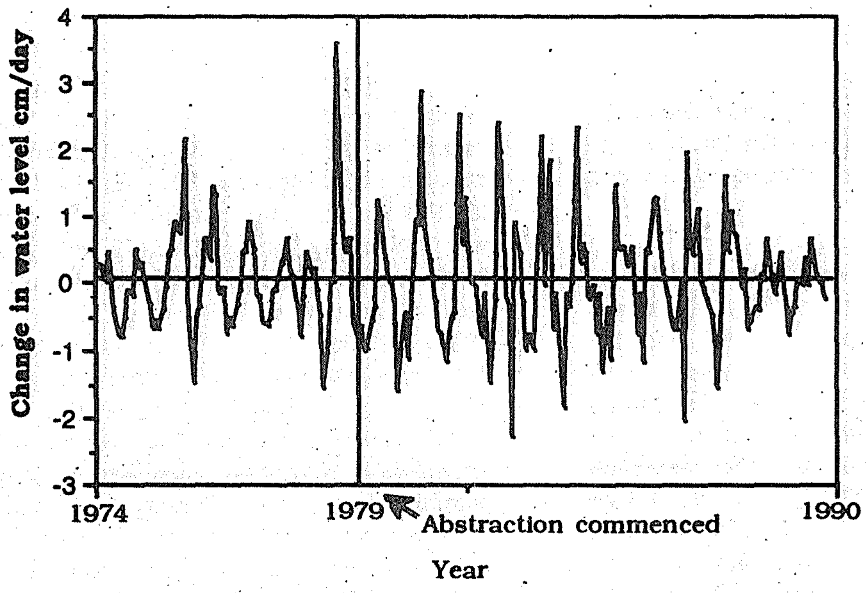

Figure 3.10 Rates of changes in water level (cm/day) at Thomsons Lake.

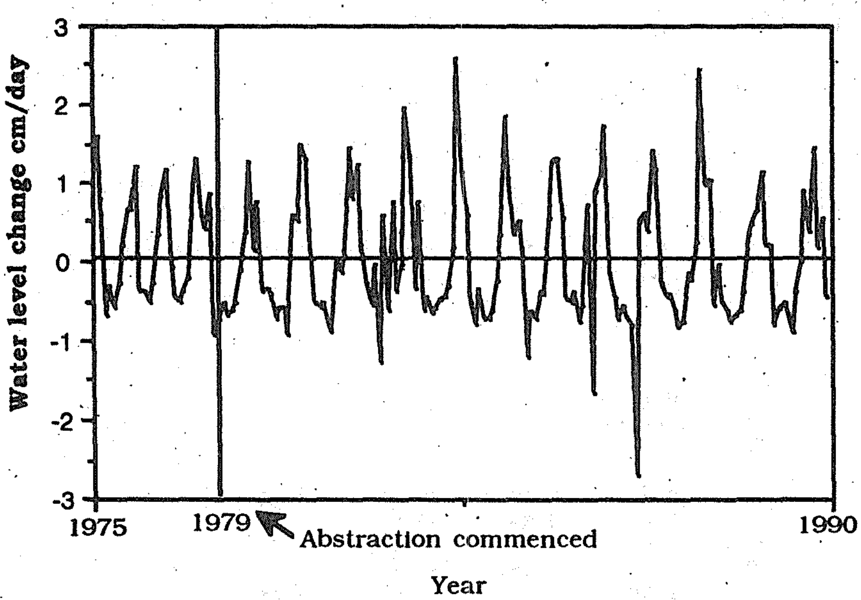

Figure 3.11 Rates of change in water level (cm/day) at well JM26.

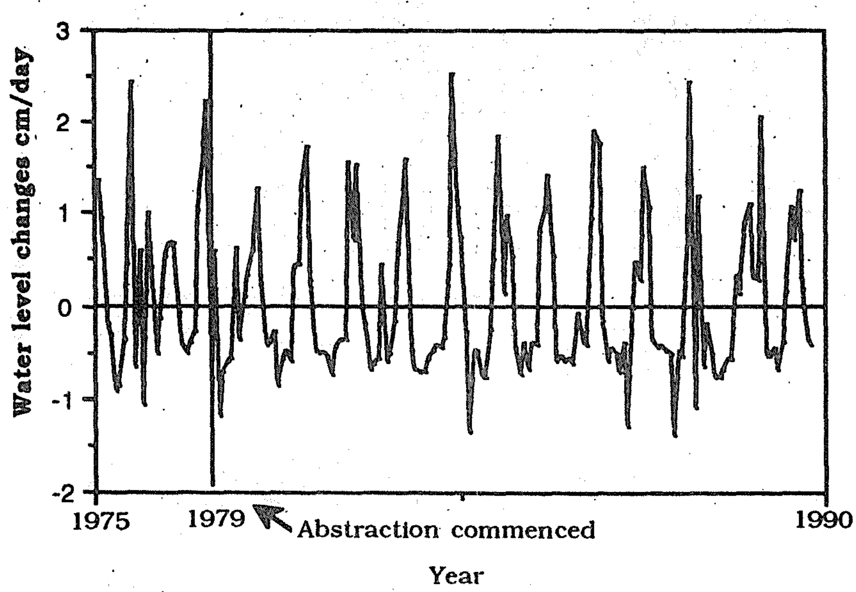

Figure 3.12 Rates of change in water level (cm/day) at well JM31.

Discussion

These six wetlands represent a range of wetlands that are a subset of the types found on the Swan Coastal Plain. While only one of the wetlands (Bartram Swamp) was truly seasonal, Jandabup Lake was only 13cm from drying and was maintained at this level artificially for several weeks. Murdoch Swamp and Nowergup Lake covered a much reduced area during the drought period with water retreating to a small, deep, central portion of both wetlands. North Lake and Thomsons Lake covered an area that only decreased slightly during the drought period.

There was also a range of nutrient levels from mesotrophic Jandabup Lake through eutrophic Bartram Swamp and Murdoch Swamp to the three hypertrophic wetlands, Nowergup Lake, North Lake and Thomsons Lake. Throughout this report, the wetlands will be arranged in order of increasing nutrient levels from Jandabup Lake to Thomsons Lake.

The size of the six wetlands also varied. Murdoch Swamp was the smallest, with Bartram Swamp not much larger. North Lake and Nowergup Lake were of a similar medium size, while Jandabup Lake and Thomsons Lake were relatively large.

Colour ranged from clear in Nowergup Lake, slightly coloured in North Lake, a redish-brown in Jandabup Lake to a deep brown in Thomsons Lake, and almost black in Bartram Swamp and Murdoch Swamp. Since Bartram Swamp and Murdoch Swamp were highly coloured, had fairly high nutrient levels, yet no biological evidence of eutrophication, these two wetlands are better characterized as dystrophic.

Rainfall has the most significant impact on groundwater levels (Ventriss 1989). Groundwater recharge occurs first in wetlands and later by infiltration from the land surface (Allen 1981). During the relatively wet period between 1920–1940 water levels would have been 2–3m higher than in the relatively dry period between 1978–1988. The magnitude of the fluctuations is influenced by the hydraulic parameters of the aquifer which vary from site to site (Ventriss 1989).

The main groundwater recharge in response to rainfall is during the period April to October. This is accompanied by a rise in the water table of about 0.2m near the coast, 0.5–1.5m on the Bassendean Dunes and up to 4.5m in the Pinjarra Plain (Moncrieff 1974). Groundwater levels are lowest in March–April and rise quickly after the start of the winter rain to peak in September–October.

Records for the past 30 years show that it was common for the seasonal wetlands on the Jandakot Mound between Forrestdale Lake and Thomsons Lake (and probably elsewhere on the Swan Coastal Plain including the Gnangara Mound) to remain dry for four or five months most years. In years of high rainfall many of the wetlands do not dry at all. In years of average or below average rainfall the length of the dry phase can vary from only a few weeks to 7 months.

The timing of refill of seasonal wetlands appears to be directly in response to rainfall, because the dry phase ceased when a large volume of rain fell and refill occurred rapidly. A rise in water levels of 2.2–2.8cm/day is not uncommon in Thomsons Lake. The timing of drying was affected by the previous years rainfall, and the previous years maximum and minimum water levels. In years of below average rainfall the groundwater levels are lower and therefore, drying of the seasonal wetlands occurs earlier. The timing of drying is primarily a response to the volume of rainfall, while the timing of refill is primarily a response to the timing of rainfall.

For Thomsons Lake and the hypothetical wetlands at monitoring bores JM26 and JM31 there was a correlation between the minimum groundwater levels and the number of dry months. The lower the water levels the longer the wetlands were dry. The hypothetical wetlands at JM26 and JM31 produced a correlation between rainfall and the previous years maximum groundwater levels, but this relationship was not significant at Thomsons Lake probably due to the drains entering the wetland.

Water levels in Water Authority monitoring bores JM26 and JM31 only exceeded a decrease of 2cm/day on a very few occasions and only after groundwater extraction had commenced. These data suggest that it is possible that groundwater extraction has lowered the groundwater level and prolonged the dry phase at monitoring bores JM26 and JM31 and may have increased the rate of drop of the water table. It is possible that the maximum rate of drop in the water level of Thomsons Lake may have also increased following the commencement of groundwater extraction in 1979.

Intuitively, a drop of a meter in one month (3cm/day) seems too rapid in these shallow

wetlands, because this would mean a decrease from maximum water levels to dry within a month in some wetlands (e.g. Bartram Swamp or Gibbs/Bartram Swamp). Care needs to be taken to ensure that groundwater extraction does not increase the maximum rate of drop in water level above 2cm/day, and should usually be much less than this.

4 Information on individual taxa

This chapter contains information on the spatial and temporal characteristics of individual taxa and uses it to elucidate their possible response to seasonal drying, nutrient enrichment and the presence fish.

Introduction

Management of the wetlands of the Swan Coastal Plain needs to be based upon biological information on the species that inhabit these wetlands, in particular, on a knowledge of life histories and habitat requirements of individual taxa. However, there is little information on the life histories or habitat requirements of most of the aquatic fauna. An abundance of information is available on the introduced mosquitofish *Gambusia holbrooki* (see Lloyd *et al.* 1986 for an Australian perspective), while much less is known of the goby *Pseudogobius olorum* (Gill pers. comm.). Aspects of the biology and habitat preferences of the frogs are documented (Main 1965), and the same is true of the tortoise *Chelonia oblongata* (Clay 1981 and Kuchling 1988) (see Section 2). Information on the waterfowl is relatively plentiful (e.g. Jaensch & Vervest 1988) although little is known of their breeding success in urban wetlands, and this is currently under investigation (see Section 1). The invertebrates are the most abundant component of the aquatic fauna, and yet almost nothing is known about the life histories of these animals. Collections of invertebrates to establish a baseline for biological monitoring commenced in 1985 (see Davis & Rolls 1987), and stimulated interest in the ecology of the wetlands. The chironomids have received attention partly because of their nuisance value to residents living near eutrophic wetlands (Davis *et al.* 1988, 1989, 1990 and Pinder *et al.* 1991). The taxonomy of the lentic chironomid species and aspects of their biology was examined by Edward (1964). These studies notwithstanding, basic biological information on the majority of the taxa found in these wetlands is not available.

Information has been obtained to identify wetlands of particular conservation value by Davis *et al.* (1993) by examining the macroinvertebrate species present in 41 wetlands in the Perth metropolitan region. This study has classified wetland types, and identified wetlands that contain rare taxa or species with restricted distributions. Information concerning the impact of eutrophication and seasonal drying on invertebrate distribution and community structure was also produced. Only two or three samples were collected over two years from these 41 wetlands depending on whether the wetlands contained water on each sampling occasion. While this has the advantage of sampling a large number of wetlands, detailed information on individual taxa is not available. The present study with more frequent samples in just six wetlands compliments the study of Davis *et al.* (1993).

The life cycle of a species is the sequence of morphological stages and physiological processes that link one generation to the next (Butler 1984). The components of the life cycle are the same for all members of the species. The details of the variable events associated with that life cycle that make up the life history vary among individuals and populations (Butler 1984).

Life history information consists of details of reproduction (mode, fecundity and survivorship), pattern and rate of growth and development (number of instars, survivorship, longevity and mode of death), dormancy (behavioural and physiological aspects), migration, habitat requirements, response to environmental factors, seasonal timing of development, the number of generations per year, and the length of the life cycle (Oliver 1979, Waters 1979 and Butler 1984). It was impossible to determine the life histories or even life cycles of all of the species of invertebrates in Perth's wetlands in three years. Nevertheless, management of the wetlands to conserve the fauna requires this knowledge. Therefore, collections of aquatic invertebrates were made in an attempt to obtain the maximum amount of information on seasonal timing of development, abundance and distribution for as many species as possible with regard to water levels, eutrophication and the presence of fish. At the very least it can be considered as progress towards understanding the life histories of the fauna, and has the potential to identify species which might be appropriate for experimental work in the future.

Throughout the following text the term "drought period" refers to the period when Bartram Swamp and the seasonal part of Murdoch Swamp, Nowergup Lake and Jandabup Lake was dry, from mid-February to the end of July 1989. In addition, the use of the phrase "adaptation to seasonal drying" refers to physiological and behavioural adaptations to seasonal drying, being characteristics that have arisen through natural selection (*sensu* Gould & Lewontin 1979, Gould 1980, 1982, and Gould & Vrba 1982). The following abbreviations are used throughout the text: A.C.T.= Australian Capital Territory, N.S.W. New South Wales, N.T.= Northern Territory, Qld.= Queensland, S.A.= South Australia, Tas.= Tasmania, Vic.= Victoria and W.A.= Western Australia.

Methods

Collecting

Samples were collected from six wetlands (Jandabup Lake, Bartram Swamp, Murdoch Swamp, Nowergup Lake, North Lake and Thomsons Lake) at approximately 21 day intervals between 11 August 1988 and 11 September 1989. Heuschele (1969) recommends bi-weekly sampling in order to follow the life cycles of many insects. Initially, bi-weekly samples were collected. Processing of these samples (sorting, identification, counting and measuring), required a minimum of 1.2 weeks per sample. Bi-weekly sampling would have generated 156 samples from the six wetlands, requiring 3.6 years to process. This was unacceptable, and consequently, samples were taken tri-weekly, generating 104 samples which required only 2.4 years to process.

Samples were obtained using a sweep net (dimensions 0.36x0.295x0.295m) with a 0.250mm mesh. The sweeps were taken in 1m units over a measured distance, usually 50m. The sweep net was moved up and down the water column to touch the substrate, and where possible through submerged or emergent aquatic vegetation. The net was moved as rapidly as possible with a view to catching fish in addition to the faster moving invertebrates such as odonates and notonectids. The samples were biased towards those animals that occupied the water column and vegetation rather than exclusively benthic animals. However, some benthic animals were collected since the sweeps sampled the uppermost benthic sediments. Cheal *et al.* (in press) also found that sweeps were more appropriate than cores or tows for sampling invertebrates in Perth's wetlands because they captured both benthic and water column taxa.

The volume of water sampled in each wetland varied between 2.228m^3 (30m sweep) when the wetlands were drying, to 18.570m^3 (250m sweep) in some early samples, but was usually 3.714m^3 (50m sweep). The volume of water sampled depended on the amount of habitat available to sample and this was directly influenced by water depth. The volumes of each sample are shown in Table 4.1. Early samples were very large (up to nine cubic metres of water sampled) and because of the time involved in processing these samples (up to three weeks per sample), it became evident that smaller samples (less than two cubic metres) were more suitable. The samples were preserved in the field by the addition of 100% ethanol. Animals removed from these samples in the laboratory were stored in 70% ethanol.

Table 4.1 The volume of water sampled in cubic metres for each sample.

Date	Wetland					
	Jandabup	Bartram	Murdoch	Nowergup	North	Thomsons
11 Aug 88	8.357				3.343	1.486
27 Aug 88	9.258				3.714	1.857
19 Sep 88	7.428	1.857	1.857	1.857	3.714	1.857
10 Oct 88	3.714	1.857	1.857	1.857	1.857	1.486
31 Oct 88	3.714	1.857	1.857	1.857	1.857	1.857
23 Nov 88	1.857	1.857	1.857	1.857	1.486	1.486
15 Dec 88	1.857	1.857	1.857	1.114	1.857	2.228
05 Jan 89	1.857	1.857	1.857	1.114	1.857	1.857
25 Jan 89	1.857	1.857	1.857	1.857	1.857	1.857
16 Feb 89	1.857		1.857	1.486	1.857	1.857
09 Mar 89	1.857		1.857		1.857	1.857
30 Mar 89	1.857		1.857		1.857	1.857
20 Apr 89	1.857		1.857		1.857	1.486
11 May 89	1.857		1.857		1.857	1.857
30 May 89	1.857	0.929	1.857	1.857	1.857	1.857
19 Jun 89	1.857		1.857	1.857	1.857	1.857
05 Jul 89	1.857		1.857	1.857	1.857	1.857
31 Jul 89	1.857	1.857	1.857	1.857	1.857	1.857
22 Aug 89	1.857	1.857	1.857	1.857	1.857	1.857
12 Sep 89	1.857	1.857	1.857	1.857	1.857	1.857

Sorting and counting animals
The vegetation (individual leaves and sticks) in the preserved samples was washed to remove animals. Mats of algae were retained since animals were entangled within them. The samples were passed through Endacott sieves (mesh size 2, 1, 0.5 and 0.25mm) either as a whole sample or in portions where samples weighed several kilograms. The contents of each sieve were placed into individual graduated beakers. The animals were detected using a Wild ME 5 dissecting microscope. The 2mm and 1mm sieve contents were seldom subsampled, while the 0.5 and 0.25mm sieve contents were often subsampled volumetrically.

Identification
Many macroinvertebrates were identified to species level. However, the zooplankton and Diptera which required micro-dissection and mounting on slides for species determination, were only identified to family level using the dissection microscope. The texts used for invertebrate identification were: CSIRO (1970), Williams (1980), Merrit & Cummins (1984) numerous taxa; De Deckker (1978, 1981a,b,c, 1982) Ostracoda; Williams & Barnard (1988), Williams (1962) Amphipoda; Nicholls (1944) Isopoda; Serventy (1938), Bray (1976) Palaemonidae; Watson (1962) Odonata; Lansbury (1970), Knowles (1974), Hemiptera; Watts (1963, 1978), Matthews (1980) Coleoptera; Allen (1982) fish. Trichoptera were identified by Alice Wells, *C. quincecarinatus* was identified by Ivor Growns, and Chris Watts confirmed and corrected the identifications of some of the Coleoptera.

Assigning animals to size classes
Animals were assigned to size classes to obtained evidence of cohorts in taxa identified to species and to obtain estimates of biomass where identification was only to family level. The precise measurement of all taxa collected was not possible because of the number of animals collected (over 5.9 million), and so the majority of taxa were divided into size classes based on the maximum length of the specimen. The size of individuals was estimated relative to a 6mm standard. Smaller animals such as the cyclopoid copepods were divided into only two size classes, while larger taxa (e.g. coleopteran larvae) were divided into as many as four size classes. The adult Coleoptera were relatively uniform in size within a species and were not divided into size classes. Table 4.2 details the size classes used.

The Odonata and the fish were selected for more detailed measurements. They were numerous, large and relatively long-lived, and therefore, ideal candidates for following cohorts over time. The width of the head capsules of the odonates was measured at its widest point using a stage graticule to 0.01mm. Odonates previously collected for wetland studies from July 1986 to May 1987 and from November 1987 to May 1988 were also identified and measured. Total length of the fish was measured to 0.1mm under the dissection microscope.

Frequency histograms of the head widths for more abundant odonate species were used to determine instars. Less numerous species were divided into four size classes (see Table 4.2). Frequency histograms were also constructed for the fish, but discrete size classes were not evident, and the fish were divided into arbitrary size classes with an interval of 5mm.

Data processing
The options for presentation of the data were as (a) raw numbers, (b) percentage frequency, or (c) numbers per cubic metre. Since the size of the samples differed between sampling dates and wetlands, use of raw numbers would have precluded comparisons of numbers of animals between samples. This method is most appropriate where sampling effort remains constant. Percentage frequency would enable comparison between samples without providing information on differences in abundance of animals. This method suits qualitative data, however, this data was collected quantitatively. The conversion of raw numbers to numbers of animals per cubic metre allowed the comparison of the number of animals within each size category and the relative abundance of animals between samples.

Raw numbers for each species were converted to number of animals per cubic metre based on the volumes shown in Table 4.1. The numbers were rounded to two decimal places and both the numbers within the size categories and the total numbers were derived from the raw data, rather than adding the converted numbers across the columns, to give a more accurate total. The information for each taxa is derived from this processed data and presented in the results.

Other sources of information
On 16 February 1989 at Murdoch Swamp, the water level had receded to the excavated portion of the wetland, leaving a small pool of water in the seasonally inundated part of the wetland of 1.3 x 0.8m in area. A qualitative collection of animals was obtained from this pool with the sweep net, and the animals were counted and identified.

From this same dry pool, animals were collected from moist substrate on 10 February 1991, when the water table was 0.3m below the lowest part of

Table 4.2 Size classes assigned to each taxa.

Taxa	Size classes Small	Medium	Large	V.lrg
Cnidaria: *Hydra* spp.	<2mm	>2mm		
Turbellaria: Tricladida spp.	<3mm	<6mm	>6mm	
Nematoda spp.	<3mm	<6mm	>6mm	
Annelida: Oligochaeta spp.	<3mm	<6mm	>6mm	
Hirudinea spp.	<3mm	<6mm	>6mm	
Mollusca: Bivalvia: *Sphaerium kendricki*	<3mm	<6mm	>6mm	
Gastropoda: *Ferrissia* sp 1	<2mm	<4mm	>4mm	
Gyrulus sp 1			>4mm	
Glyptophysa sp 1	<3mm	<6mm	<8mm	>8mm
Physa acuta	<3mm	<6mm	>6mm	
Lymnaea columella	<3mm	<6mm	>6mm	
Helisoma duryi	<3mm	<6mm	>6mm	
Arachnida: Hydracarina spp.	<1mm	<2mm	>2mm	
Orabatidae spp.	<2mm			
Crustacea:				
Conchostraca *Lynceus* sp 1	<3mm	<5mm	>5mm	
Cladocera: Sididae spp.	<1mm	<2mm	>2mm	
Chydoridae spp.	<2mm			
Macrothricidae spp.	<1mm	<2mm	>2mm	
Moinidae spp.	<2mm			
Daphniidae: *Daphnia* spp.	<1mm	<2mm	>2mm	
Simocephalus	<1mm	<2mm	>2mm	
Ostracoda: *Bennelongia australis*	<1mm	<2mm	>2mm	
Cypretta baylyi	<2mm			
Sarscypridopsis aculeata	<2mm			
Gomphodella maia	<2mm			
Lymnocythere mowbrayensis	<2mm			
Candonocypris novaezelandiae	<1mm	<2mm	>2mm	
Alboa woroora	<1mm	<2mm	>2mm	
Mytilocypris ambiguosa			>3mm	
Copepoda: Calanoidea spp.	<1mm	<2mm	>2mm	
Cyclopoidea spp.	<1mm	>1mm		
Harpactacoidea spp.	<1mm	>1mm		
Isopoda: *Paramphisopus palustris*	<3mm	<6mm	<10mm	>10mm
Amphipoda: *Austrochiltonia subtenuis*	<3mm	<5mm	>5mm	
Perthia acutitelson	<3mm	<6mm	<10mm	>10mm
Decapoda: *Cherax quinquecarinatus*	<30mm			
Palaemonetes australis		<20mm	>20mm	
Insecta:				
Ephemeroptera: *Cloeon* sp 1	<3mm	<6mm	>6mm	
Tasmanocoenis tillyardi	<3mm	<6mm	>6mm	
Odonata: *Austroagrion cyane*	<1mm	<2mm	>2mm	
Argiolestes pusillus	<1mm	<2mm	>2mm	
Procordulia affinis	<2mm	<3mm	>3mm	
Hemicordulia australiae	<2mm	<3mm	>3mm	
Orthetrum caledonicum	<2mm	<3mm	>3mm	
Diplacodes bipunctata	<2mm	<3mm	>3mm	
Austrothemis nigrescens	<2mm	<3mm	>3mm	
Zygopytera juveniles	<1mm			
Anisoptera juveniles	<2mm			
Hemiptera: Gelastocoridae *Nethra* sp 1		<8mm	>8mm	
Leptopodidae sp1	<3mm	<5mm	>5mm	
Saldidae *Saldula* sp 1	<2mm		>3mm	
Hydroimetridae sp 1	<3mm	<5mm	>5mm	
Gerridae sp 1		<5mm	>5mm	
Veliidae sp 1			>3mm	
Mesoveliidae sp 1	<2mm	<3mm	>3mm	
Diaprepocoris spp.	<3mm	<6mm	>6mm	
Sigara sp 1	<3mm	<6mm	>6mm	
Agraptocorixa eurynome	<3mm	<6mm	>6mm	
Agraptocorixa parvipunctata	<3mm	<6mm	>6mm	
Agraptocorixa hurtifrons	<3mm	<6mm	>6mm	
Micronecta robusta	<2mm	<3mm	>3mm	
Corixidae juvenile	<2mm	<6mm		
Ranatra sp 1	<20mm	<30mm	>30mm	
Enithares sp 1			>6mm	
Nychia sp 1	<4mm	<7mm		
Anisops spp.	<4mm	<6mm	>6mm	
Plea brunni	<2mm	<3mm	>3mm	
Neuroptera: Sisyridae sp 1	<3mm	<4mm	>4mm	

cont...

Taxa	Size classes Small	Medium	Large	V.lrg
Diptera: Tipulidae spp.	<3mm	<6mm	>6mm	
Culicidae spp.	<3mm	<6mm	>6mm	
Psychodidae spp.	<5mm			
Thaumeliidae spp.	<3mm	<6mm	>6mm	
Chironomidae spp.	<3mm	<6mm	<10mm	>10mm
Ceratopogonidae spp.	<3mm	<6mm	<10mm	>10mm
Stratiomyidae spp.	<3mm	<6mm	<10mm	>10mm
Tabanidae spp.	<3mm	<6mm	>6mm	
Empididae spp.	<3mm	>3mm		
Ephydridae spp.	<3mm	<6mm	>6mm	
Diptera pupae	<3mm	<6mm	>6mm	
Lepidoptera spp.	<3mm	<6mm	>6mm	
Trichoptera: Acritoptila globosa	<3mm	<6mm	>6mm	
Ecnomus turgidus	<3mm	<6mm	>6mm	
Notalina fulva	<3mm	<6mm	>6mm	
Triplectides australis	<3mm	<6mm	>6mm	
Oecetes sp 1	<3mm	<6mm	>6mm	
Coleoptera:				
Haliplidae				
Haliplidae sp1 L			>6mm	
Dytiscidae				
Hyphydrus elegans L	<3mm	<6mm	>6mm	
Antiporus spp L	<3mm	<6mm	>6mm	
Megaporus sp1 L	<3mm	<6mm	>6mm	
Sternopriscus sp1 L	<3mm	<6mm	>6mm	
Sternopriscus sp2 L	<3mm	<6mm	>6mm	
Necterosoma darwini L	<3mm	<6mm	>6mm	
Spencerhydrus pulchellus	<4mm	<10mm	>10mm	
Lancetes lanceolatus L, A	<4mm	<10mm	>10mm	
Laccophilus sp1 L			>6mm	
Rhantus suturalis	<4mm	<10mm	>10mm	
Copelatus sp1 L	<4mm	<10mm	>10mm	
Cybister tripunctatus L	<20mm	<30mm	>30mm	
Cybister sp2 L	<20mm	<30mm	>30mm	
Homoeodytes scutellaris L	<20mm	<30mm	>30mm	
Dytiscidae sp2 L	<3mm			
Hydrophilidae				
Berosus sp1 L	<3mm	<6mm	>6mm	
Berosus sp2 L	<3mm	<6mm	>6mm	
Berosus sp3 L	<3mm	<6mm	>6mm	
Berosus sp4 L	<3mm	<6mm	>6mm	
Berosus sp5 L	<3mm	<6mm	>6mm	
Hydrophilidae sp1 L	<3mm	<6mm	>6mm	
Hydrophilidae sp2 L	<3mm	<6mm	>6mm	
Hydrophilidae sp3 L	<3mm	<6mm	>6mm	
Hydrophilidae sp4 L	<10mm	<20mm	>20mm	
Helodidae				
Helodidae sp1 L	<3mm	<6mm	>6mm	
Helminthidae				
Helminthidae sp1 L			>6mm	
Staphylinidae				
Staphylinidae sp1 L	<3mm			
Ptilodactylidae				
Ptilodactylidae sp1 L			<5mm	
Ptilodactylidae sp2 L			<5mm	
Sphaeriidae				
Sphaeriidae sp1 L			<5mm	
Chrysomelidae				
Chrysomelidae sp1 L			>6mm	
Tadpoles	<10mm	<20mm	<30mm	>30mm

the depression.

A series of samples were taken from Bartram Swamp as reflooding occurred in 1990. These were qualitative samples obtained with a sweep net on 16 July, 25 July, 2 August and 11 October. The animals were examined in the field and returned to the water. The taxa collected are listed in the results section.

Samples of dry substrate were obtained from Bartram Swamp and submerged in aerated aquaria from 12 March to 6 April 1990. A list of animals found in these aquaria is provided in the results section, and incorporated into the analysis of individual species.

Data from previous studies on these wetlands (with due reference) has been incorporated in the results to provide information on the inter–annual variation in the temporal distribution of taxa.

Results

Data on the spatial and temporal distribution and abundance of each taxa is presented below. It is an integration of the raw data collected in this study and previous records for each taxa to provide as much information as possible on distribution and the seasonal timing of development. The inferance derived from this data forms the basis for formulating management implications. The phenology of each taxa in each wetland and in all six wetlands combined is contained in Appendix 2.

The taxa collected from Bartram Swamp during refill are listed in Table 4.3. The results of reflooding dry substrate from this wetland in laboratory aquaria are shown in Table 4.4. Table 4.5 provides a list of taxa recovered from a drying pool in the seasonal part of Murdoch Swamp, and Table 4.6 is a record of the taxa collected in moist detritus from this same pool when free water had been absent for at least four weeks.

Size classes for odonate larvae and fish were derived from Figures 4.1 to 4.11.

Cnidaria: Hydridae: Hydra spp.
Spatial distribution and abundance: Collected from Nowergup Lake and Thomsons Lake, and abundant in both.
Temporal distribution and abundance: Collected during January, February, April, May and September in approximately comparable numbers.
Previously collected from Herdsman Lake in July, September, and November 1986 (Rolls *et al.* 1990).
Inference: The occurrence of this taxa in permanent wetlands during the drought period indicates that this species may require permanent wetlands.

Turbellaria: Tricladida spp.
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Nowergup Lake and North Lake. Most abundant in North Lake, moderately abundant in Jandabup Lake and Nowergup Lake in comparable numbers, and least abundant in Bartram Swamp.
Temporal distribution and abundance: Collected during November, January, May and June. Most abundant in January in North Lake.
Previously collected from Jandabup Lake in July 1985, and from North Lake in April and July 1985, and January 1986 (Davis & Rolls 1987). Found in moist mud in Thomsons Lake in May 1986 (Pinder 1986) when the lake was dry.
Inference: Possible adaptation to seasonal drying of this taxa based on the evidence of Pinder (1986) and their presence in Bartram Swamp.

Nematoda spp.
Spatial distribution and abundance: Collected from Jandabup Lake, Murdoch Swamp, Nowergup Lake, North Lake and Thomsons Lake. Most abundant in Jandabup Lake.
Temporal distribution and abundance: Collected during January, March and May. Most abundant in May.
Previously collected from Jandabup Lake in April 1985, January 1986, May 1987, from Herdsman Lake in November 1986, from Lake Joondalup in October 1985, from Lake Monger in July and October 1985 and January 1986, from North Lake in July 1985 and January 1986 and from Thomsons Lake in July 1985 (Davis & Rolls 1987 and Rolls *et al.* 1990). Pinder (1986) recovered nematodes from dry soil from Thomsons Lake and Forrestdale Lake in 1986, after it had been artificially inundated for several days.
Inference: Although not collected from seasonal Bartram Swamp, the evidence of Pinder (1986) indicates an adaptation to seasonal drying. The eggs of some species are resistant to dessication (Williams 1980).

Annelida: Oligochaeta spp.
Spatial distribution and abundance: Collected from all six wetlands. Most abundant in Jandabup Lake, Thomsons Lake and North Lake.
Temporal distribution and abundance: Collected during all months. Least abundant in spring with numbers fluctuating in other seasons.
Previously collected in all wetlands studied to date (Davis & Rolls 1987 and Rolls *et al.* 1990) with no clear pattern to seasonal distribution.
Inference: Insufficient information is available for this taxa. A more appropriate sampling method for this benthic animal may yeild more information.

Annelida: Hirudinea spp.
Spatial distribution and abundance: Collected from all six wetlands, and most abundant in North Lake and Thomsons Lake.
Temporal distribution and abundance: Collected all year, and most abundant in summer and autumn.
Previously collected from most wetlands throughout the year (Davis & Rolls 1987 and Rolls *et al.* 1990).
Inference: Possible adaptation to seasonal drying by aestivating in dry sediments since large adults were found in a small puddle in Bartram Swamp after the first heavy rains in autumn 1990. Highest abundance occurred in the two most eutrophic wetlands, indicating a positive response to eutrophication.

Mollusca: Gastropoda:
Ferrissia spp.
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp and Thomsons Lake. Most abundant in Thomsons Lake, common in Bartram Swamp and rare in Jandabup Lake.
Temporal distribution and abundance: Collected almost continuously from August to March with the highest numbers in November, December and Janauary.
Previously collected from Lake Joondalup in November 1986, and Lake Goolellal in July 1986 and January 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990).
Inference: Temporal distribution appears to be similar from year to year. Its presence in Bartram Swamp following reflooding indicates an adaptation to seasonal drying. Lake *et al.* (1989) also collected *Ferrissia* from a seasonal wetland.

Glyptophysa sp 1 Quoy & Gairnard
Spatial distribution and abundance: Collected from all six wetlands. Most abundant in North Lake and least abundant in Murdoch Swamp and Nowergup Lake.
Temporal distribution and abundance: Almost continuously present in Jandabup Lake, with a more discrete distribution in the other wetlands. No specimens were collected in April & May. Increased numbers of small individuals occurred in September in North Lake, Bartram Swamp and Thomsons Lake, although a number of peaks in the number of small individuals occurs at other times in Jandabup Lake, North Lake and Thomsons Lake.
Previously collected from most wetlands throughout the year

Table 4.3 Invertebrates found in Bartram Swamp during refill in winter 1990.

Date	Taxa
16 Jul 90	Hydracarina
	Ostracoda
	Isopoda *Paramphisopus palustris*
	Coleoptera adults *Cybister* sp.
25 Jul 90	Copepoda
	Ostracoda
	Cladocera
	Isopoda *Paramphisopus palustris*
	Amphipoda *Perthia acutitelson*
	Coleoptera adutls
02 Aug 90	Hydracarina
	Copepoda
	Cladocera
	Ostracoda
	Isopoda *Paramphisopus palustris*
11 Oct 90	Hydracarina
	Conchostraca
	Copepoda
	Ostracoda
	Isopoda *Paramphisopus palustris*
	Hemiptera *Anisops* spp., *Agraptocorixa* spp.
	Zygoptera

Table 4.5 Taxa collected from drying pool (1.0m wide by 1.5m long and a maximum of 0.18m deep) in the seasonally dry area of Murdoch Swamp on 16 February 1989. The water temperature was 25°C.

Taxa	Number
Crustacea: Ostracoda: *Alboa woroora*	3
Copepoda: Calanoidea spp	>1000
Ephemeroptera: *Cloeon* sp	6
Hemiptera: *Enithares* sp1	1
Leptopodidae sp1	4
Agraptocorixa eurynome	2
Sigara truncatipala	11
Ranatra sp1	2
Anisops spp	4
Mesoveliidae sp1	5
Diptera: Chironomidae spp	9
Trichoptera: *Triplectides australis*	21
Coleoptera: *Enochrus* sp4 (adult)	1
Hyphydrus elegans (adult)	14
Limnoxenus macer (adult)	7
Rhantus suturalis (adult)	57
Liodessus dispar (adult)	2
Liodessus inornatus (adult)	1
Helodidae sp1 (larvae)	2
Lancetes lanceolatus (adult)	2
Paracymus pigmaeus (adult)	5
Tadpoles	7

Table 4.4 Taxa collected from dry Bartram Swamp substrate reflooded in the laboratory.

Taxa	Day first recorded
Protozoa	25
Nematoada	7
Rotifers	7
Cladocera: *Daphnia* sp.	7
Ephipial eggs	33
Chydoridae	33
Ostracoda	7
Copepoda: Cyclopoidea	33
Calanoidea	25
Conchostraca	33
Coleoptera: *Limnoxenus macer*	1

Table 4.6 Taxa collected from moist substrate from Murdoch Swamp on 10 February 1991.

Taxa
Hemiptera: Gelastocoridae *Nethra* sp1
Odonata: *Aeshna brevistyla*
Coleoptera: (adults)
Helochares tenuistriatus
Paracymus pigmaeus
Liodessus dispar
Limnoxenus macer

(Davis & Rolls 1987 and Rolls *et al.* 1990), notably during April 1985 in North Lake and May 1987 in Thomsons Lake.
Inference: Evidence of adaptation to seasonal drying based on the occurrence of this species in Thomsons Lake in 1985–87 when this wetland dried, Bartram Swamp and Jandabup Lake. It probably remained in the fringing vegetation as the water level decreased.

Physa acuta Draparnaud
Spatial distribution and abundance: Collected from Nowergup Lake, North Lake and Thomsons Lake. Most abundant in the latter two.
Temporal distribution and abundance: In Nowergup Lake and North Lake this species was present in spring and summer, whereas in Thomsons Lake its temporal distribution was continuous with a peak in abundance in December and January.
Previously collected from most wetlands in previous studies (Davis & Rolls 1987 and Davis *et al.* 1990).
General distribution: S.A., Vic., N.S.W. (Smith & Kershaw 1979).
Inference: The collection of this species from only the hyper-eutrophic wetlands indicates a positive response to eutrophication.

Lymnaea columella (Say)
Spatial distribution and abundance: Collected from Nowergup Lake, North Lake and Thomsons Lake, in low numbers.
Temporal distribution and abundance: Patchy distribution, with evidence of recruitment in North Lake in September.
Previously collected from Lake Monger July 1985, Loch McNess in September and November 1986, Lake Goolellal September and November 1986, and May 1987, and from Herdsman Lake in July 1986 (Davis & Rolls 1987 and Rolls *et al.* 1990).
General distribution: Vic., N.S.W. and W.A. (Smith & Kershaw 1979).
Inference: This is an introduced aquarium species and is unlikely to be adapted to seasonal drying. This species was not recorded in Thomsons Lake when it was seasonal and supports this possibility, however, further information is required.

Helisoma duryi Weatherby
Spatial distribution and abundance: Collected from Jandabup Lake, North Lake and Thomsons Lake. Numerous only in North Lake.
Temporal distribution and abundance: There was evidence of large recruitment in September in North Lake.
Previously collected from Lake Goolelal in July, September and November 1986, January, March and May 1987, and from North Lake in July, September and November 1986, March and May 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990).
Inference: This is an introduced aquarium species and is unlikely to be adapted to seasonal drying. Note that the small specimens collected from Jandabup Lake and Thomsons Lake may in fact belong to the genus *Amerianna*. *H. duryi* has only been collected from permanent wetlands, and it's presence in March and May indicates that it may require permanent wetlands.

Gyrulus sp 1
Spatial and temporal distribution and abundance: Collected only from Nowergup Lake as two large individuals in July. Many empty shells were collected during the rest of the year.
Inference: Not enough information is available for this species.

Bivalvia: Sphaerium kendricki
Spatial distribution and abundance: Collected from Jandabup Lake and Nowergup Lake. Most abundant in Jandabup Lake.
Temporal distribution and abundance: Collected when the water was shallow and saline in Jandabup Lake.
Previously collected from Lake Monger in April 1985, and from Jandabup Lake in March 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990).
Inference: This species may be responding to a specific stimulus, possibly raised salinity, for recruitment. Further information is required to determine if this species is adapted to seasonal drying.

Arachnida: Hydracarina spp.
Spatial distribution and abundance: Collected from all six wetlands. Most abundant in Nowergup Lake and Bartram Swamp.
Temporal distribution and abundance: Collected throughout the year with a spring peak in abundance in all wetlands from August to November.
Previously collected from most wetlands (Davis & Rolls 1987 and Rolls *et al.* 1990).
Inference: This taxa requires permanent water but is able to inhabit seasonal wetlands by virtue of the parasitic nymph stage (usually on hemipterans), which allows rapid recolonization of seasonal wetlands from permanent wetlands. Numbers were reduced in North Lake and Nowergup Lake possibly in response to the increase in the numbers of the mosquitofish *G. holbrooki* over summer. A reduction in abundance was not evident in Murdoch Swamp which did not contain fish.

Orabatidae spp.
Spatial distribution and abundance: Collected from all six wetlands, but most numerous in Murdoch Swamp.
Temporal distribution and abundance: Collected almost continuously with the exception of April and early May. Numbers were highest in spring and summer.
Previously collected from Thomsons Lake in November 1986 (Rolls *et al.* 1990).
Inference: This taxa may be adapted to seasonal drying since it occured in Bartram Swamp and was not collected in April and early May.

Crustacea:
Conchostraca: Lynceus sp 1
Spatial distribution and abundance: Collected only from Bartram Swamp. Temporal distribution and abundance: Collected from June to October, coincident with maximum water levels.
Inference: This taxa is adatpted to seasonal drying, and does not occur in permanent water. It remains in a dormant stage (eggs) after spring despite the continued presence of water.

Cladocera: Daphniidae: Simocephalus spp.
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp and Murdoch Swamp. Highest numbers occurred in Jandabup Lake.
Temporal distribution and abundance: Differing distributions occurred in the three wetlands. This taxa was most numerous in November.
Inference: The restriction of this taxa to the least eutrophic wetlands indicates a possible negative response to eutrophication. The rapid decline of the population in Jandabup Lake may have been due to predation by *G. holbrooki* which increased in numbers in summer.

Daphnia spp.
Spatial distribution and abundance: Collected from all six wetlands. Least abundant in Murdoch Swamp and Jandabup Lake.
Temporal distribution and abundance: Collected throughout most of the year but not in March and April.
Inference: This taxa is adapted to seasonal drying via ephipial eggs which are able to resist dessication. These eggs are present even in the permanent wetlands. *Daphnia* spp. were recovered from reflooded substrate from Bartram Swamp, and produced ephipial eggs within a three weeks.

Chydoridae spp.
Spatial distribution and abundance: Collected from all six wetlands, and abundant in all.
Temporal distribution and abundance: Scattered, semi-continuous distribution in Thomsons Lake, but more discrete distributions in the other wetlands. This taxa was not collected from any wetlands for a variable period in autumn. Numbers were highest from July to November, but the timing of the peak varied between wetlands.
Previously collected from Jandabup Lake in July, September and November 1986, January and May 1987, and from Thomsons Lake in July 1986 (Rolls *et al.* 1990).
Inference: The temporal distribution in Jandabup Lake appears to be consistent from year to year. At least some chydorid species appear to be adapted to seasonal drying. This is based on the collections from Bartram Swamp and the presence of chydorids in substrate reflooded in the laboratory.

Macrothricidae spp.
Spatial distribution and abundance: Collected only from Jandabup Lake in moderate abundance.
Temporal distribution and abundance: Collected from August to March, but not continuously.
Previously collected from Jandabup Lake in May 1987, Thomsons Lake in July 1986, and Forrestdale Lake in July and September 1986 (Rolls *et al.* 1990).
Inference: Since the taxa was not present in the driest months of the year, it may be adapted to seasonal drying. However, more information is required to confirm this.

Moinidae spp.
Spatial distribution and abundance: Collected from Bartram Swamp, Murdoch Swamp and Thomsons Lake. Most abundant in Murdoch Swamp.
Temporal distribution and abundance: Collected in every sample taken from Murdoch Swamp, but only intermittently in the other two wetlands.

Inference: The presence of this taxa in Bartram Swamp indicates that it may be adapted to seasonal drying. It was not present in wetlands containing fish and may be prone to predation by fish. Perhaps more significant in the distribution of this taxa is the relatively dark colour of the water in the three wetlands in which it occurs.

Sididae sp 1
Spatial distribution and abundance: Collected only from Jandabup Lake in moderate abundance.
Temporal distribution and abundance: This species was most abundant when the water level was low with a peak in abundance in March.
Inference: Since this species was absent during the driest period, it may be adapted to seasonal drying. However, further information is needed.

Ostracoda:
Limnocytheridae: Limnocythere mowbrayensis Chapman
Spatial distribution and abundance: Collected only from Jandabup Lake and Bartram Swamp. Highest numbers occurred in Jandabup Lake.
Temporal distribution and abundance: Collected from August to January, although not continuously.
General distribution: Southern Australia and New Zealand (DeDeckker 1981a).
Inference: DeDeckker (1981a) notes that this species is not found in ephemeral waters, however, it was collected from Bartram Swamp and was absent from Jandabup Lake during the drought period. Further information is required for this species.

Gomphodella maia DeDeckker
Spatial distribution and abundance: Collected from Jandabup Lake and Thomsons Lake, and most abundant in Jandabup Lake.

Temporal distribution and abundance: A semi-continuous distribution in Jandabup Lake throughout the year. In Thomsons Lake it was collected intermittently from November to May.
Previously collected from Jandabup Lake in May 1987 and Thomsons Lake in July 1986 (Davis & Rolls 1987 and Rolls *et al.* 1990).
General distribution: South-eastern S.A. (DeDeckker 1981c).
Inference: DeDeckker (1981c) noted that this species occurs only in permanent water as the eggs cannot withstand desiccation. The collection of specimens from permanent wetlands during the drought period supports the assertion that this species requires permanent wetlands.

Cyprididae: Candonocypris novaezelandiae (Baird)
Spatial distribution and abundance: Collected from Jandabup Lake, Murdoch Swamp, Nowergup Lake, North Lake and Thomsons Lake. Most abundant in Nowergup Lake.
Temporal distribution and abundance: Collected semi-continuously throughout the year. It occurred in large numbers during autumn in Thomsons Lake and Murdoch Swamp.
General distribution: New Zealand, Australia (N.S.W., S.A. and Vic.) and Japan (DeDeckker 1981a).
Inference: Its presence in autumn and absence from Bartram Swamp suggests a requirement for permanent wetlands. However, DeDeckker (1981a) recorded this species in temporary pools. Perhaps aestivation can only occur where the substrate remains moist. It is more abundant in the eutrophic wetlands which was also noted by DeDeckker (1981a).

Cypretta baylyi McKenzie
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Murdoch Swamp, Nowergup Lake and Thomsons Lake. Most numerous in Nowergup Lake.
Temporal distribution and abundance: Collected throughout the year with the exception of late March. Numbers were greatest in spring and summer.
Previously collected from several wetlands throughout the year, notably from North Lake in September and November 1986 (Davis & Rolls 1987 and Rolls *et al.* 1990).
General distribution: Western Australia and Northern Territory (DeDeckker 1981a).
Inference: This species may be adapted to seasonal drying, but it did not reappear in Bartram Swamp after refilling until September and so may require waterfowl as a passive dispersal agent to recolonize seasonal wetlands. Its absence from North Lake may indicate an upper limit of tolerance to eutrophication and environmental degredation. This species does not occur in Lake Monger (Lund 1992) which is one of the most eutrophic wetlands in Perth. More information is required for this species.

Sarscypridopsis aculeata (Costa)
Spatial distribution and abundance: Collected from all six wetlands, and was most abundant in Nowergup Lake with high numbers also recorded from Thomsons Lake and North Lake.
Temporal distribution and abundance: Present almost continuously in Thomsons Lake (and possibly also in Nowergup Lake), but the samples from North Lake from February to June contained very few individuals of this species. Numbers peak at different times in different wetlands.
Previously collected throughout the year from most wetlands studied (Davis & Rolls 1987 and Rolls *et al.* 1990). Pinder (1986) recorded densities of 24,732/m^2 from Thomsons Lake in July 1986.
General distribution: Cosmopolitan (DeDeckker 1981a).
Inference: The numbers collected from the more eutrophic wetlands are an order of magnitude higher than the less enriched wetlands, indicating that it may be responding positively to eutrophication. This species is probably adapted to seasonal drying since it was found in reflooded substrate from Bartram Swamp and was one of the first animals that reappeared when natural refilling occurred. DeDeckker (1981a) also recorded this species in temporary pools.

Alboa woroora DeDeckker
Spatial distribution and aundance: Collected from Jandabup Lake, Bartram Swamp, Murdoch Swamp, Nowergup Lake and Thomsons Lake. Most abundant in Thomsons Lake.
Temporal distribution and abundance: Collected throughout the year in Thomsons Lake except in April and early May. In the other four wetlands it was collected from May to January.
General distribution: This species inhabits lakes and temporary pools on Kangaroo Island, S.A., Vic and W.A. (DeDeckker 1981c and Lake *et al.* 1989).
Inference: This species is likely to be adapted to seasonal drying, based on the evidence of DeDeckker (1981c) and its occurrence in Bartram Swamp.

Bennelongia australis (Brady)
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Murdoch Swamp and Thomsons Lake. Most abundant in Bartram Swamp and least abundant in Thomsons Lake. Temporal distribution and abundance: Collected predominantly in winter and spring with an additional discrete group collected in Murdoch Swamp in December and January.
Previously collected from Loch McNess, Jandabup Lake, North Lake, Thomsons Lake and Forrestdale Lake (Davis & Rolls 1987 and Rolls *et al.* 1990).
General distribution: Found only in W.A. and S.A. (DeDeckker 1981c).
Inference: According to DeDeckker (1981c) this species inhabits temporary pools. Males were only found in permanent wetlands in W.A., suggesting that only parthenogenic reproduction occurs in temporary pools (DeDeckker 1981c). Evidently this species is adapted to seasonal drying and may respond negatively to eutrophication, since it occurs only in low numbers in Thomsons Lake and was not collected from the other two eutrophic wetlands North Lake and Nowergup Lake.

Mytilocypris ambiguosa DeDeckker
Spatial distribution and abundance: Collected only from Thomsons Lake in low numbers.
Temporal distribution and abundance: Collected in August 1988, but not in 1989.
Previously collected from Thomsons Lake in July and September 1986, and from Forrestdale Lake in July, September and November 1986, January and May 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990). Collected by Pinder (1986) in moist mud from Thomsons Lake after reflooding of Thomsons Lake and Forrestdale Lake in May 1986, and was abundant in June.
General distribution: W.A. and Vic. (DeDeckker 1978).
Inference: The absence of this species from Thomsons Lake when it had become a permanent wetland indicates that it may require seasonal drying. Previous collections support this idea, althoug it may have specific habitat requirements with regard to salinity, since it was not collected from seasonal Bartram Swamp which is less saline than Thomsons Lake.

Copepoda: Calanoidea spp.
Spatial distribution and abundance: Collected from all six wetlands. Most abundant in North Lake, and relatively numerous in all but Nowergup Lake where this taxa was collected only twice.
Temporal distribution and abundance: Collected throughout the year in fluctuating numbers.
Inference: Many species are adapted to seasonal drying with desiccation resistant stages which were present in reflooded substrate from Bartram Swamp. Encountered several days after refilling of Bartram Swamp in 1990 (see Table 4.3).

Cyclopoidea spp.
Spatial distribution and abundance: Collected from all six wetlands. Most numerous in Nowergup Lake, and relatively

abundant in all but Jandabup Lake.
Temporal distribution and abundance: Present continuously in Murdoch Swamp, and semi-continuously in North Lake and Thomsons Lake. In Bartram Swamp and Nowergup Lake this taxa was present only when water levels are high. In Jandabup Lake individuals were collected when water levels were lowest.
Inference: Several different species were collected, some of which may be adapted to seasonal drying. Cyclopoid copepods were found in reflooded substrate from Bartram Swamp and collected several days after natural refilling (see Tables 4.3, 4.4).

Harpactacoidea spp.
Spatial distribution and abundance: Collected from all six wetlands. Most numerous in Nowergup Lake.
Temporal distribution and abundance: Not collected when water levels were low. Numbers were highest in winter.
Inference: The presence of this taxa in Bartram Swamp, and the failure to collect individuals when water levels were low, indicates a possible adaptation to seasonal drying. Pinder (1986) found harpactacoid copepods in dry mud after it had been artificially inundated for a week.

Isopoda: Paramphisopus palustris (Glauert)
Spatial distribution and abundance: Collected from all six wetlands. Most abundant in Bartram Swamp and least abundant in Murdoch Swamp and North Lake.
Temporal distribution and abundance: Most abundant from September to December, and in low numbers from January onwards.
Previously collected from most wetlands studied (Pinder 1986, Davis & Rolls 1987 and Rolls *et al.* 1990).
General distribution: South-western W.A. (Nicholls 1944).
Inference: Adapted to seasonal drying, over-summering as medium sized individuals which appeared several days following refill of Bartram Swamp. This taxa is likely to be multivoltine, based on the discrete appearance of small individuals in Thomsons Lake at three different times.

Amphipoda: Austrochiltonia subtenuis (Sayce)
Spatial distribution and abundance: Collected from all six wetlands. Most numerous in the eutrophic wetlands, particularly Nowergup Lake and Thomsons Lake. Numbers were lowest in Murdoch Swamp.
Temporal distribution and abundance: Numbers were generally lowest in summer. Numbers peaked in autumn in Jandabup Lake and Thomsons Lake, and were generally high in winter and spring.
Previously collected from most wetlands studied (Pinder 1986, Davis & Rolls 1987 and Rolls *et al.* 1990). Pinder (1986) found this species among the *Baumea* in the dry bed of Thomsons Lake in March 1986. It was present in the water immediately after refill of both Thomsons Lake and Forrestdale Lake in 1986.
General distribution: Tas., Vic., W.A. and S.A. (Williams 1962).
Inference: Responds positively to eutrophication. Its presence in Bartram Swamp, and the evidence of Pinder (1986) indicates a possible adaptation to seasonal drying. Information on the closely related species *A. australis* provides evidence of tolerance of drying (Lake *et al.* 1989, Boulton 1989 and McKaige 1980).

Perthia acutitelson Straskraba
Spatial distribution and abundance: Collected from Bartram Swamp, Murdoch Swamp and Thomsons Lake. Numbers were highest in Bartram Swamp.
Temporal distribution and abundance: Most numerous in spring with the majority of animals collected between August and January. Several very large specimens were collected in May in Thomsons Lake.
General distribution: South-western W.A. (Williams & Barnard 1988).
Inference: The single individual collected in Murdoch Swamp may have been accidently transferred in sweep net. This species is adapted to seasonal drying, since it was found in Bartram Swamp several days after refill in 1990.

Decapoda: Cherax quinquecarinatus (Gray)
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Nowergup Lake and Thomsons Lake.
Temporal distribution and abundance: Collected as small individuals in July, August and September. Found in Bartram Swamp in autumn 1.5m underground by excavating a burrow. No free water was present although the mud at the very bottom of the burrow where the gilgies were sitting was moist. A male and female were found together and the female bore eggs.
Previously collected from Jandabup Lake in October 1985 (Davis & Rolls 1987).
General distribution: South-western W.A. (Williams 1980).
Inference: This species has a behavioural adaptation to seasonal drying.

Palaemonetes australis Dakin
Spatial distribution and abundance: Collected only from Nowergup Lake in moderate numbers.
Temporal distribution and abundance: Collected from June until October. Previously collected from Lake Joondalup in April, July and October 1985, January, September and November 1986, January, March and May 1987, from Loch McNess in July, September and November 1986, January, March and May 1987, and from Lake Goolellal in July, September, November 1986, January, March and May 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990). Bray (1976) collected females bearing eggs between September and April with a peak in breeding in November. The incubation period was about one month, and an individual female may lay 3–4 batches of eggs in a season. Serventy (1938) recorded the breeding season from the end of August to January.
General distribution: Wetlands and estuaries of south-western W.A. (Serventy 1938 and Bray 1976).
Inference: No small individuals were collected in the May sample from Nowergup Lake. It is likely that this taxa occurred throughout the year, but the animals did not occur in the fringing vegetation sampled between November and May. Previous collections record the shrimp throughout the year and while the timing of the initiation of breeding is consistent, the length of the breeding period may vary from year to year. This species requires permanent water.

Insecta
Ephemeroptera: Cloeon sp 1
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Murdoch Swamp, North Lake and Thomsons Lake. Most abundant in Murdoch Swamp and least abundant in North Lake and Thomsons Lake. Temporal distribution and abundance: Collected almost continuously from Murdoch Swamp.
Previously collected from Loch McNess in September 1986 and March 1987, from Jandabup Lake in January and March 1987, from Lake Goolellal in January and March 1987, and from Herdsman Lake in July and November 1986, January and March 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990).
Inference: This species is apparently multivoltine. The high numbers recorded in autumn indicate that this species may require water throughout the year.

Caenidae: Tasmanocoenis tillyardi (Lestage)
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp and North Lake. Most abundant in North Lake, with low numbers in Bartram Swamp.
Temporal distribution and abundance: Collected in all months from North Lake, but most numerous from November to June with numbers much reduced in winter and early spring.
Previously collected from Jandabup Lake in January 1987, from Herdsman Lake in September, November 1986, January, March and May 1987, from Lake Monger in January 1986, and from North Lake in April, July and October 1985, January, July and November 1986, March and May 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990).
General distribution: S.A., Vic. and Tas. (Campbell 1988).
Inference: This species appears to be multivoltine, with up to three generations/year (two are evident in Jandabup Lake and three in North Lake). Bunn (1988) found *T. tillyardi* in jarrah forest streams south of Perth to have a univoltine life cycle with small nymphs appearing in late summer. This species probably requires water all year round and may have specific habitat requirements.

Odonata:
Odonate larvae hatch from eggs about 0.3mm long and grow through a series of instars, numbering between 8 and 14. According to Corbet (1962) the newly hatched prolarvae undergoes its first moult in a number of seconds to hours after hatching. The terminology of Lutz (1968) was adopted here, where F refers to the final instar, F-1 to the penultimate instar and so on to F-8 or more until the first instar which is called the prolarvae. For the more abundant species, these instars were estimated from frequency histograms. For the less abundant species, arbitrary sizes classes were used (see Table 4.1).

Austroagrion cyane (Selys)
Spatial distribution and abundance: Collected in small numbers from Jandabup Lake, Murdoch Swamp, North Lake, Nowergup Lake and Thomsons Lake.
Temporal distribution and abundance: Collected from May to September.
General distribution: W.A. and S.A. (Houston & Watson 1988).
Inference: The absence of this species from Bartram Swamp may be due to this wetland not refilling until the end of July 1989. Insufficient information is available for this species.

Xanthagrion erythroneurum (Selys)
A frequency histogram of the head widths of this species and the instars derived from it is shown in Figure 4.1.
Spatial distribution and abundance: Collected from all six wetlands. Most abundant in Thomsons Lake and North Lake. It constituted 77% of the total odonates found in the six wetlands and 94% of the odonates found in the eutrophic wetlands, North Lake and Thomsons Lake.
Temporal distribution and abundance: Collected almost continuously throughout the year from North Lake and Thomsons Lake with the highest numbers in March and April. In the other four wetlands, the relatively few individuals collected were most numerous in summer. Adults fly from mid-August to late May (Watson 1962). Overall, the larvae were most abundant in summer (43%) and autumn (42%), and only 3% of this species were collected in spring.
Previously collected from most wetlands studied (Davis & Rolls 1987 and Rolls *et al.* 1990 and Davis *et al.* 1991).
General distribution: A.C.T., N.S.W., Qld., N.T., S.A., W.A., Vic. and Tas. (Houston & Watson 1988).
Inference: This species responds positively to eutrophication based on the large numbers encountered in the two most eutrophic wetlands (North Lake and Thomsons Lake). The large numbers encountered in autumn may reflect a requirement for water throughout the year.

Ischnura aurora (Brauer)
A frequency histogram of the head widths of this species and the instars derived from it is shown in Figure 4.2.
Spatial distribution and abundance: Collected from Jandabup Lake, Murdoch Swamp and North Lake. Most abundant in Murdoch Swamp.
Temporal distribution and abundance: Collected as larvae from November to March, with a peak in January and February. The majority of larvae (88%) were collected during summer between mid December and the end of March. Adults were observed to fly all year by Watson (1962).
Previously collected from North Lake in January and November 1986, January 1987, from Thomsons Lake in January 1986, January and May 1987 (a single individual), January 1988, from 'Unnamed wetland' in November 1987, from Nowergup Lake in January 1988, from Herdsman Lake in November 1986 and January 1987, from Bibra Lake in January 1987, and from Forrestdale Lake in January 1987 (Davis & Rolls 1987, Rolls *et al.* 1990 and Davis *et al.* 1991).
General distribution: A.C.T., N.S.W., Qld., N.T., W.A, S.A., Vic., Tas., Lord Howe Island, Norfolk Island, India, Sri Lanka, Burma, China, Japan, Java, and Western and Central Pacific (Houston & Watson 1988).
Inference: This species appears to be univoltine. The interannual timing of larval development is constant with the exception of a single individual collected in May 1987 from Thomsons Lake. Based on the timing of development, this species does not require water throughout the year, but it was not collected from seasonal Bartram Swamp. It may have specific habitat requirements. Further information is required.

Ischnura heterosticta (Burmeister)
A frequency histogram of the head widths of this species and the instars derived from it is shown in Figure 4.3.
Spatial distribution and abundance: Collected from Murdoch Swamp, Nowergup Lake, North Lake and Thomsons Lake. Nowergup Lake had the lowest numbers and the other wetlands had higher and comparable numbers.
Temporal distribution and abundance: Collected from December to March (66%) with a peak in January and a second cohort in Murdoch Swamp from May to July (31%). According to Watson (1962), adults occur from the end of September to the beginning of November and then sparsely until the beginning of March to mid April. No adults were recorded from mid April until September. This corresponds almost exactly with larval phenology in this study.
Previously collected from North Lake in July 1986 (Rolls *et al.* 1990).
General distribution: A.C.T., N.S.W., Qld., N.T., W.A, S.A., Vic., Aru Islands, New Guinea, Tonga, Fiji and Micronesia (Houston & Watson 1988).
Inference: The presence of larvae in May and June in Murdoch Swamp, and the evidence of Watson (1962) regarding the absence of adults from April to September indicates that this species may require wetlands throughout the year.

Argiolestes pusillus (Tillyard)
Spatial and temporal distribution and abundance: Collected from Bartram Swamp and Nowergup Lake in September and October in small numbers.
General distribution: North-west coastal and south-west coastal, W.A. (Houston & Watson 1988).
Inference: Not enough information is available for this species.

Austrolestes analis (Rambur)
A frequency histogram of the head widths of this species and the instars derived from it is shown in Figure 4.4.
Spatial distribution and abundance: Collected from all six wetlands. Most abundant in Jandabup Lake, Bartram Swamp and Murdoch Swamp. This was the second most abundant species found in the six wetlands.
Temporal distribution and abundance: Collected from June to January with a peak in September. The majority of larvae occurred in spring (71%). Watson (1962) recorded the adults flying from mid September to the end of June.
Previously collected from Jandabup Lake in July 1985, from Loch McNess in November 1987, from Thomsons Lake in November 1986 and January 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990).
General distribution: A.C.T., N.S.W., W.A., S.A., Vic. and Tas. (Houston & Watson 1988).
Inference: Previously collected in the same months, indicating that the timing of larval development is the same from year to year. A negative response to eutrophication is possible based on the relatively low numbers collected in the eutrophic wetlands. The absence of larvae from January to June suggests that this species does not require water throughout the year.

Austrolestes annulosus (Selys)
A frequency histogram of the head widths of this species and the instars derived from it is shown in Figure 4.5.
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Nowergup Lake, North Lake and Thomsons Lake. Most abundant in Thomsons Lake.
Temporal distribution and abundance: Collected from August to April, with a peak in abundance around January. Adults are found all year round (Watson 1962). Larvae occur from late spring (25%) to early summer (61%). Some final instar larvae (11%) occur in March and April in Thomsons Lake and North Lake, when the seasonal wetlands are dry.
Previously collected from Jandabup Lake in July and October 1985, September and November 1986, January and November 1987, and January 1988, from Lake Monger in July 1985, from North Lake in October 1985, November 1986, January and November 1987, and January 1988, from Thomsons Lake in October 1985, January and November 1986, January, March and November 1987, and January 1988, from Loch McNess in January and November 1987, from 'Unnamed' wetland in November 1987, from Herdsman Lake in November 1986, November 1987, from Forrestdale Lake in January and November 1987, from Lake Goolellal in January 1987, from Lake Joondalup in September 1986, January 1987, and from Bibra Lake in January 1987 (Davis & Rolls 1987, Rolls *et al.* 1990 and Davis *et al.* 1991).
General distribution: A.C.T., N.S.W., N.T., W.A, S.A., Vic. and Tas. (Houston & Watson 1988).
Inference: Because most of the larvae developed and metamorphosed before mid February when the seasonal wetlands dried, it is unlikely that this species requires water throughout the year for survival. Previous records of this species occur in the same months indicating that the timing of larval development is constant between years.

Austrolestes io (Selys)
A frequency histogram of the head widths of this species and the instars derived from it is shown in Figure 4.6.
Spatial distribution and abundance: Collected from all six wetlands. Most abundant in Murdoch Swamp.
Temporal distribution and abundance: Collected from September to January with a peak in abundance in October. Watson (1962) found the adults throughout the year, but the larvae were collected here in a clearly defined period from September to January. No larvae were collected in autumn and winter, with 62% of the larvae collected in spring and the remaining 38% in summer.
Previously collected from Thomsons Lake in October 1985, September, November 1986, January 1987, from North Lake in November 1987, from Forrestdale Lake in November 1987, Loch McNess in November 1986, from Jandabup Lake in September 1986 (Davis & Rolls 1987 and Rolls *et al.* 1990).
General distribution: N.S.W., Vic., W.A, Tas. (Houston & Watson 1988).
Inference: Based on the timing of larval development, and the collection of larvae in the same months in previous years, this species may not require water throughout the year.

Aeshna brevistyla (Rambur)
A frequency histogram of the head widths of this species and the instars derived from it is shown in Figure 4.7.
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Murdoch Swamp, Nowergup Lake and Thomsons Lake in low numbers.
Temporal distribution and abundance: Larvae were collected over

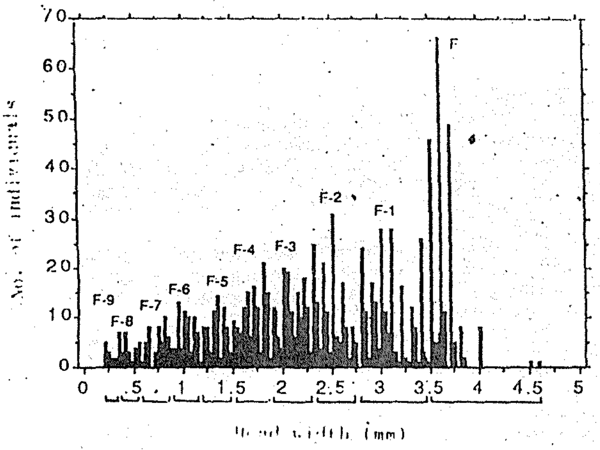

Figure 4.1 Frequency histogram of head widths (mm) of *Xanthagrion erythroneurum*. Instars estimated from graph: F (3.49-4.58), F-1 (2.77-3.48), F-2 (2.28-2.76), F-3 (1.90-2.27), F-4 (1.50-1.89), F-5 (1.18-1.49), F-6 (0.86-1.17), F-7 (0.62-0.85), F-8 (0.38-0.61), F-9 (0.20-0.37).

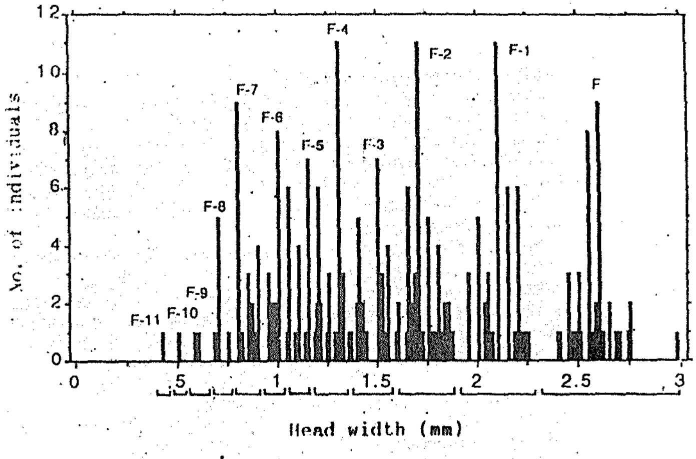

Figure 4.2 Frequency histogram of head widths (mm) of *Ischnura aurora*. Instars estimated from graph: F (2.30-3.00), F-1 (1.90-2.29), F-2 (1.65-1.89), F-3 (1.40-1.64), F-4 (1.20-1.39), F-5 (1.05-1.19), F-6 (0.93-1.04), F-7 (0.85-0.92), F-8 (0.78-0.84), F-9 (0.67-0.77), F-10 (0.57-0.66), F-11 (0.48-0.56), F-12 (0.42-0.47).

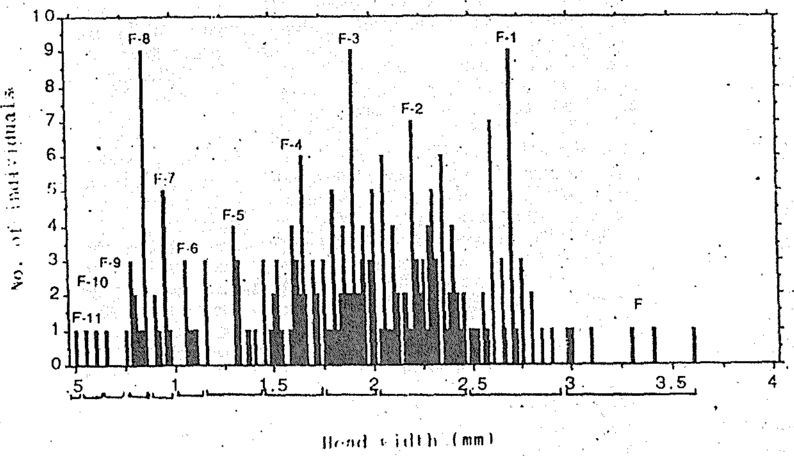

Figure 4.3 Frequency histograms of head widths (mm) of *Ischnura heterosticta*. Instars estimated from graph: F (2.95-3.65), F-1 (2.18-2.94), F-2 (2.09-2.47), F-3 (1.78-2.08), F-4 (1.40-1.77), F-5 (1.18-1.39), F-6 (1.00-1.17), F-7 (0.92-0.99), F-8 (0.74-0.91), F-9 (0.60-0.73), F-10 (0.55-0.59), F-11 (0.48-0.54).

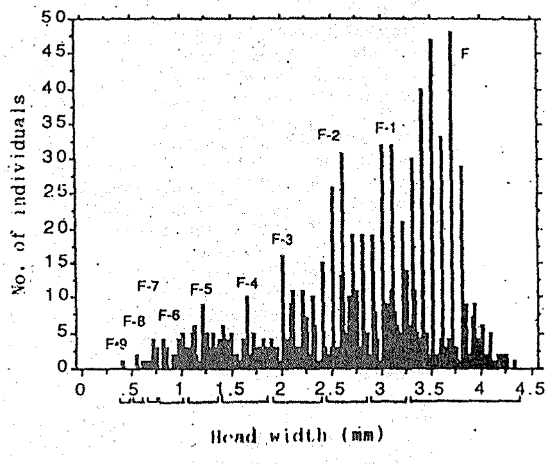

Figure 4.4 Frequency histogram of head widths (mm) of *Austrolestes analis*. Instars estimated from graph: F (3.25-4.41), F-1 (2.80-3.24), F-2 (2.40-2.79), F-3 (1.85-2.39), F-4 (1.41-1.84), F-5 (1.10-1.40), F-6 (0.76-1.09), F-7 (0.62-0.75), F-8 (0.48-0.61), F-9 (0.36-0.47).

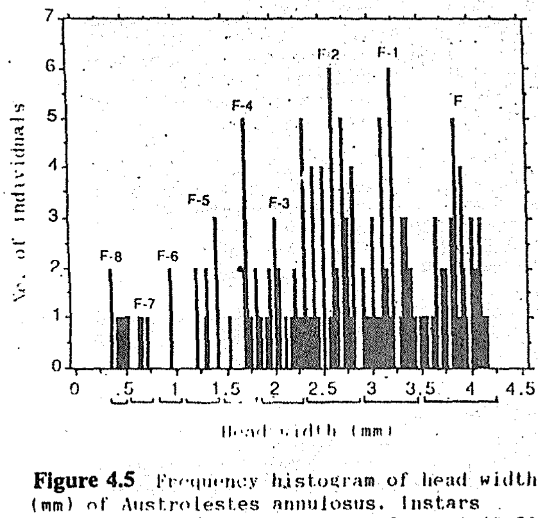

Figure 4.5 Frequency histogram of head widths (mm) of *Austrolestes annulosus*. Instars derived from graph: F (3.48-4.25), F-1 (2.82-3.47), F-2 (2.28-2.81), F-3 (1.78-2.27), F-4 (1.45-1.77), F-5 (1.10-1.44), F-6 (0.78-1.09), F-7 (0.51-0.77), F-8 (0.28-0.50).

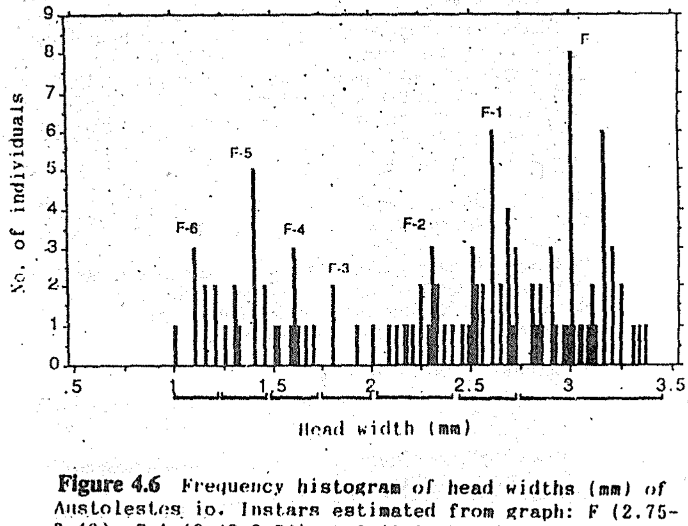

Figure 4.6 Frequency histogram of head widths (mm) of *Austolestes io*. Instars estimated from graph: F (2.75-3.40), F-1 (2.40-2.74), F-2 (2.01-2.39), F-3 (1.75-2.00), F-4 (1.48-1.74), F-5 (1.23-1.47), F-6 (0.95-1.22).

winter from 30 May to 11 September 1989. In addition, a second cohort was collected over summer from 16 December 1988 to 9 March. Watson (1962) recorded the adults from the end of August to the end of May.
Previously collected from Thomsons Lake in July 1985, January 1987, from Joondalup Lake in March 1987, and from Bibra Lake in May 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990).
General distribution: A.C.T., N.S.W., Qld., W.A, S.A., Vic., Tas., New Zealand and islands north to New Caledonia and Vanuatu (Houston & Watson 1988).
Inference: This species is a benthic dweller and would not have been adequately sampled with the sweep net. A single larvae (approx. 20mm in length) was recovered from moist detritus in a shallow depression in Murdoch Swamp in February 1991. No free water was present, the water table being 0.3m below the surface. The pool had not contained water for about four weeks, and the larva was immediately active when placed in water. This suggests that this species can aestivate in moist substrate.

<u>Hemianax papuensis</u> (Burmeister)
A frequency histogram of the head widths of this species and the instars derived from it is shown in Figure 4.8.
Spatial distribution and abundance: Collected from all six wetlands. Most abundant in Thomsons Lake.
Temporal distribution and abundance: Collected throughout the year. Data from the six wetlands combined shows two distinct larval periods, the first in spring (45%) and summer (44%) (mid-August to the end of January) and the second, smaller group in autumn (8%). Since the seasonal wetlands were dry by the end of summer, this second group of larvae only occur in the permanent wetlands.
Previously collected from Jandabup Lake in October 1985, May 1987, May 1988, from North Lake in July 1985, Thomsons Lake in July and October 1985, November 1986, January, March and May 1987, and January 1988, and Forrestdale Lake in November 1986 (Davis & Rolls 1987, Rolls *et al.* 1990 and Davis *et al.* 1991).
General distribution: A.C.T., N.S.W., Qld., N.T., W.A, S.A., Vic., Tas., Lord Howe Island, Cocos Islands, Java, Sumba, New Guinea, New Zealand, Kermadec Islands (Houston & Watson 1988).
Inference: This species may require water throughout the year.

<u>Procordulia affinis</u> (Selys)
Spatial distribution and abundance: Collected from Jandabup Lake and Murdoch Swamp in small numbers.
Temporal distribution and abundance: Collected in January, February, March and June. Watson (1958) recorded adults from mid September to the end of February.
Previously collected from Thomsons Lake in November 1987 (Rolls *et al.* 1990).
General distribution: South-western, W.A. (Houston & Watson 1988).
Inference: Few animals were collected probably because this is a benthic species and was not adequately sampled with a sweep net. More information is required for this species.

<u>Hemicordulia australiae</u> (Rambur)
Spatial and temporal distribution: Collected from Murdoch Swamp as a single larvae in late March 1989. Watson (1962) noted that it occurred as an adult from the beginning of September to the beginning of March.
General distribution: A.C.T., N.S.W. Qld., W.A, S.A., Vic., Tas., Lord Howe Island, Norfolk Island, Lesser Sunda Islands, New Zealand and Kermadec Islands (Houston & Watson 1988).
Inference: Further information is required for this species.

<u>Hemicordulia tau</u> (Selys)
A frequency histogram of the head widths of this species and the instars derived from it is shown in Figure 4.9.
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Murdoch Swamp and Nowergup Lake. Low numbers were collected from Nowergup Lake.
Temporal distribution and abundance: Larvae were collected in low numbers periodically, with no larvae collected from late July to early September. Watson (1958) observed no adults from the beginning of June to mid-August and recorded mass emergences occurred from early August to mid October. Previously collected in Jandabup Lake in July and October 1985, January and September 1986, November 1987, and July 1988, and from Thomsons Lake in January 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990).
General distribution: A.C.T., N.S.W., Qld., N.T., W.A., S.A., Vic. and Tas. (Houston & Watson 1988).
Inference: Larvae were present in the permanent part of Murdoch Swamp in autumn, suggesting that this species may require water throughout the year. However, it was not found in the other permanent wetlands in autumn. In addition, there is little correspondence between the phenology of the larvae and Watson's information on the adults. This may be becasue the sweep net indadequately sampled this benthic species. The low numbers encountered in Nowergup Lake and failure to collected this species from the eutrophic North Lake and Thomsons Lake, indicate a possible negative response to eutrophication.

<u>Orthetrum caledonicum</u> (Brauer)
Spatial distribution and abundance: Collected from Jandabup Lake in small numbers.
Temporal distribution and abundance: Collected during January. According to Watson (1962) the adults occur from mid September to the beginning of March. Alcock (1988) observed this species ovipositing in a small Perth wetland between 19 February and 7 March 1986.
General distribution: A.C.T., N.S.W., Qld., N.T., W.A, S.A., Vic., Torres Strait Islands, New Guinea, New Caledonia and Loyalty Islands (Houston & Watson 1988).
Inference: This species is a benthic dweller and was not adequately sampled with a sweep net and therefore, more information is required.

<u>Diplacodes bipunctata</u> (Brauer)
Spatial distribution and abundance: Collected from Jandabup Lake and Murdoch Swamp in low numbers.
Temporal distribution and abundance: Collected in November and December. Adults were recorded by Watson (1962) from the beginning of September to mid June.
Previously collected from Thomsons Lake in January, March, May and November 1987, and January 1988, from 'Unnamed' wetland in November 1987, from Lake Goolellal in May 1987 and from Jandabup Lake in September 1986 (Davis & Rolls 1987, Rolls *et al.* 1990 and Davis *et al.* 1991).
General distribution: A.C.T., N.S.W., Qld., N.T. W.A, S.A., Vic., Indonesia, New Guinea, New Zealand and Southwestern Pacific (Houston & Watson 1988).
Inference: This is a benthic species inadequately sampled with a sweep net. Further information is required for this odonate.

<u>Austrothemis nigrescens</u> (Martin)
Spatial distribution and abundance: Collected from Thomsons Lake and Jandabup Lake in low numbers.
Temporal distribution and abundance: Collected in July and August. Watson (1962) recorded adults from the beginning of October to mid December.
General distribution: N.S.W., Qld., W.A, S.A., Vic. and Tas. (Houston & Watson 1988).
Inference: Too few specimens were collected, and further information is required.

Hemiptera:
Gelastocoridae <u>Nethra</u> sp 1
Spatial distribution and abundance: Collected from Jandabup Lake, Murdoch Swamp and North Lake in low numbers.
Temporal distribution and abundance: Collected from August to October.
Inference: This taxa was collected in moist detritus in a shallow depression in Murdoch Swamp in February 1991 which had not contained free water for about four weeks. According to Williams (1980) this taxa is more frequently found at the edge of wetlands, it is, therefore, well adapted to seasonal drying.

Leptopodidae sp 1
Only one Australian species *Valleriola wilsonae* has been recorded, but is recorded from tropical and subtropical eastern Australia (Williams 1980) and therefore, may not be the same species as the leptopodid collected here.
Spatial distribution and abundance: Collected from Murdoch Swamp, Nowergup Lake, North Lake and Thomsons Lake. Numbers were highest in Murdoch Swamp, common in Thomsons Lake and in low numbers in Nowergup Lake and North Lake.
Temporal distribution and abundance: Collected between October and July.
Inference: Probably requires water throughout the year, since it occurred in substantial numbers in Murdoch Swamp in autumn.

Saldidae <u>Saldula</u> sp 1
Spatial distribution and abundance: Collected from Bartram Swamp, Murdoch Swamp and Nowergup Lake. Collected in high numbers from Nowergup Lake and Bartram Swamp, and in low numbers from Murdoch Swamp.
Temporal distribution and abundance: Collected from September to November with the highest numbers collected in October and November.
Inference: This species may not require water throughout the year, but in the absence of information on its life cycle, this conclusion must be regarded as provisional.

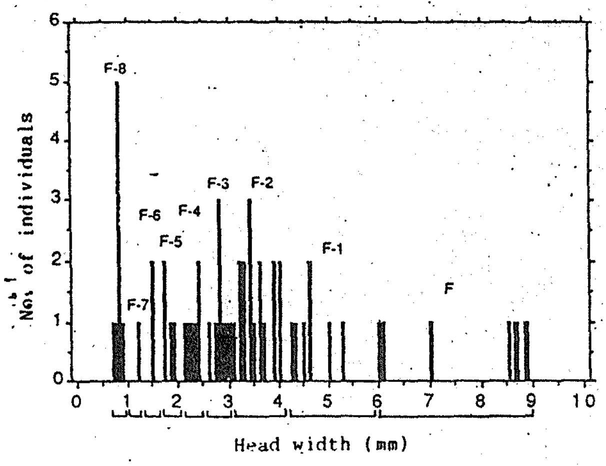

Figure 4.7 Frequency histogram of head widths (mm) of Aeshna brevistyla. Instars estimated from graph: F (5.90-8.90), F-1 (4.10-5.89), F-2 (3.01-4.09), F-3 (2.50-3.00), F-4 (2.10-2.49), F-5 (1.75-2.09), F-6 (1.25-1.74), F-7 (1.00-1.24), F-8 (0.70-0.99).

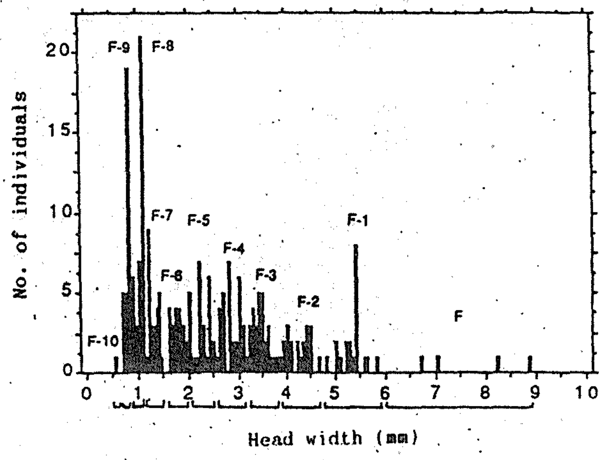

Figure 4.8 Frequency histogram of head widths (mm) of Hemianax papuensis. Instars estimated from graph: F (6.00-8.80), F-1 (4.75-5.99), F-2 (3.80-4.74), F-3 (3.15-3.79), F-4 (2.51-3.14), F-5 (2.01-2.50), F-6 (1.51-2.00), F-7 (1.20-1.50), F-8 (0.80-1.19), F-9 (0.65-0.79), F-10 (0.50-0.64).

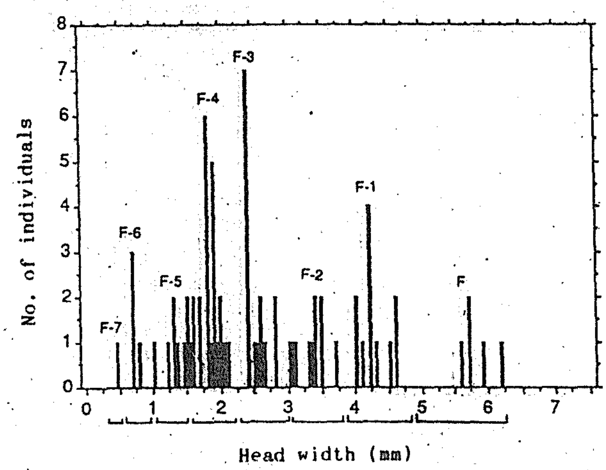

Figure 4.9 Frequency histogram of head widths (mm) of Hemicordulia tau. Instars estimated from graph: F (4.90-6.20), F-1 (3.80-4.80), F-2 (2.90-3.79), F-3 (2.21-2.89), F-4 (1.50-2.20), F-5 (1.00-1.49), F-6 (0.50-0.90), F-7 (0.30-0.40).

Hydrometridae sp 1
Spatial distribution and abundance: Collected from Murdoch Swamp and Nowergup Lake in low numbers.
Temporal distribution and abundance: Collected in January and June from Murdoch Swamp and in September from Nowergup Lake. Numbers were slightly higher in September.
Inference: Insufficient information is available for this species.

Gerridae sp 1
Spatial distribution and abundance: Collected from Murdoch Swamp in small numbers.
Temporal distribution: Collected intermittently from April to July.
Inference: This species may require water throughout the year and may also have specific habitat requirements.

Veliidae sp 1
Spatial distribution and abundance: Collected from Jandabup Lake, Nowergup Lake and North Lake. Abundance was highest in North Lake.
Temporal distribution and abundance: Collected in August, September and March.
Previously collected from Thomsons Lake in January 1987 and from North Lake in May 1987 (Rolls *et al.* 1990).
Inference: This species may require water throughout the year.

Mesoveliidae sp 1
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Murdoch Swamp and Nowergup Lake with high numbers in all but Jandabup Lake.
Temporal distribution and abundance: Collected from September to January in Jandabup Lake, Bartram Swamp and Nowergup Lake, but in Murdoch Swamp it was almost continuously present.
Previously collected from Jandabup Lake in January and May 1987, from North Lake in April and July 1985, and from Thomsons Lake in January 1986, January, March and May 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990).
Inference: This species may require water throughout the year and is probably multivoltine.

Corixidae: Diaprepocoris spp.
Spatial distribution and abundance: Collected from Jandabup Lake and Thomsons Lake. Most numerous in Jandabup Lake, with only a single individual found in Thomsons Lake.
Temporal distribution and abundance: Collected from August to March, with highest abundance in September.
Previously collected from Jandabup Lake in January and May 1987 (Rolls *et al.* 1990).
Inference: This species was not present when water level are low in Jandabup Lake, and presumably migrates to water elsewhere. This species may have specific habitat requirements.

Sigara truncatipala (Hale)
Spatial distribution and abundance: Collected from all six wetlands. Highest abundance occurred in Thomsons Lake and Bartram Swamp.
Temporal distribution and abundance: Collected throughout the year but not found in large numbers when seasonal wetlands are dry. Abundance was higher in December and January.
Previously collected from most wetlands studied (Pinder 1986, Davis & Rolls 1987 and Rolls *et al.* 1990).
General distribution: S.A., Vic., N.S.W., Tas., Qld. and W.A. (Lansbury 1970).
Inference: This species is likely to require water throughout the year.

Agraptocorixa eurynome (Kirkaldy)
Spatial distribution and abundance: Collected from all six wetlands. Abundance was greatest in North Lake.
Temporal distribution and abundance: Collected throughout the year. Present almost continuously in North Lake and Thomsons Lake and perhaps also at Nowergup Lake. Collected intermittently from the other three wetlands.
General distribution: Australia wide (Knowles 1974).
Inference: This species requires water throughout the year, and appears to respond positively to eutrophication.

Agraptocorixa parvipunctata (Hale)
Spatial distribution and abundance: Collected from Jandabup Lake and Bartram Swamp, with highest numbers from Bartram Swamp.
Temporal distribution and abundance: Collected in January, March and April with the highest numbers recorded in January.
General distribution: Australia wide (Knowles 1974).
Inference: Insufficient information is available for this species, but it is likely to require water throughout the year.

Agraptocorixa hirtifrons (Hale)
Spatial distribution and abundance: Collected from North Lake in low numbers.
Temporal distribution and abundance: Collected intermittently from April to July.
General distribution: Vic., N.S.W., Qld., N.T. and S.A. (Knowles 1974).
Inference: Insufficient information is available for this species, but it is likely to require water throughout the year.

Micronecta robusta Hale
Spatial distribution and abundance: Collected from all six wetlands. Highest abundance occurred in North Lake and Nowergup Lake.
Temporal distribution and abundance: Collected throughout the year, with highest numbers in spring and early summer.
Previously collected from most wetlands studied, all year round (Davis & Rolls 1987 and Rolls *et al.* 1990).
General distribution: S.A., N.S.W., Vic., and W.A. (Wroblewski 1970).
Inference: This species probably requires water throughout the year, and may respond positively to eutrophication (see Rolls 1989).

Nepidae: Ranatra sp 1
Spatial distribution and abundance: Collected from Bartram Swamp and Murdoch Swamp in low numbers.
Temporal distribution and abundance: Collected from November to January, with the highest numbers occurring in January.
Inference: Insufficient information about the life cycle of this species is available to determine whether it requires water throughout the year.

Notonectidae: Enithares sp 1
Spatial distribution and abundance: Collected from Jandabup Lake, Nowergup Lake and Thomsons Lake in low numbers.
Temporal distribution: Collected in July August and September.
Inference: Insufficient information is available for this species. It is likely to require water throughout the year, based on what is known of life histories of this family.

Nychia sp 1
Spatial and temporal distribution and abundance: Collected from Murdoch Swamp in September and October, in moderate numbers.
Inference: This species is likely to require water throughout the year, and may have specific habitat requirements.

Anisops spp.
Spatial distribution and abundance: Collected from all six wetlands. Abundance was greatest in Thomsons Lake.
Temporal distribution and abundance: Collected throughout the year, almost continuously from North Lake and Thomsons Lake. Abundance was highest in spring and summer.

Inference: This taxa is able to use seasonal wetlands but probably requires water throughout the year.

Pleidae: Plea brunni Kirkaldy
Spatial distribution and abundance: Collected from Murdoch Swamp and Thomsons Lake. Most abundant in Thomsons Lake.
Temporal distribution and abundance: Collected from January to July. Juveniles were collected in January. The highest numbers were collected in April.
General distribution: S.A., N.T., Qld., N.S.W., Tas., W.A. and New Guinea (Hale 1923).
Inference: Marchant (1982b) collected *P. brunni* from billabongs on Magela Creek, Northern Territory, in the dry season, but not in the wet season which is the same temporal pattern found in Thomsons Lake. This taxa probably requires water throughout the year, and may have specific habitat requirements.

Neuroptera: Sisyridae sp 1
Spatial distribution and abundance: Collected from Bartram Swamp in moderate numbers.
Temporal distribution and abundance: Collected from September to November with numbers peaking in October.
Inference: Not enough is known about this species to determine whether it requires water throughout the year. It may have specific habitat requirements.

Diptera: Tipulidae spp.
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Murdoch Swamp, Nowergup Lake and North Lake. Numbers were most abundant in North Lake.
Temporal distribution and abundance: Collections of this taxa were scattered, with the highest numbers obtained in January from North Lake.
Inference: Insufficient information is available for this taxa.

Culicidae spp.
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Murdoch Swamp, Nowergup Lake and Thomsons Lake. Highest abundance occurred in Murdoch Swamp.
Temporal distribution and abundance: Collected from August to May, almost continuously in Murdoch Swamp. Numbers were highest in March.
Inference: Some of these species are likely to require water throughout the year since numbers were high in autumn.

Psychodidae spp.
Spatial distribution and abundance: Collected from Nowergup Lake and North Lake in moderate numbers.
Temporal distribution and abundance: Collected in May, June and July with highest numbers found in the latter two months.
Inference: This taxa is likely to require water throughout the year, since seasonal wetlands did not contain water during the period when this taxa was collected.

Thaumeliidae spp.
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp and North Lake. Abundance was highest in North Lake.
Temporal distribution and abundance: Collected in a scattered distribution throughout the year, with greatest abundance recorded in winter.
Inference: Insufficient information is available for this taxa.

Chironomidae spp.
Spatial distribution and abundance: Collected from all six wetlands in relatively large numbers. North Lake had the highest numbers.
Temporal distribution and abundance: Present continuously throughout the year in fluctuating numbers.
Inference: Most of these species probably require water throughout the year.

Ceratopogonidae spp.
Spatial distribution and abundance: Collected from all six wetlands. This taxa was least abundant in Jandabup Lake.
Temporal distribution and abundance: Almost continuously present in Murdoch Swamp. Collected only in January in Bartram Swamp and intermittently in the other four wetlands. Abundance was generally highest in summer.
Inference: Most of these species probably require water throughout the year.

Stratiomyidae spp.
Spatial distribution and abundance: Collected from all six wetlands. Abundance was greatest in Nowergup Lake.
Temporal distribution and abundance: Collected as two discrete groups; one from September to March and a second from May to July. Overall, this taxa was most abundant in summer.
Inference: It is possible that some species may not require water throughout the year and others do. More information is required for this taxa.

Tabanidae spp.
Spatial distribution and abundance: Collected from Bartram Swamp, Nowergup Lake and North Lake, with highest numbers in Nowergup Lake.
Temporal distribution and abundance: Collected in Bartram Swamp and North Lake only in January, and in Nowergup Lake from May to July and in September. Numbers are highest in July in Nowergup Lake.
Inference: More information is required for this taxa.

Empididae spp.
Spatial distribution and abundance: Collected from Murdoch Swamp and North Lake in moderate numbers.
Temporal distribution and abundance: Collected in September in Murdoch Swamp and in May and July in North Lake. Numbers are highest in July in North Lake.
Inference: More information is required for this taxa.

Ephydridae spp.
Spatial distribution and abundance: Collected from Bartram Swamp, Murdoch Swamp, Nowergup Lake, North Lake and Thomsons Lake. This taxa was least abundant in Thomsons Lake, and most abundant in Bartram Swamp.
Temporal distribution and abundance: Collected in two discrete groups: The first group occurred from October to December, and a second group occurred from May to September. Numbers were highest in Bartram Swamp in October associated with the floating aquatic plant *Lemna* sp. where almost half of the individuals were found inside individual leaves.
Inference: The absence of this taxa from the permanent wetlands in autumn suggests that ephydrids may not require throughout the year.

Lepidoptera spp.
Spatial distribution and abundance: Collected from all six wetlands in moderate numbers.
Temporal distribution and abundance: Collected throughout the year, but for individual wetlands, the distributions tend to be grouped into discrete periods.
Previously collected from Lake Goolellal in July 1986, from Thomsons Lake in March 1987 and from Forrestdale Lake in January 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990).
Inference: Several species (at least six) are involved. Some may be adapted to seasonal drying, and others may require water throughout the year. It is likely that individual species have specific habitat requirements.

Trichoptera:

Hydroptilidae: Acritoptila globosa Wells

Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp and Thomsons Lake. This species was most abundant in Jandabup Lake and was collected in low numbers in the other two wetlands.

Temporal distribution and abundance: Collected in all months except for May. Almost continuously present in Jandabup Lake, but collected only on one occasion in Bartram Swamp and Thomsons Lake. In Jandabup Lake the numbers fluctuate throughout the year.

Previously collected from several wetlands studied (Davis & Rolls 1987 and Rolls *et al.* 1990). In particular, this species was collected from Thomsons Lake in November 1986, January and March 1987.

General distribution: South-west W.A. (Neboiss 1988).

Inference: This species probably has specific habitat preference with regard to suitable vegetation for constructing cases. It appears to be multivoltine. Numbers are low in autumn in Jandabup Lake, reflecting the less suitable habitat during low water levels. This species may require water throughout the year.

Leptoceridae: Notalina fulva Kimmins

Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, North Lake and Thomsons Lake. Abundance was highest in Jandabup Lake.

Temporal distribution and abundance: Collected almost continuously throughout the year in Jandabup Lake. Numbers fluctuate, but are consistently low from March to September.

Previously collected from Jandabup Lake in November 1986, January, March and May 1987, from North Lake in April and October 1985, and from Thomsons Lake January 1986, January and March 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990).

General distribution: Vic., N.S.W., W.A. and Tas. (Neboiss 1988).

Inference: This species probably requires water throughout the year, and the lower numbers collected from March to September in Jandabup Lake probably reflect the less suitable habitat provided by that wetland for that period.

Triplectides australis Navas

Spatial distribution and abundance: Collected from all six wetlands, with the lowest numbers in Jandabup Lake.

Temporal distribution and abundance: Collected throughout the year, almost continuously in Murdoch Swamp and Thomsons Lake. Numbers were generally highest from October to December.

Previously collected from most wetlands studied (Davis & Rolls 1987 and Rolls *et al.* 1990).

General distribution: N.S.W., A.C.T., Vic., Qld., S.A., N.T. and W.A. (Neboiss 1988).

Inference: High numbers occurred in North Lake and Thomsons Lake in autumn, indicating that this species may require water throughout the year.

Oecetes sp 1

Spatial distribution and abundance: Collected in moderate numbers from Jandabup Lake, Bartram Swamp, Murdoch Swamp, North Lake and Thomsons Lake.

Temporal distribution and abundance: Collected throughout the year in a patchy distribution. It occurred only in April in Thomsons Lake, and was most frequently collected in Jandabup Lake. Numbers fluctuated throughout the year.

Previously collected from Jandabup Lake, Lake Goolellal, Lake Monger, North Lake and Thomsons Lake (Davis & Rolls 1987 and Rolls *et al.* 1990).

Inference: Based on the continuous occurrence of this species, it probably requires water throughout the year.

Ecnomidae: Ecnomus turgidus Neboiss

Spatial distribution and abundance: Collected from Jandabup Lake and Bartram Swamp. Abundance was greatest in Jandabup Lake.

Temporal distribution and abundance: Collected intermittently throughout the year, but not from March to July. Numbers were highest in January, with another peak in September in Jandabup Lake.

Previously collected from Jandabup Lake in July 1986, and from North Lake in October 1985, January 1986, January and March 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990).

Distribution: South-west W.A. (Neboiss 1988).

Inference: It is possible that this species does not require water throughout the year, but further information is required.

Coleoptera:

Haliplidae: Haliplus sp 1 Adults

Spatial distribution and abundance: Collected from Jandabup Lake and Thomsons Lake, with low numbers in both wetlands.

Temporal distribution: Collected in August from Jandabup Lake and December in Thomsons Lake.

Previously collected from Thomsons Lake in July and October 1985, November 1986, and Forrestdale Lake in July, September and November 1986, from Jandabup Lake in July and October 1985, (Davis and Rolls 1987 and Rolls *et al.* 1990).

Inference: Insufficient information is available for this species.

Haliplidae sp 1 Larvae

Spatial and temporal distribution and abundance: Collected from Jandabup Lake in January in low numbers.

Previously collected from Forrestdale Lake in September 1986, and from Loch McNess in September and November 1986 (Rolls *et al.* 1990).

Inference: Insufficient information is available for this species.

Dytiscidae: Hyphydrus elegans (Montrouzier) Larvae & adults

Spatial distribution and abundance: Collected from all six wetlands. Most abundant in Bartram Swamp, Murdoch Swamp and Nowergup Lake and North Lake. Low numbers in Jandabup Lake and Thomsons Lake.

Temporal distribution and abundance: Adults appeared first, reproduced and disappeared from the wetlands as the larvae develop. Collected from August to March.

Larvae were previously collected from Lake Joondalup in January 1986, from Lake Monger in October 1985 and January 1986, from North Lake in October 1985, November 1986, January 1987, Bibra Lake in November 1986, January 1987, from Forrestdale Lake January 1987, and from Loch McNess in November 1986. Adults were previously collected from Bibra Lake in March 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990).

General distribution: W.A., S.A., Vic., N.S.W., Qld., N.T., extralimital to Indonesia, Papua New Guinea, Vanuatu, New Caledonia and New Zealand (Lawrence *et al.* 1987).

Inference: The timing of development appears to be similar from year to year. Adults were not collected between March and August, which indicates that this taxa may have some adaptation to seasonal drying.

Liodessus dispar (Sharp) Adults

Spatial distribution and abundance: Collected from Bartram Swamp, Murdoch Swamp and Nowergup Lake. Most numerous in Nowergup Lake.

Temporal distribution and abundance: Intermittently collected from August to November and in March. The highest numbers were collected in October in Nowergup Lake.

Previously collected from Lake Joondalup in July 1986, and from Thomsons Lake in November 1986, January 1987 (Rolls *et al.* 1990).

General distribution: Southern and northern W.A. (Lawrence *et al.* 1987).

Inference: Insufficient information is available for this species.

Liodessus inornatus (Sharp) Adults
Spatial distribution and abundance: Frequently collected from Murdoch Swamp and only on one occasion from Bartram Swamp, Nowergup Lake, North Lake and Thomsons Lake.
Temporal distribution and abundance: The numbers were highest in May and June. The collections of this taxa in Murdoch Swamp occurred in two discrete groups; the first in spring and summer and the second from April to July.
General distribution: South-west W.A. (Lawrence *et al.* 1987).
Inference: One adult was recovered from moist detritus in a shallow depression from Murdoch Swamp in February 1991 when free water had not been present for about four weeks. This species evidently uses permanent wetlands during the dry period but may also be able to aestivate in moist substrate. There may be two generations per year, based on the collections from Murdoch Swamp.

Gibbidessus sp 1 Adults
Spatial distribution and abundance: Collected from Murdoch Swamp in low numbers.
Temporal distribution and abundance: Collected on one occasion in August.
Inference: Insufficient information is available for this species.

Uvarus pictipes (Lea) Adults
Spatial distribution and abundance: Collected from Jandabup Lake as a single individual.
Temporal distribution and abundance: Collected from Jandabup Lake in January.
General distribution: South-west W.A. (Lawrence *et al.* 1987).
Inference: Insufficient information is available for this taxa.

Antiporus spp. Larvae
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Murdoch Swamp, Nowergup Lake and North Lake. This taxa was most abundant in Murdoch Swamp and least abundant in Jandabup Lake.
Temporal distribution and abundance: Collected from June to October. Numbers peaked in September and October.
Previously collected from Jandabup Lake in July 1985, January 1986, from Thomsons Lake in October 1985, September and November 1986, and from Loch McNess in July 1986, September and November 1986 (Davis & Rolls 1987 and Rolls *et al.* 1990).
Inference: Larvae of the three *Antiporus* species appear to occur when water levels are highest. Further information is required to distinguish between the larvae.

Antiporus femoralis (Boheman) Adults
Spatial distribution and abundance: Collected from Bartram Swamp, Murdoch Swamp, Nowergup Lake, North Lake and Thomsons Lake. Slightly higher numbers were collected from Nowergup Lake.
Temporal distribution and abundance: Most individuals were collected from September to November but animals were also collected in May from Nowergup Lake.
General distribution: South-west W.A., Vic., N.S.W., A.C.T., Tas., extralimital to New Zealand (Lawrence *et al.* 1987).
Inference: It is possible that this species requires water throughout the year, based on the collected of individuals in May from Nowergup Lake.

Antiporus sp 1 (sp. nov. Watts pers. comm.) Adults
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Murdoch Swamp and Nowergup Lake and was most abundant in Nowergup Lake and Murdoch Swamp.
Temporal distribution and abundance: Collected from July to January, and in May. Numbers were highest in August and January in Murdoch Swamp.
General distribution: Apparently confined to the south-west of W.A. (Watts pers. comm.).
Inference: This species may require water throughout the year, based on the collection of one individual in Murdoch Swamp in May.

Antiporus gilberti (Clark) Adults
Spatial distribution and abundance: Collected from North Lake, Nowergup Lake and Thomsons Lake in low numbers.
Temporal distribution and abundance: Collected in October, February, May and July in equal abundance.
General distribution: W.A., S.A., Vic., Tas., N.S.W., Qld. and A.C.T. (Lawrence *et al.* 1987).
Inference: This species may respond positively to eutrophication since it was collected from only the eutrophic wetlands. The presence of individuals in May and early June suggests that this species may require water throughout the year.

Megaporus spp. Larvae
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Nowergup Lake, North Lake and Thomsons Lake. High numbers were collected from North Lake.
Temporal distribution and abundance: Collected from August to December. Highest numbers were collected in August from North Lake.
Previously collected from Thomsons Lake in October 1985, September and November 1986, January, March, May 1987, from Lake Joondalup in September 1986, from Bibra Lake in November 1986, January 1987, and from North Lake in November 1986 and January 1987 (Davis & Rolls 1987 and Rolls *et al.* 1990).
Inference: Previous collections occurred in the same months, with the exception of larvae collected from Thomsons Lake in March and May 1987 when this wetland was seasonal. It is possible that this species may not require water throughout the year. Confirmation of this requires further investigation.

Megaporus solidus (Sharp) Adults
Spatial distribution and abundance: Collected from Bartram Swamp, Murdoch Swamp, North Lake and Thomsons Lake in low numbers.
Temporal distribution and abundance: Collected from July to September, January and May, with numbers slightly higher in September.
Previously collected in Thomsons Lake in January, March and May 1987 (Rolls *et al.* 1990).
General distribution: South-west W.A. (Lawrence *et al.* 1987).
Inference: The collection of this species from Bartram Swamp in May occurred when the wetland was beginning to refill, and contained only a few centimetres of water. It is possible that this species aestivates in the dry bed or is otherwise adapted to seasonal drying.

Megaporus sp 2 Adults
Spatial and temporal distribution and abundance: Collected only from Jandabup Lake in low numbers, during January.
Previously collected from Loch McNess in May 1987, and from Herdsman Lake in January 1987 (Rolls *et al.* 1990).
Inference: Insufficient information available for this species.

Megaporus howitti (Clark) Adults
Spatial distribution and abundance: Collected from Jandabup Lake and North Lake in low numbers.
Temporal distribution and abundance: Collected intermittently in low numbers in February, May, July and August.
General distribution: W.A., N.T., S.A., N.S.W., Vic., and Qld. (Lawrence *et al.* 1987).
Inference: Insufficient information available for this species.

Sternopriscus sp 1 Larvae
Spatial distribution and abundance: Collected from Jandabup Lake and Bartram Swamp in low numbers.
Temporal distribution and abundance: Collected from October to

January, with slightly higher numbers in November.
Previously collected from Jandabup Lake in January 1987 (Rolls *et al.* 1990).
Inference: Insufficient information available for this species.

__Sternopriscus__ sp 2 Larvae
Spatial distribution and abundance: Collected form Jandabup Lake in moderate abundance.
Temporal distribution and abundance: Collected from August to March with highest numbers obtained from October to January.
Inference: This taxa may be a combination of several species since there are four adult *Sternopriscus* species. Further information is required to distinguish between the larvae.

__Sternopriscus browni__ Sharp Adults
Spatial and temporal distribution and abundance: Collected from Jandabup Lake and North Lake in low numbers during November and January.
General distribution: South-west W.A. (Lawrence *et al.* 1987).
Inference: Insufficient information available for this species.

__Sternopriscus__ sp 6 Adults
Spatial distribution and abundance: Collected from Jandabup Lake in relatively high numbers.
Temporal distribution and abundance: Collected from August to October with the highest numbers in September and October.
Previously collected from Jandabup Lake in July, September and November 1986, and March 1987 (Rolls *et al.* 1990).
Inference: Previous collections have occurred in different months, indicating that this species may not develop at the same time every year. Since it has only been recorded at Jandabup Lake, it may have specific habitat requirements. Further information is required for this species.

__Sternopriscus multimaculatus__ (Clark) Adults
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Murdoch Swamp, North Lake and Thomsons Lake. Numbers were highest in Bartram Swamp.
Temporal distribution and abundance: Collected from November to January, and from May to August in two discrete groups. Numbers were greatest in December in Bartram Swamp.
Previously collected from Jandabup Lake in October 1986, January and March 1987 and from Lake Monger in January 1987 (Rolls *et al.* 1990).
General distribution: W.A., N.T., S.A., N.S.W. and Vic. (Lawrence *et al.* 1987).
Inference: The collection of individuals from Jandabup Lake in autumn indicates that this species may require water throughout the year.

__Sternopriscus__ sp 2 (sp. nov. Watts pers. comm.) Adults
Spatial distribution and abundance: Collected from Murdoch Swamp, Nowergup Lake and Thomsons Lake. Abundant in Nowergup Lake.
Temporal distribution and abundance: Collected in December and January, with highest numbers in January.
Inference: Insufficient information available for this species.

__Necterosoma darwini__ (Babington) Larvae & adults
Spatial distribution and abundance: Adults collected from Bartram Swamp and Murdoch Swamp, and larvae collected from Jandabup Lake, Bartram Swamp and Nowergup Lake. Numbers were consistently low.
Temporal distribution and abundance: Larvae collected in July to October while the adults were collected in October, January and February. Larvae were previously collected from Jandabup Lake in July, September 1986, and from Lake Monger in July and November 1986 (Rolls *et al.* 1990).
General distribution: North-west and south-west W.A. (Lawrence *et al.* 1987).
Inference: Previous collections of this species occurred in the same months, indicating that the timing of development is the same from year to year. Further information is required to determine whether this species requires water throughout the year.

__Spencerhydrus pulchellus__ Sharp Adults & larvae
Spatial distribution and abundance: Larvae were collected from Bartram Swamp, Murdoch Swamp and North Lake and an adult was collected from Jandabup Lake. This taxa was least abundant in North Lake.
Temporal distribution and abundance: Larvae were collected from July to October with a numerical peak in August. The adult was collected in August.
General distribution: South-west W.A. (Lawrence *et al.* 1987).
Inference: Further information on the adults is required for this species.

__Lancetes lanceolatus__ (Clark) Larvae and adults
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Nowergup Lake, North Lake and Thomsons Lake. Most abundant in North Lake and Bartram Swamp.
Temporal distribution and abundance: Adults were collected in November from Nowergup Lake and in February from Jandabup Lake. Larvae collected from all 5 wetlands from July to September. Numbers were highest in winter. Larvae were previously collected from Forrestdale Lake in July 1986 (Rolls *et al.* 1990).
General distribution: W.A., A.C.T., S.A., Vic., N.S.W. (Lawrence *et al.* 1987).
Inference: Since neither larvae or adults were collected during autumn, it is likely that this species is adapted to seasonal drying.

__Laccophilus__ sp 1 Larvae
Spatial and temporal distribution and abundance: Collected from Jandabup Lake in low numbers during August.
Inference: Insufficient information is available for this species.

__Rhantus suturalis__ (W.S. Macleay) Larvae and adults
Spatial distribution and abundance: Collected from Bartram Swamp, Murdoch Swamp, Nowergup Lake and North Lake. This taxa was most abundant in North Lake.
Temporal distribution and abundance: Adults were collected in May from Bartram Swamp and in August from North Lake. Adults (57 individuals) were recovered from a drying pool in Murdoch Swamp on 16 February 1989, and in Bartram Swamp soon after refill in May. Larvae were collected in June and from August to October. Numbers were greatest in August and October.
General distribution: W.A., S.A., N.T., N.S.W., A.C.T., Qld., Tas., Vic, extralimital to Asia and Europe (Lawrence *et al.* 1987).
Inference: The appearence of adults in the refilling Bartram Swamp suggests that this species may aestivate in the bed of the wetlands during the drought period.

__Copelatus__ sp 1 Larvae
Spatial and temporal distribution and abundance: Collected from Bartram Swamp and Murdoch Swamps in July in low numbers.
Inference: Insufficient information is available for this species.

__Cybister tripunctatus__ (Olivier) Larvae and adults
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Murdoch Swamp, Nowergup Lake and North Lake. Abundance was highest in Jandabup Lake.
Temporal distribution and abundance: A single adult was collected from Murdoch Swamp in January. Larvae were collected from July to November, with a numerical peak in August.
Larvae were previously collected from Jandabup Lake in

September 1986, from Lake Joondalup in September and November 1986, and from Thomsons Lake in September 1986 (Rolls *et al.* 1990).
General distribution: W.A., S.A., N.S.W., Qld., N.T., extralimital to Africa and southern Asia (Lawrence *et al.* 1987).
Inference: Since larvae and adults were not collected during the dry period, it is possible that this species is adapted to seasonal drying.

<u>Cybister</u> sp 1 Larvae
Spatial distribution and abundance: Collected from Bartram Swamp and North Lake in low numbers during October and November.
Previously collected from Forrestdale Lake in January 1987 (Rolls *et al.* 1990).
Inference: Insufficient information is available for this species.

<u>Homoeodytes scutellaris</u> (Germar) Larvae and adults
Spatial distribution and abundance: Collected from all six wetlands, and most abundant in Bartram Swamp.
Temporal distribution and abundance: Adults were collected from Bartram Swamp in January. Larvae were collected from July to January and in March from Thomsons Lake. Abundance was highest in October. Larvae were previously collected from Loch McNess in November 1986 (Rolls *et al.* 1990).
General distribution: S.A., W.A., A.C.T., N.S.W., Vic., Qld. (Lawrence *et al.* 1987).
Inference: The presence of larvae in March in Thomsons Lake may reflect a requirement for water throughout the year. Further information is required to clarify this possibility.

Dytiscidae sp 2 Larvae
Spatial and temporal distribution: Collected from Jandabup Lake in July.
Inference: Insufficient information is available for this species.

Hydrophilidae: <u>Hydrochus</u> sp 2 Adults
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Murdoch Swamp and Nowergup Lake. Most numerous in Jandabup Lake. Temporal distribution and abundance: Intermittently present throughout the year with a conspicuous absence in March, April and early May. Most frequently encountered in Jandabup Lake, in fluctuating numbers. Previously collected from Jandabup Lake in May 1987 (Rolls *et al.* 1990).
Inference: The absence of this species in autumn and it's reappearance in all four wetlands on 30 May suggests that this species may be adapted to seasonal drying.

<u>Berosus</u> sp 1 Larvae
Spatial distribution and abundance: Collected from Jandabup Lake and Bartram Swamp in small numbers.
Temporal distribution and abundance: Collected from September to December with a peak in October.
Inference: Insufficient information ia available for this species.

<u>Berosus</u> sp 2 Larvae
Spatial and temporal distribution: Collected from Jandabup Lake in low numbers during February.
Inference: Insufficient information is available for this species.

<u>Berosus</u> sp 3 Larvae
Spatial and temporal distribution: Collected from Bartram Swamp in large numbers in September.
Inference: Insufficient information is available for this species.

<u>Berosus</u> sp 4 Larvae
Spatial distribution and abundance: Collected from Jandabup Bartram Nowergup and North Lake. Numbers are highest in Bartram Swamp.
Temporal distribution and abundance: Collected from September to January, with highest numbers collected in September in Bartram Swamp.
Inference: Insufficient information is available for this species.

<u>Berosus</u> sp 5 Larvae
Spatial distribution and abundance: Collected from Nowergup Lake and Thomsons Lake. Highest abundance occurred in Nowergup Lake.
Temporal distribution and abundance: Collected intermittently throughout the year, with largest numbers encountered in November from Nowergup Lake.
Inference: Larvae were collected from Thomsons Lake in March and May when seasonal wetlands were dry, and therefore, this species may require water throughout the year.

<u>Berosus discolor</u> Blackburn Adults
Spatial distribution and abundance: Collected from Jandabup Lake, Nowergup Lake and North Lake with highest numbers found in Jandabup Lake.
Temporal distribution and abundance: Collected from July to November continuously in Jandabup, with highest numbers occurring in September.
Previously collected from Jandabup Lake in July 1985, October 1985 and January 1986, July 1986, and May 1987, from Thomsons Lake in April 1985,
and from Lake Joondalup in July 1986 (Davis & Rolls 1987 and Rolls *et al.* 1990).
Inference: Previous collections of this species in April 1985 from Thomsons Lake were taken when this was a seasonal wetland, and together with the collections from Jandabup Lake in 1988–89, indicates that this species may be adapted to seasonal drying.

<u>Berosus</u> sp 3 Adults
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp and Murdoch Swamp in low numbers.
Temporal distribution and abundance: Collected in January, March, May and July in similar numbers.
Previously collected from Forrestdale Lake in September 1986, from Herdsman Lake in March 1987 and from Lake Monger in October 1986 (Rolls *et al.* 1990).
Inference: Insufficient information is available for this species.

<u>Berosus</u> sp 4 Adults
Spatial distribution and abundance: Collected from Bartram Swamp, Murdoch Swamp and Nowergup Lake in low numbers.
Temporal distribution and abundance: Collected in May and July and from August to November in similar numbers.
Inference: Insufficient information is available for this species.

<u>Berosus</u> sp 6 Adults
Spatial distribution and abundance: Collected from Bartram Swamp and Nowergup Lake. This taxa was most abundant in Bartram Swamp.
Temporal distribution and abundance: Collected in May, and from July to October. Numbers were highest in July.
Inference: Insufficient information is available for this species.

<u>Paracymus pigmaeus</u> Adults
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp, Murdoch Swamp and Nowergup Lake. Highest abundance occurred in Nowergup Lake.
Temporal distribution and abundance: Collected from May to July, and from September to February. Most abundant in October in Nowergup Lake. High numbers were also collected from Bartram Swamp in May when the wetland was beginning to refill. Two individuals were recovered from a drying pool in Murdoch Swamp on 16 February 1989. In February 1991 from this same pool, after free water had been absent for four weeks, most detritus contained several adults of this species.

Previously collected from Jandabup Lake in May 1987, from North Lake in July 1986, from Thomsons Lake in January 1987, from Forrestdale Lake in January 1987 (Rolls *et al.* 1990).
Inference: This species may be adapted to seasonal drying with evidence suggesting that it may aestivate in the dry bed of wetland.

Anacaena sp 1 Adults
Spatial and temporal distribution: Collected from Bartram Swamp in October.
Inference: Insufficient information is available for this species.

Enochrus sp 1 Adults
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp and Nowergup Lake. Most abundance in Nowergup Lake.
Temporal distribution and abundance: Collected in September, October, February, March and May to July. Most numerous in October in Nowergup Lake.
Previously collected from Thomsons Lake in January 1987, March 1987, and from Forrestdale Lake in January 1987 (Rolls *et al.* 1990).
Inference: Insufficient information is available for this species.

Enochrus sp 2 Adults
Spatial distribution and abundance: Collected from Jandabup Lake, Nowergup Lake and Thomsons Lake in low numbers.
Temporal distribution and abundance: Collected in February, May and July on one occasion in each of the three wetlands. Numbers were highest in Thomsons Lake in May.
Inference: Insufficient information is available for this species.

Enochrus sp 3 Adults
Spatial distribution and abundance: Collected from Bartram Swamp, Murdoch Swamp, Nowergup Lake, North Lake and Thomsons Lake. Most abundant in Murdoch Swamp.
Temporal distribution and abundance: This taxa had a semi-continuous distribution, particularly in Murdoch Swamp. Individuals were collected in autumn in Murdoch Swamp and Thomsons Lake.
Inference: The collection of individuals in autumn indicates that this species may require water throughout the year.

Helochares tenuistriatus Regimbart Adults
Spatial distribution and abundance: Collected from Murdoch Swamp, Nowergup Lake, North Lake and Thomsons Lake. Abundance was highest in North Lake.
Temporal distribution and abundance: Collected sporadically throughout the year with the exception of late summer and autumn. Several individuals were collected from moist detritus in a shallow depression in Murdoch Swamp in February 1991.
Previously collected from Lake Joondalup in September 1986, from Thomsons Lake in July 1985, from North Lake in November 1986 (Rolls *et al.* 1990).
Inference: This species may be adapted to seasonal drying by aestivating in the bed of wetlands.

Limnoxenus macer Adults
Spatial distribution and abundance: Collected from Bartram Swamp, Murdoch Swamp, Nowergup Lake, North Lake and Thomsons Lake. Most abundant in Bartram Swamp.
Temporal distribution and abundance: Collected from May to January. Most abundant in May from Bartram Swamp. Seven individuals were recovered from a drying pool in Murdoch Swamp on 16 February 1989, and a single individual was recovered from moist detritus after the same pool had been without free water for four weeks in February 1991. This species was also recovered from reflooded substrate from Bartram Swamp.
Inference: This species is known to aestivate in the dry bed of wetlands.

Hydrophilidae sp 1 Larvae
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp and North Lake, Abundance was highest in Bartram Swamp.
Temporal distribution and abundance: Collected from July to November, with numbers highest in September in Bartram Swamp.
Previously collected from Lake Joondalup in July 1986, Lake Goolellal in July 1986, from North Lake in March 1987, from Bibra Lake in March 1987, from Thomsons Lake in January 1987, March 1987, Forrestdale Lake in July 1986 (Rolls *et al.* 1990).
Inference: Identification of the adults of this species is required.

Hydrophilidae sp 2 Larvae
Spatial distribution and abundance: Collected from Murdoch Swamp and Thomsons Lake in low numbers.
Temporal distribution and abundance: Collected from October to December and in March in similar numbers.
Previously collected from Jandabup Lake in July 1986 (Rolls *et al.* 1990).
Inference: Identification of the adults of this species is required.

Hydrophilidae sp 3 Larvae
Spatial distribution and abundance: Collected from Murdoch Swamp, Nowergup Lake and North Lake. Numbers were highest in North Lake.
Temporal distribution and abundance: Collected from July to February with a numerical peak in October in North lake.
Inference: Identification of the adults of this species is required.

Hydrophilidae sp 4 Larvae
Spatial distribution and abundance: Collected from Jandabup Lake, Bartram Swamp and Thomsons Lake in low numbers.
Temporal distribution and abundance: Collected almost continuously from August to December in different wetlands. Numbers were comparable.
Inference: The adults of this species need to be identified.

Hydrophilus latipalpus Castelnau Adult
Spatial and temporal distribution: Collected as a single individual from Bartram Swamp in September.
Inference: Insufficient information is available for this species.

Hydrophilus albipes Castelnau Adult
Spatial and temporal distribution and abundance: Collected from Murdoch Swamp in January as a single individual.
Inference: Insufficient information is available for this species.

Helodidae: Helodidae sp 1 Larvae
Spatial distribution and abundance: Collected from all six wetlands. This taxa was most abundant in Bartram Swamp and Murdoch Swamp.
Temporal distribution and abundance: Collected from July to December, with numbers peaking in August to October.
Previously recorded from Lake Joondalup in July 1986, September 1986 (Rolls *et al.* 1990).
Inference: The absence of a corresponding adult for this species, appearing after the larvae had been so numerous in Murdoch Swamp, suggests that the adults may be terrestrial. Since larvae were found during maximum water levels, this species could be regarded as adapted to seasonal drying.

Staphylinidae: Hydraena sp 1 Adults
Spatial distribution and abundance: Collected from Jandabup Lake, Murdoch Swamp and Nowergup Lakes. Number were most abundant in Murdoch Swamp.
Temporal distribution and abundance: Collected from May to August and in October with the highest numbers occurring in July and August in Murdoch Swamp.
Previously collected from Loch McNess in May 1987 and from

Jandabup Lake in September 1986 (Rolls *et al.* 1990).
Inference: This taxa may be adapted to seasonal drying based on its temporal distribution. It has been collected in the same months in different years suggesting a constant timing of development between years.

Ochthebius sp 1 Adults
Spatial distribution and abundance: Collected from Bartram Swamp, Murdoch Swamp and Nowergup Lake. This species is most numerous in Bartram Swamp.
Temporal distribution and abundance: Collected in November, January and May. Most abundant in May in Bartram Swamp.
Previously collected from Jandabup Lake in May 1987, from Thomsons Lake in July 1986 (Rolls *et al.* 1990).
Inference: Insufficient information is available for this species.

Staphylinidae sp 1 Larvae
Spatial and temporal distribution and abundance: Collected from Jandabup Lake and Murdoch Swamp in May and July. Numbers were highest in Jandabup Lake.
Inference: Insufficient information is available for this species.

Curculionidae: Curculionidae sp 2 Adults
Spatial distribution and abundance: Collected from Jandabup Lake, Nowergup Lake and Thomsons Lake. This species was most abundant in Jandabup Lake.
Temporal distribution and abundance: Collected from July to October continuously in Jandabup Lake, and on only one occasion in Nowergup Lake and Thomsons Lake. Generally, numbers were highest in August.
Previously collected from Loch McNess in May 1987 and from Lake Goolellal in July 1986 (Rolls *et al.* 1990).
Inference: Since this species was not collected during the drought period, it is possible that it is adapted to seasonal drying.

Curculionidae sp 5,6,7,8,10 Adults
It is likely that these species are not aquatic and they will not be considered further. Nevertheless, the information obtained for these species is in Appendix 2.

Helminthidae: Helminthidae sp 1 Larvae
Spatial distribution and abundance: Collected from Bartram Swamp and Murdoch Swamp in low numbers.
Temporal distribution: Collected on one occasion in September in Bartram Swamp and in November in Murdoch Swamp.
Inference: Insufficient information is available for this species.

Ptilodactylidae sp 1 Larvae
Spatial and temporal distribution and abundance: Collected from Jandabup Lake in September in low numbers.
Inference: Insufficient information is available for this species.

Ptilodactylidae sp 2 Larvae
Spatial and temporal distribution and abundance: Collected from Murdoch Swamp in September in low numbers.
Inference: Insufficient information is available for this species.

Sphaeriidae sp 1 Larvae
Spatial and temporal distribution and abundance: Collected from Bartram Swamp and Murdoch Swamp in October and November (respectively) in low numbers.
Inference: Insufficient information is available for this species.

Gyrinidae sp 1 Adult
Spatial and temporal distribution and abundance: Collected from Murdoch Swamp as a single individual in April.
Inference: The collection of this individual in April suggests that this species requires water throughout the year.

Chrysomelidae sp 1 Larvae
Spatial and temporal distribution and abundance: Collected from Murdoch Swamp in September as a single individual.
Inference: Insufficient information is available for this species.

Chrysomelidae sp 1 Adults
Spatial and temporal distribution and abundance: Collected from Bartram Swamp in May in moderate numbers.
Previously collected from Thomsons Lake in July 1986, from Forrestdale Lake in July 1986 (Rolls *et al.* 1990).
Inference: This species has been collected only from seasonal wetlands soon after refill, and may be adapted to seasonal drying.

Chrysomelidae sp 3 Adults
Spatial distribution and abundance: Collected from Jandabup Lake and Nowergup Lake. This species was most numerous in Jandabup Lake.
Temporal distribution and abundance: Collected intermittently between May and December, and most abundant in September in Jandabup Lake.
Inference: Insufficient information is available for this species.

Chrysomelidae sp 4 Adults
Spatial and temporal distribution and abundance: Collected from Jandabup Lake in September on one occasion in low numbers.
Inference: Insufficient information is available for this species.

Chrysomelidae sp 5 Adult
Spatial and temporal distribution: Collected from Bartram Swamp in October as a single individual.
Inference: Insufficient information is available for this species.

Limnichidae sp 1 Adults
Spatial distribution and abundance: Collected from Jandabup Lake in large numbers.
Temporal distribution and abundance: Collected from August to November, with numbers greatest in August and September.
Inference: This species may have specific habitat requirements because of the restricted distribution. Based on the temporal distribution it may be adapted to seasonal drying.

Fish: Poecilidae: Gambusia holbrooki (Girard)
Frequency histograms of total length and details of the size classes used are given in Table 4.10.
Spatial distribution and abundance: Collected from Jandabup Lake, Nowergup Lake and North Lake. Numbers were highest in North Lake.
Temporal distribution and abundance: Collected throughout the year, with a numerical peak generally in January, February and March with juveniles collected from October to April.
Inference: This species requires permanent wetlands.

Gobiidae: Pseudogobius olorum (Sauvage)
Frequency histograms of total length and details of the size classes used are given in Table 4.11.
Spatial distribution and abundance: Collected from North Lake in moderate to high numbers.
Temporal distribution and abundance: Collected throughout the year with a numerical peak in July, August and September. Recruitment occurred from July to September.
Inference: This species requires permanent wetlands.

Based on the information on the spatial and temporal distribution of each taxa, the taxa which may respond to eutrophication are listed in Table 4.7. Table 4.8 lists the taxa that may be affected by the presence of fish. There was no evidence that any macroinvertebrate taxa responded positively to the presence of fish.

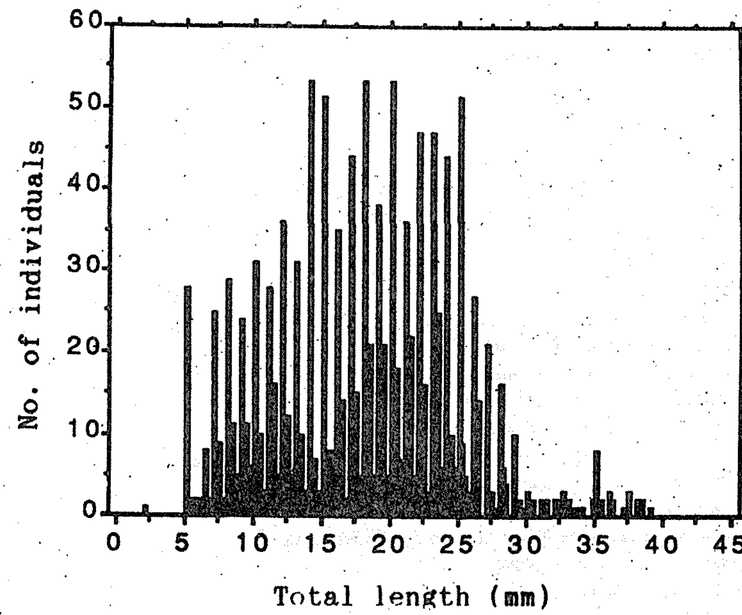

Figure 4.10 Frequency histogram of total length (mm) of Gambusia holbrooki. Size classes: 1: 0-5mm, 2: 5.1-10mm, 3: 10.1-15mm, 4: 15.1-20mm, 5: 20.1-25mm, 6: 25.1-30mm, 7: 30.1-35mm, 8: 35.1-40mm, 9: 40.1-45mm and 10: 45.1-50mm.

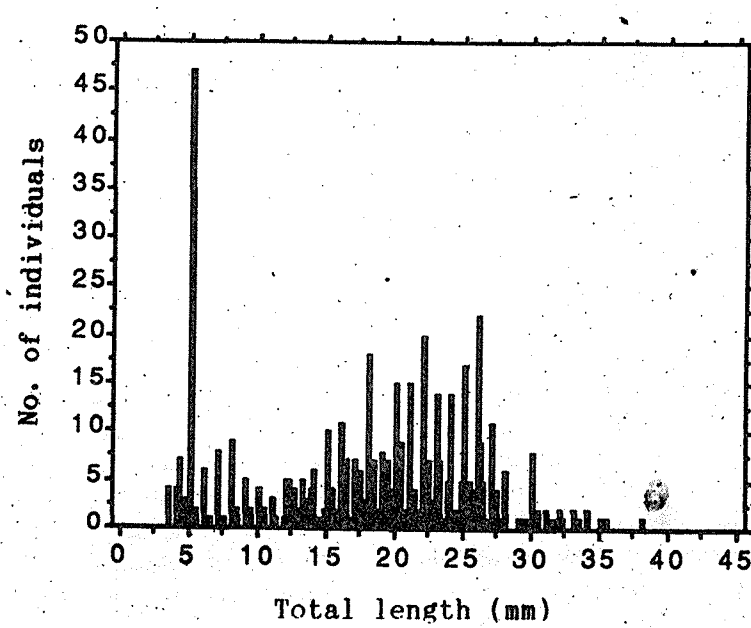

Figure 4.11 Frequency histogram of total length (mm) of Pseudogobius olorum. Size classes: 1: 0-5mm, 2: 5.1-10mm, 3: 10.1-15mm, 4: 15.1-20mm, 5: 20.1-25mm, 6: 25.1-30mm, 7: 30.1-35mm and 8: 35.1-40mm.

Table 4.7 Taxa which may respond to eutrophication.

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1. Taxa which may respond positively to eutrophication:
   a) Taxa which occurred only in eutrophic wetlands (Nowergup Lake, North Lake and Thomsons Lake).
      Gastropoda: *Physa acuta**, *Lymnaea columella*
      Coleoptera: *Antiporus gilberti*
   b) Taxa which were more abundant in the eutrophic wetlands.
      Hirudinea spp.
      Ostracoda: *Candonocypris novaezelandiae**, *Sarscypridopsis aculeata*
      Amphipoda: *Austrochiltonia subtenuis**
      Odonata: *Xanthagrion erythroneurum**
      Hemiptera: *Agraptocorixa eurynome**, *Micronecta robusta**
2. Taxa which may respond negatively to eutrophication:
   a) Taxa which only occurred in the non-eutrophic wetlands (Jandabup Lake, Bartram Swamp and Murdoch Swamp).
      Cladocera: *Simocephalus* spp.
      Coleoptera: *Berosus* sp 3 (adult)
   b) Taxa which were more abundant in the non-eutrophic wetlands.
      Ostracoda: *Bennelongia australis*
      Ephemeroptera: *Cloeon* sp 1*
      Odonata: *Austrolestes analis*, *Hemicordulia tau*
      Coleoptera: *Hydrochus* sp 2.

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*Davis *et al.* (1993) also found that the taxa marked with an asterisk responded in a similar manner in 41 wetlands on the Swan Coastal Plain.

Table 4.8 Taxa that may be affected by the presence of fish

Taxa which may respond negatively to the presence of fish:

a) Taxa which occurred only in wetlands without fish (Bartram Swamp, Murdoch Swamp and Thomsons Lake):
   Cladocera: Moinidae spp.
   Amphipoda: *Perthia acutitelson*

b) Taxa which were more abundant in wetlands without fish:
   Coleoptera: Helodidae sp 1 (larvae)

c) Taxa which may be responding negatively to the presence of *P.olorum* because of their absence from North Lake:
   Ostracoda: *Cypretta baylyi*, *Alboa woroora*

Wiggins *et al.* 1980 divided aquatic invertebrates into four groups according to the way they are adapted to seasonal fluctuations in water level. Group 1 are permanent residents capable of only passive dispersal and dormant during the unfavourable period. Group 2 are residents capable of some active dispersal and dormant during unfavourable seasons with a requirement of water for egg laying. Group 3 are residents capable of active dispersal and dormant during the unfavourable period, but do not require water for egg laying. Group 4 are residents capable of active dispersal where the unfavourable season is spent in permanent water elsewhere.

Williams (1985) modified this scheme to suit temporary waters of the semi-arid zone by replacing group 3 with animals that disperse widely and have no resistant stage. For the purposes of this study, aspects of these classifications are incoporated into a new system with particular reference to the height of the water table. Based on the evidence obtained in this study and a review of the literature, taxa have been assigned to the different categories. Relative to the ground water level, the aquatic fauna of the Perth wetlands falls into 5 categories:

1. Animals which require permanent wetlands and are not mobile.
2. Animals which are able to use seasonal wetlands, but require permanent wetlands when the seasonal wetlands are dry, because they have no adaptation to seasonal drying.
   a) Taxa with mobile, aquatic adults

b) Taxa with short lived, non-aquatic adults

c) Taxa with a parasitic phase

3. Animals which use seasonal wetlands during years of average or above average rainfall. However, in years of below average rainfall where wetlands refill late or dry early, these animals use permanent wetlands. They have long-lived non-aquatic adults.

4. Animals that are adapted to seasonal drying, but require that the water table remains near the wetland bed to maintain a moist substrate in which to aestivate.

5. Animals that are adapted to seasonal drying, and do not require a moist environment, so the depth of the water table is not important.

a) Taxa with desiccation resistant eggs

b) Taxa which have aestivating adults.

The taxa which can be assigned to these categories on the basis of information obtained in this study are shown in Figure 4.12. The number of taxa in each category in each wetland, those of unknown seasonal adaptations and those for which information is insufficient in each of the six wetlands and for all the taxa combined is displayed in Table 4.9. It should be noted that 2.9% of the fauna was regarded as possibly terrestrial and are not included in this table. The seasonal wetland Bartram Swamp had no animals that require permanent wetlands, nor did Murdoch Swamp. However, the relative abundance of taxa in each category is the same for each wetland.

Taxa which may be adapted to seasonal drying but the mechanism is not known, are listed in table 4.10. They may a) migrate, b) aestivate in moist substrate, or c) aestivate in dry substrate. Taxa for which information is insufficient to determine whether they require permanent wetlands or are adapted to seasonal drying are listed in Table 4.11.

Table 4.10 Taxa which may be adapted to seasonal drying, but the exact mechanism is not known.

Annelida: Hirudinea spp.
Gastropoda: Ferrissia sp 1
Glyptophysa sp 1
Acarina: Orabatidae spp.
Ostracoda: Candonocypris novaezelandiae
Coleoptera: Hyphydrus elegans
Megaporus solidus
Rhantus suturalis
Cybister tripunctatus
Hydrochus sp 2
Berosus discolor
Limnichidae sp 1 A
Chrysomelidae sp 1 A
Hydraena sp 1
Curculionidae sp 2

Table 4.9 The number of taxa in each category of adaptations to seasonal drying, those adapted to seasonal drying by an unknown mechanism, and those for which the information is insufficient.

Wetland Category	Jandabup	Bartram	Murdoch	Nowergup	North	Thomsons	Overall	
1	2	0	0	2	2	4	5	3.0%
2	25	25	28	24	26	27	38	22.6%
3	7	8	6	6	6	6	8	4.8%
4	7	8	7	7	6	7	10	6.0%
5	10	12	12	10	9	12	13	7.7%
Seasonal?	12	10	11	9	6	9	15	8.9%
?	44	34	31	25	19	12	74	44.1%

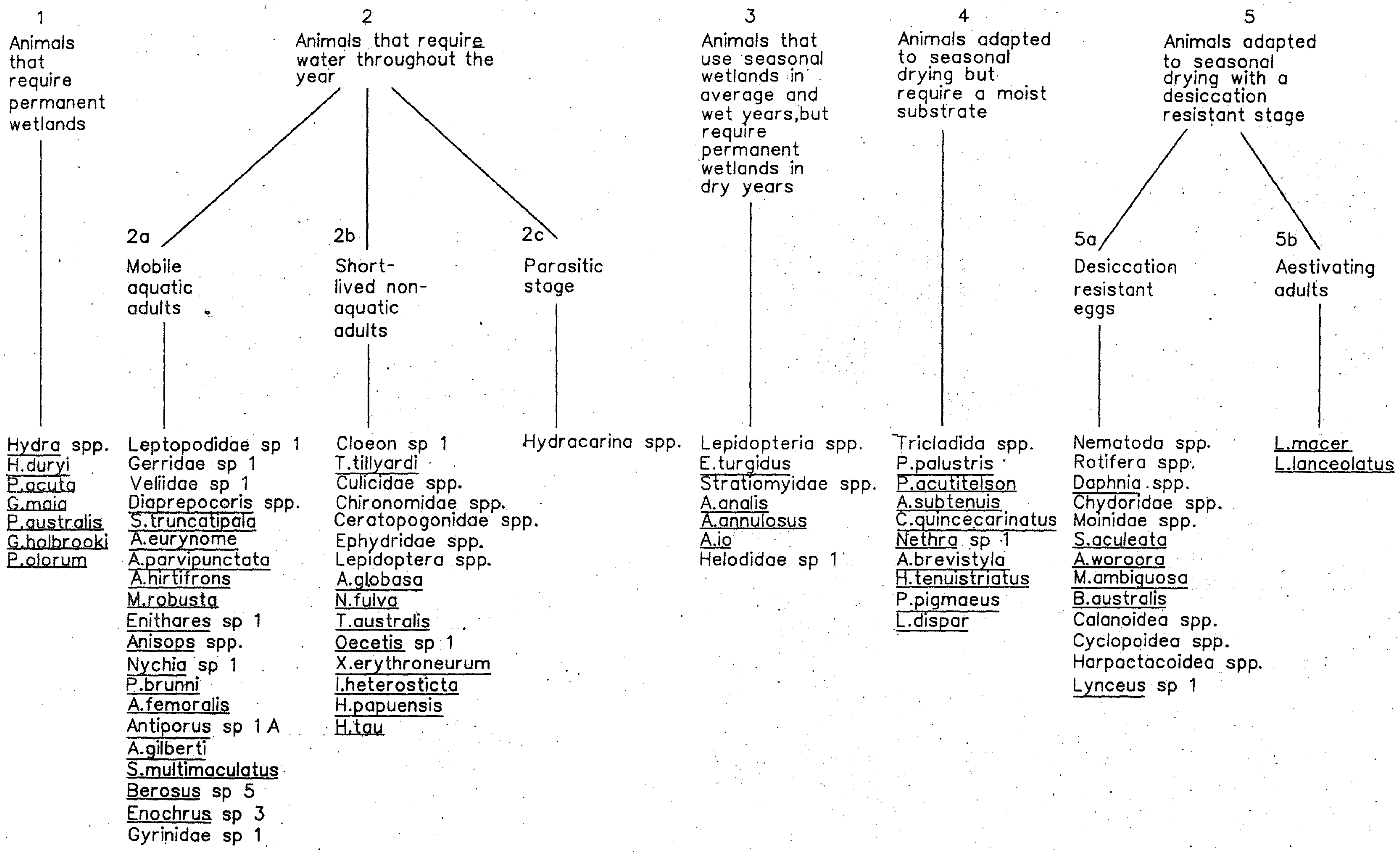


Figure 4.12 Schematic classification of taxa into five categories with regard to groundwater levels. Full descriptions of the categories are given in the text.

Table 4.11 Taxa for which information is insufficient to determine water level requirements.

Oligochaeta	spp.
Gastropoda:	Lymnaea columella
	Gyrulus sp 1
	Sphaerium kendricki
Cladocera:	Macrothricidae spp.
	Sididae sp 1
	Simocephalus sp 1
Ostracoda:	Cypretta baylyi
	Limnocythere mowbrayensis
Odonata:	Ischnura aurora
	Argiolestes pusillus
	Hemicordulia austrliae
	Procordulia affinis
	Diplacodes bipunctata
	Orthetrum caledonicum
	Austroagrion cyane
	Austrothemis nigrescens
Hemiptera:	Hydrometridae sp 1
	Ranatra sp 1
	Saldula sp 1
Neuroptera:	Sisyridae sp 1
Diptera:	Tipulidae spp.
	Thaumeliidae spp.
	Tabanidae spp.
	Empididae spp.
Coleoptera:	Haliplus sp 1 (adult)
	Haliplus sp 1 (larvae)
	Gibbidessus sp 1 (adult)
	Liodessus inornatus (adult)
	Uvarus pictipes (adult)
	Megaporus spp. (larvae)
	Megaporus sp 2 (adult)
	Megaporus howitti (adult)
	Antiporus spp. (larvae)
	Sternopriscus sp 1,2 (larvae)
	S. browni (adult)
	Sternopriscus sp 6 (adult)
	Sternopriscus sp 2 (adult)
	Necterosoma darwini
	Spencerhydrys pulchellus
	Laccophilus sp 1
	Copelatus sp 1
	Cybister sp 1
	Homoeodytes scutellaris
	Dytiscidae sp 2
	Octhebius sp 1 (adult)
	Berosus sp 1,2,3,4 (larvae)
	Berosus sp 3,4,6 (adults)
	Anacaena sp 1 (adult)
	Hydrophilidae sp 1,2,3,4 (larvae)
	Enochrus sp 1,2
	Hydrophilus latipalpus
	H. albipes
	Staphylinidae sp 1
	Helminthidae sp 1
	Ptilodactylidae sp 1,2
	Sphaeriidae sp 1
	Chrysomelidae sp 1 (larvae), sp 3,4,5 (adults)

Discussion

Determining the potential impact of altered water levels, eutrophication and introduced fish on the aquatic fauna requires information on the response of individual species. Information on spatial and temporal distribution and abundance of taxa in these six wetlands provides some indication of their life history characteristics with regard to these potential impacts. Some life history information is derived from the temporal distribution and relative abundance of each taxa. The six wetlands afford a comparison of the spatial distribution and relative abundance of species in seasonal, partly seasonal and permanent wetlands, wetlands of differing trophic state, and wetlands with and without fish.

Life history information involves enumeration, measurement, categorization and observation, to determine densities, sizes, life cycle stages and behaviour of organisms at any point in time. When carried out over a period of time, the values obtained for these variables provide information on various life history parameters. When these parameters are considered in a temporal context, two additional life history features emerge: voltinism and phenology. Phenology involves both the seasonal timing of the life cycle processes and the population synchrony of these processes, and voltinism refers to the number of life cycles completed in a year (Butler 1984).

Where growth (size) intervals are used instead of true developmental categories (instars), sexual dimorphism and other sources of variance in growth can complicate analysis of the length of the life cycle using serial histograms of developmental stages (Butler 1984). Detection of multivoltinism may require weekly or even more frequent samples (Butler 1984). Therefore, little emphasis was placed on determining voltinism here.

Other limitations of the data must be noted. With regard to sampling method it is generally acknowledged that sweeps do not adequately sample benthic fauna. Evidence of this is the under-representation of bottom dwelling odonates known to inhabit these wetlands (see Watson 1962). However, sweeps do sample a greater proportion of the fauna than any other method available (Cheal *et al.* in press).

Another potential problem with the analysis of spatial distribution of taxa in the six wetlands is that of the circular argument (e.g. species x only occurs in permenent wetlands therefore it requires permanent wetlands). Care has been taken to avoid this argument and it is stressed that the conclusions drawn in the following discussion are provisional and need to be confirmed experimentally.

Table 4.7 indicates which species may need to be used in an experimental investigation on the effects of eutrophication. Priority should be given to the taxa which may be adversely affected by eutrophication. Table 4.8 lists those taxa which could be used in experiments to assess the role of fish predation in influencing the distribution and abundance of invertebrates.

Very few taxa appear to require permanent wetlands. Those that are listed in Figure 4.12 represent only 3% of the total taxa collected. Of these, the snails *Helisoma duryi* and *Physa acuta*, and the fish *Gambusia holbrooki*, are introduced. The shrimp *Palaemonetes australis* and the goby *Pseudogobius olorum* are also found in rivers and estuaries. Loss of these species from the wetlands of the Perth region would not affect their conservation status. The ostracod *Gomphodella maia*, is not restricted in distribution to south-western Western Australia and may be amenable to passive dispersal, since it was collected in Thomsons Lake, which had been a seasonal wetland in the ten years prior to 1989. Without identification to species level little can be said of the distribution of *Hydra* spp. Other taxa which may require permanent wetlands would come from the non-mobile groups such as the Turbellaria, Annelida, Mollusca and Crustacea. Within these groups, nine taxa have unknown requirements with regard to seasonal drying. Therefore, it is possible that between 3.0 and 8.3% of the taxa identified in this study may require permanent wetlands.

The taxa in category 2 require water throughout the year, and at present, permanent wetlands fulfill this role. However, artificial maintenance of wetland water levels during the drought period would allow flexibilty from a management perspective. A particular wetland need not be permanent over time, but could be artificially maintained over the drought period in some years as part of a regional mosaic of wetlands.

Category 3 animals require permanent wetlands for long term survival, and together with animals in categories 1 and 2, constitute 30.4% of the taxa which are regarded provisionally as requiring permanent wetlands. The taxa that are provisionally assigned to categories 4 and 5 consistute 13.7% of the total number collected. While some attempt was made to locate animals in dry wetland beds, the effort was considerably less than that devoted to sampling the aquatic environment. Therefore, the number of taxa in categories 4 and 5 is likely to be a substantial underestimate.

Within category 5, several taxa (e.g. rotifers, some cladocerans, ostracods and the conchostracan) require seasonal drying as part of the stimulus for hatching and continued survival. It is possible that more species would be lost if all wetlands became permanent, than if all wetlands became seasonal.

It should be stressed that 53% of the taxa collected remain unassigned to a particular category, although 8.9% are believed to have some unidentified adaptation to seasonal drying. In fact, if the terrestrial taxa (2.9%) and the taxa which potenially require permanent wetlands (8.3%, see above) are subtracted from the total, 88.8% of the taxa are in some way adapted to the seasonal drying of wetlands via migration (category 2), having long-lived non-aquatic adults (category 3) or aestivating (categories 4 and 5). It is also likely that an individual species employs several means of surviving the drought period, with some proportion of the population migrating and another proportion aestivating.

While there are a few species that live in permanent wetlands and are non-mobile, the remainder of the fauna is highly mobile and adapted to seasonal drying. This reflects the selective influence of historically drier periods. The high mobility of the fauna indicates that the south-west corner of Western Australia must be regarded from a regional perspective. The southern part of this region receives higher rainfall and consequently, contains a greater proportion of permanent wetlands (including rivers) than the Swan Coastal Plain. It is possible that these southern wetlands act as drought refuges for a large number of taxa.

Taxa for which the known distribution is confined to wetlands of south-western Western Australia are: the amphipod *Perthia acutitelson*, the isopod *Paramphisopus palustris*, the gilgie *Cherax quincecarinatus*, the dragonfly *Procordulia affinis*, the trichopterans *Acritoptila globosa* and *Ecnomus turgidus* and the beetles *Megaporus solidus*, *Sternopriscus browni*, *Sternopriscus* sp6, *Necterosoma darwini*, *Spencerhydrus pulchellus*, *Uvarus pictipes*, *Liodessus inornatus* and *Antiporus* sp. nov. Priority should be given to researching the life histories of these species because of their restricted distributions. It is extremely important to determine their habitat requirements in order to effectively conserve these species.

5 Macroinvertebrate community structure

Introduction

This chapter examines the impact of seasonal drying, nutrient enrichment and the presence of fish on the structure of the macroinvertebrate communities of the six wetlands. Macroinvertebrate communities are composed of interacting animals. The community can be characterized according to the focus of research interests. For example a community may be divided into trophic levels such as primary and secondary consumers, or partitioned on the basis of functional feeding groups. Community structure encompases species composition, diversity (richness and equitability), abundance, temporal changes and relationships between species (Hurlbert 1971 and Krebs 1978). Here species richness and abundance are considered.

The impact of seasonal drying, eutrophication and the presence of fish is reviewed in Section 2. The available information indicates that eutrophication is likely to decrease species richness and incr/ease abundance (e.g. Hellawell 1986). The presence of fish may reduce both species richness and abundance (e.g. Bence 1988). The impact of seasonal drying is less clear. Several studies have positively correlated species richness in temporary water with the length of the flooded period (Stout 1964, Driver 1977, Kownacki 1985 and Ebert & Balko 1987). For example, chironomid diversity increases gradually from very temporary ponds to permanent ponds. Kulp & Rabe (1984) found a significantly lower number of taxa in vernal pools (flooded for three to four months) than in nearby permanent wetlands and attributed this to a lower diversity of microhabitat in pools which lack aquatic macrophytes, and the inability of some taxa to cope with seasonal drying. Shiel (1980) found the diversity of macroinvertebrates was greater in permanent billabongs of the River Murray than those which dry seasonally and attributed this to community stability. However, Neckles *et al.* (1990) did not observe an increase in the number of taxa with increased water permanence (seasonal 3.5 months , semipermanent seven months) and attributed this lack of response to the newness of the semipermanent flooding regime.

The basis of the contradictions between these studies may be the length of the flooded period. For example, many of the pools studied by Ebert & Balko (1987) dried five times within two months and are more appropriately regarded as ephemeral pools (cf. Begon & Mortimer 1981), or temporary wetlands and are not directly comparable with the seasonal wetlands studied here or those of Outridge (1987), Davis *et al.* (1993) or Boulton & Lloyd (1991) which share the characteristic of containing water for many months.

Methods

The collection and processing of the invertebrates was described in Chapter 4 with the exception of the details of obtaining biomass estimates of the invertebrates. This was achieved by weighing individual invertebrates, or a number of specimens and then dividing this weight to obtain the weight of a single individual. Wet weights were used after the animals had been blotted dry of superficial moisture. The animals had been stored in alcohol for several months and consequently would have lost weight with time, however the weight loss is asymptotic with little loss occuring after 60 days (Howmiller 1972 and Wiederholm & Eriksson 1977). Consequently, as with the work of Nelson *et al.* (1990), these biomass estimates are best viewed as relative biomass indices. A list of the biomass for each species in different size classes is provided in Appendix 3. The odonates and fish had been removed for detailed measurements of size and stored in separate vials, and so were weighed per sample, rather than individually.

For the analysis of community structure, the data was classified and ordinated using multivariate techniques from the Pattern Analysis (PATN) software package (Belbin 1989), and Two Way Indicator Species Analysis (TWINSPAN) (Hill 1979). Multivariate techniques can bring to light some new details or relationships and is an ideal tool for generating hypotheses about how processes are determining data variation (Gauch 1982, Belbin 1989 and Digby & Kempton 1987).

Classification of the data using cluster analysis produces clusters of objects whether natural clusters exist or not. Where natural clusters do not exist, the groups may have recognizable qualities, but tend to merge into one another with no clearly defined discontinuities. The benefit is that identification of the clusters, natural or not, presents direct evidence for the variation in the data and less direct evidence about the underlying processes. Clustering divides the data into groups of similar samples, whereas ordination displays interrelationships among the samples.

TWINSPAN is a polythetic divisive technique that employs Correspondence Analysis to classify the samples and then divides the data into two groups. Each group is subsequently divided independently and the process is repeated for as many times as specified by the analyst. During the analysis, the taxa are assessed for their utility in assigning samples to one group or another, yielding indicator species for each group. Full details are given in Hill (1979). The principle advantages of TWINSPAN are its speed with large data sets and the production of diagnostic information about which species are responsible for a given division. A potential disadvantage it is reliance on the calculation of dissimilarity among samples using a chi-squared dissimilarity measure which Faith *et al.* (1987) found to be one of the least robust measures of dissimilarity when used with ecological data.

While TWINSPAN is divisive, Sequential Agglomerative Heirarchical Non-overlapping (SAHN) clustering is a polythetic method of aggregating samples in a hierarchical fashion according to some criterion (Sneath & Sokal 1973). Flexible Unweighted Pair Group Arithmetic averaging strategy (UPGMA) (where equal weight is given to objects, not groups) was used to classify the data. It represents a robust but conservative means of grouping samples (Clifford & Stephenson 1975 and Belbin 1989). Diagnostic information which help discriminate between groups based on attributes can also be produced (GSTA).

The data was standarized using a range transformation to values between 0-1 (essentially percentage values) for the equal weighting of attributes prior to the use of association measures. The analyses used here involved a disimilarity measure which is used for both classification and ordination. This dissimilarity measure will equal zero when two samples are identical (Faith *et al.* 1987). The Kulczynski coefficient has provided good measures of association for ecological applications Faith *et al.* (1987) and was used here to produce an association matrix for the invertebrates. The Gower Metric association measure is used with continuous data with a linear response (Williams *et al.* 1987), and was used here for the physicochemical data.

Ordination methods attempt to condense the information contained in the data into two or three new attributes. If this can be achieved with little loss of information, the objects can be displayed on bivariate plots so that the distance between objects in the plot represents the degree of similarity between the objects as measured by the attributes. Objects that are close in the reduced 'space' are those that are similar, while those that are separated by large distances are dissimilar in terms of the attributes used in the data. A very powerful product of this form of display is that overall trends (gradients) may be more clearly perceived. By comparing the reduced space with intrinsic (used in the analysis) or extrinsic attributes, any trends that are evident may be named and processes inferred (Belbin 1990).

The data was ordinated using semi-strong-hybrid multidimensional scaling (SSH; Belbin 1989) to produce a map of a dissimilarity matrix in a given number of dimensions specified by the analyst. SSH optimizes its map by regressing the distances between the points on the map with their dissimilarities. The goodness of fit of a particular map is given by a stress formula that measures the degree to which the spatial configuration of points on the map has to be altered to fit the dissimilarity values among the sample points. The lower the stress, the better the fit. The number of dimensions required to adequately described the data was determined by plotting the lowest stress level produced from ten random starts from dimensions 1 to 6 and observing when an increase in the number of dimensions no longer gave a large decrease in stress. The final solution for the chosen number of dimensions was obtained from the best of 100 random starts.

Several methods were used to display and evaluate the data: Principal axis correlation (PCC) uses a multiple-linear regression to see how well a set of attributes can be fitted to an ordination space. It is designed to determine the linear relationship between the multidimensional ordination (invertebrate data) and a set of attributes (physico-chemical data), and gives a correlation coeficient that can be used as an indicator of significance (Belbin 1989). Procrustes rotation (PROC) may be used to compare two ordinations of the same objects or to compare an ordination with an hypothesized or known configuration. The analysis yields measures of the overall fit (Belbin 1989) and was used to compare the ordination of the invertebrates with the physicochemical data.

Results

Species richness

A total of 176 taxa were collected from the six wetlands combined. The number of taxa collected from each wetland on each sampling date, both as raw numbers and per cubic metre is presented in Table 5.1 with the number of taxa per cubic metre graphically displayed in Figure 5.1. The hyper-trophic wetlands (Nowergup Lake, North Lake and Thomsons Lake) contained fewer taxa than the less nutrient enriched wetlands. Bartram Swamp which dried completely, and Jandabup Lake which was artificially maintained with 13cm of water during autumn, contained the highest number of taxa. The two wetlands that dried to deep pools (Murdoch Swamp and Nowergup Lake) contained intermediate

Table 5.1 The number of taxa in each wetland on each sampling occasion with totals. When Bartram Swamp was dry no aquatic animals were collected, while blank spaces indicate that samples were not taken.

Date	Jandabup		Bartram		Murdoch		Nowergup		North		Thomsons		Total
	Raw	/m^3	Raw	/m^3	Raw	/m^3	Raw	/m^3	Raw	/m^3	Raw	/m^3	Raw
11 Aug 88	59	7.06							25	7.48	32	21.53	74
27 Aug 88	44	4.77							25	6.73	28	15.08	64
19 Sep 88	42	5.65	37	19.93	35	18.85	35	18.85	24	6.46	22	1.85	87
10 Oct 88	40	10.77	48	25.85	36	19.39	34	18.31	23	12.39	23	15.48	88
31 Oct 88	38	10.23	31	16.69	41	22.08	39	21.00	31	16.69	18	9.69	79
22 Nov 88	45	24.23	58	31.23	35	18.85	27	14.54	26	17.50	26	17.50	95
15 Dec 88	39	21.00	35	18.85	29	15.62	30	26.93	27	14.54	42	18.85	84
06 Jan 89	42	22.62	40	21.54	40	21.54	33	29.64	31	16.69	36	19.39	88
25 Jan 89	31	16.69	37	19.93	37	19.92	23	12.39	24	12.92	31	16.69	78
16 Feb 89	33	17.77	0	0	23	12.39	10	6.73	19	10.23	35	18.85	67
09 Mar 89	30	16.16	0	0	28	15.08			15	8.08	29	15.62	59
29 Mar 89	22	11.85	0	0	25	13.46			22	11.85	23	12.39	49
20 Apr 89	17	9.16	0	0	23	12.39			15	8.08	27	18.17	46
11 May 89	18	9.69	0	0	23	12.39			16	8.62	25	13.46	50
30 May 89	26	14.00	15	16.15	34	18.31	30	16.16	21	11.31	28	15.08	78
19 Jun 89	33	17.77	0	0	36	19.39	24	12.92	23	12.39	23	12.39	70
05 Jul 89	37	19.92	0	0	30	16.16	33	17.77	32	17.23	16	8.62	84
31 Jul 89	32	17.23	19	10.23	25	13.46	31	16.69	23	12.39	21	11.31	74
21 Aug 89	25	13.46	27	14.54	25	13.46	25	13.46	28	15.08	22	11.85	71
11 Sep 89	38	20.46	39	21.00	22	11.85	40	21.54	28	15.08			85
Total	110		108		99		93		80		80		176
Spring	66	13.20	84	16.80	70	14.00	69	13.80	54	10.80	39	9.75	140
Summer	62	15.50	56	14.00	57	14.25	43	10.75	44	11.00	57	14.25	117
Autumn	52	10.40	15	15.00	56	11.20	30	30.00	34	6.80	48	9.60	103
Winter	77	12.83	30	7.50	49	12.25	52	13.00	51	8.50	52	8.67	125

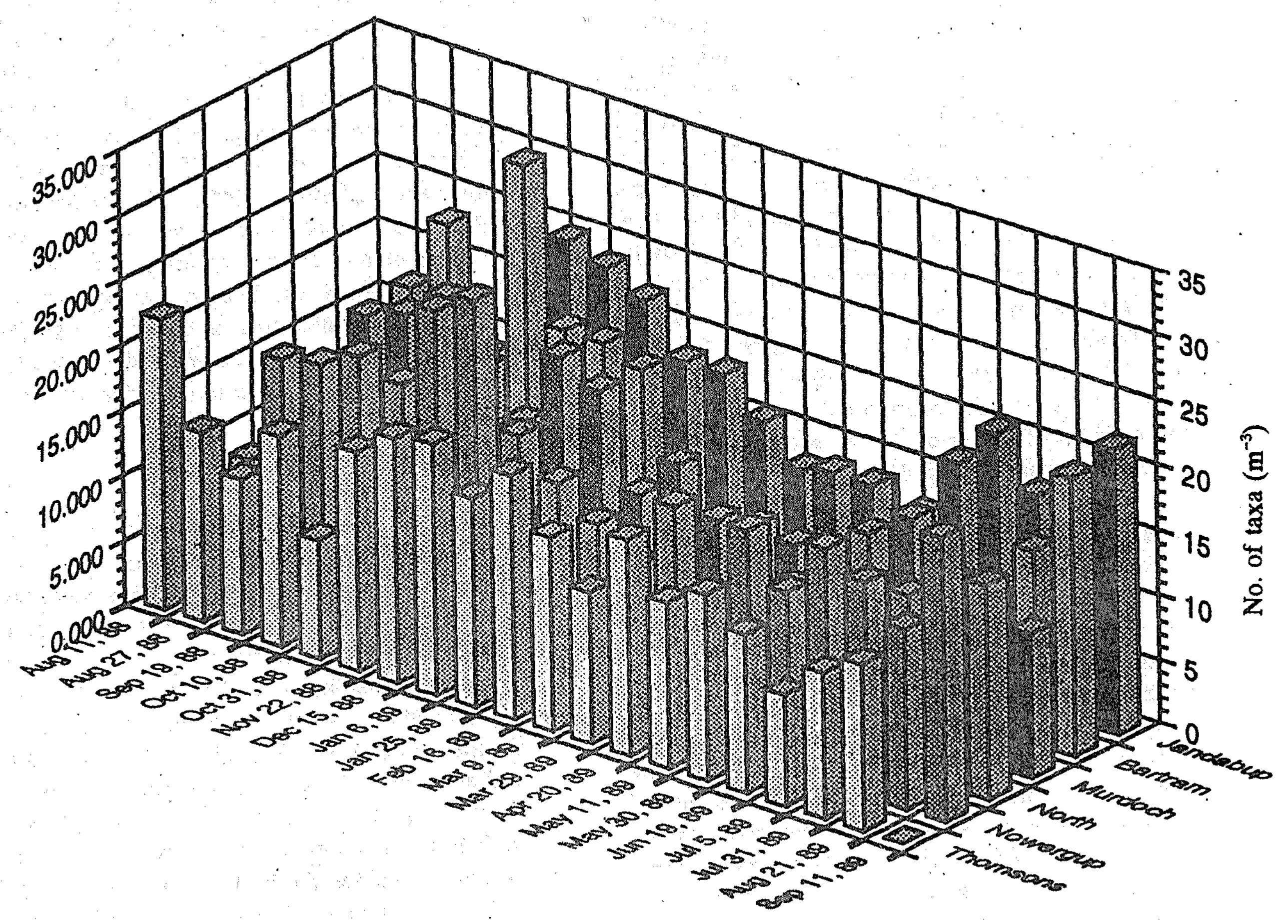


Figure 5.1 The number of taxa/m^3 on each sampling occasion from each wetland.

numbers of taxa, while the two permanent wetlands (North Lake and Thomsons Lake) contained the lowest number of taxa. Generally, the number of taxa was lowest from late summer (February) until mid-winter (early July). The number of taxa unique to Jandabup Lake was 17, Bartram Swamp 12, Murdoch Swamp 10, Nowergup Lake 3, North Lake 2 and Thomsons Lake 1.

The seasonal distribution of taxa is also given in Table 5.1. The number of taxa unique to spring was 19, to summer 9, autumn 4 and winter 8. Overall, the highest number of taxa occurred in spring, followed by winter, summer and the lowest number of taxa occurred in autumn. However, within each wetland this pattern is not consistent. This may have been because the number of samples in each season is not equal; spring – up to 5 samples, summer 4, autumn 5, winter 6. To correct for this, the average number of taxa per season is shown in Table 5.1. Four of the wetlands, (Jandabup Lake, Murdoch Swamp, North Lake and Thomsons Lake) have a maximal number of taxa in summer, and a minimum number in autumn. Bartram Swamp had a maximum number of taxa in spring and a minimum in winter, while Nowergup had a maximum in autumn, (based on one sample only) and a minimum number of taxa in summer. Again the pattern between wetlands is not consistent, but overall, the highest number of taxa occurs in spring and summer in each wetland and corresponds to peak water levels. The lowest number of taxa occurs in autumn and corresponds with low water levels.

Scheffe's multiple contrasts (Zar 1984) were used to compare groupings of the six wetlands (see Table 5.2). Because the relationships are based on only six wetlands, they should be regarded as provisional. Experimental work or comparisons between a greater number of wetlands is needed to confirm the trends found with these six wetlands. The number of taxa was significantly greater in the seasonal and semi-seasonal wetlands than in the permanent wetlands (S=3.36, p0.10), and in the well vegetated wetlands compared to the poorly vegetated North Lake (S=3.54, p0.05). However, the difference in species richness between the less enriched and the hypertrophic wetlands was not significant.

Table 5.2 Scheffe's multiple comparisons between various groupings of the six wetlands. Significance levels are denoted with asterisks: * S=3.09 (p0.10), ** S=3.39 (p0.05), *** S=4.01 (p0.01); n=102. Abbreviations: Jan = Jandabup Lake, Bar = Bartram Swamp, Mur = Murdoch Swamp, Now = Nowergup Lake, Nor = North Lake and Tho = Thomsons Lake.

Comparison	Feature compared	Direction of relationship	S
Dried completely (Bar) vs Did not dry (Jan Mur Now Nor Tho)	No. of taxa	>	2.79
	Abundance	<	1.97
	Biomass	<	1.57
Dried substantially (Jan Bar Mur Now) vs permanent (Nor Tho)	No. of taxa	>	3.36*
	Abundance	<	1.82
	Biomass	<	2.30
Less enriched (Jan Bar Mur) vs Hypertrophic (Now Nor Tho)	No. of taxa	>	1.90
	Abundance	<	3.11**
	Biomass	<	5.41***
No algae blooms (Jan Bar) vs algal blooms (Mur Now Nor Tho)	No. of taxa	>	1.53
	Abundance	<	3.51**
	Biomass	<	3.53**
Mesotrophic (Jan) vs Eu- & hypertrophic (Bar Mur Now Nor Tho)	No. of taxa	>	1.26
	Abundance	<	2.75
	Biomass	<	3.28*
Without fish (Bar Mur Tho) vs With fish (Jan Now Nor)	No. of taxa	>	2.16
(Also coloured vs not coloured)	Abundance	<	0.49
	Biomass	<	0.69
Aquatic vegetation (Jan Bar Mur Now Tho) vs none (Nor)	No. of taxa	>	3.54**
	Abundance	<	1.30
	Biomass	<	0.59
Small size (Mur Bar) vs Large (Jan Now Nor Tho)	No. of taxa	>	2.80
(Also extremely coloured vs less coloured)	Abundance	<	1.24
	Biomass	<	3.22*

Table 5.3 The number of individual invertebrates (abundance) per cubic metre in each wetland on each sampling occasion. Mean abundance in each wetland and in each season is listed at the end.

Date	Wetland					
	Jandabup	Bartram	Murdoch	Nowergup	North	Thomsons
11 Aug 88	4223.76				106284.50	75791.38
27 Aug 88	3341.54				8359.45	49311.25
19 Sep 88	5637.72	24844.37	80269.78	66146.47	24453.96	52368.87
10 Oct 88	2676.90	10468.50	41015.08	35162.09	36823.91	33901.08
31 Oct 88	29719.43	8015.62	102037.69	82380.18	13460.42	33451.27
22 Nov 88	15393.65	8653.20	76199.78	40289.71	14566.62	17201.21
15 Dec 88	743.67	2334.41	12674.74	69551.17	5882.07	9747.31
06 Jan 89	1369.41	9501.35	63502.96	108594.25	3469.58	16800.75
25 Jan 89	1826.60	6623.59	25947.23	89609.58	11892.84	37772.21
16 Feb 89	5206.79	0	6851.91	19467.70	5103.93	13666.67
09 Mar 89	3719.98	0	9656.97		1617.12	5789.98
29 Mar 89	11017.23	0	53506.73		1580.51	34659.13
20 Apr 89	3224.02	0	17439.96		11405.49	94518.16
11 May 89	1827.14	0	12565.97		8415.72	39892.84
30 May 89	1779.21	118.41	28351.10	1670.44	11593.97	11199.25
19 Jun 89	16012.92	0	21108.24	14144.86	3206.25	58096.39
05 Jul 89	14795.91	0	21508.35	15593.43	12563.27	38756.60
31 Jul 89	9463.65	9661.28	22517.50	38778.14	109897.68	16821.76
21 Aug 89	7513.19	21911.69	17175.55	39761.98	274660.74	93477.65
11 Sep 89	8451.27	16213.25	30956.92	40945.61	144655.89	
Mean	7397.20	10758.69	35738.13	47292.54	40494.69	38590.72
Spring	12375.79	13638.99	66095.84	52984.81	46792.15	34230.60
Summer	2286.62	6153.11	27244.21	71805.67	6587.10	19496.73
Autumn	4313.52	118.41	24304.14	1670.44	6922.56	37211.86
Winter	9225.16	15786.48	20577.41	27069.69	85828.64	55375.83

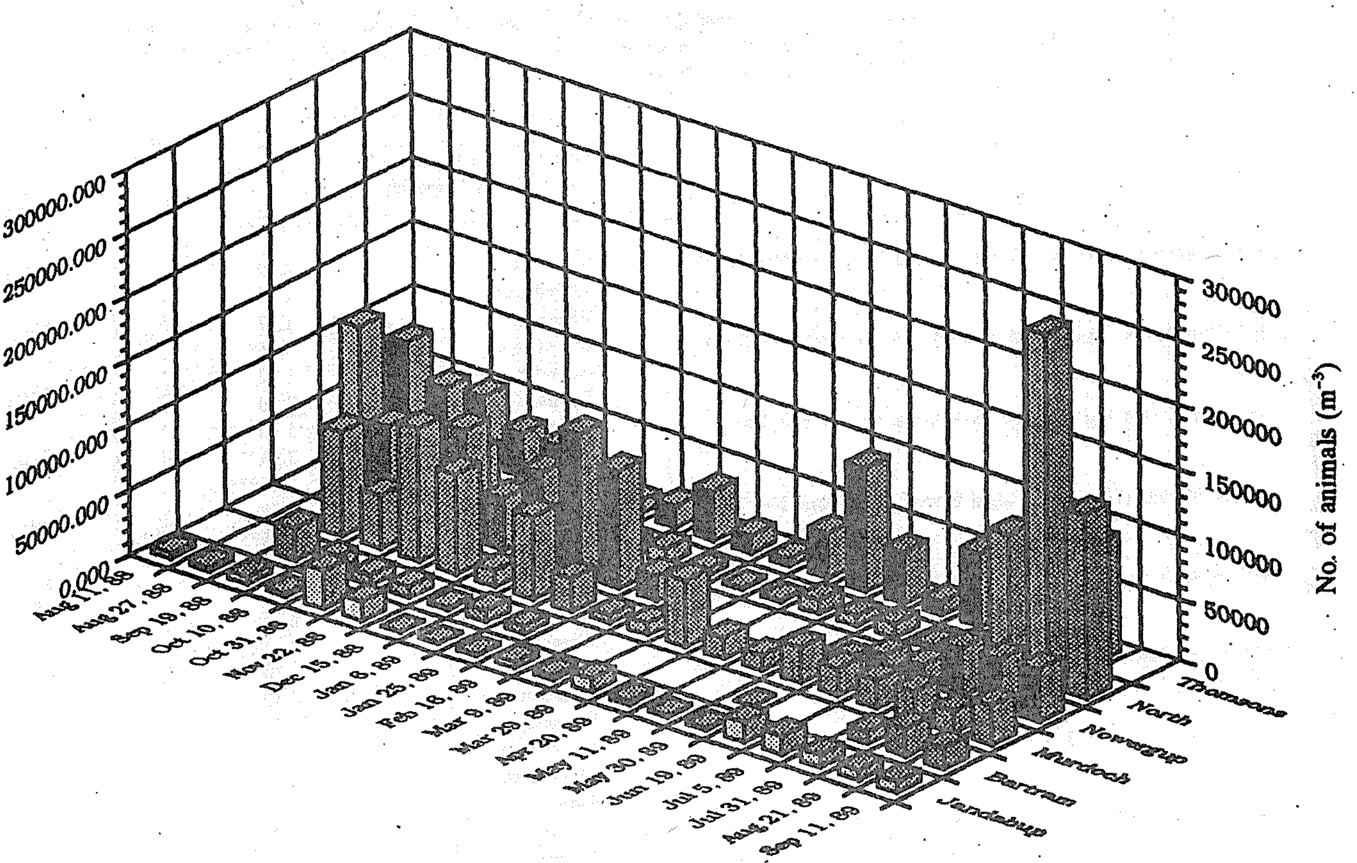


Figure 5.2 The abundance of macroinvertebrates/m^3 on each sampling occasion from each wetland.

Table 5.4 Biomass (in grams) of invertebrates in each wetland per cubic metre on each sampling occasion. The mean biomass in each wetland and the mean biomass in each season is listed at the end.

Date	Wetland					
	Jandabup	Bartram	Murdoch	Nowergup	North	Thomsons
11 Aug 88	2.28				16.40	47.30
27 Aug 88	2.15				11.58	44.63
19 Sep 88	6.91	20.48	15.34	50.13	24.96	38.87
10 Oct 88	1.98	14.49	5.33	24.99	46.52	22.80
31 Oct 88	3.58	4.15	16.65	82.69	18.78	23.28
22 Nov 88	4.74	9.29	6.94	28.47	18.63	13.07
15 Dec 88	1.80	5.31	1.51	38.14	8.00	37.30
06 Jan 89	2.01	3.63	7.65	53.73	3.71	26.75
25 Jan 89	3.55	5.94	5.18	23.48	6.80	15.31
16 Feb 89	4.98	0	1.95	10.01	2.23	18.89
09 Mar 89	2.71	0	2.23		2.36	4.27
29 Mar 89	2.97	0	7.62		6.16	41.98
20 Apr 89	0.85	0	2.49		2.82	78.03
11 May 89	1.43	0	1.85		2.82	21.97
30 May 89	1.11	1.54	1.76	0.45	1.67	2.54
19 Jun 89	3.46	0	3.66	2.85	2.00	23.30
05 Jul 89	5.05	0	1.73	7.17	3.64	9.08
31 Jul 89	3.36	2.40	3.10	49.23	12.56	21.68
21 Aug 89	1.98	4.45	5.25	42.62	17.81	40.31
11 Sep 89	3.39	6.07	5.66	30.39	39.44	
Mean	3.92	7.07	5.33	31.74	12.46	27.97
Spring	4.12	10.90	9.98	43.33	29.67	24.51
Summer	3.09	4.96	4.07	31.34	5.19	24.56
Autumn	1.81	1.54	3.19	0.45	3.26	29.76
Winter	3.05	3.43	3.44	25.47	10.67	31.05

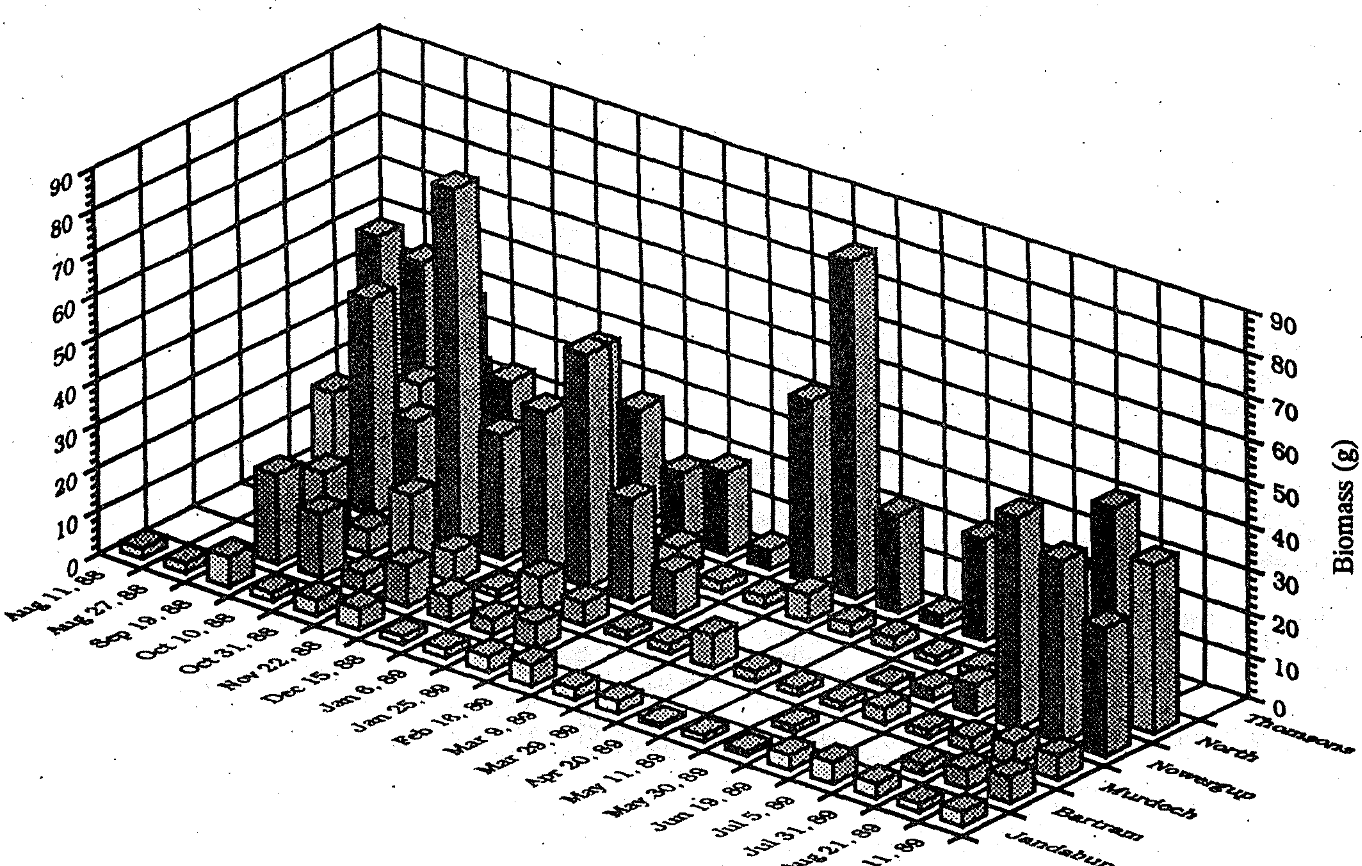


Figure 5.3 The biomass of macroinvertebrates/m^3 on each sampling occasion from each wetland.

Abundance

The abundance of invertebrates per cubic metre in each wetland on each sampling occasion is given in Table 5.3 and Figure 5.2. Abundance of invertebrates was relatviely low in Jandabup Lake and Bartram Swamp, and higher in the other (permanent) wetlands. Abundance varied considerably in consecutive samples as populations of crustaceans, corixids and chironomids fluctuated. Abundance tended to be lower in autumn than in other seasons, but maximum abundance occurred in different seasons in each wetland. Scheffe's multiple contrasts (Table 5.2) indicated that abundance was significantly greater in wetlands with cyanobacterial blooms (North Lake, Nowergup Lake and Thomsons Lake) and Murdoch Swamp which had a green algal scum in autumn than in Jandabup Lake and Bartram Swamp which showed no evidence of algal blooms (S=3.51, p0.05). Abundance was significantly greater in the hypertrophic wetlands Nowergup Lake, North Lake and Thomsons Lake than in the less enriched wetlands (S=3.11, p0.10).

Biomass

The biomass of invertebrates in each wetlands is given in Table 5.4 and Figure 5.3. The hypertrophic wetlands (Nowergup Lake, North Lake and Thomsons Lake) had a significantly higher biomass than the less enriched wetlands (Scheffe's multiple comparisons: S=5.41, p0.01). Biomass was also signficantly greater in the four wetlands with green algal blooms (Murdoch Swamp) or cyanobacterial blooms (Nowergup Lake, North Lake and Thomsons Lake) (S=3.53, p0.01). When the mesotrophic Jandabup Lake was compared to the other five wetlands, the biomass was found to be significantly greater in the more enriched wetlands (S=3.28, p0.10). For all but Thomsons Lake, spring samples had the highest biomass, and autumn the lowest. Biomass was also signficantly greater in the four larger wetlands compared to the small Bartram Swamp and Murdoch Swamp (S=3.22, p0.10), although these two wetlands are also the darkest colour.

Table 5.5 summarizes the species richness, abundance, biomass, autumn water levels and trophic state of each of the six wetlands.

Table 5.5 Summary of species richness, abundance, biomass, autumn water levels and trophic state in each of the six wetlands. Perm=permanent water, Meso=mesotrophic, Eut=eutrophic, Hyper=hypertrophic.

	Wetland					
	Jandabup	Bartram	Murdoch	Nowergup	North	Thomsons
No. of taxa	110	108	99	93	80	80
No. of Crustacea	18	18	15	14	9	15
No. of Odonata	12	9	12	10	8	9
No. of Hemiptera	9	8	14	10	8	8
No. of Coleoptera	43	44	38	31	23	22
Mean no. of taxa per sample	35.15	35.46	30.39	30.79	26.05	26.37
No. of taxa/m^3	14.53	19.63	16.37	17.64	12.09	14.94
Abundance/m^3	147944	118346	643286	662096	809894	733224
Biomass/m^3(g)	78.40	77.77	95.94	444.36	249.20	531.43
Autumn water level	Shallow	Dry	Pool	Pool	Perm.	Perm.
Trophic state	Meso.	Eut.	Eut.	Hyper.	Hyper.	Hyper.
Fish	Yes	No	No	Yes	Yes	No

Fish

Table 5.6 presents the mean number of fish per cubic metre in the three wetlands in which fish were caught (Jandabup Lake, Nowergup Lake and North Lake). It should be noted that a sweep net is an inefficient way of catching fish and that these figures should be regarded as relative rather than an absolute measure of abundance.

Table 5.6 Mean number of fish per cubic meter in each wetland.

Species	Wetland	No./m^3
P. olorum	North Lake	22
G. holbrooki	North Lake	16
G. holbrooki	Jandabup Lake	13
G. holbrooki	Nowergup Lake	46

Nowergup Lake contained the highest numbers of *G. holbrooki* of the three wetlands. The dense fringing vegetation (*Polygonum* sp.) probably affords protection from predation as populations increase over summer, before the water recedes to the exposed centre of the lake. They also survive to a larger size (48.5mm) in this wetland than in Jandabup Lake (42.1mm) and North Lake (36.0mm). *P. olorum* reached a maximum size of 38.0mm in North Lake.

P. olorum reproduces from July to September, taking advantage of the maximum water depth and invertebrate productivity in spring. *G. holbrooki* reproduces from October to March, and as a consequence, attains high population levels as the wetlands dry. The population inhabiting Jandabup Lake was observed to suffer severe predation by birds when the water depth was below 20cm. Jandabup Lake had the fewest fish per cubic metre (13), North Lake was intermediate at 38m^{-3}, and Nowergup Lake had the highest density of fish at 46 fish per cubic metre. The dense fringing vegetation at Nowergup Lake probably affords protection from predation until water levels recede to the centre of the wetland.

The impact of the presence of *G. holbrooki* on invertebrate communities was not evident in these wetlands when compared with the three wetlands that did not contain fish (see Table 5.2). The presence of fish did not appear to influence the number of taxa, abundance of invertebrate or the biomass.

Multivariate analysis of individual wetlands

Classification of samples using taxa (with UPGMA), within individual wetlands produced six dendrograms (one for each wetland) which are shown in Figure 5.4. Within each wetland, the samples are loosely grouped into seasons and each group usually contains consecutive samples. There is less temporal continuity in Nowergup Lake, North Lake and Thomsons Lake where some mixing of the samples occurs. Therefore, it is possible that the seasonal divisions are not as clear in the hypertrophic wetlands.

Ordination of samples using taxa within each individual wetland is shown in Figure 5.5. The grouping of samples from the classification using UPGMA has been overlayed on the ordinations. The separation of these groupings in ordination space supports the results of the classification as evidence of seasonal groupings.

Multivariate analyses of the wetlands combined

<u>Physicochemical data:</u>

In the classification of samples (with UPGMA) using the physicochemical data (Figure 5.6) there is a striking separation of two Thomsons Lake samples in May because they are more saline than all the other samples. Generally, the less enriched wetlands (Jandabup Lake, Bartram Swamp and Murdoch Swamp) are separated from the highly enriched (hypertrophic) wetlands (Nowergup Lake, North Lake and Thomsons Lake). The basis for this grouping is pH (Cramer value 0.76), conductivity (0.72) and depth (0.78); the samples on the left of the figure were shallower, with a lower pH and conductivity than those on the right. Within this broad clustering were divisions due to temperature (Cramer value 0.53). Cramer values for chlorophyll a, total nitrogen and total phosphorus were below 0.5.

Ordination of samples using physicochemical data. Figure 5.7 displays the data in 4 of the 5 dimensions (axes) needed to reduce stress to acceptable levels. The saline samples in Thomsons Lake in May always occur as outliers. Samples from each wetland tended to cluster together, and each wetland separated reasonably well from the body of samples on at least one axis. As a result, each wetland can be regarded as having characteristic physicochemical properties (see Chapter 3).

<u>Invertebrate data:</u>

Classification of taxa

The taxa were classified with TWINSPAN (Figure 5.8) and interpretation of the data required comparison of the spatial and temporal distribution and relative abundance of the taxa in each group. The two way tables generated with this data were too large to present. The first division of taxa

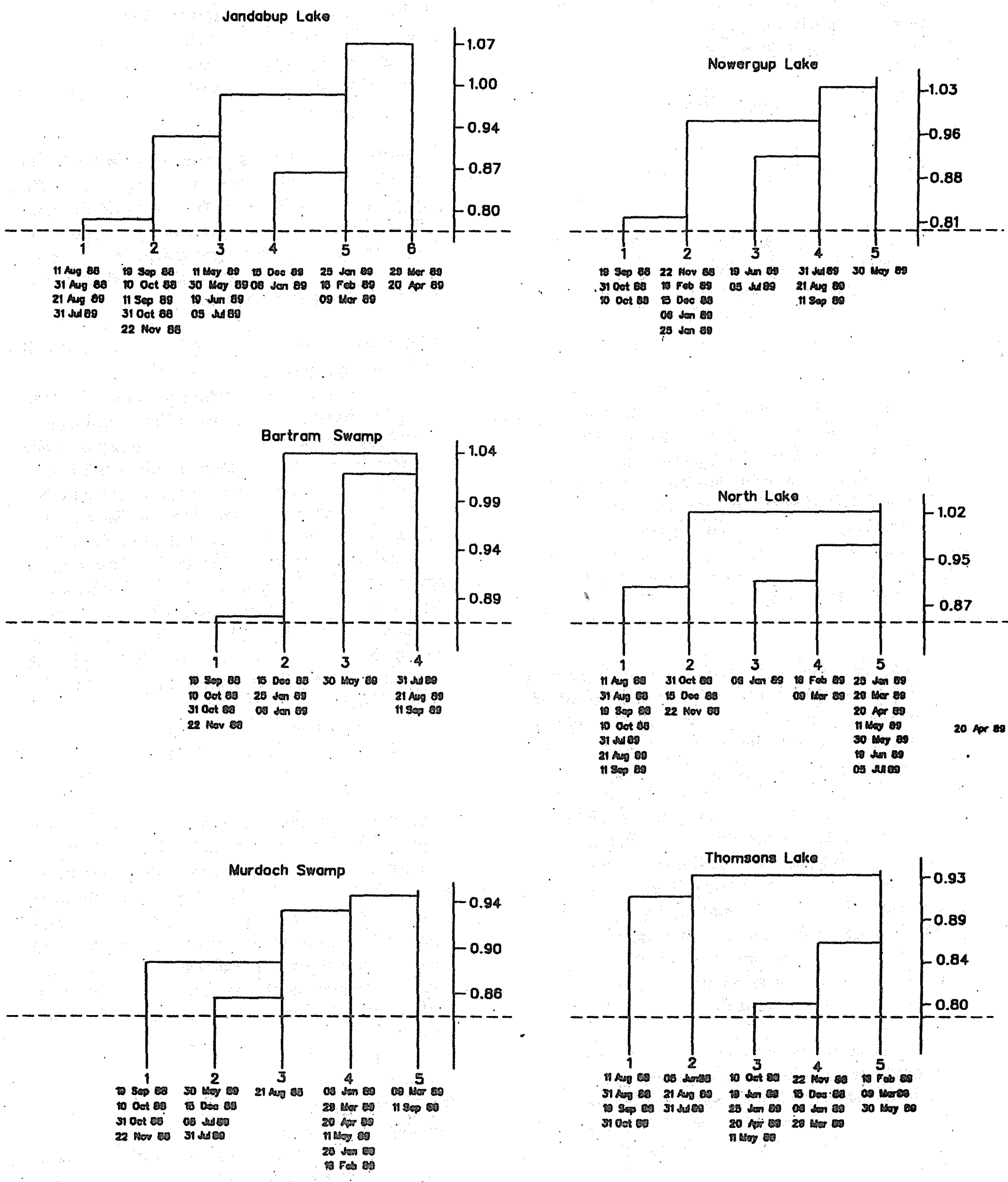


Figure 5.4 Dendrograms of the classification of samples using taxa for each wetland. Numbers on the right margins are a measure of dissimilarity.

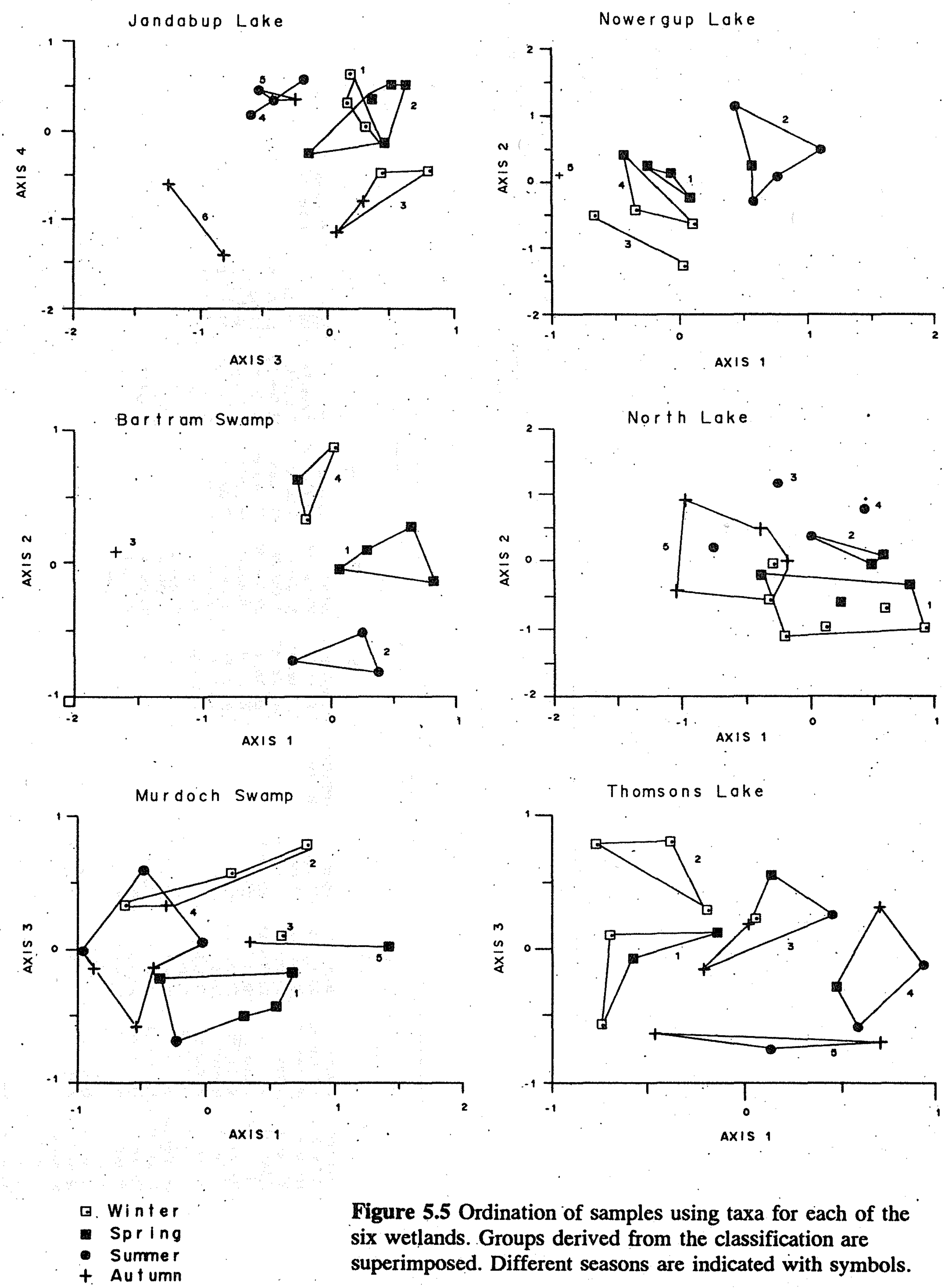


Figure 5.5 Ordination of samples using taxa for each of the six wetlands. Groups derived from the classification are superimposed. Different seasons are indicated with symbols.

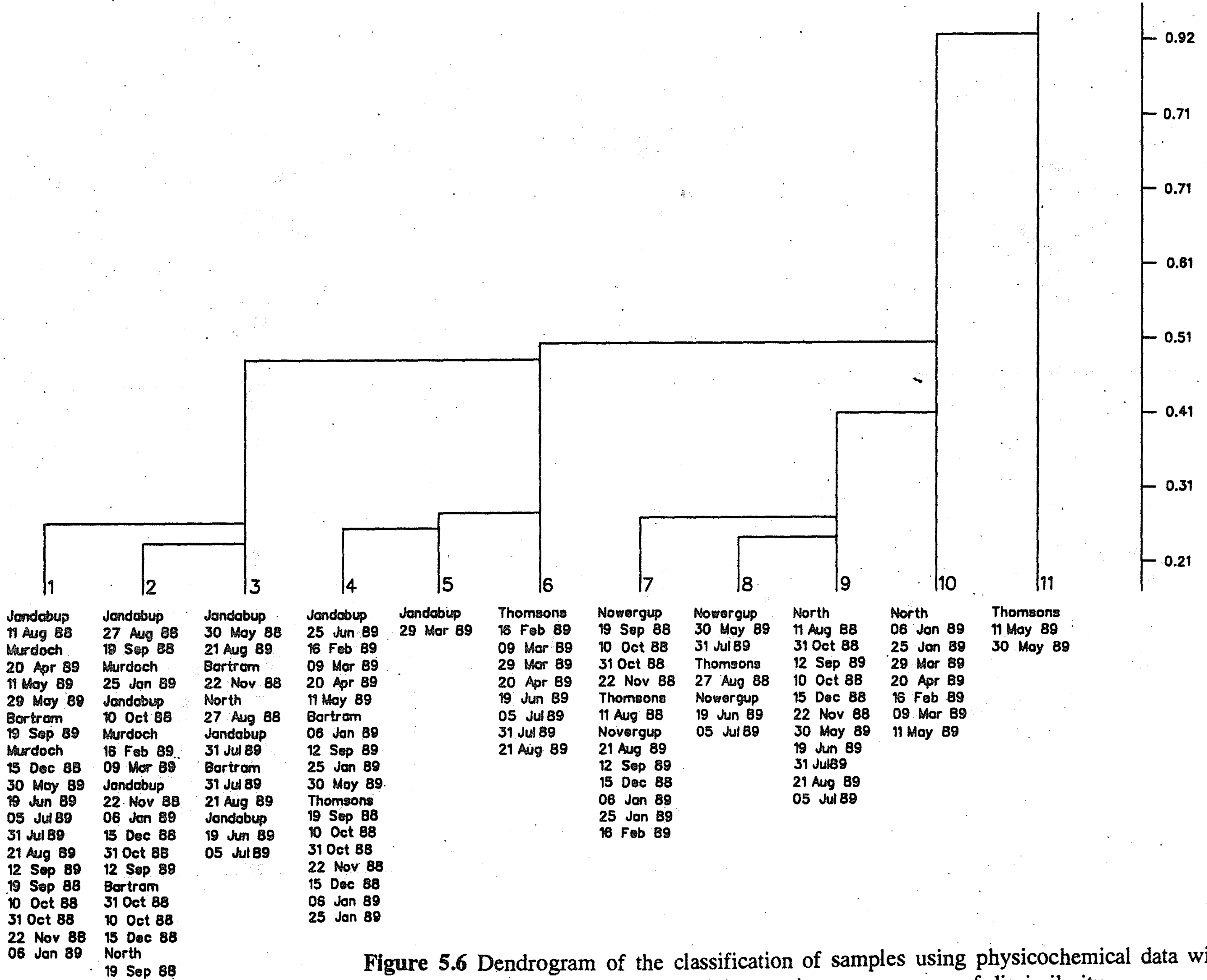


Figure 5.6 Dendrogram of the classification of samples using physicochemical data with flexible UPGMA. Numbers on the right margin are a measure of dissimilarity.

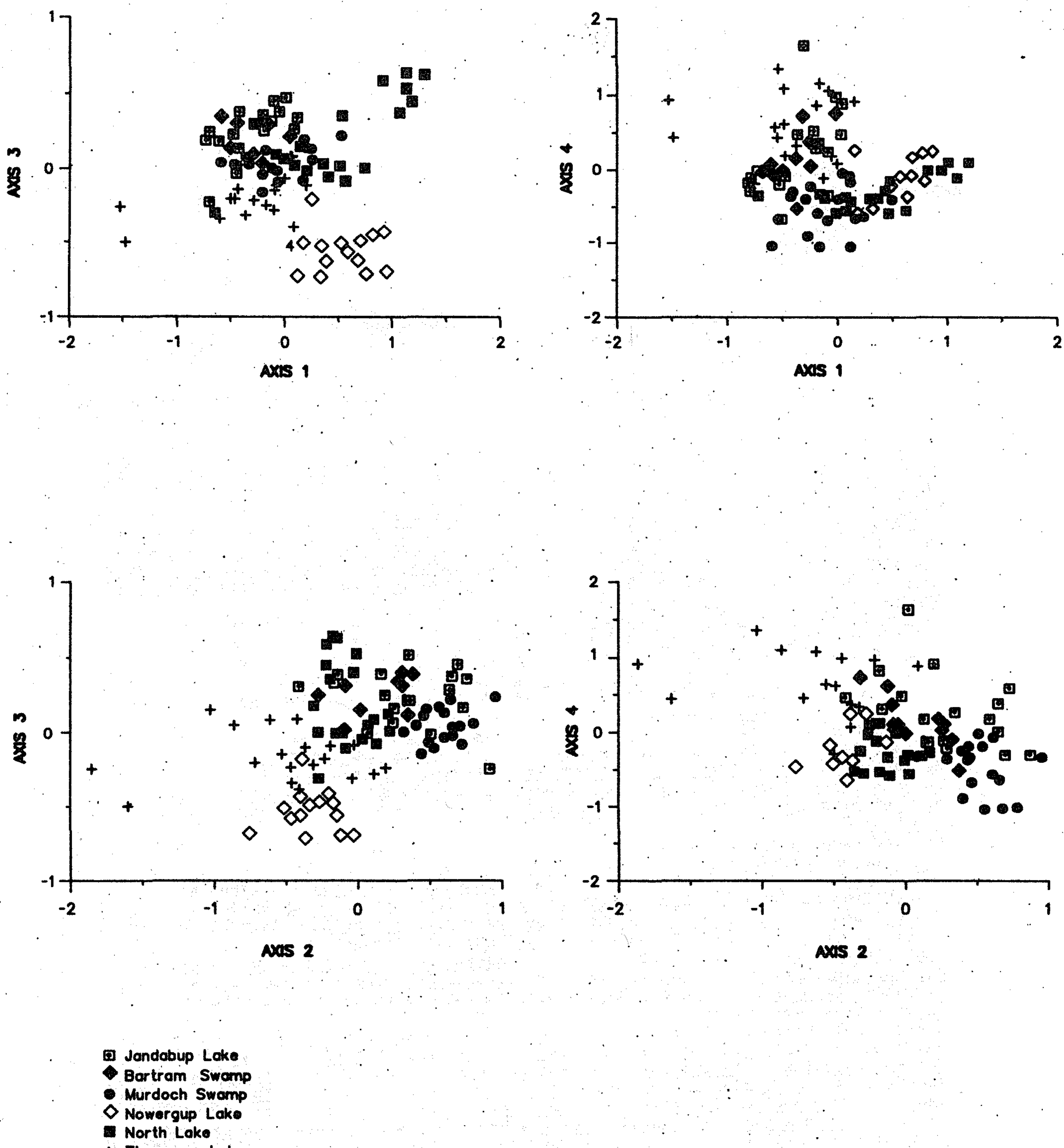
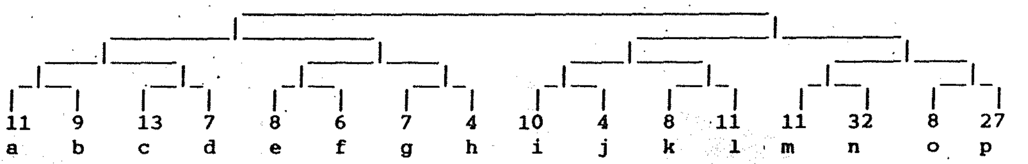


Figure 5.7 Ordination of all samples using physicochemical data.

Figure 5.8 The spatial and temporal distribution and abundance of the taxa groups from the TWINSPAN classification of taxa.



Spatial distribution: mostly in North Nowergup Thomsons — widespread — mostly in Jandabup Bartram and Murdoch

Temporal distribution: discrete — most cont. — disc. — mostly cont. — some continuous some discrete — discrete absent in autumn — discrete

Abundance: mostly high abundance — some abundant — low abuandance

a. Hydra sp1, Gyrulus sp1, Physa acuta, Lymnaea columella, Helisoma duryi, Mytilocypris ambiguosa, Palaemonetes australis, Plea bruni, Psychodidae, Antiporus gilberti (adults), Berosus sp5 (larvae).
b. Daphnia spp, Austrolestes annulosus, Veliidae, Enithares sp1, Tabanidae, Homoeodytes scutellaris, Enochrus sp2 (adults), Helochares tenuistriatus, Hydrophilidae sp3 (larvae).
c. Hirudinea sp, Sphaerium kendricki, Sarscypridopsis aculeata, Candonocypris novaezelandiae, Austrochiltonia subtenuis, Xanthagrion erythroneurum, Agraptocorixa eurynome, Micronecta robusta, Corixidae juveniles, Stratiomyidae, Hyphydrus elegans (adults), Antiporus femoralis (adults), Rhantus suturalis (larvae).
d. Tasmanocoenis tillyardi, Austroagrion cyane, Agraptocorixa parvipunctata, A. hirtifrons, Empididae, Megaporus howitti (adults), Cybister sp1 (larvae).
e. Hydracarina spp, Cyclopoidea spp, Ischnura heterosticta, Zygoptera juveniles, Anisops spp, Diptera pupae, Triplectides australis, Sternopriscus sp2 (adults).
f. Chydoridae spp, Cypretta baylyi, Paramphisopus palustris, Hemianax papuensis, Chironomidae spp, Limnoxenus macer (adults).
g. Tricladidae spp, Oligochaeta spp, Thaumeliidae spp, Megaporus spp (larvae), Megaporus solidus (adults), Sternopriscus browni (adults), Necterosoma darwini (adults).
h. Harpactacoidea spp, Cherax quinquecarinatus, Lancetes lanceolatus (larvae and adults).
i. Ferrissia spp, Gompodella maia, Alboa woroora, Calanoidea spp, Perthia acutitelson, Austrothemis nigrescens, Sigara truncatipala, Lepidoptera spp, Berosus sp4 (larvae), Enochrus sp1 (adults).
j. Nematoda spp, Glyptophysa sp1, Tipulidae spp, Oecetis sp1.
k. Argiolestes pusillus, Leptopodidae sp1, Saldula sp1, Hydrometridae sp1, Ceratopogonidae spp, Hyphydrus elegans (larvae), Paracymus pigmaeus, Enochrus sp3 (adults).
l. Orabatidae spp, Moinidae spp, Austrolestes io, Culicidae spp, Ephydridae spp, Liodessus dispar (adults), L. inornata (adults), Spencerhydrus pulchellus (larvae), Rhantus suturalis (adults), Hydrophilidae sp2 (larvae), Helodidae sp1 (larvae).
m. Austrolestes analis, Anisoptera juveniles, Nethra sp1, Haliplidae sp1 (adults), Sternopriscus multimaculatus (adults), Necterosoma darwini (larvae), Cybister tripunctatus (larvae), Berosus sp6 (adults), Hydrophilidae sp4 (larvae), Curculionidae sp2 (adults), Chrysomelidae sp3 (adults).
n. Sididae sp1, Macrothricidae spp, Simocephalus spp, Limnocythere mowbrayensis, Orthetrum caledonicum, Diplacodes bipunctata, Diaprepocoris sp1, Ranatra sp1, Acritoptila globosa, Ecnomus turgidus, Notalina fulva, Haliplidae sp1 (larvae), Uvarus pictipes, Megaporus sp2 (adults), Sternopriscus sp2 (larvae), Sternopriscus sp6 (adults), Spencerhydrus pulchellus (adults), Laccophilus sp1 (larvae), Homoeodytes scutellaris (adults), Dytiscidae sp2 (larvae), Hydrochus sp2 (adults), Berosus sp2, sp3, sp4 (larvae), Berosus discolor (adults), Hydrophilidae sp1 (larvae), Hydrophilus latipalpus (adults), Staphylinidae sp1 (larvae), Curculionidae sp5 (adults), Ptilodactylidae sp1 (larvae), Chrysomelidae sp4 (adults), Limnichidae sp1 (adults).
o. Lynceus sp1, Bennelongia australis, Aeshna brevistyla, Hemicordulia tau, Antiporus spp (larvae), Sternopriscus sp1 (larvae), Berosus sp1 (larvae), Berosus sp3 (adults).
p. Cloeon sp1, Ischnura aurora, Procordulia affinis, Hemicordulia autraliae, Gerridae sp1, Mesoveliidae sp1, Nychia sp1, Sisyridae sp1, Gibbidessus sp1 (adults), Antiporus sp1 (adults), Copelatus sp1 (larvae), Cybister tripunctatus (adults), Anacaena sp1 (adults), Hydrophilus albipes (adults), Hydraena sp1 (adults), Ochthebius sp1 (adults), Curculionidae sp6, sp7, sp8 sp10 (adults), Helminthidae sp1 (larvae), Ptilodactylidae sp2 (larvae), Sphaeriidae sp1 (larvae), Gyrinidae sp1 (adults), Chrysomelidae sp1 (larvae), Chrysomelidae sp1, sp5 (adults).

appears to be based on spatial distribution and abundance. The 2nd and 3rd divisions refines this and the 4th division is based on temporal distribution.

Classification of taxa using UPGMA with transposed "samples by taxa" matrix is shown in Figure 5.9. Once again, analysis of the temporal and spatial distribution and abundance was used to interpret this output. There appears to be more integration of spatial and temporal distribution and abundance in these groupings than in the TWINSPAN classification of taxa. Within each group there was greater consistency, and the output contains more seasonal groupings of taxa.

Classification of samples
The first division of the TWINSPAN classification of samples using taxa separated the majority of the hypertrophic wetlands from the less enriched wetlands with the exception of two samples from Jandabup Lake and one from Bartram Swamp (Figure 5.10). By division five, these hypertrophic wetlands are separated into semi-discrete groups, and the mesotrophic Jandabup Lake and eutrophic Bartram Swamp and Murdoch Swamp were completely separate. Of all the wetlands, Murdoch Swamp samples had the most discrete distribution. By the 6th division samples had been divided into general seasonal groupings of consecutive samples.

Classification of samples using UPGMA based on the invertebrates again separated the hypertrophic wetlands from the less enriched wetlands (Figure 5.11). While the less enriched wetlands group into separate entities, the hypertrophic wetlands samples are intermixed. Division into seasons is evident for Jandabup Lake and Bartram Swamp. Groups 1,2 and 3 contained a variety of Coleoptera and Trichoptera and the odonate *A. analis*. Groups 6–10 contained many taxa associated with nutrient enrichment with groups 4 and 5 being intermediate.

The samples were ordinated using the taxa in 5 dimensions to reduce the stress to acceptible levels. Separation of the wetlands was good for Jandabup Lake, Bartram Swamp and Murdoch Swamp, however, the hypertrophic wetlands tended to group together (see Figure 5.12). In addition, there is a separation of samples on a seasonal basis (see Figure 5.13). Correlations of the ordination of the physicochemical data with the ordination of the taxa are displayed alongside the ordinations. The correlation coefficients are: temperature 0.60, conductivity 0.68, pH 0.71, depth 0.63, chlorophyll a 0.31, total nitrogen 0.40 and total phosphorus 0.39. The first four are relatively strong correlations, and vary linearly with season and therefore correspond well to seasonal groupings.

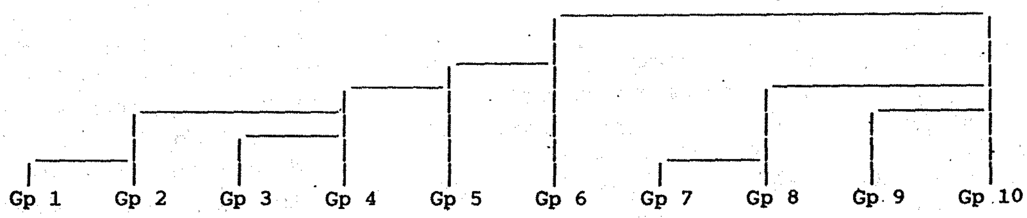
As a measure of the overall fit of the physicochemical ordination to the ordination of the taxa (PROC), the root-mean-square symmetric error is the square root of the mean of the squared distances between corresponding points in the fitted and target ordinations (Belbin 1990). The value of the root-mean-squared symmetric error varies between 0 (identical ordinations) to 1 (dissimilar), and here the error was 0.09. Therefore, the ordinations of the physicochemical data and the taxa were similar. This indicates that the physicochemcial characteristics and the invertebrates differ between the less eutrophic wetlands, but are more similar in the highly enriched wetlands. In addition both the physicochemical characteristics and the invertebrates change with the seasons.

Discussion

The number of taxa collected in this study is high. A total of 176 taxa were collected from the six wetlands. It should be noted that members of the Hydracarina, Cladocera, Copepoda, and Diptera were not identified to species. The related Wetlands Classification project (Davis *et al.* 1993) did identify these taxa to species and obtained a total of 240 taxa from 40 wetlands. These numbers are probably the highest numbers recorded for Australian wetlands. Outridge (1987) found 101 taxa in billabongs of the Magela Creek in the Northern Territory using an airlift sampler. Lloyd & Bouton (1990) using sweep nets found 55 taxa in billabongs and 95 taxa from floodplain habitats (Boulton & Lloyd 1991) on the River Murray at Chowilla, South Australia. Marchant (1982b) found a total of 92 taxa from five billabongs on Magela Creek using a sweep net. The number of Coleoptera collected in this study (82) certainly exceeds that collected by Marchant (1982b) (17) Outridge (1987) (28), and Davis *et al.* (1993) (14). The high number of taxa generally, and Coleoptera in particular, can be attributed to the high species richness of these wetlands, the intensity of sampling over time and the vigour with which the samples were obtained. For example, Davis *et al.* (1993) also used sweep nets to sample macroinvertebrates in Perth wetlands, but samples were taken within two metres of the edge of the wetland or the fringing vegetation, whereas in this study, samples were taken within the vegetation.

Species richness was generally highest in spring and early summer and lowest in autumn, corresponding to highest and lowest water levels respectively. However, within individual wetlands the number of taxa present often fluctuated considerably between samples.

Figure 5.9 Classification of taxa from UPMGA. Abbreviations: Jand=Jandabup Lake, Bart=Bartram Swamp, Murd=Murdoch Swamp, Nowe=Nowergup Lake, cont.=continuous, abund.=abundant.



	Gp 1	Gp 2	Gp 3	Gp 4	Gp 5	Gp 6	Gp 7	Gp 8	Gp 9	Gp 10
Spatial distribution	widespread		mostly Bart	only Murd	mostly Nowe	Bart Murd Nowe	only Jand	all but Jand	mostly Jand	mostly Jand and Bart
Temporal distribution	mostly cont.	some discrete some cont.	most in spring			mostly cont.	summer	autumn	absent in autumn	
Abundance	many abund.	most abund.	some abundant --------> decreasing abuandance							

Gp 1. Hydra sp1, X. erythroneurum, P. brunni, Zygoptera juveniles, Hirudinea spp, C. novaezealandiae, P. acuta, Berosus sp5 (larvae), A. annulosus, Anisops spp, Stratiomyidae spp, Sternopriscus sp2 (adults), Daphnia spp, S. aculeata, A. subtenuis, L. columella, H. duryi, A. eurynome, M. robusta, Hydrophilidae sp3 (larvae), R. suturalis (larvae), H. elegans (adults), H. tenuistriatus (adults), Tricladida spp, Tipulidae spp, Nematoda spp, T. tillyardi, S. kendricki, Oligochaeta spp, A. cyane, I. heterosticta, Glyptophysa sp1, Corixidae juveniles, A. woroora, Anisoptera juveniles, Oecetis sp1, S. multimaculatus, Ferrissia spp, H. papuensis, S. truncatipala, Lepidoptera spp, Hydracarina spp, Diptera pupae, C. baylyi, Cyclopoidea spp, Chironomidae spp, T. australis, Chydoridae spp, P. palustris, H. scutellaris (larvae), A. io, H. elegans (larvae).

Gp 2. Gyrulus sp1, Tabanidae spp, Harpactacoidea spp, Enochrus sp2 (adults), Berosus sp4, sp6 (adults), A. hirtifrons, Psychodidae spp, A. gilberti (adults), M. howitti, Thaumeliidae spp, Empididae spp, Megaporus spp (larvae), L. lanceolatus (larvae), M. solidus (adults), M. ambiguosa, A. nigrescens, H. australiae, Gerridae sp1, Gyrinidae sp1 (adults), Dytiscidae sp2 (larvae), Staphylinidae sp1 (larvae), Gibbidessus sp1 (adults), Hydraena sp1 (adults), Copelatus sp1 (larvae), Hydrophilidae sp2 (larvae), Curculionidae sp7 (adults), A. parvipunctata, N. darwini (adults), Ranatra sp1, H. scutellaris (adults), Cybister sp1 (larvae), Orabatidae spp, Calanoidae spp, Moinidae spp, Antiporus spp (larvae), Antiporus sp1 (adults), S. pulchellus (larvae), Cloeon sp1, L. inornatus, Enochrus sp3 (adults), A. brevistyla, Leptopodidae sp1, Culicidae spp, Ceratopogonidae spp, P. affinis, H. tau, I. aurora, C. tripunctatus (adults), H. albipes (adults).

Gp 3. Lynceus sp1, P. acutitelson, B. australis, Sisyridae sp1, Curculionidae sp8 (adults), Chrysomelidae sp5 (adults), Mesoveliidae sp1, Ephydridae spp, Helodidae sp1 (larvae), Berosus sp1 (larvae), Anacaena sp1 (adults), Sternopriscus sp1 (larvae), Curculionidae sp10 (adults), Helminthidae sp1 (larvae), Sphaeriidae sp1 (larvae).

Gp 4. Nychia sp1, Ptilodactylidae sp2 (larvae), Chrysomelidae sp1 (larvae).

Gp 5. C. quinquecarinatus, P. australis, Veliidae sp1, Enithares sp1, Hydrometridae sp1.

Gp 6. A. pusillus, L. dispar (adults), Enochrus sp1 (adults), Saldula sp1, P. pigmaeus (adults), L. lanceolatus (adults), A. femoralis (adults).

Gp 7. Sididae sp1, Macrothricidae spp, Berosus sp2 (larvae), Haliplidae sp1 (larvae), Megaporus sp2 (adults), Berosus sp3 (adults), O. caledonicum, U. pictipes (adults), S. browni (adults).

Gp 8. R. suturalis, Curculionidae sp6 (adults), Chrysomelidae sp1 (adults), Ochthebius sp1 (adults), L. macer (adults).

Gp 9. Simocephalus sp1, L. mowbrayensis, D. bipunctata, Sternopriscus sp2 (larvae), G. maia, A. globosa, N. fulva, E. turgidus, Hydrochus sp2 (adults), Diaprepocoris spp, Sternopriscus sp6 (adults), Limnichidae sp1 (adults), B. discolor (adults), Ptilodactylidae sp1 (larvae), Chrysomelidae sp4, sp3 (adults), A. analis, N. darwini (larvae), C. tripunctatus (larvae), Nethra sp1, S pulchellus (adults), Laccophilus sp1 (larvae), Curculionidae sp5, sp2 (adults), Haliplidae sp1 (adults).

Gp 10. Berosus sp3 (larvae), H. latipalpus (adults), Berosus sp4 (larvae), Hydrophilidae sp1, sp4 (larvae).

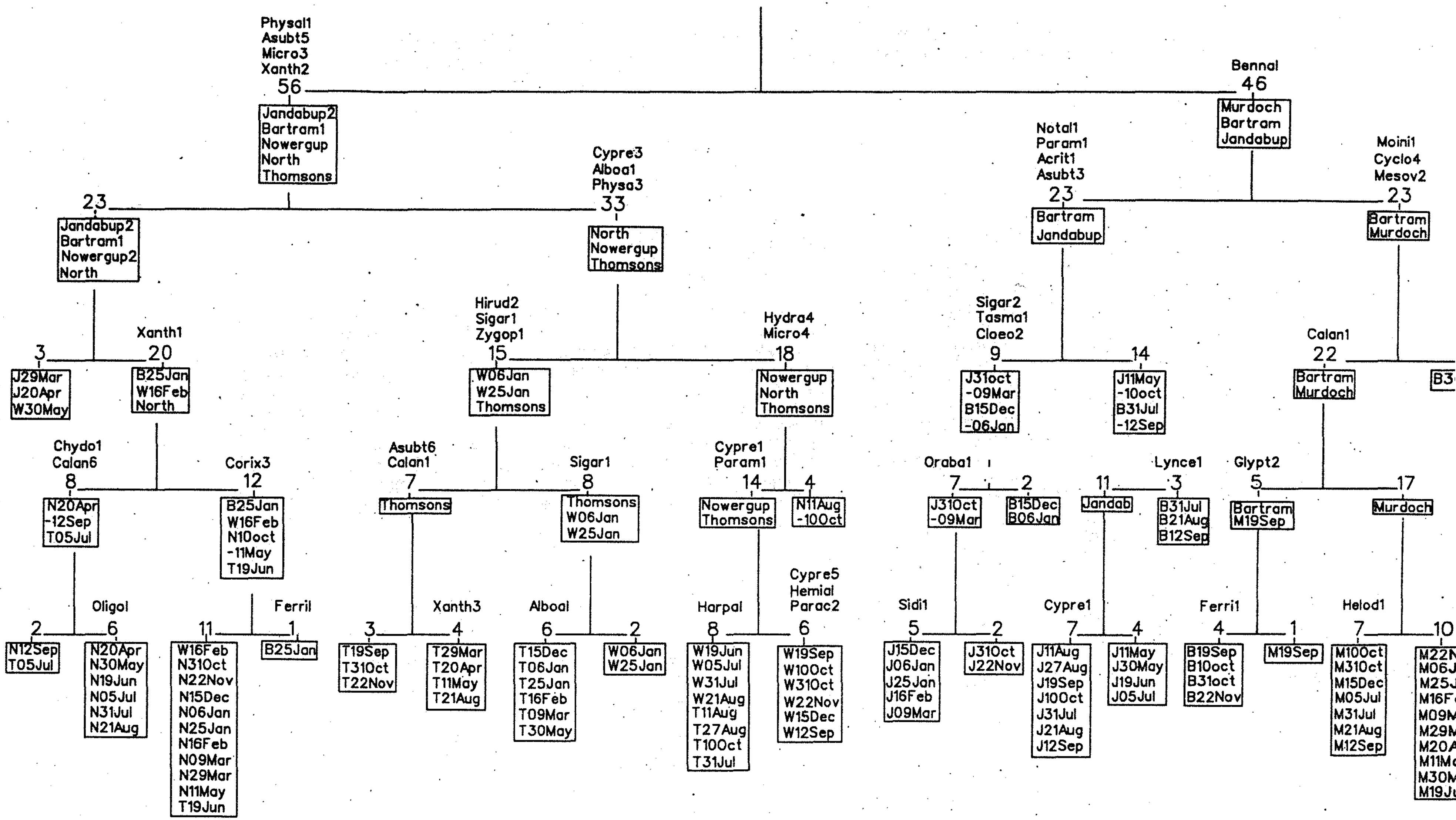


Figure 5.10 TWINSPAN classification of all samples. Abbreviations for wetlands: B-Bartram, J-Jandabup, M-Murdoch, N-North, W-Nowergup and T -Thomsons. Six abudance categories were used for the taxa: 1-0, 2-1, 3-10, 4-100, 5-1000, 6-10000. These numbers follow the abreviated taxa names. In alphabetical order these taxa are: Acrit- Acritoptila globosa, Alboa-Alboa worooa, Asubt-Austrochiltonia subtenuis, Benna-Bennalongia australis Calan-Calanoidea spp, Chydo-Chydoridae spp, Cloeo-Cloeon sp1 Corix-Corixidae juveniles, Cyclo-Cyclopoidea spp, Cypre-Cypretta baylyi, Ferri-Ferrissia sp1, Glypt-Glyptophysa sp1, Harpa-Harpactacoidea spp, Helod-Helodidae sp1(larvae) Hemia-Hemianax papuensis, Hirud-Hirudinae spp, Hydra-Hydracarina spp, Lynce-Lynceus sp1 Mesov-Mesoveliidae, Micro-Micronecta robusta, Moini-Moinidae spp, Notal-Notalina fulva, Oligo-Oligochaeta spp, Orabatidae spp, Parac-Paracymus pigmaeus, Param-Paramphisopus palustris, Physa-Physa acuta, Sidi-Sididae sp1, Sigar-Sigara truncatipala, Tasma-Tasmanocoenis tillyardi, Xanth-Xanthagrion erythroneurum, Zygop-Zygoptera juveniles. The number of samples in each group is shown above each group.

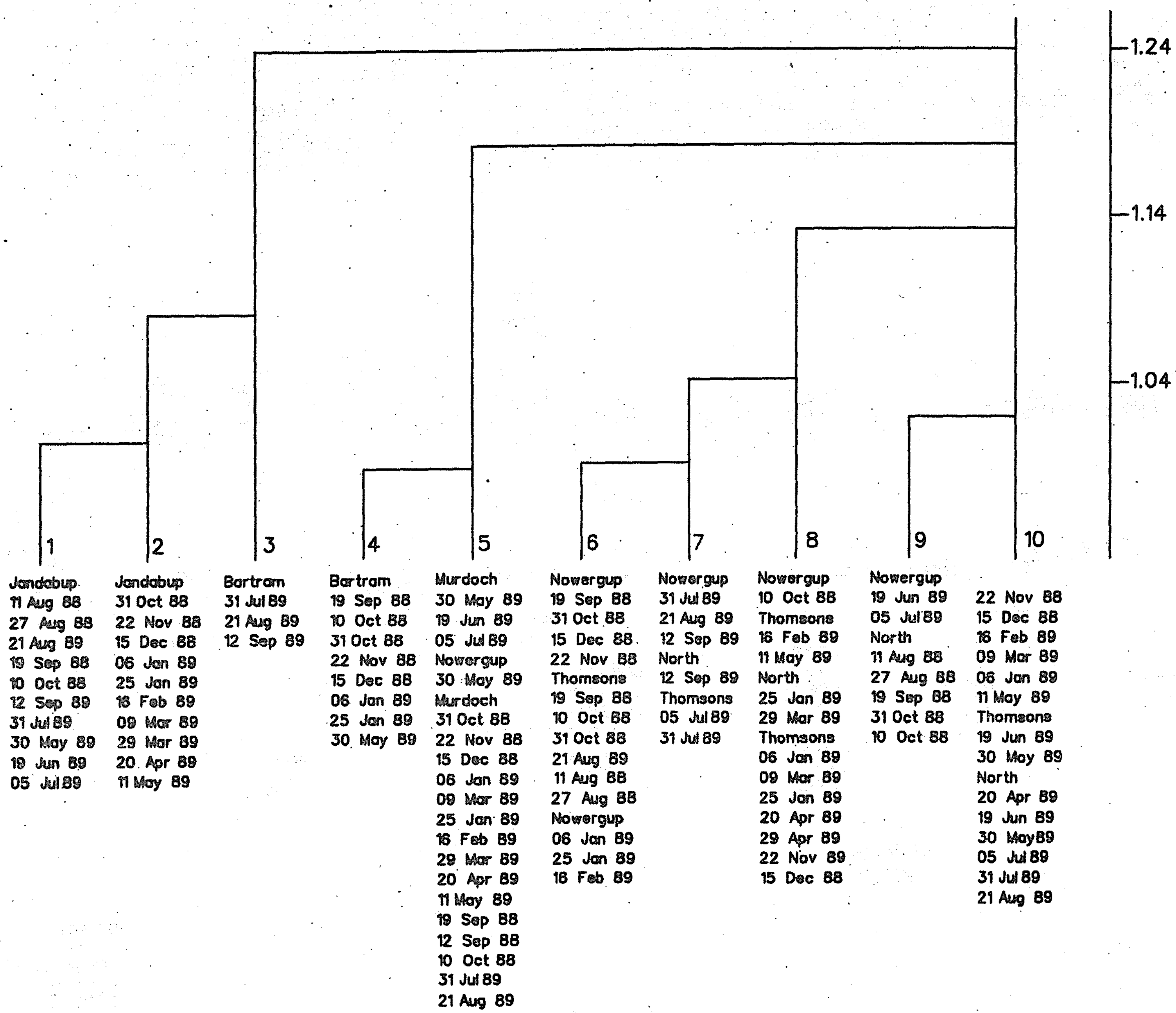


Figure 5.11 Dendrogram of classification of samples using invertebrates with flexible UPGMA. Numbers on the right margin are a measure of dissimilarity.

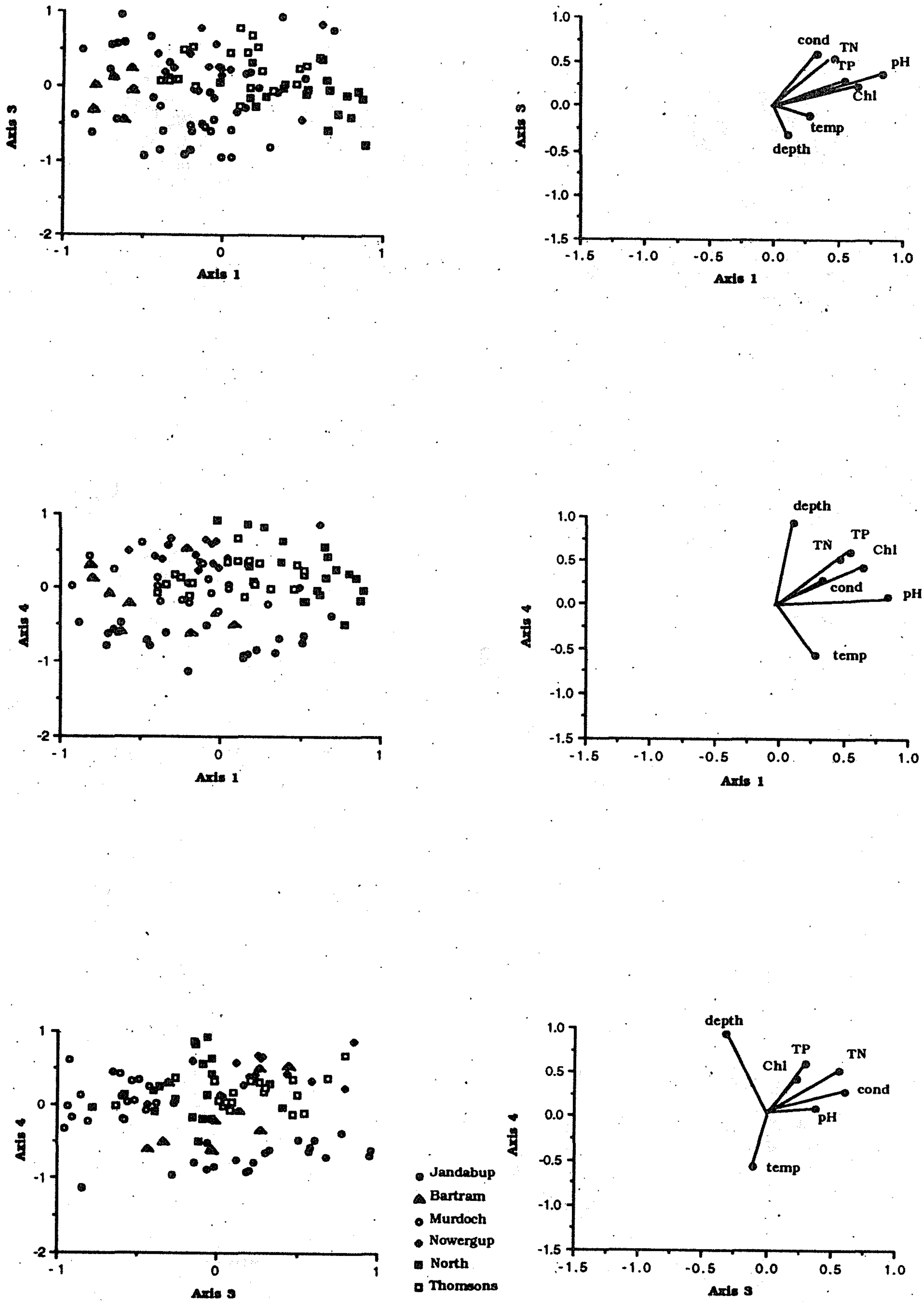


Figure 5.12 Ordination of samples based on the taxa from the entire data set with individual wetlands identified. The direction of the correlations between the ordinations of samples based on the taxa and the physicochemical data accompanies each ordination.

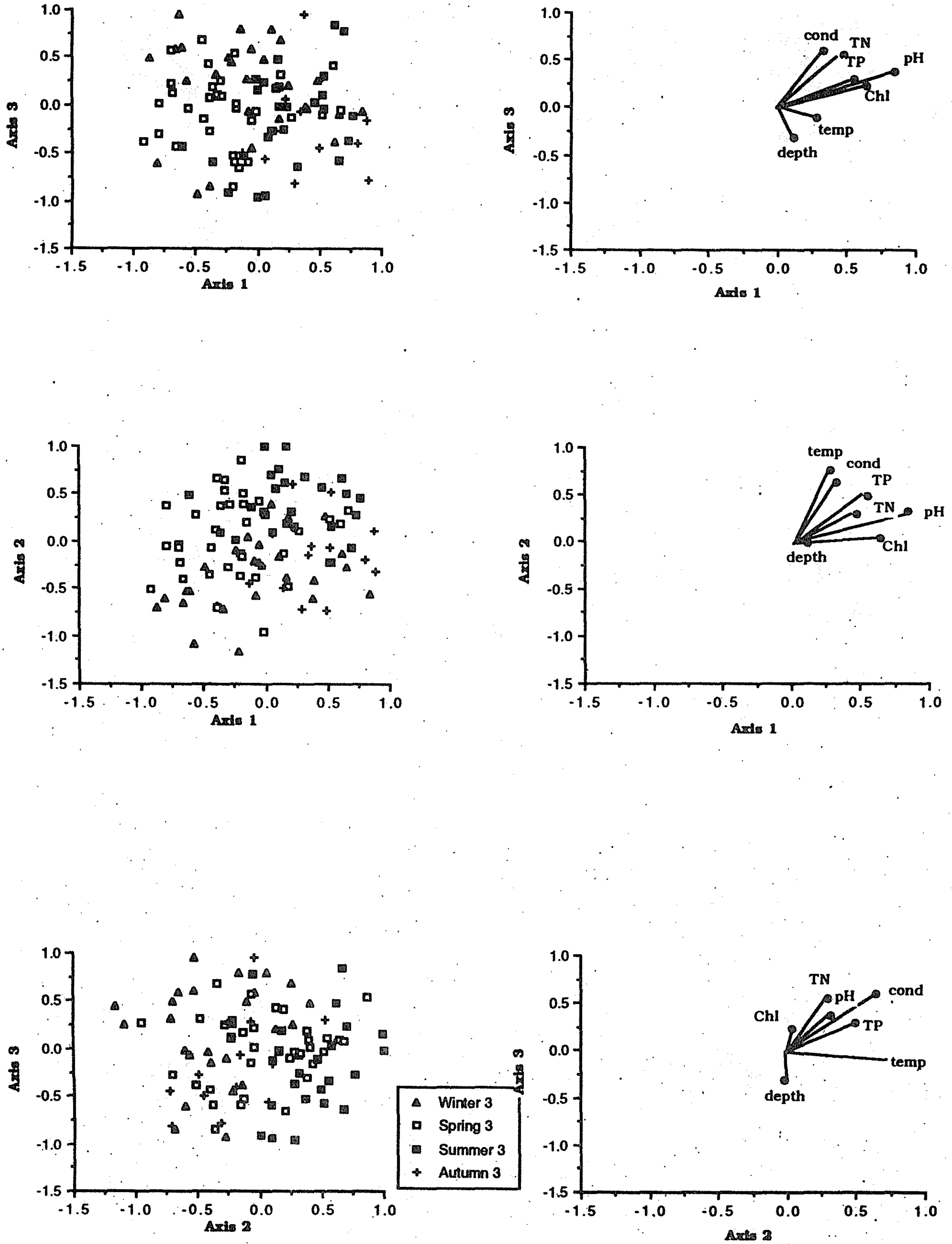


Figure 5.13 Ordination of samples based on the taxa from the entire data set with seasons identified. The ordination is the same as in Figure 5.12 with different axes displayed. Correlations between the ordination of samples based on the taxa and the physicochemical data accompanies each ordination.

Abundance of invertebrates is comparable with that found elsewhere. For example, the number of copepods and cladocera collected by Moore (1970) in a Louisiana swamp ranged from 0 to 826,000/m3. Biomass of invertebrates is comparable to other Australian wetlands where the benthos has been recorded from 0.7 to 16.8g/m^2 (Timms 1980). Abundance and biomass were low in all six wetlands in early March and in late May, but fluctuated considerably between samples and no consistent peaks were evident over time in individual wetlands or overall.

The impact of seasonal drying on community structure

Classification and ordination of the data revealed strong seasonal trends within each wetland and with all wetlands combined. The seasonal changes were evident in both the physicochemical data and in the invertebrate data. The seasonal partitioning of samples was clearest in the less enriched wetlands. August and September samples for the first and second years were classified together for Jandabup Lake, and North Lake, but they were classified separately in Bartram Swamp, Murdoch Swamp, Nowergup Lake and Thomsons Lake. It is not obvious why this was so for the latter three wetlands, however, Bartram Swamp in the second winter and spring was much shallower than the previous year due to lower rainfall, which modified the physical and chemical features and consequently, the taxa present. Crome and Carpenter (1988) found an annual cycling in the composition of zooplankton community in a billabong which returned to the same point whether drying did nor did not occur. The ordinations show that samples from August and September 1988 and 1989 are relatively close together, implying that these invertebrate communities also cycle through time on an annual basis.

The data from the six wetlands suggests that seasonal drying is associated with high species richness since Bartram Swamp which dried completely had the highest number of taxa per cubic metre, and the two wetlands that contracted over a large portion of their surface area to deep central pools also had higher species richness than the two permanent wetlands. Davis *et al.* (1993) also found that the seasonal wetlands had a significantly higher species richness than the permanent wetlands, as did Outridge (1987) in seasonal billabongs compared with permanent billabongs on the Magela Creek, Northern Territory, and Boulton & Lloyd (1991) and Thompson (1986) in a seasonal billabongs relative to permanent floodplain habitats in the River Murray in South Australia.

Outridge (1987) proposed that rarefaction (the density-independant elimination of organisms) may account for high diversity in Magela Creek billabongs. Removal of organisms either by predation (Paine 1966) or environmental disturbance (Connell 1978) can maintain populations at sub-maximum densities, leading to reduced exclusion of competetively inferior species and an overall increase in diversity. Dry season reductions in species numbers and abundance were correlated with declining water quality which Outridge believed may maintain benthic populations at relatively low densities, thereby encouraging increased diversity. In addition, high species diversity in these wetlands may have been maintained by the predicatable environmental heterogeneity of monsoonal variation in flow and water qualtiy (Outridge 1987). Temporal predictiabilty of the environment allows species to evolve specialized patterns of resource usage or to become dependant on particular environmental conditions resulting in a seasonal replacement of species and a higher overall diversity (Hutchinson 1961). Temporal predictability also allows seasonal partitioning of the resource (Southwood 1978) which promotes species diversity. Bunn *et al.* (1986) regarded the timing of rainfall in south-western Western Australia as predictable; only the quantity varied from year to year. In seasonal wetlands in which the dry period is cyclical and predictable, the community is ultimately controlled by physical constraints, although it will be subject to proximal control by biotic factors (Menge & Sutherland 1976).

The well vegetated wetlands had a significantly higher species richness than North Lake which had almost no emergent and submerged aquatic macrophytes. The aquatic vegetation provides a diversity of habitats which are not available in open water. Morgan & Boy (1982) used macroinvertebrates to classify Mediterranean wetlands in northern Africa and found that the percentage of emergent vegetation was one of the principle factors involved in the classification in addition to water regime and salinity.

The mean abundance of invertebrates was lowest in the seasonal Bartram Swamp and in Jandabup Lake which became very shallow, than in the other four wetlands. Seasonal drying may have been responsible for the lower abundance of invertebrates in Bartram Swamp compared with Murdoch Swamp since that was the major difference between the two wetlands - being of similar size, water colour, trophic state and both lacking fish. However, Murdoch Swamp is a closed canopy swamp and had more emergent aquatic vegetation than Bartram Swamp. The role of vegetation in enhancing the abundance of invertebrates (Krull 1970, Wegener *et al.* 1974 and Voigts 1976) may be operating here (but see discussion on algae below). Data on invertebrate abundance from Davis *et al.* (1993) shows no significant difference in abundance of seasonal and permanent wetlands.

Impact of eutrophication on community structure

Classification and ordination indicated that each wetland was physically and chemically unique. Numerous taxa were unique to Jandabup Lake, Bartram Swamp and Murdoch Swamp. In the hypertrophic wetlands the invertebrate fauna was less, distinctive, and the ordination of the taxa grouped the hypertrophic wetlands together.

The number of taxa collected from the six wetlands shows a trend of decreasing species richness with increasing nutrient enrichment although this trend was not significant when the number of taxa per cubic metre was considered. Macroinvertebrate abundance and biomass was significantly higher in the three hypertrophic wetlands and the four wetlands where cyanobacterial and green algal blooms occurred. Biomass was also significantly lower in mesotrophic Jandabup Lake. Davis *et al.* (1993) found that highly enriched wetlands had a significantly lower species richness and higher abundance than the less enriched wetlands. In the present study, North Lake which had the most pronounced symptoms of hypertrophy with its continuous cyanobacterial bloom (see Jeffries & Mills 1990), had a lower biomass than its hypertrophic partners Nowergup Lake and Thomsons Lake. North Lake did have the lowest number of taxa per cubic metre and highest abundance of invertebrates. Evidently, North Lake contained an extremely large number of small macroinvertebrates. The major difference between this wetland and the other two hypertrophic wetlands was the almost complete absence of aquatic macrophytes at North Lake and the domination of cyanobacteria. The proliferation of small invertebrates in this wetland suggests that the community is composed largely of grazers and detritivores. It is possible that macrophytes are necessary to encourage the presence of larger invertebrates.

The high abundance (but low biomass) at Murdoch Swamp is likely to be due to a moderately high number of small invertebrates consuming the filamentous green algae that formed a scum on the water surface in summer and autumn when the water had contracted to the excavated pool. There was no corresponding algal scum on Bartram Swamp at this time because it had dried.

The role of colour

Two of the wetlands (Bartram Swamp and Murdoch Swamp) had dark brown water, Thomsons Lake was moderately dark brown, Jandabup Lake a red–brown colour, North Lake had very little colour and Nowergup Lake was uncoloured.

Decomposition of littoral vegetation and leaching of the resultant organic material from sandy soils appear to be the major sources of colour in wetlands on the Swan Coastal Plain (Wrigley *et al.* 1988). Coloured wetlands often support lower abundances of phytoplankton and invertebrates than would be expected from their nutrient levels (Jackson & Hecky 1980 and Wrigley *et al.* 1988). Colour reduces light levels available to primary producers and changes the available wavelength (Kirk 1976, Bowling 1988 and Wrigley *et al.* 1988. It is possible than when iron or manganese are present and particularly at low pH, phosphate becomes bound to the humic compounds and is unavailable to phytoplankton (Jones *et al.* 1988). Jackson & Hecky (1980) suggested that humic substances restrict the availability of iron to phytoplankton. Another possible mechanisms is that humic compounds may have a direct toxic effect on both plants and animals (Petersen & Kullberg 1985). The dark colour of Bartram Swamp and Murdoch Swamp probably limited algal production despite the eutrophic nutrient status and may account for the significantly lower biomass in these two wetlands compared with the others. At Thomsons Lake, the moderately dark water was not able to prevent the development of cyanobacterial blooms in autumn.

The impact of fish on community structure

Gambusia holbrooki is generally regarded as a pest and is known to have an adverse impact on native fish and invertebrate communities. However, *Pseudogobius olorum* co–exists with *G. holbrooki* in North Lake and appears to be able to withstand predation and competition from *G. holbrooki*. This is partly because the goby dwells on the sediment, while *G. holbrooki* swims near the surface. It is also due to the early spring reproduction of *P. olorum* which allows offspring to attain a size too great for predation by *G. holbrooki* which becomes numerous in summer. Therefore, there may be little competition or predation between these two species.

G. holbrooki were less abundant in Jandabup Lake which could be due to the smaller food resource, or to heavy fish predation by birds in the shallow water.

P. olorum was observed to produce offspring from July until September in North Lake. Mutton (1973) and H. Gill (pers. comm.) found *P. olorum* in breeding condition from September to December in lakes and rivers on the Swan Coastal Plain. Estuarine and riverine populations of *P. olorum* have individuals as large as 60mm (H. Gill pers. comm.). The taxonomy of these wetland and estuarine species is currently being reviewed by H. Larson of the Darwin Museum, and it is possible that they may be different species (H. Gill, pers. comm.).

There was no detectable impact of the presence of fish in this study on species richness, abundance and biomass and no detectable groupings of the wetlands with and without fish in the classifications or ordinations. Further experimental work could be conducted to investigate the impact of fish and Jandabup Lake provides an ideal site for field manipulations where *G. holbrooki* could be elimated by allowing the wetland to dry.

6 How does the timing of drying and refill affect the fauna?

This chapter is concerned with the seasonal and interannual changes in wetland water levels and the consequences for wetland invertebrates.

Introduction

In order to manage the wetlands to conserve the aquatic invertebrates it is important to determine the length of the invertebrate's life cycles, when the animals are present and whether they are present at the same time each year. This information would assist in determining the consequences if Jandabup Lake had dried instead of the water level being artificially maiantained in 1989. In a broader context, the conservation of macroinvertebrates requires some idea of where they go during the drought period. These questions are addressed in this section.

Methods

Collection and processing of the macro-invertebrates has been described in previous sections. Using the information collected on temporal distribution and abundance it was theoretically possible to estimate the length of the life cycles of the more numerous taxa collected from the wetlands. This information is contained in Appendix 2, and was used to get an indication of the length of life cycles, when the animals were present and the consequences of Jandabup Lake drying. In order to determine whether individual species are present at the same time each year, the collections made in this study were compared with previous collections in the same wetlands. While there was only time for one year of sampling in this study, previous collections of invertebrates have been made since 1985 at intervals of several months (Davis & Rolls 1987 and Rolls 1989). It is possible to compare collections of odonates in this study with the times they were collected in previous studies. Odonate collections were re-examined to ensure accurate identifications.

Results and discussion

How long are the invertebrates' life cycles?

The timing of refill and drying determines the length of time water is present in the seasonal wetlands, and thus, determines the length of the period in which the inhabitants must complete their aquatic phase. Species with long life cycles should be most vulnerable to changes in the timing of drying and refill. The taxa with larger body size such as the Odonata (dragonflies) and Coleoptera (beetles) are relatively long-lived inverterbrates. In both these groups, the larval phase cannot move from one wetland to another, and generally cannot survive drying. However, once the adult phase is reached they can disperse as flying adults.

For the Odonata the length of the larval phase can range from two months to two years (Tillyard 1916, Watson 1958 and 1962). Butler (1984) emphasized that the number of generations per year, and therefore, the rate of development, varies at the population level, and is not constant for a species throughout its geographic range. Environmentally induced variation probably exists for the majority of aquatic insects (Wallace & Merritt 1980) and the length of adult life in the odonates has not been ascertained for populations in south-western Western Australia. The rate of larval development increases substantially with temperature (Watson 1958 and Chutter 1961). Most Anisoptera throughout the world complete larval development in 100–200 days, with adults living up to 13 weeks (Corbet 1980). However, Watson (1963) noted that adult life is often longer in temporary pond species and this is accompanied by a greater tendency to disperse. Most adults do not rely on drought resistant larvae, rather they are opportunistic with short lives of 40–60 days. In Bangladesh, Begum *et al.* (1982) found the libellulid *Brachythemis contaminata* completes the aquatic phase in 85–94 days at 30–33°C. Kumar (1972) found that larvae in monsoonal ponds in India completed development in 60–120 days and remained as adults for 8–9 months. In Italy larval development of *Lestes barbarus* (Fab.) and *L. virens* (Charp.) in a seasonal pond was 3 and 2 months respectively (Carchini & Nicholai 1984). It is possible that some odonates of the Perth region may also have prolonged adults lives in response to the seasonal drying of the larval habitat.

Faster development in odonates and other aquatic insects at higher temperatures results largely from a decrease in the duration of each of the larval stages (Headley 1940, Huffaker 1944, Bar-Zeev 1958, Brust 1967, Hanac & Brust 1967 and Lutz 1974), or from a decrease in both the duration and number of instars (Ross & Merritt 1978). Some species have more instars at higher temperature even though the duration of the larval period decreases (Pritchard & Pelchat 1977). For those species where the number of growth stages remains unchanged, temperature affects the duration of each instar but not the proportion of time spent in a given instar (Huffaker 1944 and Brust 1967). Unseasonably high temperatures can reduce larval developmental time (Brittain 1976a,b, Gledhill 1960, Illies 1971, Langford 1975, Hynes 1976, Sweeney & Vannote 1978, 1981 and Vannote & Sweeney 1980). For multivoltine species (with several generations each year) developmental time is significantly shorter for summer cohorts (Fahy 1973, Clifford & Boerger 1974, Sweeney 1978 and Illies 1979).

The significance of the increase in development rate with temperature to the invertebrates is that as drying occurs and the wetlands become shallow, the temperatures for Perth are at their highest. During January 1990 daily recordings of temperature were made from Bartram Swamp when water depth decreased from 28 to 14cm. The mean maximum water temperature was 32.2°C, and mean minimum 20.6°C. The maximum temperature of 37°C was recorded when the water was 16cm deep. As the Perth wetlands dry, the water temperature increases and the rate of development of the invertebrates should increase.

For the taxa that were not identified to species level (Oligochaeta, Nematoda, Hirudinea, Hydracarina, Diptera, and Lepidoptera) nothing could be ascertained from the data because of the possibility that several species may have been involved. Cohorts were generally not evident for any of the Gastropoda. The smaller Crustacea probably complete a life cycle in two to three weeks, so that sampling every three weeks was unlikely to identify cohorts.

The amphipods *A. subtenuis* and *P. acutitelson* and the isopod *P. palustris* might be expected to require more time to complete a life cycle because they are larger, but examination of the data revealed no evidence of cohorts (for example, see Figure 6.1 and Appendix 4.1). Smith & Williams (1983) found asynchrony in the related amphipod *Austrochiltonia australis*, so it is likely that *A. subtenuis* also has asynchronous development. No juvenile shrimps (*P. australis*) were found, which precludes determination of the length of the life cycle. No cohorts were evident in either of the two species of Ephemeroptera. Several of the Odonata (*A. cyane*, *A. pusillus*, *P. affinis*, *H. australiae*, *O. caledonicum*, *D. bipunctata*, and *A. nigrescens*) were not collected in sufficient numbers to enable cohorts to be identified. Although about 10,000 *X. erythroneurum* were collected there was no evidence of cohorts (see Figure 6.2 and Appendix 4.2). For *I. aurora* in Murdoch Swamp it is possible that a cohort completed the larval phase in 63 days (Figure 6.3 and Appendix 4.3). For *A. analis*, sampling commenced in the middle of the development of a cohort and so the length of the larval phase was probably more than 60 days (Figure 6.4 and Appendix 4.4). According to Watson (1958) *A. analis* completes larval development in 28–42 days. For *I. heterosticta*, *A. annulosus*, *A. io* and *A. brevistyla* cohorts could not be followed on consecutive sampling occasions and small instars were seldom collected. According to Watson (1958), *H. tau* requires 50–60 days from oviposition to emergence at temperatures between 29 and 30°C. Although cohorts are not particularly clear for *H. papuensis*, larvae (including small instars) were collected for a period of 109 days in Bartram Swamp. No larvae were collected for several weeks before the wetland dried, implying that 109 days was enough time for this species to develop and metamorphose to adult. In fact, it is possible that two cohorts developed during this period, and the first (with a more complete range of instars) may have taken close to 50 days for the larval phase. Rowe (1991) in New Zealand found that from egg to final instar required 122 days, and the entire life cycle less than six months at 20°C. At the higher temperatures encountered in Perth, this time could be reduced considerably (Hodgkin & Watson 1958). No cohorts could be followed in the Hemiptera and Trichoptera despite the large numbers collected. Few of the coleopteran larvae could be identified to species level, and where they were identified, larval cohorts could not be followed because there were too few individuals. *H. elegans* larvae were collected for a period of approximately 100 days in several wetlands, *H. scutellaris* was collected for a period of 87 days, *C. tripunctatus* 67 days, *R. suturalis* 81 days, and *L. lanceolatus* 58 days. Since cohorts were not evident, the length of the larval phase for these Coleoptera is likely to be shorter than these periods.

Development in many taxa appears to be asynchronous. However, it is possible that each individual adult lays only a few eggs in each wetland so that the detection of cohorts is not possible. In addition, the continuous immigration of adults of the Coleoptera and Hemiptera confounds the detection of cohorts. Poorly synchronized life histories are common in Australian streams (Lake *et al.* 1985). Bunn (1988) found a high incidence of synchronous development in stream invertebrates of the northern jarrah forests near Perth and attributed this to the high predictability of stream flows and stream temperature regimes. In comparison to the streams near Perth, the wetlands are warmer on average and the maximum and minimum temperatures are higher. Australian species known to have synchronous life histories come from relatively cool habitats (Campbell 1983 and Lake *et al.* 1985). Therefore, the wetlands are likely to have more taxa with asynchronous life histories than the cooler streams of the jarrah forest.

There are several reasons why cohorts were generally not detected in these collections. It is possible that each sample removed a substantial proportion of a cohort of a species so that this

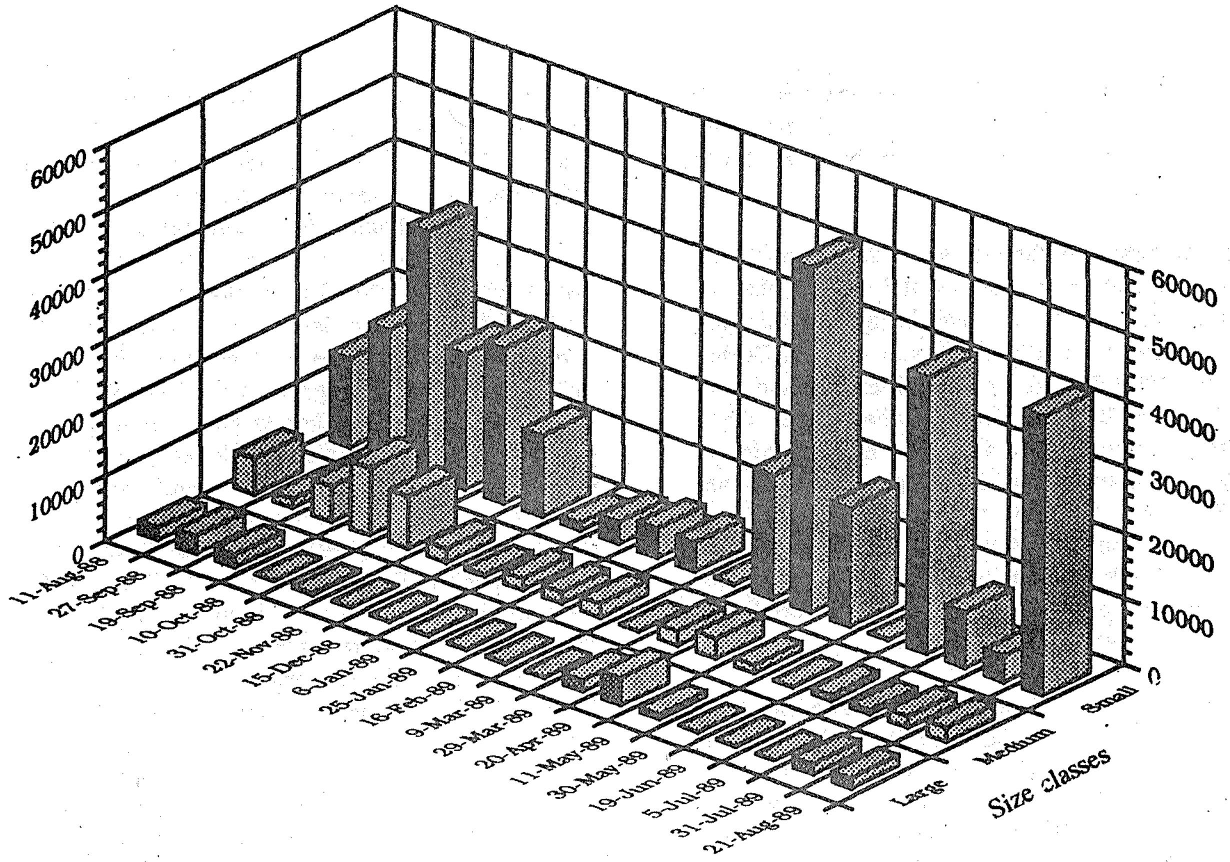


Figure 6.1 Histograms of the number (m^{-3}) of large, medium and small *Austrochiltonia subtenuis* collected from Thomsons Lake on each sampling occasion.

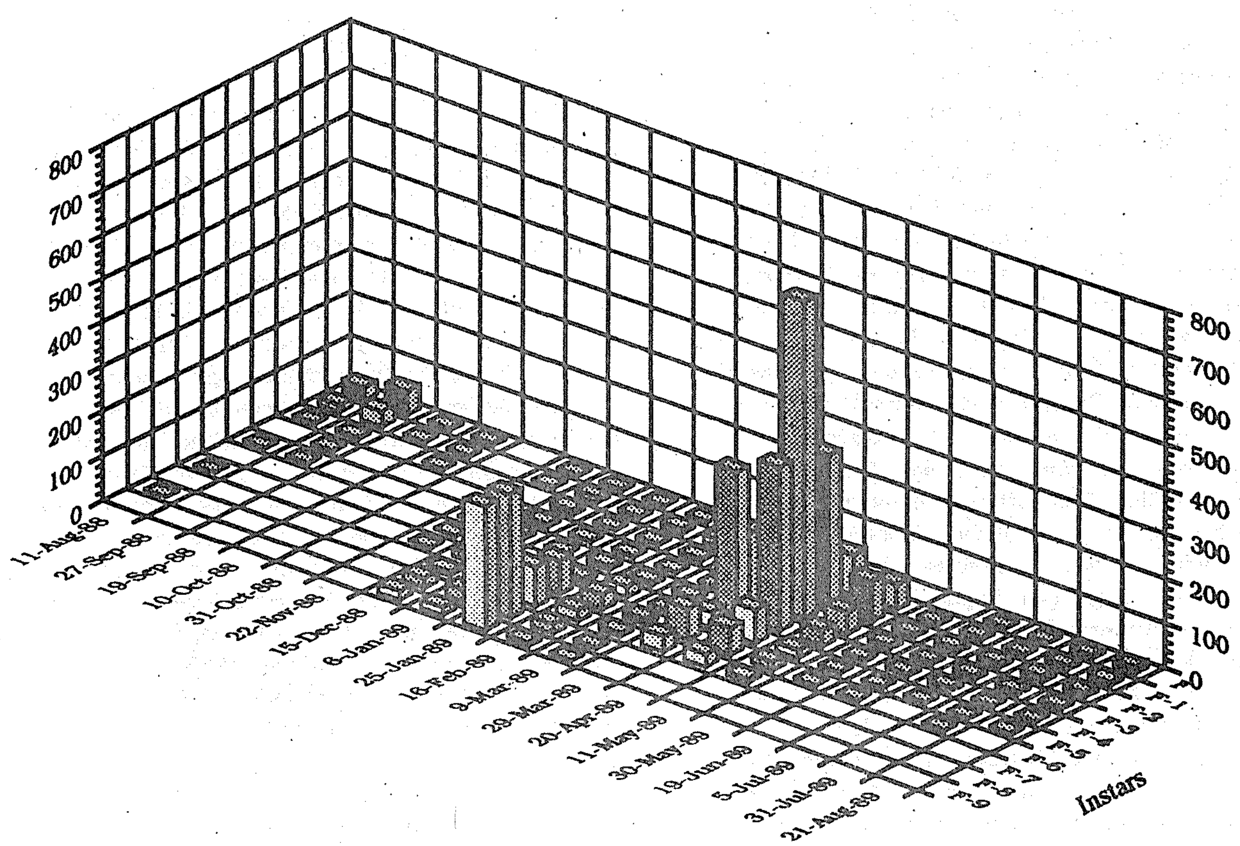


Figure 6.2 Histograms of the number (m^{-3}) of different instars of *Xanthagrion erythroneurum* collected from Thomsons Lake on each sampling occasion.

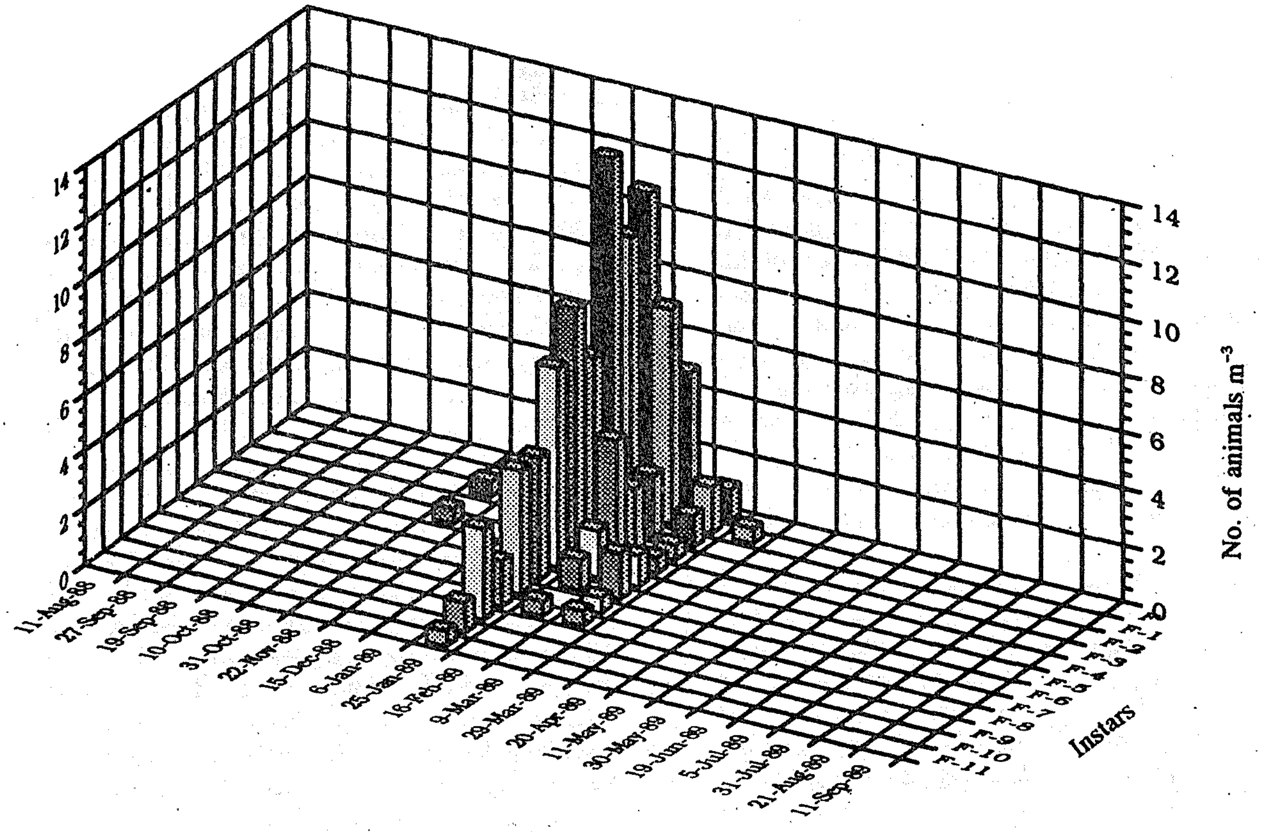


Figure 6.3 Histograms of the number (m^{-3}) of diffent instars of *Ischnura aurora* collected from Murdoch Swamp on each sampling occasion.

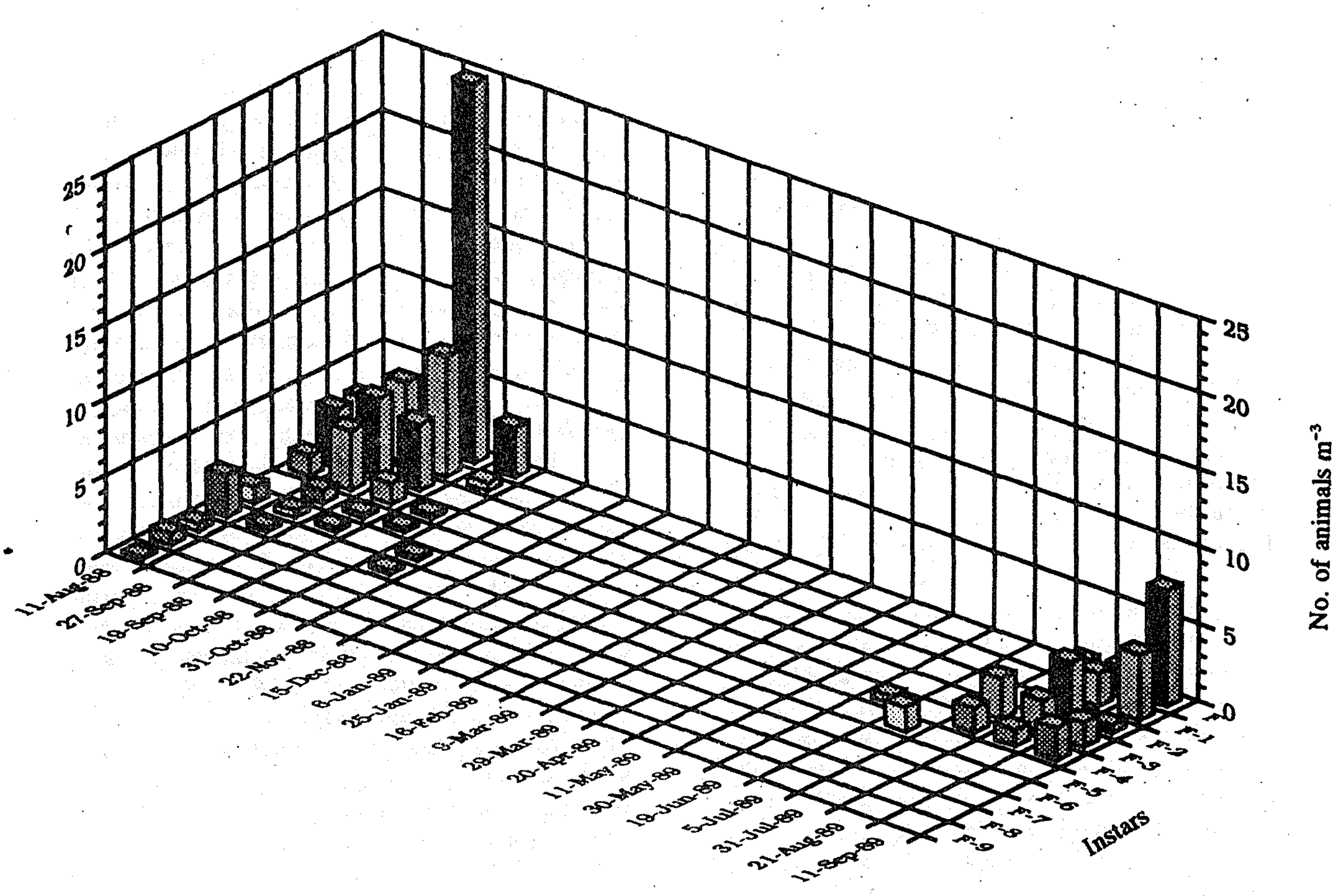


Figure 6.4 Histograms of the number (m^{-3}) of different instars of *Austrolestes analis* collected from Jandabup Lake on each sampling occasion.

cohort did not appear in subsequent samples. This might account for the absence of visible cohorts in the less common taxa, but not in the amphipods, isopods and the odonate *X. erythroneurum* which were numerous. It is possible that the samples were not taken in the appropriate habitat for all life stages. This is likely for the taxa collected in low numbers, for example the less common mud dwelling odonates, shrimp and some of the more abundant odonates where early instars dwell in mud or the base of plants (Corbet 1957 and Lawton 1970). Alternatively, it is possible that samples were taken too infrequently and cohorts were not seen because the invertebrates developed rapidly.

Even in the driest year for which there are records of wetland water levels, there was 121 days between the beginning of August and the end of November when the wetlands contained water. All of the taxa for which estimates of the period of larval development is possible had a development time shorter than this. This suggests that all of the taxa are able to complete development from egg to reproductive adult while the seasonal wetlands contain water as long as the wetlands do not dry before 30 November.

When are the animals present?

The timing of drying and refill also has a role in determining the phenology (seasonal timing of development) of wetland invertebrates. As Wolda (1988) notes in his review of insect seasonality, the length of time each species is present is less than the total time water is present, and the phenology of individual species tend to be staggered so that together they cover the entire period water is present. The phenology of individual taxa depends on life history characteristics such as the response to seasonal drying, the rate of larval development and adult longevity (Wolda 1988). There must be adequate food, the physical conditions must be tolerable with the presence of suitable egg laying sites, and predators, competitors, and parasites should not be too prevalent. However, in order to understand individual seasonal patterns detailed data on the complete life cycles is needed (Danks 1978). The information gained in this study is a beginning.

The phenology of each taxa from each wetland is given in Appendix 2. Those taxa which occur in late summer, autumn and early winter are likely to be vulnerable to variation in the timing of drying and refill. In fact, only those taxa that occur in spring are guaranteed the presence of water in the seasonal wetlands. While only five taxa had over 90% of their individuals collected in spring, a total of 39 of the 176 taxa had over 50% of individuals collected in spring.

When uncommon taxa, represented by less than 10 individuals, are removed (because low numbers may imply inaccurate phenologies), 108 taxa remain. Most (70%) of the remaining taxa had the majority (>90%) of their individuals collected when the seasonal wetlands contained water in 1989 (drying in mid–February and refilling in late July). Very few Coleoptera were collected between mid–February and when the first rain–filled pools formed in late May. All five Trichoptera were collected during this dry period, as were the Ephemeroptera, Lepidoptera spp., Acarina and Gastropoda all but one (*Nychia* sp 1) of the Hemiptera, seven of the nine Odonata, and 17 of the 23 Crustacea. While most of the taxa had low numbers present, ten taxa had large proportions (over 25%) of their individuals collected during this dry period; *Hydra* spp., Oligochaeta spp., Hirudinea spp., *S. kendricki*, Sididae sp 1, Macrothricidae spp., *G. maia*, *C. novaezelandiae*, *X. erythroneurum* and *I. aurora*. Therefore, the majority of the taxa were either absent or in low numbers when the seasonal wetlands were dry.

What would have been the consequences if Jandabup Lake had dried instead of the water level being artificially maintained in 1989?

Between 30 March and 11 May 1989, the water level in Jandabup Lake was between 0.13m and 0.17m. If the wetland had been allowed to dry during this period, several taxa might have had significant (>50%) reductions in the number of individuals collected from this wetland: Hirudinea spp., *S. aculeata*, *A. parvipunctata*, Tipulidae spp., Ceratopogonidae spp. (see Appendix 2.1). However, all of these taxa have some adaptation to seasonal drying. Overall, 28% of the taxa collected from Jandabup Lake occurred during this period; 15 of these taxa are mobile as adults, 16 are non–mobile but adapted to seasonal drying. From the data the majority of individuals of *S. kendricki* were present during the driest period. Evidently, the conditions (probably salinity requirements) for *S. kendricki* were ideal at this time. However, Davis *et al.* (1993) collected this species in November and January from Jandabup Lake and since this species is adapted to seasonal drying, it is unlikely that numbers of this species would have been diminished by the lake drying. Of the 31 taxa which occur during the dry phase in Jandabup Lake, Nematoda spp, Tipulidae spp. and *S. multimaculatus* do not occur in the permanent wetlands at this time. The data suggest that only two taxa appear to have a restricted phenology (*S. kendricki* and Macrothricidae spp.), and these are found in several other wetlands on the Swan Coastal Plain in different months (Davis *et al.* 1993) and are probably opportunistic in the timing of their development. Based on the information on individual taxa (Section 4), the non-mobile fauna are all able to tolerate drying by producing dessication resistant eggs or, burrowing and aestivating as adults. The mobile fauna occur in permanent wetlands during this time and may require permanent water. None of these taxa are unique to Jandabup Lake, therefore there would probably have been no loss of species richness on the Swan Coastal Plain if Jandabup Lake had been allowed to dry that year. In the following year it is likely that the macroinvertebrate species would be largely unchanged except for the benefit of the removal of the introduced fish *G. holbrooki*.

Are the animals present at the same time each year?

Whether or not taxa are affected by the timing of drying and refill depends on the flexibility of their phenology. For example, a species may have to reproduce or emerge at a particular time each year (equivalent to "rigidity" in Lake *et al.* 1985) or there may be some flexibility. Those taxa which have an aquatic phase from August to December are most likely to have ridigly timed phenology because this is when water is predictably present in the seasonal wetlands. From the data collected in this study, the taxa which are likely to have inflexible phenology are: *A. pusillus*, *A. analis*, *A. annulosus*, *A. io*, *D. bipunctata*, *Nethra* sp1, Leptopodidae sp1, Veliidiae sp 1, *L. dispar* (adults), *Berosus* sp3 (larvae) and Chrysomelidae sp3 (adults).

The occasions when seven odonate species were collected between 1986 and 1989 is shown in Table 6.1. Only the presence (not absence) of larvae is considered significant. Of the seven species two (*I. aurora* and *H. papuensis*) had larvae collected at different times in previous years. This is some evidence to suggest that these two species have some degree of flexibility in their phenology, and that the other five may less flexible.

If these seasonal wetlands had dried as early as December and not refilled until August, and the timing of phenology of the taxa was inflexible, then only 32% of the taxa would have been present when the seasonal wetlands contained water. Since 70% of the taxa were collected when the seasonal wetlands contained water in 1988/89, somewhere between 32–70% of the taxa may be either flexible and would not be affected by the timing of drying and refill varying, or inflexible and affected in a dry year. It seems likely that most of the taxa should be flexible in their phenology. Davis *et al.* (1993) collected samples from 40 wetlands in two consecutive springs and found significant interannual variability. Although it is perhaps significant that these samples were not taken on the same dates and as Appendix 2 demonstrates, the composition of the fauna can change dramatically within three weeks.

Those taxa that are not flexible in their phenology would be most affected by the variablility in the timing of drying and refill. During years of low rainfall, when the seasonal wetlands are dry, these inflexible taxa must (a) use permanent wetlands instead of seasonal wetlands, or (b) leave the local region in search of suitable habitat or (c) die without reproducing. Where the options are either b or c, the result, at least locally, is a reduction in species richness. For the rest of the taxa which have flexible phenologies, the timing of drying and refill is not important as long as the wet period is long enough to reproduce sufficient offspring for subsequent generations either during the next wet period or in a permanent wetland.

Where do the invertebrates go in the dry period?

The phenology of individual species is likely to be closely regulated by environmental factors in a seasonal wetland. Habitat quality can vary in both time and space and diapause and dispersal are respective means of tracking favourable or escaping unfavourable, conditions (Southwood 1977).

Taxa were grouped into mobile (dividing those with non-aquatic adults from those with a fully aquatic life cycle) and non-mobile categories, and then separated into groups with continuous phenologies (collected on 15 or more occasions) and taxa with discrete phenologies (collected on 14 or fewer occasions) (see Table 6.2). Figure 6.5 details these relationships.

Only 21% of the taxa were non-mobile taxa, and the proportions of taxa with discrete and continuous phenologies are almost equal (45.7% and 54.3% respectively). Of the 19 taxa with continuous phenologies, two (*P. acuta* and *G. maia*) appear to require permanent water, and 10 are able to inhabit seasonal wetlands with a dessication resistant stage (for the remaining seven there is insufficient information). For the 16 taxa with discontinuous phenologies, three (*Hydra* spp., *H. duryi* and *P. australis*) probably require permanent water and the discrete distribution probably results from inadequately sampling for these taxa. While all of the 13 non-mobile taxa with discrete phenologies have a dessication resistant stage, only one may actually require seasonal drying; the conchostracan *Lynceus* sp 1. The other 12 taxa also occurred in wetlands that did not dry. However, some taxa may require cues associated with the drying process for stages in their life histories. The relatively high salinities, and low oxygen concentrations in

Table 6.1 Collections of larval odonates from Thomsons Lake between 1986 and 1989. The bars indicate when the wetland dried in 1987 and 1988. Thomsons Lake did not dry in 1989.

Species	Date	J	A	S	O	N	D	J	F	M	A	M	J
Ischnura aurora	86/87							*				*	
	87/88							*					
	88/89			*		*	*	* * *	* * *	* * *			
Austrolestes analis	86/87							*					
	87/88												
	88/89	*	* * * *	* * *	* * *	* * * *	* * *	* * *					**
Austrolestes annulosus	86/87					*		*		*			
	87/88				*			*					
	88/89		* *	* * *	* * *	* * * *	* * *	* * *	* *	* *	* *		
Austrolestes io	86/87			*		*		*					
	87/88												
	88/89			*	* * *	* * * *	* * *	* * *					
Aeshna brevistyla	86/87							*					
	87/88												
	88/89	* *	* * *	* *			*	* * *	* * *	* *		* *	* *
Hemianax papuensis	86/87					*		*		*		*	
	87/88							*					
	88/89		*	* * *	* * * *	* * *	* * *	* * *	*		* *	* * *	* *
Hemicordulia tau	86/87							*					
	87/88												
	88/89			*	* * * *	* * *	* * *	* * *	* *	*	* * *	*	*

Table 6.2 Taxa divided firstly into mobile and non-mobile categories, and secondly into groups with discrete or continuous phenologies. The phenology here is the percent of the total number of each taxa present on each sampling occasion in all 6 wetlands.

Taxa	Sampling occasion																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Mobile taxa																				
1.1. Non-aquatic adults																				
1.1.1. Discrete phenology																				
A. analis	*	*	*	*	*	*	*	*								*	*	*	*	*
Sisyridae sp 1			*	*		*														
E. turgidus	*	*	*	*				*		*								*		*
Ephydridae spp.				*	*	*	*									*		*	*	*
A. io			*	*	*	*	*	*	*											
Tipulidae spp.				*		*		*						*	*	*	*			
Stratiomyidae spp.				*	*	*	*	*	*	*	*				*	*	*	*		*
H. tau			*	*	*	*	*	*	*	*		*	*	*		*				*
I. aurora						*	*	*	*	*	*	*								*
A. annulosus	*	*	*	*	*	*	*	*	*	*		*	*					*		*
A. brevistyla		*					*	*	*	*	*				*	*		*	*	*
I. heterosticta							*	*	*	*	*				*	*	*			*
Culicidae spp.	*		*	*	*	*	*	*	*	*	*	*	*	*	*					
Psychodidae spp.						*		*		*					*	*	*			
Tabanidae spp.								*							*	*	*			*
Empididae spp.			*												*		*			
Thaumeliidae spp.															*	*	*	*		
1.1.2. Continuous phenology																				
Chironomidae spp.	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
T. australis	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Lepidoptera spp.	*		*	*	*	*	*	*	*	*		*	*	*	*		*			*
Tasmanocoenis sp 1					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
H. papuensis	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*				
Oecetes sp 1	*			*	*	*	*	*	*		*	*	*	*	*	*	*			*
Ceratopogonidae spp.	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
N. fulva	*	*	*	*	*	*	*	*	*	*	*	*	*	*			*	*	*	*
A. globosa	*	*	*	*	*	*	*	*	*	*	*	*	*			*	*	*		*
X. erythroneurum	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Cloeon sp 1			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1.2. Fully aquatic life cycle																				
1.2 1. Discrete phenology																				
Limnichidae sp 1 A	*	*	*			*													*	*
Sternopriscus sp 6 A	*	*	*	*																*
Rhantus suturalis L	*			*	*															
Hyphydrus elegans A	*	*	*	*		*	*	*	*	*	*								*	*
H. tenuistriatus A	*	*	*		*			*							*	*				*
Curculionidae sp 2 A	*	*	*	*												*	*	*	*	*
C. tripunctatus L	*	*	*	*		*										*	*	*	*	*
Hydrochus sp 2 A	*	*	*			*		*	*	*					*	*	*	*	*	
Chrysomelidae sp 3 A		*	*			*	*								*					
Nychia sp 1			*	*																
Diaprepocoris spp.	*	*	*	*	*	*	*	*	*		*								*	*
Berosus discolor A	*	*	*	*	*	*											*	*	*	*
Antiporus spp L	*	*	*	*	*	*										*	*	*	*	*
Helodidae sp 1 L	*	*	*	*	*	*	*										*	*	*	*
Enochrus sp 1 A				*						*	*				*	*	*			*
H. scutellaris L	*		*	*	*	*	*	*			*						*	*	*	*
Hydrophilidae sp 3 L		*	*	*	*		*	*	*	*							*	*	*	*
Liodessus dispar A					*	*												*	*	*
Hyphydrus elegans L			*	*	*	*	*	*	*											
Paracymus pigmaeus A			*		*	*	*	*	*	*					*	*	*	*	*	
Sternopriscus sp 2 L	*		*		*	*	*	*		*	*									
Berosus sp5 L			*	*		*	*	*	*	*	*				*			*		
S. multimaculatus A						*	*		*					*	*	*	*	*	*	
Sternopriscus sp 2 A							*	*												
Antiporus sp 1 A			*	*	*	*	*	*							*		*		*	
Ochthebius sp 1 A						*		*	*						*					
P. brunni								*	*	*	*	*	*	*	*		*	*		
L. macer A	*				*		*	*							*	*	*			
Liodessus inornatus A	*		*		*	*	*	*	*				*	*	*	*	*	*		
Enochrus sp 3 A		*	*		*	*	*	*	*		*	*	*		*	*	*	*		
Hydraena sp 1 A				*	*										*	*	*	*	*	

cont...

Taxa	Sampling occasion																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
<u>Laccophilus</u> sp 1 L	*	*														*	*	*	*	*
<u>S. pulchellus</u> L	*	*	*	*													*	*	*	*
<u>Megaporus</u> spp L	*		*	*	*	*	*												*	*
<u>Berosus</u> sp4 L				*	*	*	*	*	*											*
Hydrophilidae sp 1 L	*			*		*										*	*	*	*	*
Veliidae sp 1	*											*								*
<u>Berosus</u> sp3 L			*																	*
2.2.2. Continuous phenology																				
<u>A. eurynome</u>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
<u>M. robusta</u>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Mesoveliidae sp 1			*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*
<u>Saldula</u> sp 1			*		*	*	*	*	*	*	*	*	*	*	*	*	*			
<u>S. truncatipala</u>	*		*	*	*	*	*	*	*	*	*			*	*	*	*		*	
<u>Anisops</u> spp.	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2. Non-mobile taxa																				
2.1. Discrete phenology																				
<u>H. duryi</u>	*	*	*			*	*				*									
<u>Hydra</u> spp.									*	*			*	*						*
<u>P. australis</u>			*		*											*	*	*	*	*
<u>C. quinquecarinatus</u>	*	*																*	*	*
<u>M. ambiguosa</u>	*	*																		
<u>P. acutitelson</u>			*	*	*	*	*	*						*					*	*
Conchostraca sp 1			*	*														*	*	*
<u>Lymnaea columella</u>			*	*				*	*	*	*					*	*	*		
<u>B. australis</u>	*	*	*	*	*	*	*	*							*	*	*	*	*	*
<u>L. mowbrayensis</u>	*	*		*	*	*	*	*	*											
<u>Ferrissia</u> sp. 1			*	*	*	*	*	*	*	*	*								*	*
Tricladida spp.						*		*							*	*				
Sididae sp 1							*	*	*	*	*									
Macrothricidae spp.	*					*	*		*	*	*	*								
<u>Sphaerium kendricki</u>												*	*	*			*	*	*	
Nematoda spp.								*	*					*	*					
2.2. Continuous phenology																				
<u>A. woroora</u>	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*
Chydoridae spp.	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*
<u>P. palustris</u>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Hydracarina spp.	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Moinidae spp.			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
<u>Physa acuta</u>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
<u>Simocephalus</u> sp 1	*	*	*	*	*	*	*	*	*			*	*	*	*		*			*
<u>A. subtenuis</u>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Cyclopoidea spp.	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
<u>C. baylyi</u>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
<u>C. novaezealandiae</u>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
<u>G. maia</u>	*	*	*	*		*	*	*		*	*	*		*	*	*	*	*		*
Hirudinea spp.				*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*
Oligochaeta spp.	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
Harpactacoidea spp.	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Orabatidae spp.	*	*	*	*	*	*	*	*	*	*	*	*			*	*	*	*	*	*
Calanoidea spp.	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
<u>S. aculeata</u>	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
<u>Daphnia</u> spp.	1*	*	*	*	*	*	*	*	*	*				*	*	*	*	*	*	*
<u>Glyptophysa</u> sp 1	*	*	*	*	*	*	*	*	*	*	*	*			*	*	*	*	*	*

Figure 6.5 A spatial representation of the information contained in Table 6.6, based on the percentage of the fauna in each category.

Mobile 79%	Non-aquatic adults 20%	Continuous phenology 10.2%	Disperse to permanent water (11 taxa) (short lived)
		Discrete phenology 15.7%	Disperse or aestivate (17 taxa)
	Aquatic adults 59%	Continuous phenology 6.5%	Disperse to permanent water (7 taxa)
		Discrete phenology 35.2%	Disperse or aestivate (31 taxa unknown, 7 aestivate)
Non-mobile 21%	Fully aquatic 21%	Continuous phenology 17.6	Require permanent water (2 taxa, 7 unknown) or aestivate (10 taxa)
		Discrete phenology 14.8%	Require permanent water (3 taxa) or aestivate (13 taxa)

Jandabup Lake when it was very shallow, may have triggerred hatching of eggs in Macrothricidae spp. and Sididae sp 1.

As a life history variable, dormancy is often critical to proper temporal syncronization of the life cycle in relation to benign and adverse environmental seasonality (Begon & Mortimer 1981). Dormancy can be a period of quiescence directly caused by environmental factors or can be a genetically programmed "true diapause" that is initiated in a particular life–cycle stage by an environmental cue (Danks 1979 and Tauber & Tauber 1976). True diapause has been reported for the egg stage of several insects (Butler 1984).

Most (79%) of the fauna is mobile (21% is non–mobile), with 20% having non–aquatic adults and 59% with a fully aquatic life cycle. Of the mobile taxa 76.4% have discrete phenologies and 23.6% have continuous phenologies. It is significant that 87.2% of those mobile taxa including those with fully aquatic life cycles, were not collected during the dry part of the year when the seasonal wetlands were dry. Exceptions were *H. tau*, Stratiomyidae spp., *A. annulosus*, Culicidae spp., *P. brunni*, *L. inornatus* and *Enochrus* sp 3 (adult). The majority of the mobile taxa either disperse to permanent water or aestivate in the dry beds of seasonal wetlands.

Random dispersal may be a very general means of population persistence in spatiotemporally varying environments (Goodman 1987). Taxa differ in the dispersal abilities (Bird & Hynes 1981), but seasonal dispersal is fairly common in insects (Wolda 1988). For example, the hemipteran *Gerris* spp. migrate between habitats in different seasons (Vepsalainen 1974). While Diptera, especially chironomids, disperse widely (Johnson 1969 and Cheng & Birch 1977) and many trichopterans are strong fliers (Ulfstrand 1970, Svensson 1974, Crichton *et al.* 1978 and Roy & Harper 1981), the Hemiptera, Odonata and Coleoptera probably disperse furthest. Odonate adults may shelter in nearby forests for up to 8–9 months (Kumar 1972 and Corbet 1980), or disperse to permanent wetlands (often several hundred kilometers away) where they reproduce (Corbet 1980). Long–lived aquatic adults of Coleoptera and Hemiptera disperse widely and persist with or without reproducing for some time in invaded habitats (Sheldon 1984). In seasonal environments most of the colonizing insects arrive as adults (e.g. Gray 1981 and Gray & Fisher 1981).

If the Odonata and Coleoptera disperse to other wetlands, then where do they go when the seasonal wetlands are dry? They were not found in any of the five permanent wetlands, in this study, nor in Lake Monger in autumn (Lund 1992), and unfortunately, Davis *et al.* (1993) has no data for autumn. If they disperse to other wetlands, restrictions imposed by adult behaviour (e.g. in selection of oviposition sites) and larval requirements can reduce the number of successful colonists (Sheldon 1984). Odonate adults are often selective in their choice of suitable habitat for egg laying. The act of selection is of great significance in their life-history, since the eggs, and to some extent the larvae, must be placed in a site which is optimal for development (Corbet 1962). Some species deposit eggs endophytically (inside plants) which are in or near wetlands, while other species deposit eggs exophytically, releasing them above or upon a surface (Corbet 1980). Odonates that deposit eggs endophytically are commonly selective when choosing plants. Eggs may develop directly or have delayed development. The shape and size of a water body are important in habitat selection, and both the kind and distribution of aquatic plants affects species composition and abundance of larvae in wetlands (Corbet 1962).

Panjunen (1971, 1982) illustrated the importance of colonization in the life histories of corixids. Two corixid species overwinter in deeper pools, but disperse to smaller and often temporary pools for reproduction. In addition to these regular seasonal movements, continuous diffusion-like dispersal between breeding pools probably minimized the risk that a female will place all her eggs in a single pool that will dry before her offspring mature. Similar behaviour for many of the mobile taxa probably occurs in the invertebrates of the Perth wetlands. The available evidence suggests that while some of the taxa (notably the Hemiptera) migrate away from the metropolitan wetlands, many others (particularly some of the Coleoptera) aestivate.

The wetlands of Perth are part of a continuum of wetland habitats from Geraldton in the north to Augusta in the south, and east to Esperance similar to a range of Mediterranean wetlands described by Morgan (1982a,b) and Morgan & Boy (1982). Each species will have a unique distribution. For some species, individuals inhabiting wetlands throughout the whole of the south west will be an interacting population. For other species (e.g. mites, crustaceans and other non-mobile animals) each wetland may contain a separate population and the distribution of these populations range throughout the southwest or some restricted portion (e.g. only the Swan Coastal Plain).

A metapopulation is a population of populations and may defined as a set of local populations which interact via individuals moving among populations (Hanski & Gilpin 1991). At the local scale, individuals move and interact with each other in the course of their routine feeding and breeding activities. At the metapopulation scale, individuals infrequently move from one place (population) to another, typically across habitat types which are not suitable for their feeding and breeding acitivities, and often with substantial risk of failing to locate another suitable habitat patch in which to settle. At the geographical scale (the species entire geographical range), individuals typically have no possibility of moving to most parts of the range (Hanski & Gilpin 1991). These scales are continuous and hierarchical.

Table 6.3 lists the taxa which fall into categories of metapopultions with differing spatial scales. The role of passive dispersal is ignored since it is likely to be governed by stochastic processes.

Table 6.3 Provisional groupings of taxa according to how many wetlands constitute a population.

1 wetland	Several close wetlands	Large region of wetlands	Entire south-west wetlands
Hydra spp.	Ephemeroptera	Other Diptera	Hydracarina
Tricladida	Chironomidae	Lepidoptera	Odonata
Nematoda	Tipulidae	Trichoptera	Hemiptera
Oligochaeta	Ceratopogonidae		Coleoptera
Hirudinea			
Gastropoda			
Crustacea			

Figure 6.6 shows the regions of Western Australia classified according to rainfall. It indicates that taxa in Perth wetlands (but not nececarily restricted to Perth) which require water throughout the year could move to the wetter south-west each year. Those taxa for which a single wetland constitutes a metapopultion are non-mobile taxa. Those taxa which are mobile as adults but are probably not particularly robust fliers will reproduce in a few close wetlands. Taxa which are stronger fliers (many Diptera and Trichoptera) probably reproduced in a large number of relatively distant wetlands. Finally, the taxa which have strong flying adults such as the Odonata, Coleoptera and Hemiptera could probably fly several hundred kilometers and thus, the entire south-west region may constitute a single, interacting metapopulation. Areas occasionally frequented by tropical rain could also be used by these taxa, but as Figure 6.6 shows

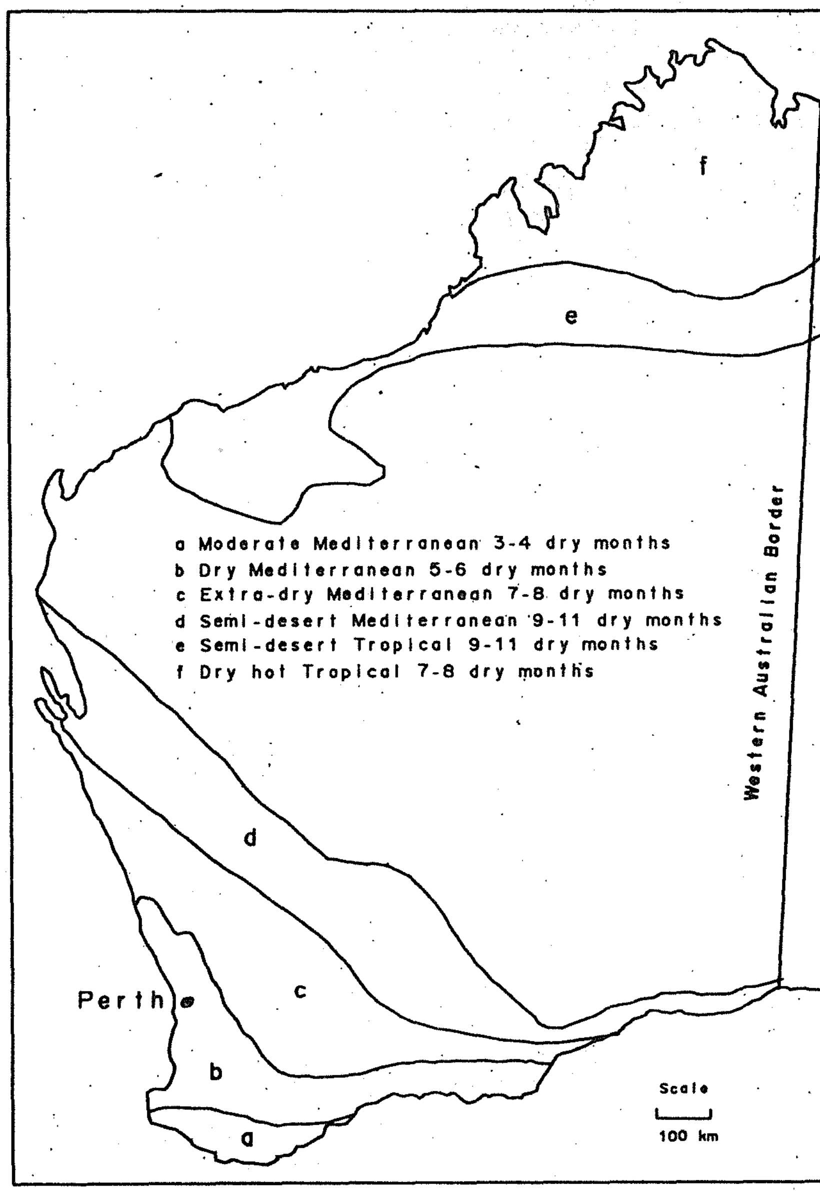


Figure 6.6 Bioclimates of Western Australia where classification is based on the season and the length of the dry period. This accords well with vegetation boundaries. Boundaries are drawn at 4.5, 6.5 and 8.5 dry months. Modified from Beard (1990).

they would have to travel many hundreds of kilometres.

Therefore, to maintain species diversity within the Perth wetlands, not only do individual wetlands containing rare and uncommon taxa need to be conserved, but for the more mobile and usually uncommon larger animals (Odonata and Coleoptera) wetlands throughout the south-west of Western Australia need to be conserved. In addition, a mosaic of seasonal and permanent wetlands is needed and within these two broad types, a diversity of wetlands of differing vegetation types, water colour, pH and salinities need to be conservated so that the specific requirements of each species are met.

7 Conclusions, conservation and management

The wetlands

The six wetlands in this study are surface expressions of a superficial unconfined aquifer and receive inputs from the groundwater and runoff from surface catchments. Outflow from these wetlands occurs via the groundwater and water is lost directly from the wetlands with evaporation and evapotranspiration. The mediterranean-type climate, with hot, dry summers and cool, wet winters, in concert with the existence of the unconfined aquifer, profoundly shapes the character of these wetlands. The four seasons are quite distinct in terms of temperature and rainfall. There is a long decline in the quality of the environment through summer and autumn, an abrupt transition from drought to winter wet and cold, a relatively short improvement in environmental quality culminating in spring and a gradual turnover from spring to summer. The annual sequence of seasonal change is predictable; only the length of the wet and dry seasons varies.

The six wetlands are a subset of the wetland types on the Swan Coastal Plain. They are fresh to slightly saline lakes with areas of open water. They range in size from small (1.3ha) to large (232.3ha). Only one, Bartram Swamp, dried completely, while Jandabup Lake became very shallow (0.13m deep) and Murdoch Swamp and Nowergup Lake contracted over a large proportion of their surface area to deep pools. The two remaining wetlands, Thomsons Lake and North Lake, contained water over most of their surface area all year. Of these six wetlands, only Nowergup Lake is deep enough to have contained permanent water in the recent past. Records indicate that each of the other five wetlands have dried previously. Murdoch Swamp was artificially deepened in the 1930's and has not dried since.

These wetlands encompass a range of depths, pH, conductivities, nutrient levels and colour. Jandabup Lake had the lowest nutrient levels (classified as mesotrophic), while Bartram Swamp and Murdoch Swamp were moderately enriched (eutrophic). However, these two wetlands did not exhibit symptoms of enrichment, probably because of the dark colour of the water, and are more properly classified as dystrophic. The remaining three wetlands, Nowergup Lake, North Lake and Thomsons Lake were hypertrophic. Only North Lake exhibited continuous cyanobacterial blooms throughout the year and very little fringing vegetation remains around this wetland. The other five wetlands were relatively well endowed with aquatic macrophytes and fringing vegetation. Murdoch Swamp is a closed canopy wetland, flooding *Melaleuca* sp. and *Banksia* sp. when water levels are high. The occurrence of cyanobacterial blooms in Thomsons Lake appear to be associated with the decline of the aquatic macrophyte *Myriophyllum* sp. as water levels rise and preclude drying. Evidently the moderately dark water in Thomsons Lake could not limit algal production in autumn.

The invertebrates

The wetlands change physically and chemically through the seasons and so do the invertebrate communities. Seasonal changes in the invertebrate communities were most pronounced in the less enriched wetlands. Samples taken from two consecutive springs were very similar in each wetland. The physical and chemical characteristics and invertebrate communities cycled through the seasons and probably follow the same pattern each year. Invertebrate communities in less enriched wetlands differed between wetlands. Communities in enriched wetlands were more similar to eachother, while each of the less enriched wetlands contained more unique species.

The information gathered in this study was insufficient to properly ascertain the impact of fish on the macroinvertebrate communities in these wetlands.

The number of taxa collected from these wetlands (176) was high with a substantial number of Coleoptera. The high species richness may be a consequence of the annual fluctuations in water level of 1–1.5m, promoting the growth of macrophytes and the annual flooding of terrestrial vegetation, which provides a food source and shelter. These six wetlands were generally productive; abundance and biomass is comparable to that found in wetlands elsewhere. Species richness was generally highest in spring. There were no consistent peaks in abundance and biomass over time in individual wetlands or overall. Abundance and biomass were lowest in autumn but maximums occurred in different seasons for different wetlands. Abundance, and to a lesser extent, biomass varied considerably in consecutive samples as populations of crustaceans, corixids and chironomids flucutated.

High species richness appeared to be associated with seasonal drying. The seasonally dry Bartram Swamp had the highest species richness per cubic metre, and the shallow Jandabup Lake and the two wetlands that contracted to deep pools had a significantly higher species richness than the permanent wetlands. This may be because seasonal drying maintains populations at sub-maximum densities, leading to reduced exclusion of competatively inferior species and an overall increase in diversity. The five well vegetated wetlands had a significantly higher species richness in comparison to North Lake which had very little aquatic macrophytes and fringing vegetation. The presence of aquatic vegetation provides macroinvertebrates with habitat for egg laying, feeding and shelter.

Invertebrate abundance was relatively low in mesotrophic Jandabup Lake and eutrophic Bartram Swamp. Bartram Swamp and Murdoch Swamp had similar nutrient levels, but invertebrate abuandance was considerably higher in Murdoch Swamp. It is possible that seasonal drying resulted in the lower abundance of invertebrates in Bartram Swamp compared with Murdoch Swamp. There was no corresponding difference in biomass which was low in the three less enriched wetlands (Jandabup Lake, Bartram Swamp and Murdoch Swamp) and high in the hypertrophic wetlands (Nowergup Lake, North Lake and Thomsons Lake). It is likely that the green algal scum on the water surface of Murdoch Swamp present during summer and autumn (when Bartram Swamp was dry) provided the food source for a large number of small animals which contributed to the high abundance in Murdoch Swamp. While all three hypertrophic wetlands had high abundance and biomass, North Lake with the most chronic symptoms of hypertrophy (i.e. a continuous cyanobacterial bloom) had the lowest biomass. North Lake has almost no aquatic macrophytes, and it is possible that macrophytes are required by the larger invertebrates.

Water levels

Observations of other seasonal wetlands indicated that water level changes in Bartram Swamp were generally representative of seasonal wetlands. During the past 30 years or more, the seasonal wetlands have been dry for four or five months each year when the annual rainfall is average. If the previous years rainfall was below average, the wetlands dry for longer; up to six or eight months from December to August. Water was only consistently present in the wetlands from August to the end of November.

The timing of drying is determined by the level of the groundwater which is dependent on the quantity of the previous years rainfall. The rate of drying is relatively slow compared to the rate of refill, and drying can occur between December and April. The timing of refill is determined by the beginning of the winter rains. Refill is rapid and can occur between April and July.

Most (70%) of the taxa were present when the seasonal wetlands contained water. However, individual taxa were present for only part of this period, so that the seasonal timing of development (phenology) of different species occurred at different times. This allows each species to avoid competition with similar taxa for food and space, avoid predation, and coincide with the availability of egg laying sites and particular prey species.

The majority (79%) of the taxa are mobile, with 59% having aquatic adults and 20% with non-aquatic adults. Of these mobile taxa 23.6% were collected throughout the year, but most (76.4%) were collected for a discrete period. Most (87.2%) of these mobile taxa were not collected from any of the six wetlands (including permanent wetlands) when the seasonal wetlands were dry. These taxa rely on seasonal wetlands and most use permanent wetlands opportunistically. Consequently, they either disperse to wetlands in the south-west or aestivate once the seasonal wetlands are dry until the rains begin.

Based on available information, only 3% of the taxa require permanent wetlands and all of these are non-mobile. However, 27.4% of the taxa require water when the seasonal wetlands are dry, and these are mobile animals with short-lived non-aquatic adults or have aquatic adults with no desiccation resistant stage (some Diptera, Ephemeroptera, Trichoptera, Lepidoptera, some Odonata, Hemiptera, Hydracarina, some Coleoptera). Perhaps as much as 70% of the fauna have no requirement for water throughout the year because they have either long-lived non-aquatic adults or a desiccation resistant stage.

Even in low rainfall years, there are about four months when water may be present in the seasonal wetlands. None of the taxa were found to have larval phases that were longer than this, and most were at about half this period.

While clearing the bush and urbanization produces higher water levels (by reducing evapotranspiration and increasing groundwater recharge via increased runoff), groundwater extraction opposes this trend and the result is a mitigation of both effects. At present, extraction has a more significant impact on groundwater and wetland water levels on the Gnangara Mound than on the Jandakot Mound. This is because the depth to groundwater is greater on the Gnangara Mound and thus the wetlands tend to be relatively discrete. The depth to groundwater on the Jandakot Mound is much less and there are extensive areas of interconnected damplands, swamps and lakes. As a consequence, there is considerable loss of groundwater via evaporation on the Jandakot Mound, and hence the relative impact of extraction is diminished. When extraction commences from the Jandakot Stage 2 wells there will be an increased impact on the groundwater levels. The overall impact of urbanization and extraction on the Jandakot Mound will be reductions of 0.1 to 1.10m in the water table. Declines in groundwater levels on the Gnangara Mound are between 1–2.5m. The size of the decrease is positively correlated with the proximity of the wellfield. Past records and modelling indicate that changes in rainfall have a greater impact on groundwater levels than extraction, although extraction is likely to exacerbate the effects of a series of low rainfall years. In addition to lowering wetland water levels, it is likely that extraction will reduce the period seasonal wetlands contain water, ensuring that drying will occur earlier. The timing of refill is influenced by rainfall draining into wetlands from the surrounding catchments as well as the level of the groundwater and so is likely to be delayed to a lesser extent.

Groundwater extraction may also increase the rate of drying. Examination of the natural rates of wetland drying and decreases in groundwater bores suggests that the rate of decrease in groundwater level does not exceed 2cm/day. This enables the invertebrates that lay eggs in the flooded fringing vegetation to complete their life cycles before the wetland dries.

Management implications

A small number of taxa appear to require permanent wetlands (*Hydra* spp., *Physa acuta*, *Gomphodella maia*, *Palaemonetes australis* and *Pseudogobius olorum*), and others need alternative sources of water when the seasonal wetlands are dry. Therefore, some (not necessarily a large number) of the permanent wetlands should be maintained on the Swan Coastal Plain. It is likely that many of these will be within the urban area as a consequence of increased water levels due to urbanization and for aesthetic reasons (e.g. Lake Monger), while others will be deeper wetlands which are naturally permanent like Nowergup Lake. At present, species richness in these permanent wetlands is low due to their nutrient enrichement. These enriched permanent wetlands need to be rehabilitated to reduce nutrient levels, and increase growth of macrophytes and fringing vegetation. Allowing water levels to drop seasonally would encourage vegetation growth at the margins and may help moderate the effects of enrichment. Drainage entering urban wetlands needs to be stripped of nutrients (see Boyd 1970 and Cordery 1976), or preferably diverted so that there is no drainage into wetlands, becuase the volume of water entering wetlands is almost as much a problem as the quality of the water.

The majority of the macroinvertebrate fauna is mobile and adapted to seasonal drying. The seasonal wetlands are used extensively and are equally as important as permanent wetlands to the macroinvertebrates.

If there was no management (or inappropriate management) of groundwater extraction, the result could be a loss of the shallow, seasonal wetlands. Most of the shallow permanent wetlands would become seasonal while only the deepest wetlands and some urban wetlands would remain permanent. Overall there would be a substantial reduction in the number and area of wetlands on the Jandakot and Gnangara Mounds. Since already 70% of the original wetlands have been lost, further loss of wetlands is likely to result in a loss of species diversity (plant and animal) on the Swan Coastal Plain. Since the wetlands that remain are remnants of the original area of wetlands, it is probable that the invertebrates are also remnants of much larger populations. Each species has a critical lower limit to population size for long term survival of that species. For the larger, predatory taxa like the Coleoptera and Odonata, where only a few individuals occur in each wetland, the number of wetlands inhabited often determines the size of the population. Loss of wetlands, is likely to reduce population sizes, and may already have led to loss of species.

The Water Authority and the Environmental Protection Authority recognizes that this is not acceptable, hence the statutory conditions set for minimum water levels in several wetlands. However, these conditions presently prevent the drying of some wetlands. The evidence found in this study suggest that seasonal drying is beneficial, promoting greater species richness and mitigating the effect of moderate nutrient enrichment. Where water levels are being maintained for aesthetic reasons or as a result of misguided public pressure, the statutory minimums should be revised to allow natural seasonal drying.

Where no statutory conditions exist, groundwater extraction should be managed to ensure that drying of seasonal wetlands on the Jandakot and Gnangara Mounds does not occur before December, and the rate of decrease in water level should not exceed 2cm/day. Years of extremely low rainfall (as in 1940, 507mm) would potentially result in earlier and faster drying, but even cessation of abstraction would be unlikely to compensate for the lack of rainfall. The minimum level to which the groundwater falls should not be below previous records for more than one year. A single dry year may significantly reduce population numbers of the taxa inhabiting that wetland because their larval stage was not completed in time. A series of several dry years could significantly reduce species richness on the Swan Coastal Plain. While dry years have occurred in the past due to natural fluctuations in rainfall, only a remnant (20-30%) of the former wetlands exist, and further loss of suitable habitat in a number of artificially dry years may inhibit recovery of invertebrate populations.

Management of wetland water levels can be achieved by adding water from nearby production wells in wetlands deemed of value or by reducing abstraction in partiuclar bores that have an impact on water levels in nearby wetlands. Abstraction does not affect all wetlands equally because the abstraction of groundwater produces localized rather than widespread effects. Artificial maintenance wells already exist adjacent Jandabup Lake (commissioned 1988) and Nowergup Lake (1990). They are used to prevent water levels in these wetlands from dropping below the statutory minimums. In Jandabup Lake artificial maintenance prevents the wetland drying by maintaining a shallow pool of water during autumn. This is of little value to the aquatic fauna because the puddles do not provide a suitable habitat for the taxa that require water year round since they contain no vegetation and large temperature fluctuations. It is possible to estimate wetland water levels based on the previous winters rainfall. By the time water levels peak in September-October, most of the years rain has fallen and it should be possible to recognize when low rainfall and groundwater abstraction combined has reduced the groundwater level to the point where the fringing vegetation has not been sufficiently flooded. Topping up water levels in spring so that the fringing vegetation is flooded would more closely resemble the natural water regime and provide a food source and shelter for the aquatic fauna. However, if the Greenhouse Effect results in climatic changes and rainfall decreases, the reductions in wetland water levels are likely to be too large for modifications in groundwater abstraction and artificial maintenance to have any impact.

A significant proportion of the inhabitants of seasonally dry wetlands aestivate in the dry bed and in or near the fringing vegetation. The movement of heavy vehicles over the dry beds may crush the aestivating animals. Excavation of the dry beds would also endanger the animals. If excavation of a wetland bed is necessary in order to artificially deepen a wetland, it may be less detrimental to the fauna to do so while water is present. While many of the aestivating animals are mobile and could easily recolonize an excavated wetland, others rely on passive dispersal (e.g. crustaceans) and would take much longer to recolonize.

Aquatic fringing vegetation grades into terrestrial vegetation surrounding wetlands and should be preserved for animals with non-aquatic adults to use as habitat for feeding, breeding and shelter. For example, adult odonates sometimes use neighbouring forests for shelter during the dry months (Fraser 1955, Gambles 1960 and Kumar 1972). These areas of terrestrial vegetation would also function as buffer zones which would act as barriers to adult chironomid swarms (see Pinder *et al.* 1991). In addition, avian and mammalian fauna (e.g. bandicoots) are often associated with bush surrounding wetlands, often using wetland invertebrates as a food source (L. Thomas pers. comm.).

The potential for rehabilitation of wetlands is good. Because of the rigours imposed by mediterranean-type climates, the plant and animal communities of these regions display an exceptional capacity to recover after disturbance (Dell *et al.* 1986). With regard to the wetlands of metropolitan Perth, the adaptations to seasonal drying and general mobility of the fauna are likely to result in rapid recolonization of rehabitliatied wetlands. The major factor involved in rehabilitation is reduction of nutrient inputs. North Lake was subject to almost continuous cyanobacterial blooms in 1988-89, and during 1990 a drain responsible for a large nutrient input was diverted elsewhere. Observations of North Lake during 1991 and 1992 indicated lower water levels and periods without severe cyanobacterial blooms, and the appearence of filamentous green algae. Brugam (1978) documented similar abrupt changes in the trophic state of a small wetland. The rapid transformation in North Lake should encourage attempts at rehabilitation through nutrient reduction in other urban wetlands in Perth. Wetlands with larger volumes would not be expected to alter so suddenly (Brugam 1978), but most of the wetlands on the Swan Coastal Plain are not large by world standards.

Habitat heterogeneity promotes higher species diversity (Westman 1986) and hence, conservation of a mosaic of wetland types would conserve invertebrate species richness on the Swan Coastal Plain. It is probably most productive to preserve wetland structure (especially vegetation) and rely on self regulation of wetland systems to preserve processes. The major problem with this is the recognition of different wetland types. Semeniuk

(1987) devised a geomorphic method of wetland habitat classification and used it to identify suites of wetlands on the Swan Coastal Plain (Semenuik 1988). Features used to identify these suites were water permanence, shape, size and salinity. However, within each suite, a range of lakes, swamps and waterlogged soils can exist, with differing vegetation structures. This means that this system is not appropriate for identifying wetland types in relation to the aquatic fauna. A more recent system (Semeniuk *et al.* 1990) devised to classify wetland vegetation patterns and floral assemblages shows more promise as a means of identifying wetland types in relation to the invertebrates. As yet there has been no attempt at a widespread application of this classification system to the Swan Coastal Plain. Davis *et al.* (1993) found that of 40 wetlands (permanent and seasonal, predominantly open water habitats) physicochemical data and invertebrate fauna enabled the wetlands to be classified into coloured wetlands, saline wetlands and a gradation from oligotrophic to hypertrophic wetlands. Evidence from the present study suggests that differences in wetland vegetation also influence invertebrate community composition. For example, a large number of hemipteran taxa were found in the closed canopy Murdoch Swamp, but not in the other five wetlands. Ideally, a survey of all the Swan Coastal Plain wetlands with regards to colour, salinity, trophic state and vegetation patterns and assemblages, is needed to more completely assess how many wetland types exist. This information is required to ensure the conservation of all types of wetlands on the Swan Coastal Plain. In the absence of more information it is probably wise to conserve as many of the remaining wetlands as possible. The danger is that less recognizable wetlands (swamps and damplands) will be lost. The continued expansion of the urban area is directly responsible for loss of wetlands and degradation of the wetlands that become engulfed in the urban area. Provision of water to the inhabitants of these additional urban areas also results in loss of wetland area by reducing groundwater levels. In the long term, conservation of wetlands requires that limits to population growth in Perth are addressed.

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Appendix 1 Physical and chemical parameters for the six wetlands. (Temp = temperature, Cond = conductivity, Chl a = Chlorophyll a, TP = Total phosphorus, TN = Total nitrogen).

Jandabup Lake

Date	Depth	Temp	Cond	pH	Chl a	TP	TN
	m	^{o}C	$mScm^{-1}$		mgm^{-3}	mgm^{-3}	mgm^{-3}
11 Aug 88		15.8	0.557	6.06			
27 Aug 88							
19 Sep 88		21.0	0.477	6.03			
10 Oct 88	1.11	21.0	0.480	6.15			
31 Oct 88	1.07	22.5	0.541	7.21		16	776
22 Nov 88	0.94	25.0	0.572	6.28	18		
15 Dec 88	0.79	20.2	0.761	5.69	8	36	611
06 Jan 89	0.71	25.0	1.083	5.93	6		
25 Jan 89	0.60	22.0	1.258	7.83	7	1	1552
16 Feb 89	0.47	24.5	1.506	7.76	5		
09 Mar 89	0.34	26.0	1.971	7.23	9	13	2941
29 Mar 89	0.13	28.0	3.310	7.03	18		
20 Apr 89	0.13	19.0	1.479	7.67	19		
11 May 89	0.17	19.5	1.049	7.86	31	107	2594
30 May 89	0.50	15.8	0.548	6.84		65	645
19 Jun 89	0.57	12.0	0.589	7.45	5	54	879
05 Jul 89	0.65	11.0	0.502	6.67	6	86	997
31 Jul 89	0.80	14.5	0.357	6.37	9		
21 Aug 89	0.96	15.0	0.395	6.78	8	92	1070
11 Sep 89	0.86	20.8	0.440	7.11	9		

Bartram Swamp

Date	Depth	Temp	Cond	pH	Chl a	TP	TN
	m	^{o}C	$mScm^{-1}$		mgm^{-3}	mgm^{-3}	mgm^{-3}
11 Aug 88							
27 Aug 88							
19 Sep 88		18.0	0.345	6.51			
10 Oct 88	1.05	19.0	0.332	6.62			
31 Oct 88	1.00	20.5	0.356	6.79	5	688	1482
22 Nov 88	0.90		0.417	6.84	7		
15 Dec 88	0.66	20.0	0.661	6.66	8	676	4871
06 Jan 89	0.43	20.7	1.106	7.36	33		
25 Jan 89	0.25	33.7	1.801	7.82	122	431	6423
16 Feb 89	---------------------dry---------------------						
09 Mar 89	---------------------dry---------------------						
29 Mar 89	---------------------dry---------------------						
20 Apr 89	---------------------dry---------------------						
11 May 89	---------------------dry---------------------						
30 May 89	0.13	16.8	0.086	7.20		576	8633
19 Jun 89	0.03						
05 Jul 89	0.03						
31 Jul 89	0.40	14.3	0.763	6.99	13	179	2360
21 Aug 89	0.46	14.5	1.189	7.07	9	111	6727
11 Sep 89	0.45	21.0	1.968	7.14	11		

cont...

Murdoch Swamp

Date	Depth m	Temp ^{o}C	Cond $mScm^{-1}$	pH	Chl a mgm^{-3}	TP mgm^{-3}	TN mgm^{-3}
11 Aug 88							
27 Aug 88							
19 Sep 88		16.0	0.384	5.14			
10 Oct 88	3.08	18.8	0.359	5.52			
31 Oct 88	2.94	18.0	0.349	5.40	2	24	3694
22 Nov 88	2.83	19.4	0.497	5.51	8		
15 Dec 88	2.68	18.0	0.459	6.61	13	77	1671
06 Jan 89	2.52	23.0	0.534	5.01	3		
25 Jan 89	2.30	21.5	0.615	6.08	13	32	3671
16 Feb 89	1.98	22.5	0.616	6.22	4		
09 Mar 89	1.95	22.0	0.662	6.26	18	42	2024
29 Mar 89	1.73	18.5	0.620	6.27	12		
20 Apr 89	1.66	17.0	0.562	6.20	158		
11 May 89	1.58	14.5	0.522	6.23	78	148	3254
30 May 89	1.77	13.5	0.590	5.30		70	2959
19 Jun 89	2.04	13.0	0.715	6.09	6	40	1363
05 Jul 89	2.24	9.0	0.593	5.57	9	148	3532
31 Jul 89	2.62	11.6	0.403	6.15	11		
21 Aug 89	2.78	13.5	0.398	5.74	10	105	2344
11 Sep 89	2.72	14.2	0.407	5.20	10		

Nowergup Lake

Date	Depth m	Temp ^{o}C	Cond $mScm^{-1}$	pH	Chl a mgm^{-3}	TP mgm^{-3}	TN mgm^{-3}
11 Aug 88							
27 Aug 88							
19 Sep 88		20.5	1.640	7.57			
10 Oct 88	4.01	20.5	1.560	7.52			
31 Oct 88	3.98	22.7	1.648	7.43		34	141
22 Nov 88	3.89	22.0	1.661	7.36	30		
15 Dec 88	3.80	22.5	1.917	6.83	196	1823	20634
06 Jan 89	3.62	23.0	2.300	6.98	43		
25 Jan 89	3.58	22.5	2.320	7.93	41	80	2329
16 Feb 89	3.35	23.0	2.210	7.77	37		
09 Mar 89	---------------- not sampled ----------------						
29 Mar 89	---------------- not sampled ----------------						
20 Apr 89	---------------- not sampled ----------------						
11 May 89	---------------- not sampled ----------------						
30 May 89	3.36	15.5	1.381	7.31		313	1935
19 Jun 89	3.46	10.3	1.834	7.83	32	82	2785
05 Jul 89	3.46	11.0	1.652	7.93	16		
31 Jul 89	3.66	14.2	1.521	7.01	283		
21 Aug 89	3.78	15.0	1.466	7.76	12	50	879
11 Sep 89	3.80	18.7	1.727	7.79	10		

cont...

North Lake

Date	Depth m	Temp °C	Cond $mScm^{-1}$	pH	Chl a mgm^{-3}	TP mgm^{-3}	TN mgm^{-3}
11 Aug 88			0.631	7.09			
27 Aug 88		15.0					
19 Sep 88		19.0	0.618	6.81			
10 Oct 88	3.37	20.5	0.599	7.46			
31 Oct 88	3.28	20.5	0.601	7.08	64	330	2353
22 Nov 88	3.20		0.628	8.09	197		
15 Dec 88	3.01	22.0	0.726	6.90	87	332	6024
06 Jan 89	2.85	23.0	0.802	9.23	202		
25 Jan 89	2.77	24.8	0.831	9.16	107	229	2777
16 Feb 89	2.59	25.0	0.807	9.60	84		
09 Mar 89	2.58	25.0	0.776	9.74	87	160	4024
29 Mar 89	2.41	23.5	0.776	9.45	67		
20 Apr 89	2.33	22.0	0.800	9.16	110		
11 May 89	2.34	18.5	0.808	8.87	31	305	3972
30 May 89	2.51	17.0	0.666	7.02		345	3166
19 Jun 89	2.55	15.3	0.765	7.66	24	228	1905
05 Jul 89	2.63	14.8	0.670	7.57	37	875	6156
31 Jul 89	2.74	16.0	0.626	7.44	59		
21 Aug 89	2.86	16.8	0.574	7.35	54	179	2418
11 Sep 89	2.90	20 0	0.620	7.26	25		

Thomsons Lake

Date	Depth m	Temp °C	Cond $mScm^{-1}$	pH	Chl a mgm^{-3}	TP mgm^{-3}	TN mgm^{-3}
11 Aug 88			1.623	7.31			
27 Aug 88		14.2					
19 Sep 88		18.0	1.290	7.16			
10 Oct 88	1.55	20.0	1.720	7.45			
31 Oct 88	1.53	19.5	1.602	7.17	10	294	2235
22 Nov 88	1.45	17.0	1.844	6.78	5		
15 Dec 88	1.35	19.0	2.260	6.56	22	214	3200
06 Jan 89	1.23	22.5	2.820	6.82	12		
25 Jan 89	1.09	23.0	3.040	7.70	56	476	3647
16 Feb 89	0.92	20.5	3.090	8.31	19		
09 Mar 89	0.89	20.5	3.550	8.31	23	140	2682
29 Mar 89	0.74	18.5	3.950	8.23	18		
20 Apr 89	0.66	19.0	4.740	8.32	64		
11 May 89	0.67	15.5	4.720	8.26	1910	1799	42812
30 May 89	0.90	14.5	3.430	8.12	2383	1945	42812
19 Jun 89	0.80	12.5	3.330	7.66	14	160	6727
05 Jul 89	0.85	11.2	3.300	8.01	10	151	5760
31 Jul 89	1.11	14.3	2.570	8.04	22		
21 Aug 89	1.17	14.2	2.228	7.68	14	65	3312
11 Sep 89	1.35	18.8	2.220	7.25	11		

Appendix 2.1 Relative abuandance expressed as a percentage of the total number of each taxa present c each sampling occasion in Jandabup Lake.

Taxa	Sampling occasion																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Tricladida spp.															11	89				
Nematoda spp.											1			1	97	1				1
Oligochaeta spp.		1	1			7	0	21	9	18	26	9	0	6	2	0	0			0
Hirudinea spp.											25			50		25				
Sphaerium sp 1												81	7	9			2			
Ferrissia spp.				78		6														17
P. georgiana	1	10	12	10		25	1	1	1	2	13				1	2	2	7	1	12
H. duryi	100																			
Hydracarina spp.	4	28	13	22		3		2				2			15		2	3		5
Orabatidae spp.	12	4	13	11	13	6	1	11	0	16	0				2	0	6	0	5	0
Sididae sp 1							0	2	17	18	64									
Chydoridae spp.	7	8	22	7	9	15	3	2	0	8	1				1	0	4	0	2	12
Macrothricidae spp.	6					7	0		25	10	36	16								
Daphnia spp.															0	4		64	31	0
Simocephalus sp 1	5	4	15	10	20	27	3	0	0					1	1		5			10
B. australis	7	4	14	8	9	12	1								1	11	21	2	5	4
C. baylyi	16	3	4	5	4	2	1	3				46	1					4	8	3
S. aculeata	0	1	0			3	0	2	0	7	5	58	25							
G. maia	21	5	2	3			1	4		42		4		5		2	2	1		8
L. mowbrayensis	4	24		1	60	9		3												
C. novaezelandiae	0						0	2	33	42		23	0							
A. woroora	5	2	2	2	16	6								19	9	9	16	1	7	7
Calanoidea spp.	3	2	1	1	28	12	0					1	0	1	1	15	15	9	7	7
Cyclopoidea spp.													25	20	52					2
Harpactacoidea spp.	0	6			7	11	2		11	6	17	41								
P. palustris	6	4	13	1	6	11	10	5	10	7	2	1			1	1	7	4	1	10
A. subtenuis	1	1	7	2	5	3	0	1		1	0	34	8	5	5	7	10	5	3	2
C. quinquecarinatus	52	48																		
Cloeon sp 1					8	1	15			40	36									0
T. tillyardi						12	1	3	1	75	7	1	0							
X. erythroneurum	1	2	1	11	17	19	17		26	4	2									
I. aurora							43	57												
A. analis	13	17	35	4	1											1	2	5	10	14
A. annulosus	4			8	40	32												16		
A. io				14	71	14														
A. brevistyla		2						36	54						9					
H. papuensis	1	2	58	24	12			3												
P. affinis											100									
H. tau				9	15	47	12		12							6				
O. caledonicum								50	50											
D. bipunctata						100														
A. nigrescens																	100			
Anisoptera juveniles	0	2		7	14	7	4	5		2	2	1	1	3	8	5	18	3	1	19
Zygoptera juveniles	3	0		7	7	12		19		2					5	7	14	2		21
Nethra sp 1	43	57																		
Veliidae sp 1	100																			
Mesoveliidae sp 1					8		15	77												
Diaprepocoris spp.	0	3	49	18	1	10	6	2	0		1								1	10
S. truncatipala	1		6	6	2	10	4	2	29	15	22								2	
A. eurynome	2							70	14		14									
A. parvipunctata												50	50							
M. robusta	7	8	13		8	5	1		0				1	2	7	26	9	0	13	1
Corixidae juveniles	1	4	12	19	50	4	1				0	0	0			0	1	2	2	3
Enithares sp 1	100																			
Anisops spp.	2	6	55	1	0	6				8		1				1	3	2	3	12
Tipulidae spp.														75			25			
Culicidae spp.	100																			
Thaumeliidae spp.															100					
Chironomidae spp.	2	3	6	6	6	4	3	3	7	26	13	1	0	2	5	12	1	0	0	1
Ceratopogonidae spp.	1							3	2					52	30	8	3			
Stratiomyidae spp.							23	77												
Diptera pupae	18	0	30	1	9	17			1	11	1	1			6	1	1		1	2
Lepidoptera spp.	1			1		6	14	63	15	1										
A. globosa	1	3	7	20	0	2	1	9	1	19	17	0	0			0	1	6		14
E. turgidus	6	4	26	1				38		11								4		9
N. fulva	1	1	18	1	0	10	13	6	7	18	11	1	1	0			2	1	1	10
T. australis	0			1	1	2	23	42	8	5	1					6	4	4		2
Oecetes sp 1	0			1	1	38	3	9			3	27	11	4	1		3			1

cont...

Taxa	Sampling occasion																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Haliplidae sp 1 L									100											
Haliplus sp 1 A	52	48																		
Hyphydrus elegans L						100														
Uvarus pictipes A								100												
Antiporus spp L	15	34	23	6												6		6		11
Antiporus sp 1 A																	100			
Megaporus spp L	5		59		12	24														
Megaporus sp 2 A									100											
Megaporus howitti A										100										
Sternopriscus sp 1 L							50	50												
Sternopriscus sp 2 L	1		3		22	25	14	20		13	1									
S. browni A								100												
Sternopriscus sp 6 A	12	4	43	37				3												
S. multimaculatus A														14	14	28	28	14		
N. darwini L	8	49	44																	
L. lanceolatus L																33	67			
L. lanceolatus A										100										
Laccophilus sp 1 L	100																			
C. tripunctatus L	19	43	6	3														14	6	9
H. scutellaris L																	33			67
S. pulchellus A	100																			
Dytiscidae sp2 L																		100		
Hydrochus sp 2 A	11	4	23			0		2	5	12					17	9	12	0	6	
Berosus sp1 L			100																	
Berosus sp2 L										100										
Berosus sp4 L					4	44	30	22												
Berosus discolor A	6	7	45	3	1	1											2	7	14	15
Berosus sp 3 A									67		33									
P. pigmaeus A							33	33								33				
Enochrus sp 1 A										25	25					25	25			
Enochrus sp 2 A										100										
Hydrophilidae sp 1 L	44															28	28			
Hydrophilidae sp 4 L				60	40															
Helodidae sp 1 L	27		73																	
Hydraena sp 1 A					100															
Staphylinidae sp1 L																		100		
Curculionidae sp 2 A	11	15	9	3													22	6	25	9
Curculionidae sp 5 A		100																		
Ptilodactylidae sp1 L			100																	
Chrysomelidae sp 4 A			100																	
Chrysomelidae sp 3 A		2	97				1													
Limnichidae sp 1 A	35	6	55			0													3	0

Appendix 2.2 Relative abundance expressed as a percentage of the total number of each taxa present on each sampling occasion in Bartram Swamp.

Taxa	Sampling occasion																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Tricladida spp.						100														
Oligochaeta spp.						-	94	4	2											
Hirudinea spp.					67	12	15	3	3											
<u>Ferrissia</u> sp. 1			23	2	2	36	23	9	4										1	0
<u>Glyptophysa</u> sp 1			23	28	11	17	5	3	0									0 2	11	
Hydracarina spp.			34	15	19	26	1	0	0									1	3	1
Orabatidae spp.			62		38				0											
Conchostraca sp 1			72	1														9	7	10
Chydoridae spp.			74	16	6	4														
Moinidae spp.			95	1		2			2											
<u>Daphnia</u> spp.																		47	49	4
<u>Simocephalus</u> sp 1			5	7	8	45	24	1												10
<u>B. australis</u>			39	32	14	7												3	2	5
<u>C. baylyi</u>			27	4	16	14			27											12
<u>S. aculeata</u>			70	26					2										0	2
<u>L. mowbrayensis</u>							48		52											
<u>A. woroora</u>			25	39	15	14	2	0											3	3
Calanoidea spp.			11	1	6	7	1	14	5									5	28	23
Cyclopoidea spp.			4	5	3	2	1	2	48									31	2	1
Harpactacoidea spp.																		67		33
<u>P. palustris</u>			42	21	3	14	10	6	1									0	1	2
<u>A. subtenuis</u>			13	51	4	22	4	4	1									0	2	0
<u>P. acutitelson</u>			88	5		0		5											1	2
<u>C. quinquecarinatus</u>																		50	50	
<u>Cloeon</u> sp 1						14	4	79	2										1	
<u>T. tillyardi</u>								50	50											
<u>X. erythroneurum</u>						26	53	5	16											
<u>A. pusillus</u>			100																	
<u>A. analis</u>			22	9	1	1	3											5	9	51
<u>A. annulosus</u>					10	70			20											
<u>A. io</u>			36	36	5	18		5												
<u>A. brevistyla</u>							13	75	13											
<u>H. papuensis</u>			27	12	17	15	27	2												
<u>H. tau</u>			7				7	7	71											7
Anisoptera juveniles					1	98		1												
Zygoptera juveniles								100												
<u>Nethra</u> sp 1																			100	
<u>Saldula</u> sp 1						100														
Mesoveliidae sp 1			10	67	12	12														0
<u>S. truncatipala</u>						6	6	7	81											
<u>A. eurynome</u>								4	96											
<u>A. parvipunctata</u>									100											
<u>M. robusta</u>				1		66	7		23						3				1	
Corixidae juveniles				1	23	33	8	6	29											
<u>Ranatra</u> sp 1						8	38	46	8											
<u>Anisops</u> spp.			13	9	18	16	11	5	27									0	0	1
Sisyridae sp 1			28	55		17														
Tipulidae spp.						100														
Culicidae spp.			44			56														
Thaumeliidae spp.						41		3										55		
Chironomidae spp.			9	24	6	15	13	6	19						0			1	1	6
Ceratopogonidae spp.									100											
Stratiomyidae spp.							70	2	28											
Tabanidae spp.								100												
Ephydridae spp.				1	72	27									1					
Diptera pupae			7	5	42	35	7	1	1											2
Lepidoptera spp.			5	4		71	18								1					1
<u>A. globosa</u>						100														
<u>E. turgidus</u>								100												
<u>N. fulva</u>				8			13													79
<u>T. australis</u>			2	6	12	47	31	1	0											1
<u>Oecetes</u> sp 1				2		5	22		5											67
<u>Hyphydrus elegans</u> L				38	9	1	4	28	20											
<u>Hyphydrus elegans</u> A			4				4	4	88											
<u>Liodessus dispar</u> A						33													33	33
<u>Liodessus inornatus</u> A															100					
<u>Antiporus</u> spp L			11	50																39
<u>A. femoralis</u> A				100																

cont...

Taxa	Sampling occasion																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Antiporus sp 1 A			25	50				25												
Megaporus sp 1 L				83		17														
M. solidus A															50					50
Sternopriscus sp 1 L				20		80														
S. multimaculatus A						6	86		6											
Sternopriscus sp 2 A																				
N. darwini L				100																
N. darwini A				25					75											
S. pulchellus L			13																69	19
L. lanceolatus L																		12	47	41
Rhantus suturalis L																			100	
Rhantus suturalis A															100					
Copelatus sp 1 L																		100		
C. tripunctatus L				60		40														
Cybister sp 1 L							100													
H. scutellaris L			13	67		20														
H. scutellaris A								100												
Hydrochus sp 2 A						11		67							22					
Berosus sp1 L				75	13	13														
Berosus sp3 L			2																	98
Berosus sp4 L				5																95
Berosus sp 3 A															100					
Berosus sp 4 A																			50	50
Berosus sp 6 A				10														60	20	10
P. pigmaeus A					6	1	1	7							86					
Anacaena Sp 1 A					100															
Enochrus sp 1 A															100					
Enochrus sp 3 A						100														
L. macer A						4		8							88					
Hydrophilidae sp 1 L				4		4												4	7	82
Hydrophilidae sp 4 L																				100
H. latipalpus A																				100
Helodidae sp 1 L			22	37	28	12														0
Curculionidae sp 6 A															100					
Curculionidae sp 8 A				100																
Helminthidae sp1 L						100														
Octhebius sp 1 A						3									97					
Sphaeriidae sp1 L						100														
Chrysomelidae Sp 5 A				100																
Chrysomelidae sp 1 A															100					

Appendix 2.3 Percent of the total number of each taxa present on each sampling occasion in Murdoch Swamp.

Taxa	Sampling occasion																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Nematoda spp.															100					
Oligochaeta spp.									13	13	2	0	66	6						
Hirudinea spp.					13		13							75						
Glyptophysa sp 1			89		11															
Hydracarina spp.			8	12	42		10	0	0		1	4	1	1	5	4	0	1	9	2
Orabatidae spp.			16		4	4	2	10	16	1	2	1			2	1	1	32	6	1
Chydoridae spp.			9	11	51	16	1	5	0					5		1	2			
Moinidae spp.			19	4	18	9	2	6	2	1	2	12	3	2	1	3	2	1	4	9
Daphnia spp.				1															92	7
Simocephalus sp 1								49				47	4							
B. australis			5	5	0		2	58	10						3	1	4	6	4	1
C. baylyi			36	12	22	3	2	4	4		0		0	4	2	5	0	0	3	2
S. aculeata			6								94									
C. novaezelandiae						2		13			0	14	33	22	8	7	1			
A. woroora			19	15	32	5	1	20	3								1	2	1	0
Calanoidea spp.			7	9	14	16	3	13	5	1	1	5	2	2	8	3	5	4	2	2
Cyclopoidea spp.			11	4	15	4	0	18	3	2	3	24	5	4	2	1	2	3	0	0
Harpactacoidea spp.				3									97							
P. palustris			66			34														
A. subtenuis			14	22	5			8			20						3	10		20
P. acutitelson							100													
Cloeon sp 1			1	0	0		0	6	17	7	1	8	1	7	3	45	3	0	0	1
A. cyane														20	40	40				
X. erythroneurum								50				6		19		13	13			
I. aurora						1		7	63	21	8	1								
I. heterosticta							1								2	90	5			2
A. analis			45	39	2	1												1	3	10
A. io					50	7	10	25	8											
A. brevistyla								19	38	19	5					19				
H. papuensis					26				35		39									
P. affinis								50		25						25				
H. australiae												100								
H. tau								36		9		14	14	23		5				
D. bipunctata							100													
Anisoptera juveniles			6	41	14		1	1	1			1	3	4	15	6	6			
Zygoptera juveniles			0	2	2		0	14	8			1	1		1		1	73	1	
Nethra sp 1																			100	
Leptopodidae sp 1						0	1	8	47	2	8	4	4	3	6	12	6			
Saldula sp 1					50	50														
Hydroimetridae sp 1									80							20				
Gerridae sp 1													67			17	17			
Mesoveliidae sp 1			52	4		0		2	3	0	1	0		1	1	25	6	2	0	1
S. truncatipala					15	15		12	18	3	18			18						
A. eurynome					6					38	25	25			6					
M. robusta					0	89									6	4	0	0		
Corixidae juveniles			20	78	1			1												
Ranatra sp 1									100											
Nychia sp 1			76	24																
Anisops spp.				10	5	10	5	15	30	10					5	10				
P. brunni											100									
Tipulidae spp.				67											25	8				
Culicidae spp.			0	0	0			1	18	25	2	25	20	9	1					
Chironomidae spp.			10	3	18	4	2	5	4	6	14	9	7	13	2	1	0	2	1	0
Ceratopogonidae spp.			4	0	8	5	4	27	22	13	1	7	3	3	0	0		0	3	0
Stratiomyidae spp.											67									33
Empididae spp.			100																	
Ephydridae spp.															26	1		25	46	2
Diptera pupae			1	14		15	2	4	2		1	5	5	11	3	17	1		19	
Lepidoptera spp.				13	3	46	13	14				3		9						
T. australis			1	34	25	2	1	5	5	5	1	0	1		1	7	1	8	4	1
Oecetes sp 1				3	33	3	3									58				
Hyphydrus elegans L				3	79	3	1	8	6											
Hyphydrus elegans A									67	17	17									
Liodessus dispar A											67							33		
Liodessus inornatus A			2		5	13	1	1	5				6	5	26	23	11	3		
Gibbidessus sp 1 A																			100	
Antiporus spp L			38	16	20	1											2		16	8
A. femoralis A				50		50														

cont...

Taxa	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Sampling occasion																			
Antiporus sp 1 A			7		3	10	10	35							3				32	
M. solidus A									100											
S. multimaculatus A						100														
Sternopriscus sp 2 A								100												
N. darwini A										100										
S. pulchellus L				23													6	12	59	
Rhantus suturalis L				100																
Copelatus sp 1 L																	33	67		
C. tripunctatus A									100											
H. scutellaris L					50			50												
Hydrochus sp 2 A			22												22	55				
Berosus sp 3 A																				100
Berosus sp 4 A						100														
P. pigmaeus A					4	44			28	5					5	11	2	2		
Enochrus sp 3 A					2	17		2	10			5	10		7	48				
H. tenuistriatus A					13										62	25				
L. macer A					100															
Hydrophilidae sp 2 L					25	25					50									
Hydrophilidae sp 3 L			8	75				8		8										
H. albipes A									100											
Helodidae sp 1 L			29	0	1		0										1	19	44	6
Hydraena sp 1 A															1	1	2	47	50	
Staphylinidae sp1 L															100					
Octhebius sp 1 A								20	80											
Curculionidae sp 7 A						100														
Curculionidae sp 10 A				100																
Helminthidae sp1 L			100																	
Ptilodactylidae sp1 L			100																	
Sphaeriidae sp1 L				100																
Gyrinidae sp 1 A													100							
Chrysomelidae sp1 L			100																	

Appendix 2.4 Relative abundance expressed as a percentage of the total number of each taxa present on each sampling occasion in Nowergup Lake.

Taxa	Sampling occasion																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hydra spp.																				100
Tricladida spp.															100					
Nematoda spp.								100												
Oligochaeta spp.															100					
Hirudinea spp.				3	3			71	13								11			
Sphaerium kendricki																	33	33	33	
Gyrulus sp 1																	100			
Glyptophysa sp 1																				100
P. acuta			2	2	9	31	11	12									0	2	0	31
L. columella				29				22	16									33		
Hydracarina spp.			17	40	9		2								0	1	12	7	1	10
Orabatidae spp.			24	27	14		15			2					4		8		6	
Chydoridae spp.			14	1	18	2	1	7								3	3	4	0	48
Daphnia spp.			1	0	8	1	4								0	1	2	19	48	18
C. baylyi			8	2	10	6	11	28	22							1	0	3	1	9
S. aculeata			5	2	2	1	9	25	31	5					0	3	2	6	6	2
C. novaezelandiae				0	2		9	15	18	54					0	2		1		
A. woroora			9	26	12	37											9	1		6
Calanoidea spp.			95												5					
Cyclopoidea spp.			2	6	28	4	40	3							0	8	9	0		1
Harpactacoidea spp.															8	50	40	0	2	
P. palustris			15	5	32	5		2							2	3	7	5	1	23
A. subtenuis			17	9	22	12	10	11	0						0	0	0	6	4	8
C. quinquecarinatus																			14	86
P. australis			5		2											1	4	4	12	72
A. cyane																				100
X. erythroneurum			2		23	10	15	26	22	3										
I. heterosticta							12	12	70											7
A. pusillus					100															
A. analis			38		5	5		4										7	7	36
A. annulosus			8		5	8	36	32	8									3		
A. io							75	25												
A. brevistyla									6									50	13	31
H. papuensis			12	4		24	20	27	12											
H. tau					100															
Anisoptera juveniles			13		75															13
Zygoptera juveniles					2		91	3										2		
Leptopodidae sp 1									100											
Saldula sp 1			1		99															
Hydroimetridae sp 1																				100
Veliidae sp 1																				100
Mesoveliidae sp 1				22	66															11
S. truncatipala								93	7											
A. eurynome			10	10		5	28	25	3	12							4	2		
M. robusta			10	21	16	5	22	18	1						0	1	6	0	1	1
Corixidae juveniles			45	1	19	19	8	0	0										8	
Enithares sp 1																				100
Anisops spp.			1	3	24	0	7	57	1	2						0	2			3
Tipulidae spp.															100					
Culicidae spp.															100					
Psychodidae spp.															3	97				
Chironomidae spp.			31	3	8	5	9	14	1	0					1	2	8	6	3	7
Ceratopogonidae spp.															66		34			
Stratiomyidae spp.				3	11	4	3	68	9						0	0	1	1		
Tabanidae spp.															6	12	43			39
Ephydridae spp.						90													1	9
Diptera pupae			3	8	42		3	23	1						3		10	1		6
Lepidoptera spp.			62					43									45			3
T. australis			24	5	9	12	30	5	2	0						12			0	
Hyphydrus elegans L				52	6	2	32	4												
Hyphydrus elegans A						31				38										31
Liodessus dispar A					100															
Liodessus inornatus A															100					
Antiporus spp L			53	23														7		18
A. femoralis A			30		40										20					10
A. gilberti A				100																
Antiporus sp 1 A																	100			
Megaporus spp. L					100															

cont...

Taxa	Sampling occasion																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Sternopriscus sp 2 A								100												
N. darwini L																	100			
L. lanceolatus L																	13	50	38	
L. lanceolatus A						100														
Rhantus suturalis L																100				
C. tripunctatus L			38	13														13	13	25
H. scutellaris L			6	23	17		10											6	17	23
Hydrochus sp 2 A															100					
Berosus sp4 L									100											
Berosus sp5 L			2	2		77	3	12	2	2										
Berosus discolor A				100																
Berosus sp 4 A				17											17		66			
Berosus sp 6 A				50											50					
Paracymus pigmaeus A			5		68	1	13	10							1	0				2
Enochrus sp 1 A					98															2
Enochrus sp 2 A																	100			
Enochrus sp 3 A			7				12									44	15	22		
H. tenuistriatus A			8		47			13								24				8
Limnoxenus macer A					50											25	25			
Hydrophilidae sp 3 L							19										25	44	5	7
Helodidae sp 1 L																		33	33	33
Hydraena sp 1 A				50											50					
Ochthebius sp 1 A															100					
Curculionidae sp 2 A																100				
Chrysomelidae sp 3 A						93									7					

Appendix 2.5 Relative abundance expressed as a percentage of the total number of each taxa present on each sampling occasion in North Lake.

Taxa	Sampling occasion																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Tricladida spp.								100												
Nematoda spp.								20	80											
Oligochaeta spp.	0	5			10		4		30			2	0	25	8	5	19	0	0	
Hirudinea spp.					8	29	11	2	5	20		0		7				0	17	
Glyptophysa sp 1										0		1				0	1	1	18	79
Physa acuta	1	1	35	21	38	2	0	1		0	0									
Lymnaea columella			96													3	1			
H. duryi	1	8	87			0	4				1									
Hydracarina spp.	14	9	15	39	6	2	0	0		0	0	0					1	6	6	1
Orabatidae spp.	68	11	4									1			2				14	
Chydoridae spp.	8	11	11	25	3											1	2	15	10	14
Daphnia spp.	0														0	0	0			99
S. aculeata	22	7	5	32	3	4	1	2	1			0				0	1	4	15	3
C. novaezelandiae			1		1	1		3		40	39	15	0		0					
Calanoidea spp.	15	0	2	0	0	0	0	0	2	0		0	2	1	2	0	2	17	41	16
Cyclopoidea spp.		13	9	11	7	26	1	1	1	1		1	3		4	1	4	0		19
Harpactacoidea spp.	52	29	5						1								1		12	
P. palustris					7	41			51									1		
A. subtenuis	3	2	7	4	23	31	12	3	0			0	0	0	0	0	1	1	5	7
Cloeon sp 1								100												
T. tillyardi					1	41	10	5	4	6	6	2	1	13	5	5	1	0	0	0
A. cyane														50	50					
X. erythroneurum	1	1	1	0	1	1	1	3	14	1	0	31	4	16	11	7	3	1	0	2
I. aurora						20														80
I. heterosticta							7	1	92											
A. analis																				100
A. annulosus								43	14			14								28
A. io								100												
H. papuensis					71		29													
Anisoptera juveniles				1			1													98
Zygoptera juveniles							3	1	63			20	2	2	6	3	0		0	
Nethra sp 1					100															
Leptopodidae sp 1									91			9								
Veliidae sp 1												100								
S. truncatipala						33		18		9				18		5	9		9	
A. eurynome	6	17	7	35	8	1	1	0	4	0	0		0	1	0	0	1	6	6	6
A. hirtifrons													50			17	17	17		
M. robusta	1	0	5	51	7	7	1	1	1	1	1	0	0	0	0	1	3	10	10	1
Corixidae juveniles	0	1	2	11	7	2	1	1	2	0	0	0	0	0			0	0	0	73
Anisops spp.	2	2		17	9	11	7		13	0	0		2	0	2	1	3	6	1	23
Tipulidae spp.								98								2				
Psychodidae spp.															3		97			
Thaumeliidae spp.										1						1	42	57		
Chironomidae spp.	8	1	4	12	5	8	2	2	4	5	3	1	0	1	3	4	6	1	23	8
Ceratopogonidae spp.								0		91	0	0			0	7				
Stratiomyidae spp.					4		16	75	4	1										
Tabanidae spp.								100												
Empididae spp.															7		93			
Ephydridae spp.				100																
Diptera pupae	1	1	22	32	6	10	3	1		0	1	0			1				7	10
Lepidoptera spp.	1			79	20															
N. fulva																	33			67
T. australis	0	0	0	33	2	2	6	5	1		0	3	0	2	2	2	5	2	2	32
Oecetes sp 1					10		20	57			3			2		2				7
Hyphydrus elegans L			79		1		21													
Hyphydrus elegans A	75	12		5															3	5
Liodessus inornatus A																		100		
Antiporus spp L																				100
A. femoralis A						38											62			
A. gilberti A																	100			
Megaporus spp. L																			90	10
M. solidus A									20								20	20	40	
M. howitti A															33		33		33	
S. browni A						100														
S. multimaculatus A						100														
S. pulchellus L	77	33																		
L. lanceolatus L		2															25	18	56	
Rhantus suturalis L	55			41	1															3

cont...

Taxa	Sampling occasion																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Rhantus suturalis A		100																		
C. tripunctatus L				100																
Cybister sp 1 L					100															
H. scutellaris L	4		11	45	8	9	23													
Berosus sp4 L					100															
Berosus discolor A																				100
Enochrus sp 3 A							100													
H. tenuistriatus A	53	45	2																	
Limnoxenus macer A						100														
Hydrophilidae sp 1 L																			100	
Hydrophilidae sp 3 L		8	5	59	13			7	3								1		4	
Helodidae sp 1 L			100																	

Appendix 2.6. Percent of the total number of each taxa present on each sampling occasion in Thomsons Lake.

Taxa	Sampling occasion 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hydra spp.									28	1			46	25						
Nematoda spp.								100												
Oligochaeta spp.							0	19		1	40		8	17	16					
Hirudinea spp.				1		1		19	6	13	3	35	7	4		5			8	
Ferrissia sp 1					1		60	37	1	2	0									
Glyptophysa sp 1		12	8	1		1	79													
Physa acuta	3	8	0	1	1	1	24	30	7	9	1	7	5	1	0	0	0	1	1	
Lymnaea columella										50	50									
H. duryi			100																	
Hydracarina spp.		42		1			33		10	7		0	3			0	0	3		
Orabatidae spp.				24			51									25				
Chydoridae spp.	60	10	2	4			4	5		1			1		2		2	8	1	
Moinidae spp.			25				19	21				32			1	2				
Daphnia spp.	31	4		0			0	0	1	1				0	0	1	26	5	32	
B. australis	100																			
C. baylyi	7			1		1	2	65	3	3	2			3	14			1		
S. aculeata	33	8	1		1	0	1	1	2	4	2	4	6	8	5	12	4	6	3	
G. maia						3	7	9		14	33				35					
C. novaezelandiae	1	6		0	0	5				13	16	4	45	5	2	4			2	
A. woroora	17	67	2	0	2	7	1	0	0	1	0	0			0	0		1		
M. ambiguosa	20	80																		
Calanoidea spp.	4		0	2	0	0			20		0	4	14	8		3	16	1	28	
Cyclopoidea spp.	8	2				0	5	14	7		7	1	44	2	1	6			4	
Harpactacoidea spp.	0	1	1								1	6		6	79			5		
P. palustris	5	3	9	2	8	15	44	0	0	1		2	0	5		0		5	1	
A. subtenuis	5	6	11	8	8	4	0	1	2	2	0	6	15	5	0	11	2	2	12	
P. acutitelson				14	62	3		4						13					4	
C. quinquecarinatus	100																			
Cloeon sp 1									100											
A. cyane															11	11	34	44		
X. erythroneurum	1	2	0	0		0	3	3	18	4	1	14	42	7	1	1	1	1	1	
I. heterosticta								90		4	7									
A. analis	39	10					51													
A. annulosus		1				13	12	18	26	6		18	7							
A. io							100													
A. brevistyla																		100		
H. papuensis					6	3	68	3				3	14	2	1	1				
A. nigrescens	100																			
Zygoptera juveniles		0	0		0	0	7	22	12	4	17	19	16	3		0			0	
Leptopodidae sp 1				4			32	1	3	9		51								
Diaprepocoris spp.									100											
S. truncatipala						1	82	1	2	6	4				4					
A. eurynome	15	25	4	2	5	2		1	1	15			9	3	9	1			10	
M. robusta	47	9	3	4	1	2	6	13	1	7	1				1		0	4	2	
Corixidae juveniles	43	0	0	2	1	0	15	1	1	1	7	16	2	7	0	0	0	2	1	
Enithares sp 1																		100		
Anisops spp.	5	0	0	4	1	9	11	1	5	22	1	9	4	2	0	0	0	2	25	
P. brunni								6	11	3	17	20	29	8	0		0	5		
Culicidae spp.							21	21	3	5	50									
Chironomidae spp.	3	0	0			0	5	11	12	9	4	1	16	14	10	7	0	9	0	
Ceratopogonidae spp.	21	21	29	2	10			0					13		4				0	
Stratiomyidae spp.						6	38	27	17	11	1									
Ephydridae spp.							100													
Diptera pupae	2	6	0	2	2	0	7	0	15	2	2		47	4	2	9	1			
Lepidoptera spp.							65	25	1	3		2	5							
A. globosa										100										
N. fulva													100							
T. australis				15		2	19		0			19	36	2		3	1		2	
Oecetes sp 1													100							
Haliplus sp 1 A							100													
Hyphydrus elegans L			100																	
Hyphydrus elegans A		100																		
L. inornatus A	100																			
A. femoralis A			100																	
A. gilberti A										50				50						
Megaporus sp 1 L							100													
M. solidus A		100																		
S. multimaculatus A																			100	

cont...

Taxa	Sampling occasion																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Sternopriscus sp 2 A							100													
L. lanceolatus L	100																			
H. scutellaris L							57	17			17								9	
Berosus sp5 L							55			21	4				16			4		
Enochrus sp 2 A															100					
Enochrus sp 3 A		17									17				66					
H. tenuistriatus A	100																			
L. macer A	31						21	49												
Hydrophilidae sp 2 L							100													
Hydrophilidae sp 4 L	60						40													
Helodidae sp 1 L	83	8			8															
Curculionidae sp 2 A	100																			

Appendix 3 Relative biomass (in grams) of invertebrates.

Taxa	Small	Medium	Large	V. large
Hydra	.0000857	.00047		
Oligochaeta	.0000857	.00047	.003	
Nematoda			.0009	
Bivalvia Sphaerium kendricki	.000957	.00048	.0014	
Gastropoda Ferrissia spp	.0005	.001	.002	
Glyptophysa sp 1	.003	.017	.121	.1724
Helisoma duryi	.003	.02	.14	.21
Lymnaea colummella	.003	.017	.121	.10175
Physa acuta	.003	.017	.121	
Gyrulus sp1			.00885	
Planaria spp	.001	.00204	.00408	
Hirudinae spp	.004225	.02586	.6374	
Acarina Hydracarina spp	.000371	.00232	.01075	
Orabatidae spp	.000371			
Cladocera Moinidae spp	.0002	.0003		
Daphnidae Daphnia spp	.0004	.0006	.0008	
Simocephalus spp.	.0004	.0006	.0008	
Chydoridae spp	.0001	.0002		
Macrothricidae spp	.0002	.0003		
Sididae spp	.0003	.0006	.0007	
Ostracoda B. australis	.0002	.0007	.0009	
Alboa woroora	.0002	.0007	.0009	
Cypretta baylyi	.0002	.0004		
Gomphodella	.0002			
S. aculeata	.0002	.0003		
C. novaezelandiae	.0002	.0006	.0008	
L. mowbrayensis	.0002			
M. ambiguosa			.00403	
Copepoda Calanoidea spp.	.00002	.00004	.000165	
Cyclopoidea spp.	.00002	.00004		
Harpactacoidea spp.	.00002	.00004		
Isopoda P. palustris	.0010	.0040	.0110	.02953
Amphipoda A. subtenuis	.0004	.0012	.0080	
P. acutitelson	.00090	.0020	.006425	.0466
Conchostraca Lynceus sp1	.00507	.01317	.03045	
Decapoda P. australis		.09833	.3467	
Ephemeroptera Cloeon sp1	.00017	.0007	.0019	
T. tillyardi	.00014	.0018	.0032	
Hemiptera M. robusta	.0004	.0016	.0030	
Diaprepacoris sp1	.0004	.0050	.0060	
Agraptocorixa eurynome	.0004	.00583	.0225	
A. parvipunctata	.0004	.00583	.01293	
A. hirtifrons	.0004	.00583	.0225	
Sigara truncatipala	.0004	.00583	.01008	
Corixid juvenile	.0004	.00583		
Enitheres sp1			.0415	
Anisops spp.	.00021	.0050	.0190	.0732
Nychia sp1	.00021	.019	.0732	
Plea sp1	.0008	.00223		
Mesovelia sp1	.0002	.0003	.0004	
Veliidae sp1	.0004	.0006		
Nerthra sp1	.0165	.07425		
Ranatra Sp 1	.0120	.03855	.1031	
Saldidae Saldula sp 1	.0006	.0015	.0022	
Gerridae sp1			.01567	
Leptopodidae sp 1	.0002	.0008	.00124	
Hydrometridae sp 1			.0029	
Neuroptera Sisyra sp1	.0002	.001325	.00287	
Diptera Pupa	.0004	.0008	.0016	
Chironomidae	.00012	.0003	.0015	.00245
Tipulidae	.0012	.0024	.0048	
Ceratopogonidae	.00004	.000238	.000375	.0028
Tabanidae	.0003	.0006	.0089	
Empididae	.0006	.0012	.0097	
Culicidae	.0006	.0026	.0053	
Ephydridae	.0006	.0012	.0097	
Thaumeliidae	.0001	.0003	.00055	
Stratiomyidae	.000325	.000975	.0089	.03808
Psychodidae	.0006	.0012	.0097	
Lepidoptera	.000229	.0035	.0339	
Trichoptera A. gibbosa	.000018	.00046	.0005	
Notalina fulva	.00025	.00268	.01458	
Ecnomus turgidus	.0005	.0023	.0062	

cont...

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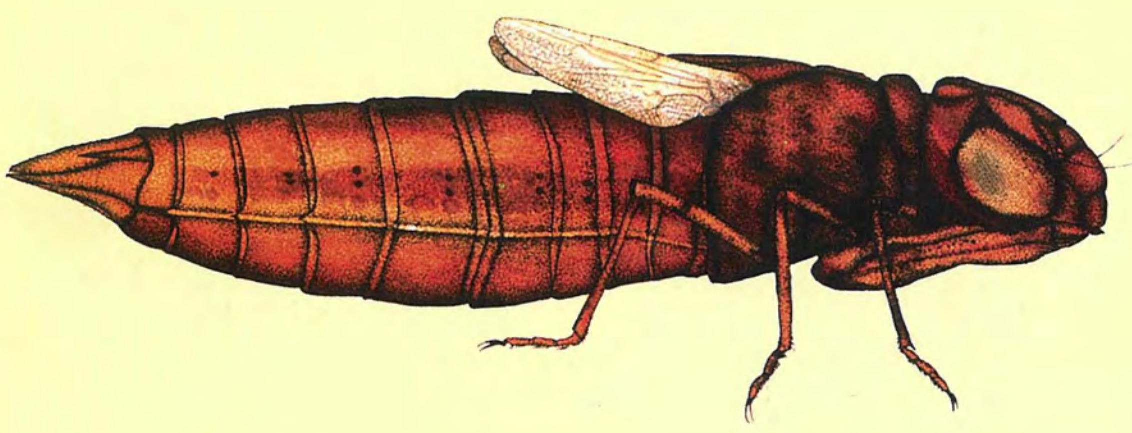
of Western Australia



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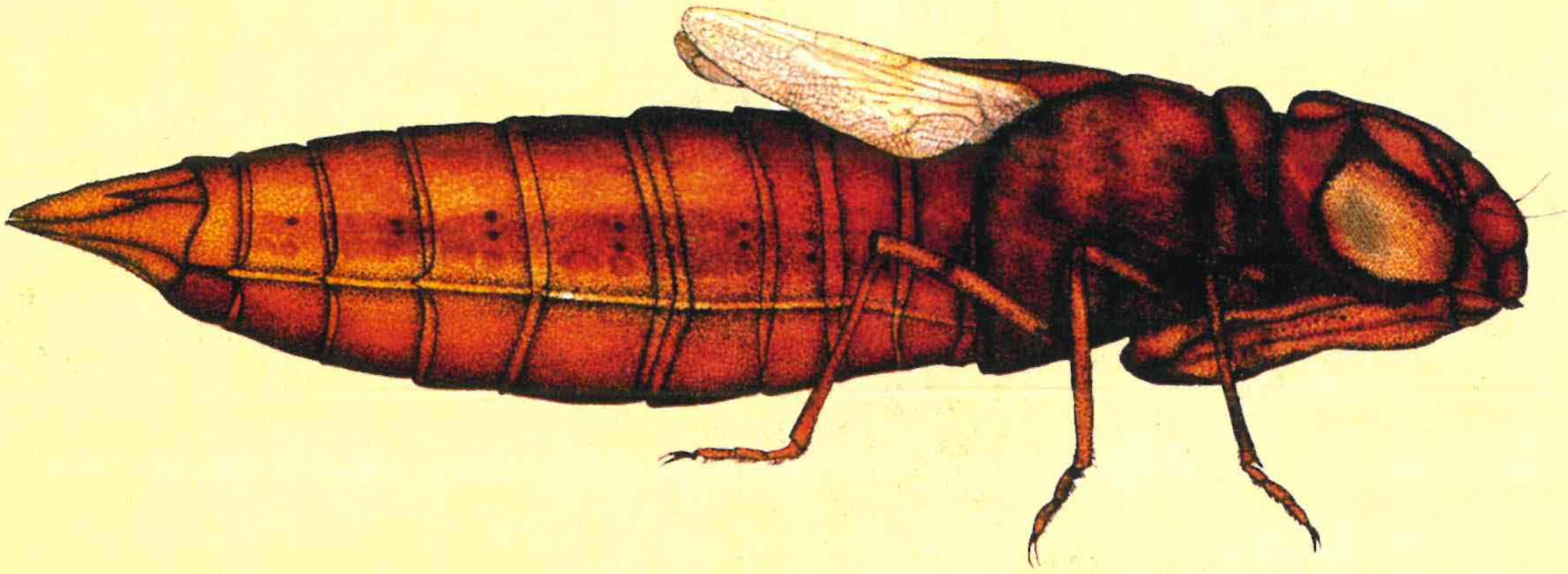

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