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Yellagonga wetlands: a study of the water chemistry and aquatic fauna

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TH COWAN
IVERSITY
PERTH WESTERN AUSTRALIA

CENTRE FOR
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MANAGEMENT

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A Study of the Water Chemistry and Aquatic Fauna

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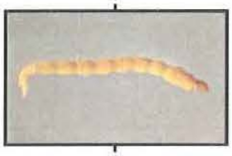

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1 INTRODUCTION

Kimberley Upton & Adrianne Kinnear

1.1 OUR THREATENED WETLANDS

Wetlands worldwide are continually threatened by urbanisation and Western Australia is no exception. Since European settlement in 1829, it has been estimated that at least 75% of the wetlands of the Swan Coastal Plain have disappeared (Halse, 1988). The remaining 25% continue to be threatened by eutrophication and pollution, changes in hydrology and water level patterns, clearing of riparian vegetation, aesthetic disruption and weed invasion (CALM, 1980; Davis and Rolls, 1987; Wrigley *et al.*, 1991; Balla and Davis, 1995). These degradation components are interrelated and largely the consequence of the extensive removal of surrounding vegetation.

The clearing of vegetation around wetlands and in wetland catchments associated with urban development results in the alteration of natural hydrological regimes due to an increase in surface run-off and local rises in the water table (Balla and Davis, 1995). Many wetlands also receive drainage waters acting as compensating basins for the urban stormwater drainage network (Congdon, 1986; City of Wanneroo, 1994). Increasing urbanisation within the metropolitan area has also led to an increase in the extraction of groundwater from the Gnangara and Jandakot Mounds (Davis and Rolls, 1987). This has led to a lowering of the water levels in many wetlands and may result in prolonged summer drying in seasonal wetlands (Balla and Davis, 1995).

Fringing wetland vegetation acts as a filter for surface run-off that enters the groundwater via wetlands (CALM, 1980). The excessive use of fertilisers, detergents and other pollutants, associated with extensive urban and agricultural development, results in contamination of groundwater and surface run-off. Run-off from roadways within wetland catchments may be a source of heavy metal pollution and other contaminants in wetland ecosystems (Lund *et al.*, 1991). The increase in surface run-off has resulted in elevated nutrient levels and pollutants in many wetlands (Congdon, 1986; Davis and Rolls, 1987).

Eutrophication of wetlands is caused by excessive nutrients, in particular phosphorus, and results in an increase in algal or macrophytic biomass, and a shift in the phytoplankton community structure to dominance by toxic cyanobacteria, such as *Anabaena spiroides* and *Microcystis aeruginosa* (Congdon, 1986).

The wetlands of the Swan Coastal Plain, like others in intensely urbanised areas, provide a variety of ecological (Folke, 1991), social and recreational services (Arnold and Wallis, 1987). They are important centres of biodiversity for the Plain and contribute to the maintenance of groundwater quality. They provide valued scenic variety and are often the significant landscape feature of popular recreational reserves. As well as a local responsibility to appropriately conserve and manage the remaining wetlands, Australia has an international responsibility to do so. The wetlands of the Swan Coastal Plain support about 100 species of birds and are important as seasonal refuges for migratory wading birds from the Northern Hemisphere. Australia, as a signatory to the "Ramsar Convention" of 1974, is committed to the management and conservation of those wetlands considered to be of international significance.

1.2 YELLAGONGA REGIONAL PARK

Yellagonga Regional Park lies in the north-west corridor of Perth, approximately 20 km north of the Perth city centre and 6 km east of the Indian Ocean. It is located within the local government boundary of the City of Wanneroo. The Park contains some of the most important wetlands of the Swan Coastal Plain consisting of, in a north to south direction, Lake Joondalup, Beenyup Swamp, Walluburnup Swamp and Lake Goollelal (Plate 1.1, Figure 1.1). These lakes provide some of the largest permanent sources of freshwater on the Swan Coastal Plain. Lake Joondalup is one of the largest permanent lakes and is an important waterbird refuge. The Park covers an area of approximately 1,400 ha of which the wetlands make up about 550 ha. The remaining area consists of land surrounding these wetlands and comprises near-natural bushland, riparian vegetation and modified recreational parkland (City of Wanneroo, 1995).

The regional park concept was introduced in Western Australia in 1955 and is intended to provide protection for regional open space areas of significance and to enhance conservation and public enjoyment of natural and modified landscapes (DPUD, 1991). The State Government agreed to the establishment of Yellagonga Regional park in 1989 in order to provide the expanding population of the Perth metropolitan area with additional conservation and recreational opportunities (DPUD, 1991).

1.3 HISTORICAL SIGNIFICANCE

On June 18, 1829 a new colony was proclaimed on the Swan River by Captain C. H. Fremantle. Previous to, and at the time of establishment of the Swan River Colony, the Nyungar Aboriginal people occupied the south-west of Western Australia. The Nyungar people consisted of tribal groups, distinguished by language dialect and geographical location (Berndt & Berndt, 1979). The Aboriginal tribe occupying the area in the Perth vicinity at the time of the first European explorations and settlement was the Whadjuk tribe. Their territory stretched as far east as York, south along the coast to Pinjarra, and north to Toodyay, as well as occupying land around the Swan River (Tindale, 1974). Yellagonga Regional Park was named to honour Yulgunga, the leader of this tribe (Brittain, 1990). The Whadjuk tribe utilised the Lake Joondalup area as a camping and hunting place due to the abundance of fresh water, waterbirds, frogs, tortoises, kangaroos and other marsupials (Brittain, 1990).

The Lake Joondalup area also appealed to the new European settlers who rapidly subdivided land into pastoral leases and utilised the natural resources of the Yellagonga wetlands during cattle droving. The Lake Joondalup site was on the Canning Stock Route and Neil Hawkins Park, at the northern end of the lake, was used as a "watering place" (James, 1989). Conflict between these early European settlers and the Aboriginal inhabitants ultimately led to the breakdown of Aboriginal life-style and culture, causing them to completely retreat from the area by the 1930s (Brittain, 1990). The Yellagonga area still retains cultural and mythological significance to the present Nyungar tribe as it forms part of their "dreaming" (James, 1989). There are numerous Aboriginal sites around Lake Joondalup registered with the Western Australian Museum, and at least four unregistered sites of interest to descendants of the original inhabitants (City of Wanneroo, 1995).

1.4 THE BIOPHYSICAL ENVIRONMENT

Landform and hydrology

The landform of Yellagonga Regional Park is characterised by high elevation sloping dunes separated by low elevation interdunal depressions occupied by the wetlands. The topography of the western side of the Park is steep, consisting of a central plateau of up to 50 metres in elevation, which drops rapidly to the wetlands' edge. By comparison, the topographical relief to the eastern portion of the Park is relatively flat with a gentle slope towards the wetlands (City of Wanneroo, 1995).

Plate 1.1 Yellagonga Regional Park set in a rapidly developing urban environment.

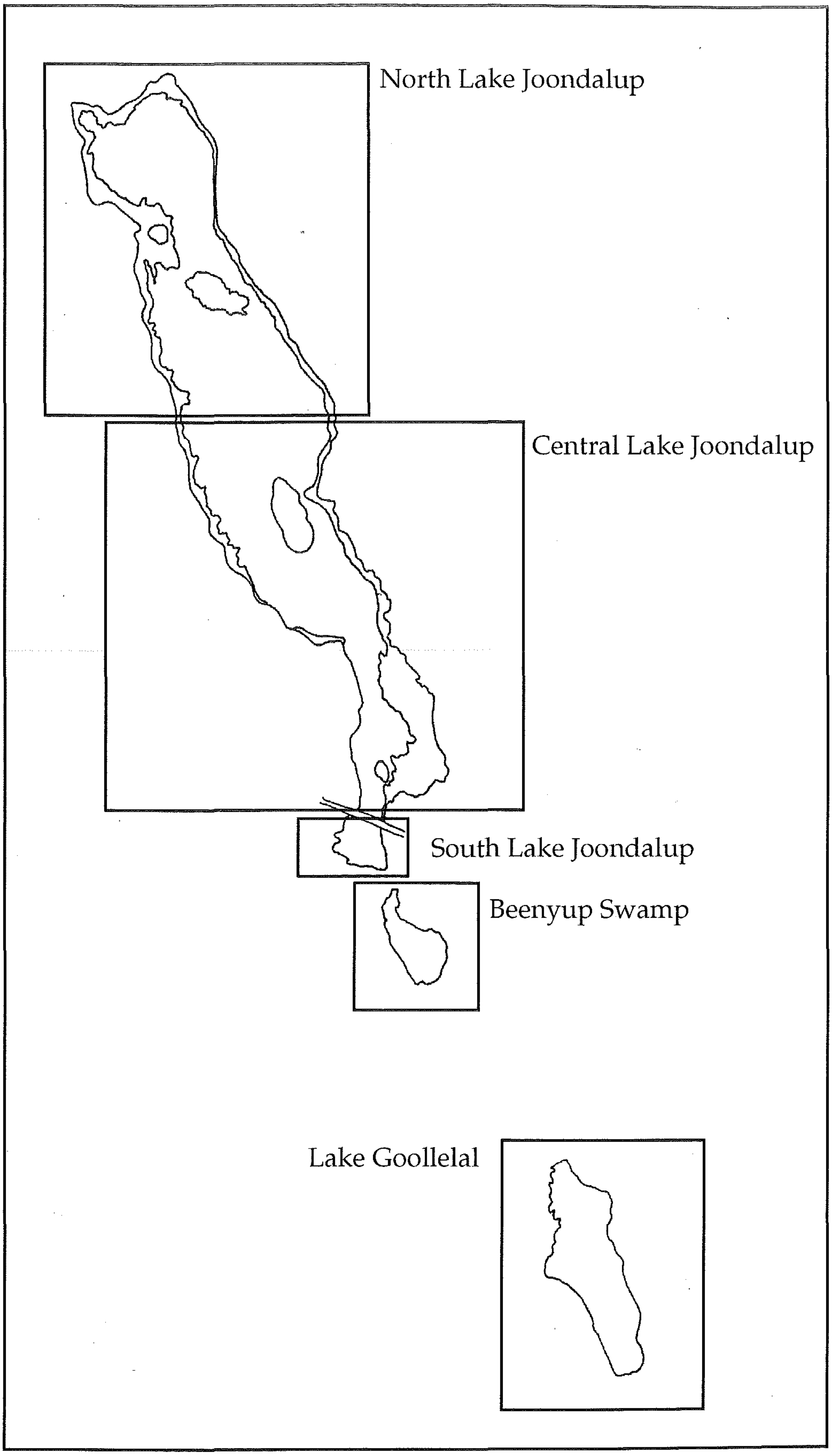


Figure 1.1 Yellagonga Regional Park showing the distribution of the major wetlands and the sampling areas of this study.

The wetlands of Yellagonga Regional Park are surface expressions of the water table of the Gnangara Mound unconfined aquifers and are part of a series of lakes which form a chain of wetlands parallel to the ocean and within the Spearwood Dune system (DPUD, 1991). The Swan Coastal Plain experiences a Mediterranean climate characterised by hot, dry summers and cool, wet winters, with 90% of the annual rainfall (870 mm) occurring between April and October. Consequently, water-levels of the wetlands fluctuate seasonally and from year to year in response to rainfall, evaporation and height of the water-table (Allen, 1976; Congdon, 1986). The groundwater inflow which supplies the Yellagonga wetland system is from shallow aquifers of up to 50 m in depth, flowing in an east to west direction towards the Indian Ocean.

Prior to urbanisation of the land surrounding Yellagonga Regional Park, rainfall over the Park's catchment (approx. 4000 ha) would have infiltrated the soil, thereby reducing potential surface water run-off (City of Wanneroo, 1994). However, the construction of roadways and the urban stormwater drainage network within this catchment have resulted in significant alteration of natural hydrological regimes and have caused an increase in the volume of surface water collected and channelled into the wetlands (Congdon, 1986). Although the greatest source of surface water for the wetlands is derived from rainfall, discharge of stormwater drainage is considered a significant addition to the lakes' water input and nutrient balance (Congdon, 1986; City of Wanneroo, 1994).

Surface water flow between the wetlands of Yellagonga Regional Park also has a significant effect on the water levels of the wetlands, particularly Beenyup Swamp and Lake Joondalup. As a result of landform elevations, surface water drains from Lake Goollelal (A.H.D. 27 m) to Walluburnup Swamp (A.H.D. 19 m) via culverts under Hocking road and Whitfords Avenue (City of Wanneroo, 1995). From Walluburnup Swamp, surface water flows into the adjacent Beenyup Swamp (A.H.D. 18 m), and then into the southern region of Lake Joondalup (A.H.D. 18 m) via a connecting stream. The southern region of Lake Joondalup is separated from the main water body by Ocean Reef Road. An engineered tunnel that passes underneath Ocean Reef Road connects these two waterbodies. Consequently, surface water flows from the southern region into the main water body when water levels are sufficiently high, during the winter months.

The soils and vegetation

Yellagonga Regional Park is located within the coastal limestone belt of the Swan Coastal Plain (Allen, 1976). This quaternary dune system corresponds to the geomorphic element of permeable, aeolian sands known as the Spearwood Dune System. The Spearwood Dunes are an intermediate-aged dune system comprising a core of consolidated, windblown, calcareous sand with a hard capping of secondary calcite formed by the leaching of carbonate from the upper horizon (McArthur & Bettanay, 1974). Three different soil types are present within Yellagonga Regional Park and have been described as:

- Karrakatta Sand / Yellow Phase - displaying a grey/ brown surface passing into a bright yellow sand with limestone occurring within the first two metres.
- Spearwood Sand - characterised by a dark brown sandy surface grading into yellow/brown or brown sand with limestone occurring within one metre of the surface.
- Beonaddy Sand - dark grey surface sand becoming lighter with depth.

The vegetation situated in and around the wetlands of Yellagonga Regional Park has been subjected to alteration by land-use practices from the time of European settlement. The majority of the vegetation within the Yellagonga Regional Park catchment has been cleared for urban development or agricultural practice. Remnant stands of near-natural vegetation, both terrestrial and aquatic, are therefore of high conservation value. The vegetative communities of Yellagonga Regional Park have been well-described (Beard, 1979; DPUD, 1991) and include:

- Fringing Paperbark Woodland (*Melaleuca rhaphiophylla*)
- Flooded Gum Woodland (*Eucalyptus rudis*)
- Jarrah-Marri-Banksia Open Forest (*E. marginata, E. calophylla, Banksia attenuata*)
- Tuart-Jarrah-Marri Open Forest (*E. gomphocephala, E. marginata, E. calophylla*)
- Emergent Aquatic Vegetation (*Baumea articulata, Typha orientalis, Schoenoplectus validus*)
- Disturbed Areas (agricultural areas, grassed areas, weed invasion eg Arum Lily - *Zantedeschia aethiopica*)

The fauna

The wetlands of Yellagonga Regional Park serve as an important feeding and mating ground for a highly diverse bird population, many of which are trans-migratory wading birds (Bekle, 1979). The wetlands of the Swan Coastal Plain are visited by migratory wading birds each summer and Australia, as a signatory to international treaties, has an obligation to protect the habitats of many of these bird species (Arnold and Wallis, 1987). Lake Joondalup, in particular, supports a diverse community of birds and reptiles in a range of habitats. Waterbirds utilise many of these habitats within the Park for feeding, shelter and breeding. In addition, landbird species within the area utilise specific vegetation associations within the confines of the Park for particular functions. Thus, management for maximum diversity of bird and other vertebrate species requires appropriate conservation of the full range of available habitats.

Previous surveys of the aquatic fauna of the wetlands of Yellagonga Regional Park are very limited and have been focused on the main water body of Lake Joondalup. An early study of the fauna of the Swan Coastal Plain wetlands found that Lake Joondalup contained an abundant aquatic fauna, with 21 species recorded (Hembree & George, 1978). Davis *et al.* (1993), in a survey of the aquatic fauna of selected Perth wetlands, found 18 species in Lake Joondalup and concluded that it was depauperate of aquatic invertebrate fauna and missing important higher order consumer levels. The same authors described a somewhat similar aquatic invertebrate fauna for Lake Goollelal. We could find no published records of the fauna of Beenyup Swamp.

1.5 URBANISATION AND WETLAND DEGRADATION

The wetlands of Yellagonga Regional Park are situated in an area of intense urbanisation. In 1988 the area was the second fastest growing Local Area Authority in Western Australia (DPUD, 1991). The Park has been influenced by the impact of increasing numbers of residential dwellings and a range of other land uses such as market gardens, parkland, horse agistment and other commercial activities (eg caravan parks and poultry farming). Anthropogenic activities influencing water quality of the wetlands include drainage and stormwater flows (twenty outfalls discharge stormwater into the lakes of the Park), pollution and excessive nutrient input, and groundwater abstraction (City of Wanneroo, 1994).

Two government authorities currently maintain responsibility for the Park: The City of Wanneroo and the Department of Conservation and Land Management (CALM). In addition, there are diverse community and local government interest groups which have Yellagonga Regional Park as part, or all of their brief. These include The Friends of Yellagonga, the Perry's Paddock Group, Fire and Rescue Service, Yellagonga Community Advisory Committee, Yellagonga Management

Committee and others. Despite this, there is no holistic management plan that protects the biota and accommodates the interests of diverse users, both present and future, within a conservation framework.

Like other wetlands of the Swan Coastal Plain, the wetlands of Yellagonga Regional Park are increasingly threatened by eutrophication and degradation. Vegetation in and around Yellagonga Regional Park has been subjected to alteration from the time of European settlement and large areas of land surrounding the Park have been cleared for agricultural practice, recreational facilities and extensive urban development. Currently, the major land-use surrounding Yellagonga Regional Park is developed residential areas including the suburbs of Joondalup, Edgewater, Woodvale, Kingsley and Wanneroo, and land modified for horticultural/ agricultural practice (City of Wanneroo, 1994).

The last two decades have seen several studies of the nutrient status of wetlands of the Swan Coastal Plain. Studies of the Yellagonga wetlands have generally focused on Lake Joondalup due to its size and dominance of the Park's visual scenery. Congdon & McComb (1976) in the first study of nutrients and planktonic algae in Lake Joondalup concluded that the lake was "mildly eutrophic" on the basis of relatively high phosphorus and nitrogen concentrations and the occurrence of algal blooms. In Congdon's later study of Lake Joondalup, the remaining Yellagonga wetlands were also sampled in order to reveal possible sources of nutrient input. Congdon (1986) concluded that the Yellagonga wetlands were eutrophic on the basis of total phosphorus concentrations, and that Lake Joondalup was excessively eutrophic. Davis *et al.*(1993) described Lake Joondalup as mesotrophic.

Nutrient enrichment of Lake Joondalup is believed to be caused by excessive phosphorus input carried in surface water flow from Walluburnup Swamp, through the southern section of Lake Joondalup and into the main waterbody (Congdon, 1986). Nutrient levels in the southern-most wetland, Lake Goollelal were significantly less than those of Walluburnup and Beenyup Swamps, suggesting that nutrient input is originating from areas adjacent to the Walluburnup/Beenyup Swamp system. Congdon (1986) suggested that excessive nutrient input is occurring as a result of animal husbandry practices and excessive use of fertilisers in the agricultural area east of Walluburnup Swamp. Furthermore, contamination by stormwater drainage contributes to degradation of these wetlands (City of Wanneroo, 1994).

1.6 AIMS OF THE STUDY

The previous studies of Lakes Joondalup and Goollelal have demonstrated increasing nutrient enrichment, some spatially-restricted seasonal algal blooms and a potentially depauperate fauna, the latter in the main water body of the larger wetland, Lake Joondalup. These studies have either concentrated on water chemistry alone or if faunal sampling has been carried out, it has been seasonally or spatially restricted. As a result, very little is known of the responses of the fauna to the substantial external phosphorus loading of these wetlands, or to the increasing urbanisation of the wetland surrounds which has occurred in the past decade. There are no faunal data on which to base effective management plans.

This study focused on the aquatic invertebrate and avian communities of the Yellagonga wetlands, providing detailed baseline information on these fauna for each of the major wetland areas in the Park.

1.7 THE STUDY AREA

The three major wetlands in Yellagonga Regional Park, Lake Goollelal, Beenyup Swamp and Lake Joondalup were selected for study. They have the following characteristics:

Lake Joondalup is a large permanent wetland approximately 450 ha in area (Plates 1.2 & 1.3). Large sections retain the natural fringing vegetation of *Melaleuca raphiophylla* and sedges (Plates 1.6 & 1.7), and two central islands are surrounded by sedge habitat. Eighty percent of the lake's volume has depths of 1.2-2.0 metres. A rich benthic flora and a suspended "sediment" of unknown origin called metaphyton inhabits the northern lake areas. The southern section of this wetland, south of the bisecting highway is seasonal, and dries out during summer (Plate 1.8).

Beenyup Swamp is the smallest and most shallow water body of the three (Plate 1.4) and usually dries out completely during the summer months. The swamp retains most of the fringing vegetation and is heavily shaded throughout with *Melaleuca* sp. (Plate 1.9).

Lake Goollelal is also a permanent wetland of approximately 50 ha (Plate 1.5). Its surrounds are heavily urbanised and it retains only a very small proportion of the natural fringing vegetation (Plate 1.10).

Previous studies have identified somewhat different chemical and botanical characters for the extreme southern and northern regions of Lake Joondalup. For example, the southernmost end of this lake (Plate 1.8) is seasonal, has little benthic flora and has been described as excessively enriched (Congdon, 1986). On the other hand, the deeper main water body (Plates 1.6 & 1.7) is permanent, has been described as mesotrophic or mildly eutrophic, is known to support a rich benthic flora and has a unique suspended sediment called metaphyton distributed throughout the water column. As described earlier, a road and subsurface drain interrupts the natural lake contours and south-north drainage (Plate 1.3). For these reasons, Lake Joondalup was divided into three areas designated South, Central and North Lake Joondalup (Figure 1.1). Each of these areas was sampled separately and the data analysed as such, giving, with Beenyup Swamp and Lake Goollelal, a total of five sites in all.

1.8 OBJECTIVES OF THE STUDY

Sampling of the water bodies occurred over a fifteen month period from January, 1991 to March, 1992 in order to determine the following:

(i) the abundance and diversity of the aquatic invertebrate fauna;
(ii) the spatial and temporal patterns of the invertebrate communities occupying the diverse seasonal and permanent wetland areas;
(iii) the abundance and diversity of the waterbird species in Lakes Joondalup and Goollelal and their patterns of wetland usage;
(iv) in association with the invertebrate patterns, the seasonal and spatial variation in selected aquatic physico-chemical characteristics.

The outcomes of the research have implications for the future well-being of the wetlands and we present recommendations for management which recognise the need for a multiple-use framework for the Park but place conservation and rehabilitation as objectives of the highest priority.

Plate 1.2 Lake Joondalup (North and Central areas) looking northwest. The large expanse of this lake is clearly shown, with its greater length running approximately parallel to the coastline.

Plate 1.3 Lake Joondalup (Central and South areas) looking west. The dissection of the southern end by Ocean Reef Road is clearly shown.

Plate 1.4 Beenyup Swamp looking south-east. This wetland connects with Walluburnup Swamp in the east (a portion of which is evident in the top left-hand corner of the plate) and South Lake Joondalup to the north (in the direction of the lower left-hand corner of the plate).

Plate 1.5 Lake Goollelal looking north-west. The remaining wetland areas of the study can be seen running south to north in the upper half of the plate, with the large expanse of Lake Joondalup showing clearly.

Plate 1.6 North Lake Joondalup looking east. Natural riparian and upland vegetation remains in this area of the wetland.

Plate 1.7 Central Lake Joondalup looking south.

Plate 1.8 South Lake Joondalup looking south-west. This area of the wetland adjoins small amounts of natural riparian vegetation interspersed with large expanses of cultivated grassland.

Plate 1.9. Beenyup Swamp. The area shown is representative of the open areas of the swamp.The greater area of the swamp is heavily wooded and shaded as evident in Plate 1.4.

Plate 1.10 Lake Goollelal looking east.

2

WATER CHEMISTRY

Patrick Garnett & Adrianne Kinnear

2.1 CLIMATIC CONDITIONS

The patterns of rainfall and water temperature were highly seasonal and typical of the region, with a cool, wet winter and warm, dry summers (Figure 2.1). June marked the onset of the winter rainfall.

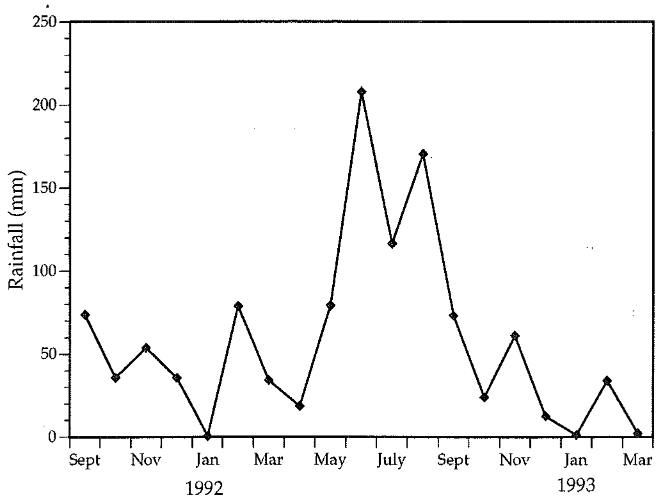


Figure 2.1 Monthly rainfall in the Wanneroo Shire over the period of this study.

The summer of 1991/1992, when sampling commenced, was unusually wet. There was abnormally high rainfall in both December and February. As a result, the wetland areas Beenyup Swamp and South Lake Joondalup, which normally dry out over summer, retained water throughout the summer-autumn period. This affected the patterns of both nutrients and fauna.

2.2 METHODS

Water samples were taken at each of the sites at two-weekly intervals for 15 months, commencing in January 1992. The variables conductivity, dissolved oxygen, temperature and pH, were measured in situ and water samples were collected for other analyses.

In situ measurements and water samples were collected about 30 cm below the surface and towards the centre of the water bodies. Water samples for analyses were collected in opaque containers and stored over ice in insulated containers while they were transferred to an analytical laboratory. Samples required for metal ions (sodium, potassium, calcium, magnesium), chloride, and total nutrient analyses were stored at -20 °C until analysed. Samples required for reactive phosphorus, nitrate/nitrite and ammonium nitrogen analyses were filtered through 0.45 µm membrane filters prior to freezing. Samples for chlorophyll *a* analysis were filtered through glass fibre filter papers and the filtered material was stored in the dark at -20 °C.

Conductivity and oxygen levels were measured *in situ* using an Orion 140 field portable conductivity meter (calibrated with 0.0100 mol L^{-1} KCl) and an Orion 840 dissolved oxygen meter respectively. pH was measured in situ using an Orion 290A portable pH meter calibrated with standard buffer solutions.

Metal ion analyses, sodium, potassium, magnesium and calcium, were undertaken using atomic absorption spectrometry following standard procedures (Clesceri *et al.*, 1989). Chloride was measured with a direct reading digital chloride meter based on a modified argentometric method using a Corning 926 chloride analyser.

Analysis of alkalinity was carried out immediately on return to the laboratory. Total alkalinity, expressed as mg L^{-1} $CaCO_3$, was determined by titration with standard 0.0200 mol L^{-1} HCl to a pH 4.5 end point using bromocresol green indicator (Clesceri *et al.*, 1989).

Nitrate/nitrite was determined spectrophotometrically following cadmium reduction using a Technicon Autoanalyser (Clesceri *et al.*, 1989). Ammonium nitrogen was determined by the formation of the intensely blue compound, indophenol, which is detected spectrophotometrically (Grasshof *et al.*, 1983). Organic nitrogen was determined by the difference between Kjeldahl nitrogen and ammonium nitrogen. Kjeldahl nitrogen, which includes ammonium and organic nitrogen, was determined by digestion followed by spectrophotometric analysis of the ammonia produced (Clesceri *et al.*, 1989). Total nitrogen was obtained by summing ammonium nitrogen, organic nitrogen and nitrate/nitrite.

Dissolved reactive phosphorus (largely orthophosphate) was determined spectrophotometrically by the single solution (ascorbic acid) method (Major *et al.*, 1972). Total phosphorus (orthophosphate, condensed inorganic phosphate and organic phosphate) was determined by the same method following digestion with perchloric acid using a block digester.

Chlorophyll *a* was used as an indicator of algal biomass (phytoplankton productivity). The chlorophyll *a* was determined spectrophotometrically following extraction from the glass fibre filter paper by grinding with acetone (Clesceri *et al.*, 1989).

Classification and ordination of sites were carried out using the seasonal mean values of seven variables - total nitrogen, total phosphorus, reactive phosphorus, chlorophyll *a*, pH, dissolved oxgygen and conductivity. Using the seasonal mean values from each site produced a reasonable number of site points in "water-chemistry" ordination space (5 seasonal means by 5 sites = 25 data points) which could be interpreted visually. The sites were classified using hierarchical polythetic agglomerative clustering (FUSE) based on the unweighted pair group arithmetic averaging strategy (UPGMA) provided in the PATN software package (Belbin, 1989). The data were then standardised using the formula

$$\frac{X-X_{min}}{X_{max}-X_{min}}$$

where X is the seasonal mean concentration of the chemical variable for a particular site. An association matrix was calculated using the Gower Metric association measure and the samples were ordinated using semi-strong hybrid multidimensional scaling (SSH).

2.3 RESULTS

The water chemistry data are presented in three sets of Figures and Tables representing varying degrees of summarisation. The scatter graphs (Figures A1 - A16 in Appendix A) represent the least summarised data and are useful for identifying localised and transient variations in water chemistry of potential significance. Figures 2.2 - 2.18 present the site data as monthly mean values and reveal broad-scale seasonal patterns and environmental gradients. These gradients are summarised as mean values and ranges for all the chemistry variables for each site in Tables 2.1 - 2.3.

Conductivity

There was a noticeable conductivity or salinity gradient in the wetlands with lower conductivities in Lake Goollelal, Beenyup Swamp and South Lake Joondalup (mean conductivity ~800 mS cm^{-1}, Table 2.1) compared with Central and North Lake Joondalup (mean conductivity ~1400 mS cm^{-1}).

The conductivity showed strong seasonal variations at all sites with the highest values occurring in late autumn and decreasing rapidly with the onset of winter rains (Figure 2.2). Mean monthly conductivities ranged from a spring minimum of ~800 mS cm^{-1} to an autumn maximum of ~2100 mS cm^{-1} in Central and North Lake Joondalup. At the other sites the mean monthly conductivities ranged from ~500 mS cm^{-1} to ~1100 mS cm^{-1}.

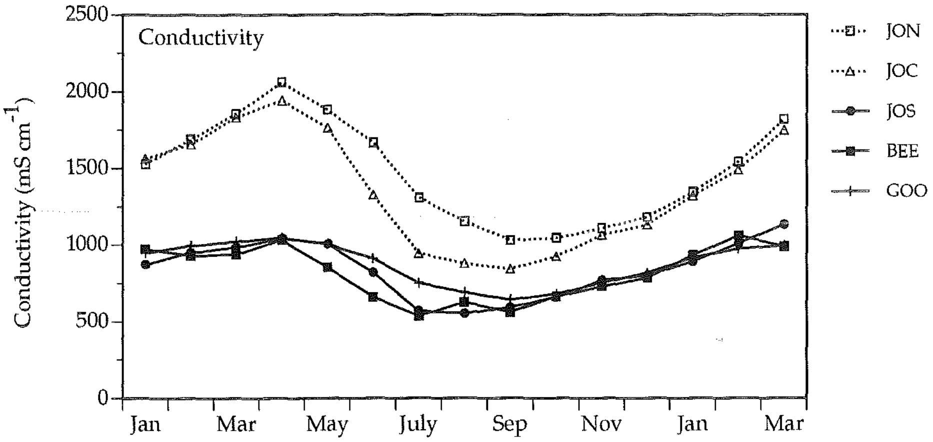


Figure 2.2 Variation in monthly mean conductivity levels for North (JON), Central (JOC) and South Lake Joondalup (JOS), Beenyup Swamp (BEE) and Lake Goollelal (GOO).

Figure 2.2 and the scatter graph (Figure A1) provide clear evidence of a decrease in conductivity in Central Lake Joondalup in early winter when increasing water levels allowed water to flow from South Lake Joondalup to Central Lake Joondalup through the Ocean Reef Road culvert. The scatter graph also shows the decline in conductivity at all sites associated with the unseasonal heavy rain that occurred in February 1992.

Metal ion concentrations

Metal ion concentrations (sodium, calcium, magnesium and potassium) also exhibited seasonal variations with highest values in late autumn followed by decreases in concentrations following the commencement of winter rains (Figures 2.3-2.6; Table 2.1).

SITE	Conductivity (mS cm^{-1})	Sodium (mg L^{-1})	Potassium (mg L^{-1})	Calcium (mg L^{-1})	Magnesium (mg L^{-1})	Chloride (mg L^{-1})
Lake Goollelal	871 627 - 1054	87 45 - 154	11 4 - 16	36 20 - 52	18 13 - 24	158 168 - 218
Beenyup Swamp	816 479 - 1096	85 50 - 127	6 4 - 9	46 26 - 67	14 9 - 19	149 85 - 212
South Lake Joondalup	859 526 - 1190	85 54 - 147	6 5 - 8	44 27 - 64	14 9 - 19	154 98 - 216
Central Lake Joondalup	1381 620 - 1977	147 50 - 233	8 2 - 17	33 18 - 47	26 11 - 46	328 132 - 598
North Lake Joondalup	1501 980 - 2160	160 99 - 234	8 2 - 17	29 18 - 36	29 19 - 41	360 156 - 578

Table 2.1 Water chemistry (conductivity, metal ions and chloride ion) for the five sampled sites. Values are the means over the 15-month period and the range of values obtained.

Sodium ion concentrations were higher in North and Central Lake Joondalup (means of 160 and 147 mg L^{-1}) than in South Lake Joondalup (85 mg L^{-1}), Beenyup Swamp (85 mg L^{-1}) and Lake Goollelal (87 mg L^{-1}).

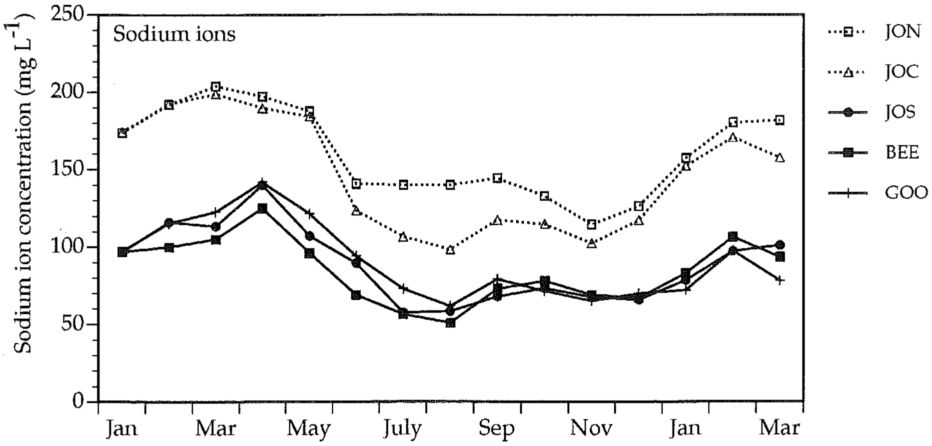


Figure 2.3 Variation in monthly mean sodium ion concentrations.

Calcium ion concentrations were generally lower in North and Central Lake Joondalup (means of 29 and 33 mgL^{-1}) and higher in South Lake Joondalup and Beenyup Swamp, and, to a lesser extent, Lake Goollelal (means of 44 , 46 and 36 mg L^{-1}, respectively).

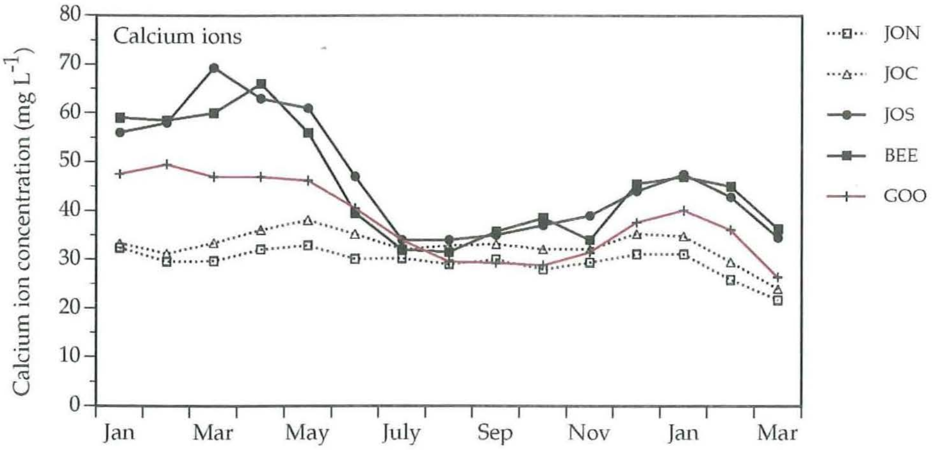


Figure 2.4 Variation in monthly mean calcium ion concentrations.

Magnesium ion concentrations were consistently higher in North and Central Lake Joondalup (means of 29 and 26 mg L^{-1}), than in South Lake Joondalup, Beenyup Swamp and Lake Goollelal (means of 14, 14 and 18 mg L^{-1} respectively).

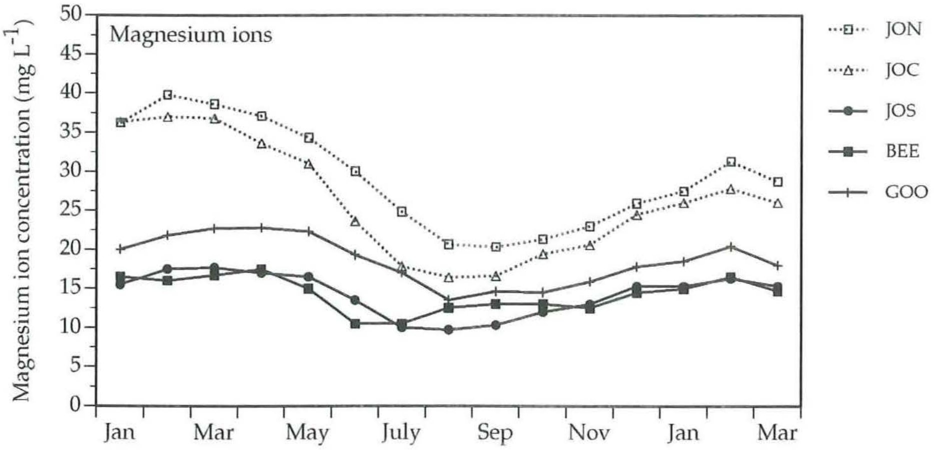


Figure 2.5 Variation in monthly mean magnesium ion concentrations.

Concentrations of potassium ion were, as expected, much lower than the levels of sodium ions with a mean of ~8 mg L^{-1} for all water bodies.

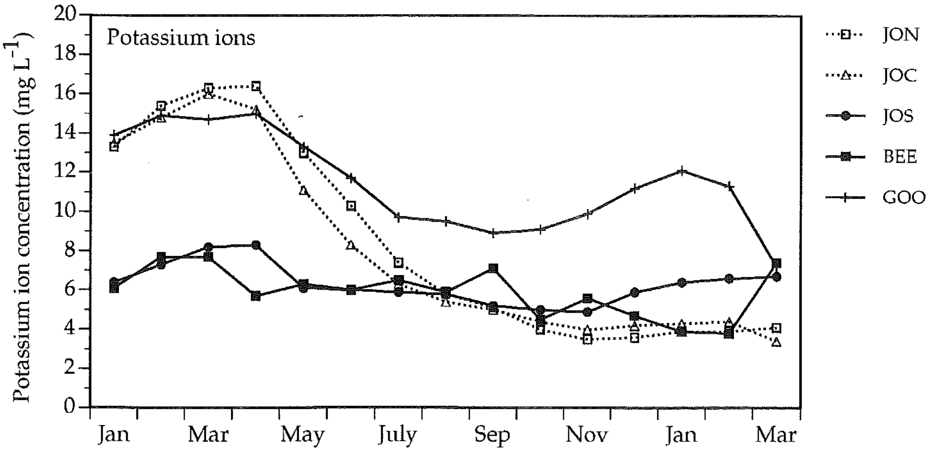


Figure 2.6 Variation in monthly mean potassium ion concentrations.

Chloride ion concentration

Chloride ion concentrations (Table 2.1; Figure 2.7) were higher in North and Central Lake Joondalup (means of 360 and 328 mg L^{-1}) with lower means of 154, 149 and 158 mg L^{-1} in South Lake Joondalup, Beenyup Swamp and Lake Goollelal. Chloride ion concentrations, which mirrored sodium ion concentrations, also exhibited seasonal variations with highest values in late autumn followed by decreases in concentrations following the commencement of winter rains.

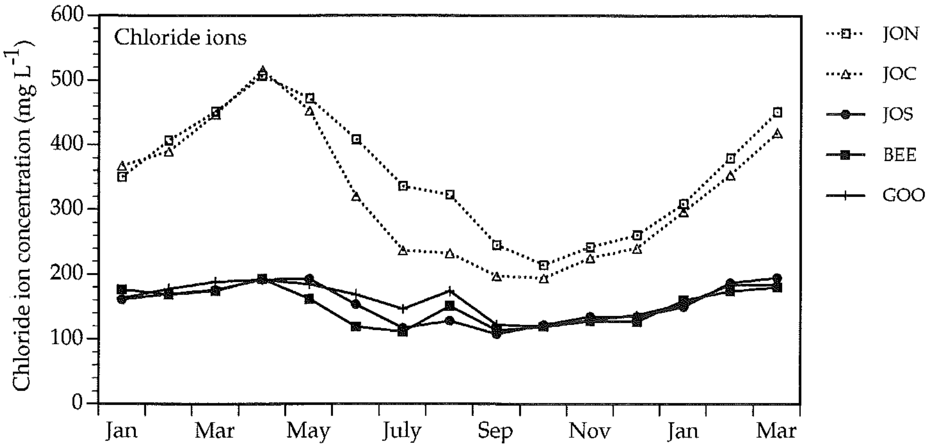


Figure 2.7 Variation in monthly mean chloride ion concentrations.

Dissolved oxygen

The levels of dissolved oxygen (Table 2.2; Figure 2.8) in Beenyup Swamp (mean 3.0 mg L^{-1}) were consistently lower than in the other wetlands, with monthly means ranging from 0.5 - 5 mg L^{-1}, and individual readings rarely exceeding 5 mg L^{-1} throughout the sampling period. Levels in South Lake Joondalup (mean 6.5 mg L^{-1}) were considerably higher than in Beenyup Swamp but rarely reached the values recorded for the remaining sites, with means of 8.8, 8.2 and 8.3 mg L^{-1} respectively in North and Central Lake Joondalup and Lake Goollelal.

SITE	Dissolved oxygen (mg L^{-1})	pH	Alkalinity (mg L^{-1} $CaCO_3$)
Lake Goollelal	8.3 5.6 - 13.0	8.4 7.3 - 10.0	104 72 - 137
Beenyup Swamp	3.0 0.3 - 10.0	7.4 6.1 - 8.1	153 92 - 230
South Lake Joondalup	6.5 1.8 - 9.0	8.1 6.9 - 9.6	160 84 - 226
Central Lake Joondalup	8.2 5.0 - 13.0	9.0 7.5 - 10.1	129 102 - 179
North Lake Joondalup	8.8 4.9 - 13.3	9.3 8.2 - 9.9	124 75 - 166

Table 2.2 Water chemistry (dissolved oxygen, pH and alkalinity) for the five sampled sites. Values are the means over the 15-month period and the range of values obtained.

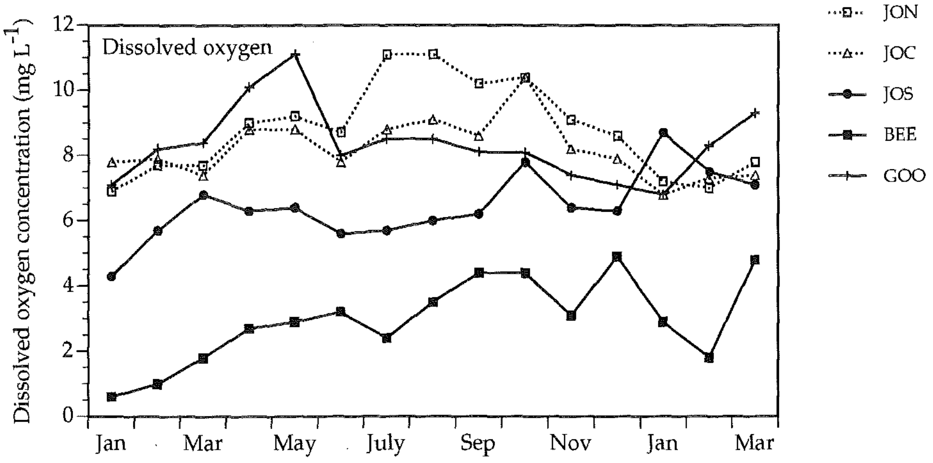


Figure 2.8 Variation in monthly mean dissolved oxygen concentrations.

Some seasonal influence is suggested in the data from North Lake Joondalup and Beenyup Swamp (Figure 2.8) with higher dissolved oxygen levels during the winter than in the summer months. There were, however, no obvious seasonal patterns in dissolved oxygen levels in the other wetlands observed.

pH and alkalinity There was a clear pH gradient across the surface-connected sites from Beenyup Swamp to North Lake Joondalup (Table 2.2; Figure 2.9). Beenyup Swamp had pH values (mean 7.4) consistently lower than South Lake Joondalup (mean 8.1), Central Lake Joondalup (mean 9.0) and North Lake Joondalup (mean 9.3). Lake Goollelal (mean 8.4) was also alkaline.

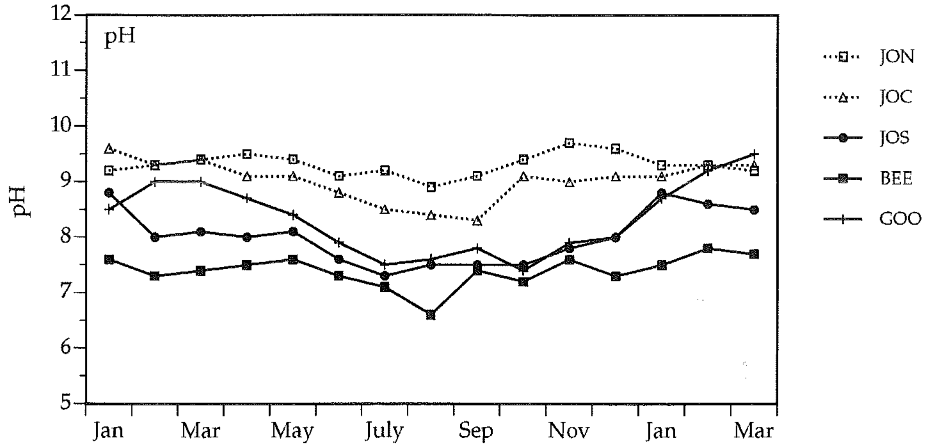


Figure 2.9 Variation in monthly mean pH levels.

Seasonal variations were observed in Lake Goollelal and, to a much lesser extent, in South Lake Joondalup and Central Lake Joondalup, with higher summer values reflecting increased productivity (Figure 2.9). In South Lake Joondalup substantially higher isolated pH values were recorded in both summers, coincident with high chlorophyll *a* values (Figure A8). There was considerable variability in pH values in Central Lake Joondalup in winter and spring which corresponded to the flow of water from South Lake Joondalup following connection of these wetlands through the Ocean Reef Road culvert.

Alkalinity values (Table 2.2; Figure 2.10) in the wetlands were lowest in Lake Goollelal (mean 104 mg L^{-1} $CaCO_3$). Across the surface-connected sites from Beenyup Swamp to North Lake Joondalup higher mean alkalinity levels were observed for the two southern sites (Beenyup Swamp, 153 mg L^{-1} and South Lake Joondalup, 160 mg L^{-1}), with lower levels in Central Lake Joondalup (129 mg L^{-1}) and North Lake Joondalup (124 mg L^{-1}).

Seasonal variations were observed in the alkalinities for Central and North Lake Joondalup and Lake Goollelal, with slightly greater alkalinities in summer than in winter. This trend was more pronounced in South Lake Joondalup and Beenyup Swamp with alkalinities of ~200 mg L^{-1} $CaCO_3$ in summer compared with ~100 mg L^{-1} $CaCO_3$ during the winter months.

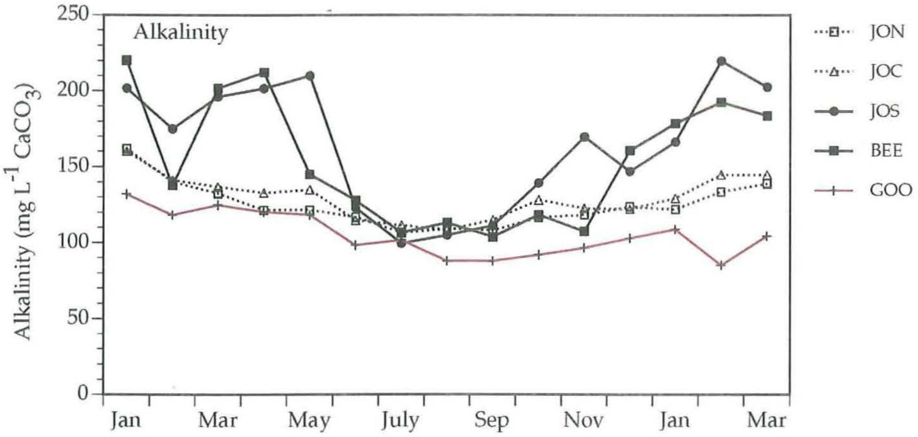


Figure 2.10 Variation in monthly mean alkalinity.

Phosphorus

Phosphorus levels (expressed as µg-P L^{-1}) for total phosphorus (TP) and dissolved reactive phosphorus (RP) are presented in Table 2.3; Figures 2.11-2.12 and Figures A10-A11.

Beenyup Swamp and South Lake Joondalup had the highest levels of TP and RP of all the sites (Table 2.3; Figures 2.11 & 2.12). Mean values for TP and RP were 322 µg L^{-1} and 195 µg L^{-1} for Beenyup Swamp and 260 µg L^{-1} and 163 µg L^{-1} for South Lake Joondalup respectively. Levels of TP and RP exceeded 100 µg L^{-1} for most of the sampling period.

There were no obvious seasonal patterns in TP or RP at these sites, though sustained high levels of TP (>300 µg L^{-1}) and RP (>200 µg L^{-1}) were a feature of the wet first summer when water was retained in both these normally seasonal water bodies. Peaks in TP and RP tended to parallel each other and the RP/TP ratio was high, with RP usually contributing >60% of TP (Figure 2.13).

The remaining three wetland sites Central and North Lake Joondalup and the geographically disjunct Lake Goollelal all had substantially lower TP and RP levels (Table 2.3). Mean

SITE	Total Phosphorus (μg L^{-1})	Reactive Phosphorus (μg L^{-1})	Total Nitrogen (μg L^{-1})	Organic Nitrogen (μg L^{-1})	Nitrate/ nitrite Nitrogen (μg L^{-1})	Ammonium Nitrogen (μg L^{-1})	Chlorophyll *a* (μg L^{-1})
Lake Goollelal	86 13 - 548	26 0 - 206	1507 854 - 3018	1502 882 - 3011	3 1 - 18	9 1 - 67	16 0 - 62
Beenyup Swamp	322 80 - 831	195 25 - 689	1257 760 - 1722	1179 656 - 1725	28 1 - 328	60 8 - 185	9 0 - 37
South Lake Joondalup	260 71 - 766	163 40 - 518	1425 807 - 4002	1370 791 - 3606	17 1 - 325	33 3 - 590	19 0 - 199
Central Lake Joondalup	117 8 - 603	33 0 - 209	2134 976 - 4515	2107 818 - 4496	5 1 - 193	23 1 - 225	22 0 - 134
North Lake Joondalup	88 9 - 555	23 0 - 218	2094 1239 - 5901	2078 1219 - 5883	4 1 - 44	15 1 - 54	10 0 - 31

Table 2.3 Water chemistry (phosphorus, nitrogen and chlorophyll *a*) for the five sampled sites. Values presented are the mean values over the 15-month period and the range of values obtained.

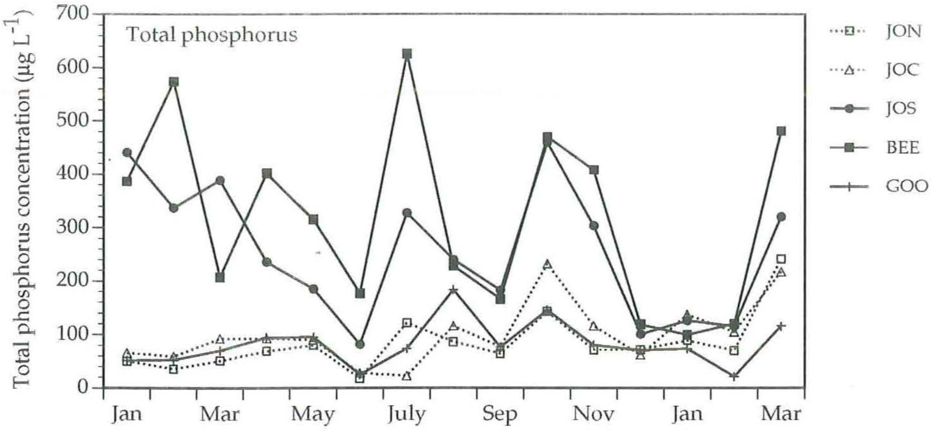


Figure 2.11 Variation in monthly mean total phosphorus levels.

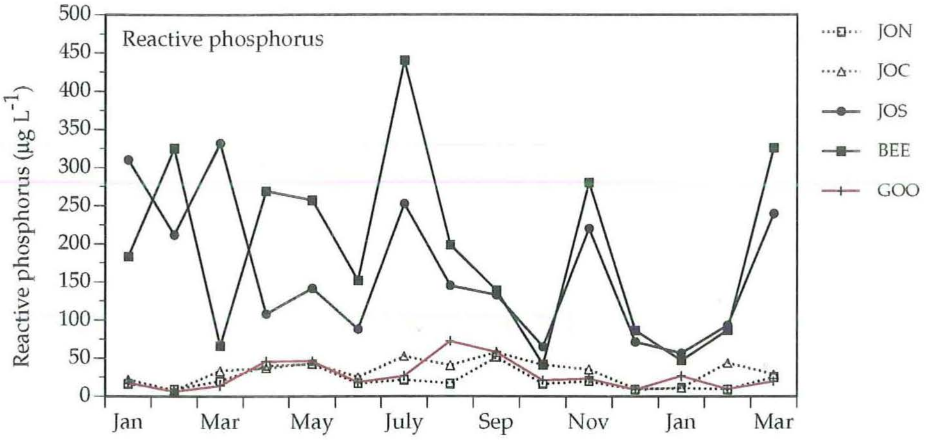


Figure 2.12 Variation in monthly mean reactive phosphorus levels.

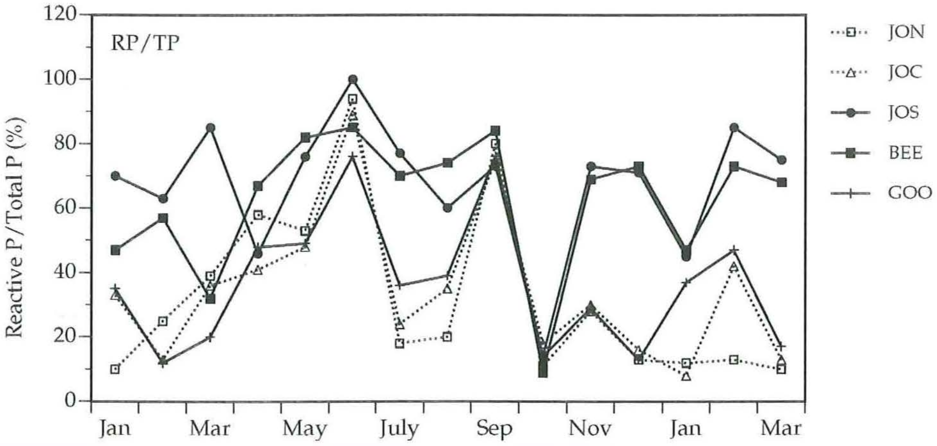


Figure 2.13 Variation in monthly mean reactive phosphorus (RP)/total phosphorus (TP) ratios.

values for TP were 117 μg L^{-1} for Central Lake Joondalup, 88 μg L^{-1} for North Lake Joondalup and 86 μg L^{-1} for Lake Goollelal. There was a clear decreasing gradient in TP and RP levels from south to north across the surface-connected sites from Beenyup Swamp to North Lake Joondalup.

The monthly means for Central and North Lake Joondalup and Lake Goollelal (Figures 2.11 & 2.12) do not exhibit any pronounced seasonal patterns though there are some small increases in monthly mean values in TP in the winter-spring months, particularly in Central Lake Joondalup. This increase was associated with an increased variability in TP which occurred with the onset of winter rains. This is evident in the increased scatter during this period (Figure A10). For example, in Central Lake Joondalup, at least three sharp though transient peaks in TP are clearly discernible in the scatter graphs, two in winter-spring and the other in the following summer. While the RP/TP ratios for these sites were variable, for the majority of samples the RP/TP ratios were <50% and RP contributed less to TP than at the Beenyup Swamp and South Lake Joondalup sites.

Nitrogen

Nitrogen levels (expressed as μg-N L^{-1}) for total nitrogen (TN), organic nitrogen (ON), nitrate (NO_3^-)/nitrite (NO_2^-) and ammonium (NH_4^+) are presented in Table 2.3, Figures 2.14-2.17 and in Figures A12-A15.

At all sites, ON contributed a very high proportion (almost always >90%) of TN. Hence, the site levels and seasonal patterns of TN discussed below are essentially identical to those for ON.

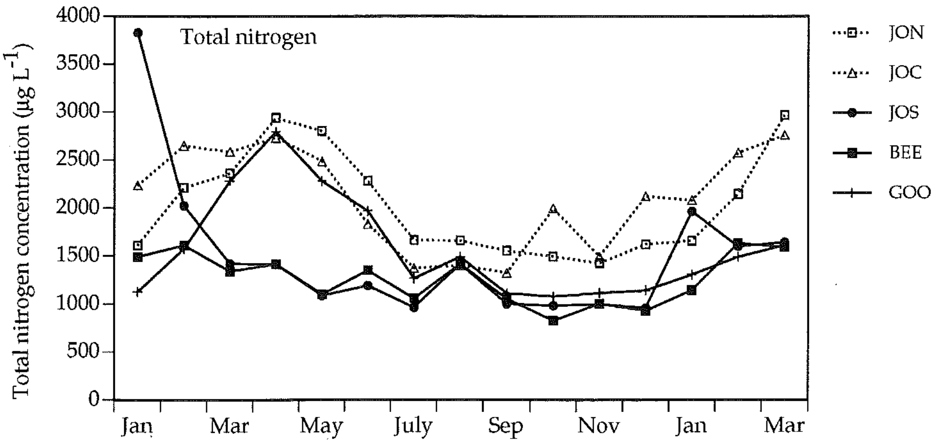


Figure 2.14 Variation in monthly mean total nitrogen levels.

The site pattern for TN levels (Table 2.3, Figure 2.14) was quite different from that observed for phosphorus, with the highest values being recorded in Central and North Lake Joondalup and the lowest values in Beenyup Swamp and South Lake Joondalup. Mean values for TN were 2134 $\mu g\ L^{-1}$ for Central Lake Joondalup and 2094 $\mu g\ L^{-1}$ for North Lake Joondalup while mean values for South Lake Joondalup and Beenyup Swamp were 1425 $\mu g\ L^{-1}$ and 1257 $\mu g\ L^{-1}$ respectively. Lake Goollelal had a mean TN of 1507 $\mu g\ L^{-1}$.

In the larger water bodies, North and Central Lake Joondalup and Lake Goollelal, TN values exhibited highly seasonal patterns. In North and Central Lake Joondalup values ranged from around 1500 $\mu g\ L^{-1}$ in late winter rising to maximum values of around 3000 $\mu g\ L^{-1}$ in summer/autumn. Considerable variability and several high TN levels were recorded in Central Lake Joondalup throughout the spring and early summer period. This is most evident in the scatter graphs (Figure A12).

In contrast to the relatively high levels in Central and North Lake Joondalup, TN levels in South Lake Joondalup and Beenyup Swamp rarely exceeded the minimal levels found in the main water body of Lake Joondalup. The only evidence of a seasonal response was the transient high levels observed in South Lake Joondalup during both summer periods.

Total nitrogen levels were dominated by organic nitrogen and only low levels of inorganic nitrogen, nitrate/nitrite and ammonium, were recorded. The site patterns for inorganic nitrogen (Table 2.3, Figures 2.16 & 2.17) were essentially the reverse of those observed for TN and ON and closely paralleled those observed for phosphorus. For nitrate/nitrite the highest mean values were recorded at Beenyup Swamp (28 $\mu g\ L^{-1}$) and South Lake Joondalup (17 $\mu g\ L^{-1}$), with very low levels in Central and North Lake Joondalup and Lake Goollelal. The highest ammonium nitrogen mean values were also at Beenyup Swamp (60 $\mu g\ L^{-1}$) and South Lake Joondalup (33 $\mu g\ L^{-1}$), with lower levels at the other sites.

There were no obvious seasonal trends in inorganic nitrogen at any of the five sites. There were, however, differences in variability in inorganic nitrogen across the sites. Inorganic nitrogen values in North Lake Joondalup and Lake Goollelal were almost uniformly low throughout the study. Greater variability was evident in Beenyup Swamp, South Lake Joondalup and Central Lake Joondalup as shown in the scatter graphs (Figures A14 & A15). In particular, ammonium values

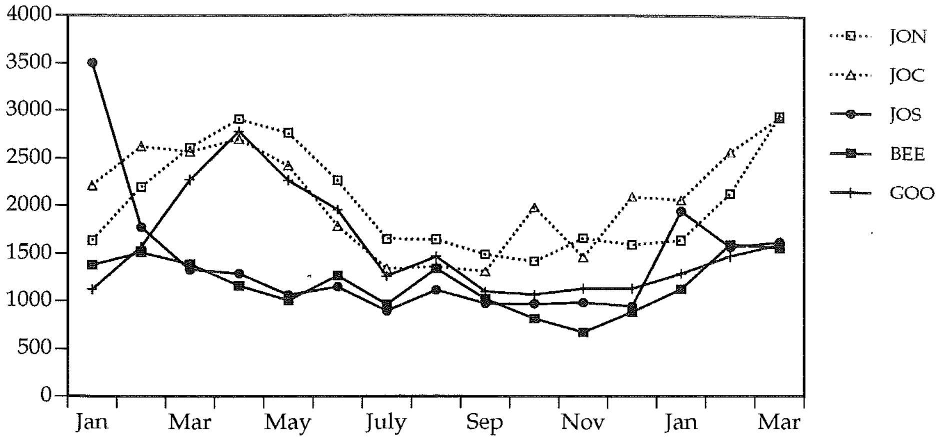


Figure 2.15 Variation in monthly mean organic nitrogen levels.

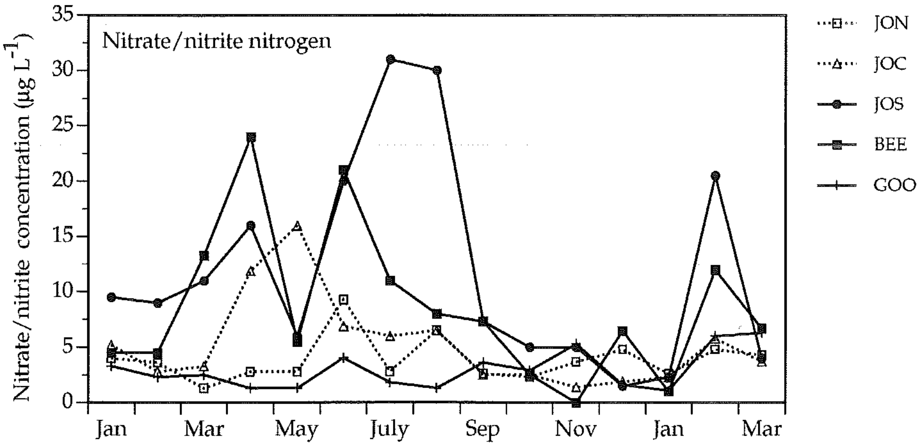


Figure 2.16 Variation in monthly mean nitrate/nitrite nitrogen levels.

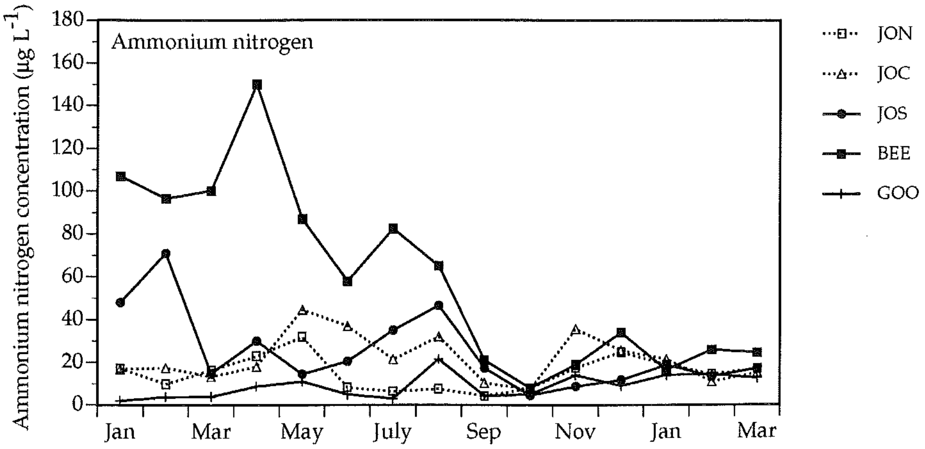


Figure 2.17 Variation in monthly mean ammonium nitrogen levels.

in Beenyup Swamp exhibited considerable variability during the unusually wet summer/autumn period in 1992, and only decreased to minimal levels at the end of winter. In Central Lake Joondalup considerable variation in ammonium nitrogen was also present, most evident in the winter/spring periods.

Chlorophyll *a* Chlorophyll *a* levels are summarised in Table 2.3, and presented graphically in Figure 2.18 and Figure A16. Proceeding from north to south the mean chlorophyll *a* levels were as follows: North Lake Joondalup (10 μg L^{-1}), Central Lake Joondalup (22 μg L^{-1}), South Lake Joondalup (19 μg L^{-1}), Beenyup Swamp (9 μg L^{-1}), and Lake Goollelal (16 μg L^{-1}).

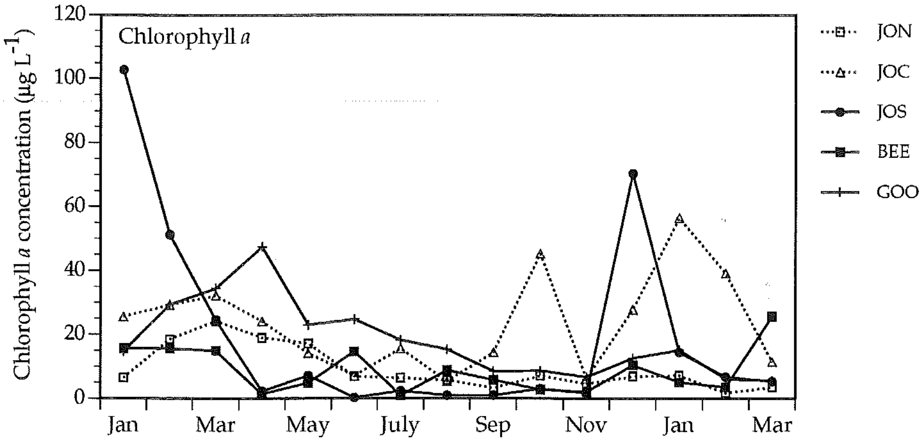


Figure 2.18 Variation in monthly mean chlorophyll *a* levels.

The most striking feature of these data was the absence of a consistent response of chlorophyll *a* to the substantial phosphate enrichment observed in Beenyup Swamp and South Lake Joondalup. Chlorophyll *a* levels in Beenyup Swamp were below 5 μg L^{-1} for most of the sampling period and this site had the lowest mean chlorophyll *a* levels of all sites. In South Lake Joondalup, chlorophyll *a* levels were also usually low, below 5 μg L^{-1}, except for isolated very high levels associated with algal blooms that occurred in both summers. These blooms appeared to be transient and for most of the year chlorophyll *a* levels were low.

Central Lake Joondalup had the highest mean chlorophyll *a* value of all the sites. The highest levels were evident in the summer months of early 1992 and again in the subsequent spring and summer months. These high values were associated with algal blooms occurring during the warmer months of the year.

North Lake Joondalup had a lower mean chlorophyll *a* value than both Central and South Lake Joondalup. For Lake Goollelal the mean chlorophyll *a* value (16 $\mu g\ L^{-1}$) was relatively high. For both these sites chlorophyll *a* levels were higher during the wet summer of 1991/1992 but these values were not replicated in the subsequent summer.

2.4 MULTIVARIATE ANALYSES

Hierarchical agglomerative clustering routines identified two clear interpretable site clusters which separated all Beenyup Swamp and South Lake Joondalup sites from the remainder (Figure 2.19). This site pattern was also obtained when the sites were ordinated over three dimensions (Figure 2.20), with the best separation occurring over axes 1 and 3. Beenyup and South Lake Joondalup sites differed from the other sites in having the highest mean levels of total and reactive phosphorus, but the lowest mean levels of total nitrogen, dissolved oxygen, pH and conductivity.

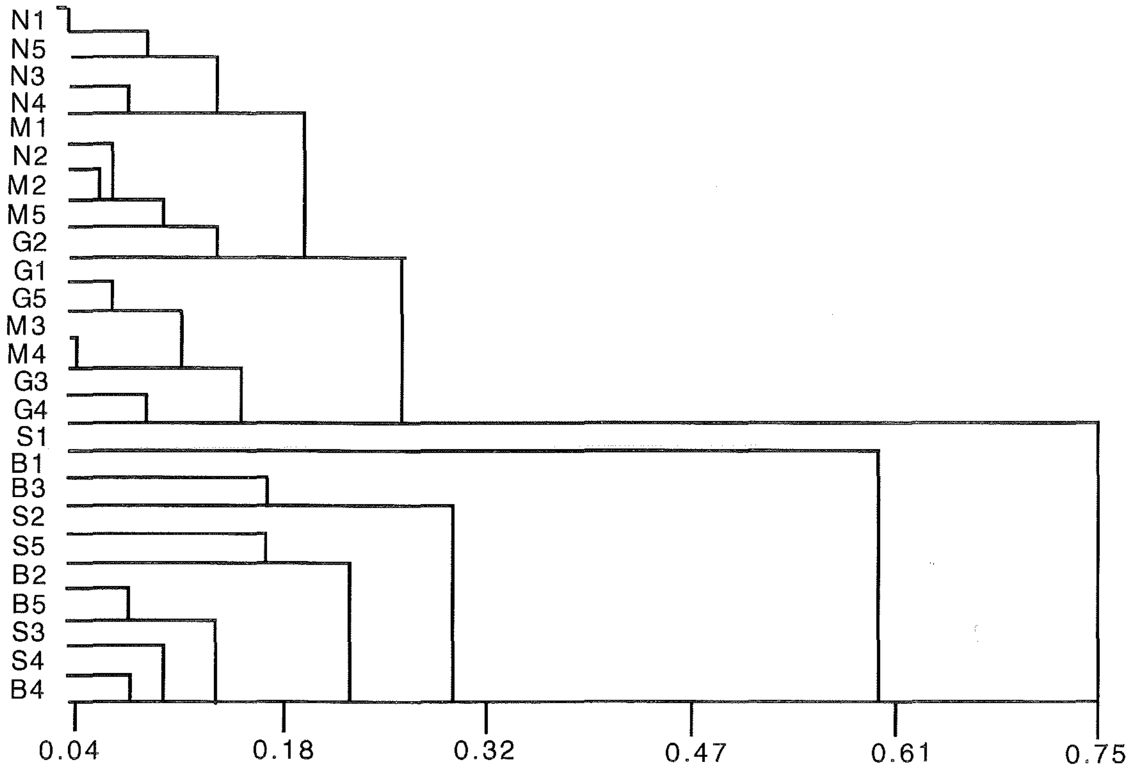
Note also that classification and ordination procedures indicated some separation of S1, the wet summer samples from South Lake Joondalup. The water chemistry of this site during this period was distinctive because of the isolated but very high, transient chlorophyll *a* levels.

2.5 DISCUSSION

Conductivity, metal ion concentrations & chloride ion concentration

The seasonal rainfall pattern and evaporation rates (wet winters and hot dry summers) are reflected in the strong seasonal changes in the conductivity and concentrations of metal and chloride ions in the wetlands. The marked seasonal variations resulted from changes in the volume of the water bodies arising from summer concentration due to evaporation and winter dilution resulting from higher rainfall and increased flow into the wetlands. These seasonal changes are particularly obvious for Lake Joondalup, where larger seasonal variations would be expected due to the relatively large surface area and shallow depth.

It was clearly noticeable from the data that the salinity levels and ionic concentrations (Figures 2.2-2.7) fell more quickly and there was greater variability in Central Lake Joondalup than in North Lake Joondalup following the onset of winter rains. This



Gower Metric Association Measure

Figure 2.19 Hierarchical agglomerative clustering of water chemistry variables (TN, nitrate/nitrite nitrogen, ammonium nitrogen, chlorophyll *a*, pH, TP, reactive phosphorus, dissolved oxygen and conductivity) of five wetland sites sampled over five consecutive seasons, 1: summer/92 to 5: summer/93.

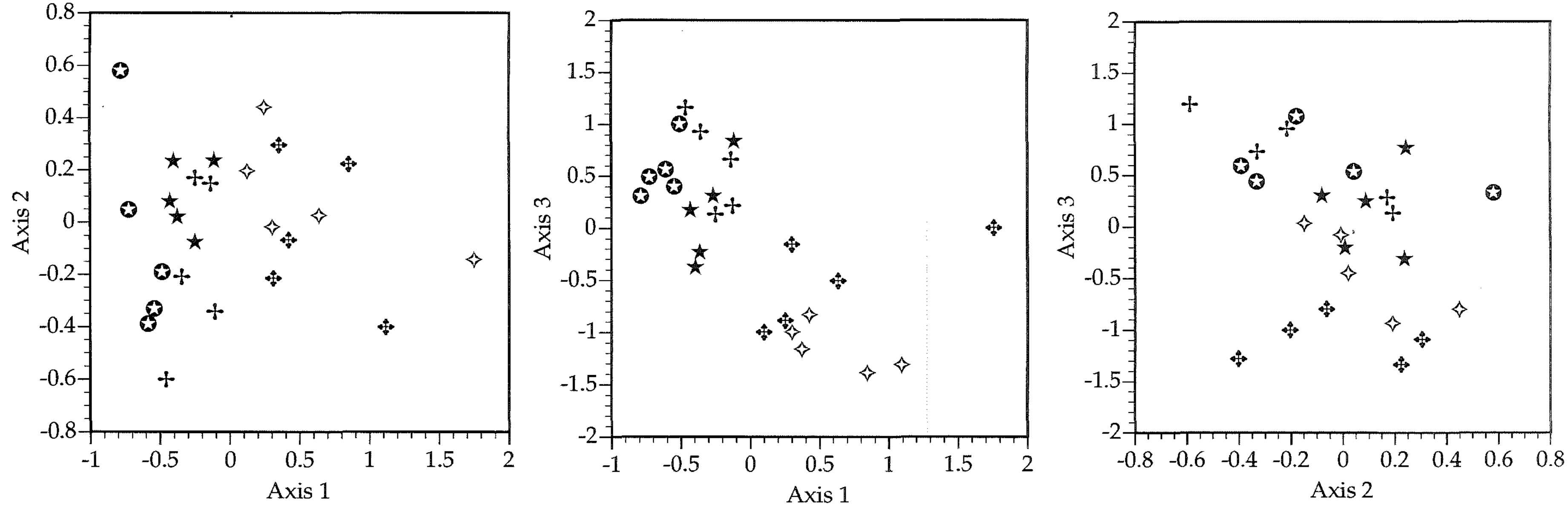


Figure 2.20. SSH ordination of selected water chemistry variables (TN, nitrate/nitrite, ammonium nitrogen, chlorophyll *a*, pH, TP, reactive phosphorus, dissolved oxygen and conductivity) of five wetland sites sampled over five consecutive seasons (summer/92 to summer/93): ✣: Beenyup Swamp; ✧: South Lake Joondalup; +: Central Lake Joondalup; ✪: North Lake Joondalup; ★: Lake Goollelal. Values ordinated are the seasonal means. Stress = 0.046.

was the result of inflow of less saline water from Beenyup Swamp and South Lake Joondalup when the water level was sufficiently high to join South and Central Lake Joondalup water bodies through the Ocean Reef Road culvert. As this flow reached the more northerly sections of the lake the salinity levels in North and Central Lake Joondalup became more similar.

The high conductivity and ionic levels in these lakes appears to be an established chemical feature of these wetlands, the mean conductivities corresponding approximately to total dissolved salts of 500 mg L^{-1} for Lake Goollelal, Beenyup Swamp and South Lake Joondalup and 900 mg L^{-1} for Central and North Lake Joondalup. These high levels are likely to be mainly a result of their proximity to the coast with consequent precipitation of ionic salts from ocean spray (Congdon & McComb, 1976). In addition, the wetland chemistry is influenced by groundwater inflow together with their location within the Spearwood Dune System and associated limestone formations.

Table 2.4 presents the mean metal ion concentrations for each site in millimoles per litre. As found in previous studies (Congdon, 1985; Davis and Rolls, 1987) sodium was clearly the dominant cation in the wetlands, followed by calcium and magnesium, and potassium. The relative dominance of sodium, together with chloride being the dominant anion, supports the contention that the precipitation of airborne sea spray is the major determinant of the ionic composition of the wetlands.

SITE	**Sodium** (mmol L^{-1})	**Potassium** (mmol L^{-1})	**Calcium** (mmol L^{-1})	**Magnesium** (mmol L^{-1})	**Chloride** (mmol L^{-1})
Lake Goollelal	3.8	0.28	0.9	0.7	4.5
Beenyup Swamp	3.7	0.16	1.1	0.6	4.2
South Lake Joondalup	3.7	0.16	1.1	0.6	4.3
Central Lake Joondalup	6.4	0.21	0.8	1.1	9.3
North Lake Joondalup	7.0	0.21	0.7	1.2	10.2

Table 2.4 Mean metal ion and chloride concentrations (millimoles per litre) for the five sampled sites.

On a millimolar concentration basis, mean calcium ion concentrations were higher than magnesium ion concentrations for Lake Goollelal, Beenyup Swamp and South Lake Joondalup. This is consistent with findings across a number of wetlands located within the Spearwood Dune System (Schmidt & Rosich, 1993). However mean millimolar concentrations for magnesium ion were greater than for calcium in both Central and North Lake Joondalup, which constitute the main body of Lake Joondalup (Table 2.4). Davis and Rolls (1987) also reported higher summer concentrations of magnesium ions than calcium ions for Lake Joondalup.

The increase in concentration of sodium, potassium, magnesium and chloride ions from South to North Lake Joondalup and the decrease in calcium ion concentrations across the same profile is consistent with Congdon's (1985) survey of Lake Joondalup. The higher concentrations of calcium ions within South Lake Joondalup and Beenyup Swamp may be the result of lower pH values in these water bodies, leading to greater dissolution of limestone, or may be due to a greater level of ground water inflow with a higher level of calcium ions.

The conductivity, metal ion and chloride ion concentrations were all somewhat lower than found in previous studies (Congdon & McComb, 1976; Congdon, 1985; Congdon, 1986; Davis & Rolls, 1987). This is almost certainly the result of the abnormally high summer rains in December 1991/February 1992 which maintained higher than normal water levels throughout the duration of the study.

Dissolved oxygen

Dissolved oxygen levels were quite high for North Lake Joondalup and Central Lake Joondalup and are comparable with those reported in earlier studies (Congdon & McComb, 1976; Gordon *et al.*, 1981). These high levels are consistent with the relatively large surface area of the wetland system and its exposure to wind. As well, the abundant benthic plants and phytoplankton may contribute to these high levels through photosynthesis in daylight hours.

Lower levels of dissolved oxygen were evident in South Lake Joondalup and, particularly, Beenyup Swamp. The lower levels of dissolved oxygen in Beenyup Swamp may be due to the higher humic acid levels in this swamp which are often associated with enhanced levels of chemical oxidation (Schmidt & Rosich, 1993). The lower levels in South Lake Joondalup probably result from the inflow of less oxygenated water from

Beenyup Swamp. The considerable variability of dissolved oxygen levels in Central Lake Joondalup (Figure A7) also probably reflects the flow of less-oxygenated water from the south.

pH and alkalinity

The pH values observed in this study are consistent with those reported for Lake Joondalup in previous studies (Congdon & McComb, 1976; Gordon *et al.*, 1981; Congdon, 1986; Davis & Rolls, 1987). The pH values for all the wetland sites in the Yellagonga Regional Park were alkaline, as expected for wetlands associated with underlying limestone formations. The lowest pH values were observed in Beenyup Swamp in this study and previously (Congdon, 1986). It is likely that humic substances in the highly vegetated Beenyup Swamp contribute to the somewhat coloured water and to the near neutral pH in this swamp, in an otherwise strongly alkaline group of wetlands.

As reported by Congdon (1986), the northward flow of water from Beenyup Swamp is likely to be responsible for pH values in South Lake Joondalup that are lower than those in Central and North Lake Joondalup. The somewhat lower mean pH value and greater variability (Figure A8) in Central Lake Joondalup in late-autumn/winter coincided with the commencement of flow of less alkaline water from the south.

The pH values were relatively stable, with only limited evidence of seasonal variation. The lack of major seasonal variations in pH is probably due to the buffering action of the carbonate/hydrogencarbonate system (CO_3^{2-}/HCO_3^-). While seasonal variations were not large and were not consistent over the various wetland sites, slightly higher pH values were observed during the summer months in Lake Goollelal, South Lake Joondalup and Central Lake Joondalup. The slightly higher levels found at these sites in summer is probably associated with higher levels of productivity (Schmidt & Rosich, 1993). Increased productivity is associated with the consumption of dissolved carbon dioxide during photosynthesis. This leads to the production of OH^- by the following hydrolysis reaction;

$$HCO_3^- + H_2O = H_2CO_3 + OH^-$$

which, in turn, leads to an increase in pH. High isolated pH values in South Lake Joondalup in both summers were associated with high chlorophyll *a* concentrations due to algal blooms. This phenomenon in South Lake Joondalup was also reported to have occurred in 1979 (Congdon, 1986).

Wetlands located within limestone formations tend to have high concentrations of carbonate and hydrogencarbonate ions. Alkalinity values observed in this study were similar to those observed by Congdon (1986) and Davis & Rolls (1987). As postulated by Congdon, the alkalinity is higher at the southern end of the surface connected sites (South Lake Joondalup and Beenyup Swamp) and lower in North and Central Lake Joondalup. This decrease in alkalinity from south to north was mainly due to a marked seasonal variability in the alkalinity of Beenyup Swamp and South Lake Joondalup. Seasonal variations in alkalinity at the other sites, Central and North Lake Joondalup and Lake Goollelal were not pronounced but alkalinities were generally slightly greater during the summer months.

Nutrients and chlorophyll *a*

Previous studies

Two decades ago, Congdon & McComb (1976) published the first study of nutrients and planktonic algae in the main water body of Lake Joondalup. The study provided a benchmark for future changes in water chemistry and productivity as urbanisation proceeded. Their description of Lake Joondalup at that time was of a "mildly eutrophic" lake, with high levels of organic nitrogen which varied seasonally, and levels of inorganic phosphorus in the range 6-40 $\mu g\ L^{-1}$. Phytoplankton counts indicated blooms of the green algae *Dispora* sp occurring in April-June. These blooms were preceded by orthophosphate peaks and, in turn, were associated with and followed by increases in organic phosphorus and nitrogen. The presence of the blue-green alga *Anabaena spiroides* in August warned of future problems with this species if further enrichment of the lake occurred. However, in 1976, the authors concluded that phosphorus levels were probably limiting algal productivity, except for a short time in August.

Five years later, Congdon's intensive monitoring of the nutrients and phytoplankton biomass of Lake Joondalup and surrounding wetlands revealed substantial nutrient enrichment of surface water flowing into the southern end of the wetland from the two southern swamps, Walluburnup and Beenyup (Congdon, 1979; Congdon, 1986). This winter surface flow contributed 73% of the phosphorus input, largely in the form of reactive phosphorus, and 30% of the nitrogen input and rendered the wetlands "eutrophic or eu-polytrophic/ polytrophic" throughout.

The nutrient enrichment recorded by Congdon was accompanied by intense algal blooms particularly in the southern end of Lake Joondalup, and also in the main water body when water levels were minimal in summer/autumn. These algal blooms were dominated by the blue-green algae, *Anabaena* sp. (in the south) and *Microcystis* sp. (in the main water body). Similar dominance of *Anabaena spiroides* was recorded in 1985/86 for both Lake Joondalup and Lake Goollelal (Davis & Rolls, 1987). While reactive phosphorus, organic nitrogen and chlorophyll *a* levels had increased in the wetlands over the period 1975-1980, it was not possible to determine whether this reflected decreases in water levels which occurred over this period, as indicated by increasing chloride levels, or actual increases in nutrient loadings. Comparison of maximum reactive phosphorus and total phosphorus levels in Lake Joondalup across the 1975/76 and 1985/86 period led Davis & Rolls (1987) to conclude that substantial increases in phosphorus enrichment had occurred over the decade, probably as a result of urbanisation. However, the most recent data prior to our study described the main water bodies of both Lake Joondalup and Lake Goollelal as "mesotrophic", based on their annual mean total phosphorus levels (Davis *et al.*, 1993).

The present study

It is apparent from our study that the excessive nutrient input into Lake Joondalup from surface flow via Beenyup Swamp, first identified by Congdon in 1979, continues unabated. Many of the patterns we obtained in 1992/93 confirm those obtained in 1975-1980 (Congdon, 1986). At the same time, we observed spatial and seasonal trends which highlight the impact of rainfall variations on nutrient levels and which suggest that algal blooms in the central water body are becoming more frequent.

Trophic status

The strong nutrient gradients that we have described across the length of Lake Joondalup result in sites within the wetland with distinctive chemistries. The results of the multivariate analysis indicate a clear separation of Beenyup Swamp and South Lake Joondalup from the other wetland sites within Yellagonga Park. These different chemistries probably explain the somewhat conflicting descriptions of the trophic status for this water body in the literature.

The results of this study indicate continuing high levels of reactive phosphorus (RP) and total phosphorus (TP) throughout the Yellagonga wetlands. Based on the mean annual TP levels (86, 322, 260, 117 and 88 $\mu g\ L^{-1}$ respectively for Lake

Goollelal, Beenyup Swamp, South Lake Joondalup, Central Lake Joondalup and North Lake Joondalup) all five sites in this study would be classified as eutrophic using either the CEPIS (Salas & Martino, 1991) or OECD (1982) classification scheme for determining trophic category.

Annual mean total nitrogen (TN) levels of 1507, 1257, 1425, 2134 and 2094 μg L^{-1} respectively for Lake Goollelal, Beenyup Swamp, South Lake Joondalup, Central Lake Joondalup and North Lake Joondalup, are indicative of eutrophic status for Central and North Lake Joondalup and borderline mesotrophic/eutrophic status for the other sites (OECD, 1982). Finally, mean annual chlorophyll *a* levels (16, 9, 19, 22 and 10 μg L^{-1} respectively for Lake Goollelal, Beenyup Swamp, South Lake Joondalup, Central Lake Joondalup and North Lake Joondalup) and peak chlorophyll *a* levels indicate eutrophic status for Lake Goollelal, South and Central Lake Joondalup and borderline mesotrophic/eutrophic status in Beenyup Swamp and North Lake Joondalup.

Changes over twenty years

The addition of a second decade of water chemistry data (Table 2.5) to that tabulated by Congdon (1986) supports the claim that the high nutrient levels first recorded in the main water body of Lake Joondalup in the 1970s are being maintained and may, in fact, be increasing if changes in water levels are taken into account. The relationships between both RP and ON with chloride ion concentration suggest that the levels of RP and ON are as great as in previous studies, if one takes account of the different average water volume (as measured by chloride concentrations). Similarly, high maximum chlorophyll *a* levels remain a feature into the 1990s, and the most recent study (Upton, 1996) recorded maximum chlorophyll *a* levels in the main water body of 280 μg L^{-1} immediately north of the Ocean Reef Road culvert.

Limiting nutrient

Ratios of total nitrogen:total phosphorus (TN:TP) and inorganic nitrogen:reactive phosphorus (IN:RP) in the main Lake Joondalup waterbody over the period 1978-1992 are provided in Table 2.6 for those studies that involved substantial sampling. These TN:TP ratios have led some authors, in comparing these ratios to the 7:1 value found in aquatic algae and macrophytes (Wetzel, 1983), to postulate that phosphorus is the limiting nutrient in this waterbody. However the IN:RP ratios, which may be a better indication of relative available nutrients, suggest that nitrogen is now more likely to be the limiting nutrient for phytoplankton growth in these wetlands, supporting Congdon's (1986) earlier proposal.

YEAR	Reactive P (µg L^{-1})	Organic N (µg L^{-1})	NO_x-N (µg L^{-1})	NH_4-N (µg L^{-1})	Chl *a* (µg L^{-1})	Chloride (mg L^{-1})	SOURCE
1973	22 2 - 130	1980 852 - 4276				386 155 - 726	Congdon (1973) as cited in Congdon (1986)
1975	19 1 - 35	1726 1260 - 2475		20 5 - 74	4 1 - 8		Gordon (1975) as cited in Congdon (1986)
1978	23 4 - 63	1538 933 - 2272	6 1 - 29	79 11 - 371	12 1 - 58	283 91 - 619	Congdon (1986)
1979	45 11 - 402	2671 845 - 4731	4 1 - 66	66 5 - 1024	17 2 - 73	507 147 - 1068	Congdon (1986)
1980	52 7 - 187	3456 425 - 23011	5 1 - 76	95 6 - 1684	47 2 - 440	617 164 - 1736	Congdon (1986)
1985/6	25 12 - 187	1638	13 2 - 13	23 12 - 101	v. low	603	Davis & Rolls (1987)
1992/3	28 0 - 218	2093 818 - 5883	4 1 - 193	19 1 - 225	16 0 - 134	334 132 - 598	This study

Table 2.5 Comparisons of selected water chemistry data obtained for the main waterbody of Lake Joondalup from studies conducted over the last two decades.

The data in Table 2.6 clearly indicate a relative increase in phosphorus in the surface connected wetlands over the last fifteen years. Ratios of TN:TP decreased from 35:1 in 1978 to 21:1 in the present study. As well, IN:RP ratios fell from 3.7 to 0.8 in the same period. The reductions in these ratios is likely to be the result of consistent input of phosphate-enriched water flowing from the south. It is worth noting that the two sites with the greatest propensity for forming blue-green algal blooms were South Lake Joondalup and Central Lake Joondalup where *Anabaena* sp. and *Microcystis* sp. were observed on many occasions throughout the study. These sites had low IN:RP ratios of 0.3:1 and 0.8:1 respectively. Schindler (1977) has suggested that an IN:RP ratio of <8:1 results in a shift in phytoplankton populations to blue-green algae because of their nitrogen fixing ability. Other sites in the wetlands also have IN:RP ratios that would make them susceptible to the formation of blue-green algal blooms.

RATIO	1978	1979	1980	1985/86	1992/93
Total nitrogen: total phosphorus (TN/TP) ratio	35	30	35	47	21
Inorganic nitrogen: reactive phosphorus (IN/RP) ratio	3.7	1.6	1.9	1.5	0.8

Table 2.6 Comparisons of total nitrogen (TN) : total phosphorus (TP) and inorganic nitrogen (IN) : reactive phosphorus (RP) obtained for the main waterbody of Lake Joondalup from studies conducted over the last two decades.

Spatial and temporal patterns

The spatial and temporal patterns of phosphorus and nitrogen (the two most important nutrients relating to eutrophication), and chlorophyll *a* levels (as an indicator of primary productivity), provide the most important information from a future management view for Lake Joondalup and its surrounds. We found distinct and unique differences in spatial and temporal patterns for each of these three eutrophic descriptors within the surface-connected wetlands of Lake Joondalup.
The negative south-to-north gradients in mean TP and mean RP levels first described by Congdon in 1986 were verified by this study, with highly phosphorus-enriched sites in Beenyup Swamp and South Lake Joondalup. The noticeably higher levels

of RP and TP observed at these sites and the relatively high RP:TP ratios suggest inflow of phosphate-enriched water into Beenyup Swamp. Congdon (1986) suggested that these high levels of phosphorus were due to water entering Beenyup Swamp from Walluburnup Swamp and that potential sources for the high nutrient levels included a caravan park and agricultural land used for market gardening, grazing, poultry farms and viticulture.
Spatial gradients in TN and ON levels were the reverse of those observed for phosphorus, with the main water body of Lake Joondalup (Central and North) having substantially higher mean values than southern sites. This is due both to higher minima in winter (means of 1500 µg L^{-1} in the north compared with 1000 µg L^{-1} in the south) and higher maxima in the warmer months when water volumes are lowest. In the main waterbody, increases in chlorophyll *a* occurred in the warmer months and contributed to the increases in organic nitrogen at these times. Thus, the higher overall mean values for ON in the main water body of Lake Joondalup appear to have two sources, one associated with phytoplankton blooms which occurred in summer/autumn and the following spring/ summer, and a higher minimum value of nitrogen natural to these areas which varies seasonally with water volume. Relatively high nitrogen values in the main water body of Lake Joondalup have been recorded previously (Congdon, 1979; Davis & Rolls, 1989) and may reflect the release of nitrogen from the dense macrophyte vegetation and benthic hydrophytes that inhabit these areas. These vegetation communities are not as evident in the southern section of the lake.

The very high organic nitrogen values which Congdon (1986) recorded for the southern end of Lake Joondalup and which obscured any south-to-north trends in his study were most likely a result of the extremely high levels of chlorophyll *a* which he measured at this site. We obtained chlorophyll *a* values approaching those of Congdon only in the warmer summer months. Otherwise, values were consistently lower.

The levels of inorganic nitrogen found throughout the wetlands are quite low in comparison to levels of organic nitrogen. The percentages of mean TN attributable to mean IN ranged from 0.8% in Lake Goollelal to 7% in Beenyup Swamp. While ON is commonly the dominant fraction of total nitrogen, usually over 90% in Swan Coastal Plain lakes (Davis & Rolls 1987; Schmidt & Rosich, 1993), the levels of inorganic nitrogen found in this study are unusually low but consistent with previous findings (Congdon, 1986; Davis & Rolls, 1987). The spatial patterns in

IN are also opposite those found for TN, with higher levels in Beenyup Swamp and South Lake Joondalup, mirroring the higher levels of RP found at these sites. The relatively high levels of ammonium nitrogen in Beenyup Swamp in the unusually wet summer period of 1991/1992 may reflect enhanced microbial activity in the sediments, a process that would also explain the very low oxygen levels in the wetland over much of this period. No such potentially biologically-limiting oxygen levels were found elsewhere in these wetlands, though substantial bottom deoxygenation over summer has been recorded in other Swan Coastal Plain lakes (Davis *et al.*, 1993).

The presence of anoxic conditions above the sediments in the heavily-vegetated Beenyup Swamp, has implications for the dynamics of sediment phosphorus and consequent management strategies. Efforts to restore shallow eutrophic lakes usually focus on reducing the external loading of phosphorus. However, this may not produce the expected reductions in phytoplankton biomass because of substantial internal loading of phosphorus from the sediments (Marsden, 1989). Significant improvements to water conditions in such situations may take 5 - 10 years, if recovery occurs at all (Krienitz, 1996). In shallow, non-stratifying lakes with high concentrations of phosphorus in the sediments (as Congdon, 1986, found for the sediments of Lake Joondalup), a sediment reservoir of labile organic material, an anaerobic hypolimnion enhancing redox-controlled P-release and a high pH can each contribute to the release of phosophorus from the sediments. The subsequent internal load can then determine the trophic status of the wetland (Marsden, 1989; Kleeberg & Kozerski, 1997). In addition, air-drying of sediments from eutrophic lakes can induce significant increases in phosphate release, under both aerobic and anaerobic conditions (Qui, 1994). Thus the regular drying of seasonal wetlands such as Beenyup Swamp and South Lake Joondalup may be followed by significant increases in internal phosphorus loadings when rewetting occurs.

The spatial patterns in mean chlorophyll *a* values did not reflect those for nutrient enrichment, particularly reactive and total phosphorus, and inorganic nitrogen. Despite the enriched water flowing into Beenyup Swamp, making it strongly eutrophic on nutrient criteria, the chlorophyll *a* levels were not as high as would be expected and, apart from the warmest summer months, rarely exceeded 5 $\mu g\ L^{-1}$. Congdon (1986) recorded a similar dystrophy during the winter-spring months and suggested that factors other than nutrients may be limiting phytoplankton growth. Beenyup Swamp is highly vegetated and shaded, with *Melaleuca* trees throughout the wetland, substantial decaying vegetation and woody material on the bottom sediment. The water is somewhat coloured, though gilvin levels are not sufficiently high to describe the wetland as "coloured" (Upton, 1996). Coloured wetlands are known to exhibit lower than expected algal growth under nutrient-enriched conditions (Wrigley *et al.*, 1988). Lower pH due to acidic humic substances and reduced light penetration have both been suggested as possible reasons for this reduction in productivity. At near-neutral pH or lower, cyanobacteria bloom genera such as *Anabaena* lose the competitive advantage they demonstrate at higher pH levels (Paerl, 1988). In Beenyup Swamp, it is likely that humic substances from this heavily-vegetated wetland contribute to the somewhat coloured water and also to the near-neutral pH in an otherwise strongly alkaline group of wetlands. Despite the relatively low gilvin levels present in Beenyup Swamp these humic substances may well be contributing to limit phytoplankton growth in a wetland characterised by high year-round phosphorus levels.

While the southern end of Lake Joondalup had a mean chlorophyll *a* level of 19 μg L^{-1}, this was largely a result of occasional very high levels associated with algal blooms. These occasional high levels were transient compared with those occurring in the adjacent central area. The water in this southern area was also noticeably coloured as a result of the northerly flow of coloured water from Beenyup and gilvin levels are intermediate between those of Beenyup Swamp and Central Lake Joondalup (Upton, 1996). (It is unlikely that the fragmented edge vegetation of this larger, open water area in South Lake Joondalup would contribute substantial gilvin). It is possible that the colour present here supported a similar process of algal inhibition to that occurring in Beenyup, though to a lesser extent. Similarly, the flow of less alkaline water from Beenyup is reflected in the pH of this southern end which is substantially below the highly alkaline levels of the main water body to the north. It should be noted, however, that the lower levels of chlorophyll *a* observed in South Lake Joondalup in this study may be atypical and may be a consequence of the higher water levels observed during this study. In Congdon's (1986) study algal blooms were a more consistent feature in this section of the lake.

In the main water body dystrophic conditions no longer prevailed to the same extent as in the adjacent south. Chlorophyll *a* levels were the highest of all in Central Lake Joondalup and algal blooms were frequently observed throughout this area, concentrated in the warmer months of spring and summer. Despite the lower levels of reactive and total phosphorus and inorganic nitrogen observed in this site the average productivity was noticeably greater than that observed for Beenyup Swamp and South Lake Joondalup.

In a recent study to investigate the nature of the relationship between phosphorus enrichment and phytoplankton growth in the southern wetland sites of Lake Joondalup (Upton, 1996), the major variables associated (negatively) with chlorophyll *a* levels in Beenyup Swamp and South Lake Joondalup were gilvin levels, pH and dissolved oxygen. The major variable associated with chlorophyll *a* concentrations in the water body immediately north of South Lake Joondalup (our Central site) was temperature. On the basis of her results, Upton (1996) suggested that the presence of toxic compounds in gilvin, originating in Beenyup Swamp, may be a significant factor in the inhibition of phytoplankton growth. Upton's results and those from this study are consistent with a higher level of productivity in Central Lake Joondalup being due to the dilution of the coloured water flowing from the south, and the consequent loss of the inhibiting effect of the coloured water on primary productivity.

Our observations and those of Upton (1996) suggest that the incidence of algal blooms in Central Lake Joondalup is increasing. Congdon's intensive sampling in 1979/80 revealed blooms only in the late summer/autumn period when evaporation produced high nutrient concentrations and water temperatures were optimal. Five years later, Davis & Rolls (1987; 1991) found no evidence of sustained or high phytoplankton growth in this area, though the limited sampling areas may have missed blooms in this large water body. They regarded Lake Joondalup as oligotrophic on this criterion. It is now clear that the main water body of Lake Joondalup can and does experience substantial algal blooms at any time of the year when temperatures are appropriate. Only during the periods of minimal winter temperatures and maximum surface flow were chlorophyll *a* levels reduced at these sites.

In North Lake Joondalup there was little obvious enhancement of phytoplankton growth, and only small increases in chlorophyll *a* were observed. This part of the lake was the least phosphorus enriched, reflecting the dilution factor in this, the deepest and most distant area from the highly-enriched south. In Lake Goollelal nutrient levels were similar to those observed in North Lake Joondalup. Interestingly, high chlorophyll *a* levels were observed during the unusually wet summer of 1991/1992 but there was no evidence of substantial algal blooms at other times. These two wetland areas, the physically isolated Lake Goollelal and the northernmost areas of Lake

Joondalup probably exemplify the least nutrient-disturbed components of the Yellagonga wetlands, with relatively low, but still eutrophic, phosphorus levels and limited phytoplankton growth.

2.6 SUMMARY

Lake Joondalup has been receiving highly nutrient-enriched water via northerly flow from Walluburnup and Beenyup Swamps for over two decades. Whether nutrient levels in the lake water are increasing or not is difficult to determine due to the different sampling designs and the varied analytical procedures used by researchers, as well as varying rainfall and run off patterns which influence lake fill and consequent dilution effects. However, there is no doubt that the wetland is strongly eutrophic due to substantial and sustained inputs of nutrients from sources that feed initially into Beenyup Swamp. This enrichment is resulting in algal blooms in the central sections of Lake Joondalup throughout the year.

Despite the flow of nutrients into the main water body, it appears that the humic substances in the highly-vegetated waters of Beenyup Swamp could be limiting phytoplankton growth in this particular wetland and, to a lesser extent, in neighbouring South Lake Joondalup. A definitive determination of the causes of the relatively low standing crop of phytoplankton in these sites is not yet possible and is worthy of further study. However, there seems to be little doubt that, in addition to providing high levels of nutrients to Lake Joondalup, the dystrophic nature of the surface water from Beenyup Swamp has a significant effect on the growth of phytoplankton in the southern parts of these surface connected wetlands.

3 MICROCRUSTACEA

Adrianne Kinnear & Patrick Garnett

3.1 METHODS

Samples were taken monthly for 15 months, commencing in January, 1992. The number of replicate samples at each of the five sites was varied to take into account the differing water areas. While the sampling method was designed primarily to sample the macroinvertebrates rather than the microcrustacea, we believe that the patterns obtained are biologically important and add significantly to the story.

Long-handled sweep nets (mesh size = 70 microns) were used to sample both the microcrustacea and macrofauna. Sampling effort at each site was standardised by netting through the entire water column for one minute. Sample sites were randomised by using a numbered grid overlay on a surface map of the wetlands and a random numbers table to select the grids which identified the sampling positions. Sampling sites were stratified by the presence or absence of emergent vegetation (described as "vegetated" or "open" habitat respectively). The pattern of the monthly sampling was as follows:

North Lake Joondalup: 12 samples (6 open water; 6 vegetated);
Central Lake Joondalup: 12 samples (6 open water, 6 vegetated);
South Lake Joondalup: 6 samples (3 open water, 3 vegetated);
Beenyup Swamp: 6 samples (3 open water; 3 vegetated);
Lake Goollelal: 12 samples (6 open water; 6 vegetated).

Faunal samples were preserved in 70% alcohol on site. They were then washed though 200 µm and 50 µm sieves and stored in fresh 70% alcohol for analysis.

For each sample, animals were identified to species wherever possible and species' abundances were recorded. When the numbers of microcrustacea were extremely large, abundances were calculated from subsamples (25% of the total sample).

Due to heteroscedascity and a lack of normality in the data despite transformation, the non-parametric Kruskal-Wallis one-way analysis of variance (SPSS software) was used to test for possible differences in mean abundance and species richness between months, sites and habitats.

For multivariate analyses, total abundances from open and vegetated habitats were pooled and mean seasonal relative abundance values for each of the five sites were calculated. The resulting site-by-species abundance matrix formed the inputs for the multivariate analyses. The 25 site-samples (5 sites x 5 seasons) were classified using hierarchical polythetic agglomerative clustering (FUSE) based on the unweighted pair group arithmetic averaging strategy (UPGMA) provided in the PATN software package (Belbin, 1989). Data for these sites were log transformed and standardised using the formula:

$$\frac{X-X_{min}}{X_{max}-X_{min}}$$

where X is the mean abundance of a species per sample. An association matrix was calculated using the Gower Metric association measure and the samples were ordinated using semi-strong hybrid multidimensional scaling (SSH).

3.2 RESULTS

Abundance and species diversity

A total of twelve microcrustacean species were identified (Table 3.1). All three orders of microcrustacea were represented at each site, though the relative abundances of the orders, and of species within the orders varied considerably both between sites and seasonally.

Both South Lake Joondalup and Beenyup Swamp sites had consistently greater abundances of microcrustacea than the other sites (Figure 3.1). This was particularly apparent in the wet first summer when water was retained in these sites over summer and into autumn. The sharp decline in abundance values in the following summer accompanied a normally dry season. The other sites showed strong seasonal abundance patterns, with peaks in the autumn-spring months.

All three variables of site, month of sampling and habitat significantly affected microcrustacean abundance. Similarly, date and site differences for species richness were significant though there was no significant difference between "open" and "vegetated" habitats (Table 3.2).

	Microcrustacean species	GOO	BEE	JOS	JOC	JON
CLADOCERA						
	Daphnia carinata	✓	✓	✓	✓	✓
COPEPODA						
	Calanoidea :					
	Calamoecia attenuata	✓	✓	✓	✓	✓
	Calamoecia tasmanica subattenuata	✓	✓	✓	✓	✓
	Boeckella sp.		✓	✓		
	Harpacticoida sp.		✓	✓		
	Cyclopoidea :					
	Cyclopoida mesocyclops	✓	✓	✓	✓	✓
	Cyclopoida macrocyclops	✓	✓	✓		
	Eucyclops sp.			✓		
OSTRACODA						
	Candonocypris novaezelandiae	✓	✓	✓		✓
	Cypretta baylyi		✓	✓		
	Sarcypridopsis aculeata			✓		
	Alboa wooroa				✓	✓
	Species Richness	6	9	11	5	6

Table 3.1 Distribution of microcrustacean species across the five sampled sites within the Yellagonga wetlands. (GOO = Lake Goollelal; BEE = Beenyup Swamp; JOS, JOC, JON = South, Central and North Lake Joondalup respectively).

	Date	Site	Habitat
Mean abundance / sample	$X^2=142.367$ $p<0.001$	$X^2=133.177$ $p<0.001$	$X^2=6.839$ $p<0.05$
Mean species richness / sample	$X^2=159.328$ $p<0.001$	$X^2=39.604$ $p<0.001$	$X^2=2.396$ $p<0.05$

Table 3.2 The Kruskal-Wallis H statistic (approximate chi-square) and levels of significance for one-way analyses of variance for relative abundance of microcrustacea and species richness on the variables site (water body sampled), habitat (open or vegetated water) and date (monthly samples).

Species richness was highest in the winter-spring period, and Beenyup Swamp and South Lake Joondalup had substantially greater species richness than the other sites (Table 3.1).

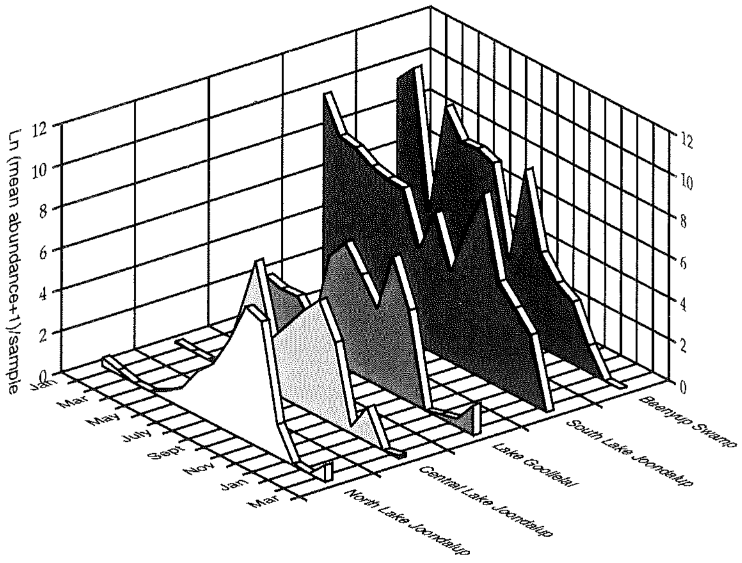


Figure 3.1 Relative total abundances by site of microcrustacea over the 15-month sampling period.

Species distributions

At the ordinal level of classification, Cladocera and Copepoda were the dominant taxa and there were seasonal differences both between and within sites.

Cladocera

The numerical dominance of the only cladoceran found, *Daphnia carinata,* in Beenyup Swamp and South Lake Joondalup was most obvious (Figure 3.2). Only with the onset of drying in the second summer period, did *Daphnia* abundances decline in these two sites.

Copepoda

The Copepoda were the numerically dominant group in Central and North Lake Joondalup and Lake Goollelal, with spring peaks at all sites. The cyclopoid, *Cyclopoida mesocyclops* was ubiquitous and relatively abundant (Figure 3.3), though abundance tended to peak earlier in the winter-spring period than the calanoid species (Figure 3.4). The remaining cyclopoid species *C. macrocyclops* and *Eucyclops* sp. were sampled only rarely and in very low numbers (often only 2-3 individuals per sample).

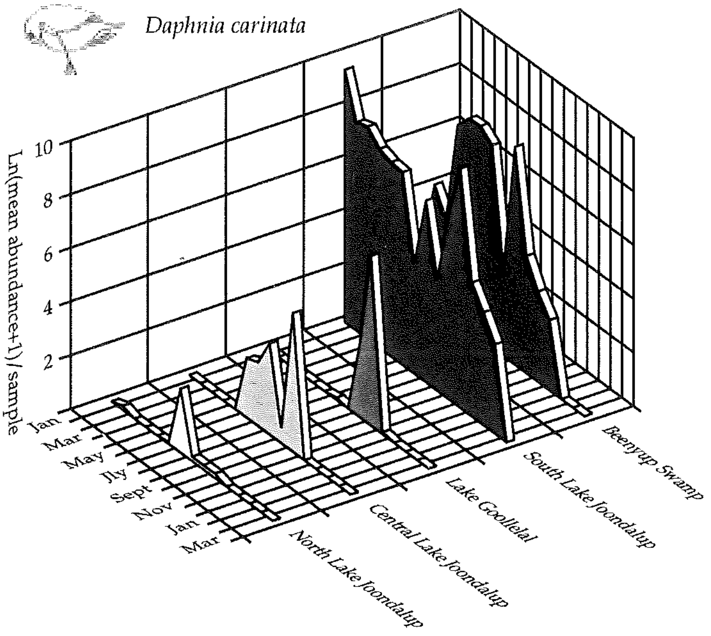


Figure 3.2 Seasonal changes in relative abundance of the cladoceran *Daphnia carinata.*

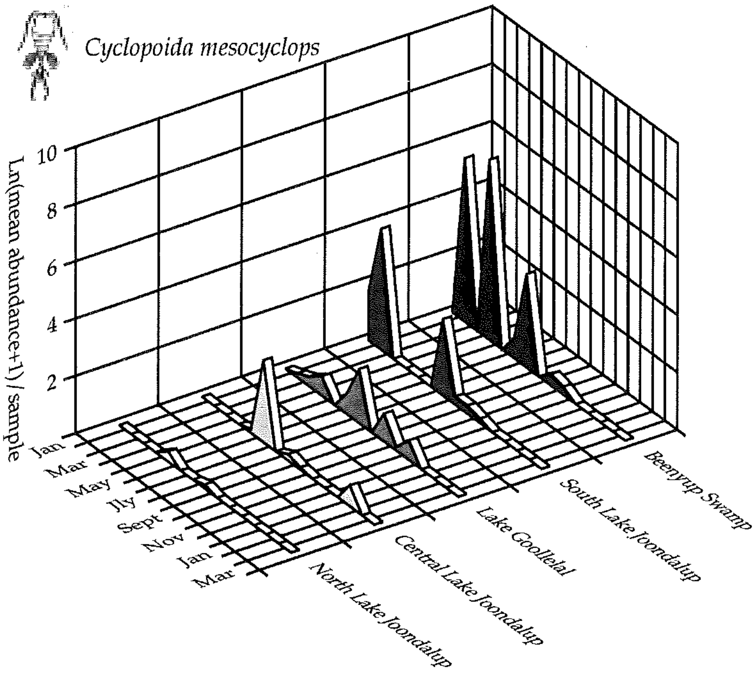
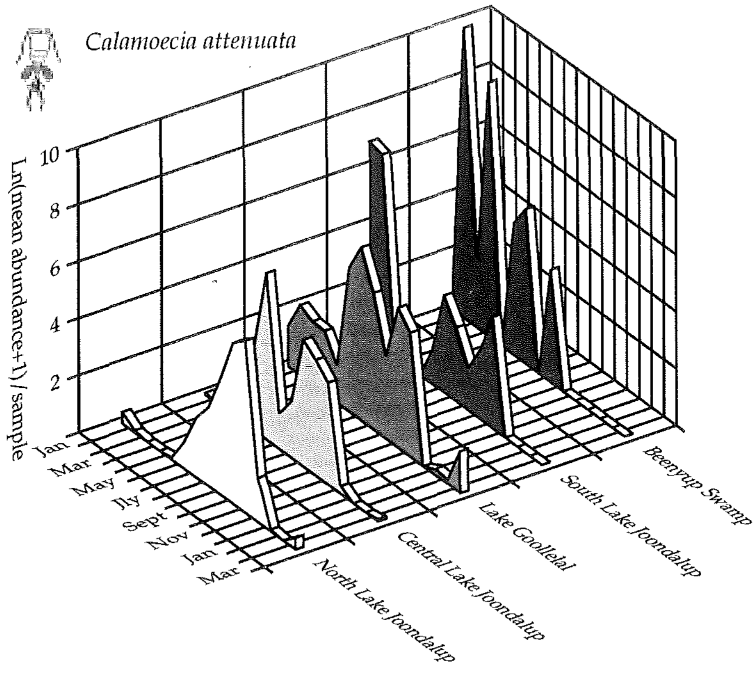


Figure 3.3 Seasonal changes in relative abundance of the cyclopoid copepod *C. mesocyclops*.



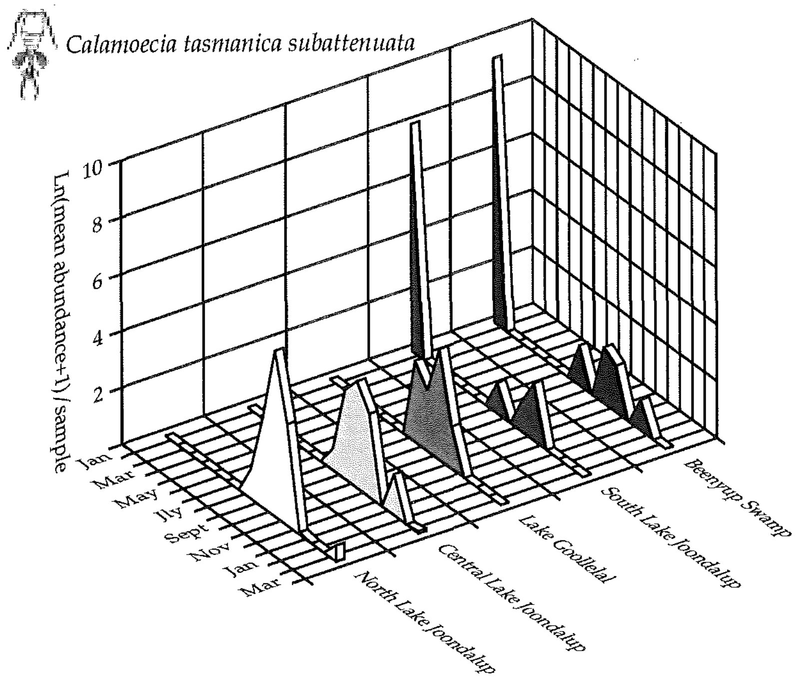


Figure 3.4 Seasonal changes in relative abundance of the calanoid copepod species.

Calanoids, in particular *Calamoecia attenuata* and *Calamoecia tasmanica subattenuata* were the most commonly sampled species (Figure 3.4). Both these calanoids were present at all five sites with peaks in the warmer spring months. In early 1992, the wet summer produced very marked but transient peaks in abundances of these two species in South Lake Joondalup and Beenyup Swamp. *C. attenuata* was more abundant generally and had a broader temporal distribution than *C. tasmanica subattentuata* which was not normally found in the wetlands until well after the onset of rains.

The two remaining calanoid species, *Boeckella* sp. and *Harpacticoida* sp. were found only in the South Lake Joondalup and Beenyup Swamp sites, and then only very transiently in the wet summer and spring.

Ostracoda

Ostracod populations were relatively small throughout the year at all sites. Numbers per sample were always below 50 in Lakes Joondalup and Goollelal and never exceeded 200 elsewhere. The distributions of the two most abundant ostracod species in the surface-connected Lake Joondalup /Beenyup Swamp wetlands were strikingly disparate. *Candonocypris novaezelandiae* was found only in the two southern sites and throughout the year, while *Alboa wooroa* was found only in the two northern sites and only in winter-spring (Figure 3.5). *Candonocypris novaezelandiae* was the only ostracod sampled from Lake Goollelal, in very low numbers and on only one sampling occasion. The remaining two species, *Cypretta baylyi* and *Sarcypridopsis aculeata* were only found rarely in South Lake Joondalup and Beenyup Swamp.

3.3 MULTIVARIATE ANALYSES

The dendogram in Figure 3.6 summarises the results of hierarchical agglomerative clustering of sites based on mean seasonal abundances of seven species occurring in at least 80% of the sample sites. Of most significance here is the production of four well-defined groups. The first two clearly separate all the highly phosphate-enriched South Lake Joondalup and Beenyup Swamp sites from the remaining sites. Samples taken from the unusually wet South Lake Joondalup and Beenyup sites in the summer (for both) and autumn (for the latter) formed a clear subgroup within the highly-enriched sites and they scored consistently high in copepod numbers over these warm months. The third grouping tended to separate out the winter-spring samples of Lake Joondalup proper and Lake Goollelal. The fourth remaining group clustered the dry summer/autumm samples from the main water body of Lake

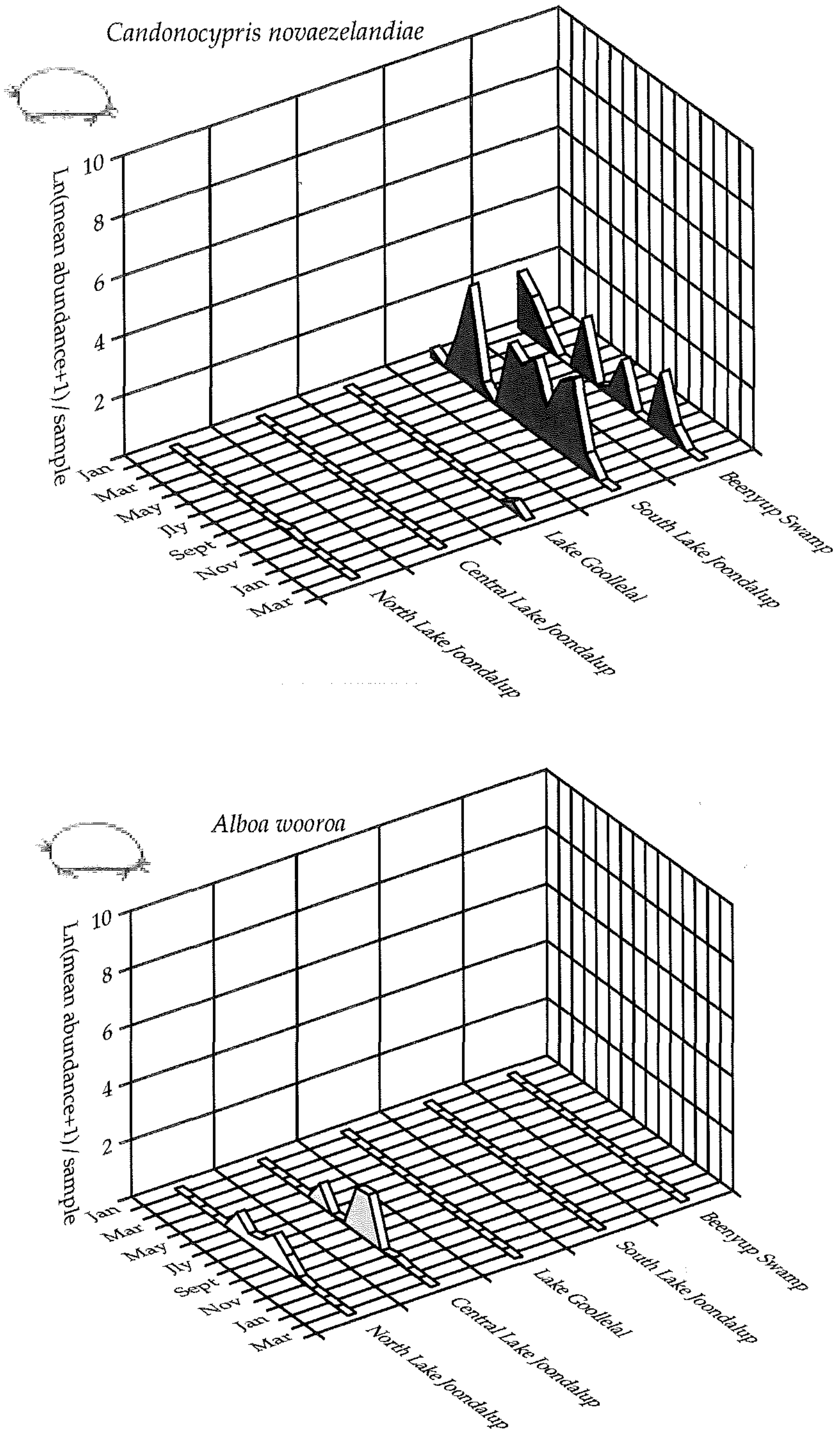
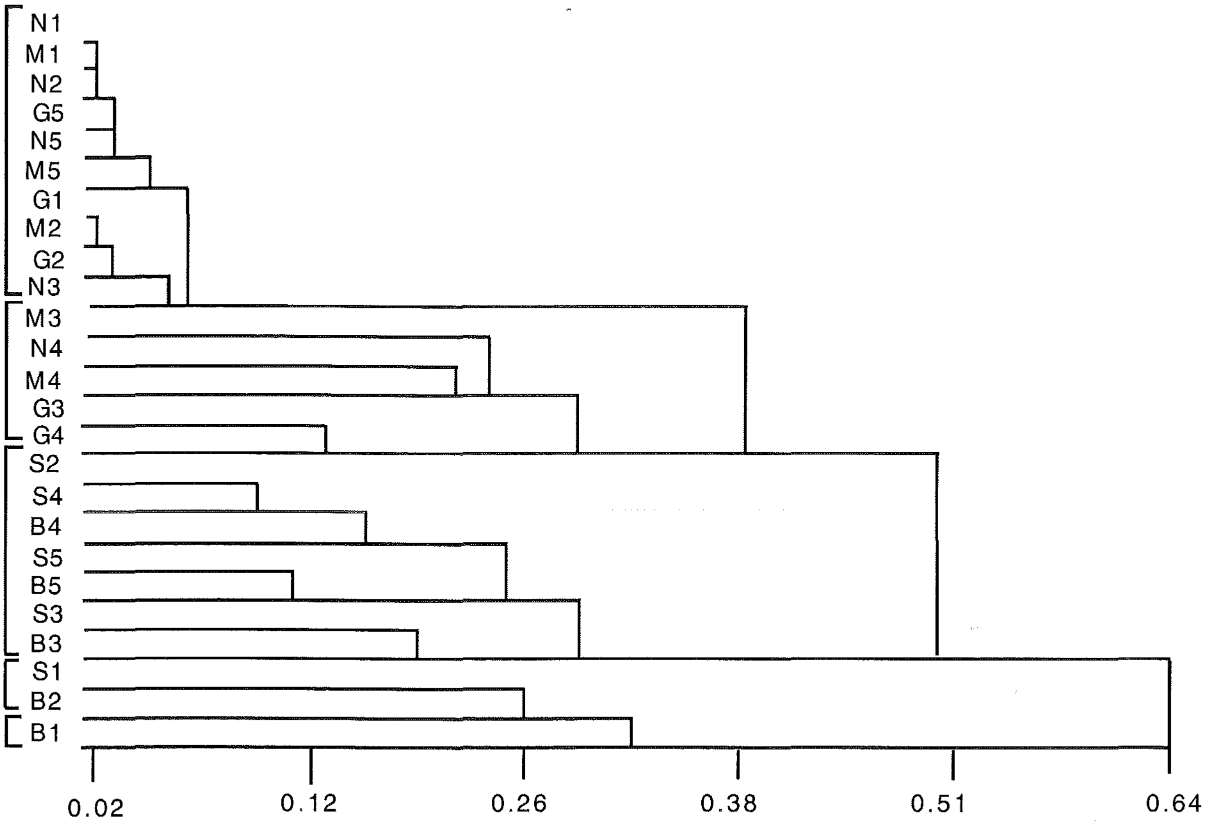


Figure 3.5 Seasonal changes in relative abundance of ostracod species.



Gower Metric Association Measure

Figure 3.6 Hierarchical agglomerative clustering of microcrustacean communities from five wetland sites sampled over five consecutive seasons (1: summer/92 to 5: summer/93).

Joondalup and Lake Goollelal. These sites were characterised at these times by an almost complete absence of microcrustacea in general, and of *Daphnia* in particular.

Figure 3.7 provides the SSH ordination plot based on abundance data of the seven species recorded at each site for each season. Ordination over three dimensions provided an acceptable stress level below 0.10. There is good concordance with the site classification pattern, with the South Lake Joondalup and Beenyup Swamp sites separating from the remaining sites, particularly along axes two and three. The ordination procedures produced extremely strong clustering of the Central and North Lake Joondalup and Lake Goolellal samples taken in the drier seasons, summer and autumn - the same samples forming the top cluster in Figure 3.6.

3.4 DISCUSSION

Microcrustacean species composition and abundance in South Lake Joondalup and adjacent Beenyup Swamp clearly separated these two sites from the others. The sustained high abundances and increased richness of this fauna likely reflects bottom-up effects of nutrient enrichment on primary and secondary productivity.

The most significant feature of the microcrustacean communities in these enriched sites was the extremely high populations of *D. carinata*. This single species, more than any other, was responsible for the high microcrustacean abundance throughout much of the year. *D. carinata* is common throughout wetlands on the Swan Coastal Plain (Davis *et al.*, 1993) and is well known to be tolerant of eutrophic conditions (Williams, 1980). Abundance more usually declines in summer in response to higher temperature (Mitchell & Williams, 1982) and is low in wetlands considered to be "coloured" (Lund *et al.*, 1991). Maintenance of water levels in South Lake Joondalup and Beenyup Swamp over the first summer, an unusual occurrence for these normally seasonal sites, was accompanied by peak abundances of this cladoceran, despite warm water temperatures. Certainly, in these enriched sites, temperature was not a factor limiting *Daphnia* abundance. A return to the dry conditions in the following summer was accompanied by a decline in cladoceran abundance more typical of seasonal wetlands.

The presence of large populations of daphiniids raises the possibility of grazing effects on phytoplankton at these sites, particularly given the observed relatively low levels of chlorophyll *a*. An increase in cladoceran populations has been correlated with decreased phytoplankton biomass and

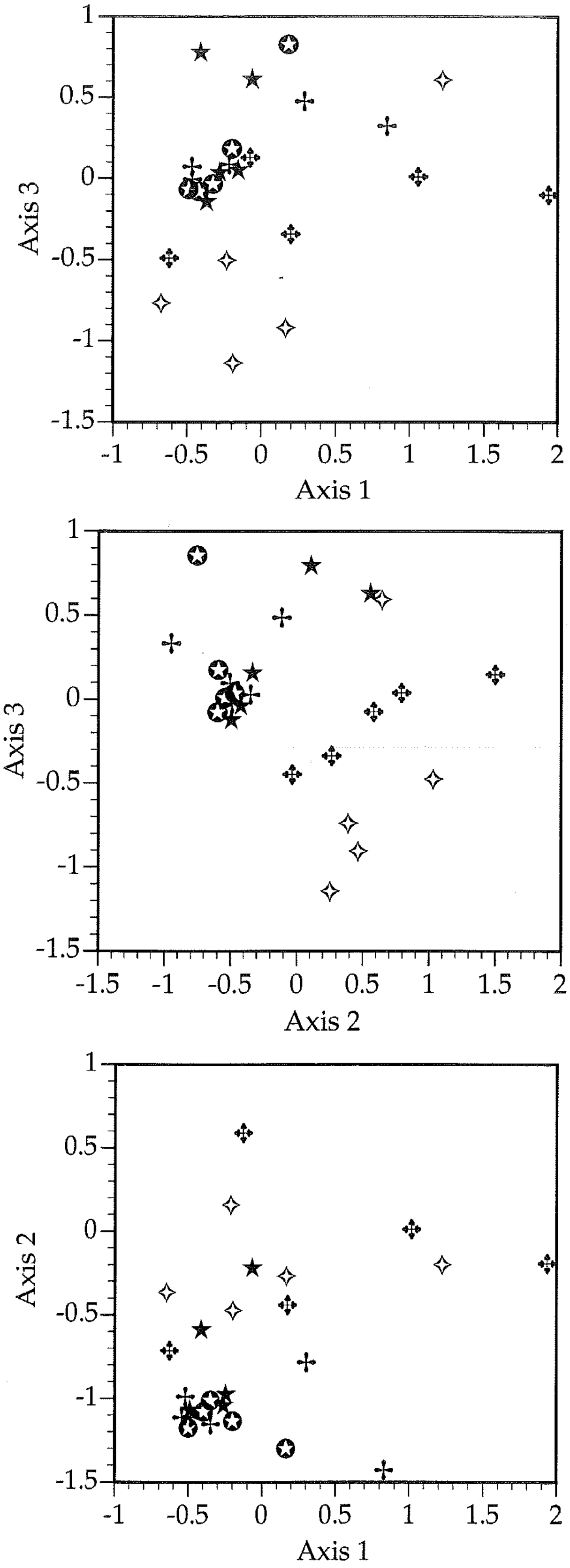


Figure 3.7 SSH ordination of microcrustacean communities from 5 wetland sites sampled over five consecutive seasons (summer/92 - summer/ 93).✣: Beenyp Swamp; ✧: South Lake Joondalup; +: Central Lake Joondalup; ✪:North Lake Joondalup; ★: Lake Goollelal. Values ordinated are the seasonal means. Stress = 0.08.

conversely, predator-removal of *Daphnia* sp. has been correlated with increases in biomass (Carvalho, 1994). As a result, species of *Daphnia* have been identified as possible top-down controllers of phytoplankton biomass. However, their ability to consume substantial amounts of phytoplankton biomass is variable (Shapiro & Wright, 1984; Post & McQueen, 1987) and depends on both the size of the cladocerans and the species of algae present (Schlinder, 1968). In particular, effective consumption of cyanobacteria which are responsible for nuisance blooms in eutrophic water bodies has not been demonstrated, probably because of their unpalatability, the presence of toxins, or their tendency to clog the filtering apparatus of the cladocerans (Gliwicz, 1990). Harris (1994) provides an eloquent discussion of the usefulness of biomanipulation procedures, noting their lack of success and constancy of outcomes in the management of eutrophic lakes in particular. He attributes the lack of success to the relative simplicity of the approach implicit in such practices in the light of the large non-linear interactions operating at various scales in these lakes and which impact on nutrient dynamics. Unlike oligotrophic and mesotrophic systems, eutrophic food chains seem to be less dependent on 'vertical' grazing links for nutrient regeneration and more connected to 'external' nutrient pools. However, the presence of substantial populations of *D. carinata* in Beenyup Swamp and South Lake Joondalup identifies the species as a major conduit for the flow of energy from primary producers through to the micro- and macro-invertebrate predators in the community.

A suite of microcrustacean species was ubiquitous throughout all the sampled sites, but with a trend towards increasing abundance in the two most P-enriched sites. This species suite was composed of the calanoid copepod C. *attenuata*, the cyclopoid C. *mesocyclops* and the ostracod C. *novaezelandiae*. Both the latter two species are very common and widespread inhabitants of Swan Coastal Plain wetlands and respond positively to both phosphate enrichment and eutrophication (De Deckker, 1983; Davis *et al.*, 1993).Calanoid copepods, on the other hand, are considered to be sensitive to both phosphate enrichment and eutrophic conditions (Mitchell and Williams, 1982). While C. *attenuata* dominated the wetlands surveyed by Davis *et al.* (1993), the calanoids in general appeared limited to those wetlands with low total phosphorus and low phytoplankton abundance. They tended to be numerically dominant in the coloured wetlands and to decrease in importance as eutrophication increased. Our observations suggest that while C. *tasmanicus subattenuata* abundance was higher in the least P-enriched sites, C. *attenuata* abundances showed no such responses. The lack of a sustained phytoplankton response in the southern sites despite the phosphorus enrichment with consequent maintenance of favourable water quality is a likely reason.

There was a second suite of species which exhibited disjunct distributions, and contributed to the separation of sites in the cluster and ordination analyses. The three species of copepods (*Boekella* sp., Harpacticoida sp. and *Eucyclops* sp.) and two species of ostracods (*C. baylyi* and *S. aculeata*) were found only in the Beenyup Swamp/South Lake Joondalup sites and then only in very small numbers and with transient populations. In contrast, *A. wooroa* was the only microcrustacean species whose distribution was restricted to the least eutrophic main water body of Lake Joondalup. This ostracod has been found only occasionally in eutrophic waters

As one would expect, a strong seasonal population effect was a common feature of the microcrustacean species with clear winter-spring abundance peaks. The wet summer in 1991/1992 produced unseasonal populations peaks in both Beenyup Swamp and South Lake Joondalup, contributing to the strong clustering of the summer samples from these sites in the classification and ordination analyses.

In summary, the two environmental variables which appear to influence most the abundance and species composition of the microcrustacea in the Yellagonga wetlands are the seasonal fluctuations in temperature and moisture, and the nutrient enrichment gradients, in particular phosphorus enrichment. The nutrient gradient which dominates the wetland areas of Yellagonga is reflected in the secondary productivity and is strong enough to reveal some of the same species correlates within the wetlands as other workers have found for inter-wetland comparisons, though the dystrophic nature of the most enriched sites dilutes these patterns to some extent.

The most phosphorus-enriched areas of South Lake Joondalup and Beenyup Swamp are characterised by extremely high and prolonged abundances of *Daphnia*, together with the enrichment-tolerant *C. mesocyclops* and *C. novaezelandiae*. Elsewhere in Lake Joondalup where phosphorus levels are lower (though still within a eutrophic range), *Daphnia* appears with the calanoid copepods *C. attenuata* and *C. tasmanicus subattenuata* and the ostracod, *A. wooroa* during the winter-spring period.

4 MACROINVERTEBRATES

Adrianne Kinnear & Patrick Garnett

4.1 METHODS

The stratified design and sampling method for the macroinvertebrates were as described for the microcrustacea in Chapter 3. With the exception of the Oligochaeta and Hirudinea, animals were identified to species wherever possible. Subsampling was not required to estimate abundances. Statistical and multivariate data analysis procedures were as described in Chapter 3.

4.2 RESULTS: FAUNAL ABUNDANCE

The mean abundance of the macroinvertebrate fauna differed between sites, between habitat types within sites and between sampling dates (Table 4.1).

	Date	**Site**	**Habitat**
Mean abundance/sample	$X^2=26.931$ $p<0.05$	$X^2=163.944$ $p<0.001$	$X^2=62.089$ $p<0.001$
Mean species richness/sample	$X^2=26.574$ $p<0.05$	$X^2=156.542$ $p<0.001$	$X^2=63.693$ $p<0.001$

Table 4.1. The Kruskal-Wallis H statistic (approximate chi-square) and levels of significance for one-way analyses of variance for relative abundance of macroinvertebrates and species richness on the variables site, habitat and date.

The largest invertebrate numbers were found in the most phosphorus-enriched sites, South Lake Joondalup and Beenyup Swamp (Figure 4.1). Peaks in faunal abundance were evident during the spring months. However, these were overshadowed by the very large abundances maintained in the three southernmost sites over the preceding summer-autumn as a result of the unusual summer rainfall.

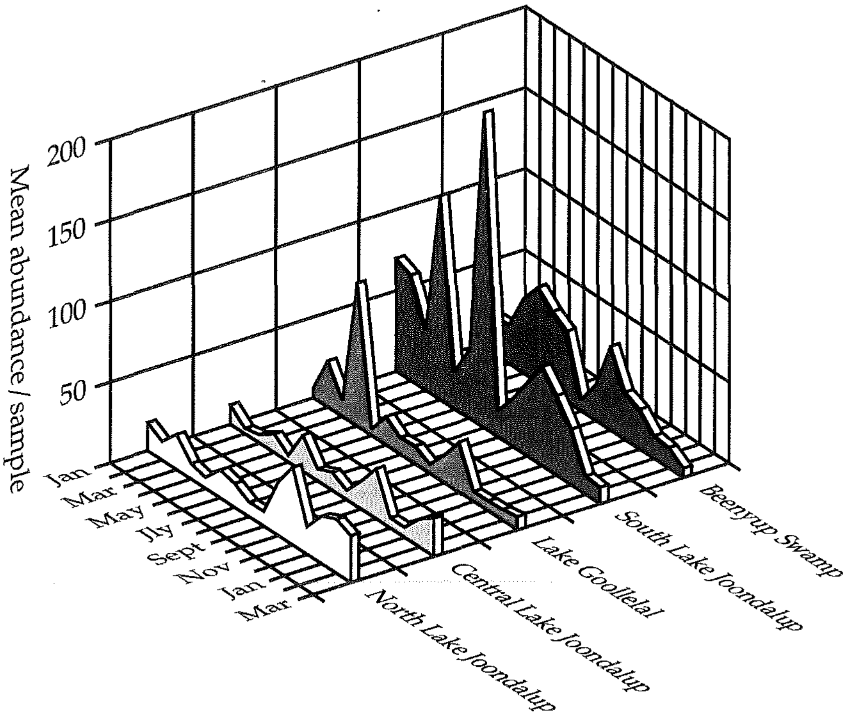


Figure 4.1 Spatial and seasonal patterns in relative abundance of macroinvertebrates over the 15-month sampling period.

The more usual dry summer of the next year saw faunal abundances decline to minimal values. Both Central and North Lake Joondalup sites retain water and hence some fauna over summer. In South Lake Joondalup, maximum abundances in late autumn correlated with large populations of the hemipteran, *Micronecta robusta*. In Central and North Lake Joondalup, and to a lesser extent, Lake Goollelal, the faunal abundance patterns reflected those of the abundant decapod *Palaemonetes australis*.

At all sites, habitats with emergent vegetation provided substantially greater abundances of macroinvertebrates than open water habitats (Table 4.2).

SITE	Habitat	Mean abundance / sample	
North Lake Joondalup	Open	13.2	1.9 (90)
	Vegetated	27.9	3.8 (90)
Central Lake Joondalup	Open	9.3	1.4 (45)
	Vegetated	28.1	4.6 (45)
South Lake Joondalup	Open	35.4	5.3 (45)
	Vegetated	74.1	23.1 (45)
Beenyup Swamp	Open	21.2	4.3 (90)
	Vegetated	39.6	7.4 (90)
Lake Goollelal	Open	4.9	0.7 (90)
	Vegetated	30.5	11.5 (90)

Table 4.2 Mean macroinvertebrate abundance by habitat for each of the wetland sites, calulated over the entire 15-month sampling period. Values indicate the Mean ± SE(n).

SPECIES RICHNESS & DIVERSITY

A total of 121 macroinvertebrate "taxa" were identified from the Yellagonga wetlands (Appendix B). Because the annelid taxon was not processed further, this total underestimates the true species diversity in the wetlands. The Decapoda (39%) and the Diptera (31%) were the numerically dominant taxa. Within these two groups, the shrimp, *P. australis* contributed almost exclusively to the decapod abundance, and the Chironomidae contributed the greater part of the dipteran abundance. Mollusca contributed 12%, followed by Ephemeroptera (4%), Oligochaeta (2%), Acarina (2%), and Trichoptera (1%). Hirudinea, Odonata and Coleoptera all contributed less than 1%.

Analysis at these higher taxonomic levels showed substantial differences in the distribution of taxa between the five wetland sites (Figures 4.2 and 4.3). The faunal community of the main water body of Lake Joondalup was dominated by the decapods (mainly *P. australis*) and gastropods (of the genus *Physa*). Relatively large numbers of *P. australis* were also found in Lake Goollelal. The proportions of Diptera (mainly Chironomidae) increased with position south and they represented the major faunal group in both Beenyup Swamp and Lake Goollelal.

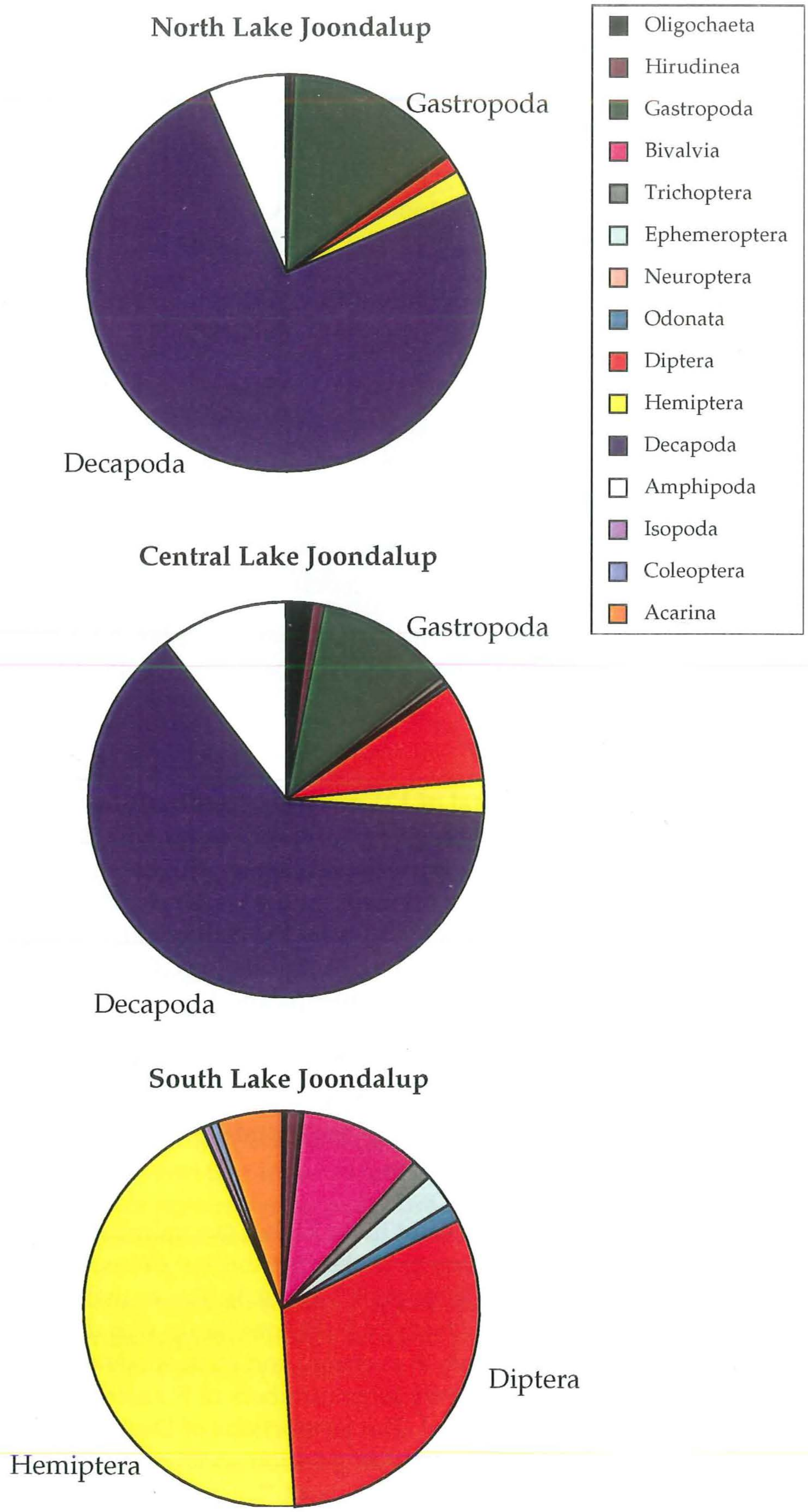


Figure 4.2 Relative abundances of ordinal taxa of macroinvertebrates sampled from three sites in Lake Joondalup.

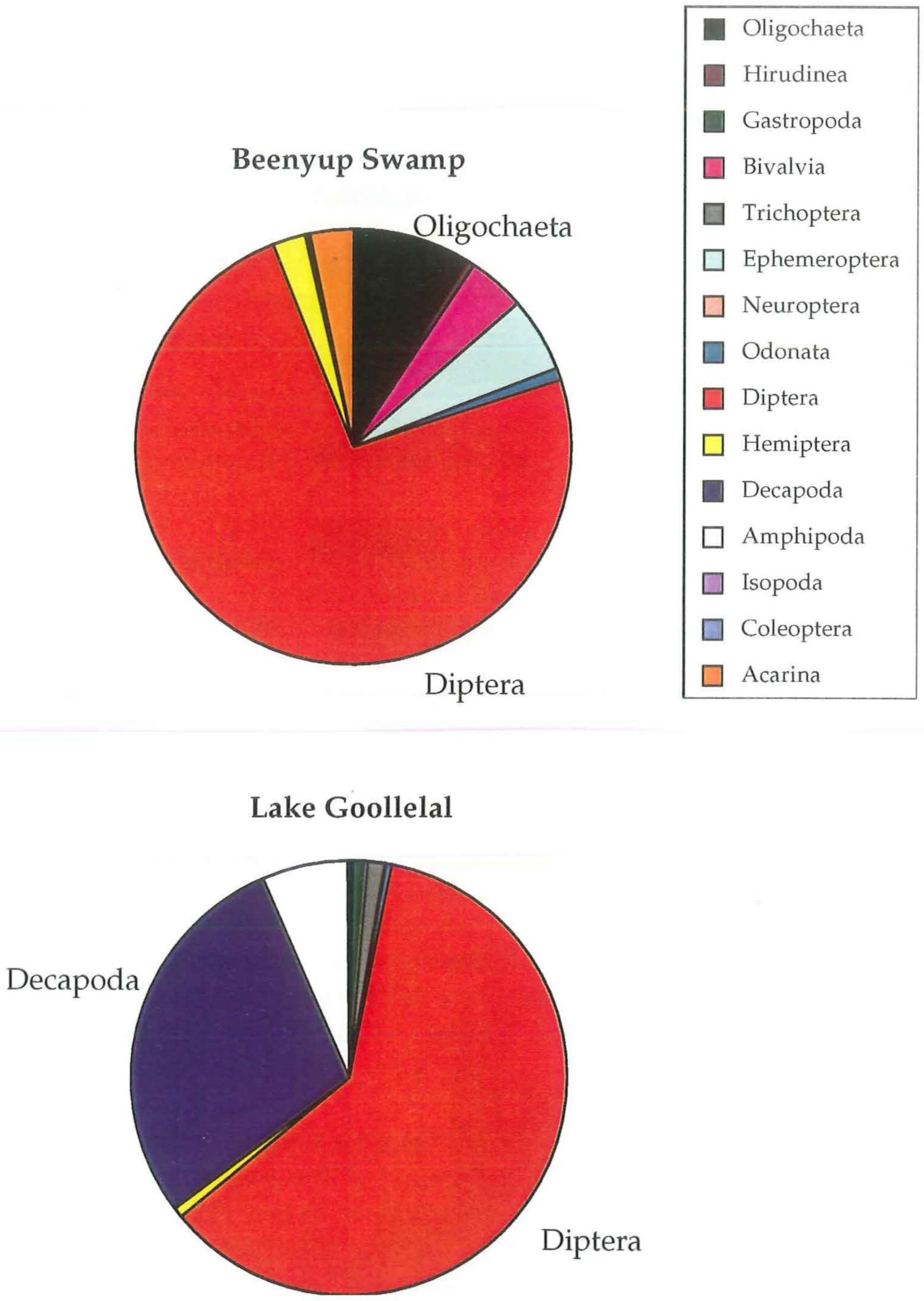


Figure 4.3 Relative abundances of ordinal taxa of macroinvertebrates sampled from Beenyup Swamp and Lake Goollelal.

South Lake Joondalup was the only site where the Hemiptera, largely *M. robusta,* were found in substantial numbers.

Species richness was higher in vegetated habitats (Table 4.3), though the differences between open water and vegetated habitats were less marked for the species-poor sites in Lake Joondalup.

SITE	Habitat	Mean species richness / sample	
North Lake Joondalup	Open	2.3	0.2 (90)
	Vegetated	2.8	0.2 (90)
Central Lake Joondalup	Open	2.1	0.2 (90)
	Vegetated	3.7	0.3 (90)
South Lake Joondalup	Open	6.7	0.6 (45)
	Vegetated	10.3	0.8 (45)
Beenyup Swamp	Open	4.2	0.4 (45)
	Vegetated	7.8	0.7 (45)
Lake Goollelal	Open	1.9	0.2 (45)
	Vegetated	4.0	0.3 (45)

Table 4.3 Mean species richness by habitat for each of the wetland sites, calculated over the entire 15-month sampling period. Values indicate Mean ± SE(n).

When data from all sampling occasions were considered, a large number of species (43) were sampled only from areas with emergent vegetation. These included well over half the species of Odonata (6 of 9), Coleoptera (9 of 14) and Trichoptera (7 of 11). On an individual site basis, the numbers of species found exclusively in habitats with emergent vegetation was relatively large (Figure 4.4).

There were significant effects of site, date and habitat type on the total numbers of species per sample (Table 4.1). South Lake Joondalup and Beenyup Swamp had the greatest number of taxa on all sampling dates, approaching the lower values in the other three sites only during the dry summer minimum (Figure 4.5). Generally, species richness was two to three times higher in these two sites (Table 4.4). The northernmost end of Lake

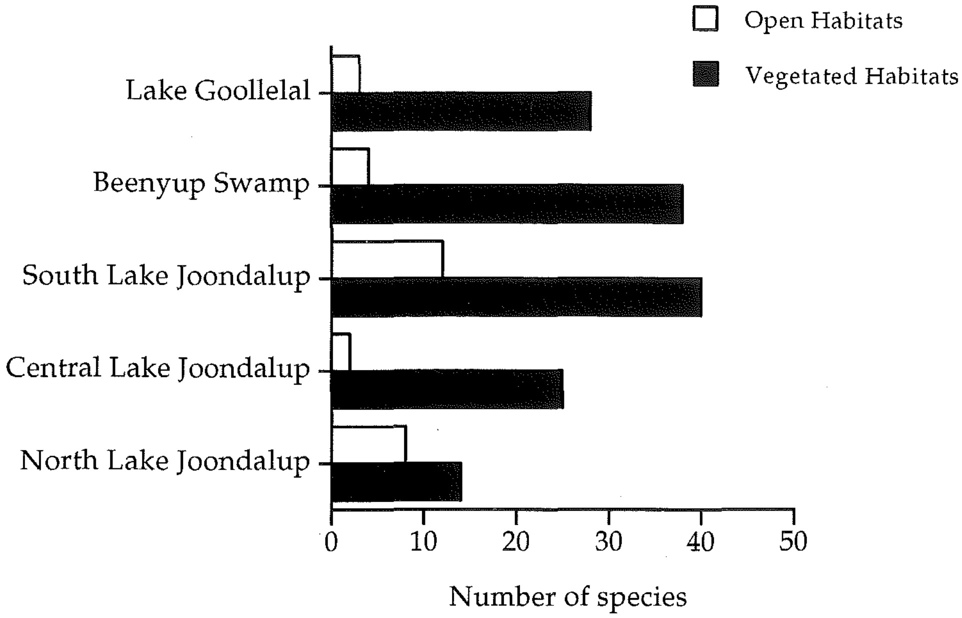


Figure 4.4 The numbers of macroinvertebrate species sampled exclusively in either open water habitats or habitats with emergent vegetation at each site.

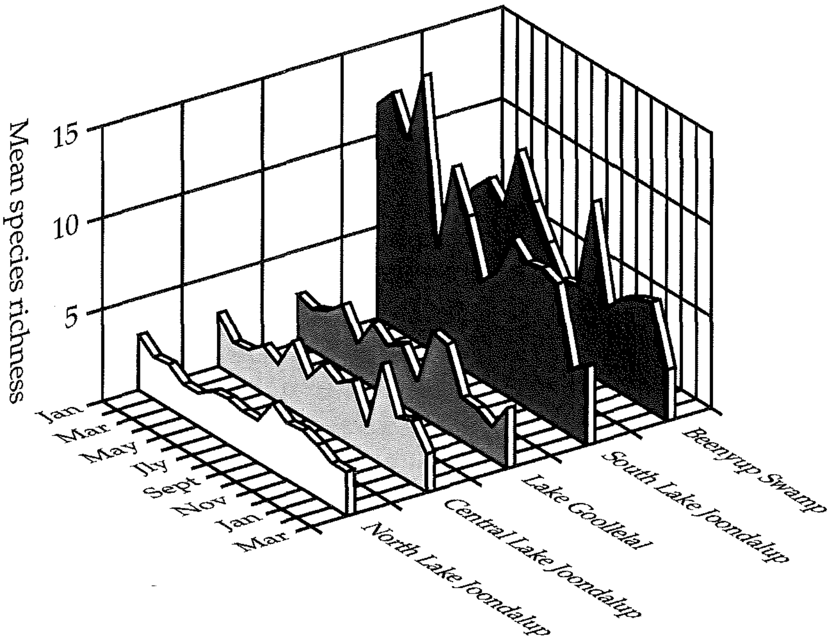


Figure 4.5 Spatial and seasonal patterns in species richness of macroinvertebrates over the 15-month sampling period.

Joondalup was particularly species-poor, averaging less than four species per sample over much of the sampling period. Increases in faunal abundance were generally accompanied by increases in species richness of samples.

Measure	JON	JOC	JOS	BEE	GOO
Species Richness	36	39	70	51	48
Heterogeneity ($N_1 = e^{H'}$)	3.52	6.48	21.65	20.57	8.31

Table 4.4 Species richness and heterogeneity calculated across all sampling occasions and for each wetland site.

The concept of species diversity is a function of both species richness and the evenness with which individuals are distributed among the species. A variety of diversity measures or indices have been developed by ecologists to compare the species diversity of communities. However, the use of such measures in ecology has been severely criticised over the years and the biological assumptions underlying the applications of the varied indices are usually ignored (Hurlbert, 1971; Peet, 1975; Krebs, 1989). One of the most commonly applied diversity indices is the Shannon-Wiener function, H', a measure based on information theory but of dubious biological relevance. Part of the appeal of this measure is that it is a "Type I" indicator - most sensitive to the rare species in the samples. Cognisant of the criticisms, and to provide some estimate of diversity to complement the species richness data (since increases in species richness need not necessarily be accompanied by increases in evenness), we have followed the advice of Peet, 1974 (as cited in Krebs, 1989) and calculated the exponential form of the Shannon-Wiener function ($N_1=e^{H'}$) to describe the site heterogeneity. This index has the advantage of its units being clearly understandable (the number of equally common species to produce the same diversity as the index H'). The index clearly indicates South Lake Joondalup and Beenyup Swamp as highly heterogeneous aquatic communities (Table 4.4).

MULTIVARIATE ANALYSIS

Hierarchical agglomerative clustering based on the seasonal abundance values of the macroinvertebrate species is summarised by the dendogram in Figure 4.6. A cluster composed of all samples from the two most phosphorus-enriched sites, South Lake Joondalup and Beenyup Swamp, clearly separates from the remaining samples.

Ordination of the species abundance data in three dimensions produced a stress value of 0.18. Ordination in four dimensions did not reduce this substantially. The stress value reflects the degree to which the lower-dimensional output successfully represents the high-dimensional data. Clarke (1993), in providing a rule of thumb for interpreting stress levels, suggests that while a stress value of between 0.1 and 0.2 can lead to a usable picture, there is increased potential for making false inferences, particularly in the upper levels of this range. This cautionary note needs to be made with respect to the SSH ordination in Figure 4.7, though some weight is added to the ordination outcome by the fact that the pattern concords with the cluster analysis, with axis 3 separating the South Lake Joondalup and Beenyup Swamp samples from all other samples (Figure 4.7). Examination of the correlation coefficients between selected environmental variables and the SSH ordination revealed strong correlations with total phosphorus (0.84), reactive phosphorus (0.89), pH (0.86) and dissolved oxygen (0.86).

Clustering procedures can be applied to either the sites to produce site-groups (as in Figure 4.6) or to species to produce species-groups. The procedure TWAY in the PATN software program (Belbin, 1989) provides a two-way comparison of the species-groups and site-groups produced by a clustering routine. Applying TWAY to groups produced with hierarchical agglomerative clustering provided an opportunity to identify species clusters which might be associated with specific sites, in this case, the five wetland sites for each of the five seasons. Figure 4.8 presents the species-site group comparisons from the TWAY procedure.

Of interest here are the four small species groups associated almost exclusively with the later seasonal samples from South Lake Joondalup and Beenyup Swamp. The species making up these groups were the most rarely-sampled, contributed substantially to the species richness at these sites and were largely composed of the immature stages of Coleoptera, Trichoptera and Odonata. The pattern is suggestive of a temporal succession of species as one moves from winter (S3, B3) through spring (S4,B4) to summer (S5,B5).

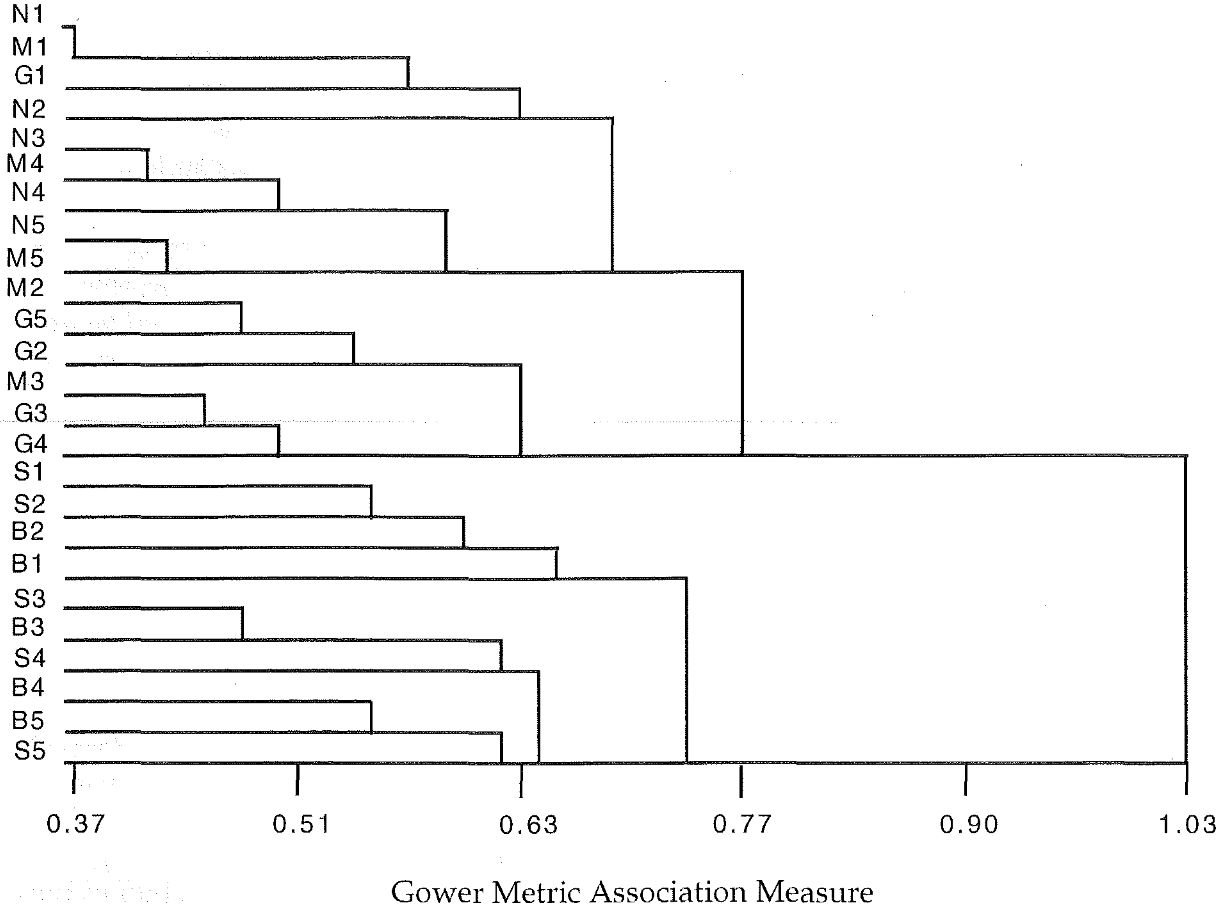


Figure 4.6 Hierarchical agglomerative clustering of macroinvertebrate communities from five wetland sites sampled over five consecutive seasons (1: summer/92 to 5: summer/93).

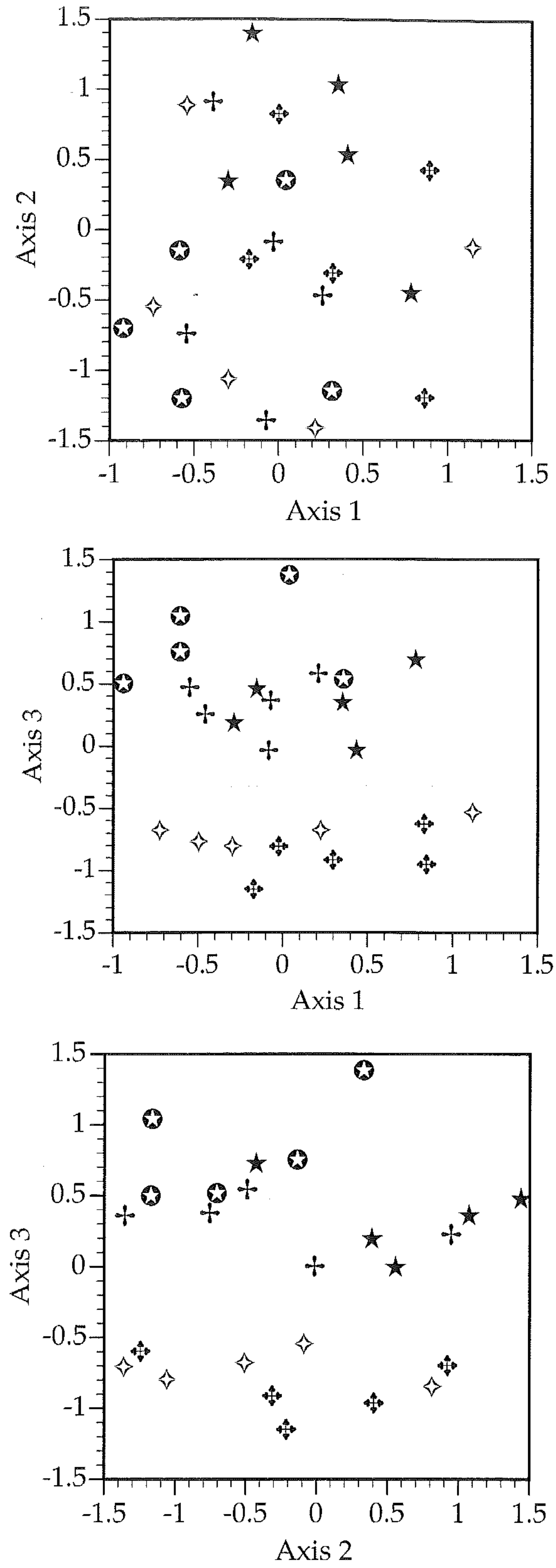


Figure 4.7 SSH ordination of macroinvertebrate communities from 5 wetland sites sampled over five consecutive seasons (summer/92 - summer/93). ✣:Beenyup Swamp; ✧: South Lake Joondalup; ✛: Central Lake Joondalup; ✪: North Lake Joondalup; ★: Lake Goollelal. Values ordinated are the seasonal means. Stress = 0.18.

GROUP 2:

Leptoceridae sp. C
Ischnura heterosticta
Leptoceridae sp. A
Leptoceridae sp. D
Leptoceridae sp. E
Limnesia sp. A

GROUP 3:

Ecnomus sp.
Neuroptera sp.
Pentaneura levidensis
Cricotopus sp.
Chrysomelidae sp.
Hemiptera sp.
Acarina sp.

GROUP 4:

Trichoptera sp.
Hyphydrus elegans
Ischnura aurora
Lancetes lanceolatus
Helminthidae sp.
Sigara sp.
Paranytarsus grimmii

GROUP 5:

Leptophreoidae sp.
Chironomus tepperi
Hemicordulia tau
Stratiomyidae sp.

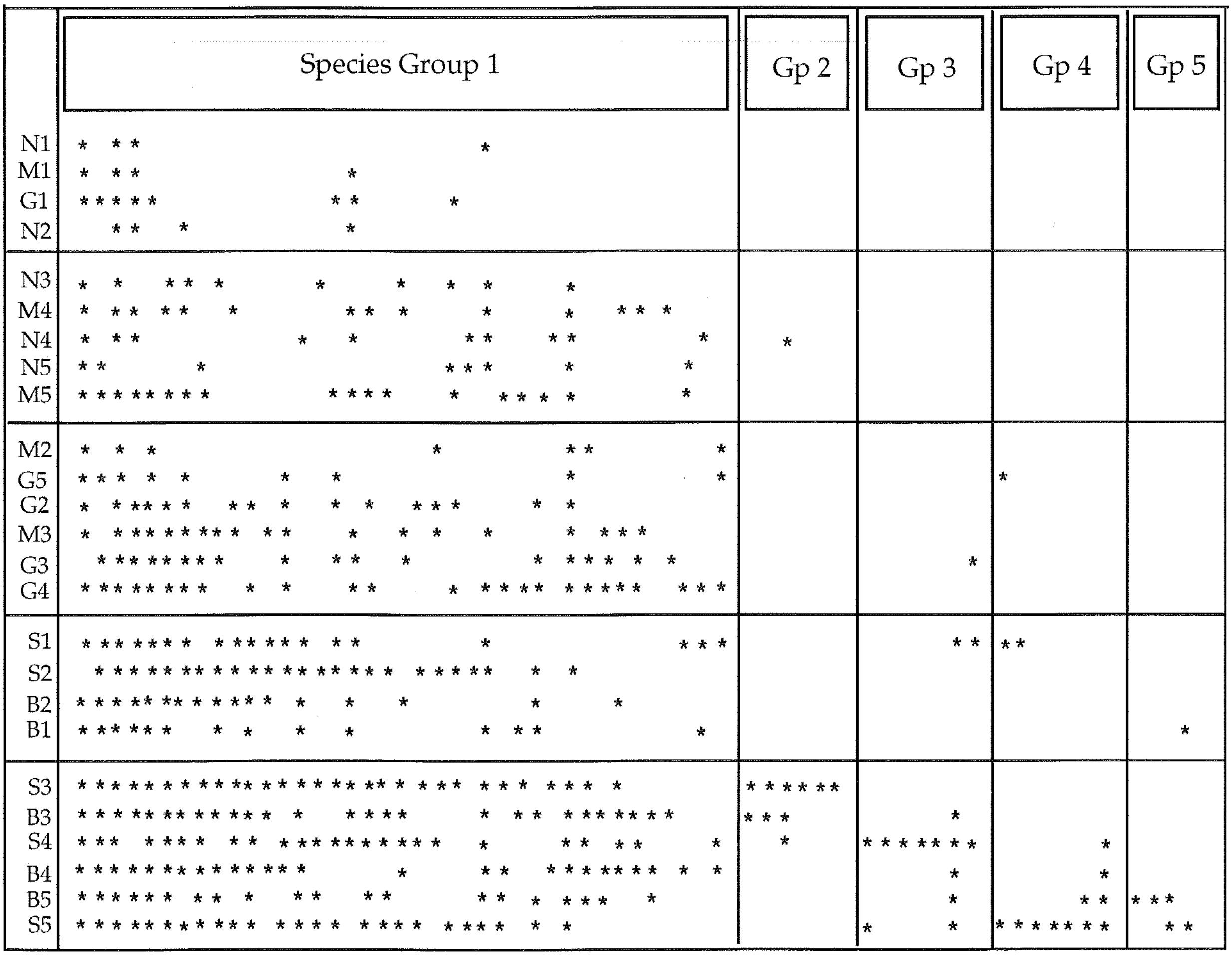


Figure 4.8 Two-way (TWAY) comparisons of sample-groups and species-groups defined by hierarchical agglomerative clustering routines.

DISTRIBUTION PATTERNS OF TAXA

Analysis of distribution and abundance at the species level showed clear differences between the sites, and between seasons. Species comparisons are displayed in Figures 4.9a, b and c. In these figures, horizontal comparisons display differences in species abundance between sites while vertical comparisons display differences in species abundance within a site. It is useful to read Figure 4.9 in conjunction with the series of figures (Figures 4.10 - 4.20) on the following pages which display the seasonal variations in faunal abundances at the ordinal level.

Oligochaeta

Oligochaetes were particularly numerous in the wet summer-autumn samples in Beenyup Swamp (Figure 4.10). As a result, they contributed 5-20% of the fauna at this site (Figure 4.9a). They appeared infrequently and in much lower numbers at other sites.

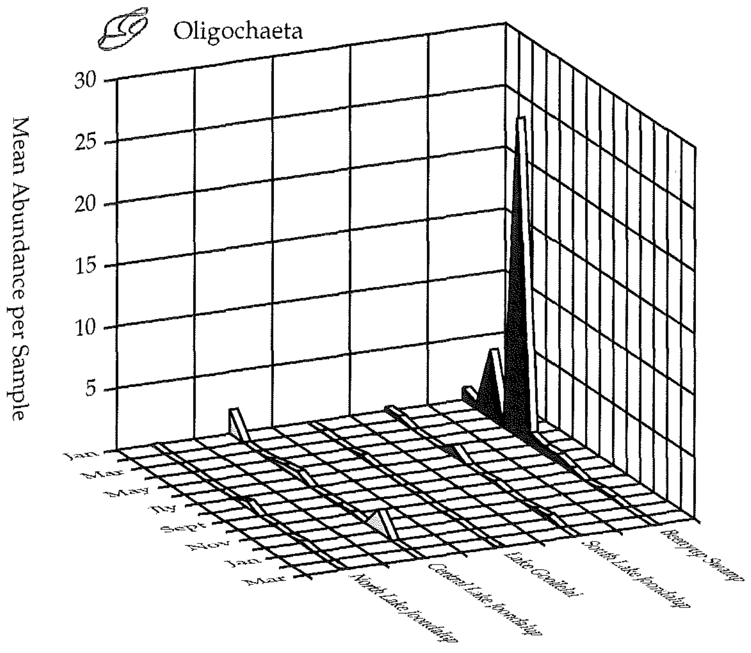


Figure 4.10 Spatial and seasonal patterns of Oligochaeta.

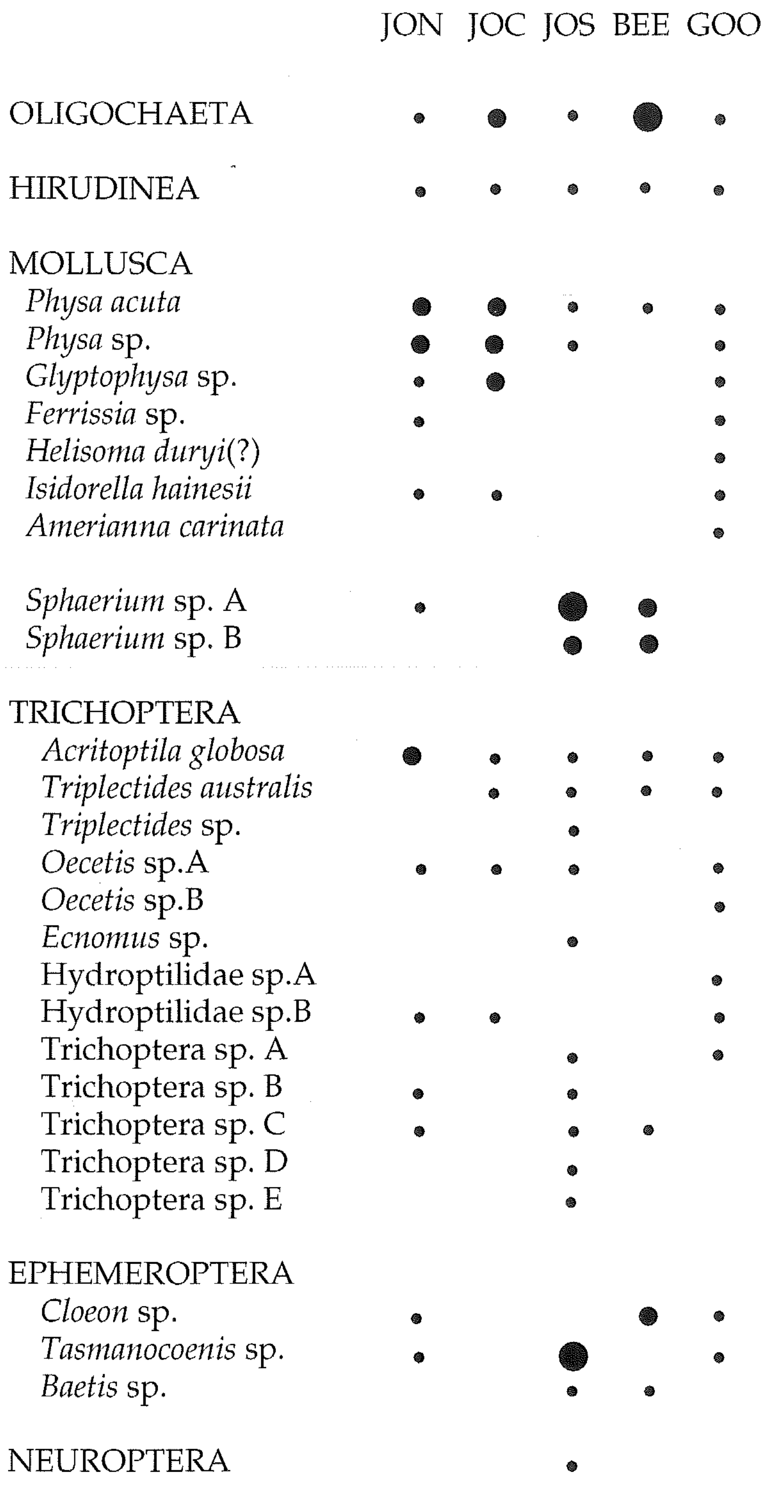


Figure 4.9a Percentage contributions of individual species to the total macroinvertebrate abundances at each site.

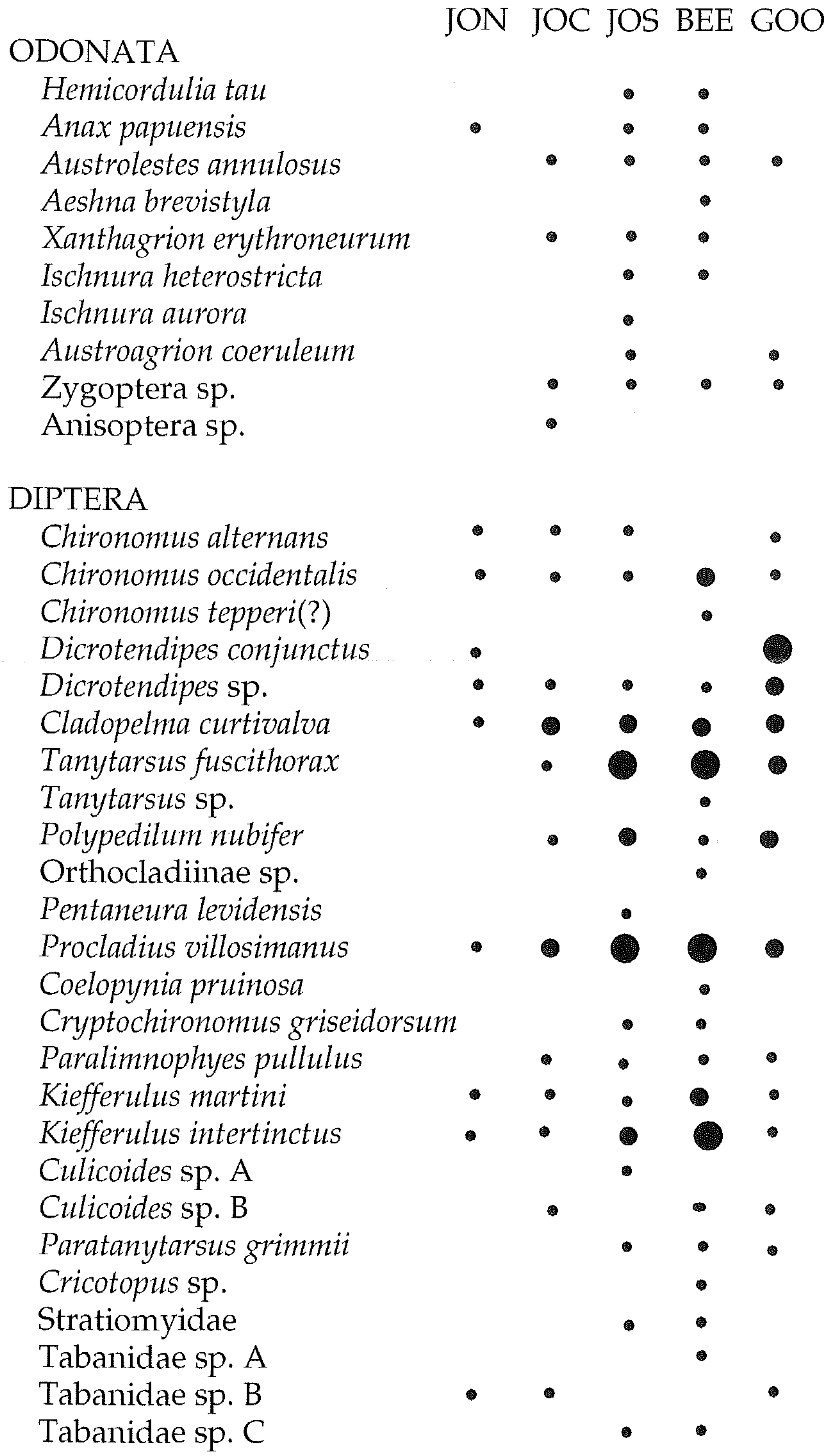


Figure 4.9b Percentage contributions of individual species to the total macroinvertebrate abundances at each site.

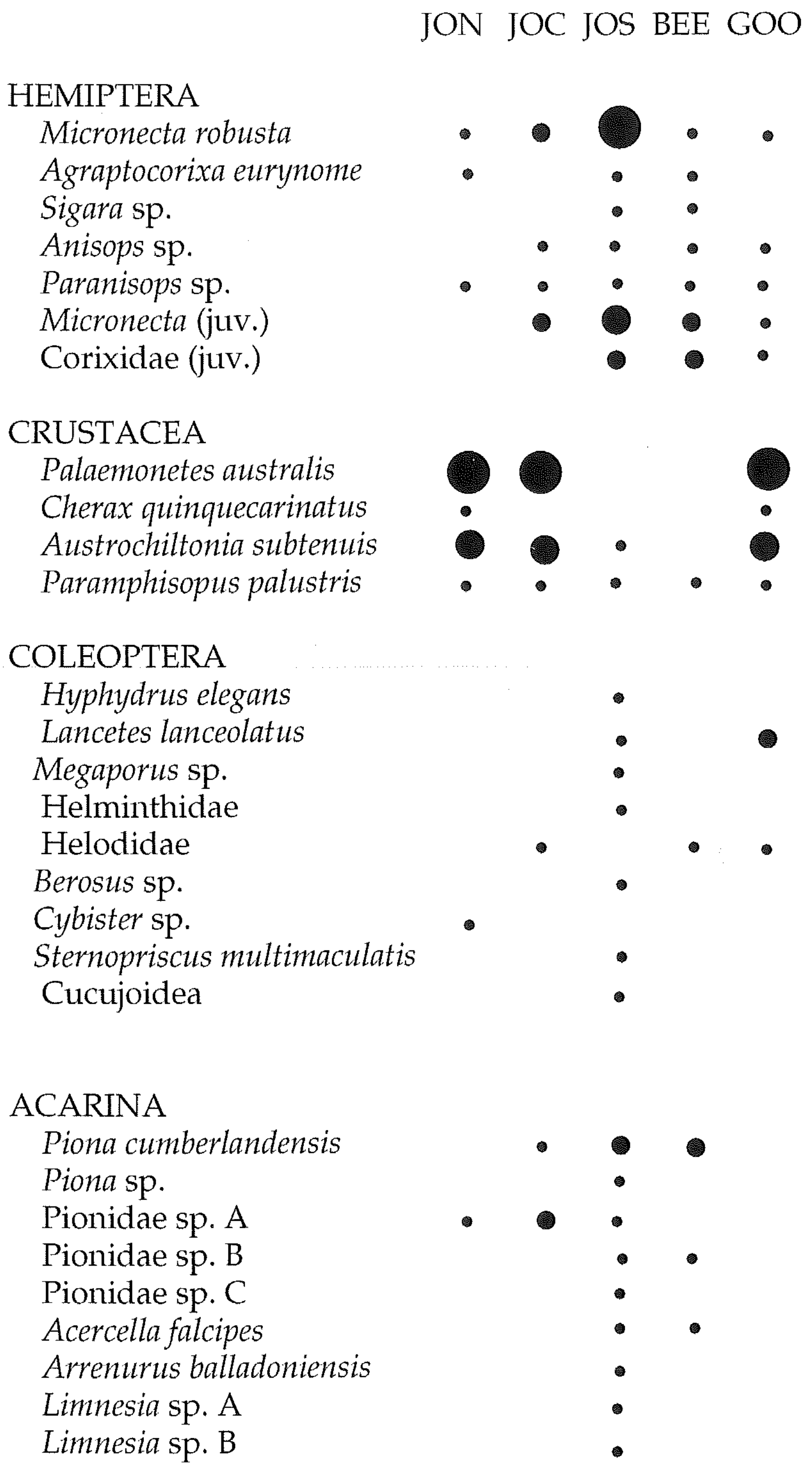


Figure 4.9c Percentage contributions of individual species to the total macroinvertebrate abundances at each site.

Mollusca The gastropod molluscs, in particular members of the genus *Physa*, contributed the greatest proportion of the molluscan fauna in North and Central Lake Joondalup sites (Figure 4.11). Though found at the other sites, they were never a substantial proportion of the fauna (Figure 4.9a). In contrast bivalves of the genus *Sphaerium* were the dominant molluscs in both South Lake Joondalup and Beenyup Swamp and almost exclusively sampled at these sites (Figure 4.12).

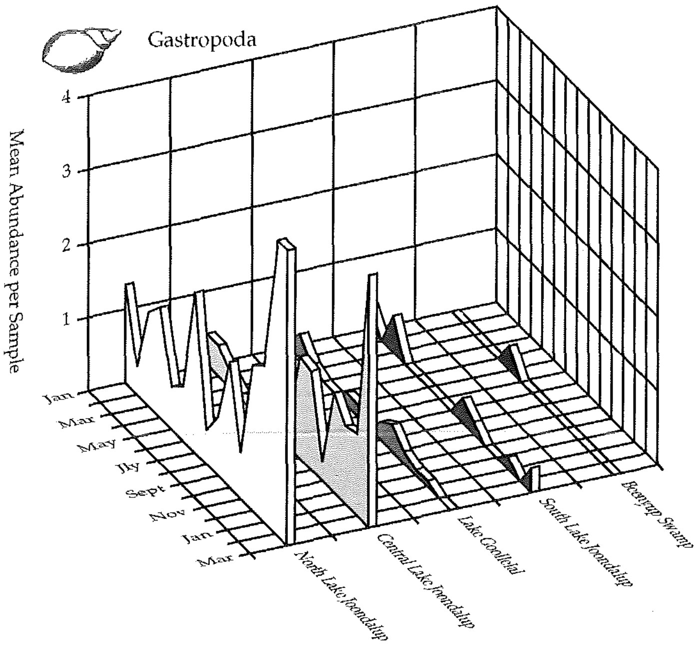


Figure 4.11 Spatial and seasonal patterns of Gastropoda.

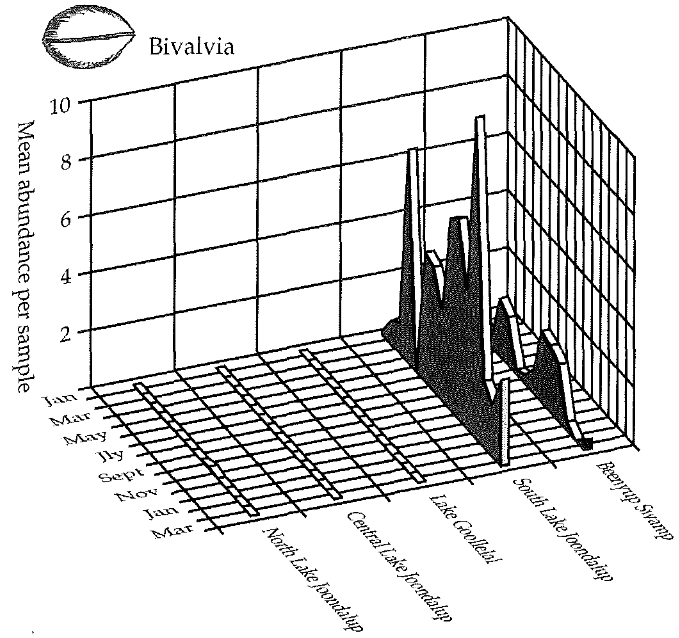


Figure 4.12 Spatial and seasonal patterns of Bivalvia.

Trichoptera, Ephemeroptera and Neuroptera

Trichoptera abundance values were always low at all sites and this taxon never exceeded 1% of fauna at any site (Figure 4.13). However, South Lake Joondalup was relatively species-rich with 10 recorded species (Figure 4.9a). Neuroptera were recorded at South Lake Joondalup only. Ephemeroptera were sampled in relatively larger numbers at the two most enriched sites (Figure 4.14) with *Tasmanocoenis* sp. dominating the South Lake Joondalup samples and *Cloeon* sp. the Beenyup samples (Figure 4.9a).

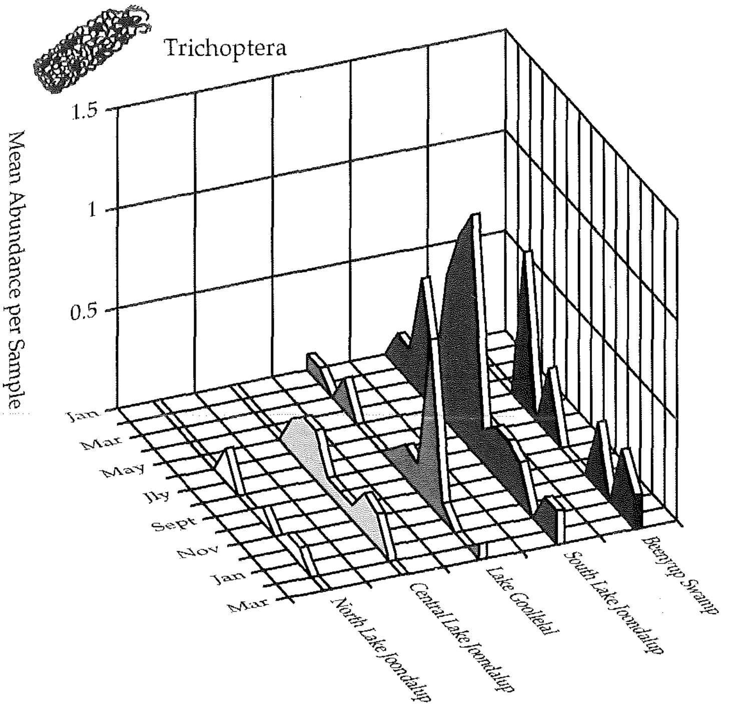


Figure 4.13 Spatial and seasonal patterns of Trichoptera.

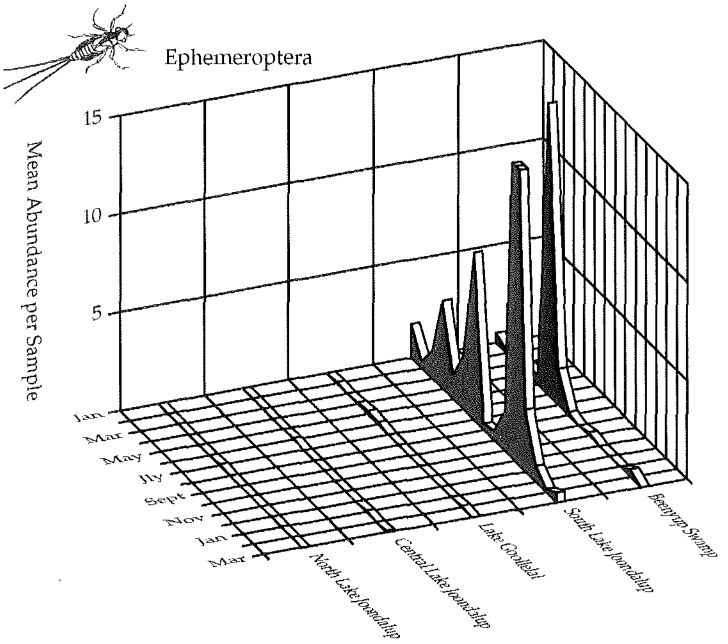


Figure 4.14 Spatial and seasonal patterns of Ephemeroptera.

Odonata This taxon is particularly interesting in that its absence from Lake Joondalup samples in previous studies led researchers to suggest a serious deficiency in trophic structure for this wetland (Davis & Rolls, 1987). These predators were indeed present though in low numbers, and mainly in association with vegetated habitats. The larval fauna was relatively species-poor in the main water body of Lake Joondalup. South Lake Joondalup and Beenyup Swamp yielded the largest number of species (Figure 4.9b) and the highest abundances (Figure 4.15).

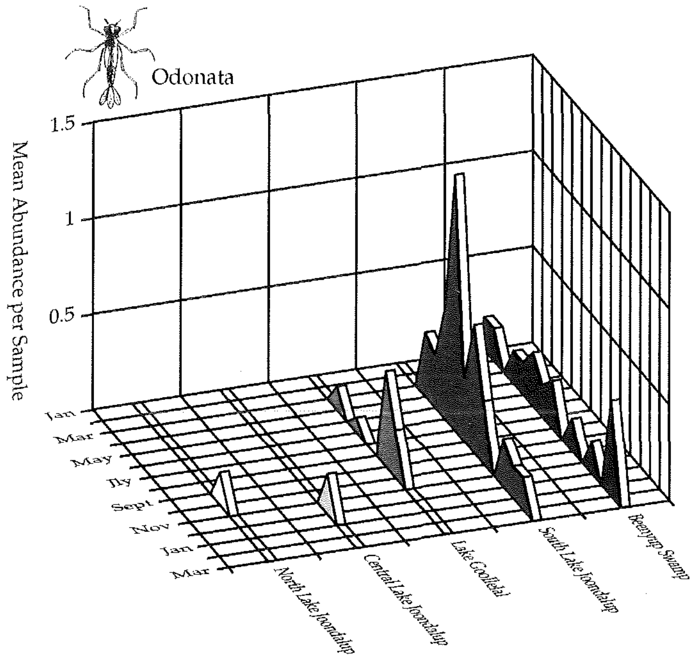


Figure 4.15 Spatial and seasonal patterns of Odonata.

Diptera The larvae of Diptera were the most abundant macroinvertebrates in all but the main water body sites (Figure 4.16) with the Chironomidae contributing the major abundance and species diversity (Figure 4.9b). There were noticeable similarities in both species richness and species distribution patterns for South Lake Joondalup and Beenyup Swamp with *Tanytarsus fuscithorax, Procladius villosimanus* and *Kiefferulus intertinctus* the most abundant species at these sites. The high relative abundance of *Dicrotendipes conjunctus* in Lake Goollelal set this site apart from the others.

Hemiptera Large numbers of hemipterans were sampled throughout much of the year at the South Lake Joondalup site, only declining with the onset of the dry summer (Figure 4.17). The dominant species was *M. robusta* which contributed more than one fifth of the total numbers of macroinvertebrate fauna at this site (Figure 4.9c). Abundances were very low at all other sites and on all sampling occasions. The pattern of increased species richness at the two most phosphorus-enriched sites continued with this group.

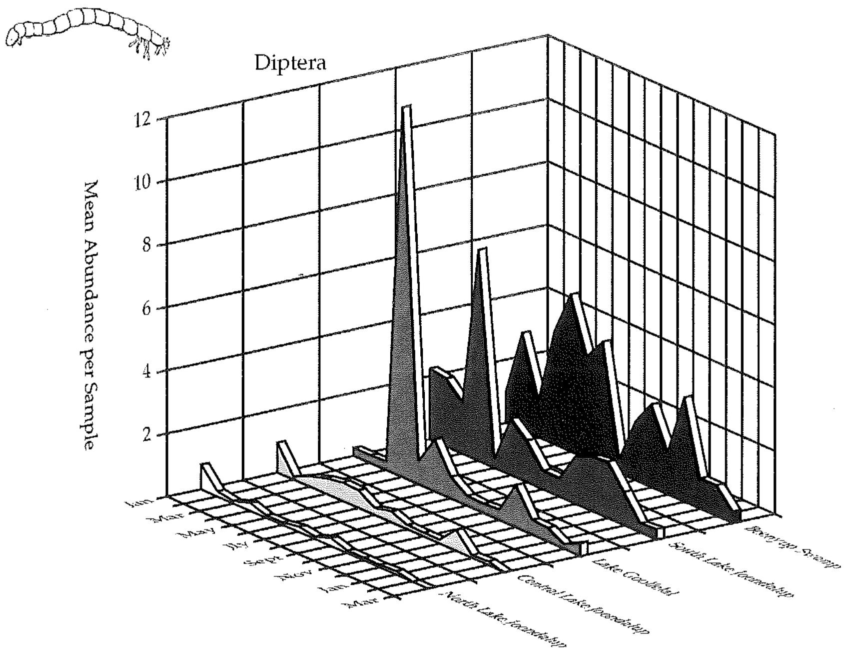


Figure 4.16 Spatial and seasonal patterns of Diptera.

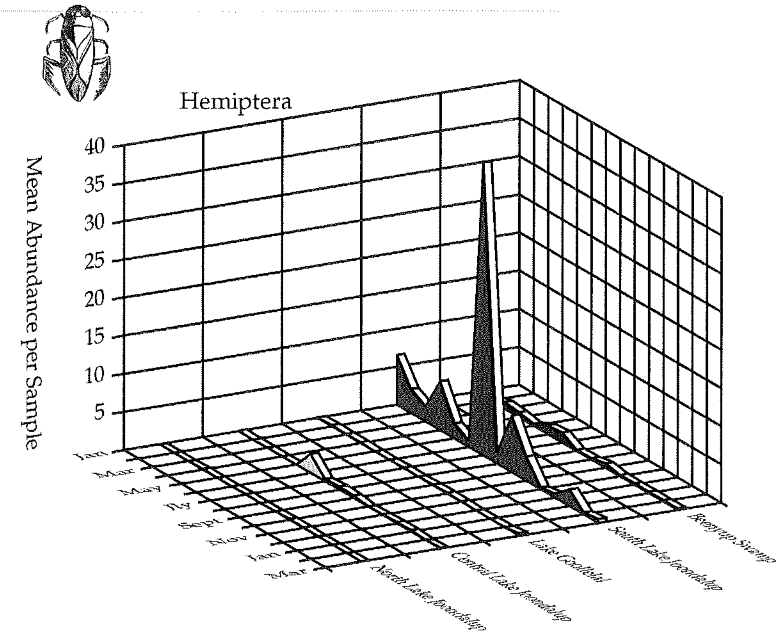


Figure 4.17 Spatial and seasonal patterns of Hemiptera.

Crustacea

Like the molluscan fauna, the macrocrustacean distribution patterns were disjunct across the sites (Figures 4.18 and 4.19). The decapod *P. australis* dominated the faunal abundance totals in the main body of Lake Joondalup and Lake Goollelal. In North Lake Joondalup it often comprised over 50% of the macroinvertebrates sampled (Figure 4.9c). The species was totally absent in samples from the remaining two sites. *Cherax quinquecarinatus* was the only other decapod species found, in Lake Goollelal and North Lake Joondalup.

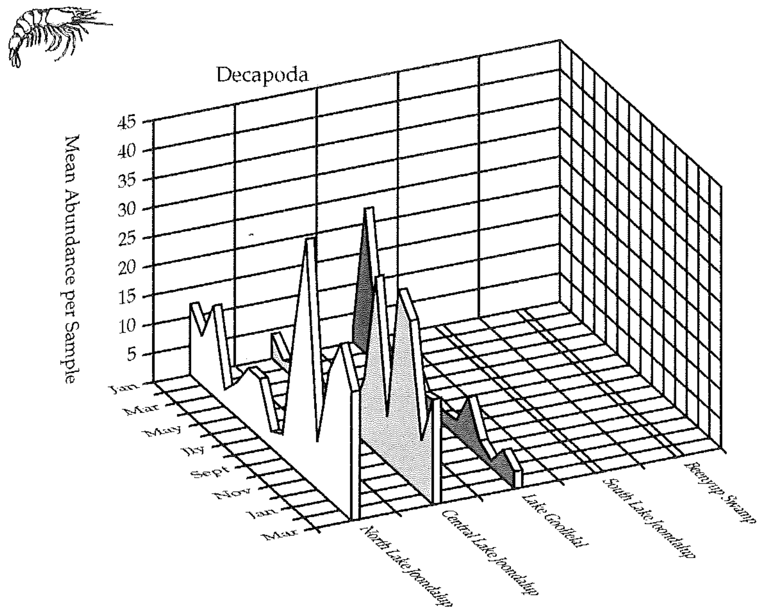


Figure 4.18 Spatial and seasonal patterns of Decapoda.

The amphipod *Austrochiltonia subtenuis* was distributed similarly to *P. australis*, with relatively large numbers in the winter-spring periods in Lake Joondalup proper and Lake Goollelal (Figure 4.19). It was never sampled in Beenyup Swamp and only sampled infrequently in South Lake Joondalup. Only one species of isopod was found, *Paramphisopus palustris*, and only in very small numbers.

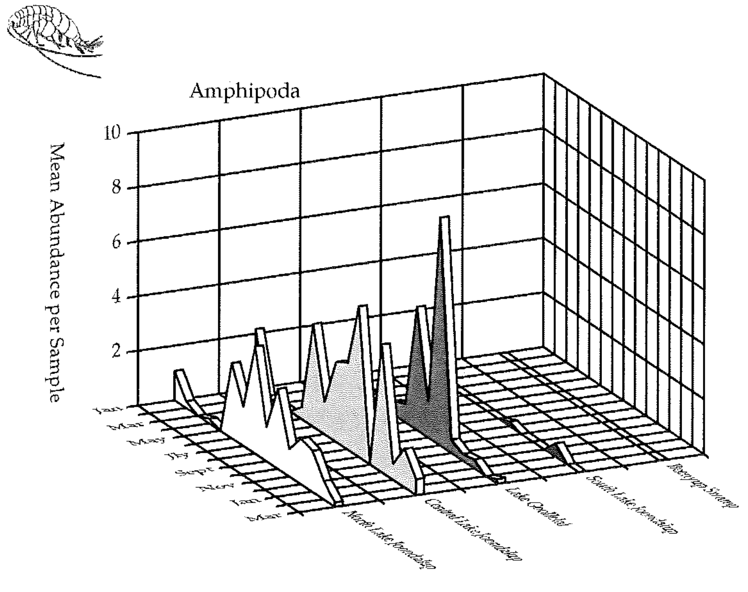


Figure 4.19 Spatial and seasonal patterns of Amphipoda.

Coleoptera Relative abundances were very low at all sites (with means always less than 1.0 per sample). Only one or two species were sampled from four of the sites with the majority of the species sampled from South Lake Joondalup (Figure 4.9c).

Acarina Mites of Pionidae, particulary *Piona cumberlandensis*, were ubiquitous but almost all the acarine populations came from South Lake Joondalup and Beenyup Swamp (Figure 4.20). Once again, the relatively species-rich status of South Lake Joondalup set it apart from the other sites (Figure 4.9c).

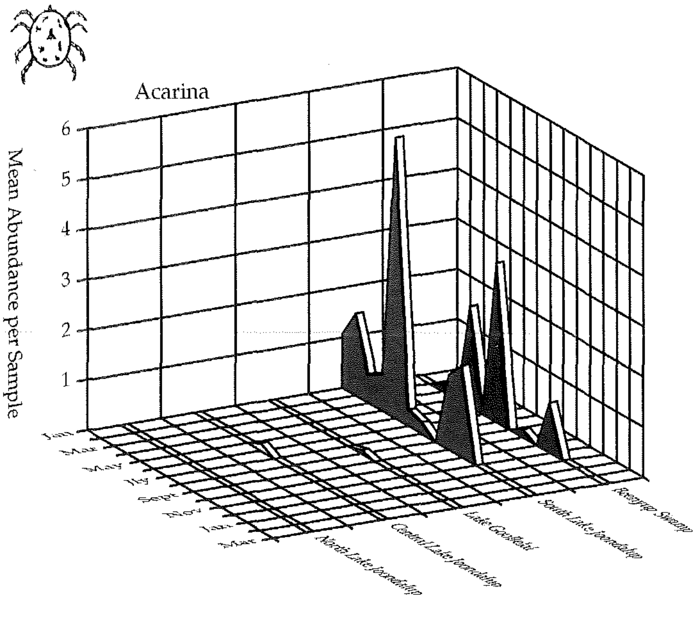


Figure 4.20 Spatial and seasonal patterns of Acarina.

4.3 DISCUSSION

The wetlands of Yellagonga Regional park support a diverse macroinvertebrate aquatic community which is at least partly, if not largely, a result of nutrient enrichment. In the surface-connected wetland sites of Beenyup Swamp and Lake Joondalup, as with the microcrustacea, the dominant spatial patterns of increasing species abundance and richness reflect the strong north-to-south gradient in phosphorus. Bottom-up effects are the most likely cause for the substantial abundance and richness in the most-enriched sites of Beenyup Swamp and South Lake Joondalup. Enrichment-induced increases in primary productivity, if reflected as enhanced macrophyte growth, could be expected to produce a flow-on enhancement of secondary productivity and increased niche diversity at these sites. Certainly, Beenyup Swamp is known to have a dense macrophyte community (Upton, 1996).

Moderate enrichment, accompanied by moderately eutrophic conditions, was observed to be associated with both high invertebrate species richness and increased numbers of rare species in wetlands of the Swan Coastal Plain (Davis *et al.*, 1993). However, wetlands classified as highly eutrophic by these authors had reduced species richness, though with a trend towards increased abundance (see also Balla & Davis, 1995). The phosphorus-enrichment of Beenyup Swamp and South Lake Joondalup is excessive rather than moderate and has shown to be so for at least two decades. However, the lack of a persistent and substantial cyanobacterial response to the enrichment at these sites reduces the possibility of unfavourable anoxic conditions developing which would reduce faunal abundance and richness. It is the combination of excessive and continuous nutrient enrichment, though with maintenance of relatively low standing cyanobacterial biomass over much of the year, which most likely results in a stimulation of secondary productivity and diversity. Balla & Davis (1995) identified seasonality as a factor enhancing species richness of wetland invertebrates and the seasonal nature of South Lake Joondalup and Beenyup Swamp may also contribute to the species richness at these sites.

The change in faunal communities between the southern end of Lake Joondalup and the main water body is striking. Despite being separated geographically by only a few meters distance, and being connected physically via a tunnel which allows seasonal water flow from south to north, the biota of the northern wetland supports smaller populations of a relatively species-poor macroinvertebrate community.

It is possible to identify two sets of factors which may be contributing to the relatively depauperate fauna in the main water body. The first set relates to the anthropogenic changes impacting on the wetland; the second identifies a naturally-depauparate macroinvertebrate community as a result of some unique habitat features.

Immediately north of the tunnel conditions prevail which are more typically eutrophic. The seasonal rains in winter re-establish the surface connections with the southern site and with this connection comes the movement of nutrient-enriched water into the main water body. The volume dilution of potential inhibitory factors, whether they be colour, toxic compounds associated with humic acids, or a reduced pH (and a possible but less likely, reduced grazing rate on phytoplankton by *Daphnia*) now results in conditions which are more favourable for phytoplankton growth resulting in a greater standing biomass. The low levels of inorganic nitrogen in the wetland, together with high levels of reactive phosphorus are likely to provide conditions which favour the growth of the nitrogen-fixing cyanobacteria, leading to the production of nuisance blooms of species such as *Anabaena spiroides* and *Microcystis aeruginosa*. Both of these species have been recorded in Lake Joondalup and implicated in blooms (Congdon, 1986). *Anabaena*, is also known to form resting cells or akinetes which can "seed" sediments during unfavourable conditions, and be stimulated to active growth by sudden environmental changes, such as a seasonal increase in the water column (Paerl, 1988). Sediments from eutrophic inland waters often reveal the presence of such akinetes.

Extensive, smelly blooms were evident on several occasions in the "central" sites over the winter-spring period, when temperatures were favourable. This area immediately north of the tunnel may be exemplifying the reduced abundance and reduced species richness relationships with eutrophy which have been described for other highly eutrophic wetlands elsewhere on the Swan Coastal Plain. There is evidence that both the incidence and intensity of nuisance blooms is increasing in this area of Lake Joondalup (Upton, 1996).

As one proceeds northward in the main water body, the biota remains relatively depauperate, despite the improved water conditions with lower phosphorus and chlorophyll *a* levels. This brings us to the second set of factors possibly affecting the macroinvertebrate communities. There is some evidence that a reduced invertebrate diversity may be a natural characteristic of this part of the water body, independent of anthropogenic processes. Previous faunal studies of Lake Joondalup are few and the exact sampling positions are not defined. Davis *et al.* (1993) reported very low species richness (N=18) from the main water body and their cluster and ordination procedures performed on a number of wetlands identified both Lake Joondalup and Lake Goollelal as species-poor. The northern area of Lake Joondalup is unusual because of the presence of "metaphyton", an orange-red particulate matter which forms a fine suspension distributed throughout the water column and merging into a loose bottom sediment (Rose, 1979). Its presence may well render the habitat unsuitable for many aquatic species, including the smaller particulate feeding and bottom-dwelling fauna likely to form the basis of food webs for larger invertebrates. For example, the normally abundant and diverse chironomid fauna were particularly rare in northern samples. Instead, the fauna was dominated by the detritus-feeding shrimp *P. australis* (unable to resist dessication, it is restricted to permanent water sites in the Park) and the grazing gastropod fauna. *P. australis* was found to be common in the benthic vegetation *Chara*, in Lake Joondalup in 1978 and probably utilises it as a food source (Hembree & George, 1978). Freshwater gastropods are also known to respond favourably to the presence of macrophytes (Timms, 1982; Cosser, 1988) and to semi-permanent flooding (Neckles *et al.*, 1990), both conditions which are characteristic of North Lake Joondalup.

Lake Goollelal represents a distinct aquatic entity, having engineered connections with the other sites in the Park, but not being subject to the same excessive sources of enrichment. However, it remains similarly susceptible to local enrichment sources associated with surrounding urbanisation. Its macroinvertebrate biota represented a somewhat intermediate position between the highly diverse Beenyup Swamp/South Lake Joondalup sites and the less rich Lake Joondalup proper. A permanent waterbody like Lake Joondalup, it maintains substantial populations of *P. australis* and gastropod molluscs. The distinctive metaphyton has not been recorded here and, like Beenyup Swamp it supports species-rich populations of dipteran fauna. However, cluster and ordination procedures consistently grouped Lake Goollelal sites with those of Central and North Lake Joondalup, suggestive of closer similarities of species abundance distributions with these sites than with the closer southern sites. Of the three wetlands sampled, the aquatic macroinvertebrate community of Lake Goollelal may represent that most typical of a non-coloured, alkaline, permanent wetland within these geomorphic elements of the Swan Coastal Plain.

This study enabled us to characterise the aquatic macroinvertebrate communities within the Lake Joondalup-Beenyup Swamp wetlands. Comparisons between southern and northern areas revealed expected similarities, but with some substantial and interesting differences which were of sufficient intensity as to consistently set the southern samples apart. This difference is most likely due to a number of factors, namely the seasonal versus permanent status of the two wetland areas, the associated water chemistry gradients, the lessening influence of the relatively coloured, humic Beenyup Swamp water along this gradient, and the unusual particulate and sediment characteristics of the northern area. We can summarise these differences as follows:

- A northern biota

(i) numerically dominated by detrital feeders *P. australis* and to a lesser extent the amphipod *A. subtenuis* and a substantial complement of herbivore grazers - gastropods largely from the Physidae;

(ii) with a dipteran, ephemeropteran and hemipteran fauna which, while sharing most of the same species with southern sites, is greatly reduced in abundance;
(iii) with a species-poor and numerically-depauperate trichopteran, odonatan, coleopteran and acarine fauna.

- A southern biota
(i) which contains relatively large numbers of macroinvertebrates representative of a wide variety of taxa and trophic levels, for example the omnivorous particulate Hemipteran *M. robusta,* the mainly herbivorous Chironomidae (in particular *T. fuscithorax* and *P. villosimanus*), the bivalve *Sphaerium* (rarely found elsewhere in Lake Joondalup) and the Ephemeropteran *Tasmanocoenis* sp.;
(ii) with a particularly species-rich complement from the taxa Diptera, Trichoptera, Odonata, Coleoptera and Acarina. These last taxa in particular appear to most influence the species richness.

5 BIRDS

Hugo Bekle

5.1 INTRODUCTION

The study sought to identify the resident and visiting populations of waterbirds and to explain the patterns of usage within Lakes Joondalup and Goollelal. While these lakes retain important natural elements, they have also been substantially modified in parts due to a long settlement history. Little detailed baseline ecological information is available on the Yellagonga Regional Park and the ecological significance of its lakes, particularly in relation to seasonal movements and changes in waterbird populations. This information is crucial before future planning and conservation can take place.

Large-scale classifications and inventories, such as Riggert (1966), can identify lakes which are in need of conservation and rehabilitation, but it is also necessary to conduct detailed studies on a local scale to determine more precisely the interactions which exist amongst the lake environment, waterbird populations, and the demands of human activities. Relatively little comparative data of this kind has so far been collected in Australia (Halse & Ward, 1987). This lack of information is probably partly due to the complexity of lake ecosystems (Bayley & Williams, 1973), and the physical difficulties involved in studying waterbirds quantitatively.

The present study sought, at least partially, to fill this gap. Lakes Joondalup and Goollelal will be described in terms of their role as waterbird habitats within the Yellagonga Regional Park, with special attention to the often subtle ecological links between individual wetland habitats. An integrative approach is required to study how these birds pattern life in time and space, so as to maximise access to the resources they require, particularly food.

With the importance of these lakes in mind this study serves the following purposes:

To identify the populations of *waterbirds* visiting and resident in the Yellagonga Regional Park, and determine their habitat preferences;

To collect information on *waterbird usage* and relate spatial and temporal variations in habitat to the composition of the waterbird communities at the two lakes;

To explain the patterns of waterbird usage in terms of *local, regional, continental and inter-continental significance*, where information gathered on birds' activities is used to identify functional linkages between distant as well as nearby habitats;

To provide a suggested framework for the future conservation and maintenance of waterbird populations on the Yellagonga Regional Park wetlands.

5.2 METHODS

For the purposes of this study waterbirds were defined as those that depend on lakes for at least some of their physiological needs, such as those associated with feeding, roosting and breeding. Most of them - ducks, herons, ibis and waterhens - are familiar birds, associated in people's minds with fresh water. They frequent the water and physically enter the body of water by either wading, swimming or diving. Some species, eg. dotterels, only inhabit the margins of wetlands, but rely substantially on food near or just below the water surface, feeding mainly by picking up small molluscs and other aquatic life from muddy shores. Several species were excluded because, while part of the wetland ecosystem (being dwellers of the "lake-space"), they do not actually use the surface water for activities such as feeding or nesting (eg. Little Grassbird, Sacred Kingfisher).

Forty fortnightly surveys were conducted on Lakes Joondalup and Goollelal between September 1991 and March 1993. These results provided information on the seasonal occurrence of individual species.

During each visit, a list of the bird species encountered was compiled, their numbers recorded, and relative distributions plotted on a blank map. The completed maps were used to compile bird census data showing species and individuals in the sites defined in Chapter 1: North Lake Joondalup, Central

Lake Joondalup, South Lake Joondalup, and Lake Goollelal, to investigate the distribution of different species in particular sites. Notes were also made on unusual behaviour patterns, breeding (pairs), moulting and the diet of birds seen feeding. By observing the waterbirds over a period it was possible to identify feeding, nesting and roosting areas. Internal movements of birds within a lake were also noted throughout the study period, as well as migration that occurred. Weather conditions were also entered on the field observation sheet.

Abundances were counted directly or estimated. Direct counts proved to be most suitable for small flocks of birds (less than 100) in flight or on open water. Estimates were used when direct counting was difficult or impossible due to the numbers of birds or the habitat. When dealing with large or mixed-species flocks it was necessary to rely on estimates derived from segment/percentage methods. This involved a direct count of a sample of the flock and an estimation of the number of such samples within the flock. For example, a group of ten or a hundred birds was counted, and then the number of such samples in the flock was estimated.

The lakes were surveyed in the early morning from a small aluminium boat. The practice followed throughout the study was to manoeuvre the boat along the shoreline, flushing birds out of the fringing sedges and paperbarks. Observations in open water were conducted using 10 x 50 binoculars, to scan the large areas of open water.

Accurate absolute counts were possible for some species, while for others, estimated abundances were recorded. Some of the difficulties experienced included similar appearance of closely related species (eg. Hoary-headed Grebe and Australasian Grebe), secretive and cryptic bird species (eg Little Bittern), and extremely abundant species (eg Eurasian Coot). Counts of large, mixed-species flocks of ducks were determined by first obtaining a total count, and then using a segment/percentage approach to identify species counts.

English names for species and their Latin equivalents are those recommended by the Royal Australasian Ornithologists Union (R.A.O.U.). Nomenclature, order of families, and English names are those given in the R.A.O.U.'s new list of vernaculars, (Christidis & Boles, 1994), with additional references to Condon (1975) and Schodde *et al.* (1978).

5.3 SPECIES PRESENT

The Western Australian Department of Fisheries and Wildlife (now Conservation and Land Management) (1978) listed 107 species of "waterbirds" recorded on wetlands (assumed to include rivers and estuaries) in south-western Australia, of which 73 were regularly observed and 34 occasionally recorded. Later, more comprehensive monitoring of wetlands in this region revealed fewer species; Jaensch *et al.* (1988) recorded 96 species across 197 sites, and Storey *et al.* (1994) identified only 79 species in a slightly larger sample of 251 wetlands. Only about 75 of these species conform to the definition used in this study. Thus about half the species of waterbirds (as defined in this study) found in South-western Australia were observed in the Yellagonga Regional Park.

A list of the 37 species recorded during this study (between September 1991 and March 1993) is given in Appendix C. There is no doubt that the list is incomplete, since observations were made at fortnightly intervals and in the early morning. Earlier studies by Bekle (1979, 1988) identified 37 and 38 species respectively. This suggests that, in general terms, species richness has remained unaltered, although the present study recorded fewer species of waders, particularly the trans-equatorial migrants (eg Curlew Sandpiper, Red-necked Stint).

5.4 ABUNDANCE OF BIRDS

The maximum population of each species of waterbird recorded on the Yellagonga Regional Park lakes during the period September 1991 to March 1993 is shown in Table 5.1. Each species has been placed in categories of 1 or 2, 3-10, 11-100, 101-1000, >1,000, according to the maximum number of birds encountered in a single census during the fortnightly surveys.

The Eurasian Coot, Black Swan, Pacific Black Duck, Australian Wood Duck and Australian Shelduck, and two large wading birds - the Australian White Ibis and Straw-necked Ibis - appear as the most abundant species. In particular, Eurasian Coot, Black Swan, Australian Shelduck and Pacific Black Duck were observed at certain times of the year in flocks of several hundred. These results are consistent with those of other larger surveys (Jaensch *et al.*, 1988; Storey *et al.*, 1994) which showed that ducks, swans and coots are numerically dominant on wetlands in the South-West Region, with Eurasian Coot as the single most abundant species. In this study, other species were frequently encountered, but in lower numbers, eg. White-faced Herons. Species recorded in very low numbers included some birds that are more plentiful in other aquatic environments, such as rivers (eg. Darter); trans-equatorial migrants,(eg Sandpipers); rare and endangered species (eg. Little Bittern); and birds with secretive or nocturnal habits (eg. Rufous Night Heron).

Table 5.1 : Maximum Populations of Waterbirds Recorded on the Yellagonga Regional Park Wetlands in a Single Census (September 1991 - March 1993)

	Species	Number of Birds	
> 1,000	Eurasian Coot	4,531	
	Black Swan	2238	Total = 2 species
101 - 1,000	Australian Shelduck	694	
	Pacific Black Duck	644	
	Australian White Ibis	273	
	Straw-necked Ibis	260	
	Australian Wood Duck	143	
	Australasian Grebe	136	
	Blue-billed Duck	105	
	Great Crested Grebe	104	
	Little Black Cormorant	101	Total = 9 species
11 - 100	Grey Teal	94	
	Musk Duck	84	
	Little Pied Cormorant	72	
	Black-winged Stilt	60	
	White-faced Heron	57	
	Hardhead	47	
	Dusky Moorhen	31	
	Australasian Shoveler	37	
	Yellow-billed Spoonbill	18	
	Black-fronted Dotterel	19	
	Purple Swamphen	16	
	Mallard	13	
	Australian Pelican	10	
	Great Egret	12	Total = 14 species
3 - 10	Pink-eared Duck	10	
	Darter	9	
	Glossy Ibis	5	
	Rufous Night Heron	7	
	Hoary-headed Grebe	4	Total = 5 species
1 or 2	Common Sandpiper	2	
	Pied Cormorant	1	
	Cattle Egret	1	
	Black-tailed Native Hen	1	
	Little Bittern	1	
	Red-necked Avocet	1	
	Common Greenshank	1	Total = 7 species

5.5 SEASONAL OCCURRENCE OF BIRDS

By comparing waterbird counts from month to month, it was possible to show changes or fluctuations in numbers of birds. Within a waterbird community, like Yellagonga Regional Park, there is a continuous turnover in bird species and numbers. These counts can be correlated with various features of the environment, which in turn suggest reasons for the varying numbers.

Species Patterns

Figure 5.1 shows that a majority of species inhabited the Yellagonga Regional Park lakes on a seasonal basis; only 10 species were recorded on every visit, whereas 18 species used the wetlands at only a certain time of year and nine species were sighted on six or less occasions. The number of species was lowest (15) in September 1991, steadily increased to 22 by November and peaked at 30 in February (Figure 5.1). The same pattern, but with slightly lower numbers, was recorded in the 1992/1993 summer.

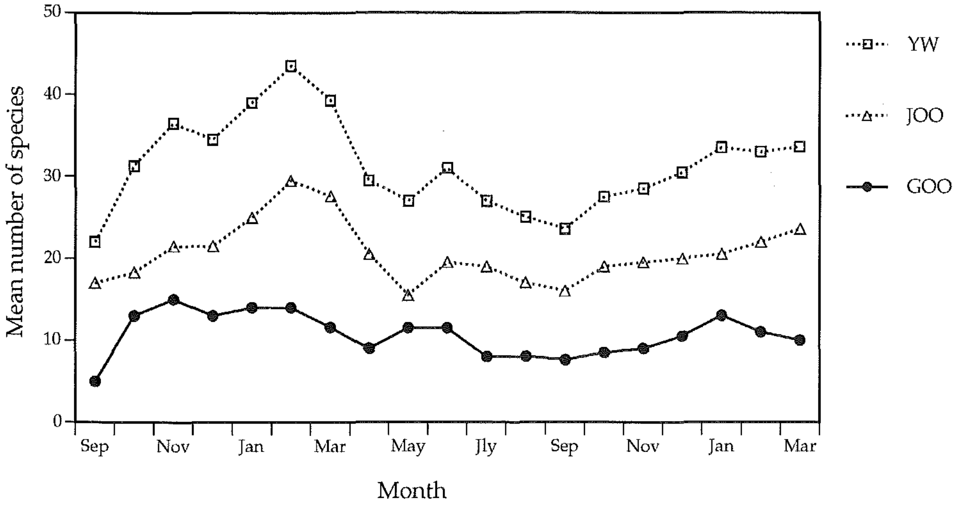


Figure 5.1 Variations in the species richness of water birds in the Yellagonga wetlands over the period of the study.
YW: Yellagonga wetlands in total; JOO: Lake Joondalup;
GOO: Lake Goollelal.

These species can be roughly categorised into three groups (resident, Australian migrant and trans-equatorial migrant) according to their seasonal occurrence. Of the 27 non-resident species, two (Common Sandpiper, Common Greenshank) are trans-equatorial migratory waders that breed in the northern hemisphere. The remaining 25 species all have their breeding grounds within Australia; for example, Gentilli & Bekle (1983) described regular movement of Grey Teal from inland breeding grounds onto the coastal plain.

Separating the migratory and non-migratory species reveals that the September-December increase in species richness was due almost entirely to the combined arrival of the two migratory waders from the northern hemisphere and, more importantly, an influx of local species as inland (breeding) wetlands were drying up. The coastal wetlands, including Lakes Joondalup and Goollelal, are a source of permanent water, providing a refuge and food for migrating waterbirds during periods of seasonal aridity (Bekle, 1988; Storey *et al.*, 1994). From April onwards a departure of both groups of migrants to their breeding grounds resulted in the steady decline in numbers of species.

Lake Joondalup (maximum of 30 species, February 1992) catered for almost twice as many species, particularly during the summer and autumn period, as Lake Goollelal (maximum of 16 species, February 1992). This discrepancy can best be explained by the fact that Lake Joondalup is much larger in area, and has a greater diversity of habitats as well as more plentiful food resources. North and Central Lake Joondalup displayed similar trends in species richness, as did South Lake Joondalup and Lake Goollelal (Figure 5.2).

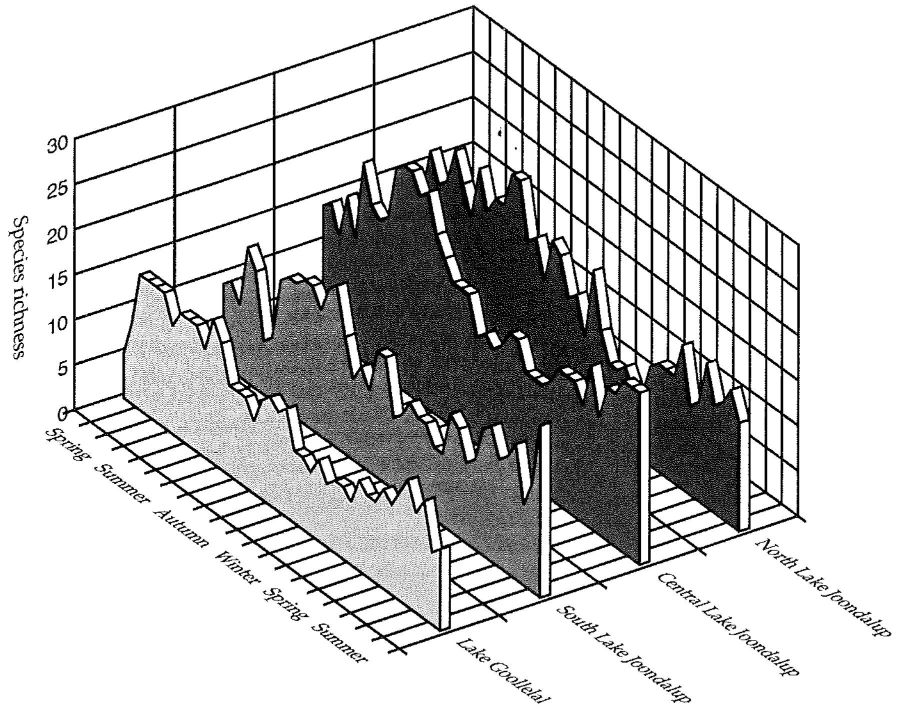


Figure 5.2 Spatial and seasonal variation in the species richness of waterbirds in Yellagonga Regional Park.

Abundance patterns

The monthly variation in the number of waterbirds of all species on the Yellagonga Regional Park lakes is given in Figure 5.3. Graphs showing changes in total abundance of selected species across the four study sites are presented in Appendix D. From an initial 300 birds in early September 1991, the population had increased three fold by the end of October, and continued to rise steadily to nearly 1,700 birds by the end of December. January and February 1992 counts fluctuated between 1,400 and 4,600 birds, mostly due to erratic changes in numbers of Eurasian Coot and Black Swan, and finally peaked at 5,200 birds by the end of April. An equally rapid fall in bird numbers occurred after April 1992, dropping to about 2,500 in May/June, and decreasing steadily until August/September 1992. A seasonal low of about 200 birds was recorded in September 1992. Thereafter numbers increased to nearly 800 by November 1992, and continued to rise rapidly to a peak of nearly 8,300 in March 1993.

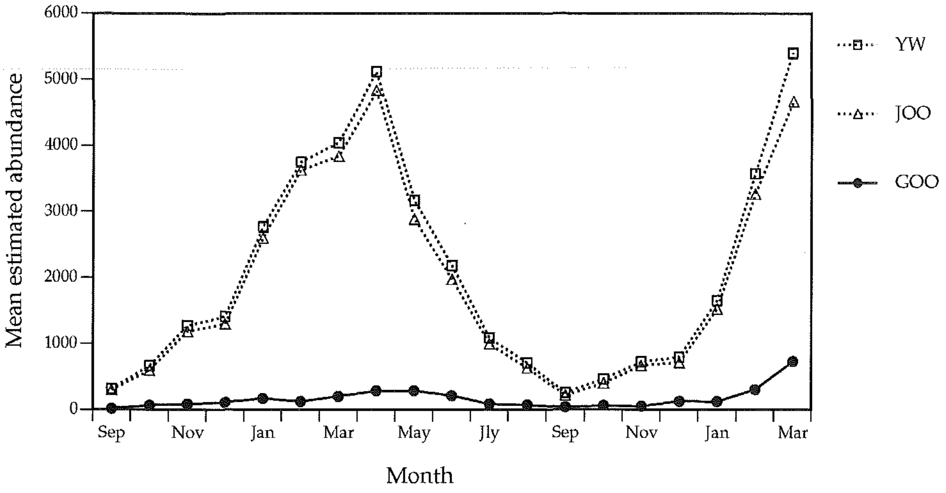


Figure 5.3 Variations in mean waterbird abundance in the Yellagonga wetlands over the period of the study.

Figure 5.4 shows that total bird numbers were substantially higher in North Lake Joondalup than in the rest of the study area, particularly during summer and autumn. Central Lake Joondalup recorded the next highest number of birds, but the summer and autumn peaks were lower, which may be related to the availability of food resources during this period. Lowest concentrations of birds occurred in the two remaining sites, with Lake Goollelal experiencing peak numbers in autumn. This may be explained by Lake Goollelal retaining relatively high water levels into January, and therefore only the shallow margins could be exploited for food by birds unable to dive.

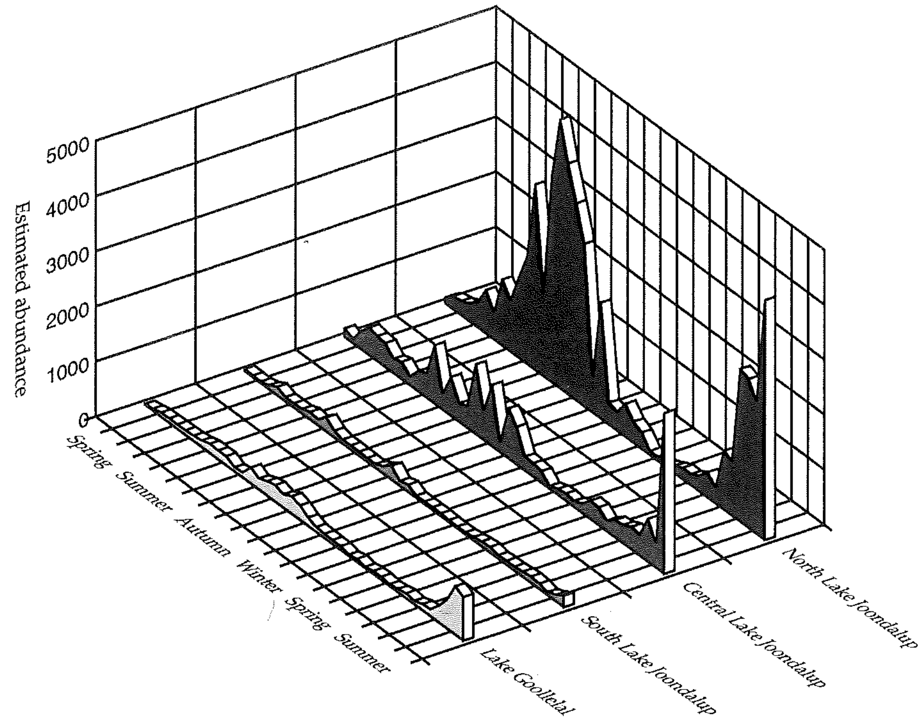


Figure 5.4 Spatial and seasonal variation in waterbird abundance in Yellagonga Regional Park.

5.6 LAKE USAGE BY WATERBIRDS

This section describes the distribution of bird species on a seasonal basis, and in relation to certain aspects of the physical environment, in particular depth of water.

Winter: preparation for breeding

The arrival of the wet season gave rise to a fresh cycle of emergence and reproduction. Late autumn rains had already caused water levels in these lakes to rise, covering much of the previously available mud flats. These changes made conditions generally unsuitable for the smaller wading birds (eg stilt, avocet, plovers), and also limited the feeding opportunities of other birds, such as Grey Teal, which prefer expanses of shallow water (Gentilli & Bekle, 1983). Instead, diving species such as Musk Duck and Blue-billed Duck were well represented on the deeper water of Lakes Joondalup and Goollelal. Blue-billed Duck preferred to assemble in large "rafts" north of Ocean Reef Road in Central Lake Joondalup (Figure D1), whereas Musk Duck were more widely scattered on both lakes (Figure D2).

The Great Crested Grebe, another diving bird, appeared on the Yellagonga Regional Park wetlands in August, and congregated in small flocks, especially in the deeper channel along the western shoreline of Lake Joondalup; similar trends in numbers and seasonal occurrence were observed for North and Central Lake Joondalup, as well as Lake Goollelal (Figure D3). In the northern end of Lake Joondalup, Great Crested Grebe were also observed feeding in patches of Water Milfoil, *Myriophyllum propinquum*; the surface foliage displayed new growing tips and numerous freshwater shrimp, *Palaemonetes australis*, were noticed in the matted structure of the plant.

Numbers of grebe continued to increase until January 1992, when the total population reached 104 birds. This figure is exceptionally large compared with previously published records (*WA Bird Notes*, 1981; Jaensch *et al.*, 1988). A similar number of birds (110) was reported by Bekle (1988) on 20 metropolitan lakes in September 1980, with 80 percent of the population located on Lakes Joondalup and Goollelal, indicating that the Yellagonga wetlands are a significant habitat for this species. Great Crested Grebe were found by Jaensch *et al.* (1988) to breed in Lake Joondalup and only four other wetlands in South-western Australia. Taking into account the bird's known distribution, it is likely that many of these individuals arrived from South-eastern Australia.

Purple Swamphens were frequently sighted in areas where fringing sedge and rush communities were interspersed with flooded grasses, including cultivated lawns and pasture (eg. Neil Hawkins Park); Central and South Lake Joondalup recorded the highest numbers (Figure D4). The germination and vigorous growth of herbs and grasses on inundated mudflats in the southern end of Lake Joondalup also provided short-term feeding opportunities for Western Swamphens as well as small concentrations of Grey Teal and Pacific Black Duck (Figures D5 and D6).

Winter rains result in wide spread flooding in the south-west of the State. As a consequence, inland breeders such as the Grey Teal vacate the Yellagonga wetlands and disperse to the smaller, more secluded swamps in the south-west to breed (Gentilli & Bekle, 1983). As additional rains raised the water levels in Lakes Joondalup and Goollelal after June, waterbird numbers declined rapidly (Figure 5.3). Between June and August 1992, the two lakes lost more than 2,000 birds as they became too deep for wading birds, and species of dabbling ducks (eg. Pacific Black Duck, Grey Teal). Among the locally breeding birds, winter was a period of considerable social stress, as birds were actively seeking mates and competing for brood territories. The intensity of courting and pairing behaviour increased in the flocks through the winter, in preparation for the spring breeding season. Certainly the most striking courtship displays were witnessed amongst Great Crested Grebe and Musk Duck, particularly on the open waters of North and Central Lake Joondalup.

The diving ducks built their nests where fairly extensive sedge and rush communities, especially bullrushes, were surrounded by medium to deep water (ie. greater than 60 cm). Sedge and rush communities were utilised for nesting by Blue-billed Duck and Rallidae, such as the Eurasian Coot and the Purple Swamphen; Blue-billed Duck showed a preference for rushes along the northern side of the Ocean Reef Road Causeway (as previously reported by Bekle, 1979; 1988). Relatively few dabbling ducks nested on Lakes Joondalup and Goollelal as these lakes are too deep to support a substantial coverage of seasonally inundated paperbarks, and their narrow shorelines have been completely, or at least partially, cleared.

Breeding condition in adult waterbirds can only be obtained if available sources of plant and animal foods are of sufficient quality to provide adequate protein (Krapu, 1979). Almost all waterbirds obtain protein from aquatic animals, especially freshwater invertebrates, which in turn are highly dependent upon water quality (Davis and Rolls, 1987). Invertebrates also complement the diets of most juvenile birds. One notable exception is the Black Swan which feeds principally upon vegetation throughout its life (Frith, 1967). Research from North America has shown that breeding densities of dabbling ducks are strongly influenced by the quality and abundance of food available to females from shallow water (Krapu, 1979; Swanson *et al.*, 1979). These shallow water conditions prevail in Central and South Lake Joondalup. The feeding niche of a laying female duck varies seasonally, and is influenced by the physiological demands and reproductive potential of the bird. Female ducks that are producing eggs consume a high proportion of their diet (greater than 70 percent) as small invertebrates, including insects, snails and crustacea. This diet provides adequate levels of calcium, total protein, and essential amino acids for reproduction. Results from this study showed that the greatest availability of this type of food occurred in the winter and spring to coincide with the breeding season.

Aquatic invertebrates are consumed when they are present in areas that are accessible to feeding ducks. Nocturnal feeding may occur when the availability of invertebrates increases between sunset and sunrise (Bekle, 1983). This occurs, for example, when aquatic insects such as midges emerge or when aquatic insect larvae come to the surface to maintain or replenish their oxygen supply. When the crustacean *Daphnia* is abundant most species of nesting ducks can effectively feed on the large adults. As the population declines and the availability of large adults is reduced, only filter feeders like the Australasian Shoveler and the highly specialised Pink-eared Duck, can continue to feed adequately on the remaining individuals. Numbers of both these species were highest in Central and South Lake Joondalup (Figures D7 & D8), with Pink-eared Duck showing a preference for the southern site. *Daphnia* was particularly abundant in the southern end of Central Lake Joondalup over winter, where the majority of ducks had assembled. The increase in numbers of *Daphnia* coincided with high concentrations of nutrients entering the lake through the culvert under Ocean Reef Road as earlier reported by Congdon (1979; 1985) and confirmed by the present study.

August signalled the emergence of newly hatched young in the study area; one family of Pacific Black Duck (six ducklings) was sighted in South Lake Joondalup. It is likely that the brood was hatched in nearby Beenyup Swamp which is well protected and provides suitable nesting conditions.

Spring: the breeding season

The pair-forming displays observed in the flocks through winter months continued into September for the spring breeding season. At this time the environmental factors and physiological mechanisms that timetable the reproduction of waterbirds ensured that the young were hatched at an optimal time for survival. The mild spring climate was associated with a gradual decline in lake depth. Plant and animal growth accelerated and food supply reached its maximum for breeding birds and the hatchlings.

As spring advanced the numbers of waterbirds increased in 1991 from approximately 300 in September to 1,400 in November (Figure 5.3). In 1992 there was a less dramatic increase from approximately 200 in September to more that 700 in November. Many species, such as Pacific Black Duck, Eurasian Coot and Blue-billed Duck began to take advantage of the feeding opportunities offered by increasing shallow water areas in South and Central Lake Joondalup. During this study, nine species (Great Crested Grebe, Black Swan, Pacific Black Duck, Australian Shelduck, Grey Teal, Blue-billed Duck, Musk Duck, Eurasian Coot, Purple Swamphen) were recorded breeding on Lake Joondalup, while young from only three species (Great Crested Grebe, Black Swan, Pacific Black Duck) were sighted on Lake Goollelal. Lake Joondalup compares favourably with other important breeding sites identified by Storey *et al.* (1994), where 12 species represented the highest count for a single wetland.

The available information suggests, however, that local breeding in the Yellagonga wetlands, particularly for dabbling ducks such as Grey Teal, Australian Shelduck and Pacific Black Duck, is relatively unimportant compared with the numerous young produced on inland breeding grounds. Broods of hatchlings were most common from October to December, and most of these birds were flying by the end of January. Great Crested Grebe, Blue-billed Duck, Black Swan and Pacific Black Duck produced the greatest proportion of young sighted on both lakes. Most of the Pacific Black Duck young hatched by October/November when the invertebrate fauna was still abundant. The ducklings at first eat mainly insects, such as water beetles and water-boatmen, but the parents are capable of utilising whatever plant or animal food is available at the time. The Great Crested Grebe delayed nesting until these lakes were at maximum depth, and young were mostly observed in deep-water habitats on both lakes in November and December; sheltered waters bordered by sedges along the western shoreline in North Lake Joondalup were a haven for Great Crested Grebe and their young. The food of the Great Crested Grebe has not been recorded in detail in Australia, but most likely consists of readily available insects, small fish and crustaceans.

Summer: congregation at drought refuges

Towards the end of spring, shallow inland breeding grounds begin to dry out, and wetland vegetation gradually dies. Some of the family groups that have occupied these inland wetlands move to the deeper fresh-water lakes of the Yellagonga Regional Park, which contain a plentiful supply of food (Gentilli & Bekle, 1983; Storey *et al.*, 1994). This movement continues throughout December and January, and steadily swells the population on these lakes to the highest level.

In the summer, the species distribution changed with increasing numbers of dabbling ducks and wading birds and smaller proportions of diving species. This substantial shift is explained by the change, within a few weeks, from a situation where the lakes were well filled to one where they were drying out rapidly. During this period the Yellagonga wetlands adopted their seasonal role as refuges for local, regional, and, to a much lesser extent, trans-equatorial waterbirds (Bekle, 1988; Jaensch *et al.*, 1988), although migratory waders are more plentiful in those years when lower water levels produce expanded areas of mudflat (Bekle, 1980). Food availability increased with the emergence of a variety of aquatic plants and food supplies became more accessible to large and small wading species with the still limited exposure of mudflats during this study. The arrival of summer migrants resulted in a combined total of 4,600 birds in February 1992, and almost 3600 in February 1993 (Figure 5.3). Most of this increase was recorded on Lake Joondalup due to the arrival of large numbers of Eurasian Coot and Black Swan (Figures D9 & D10), while numbers of birds on Lake Goollelal remained more steady.

The distribution of bird species in Lake Joondalup reflected changes in water depth. In the deep water at the northern end diving species, such as Little Pied Cormorant (Figure D11) and Little Black Cormorant (Figure D12) were prevalent, while the central and southern parts of the lake comprised mainly Pacific Black Duck, Grey Teal and Australian Shelduck (Figure D13), as well as Australasian Grebe (Figure D14). The grebe, which feed mainly on insects, arrived at a time when the rate of declining water levels was too great to allow the southern end to support large numbers of other diving birds, such as Musk Duck, Blue-billed Duck and Great Crested Grebe. However, a small population of 5 to 20 Hardhead still showed preference for the open waters of Central and South Lake Joondalup through the 1991/1992 spring/ summer period (Figure D18).

Lake Joondalup supports possibly one of the largest populations of Australian White Ibis and Straw-necked Ibis in the Perth region (Bekle, 1982, 1988). The lake was particularly suited to these species in the latter half of the summer when water depths in the northern end were dropping (Figure D15 and D16). The water receded from fringing sedge communities, where Australian White Ibis could frequently be observed probing for food. Straw-necked Ibis were observed more often in open fields outside the boundaries of the Yellagonga Regional Park than near the water; thus their preferred habitat is relatively scarce at Lake Joondalup.

A colony of Australian White Ibis and Straw-necked Ibis roost on Lake Joondalup in two adjacent sites (Bekle, 1982). The area on the north-west bank of North Lake Joondalup is by far the larger, accommodating a total of 520 ibis in late January, 1992; this figure compares well with maximum counts of 640 ibis in January 1979 (Bekle, 1980) and 54 ibis in March 1981 (Bekle, 1988). Ibis numbers recorded during this study also greatly exceeded those reported for Lake Joondalup by Storey *et al.* (1994), perhaps as a result of surveys in this study being conducted earlier in the day. The roosting site extends approximately 50 metres along the western shoreline, and where deep water is enclosed by paperbark woodland and sedges. An inner fringe of dead paperbarks lines the channel of open water and the trees are permanently immersed in the water, protecting the birds from predators. The area offers its occupants complete seclusion, ample roosting perches and protection from wind. Some other species were also observed using this roosting site at the same time, particularly cormorants, heron, spoonbill, egrets and darters. Ibis showed a preference for these dead paperbark trees whereas Great Egrets were more commonly found in trees with foliage. Ibis represented between 50 and 80 percent of all birds using this roost, with the two species often present in almost equal numbers from January to March.

Plate 5.1 The Australian White Ibis near its roosting site in the north-west of Lake Joondalup.

The Australian White Ibis mainly occupied the eastern side of the roosting site and only the lower branches on the west, whereas the bulk of the Straw-necked Ibis settled on the high branches along the western side. Most of these birds use Lake Joondalup primarily as a roosting area, leaving for nearby lakes to feed (Bekle, 1980). The outward migration of ibis occurred each morning, beginning at sunrise. Australian White Ibis were generally the first to leave the roost, moving off individually or in small groups. Straw-necked Ibis moved in larger numbers, leaving the lake immediately they were in flight. Three or four groups followed one another in formation, travelling in a north-easterly direction. The exodus of ibis occurred over about an hour. A small population of between 20 and 30 Australian White Ibis remained on Lake Joondalup to feed throughout the day, and a further 10 to 15 birds visited Lake Goollelal in summer and autumn 1992.

In a previous study, Bekle (1980) sought to locate the feeding grounds of ibis leaving the lake. Flocks of ibis were found grazing at Paul's Swamp, Beenyup Swamp and Lakes Joondalup, Mariginiup and Adams. On other occasions, ibis have also been sighted feeding at Lakes Neerabup and Nowergup. Straw-necked Ibis have been observed feeding in cleared fields some hundred of metres away from water, such as to the north-west of Lake Joondalup (Bekle, 1980); they will feed both in wet and dry areas. Australian White Ibis usually fed in shallow water, probing for water insects, snails and small fish. They thus represented the bulk of the ibis population feeding on Lake Joondalup.

The second roosting site is located north of Ocean Reef Road in the middle of Lake Joondalup. It comprises a stand of dead paperbarks situated approximately 200 metres from each of the two lake shorelines. The roosting area offers excellent protection from predators, being completely surrounded by water, but is exposed to the wind. This area was found to accommodate smaller numbers of birds, Australian White Ibis being the main species present, with small numbers of Yellow-billed Spoonbill and Straw-necked Ibis. The water was comparatively shallow at this site, with a gentle gradient on the eastern bank, enabling the Australian White Ibis to feed near the roost.

Most birds gathered to roost as the light began to fade, but the actual time of settling varied from species to species. Cormorants were usually among the first birds to enter the roost for the night. The opposite rhythm was followed by Rufous Night Heron which remained concealed during the day, emerging in the late evening to feed. Several individuals (3 to 6) were observed to roost near the ibis colony in the northern end of Lake Joondalup between December 1991 and February 1992.

Towards the end of summer, increasing numbers of small waders populated the newly exposed mudflats at the southern end of Central Lake Joondalup. The Black-winged Stilt (Figure D19) and Black-fronted Dotterel (Figure D20) were the most abundant of these wading birds. The area of mudflats was relatively small in 1992 and 1993 compared to the conditions reported in previous studies (Bekle 1980; 1988), and as a result, numbers and species of the smaller resident and trans-equatorial waders were comparatively low. Only one Red-necked Avocet was sighted during this study in December 1991, whereas Jaensch *et al.* (1988) recorded 1,200 birds and rated the species as the second most abundant on the Lake. These moist mudflats and shallow pools also provided small animals and insects for the dabbling ducks, such as Pacific Black Duck, Grey Teal and Australasian Shoveler. These ducks moved to the area late in the evening to feed, and during the day-time were observed in deeper areas further north.

The internal migration of bird populations within Lake Joondalup was most evident during summer. With the rapid decline of water levels, habitat availability altered frequently. By February, some of the Purple Swamphen, cormorant and Australasian Grebe previously resident at the southern end of Lake Joondalup had moved to deeper water in Central and North Lake Joondalup.

As summer advanced, regression of the sexual condition occurred. It is during this least sexually active stage of the annual cycle that moult and the replacement of worn feathers occurs (Frith, 1967). By late January and early February, flightless Black Swans and Australian Shelduck were recorded on North and Central Lake Joondalup. These sightings of flightless birds coincided with the period in which the lake's benthic plant communities were most extensive, particularly in the northern end. Black Swans would moult on their own, always staying close to marginal sedges, whereas the Australian Shelduck tended to gather in small moulting flocks of no more than 20 birds. Both species sought the safety of the permanent, deep water at the northern end of the lake.

Summer was also associated with the emergence of a variety of aquatic plants whose growth increased with the advent of shallower water and higher temperatures. Water Couch, *Paspalum disitichum,* began to thrive along the eastern shoreline of the southern end of Lake Joondalup. As the water level dropped, lush green mats of Water Couch encroached on the open water in depths up to 0.1 metres and also colonised deeper areas as individual plants or in small clumps. Eurasian

Coot were observed in the flooded crops of Water Couch, feeding on the leaves, shoots and stems of the emergent plants. At this time, numbers of White-faced Heron were also high in Central and South Lake Joondalup, particularly along the eastern shoreline (Figure D21).

Australian Wood Duck were similarly attracted to the Water Couch. A large concentration of 140 birds briefly used North Lake Joondalup as a staging post in November 1991. Small flocks of 20 to 40 birds also visited South Lake Joondalup through December 1991 and January 1992, with slightly lower numbers in the summer of 1992/1993 (Figure D17). According to Frith (1967), Wood Duck campsites are traditional, and in most years flocks are known to locate themselves at this site (Bekle, 1980, 1988).

Both summers revealed similar patterns in the growth and distribution of benthic flora. *Myriophyllum propinquum* was well established prior to summer and by the end of February *M. propinquum* , *Nitella congesta, Najas marina* and *Potamogeton pectinatus* occurred over large areas in the deeper North Lake Joondalup. During both summers Eurasian Coot and Black Swan were the dominant herbivores (Figures D9 and D10) and were frequently seen to be feeding on *Potamogeton pectinatus,* although other benthic species such as *Chara* may also serve as an acceptable food source. North Lake Joondalup also provided deeper water for diving species which moved up from the shallower Central and South Lake Joondalup as the water level fell. A steady increase was observed in the numbers of Cormorants, Australian Wood Duck, Musk Duck and Blue-billed Duck. Musk Duck were the last diving birds to leave the more southern parts of Lake Joondalup. During the first summer these events were delayed until early autumn 1992 due to the higher water levels associated with the unseasonal summer rains.

Within the large post-breeding concentrations of the December-February period in both summers, the differences in feeding habitat that differentiate many of the waterbirds at other times were obscured. Competition for food appeared to be at a low level and did not operate to markedly separate the distribution of species at this time. This indicates that these two lakes are rich and diverse life-support systems that form complex food-chains and food-webs which are at their most productive during the post-breeding period. The preferred feeding habitat of waterbirds using the Yellagonga Regional Park lakes is shown in Table 5.2. Only 11 species are able to feed in deep water (greater than 1.5 metres) emphasising the importance of

	Pasture				**Open Water** (m)			
	Dry	Flooded	Rushes	Mudflats	Film (0.1m)	Shallow (0-0.5m)	Medium (0-1.5m)	Deep (>1.5m)
Blue-billed Duck						▓	▓	░
Musk Duck			▓			░	▓	▓
Black Swan	░	▓			░	▓	▓	
Australian Shelduck	░	▓			░	▓		
Australian Wood Duck	▓	▓						
Pink-eared Duck					░	▓	░	
Grey Teal	░	▓			▓	▓		
Mallard	░	▓			░	▓		
Pacific Black Duck	░	▓			░	▓		
Australian Shoveler					░	▓		
Hardhead					░	▓	▓	░
Australasian Grebe						░	▓	▓
Hoary-headed Grebe						░	▓	▓
Great Crested Grebe						░	▓	▓
Darter							░	▓
Little Pied Cormorant							▓	▓
Pied Cormorant							░	▓
Little Black Cormorant							▓	▓
Australian Pelican						▓	▓	
Great Egret		░				▓		
White-faced Heron		░				▓		
Cattle Egret		░				▓		
Rufous Night Heron		░	▓					
Little Bittern			▓					
Glossy Ibis		▓				▓		
Australian White Ibis		▓				▓		
Straw-necked Ibis	▓	▓				░		
Yellow-billed Spoonbill		░				▓		
Purple Swamphen	░	▓	▓					
Dusky Moorhen	░	▓	▓					
Black-tailed Native Hen			▓					
Eurasian Coot	░	▓			░	▓	░	░
Common Greenshank				░	▓			
Common Sandpiper				░	▓			
Black-winged Stilt					▓	░		
Red-necked Avocet				░	▓			
Black-fronted Dotterel					▓			
Total Waterbirds	10	17	6	3	14	23	14	11

Table 5.2 Preferred feeding habitat of waterbirds using the Yellagonga Regional Park lakes. Lightly-shaded boxes indicate occasional use and darker-shaded boxes indicate frequent use.

fringing habitats such as mudflats and shallow water areas in these lakes.

Autumn: time of stress and niche differentiation

Autumn represented the seasonal low water mark for both lakes in the annual cycle of filling and drying. The amount of water remaining in Lakes Joondalup and Goollelal by the end of this cycle depends on the rainfall of the previous season; it is reduced to a minimum by the steadily increasing temperatures and associated evaporation of the summer season. As the bird population of the Yellagonga wetlands increased it entered a period of environmental stress. The post-breeding assemblages included the young that were now able to fly and had survived the brood period. In the early summer months these lakes provide an abundance of food resources and a comfortable environment for waterbirds. In contrast, the end of the dry season produced conditions that the birds must "endure or desert".

The waterbird populations began to move as the lakes steadily became shallower. These bird movements were initially from one part of a lake to another in search of food, followed eventually by short-distance movements from the shallow to deeper water bodies. Bekle (1988) observed that the dry season patterns of lakes in the Perth region are well established by the end of March. The bulk of the waterbird population is then located within the deep-water lakes, such as Lakes Joondalup and Goollelal. During this period waterbirds devote an increasing proportion of time to feeding.

While overall patterns of lake usage in the autumn months (March-May) were similar to those previously observed (Bekle, 1988), appreciable niche differentiation was observed in the distributions and feeding behaviours of species in the autumns of both 1992 and 1993. There were also significant differences in total abundance over the two years of the study. The March bird population for the Yellagonga wetlands reached approximately 5,000 in 1992 and 8,000 in 1993. The greater numbers observed in 1993 were due to drier conditions throughout the entire Swan Coastal Plain, and the diminishing availability of fresh water habitats . This led to a late influx of about 4,000 Eurasian Coot (Figure D9) and 1,000 Black Swans (Figure D10). Although widely distributed throughout both lakes, the largest concentrations were observed feeding on submerged macrophytes in North and Central Lake Joondalup. In 1992 significant reductions in the populations of both species did not occur until May/June, suggesting that the higher than normal water levels helped to maintain an adequate food supply for these birds. Eurasian Coot are clearly the most abundant species on Lake Joondalup with dry season numbers exceeding 4,000 birds in most years (Jaensch *et al.*, 1988; Storey *et al.*, 1994). The lake was also identified by Jaensch & Vervest (1988) as the most important site for this species in South-western Australia.

By early March, the Common Sandpipers and Common Greenshank had left on their northward migration, and the onset of winter rains resulted in the outward migration of many of the summer visitors to the wetlands. The autumnal low-water phase was a stable period before these opening rains, which then set the annual cycle of biological production in motion. Waterbirds tended to use discrete areas in more strict accordance with their habitat requirements. Between six and eight Australian Pelicans assembled in Central Lake Joondalup as fish could now be caught more easily at these seasonally lower water levels (Figure D22). Lakes Joondalup and Goollelal are relatively deep compared with other Perth metropolitan wetlands, and therefore persist throughout the summer drought period providing feeding grounds for ducks, swans, coot and a variety of other birds when nearby shallower lakes have dried out. For a short period in the drier March 1993, a large influx of 400 Musk Duck on Lake Goollelal indicated that their preferred deep water habitats had become scarce elsewhere on the coastal plain (Figure D2).

5.7 DISCUSSION

The alternation of wet and dry seasons is the principal influence on productivity and habitat, and therefore on the behaviour of the waterbirds. By following the sequence of annual events affecting particular species it is possible to illustrate seasonal changes and the close association that the waterbirds have with their dynamic habitat. This sequence, as described here, begins with the breeding season - the reproductive process is precisely timed to maximise the chances of the hatchlings' survival - and ends with a gradual concentration of waterbirds on the (Yellagonga Regional Park) wetlands which function as refuges. As summer refuges these lakes cater for the requirements of a wide range of seasonal migrants, providing both deep and shallow water habitats. Permanent open water can accommodate large numbers of Black Swan, Eurasian Coot and various duck species. Equally important is the availability of seasonal mudflats for migrant populations of local and trans-equatorial waders; unfortunately the productivity of such areas is not fully recognised and they are generally the first to suffer reclamation and drainage. Thus breeding towards the end of the wet season, an influx of local and trans-equatorial migrants onto these lakes in summer, and concentration on this important dry season habitat is the general pattern of the waterbird cycle for the Yellagonga Regional Park wetlands.

By recognising that certain birds use a number of lake ecosystems and portions of a single lake basin to satisfy their requirements, it is possible to identify different linkages and networks between functionally related habitats. Food, suitable nesting materials, shelter and roosting facilities have a spatial expression; one habitat may be connected with another, nearby or far away. Therefore, a study such as this should be considered in its broader context, particularly as such linkages contribute to the ecological stability of Lakes Joondalup and Goollelal. The fact that these two lakes are now contained within the boundary of the Yellagonga Regional Park suggests that perhaps there is growing acceptance of this important ecological concept.

The Lake Joondalup basin includes two types of habitats; the northern end of the lake is permanent open water, while the southern portion takes on the characteristics of an ephemeral lake, particularly in drier years. Waterfowl reside on the open water and along the banks during the day, moving southwards in the late evening to feed in the shallows (Bekle, 1988). Local dispersal of birds from the lake also occurs; ibis and other colonially roosting birds, while resident at Lake Joondalup during the hours of darkness, move daily to other lakes nearby to feed (Bekle, 1982). Waterbird fluctuations in a district are also closely tied to seasonal changes in water-levels and the accompanying productivity. As some lakes on the Swan Coastal Plain dry out during summer, waterbirds move to summer refuges, such as Lakes Joondalup and Goollelal, where water is still available. These lakes are somewhat deeper, but by summer have become sufficiently shallow to enable Black Swan and species of dabbling ducks to exploit expanding shallow littoral habitats.

Waterbirds, such as Grey Teal and Pink-eared Duck, also arrive on the wetlands from areas beyond the metropolitan area, using them for a limited period before moving elsewhere. These large-scale migrations occur throughout the south-west of the State, and are primarily directed towards the productive littoral feeding habitats, as well as aiming at locating suitable nesting sites (Gentilli & Bekle, 1983). The direction and timing of inter-regional migrations is largely determined by the intensity and distribution of rainfall. The importance of wildlife preservation however extends beyond the Yellagonga Regional Park wetlands and the south-west of Western Australia, because they are visited each summer by migratory wading birds from the Northern Hemisphere. Australia is signatory to international treaties which oblige it to protect the habitats of many of these species. Trans-equatorial migrants, such as sandpipers and other waders, occupied mudflats in the southern portion of Lake Joondalup. Compared with earlier surveys (Bekle, 1980; 1988), numbers of species and individuals were uncharacteristically low during this study, due to the higher water levels resulting in limited availability of mudflats.

Information regarding the effects of the alteration of lake habitat on waterbirds is comparatively scarce, although when several pressures (eg. habitat destruction and change, increased eutrophication) deplete breeding stocks, recovery may be impeded. For example, the margins and shallow water habitats are the most biologically productive part of these wetlands and also the most important for waterbirds providing nesting, roosting, and feeding habitats. The most significant functions of both lakes are highly dependent on the presence of surrounding paperbarks and reeds.

Future developments may exert considerable pressure on the buffer zone of fringing vegetation, including sedges and paperbarks, in these wetlands. Perhaps the most damaging aspect of this urban development is the effect this is likely to have on the waterbird population. Clearing has already significantly reduced the availability of habitat for many bush birds, and the protective isolation of the northern roosting area for waterbirds at Lake Joondalup may be threatened. If this habitat destruction continues it is doubtful whether the ibis will remain. Concern is also expressed for seasonal habitats, such as the southern end of Central Lake Joondalup, particularly the mudflats just north of the causeway. Rehabilitation of fringing vegetation south of the causeway is urgently required in order to minimise the impact of the Woodvale Residential development.

Recognising that the Yellagonga Regional Park wetlands are part of networks of functionally related waterbird habitats, strengthens the need to preserve existing habitats in Lakes Joondalup and Goollelal. Sound management and careful planning, such as the concentration of recreation and development in these areas, are required to ensure the continued effectiveness of both lakes as waterbird sanctuaries. The conservation of waterbirds in these wetlands is dependent on the preservation of vital habitats.

Recognising that the Yellagonga Regional Park wetlands are part of networks of functionally related waterbird habitats, strengthens the need to preserve existing habitats in Lakes Joondalup and Goollelal. Sound management and careful planning, such as the concentration of recreation and development in these areas, are required to ensure the continued effectiveness of both lakes as waterbird sanctuaries.

6 CONCLUSIONS AND RECOMMENDATIONS

Patrick Garnett, Adrianne Kinnear & Hugo Bekle

6.1 INTRODUCTION

Yellagonga Regional Park contains some of the most important wetlands of the Swan Coastal Plain including Lake Joondalup, Beenyup Swamp, Walluburnup Swamp and Lake Goollelal. These wetlands together with the remaining fringing and terrestrial vegetation have high conservation value. In addition they are important community resources scientifically, educationally, recreationally and aesthetically.

6.2 SUMMARY OF THIS STUDY

- The wetlands of Yellagonga Regional Park were divided into five major areas for descriptions of the water chemistry and the aquatic invertebrate communities. These aspects of the study extended over five seasons, from January, 1992 to February, 1993, with sampling occurring on a fortnightly (water chemistry) or monthly (invertebrates) basis. The five areas identifed were North, Central and South Lake Joondalup, Beenyup Swamp and Lake Goollelal.

- Analysis of the physico-chemical data identified two clear interpretable site clusters, each with distinctive chemistries. These clusters separated the Beenyup Swamp and South Lake Joondalup samples from all others. The former sites were characterised by higher mean levels of total and reactive phosphorus, but lower mean levels of total nitrogen, dissolved oxygen, pH and conductivity.

- There were strong seasonal variations in conductivity and in metal and chloride ion concentrations. These were due to evaporation in summer and rainfall-dilution in winter. Relatively high conductivity and ionic levels in these lakes are established features of these wetlands and are likely to be mainly a result of their proximity to the coast with consequent precipitation of ionic salts from ocean spray.

- Dissolved oxygen levels were high in the main water body of Lake Joondalup and in Lake Goollelal. Levels in Beenyup Swamp were extremely low, even anoxic at times. This may reflect enhanced oxidation processes in this relatively humic environment.

- The pH values for all wetland sites were alkaline as would be expected for wetlands within the Spearwood Dune System. Significantly lower pH levels were observed in Beenyup Swamp and (to a lesser extent) in South Lake Joondalup, probably due to higher levels of humic substances in these sites.

- On the basis of nutrient levels (total phosphorus and total nitrogen), the trophic status of all five sites in the wetlands was assessed as eutrophic. There is continued excessive nutrient input into Lake Joondalup from surface flow via Beenyup Swamp. This was first identified by Congdon (1986).

- The levels of reactive phosphorus and organic nitrogen were at least as high as those found in previous studies. Ratios of total nitrogen to total phosphorus and inorganic nitrogen to reactive phosphorus have decreased over the last two decades. These ratio reductions, together with the low inorganic nitrogen levels, suggest that nitrogen is likely to be the limiting nutrient for phytoplankton growth in these wetlands. The low inorganic nitrogen to reactive phosphorus ratios, together with alkaline pH values, indicate that all sites within the wetlands are susceptible to the formation of blue-green algal blooms.

- Chlorophyll *a* levels, as indicators of phytoplankton biomass, were highest in Central Lake Joondalup and there is evidence that algal blooms are becoming more frequent in this site. Chlorophyll *a* levels in Beenyup Swamp and, to a lesser extent, in South Lake Joondalup were not as high as expected given the level of nutrient enrichment. It is proposed that this was due, either directly or indirectly, to the presence of humic substances originating in Beenyup Swamp, even though this wetland would not be characterised as "coloured".

- A total of 133 invertebrate taxa were identified from the Yellagonga wetlands. Beenyup Swamp and South Lake Joondalup (and to a lesser extent, Lake Goollelal), support diverse and abundant invertebrate communities. This high secondary productivity may, in part, be a response to the enhanced nutrient enrichment. In contrast, the communities of Central and North Lake Joondalup are relatively sparse and species-poor.

- Water chemistry gradients superimposed on the seasonal fluctuations in temperature and moisture appear to be the major factors influencing the microcrustacean communities. *Daphnia carinata* dominated the microcrustacean communities of the most enriched sites, South Lake Joondalup and Beenyup Swamp. A suite of eutrophic-tolerant microcrustacean species was ubiquitous throughout the wetlands, with an increased abundance in the most enriched sites. A second suite of species was found exclusively in these sites.

- A combination of factors was seen as influencing the macroinvertebrate abundance and species diversity. These were the degree of seasonality of the wetland, the water chemistry gradients and the unique particulate and sediment characteristics of the northern region of Lake Joondalup.

- Northern-most areas of Lake Joondalup were relatively species-poor and characterised by two species of detrital feeders and a restricted set of gastropod grazers. Southern-most sites of Lake Joondalup and Beenyup Swamp supported a rich and abundant macroinvertebrate fauna representative of a variety of trophic levels.

- Aquatic habitats with emergent vegetation supported macroinvertebrate communities which were substantially larger and richer than open-water habitats. A significant number of species occurred exclusively in these vegetated habitats.

- Thirty seven species of waterbirds were recorded using the Yellagonga Regional Park wetlands during the study. All of these species frequented Lake Joondalup and 23 species were observed on Lake Goollelal.

- Ten species were identified as resident in the Park and evidence of breeding was observed for nine, most importantly the Great Crested Grebe, Blue-billed Duck and Musk Duck. The remaining 27 seasonal/occasional visitors included two trans-equatorial migratory species, the Common Sandpiper and Common Greenshank. The Eurasian Coot, Black Swan, Pacific Black Duck, Australian Wood Duck and Australian Shelduck, and two large wading birds (Australian White Ibis and Straw-necked Ibis) were the most abundant species.

- The wetlands provide an important dry season refuge for large concentrations of up to 8,000 birds. There were marked seasonal variations in species richness and total abundance of waterbirds; the significant increases in species richness and abundance during summer occur because Lakes Joondalup and Goollelal are sources of permanent water that provide refuge and feeding grounds for migrating waterbirds during the dry season.

- An integrated approach is required for the future management of the Yellagonga wetlands which recognises the existence of important linkages and networks between functionally related waterbird habitats at different scales: local, regional, continental and inter-continental.

6.3 CONCLUSIONS

Lake Joondalup has been receiving highly nutrient-enriched water via northerly flow from Walluburnup Swamp and Beenyup Swamp for over two decades. The unique character of Beenyup Swamp water is currently ameliorating the effects of nutrient enrichment in the Swamp and, to a lesser extent, in South Lake Joondalup. However, there is evidence of increasing algal blooms in Central Lake Joondalup. If high external loading of nutrients to these wetlands continues there is considerable potential for larger-scale algal blooms in the future. This is particularly the case for nuisance blooms of blue-green algae which have the potential to cause serious problems for the biota and to impact on the recreational and aesthetic value of the wetlands. In addition, the destruction and degradation of fringing vegetation has made the wetlands increasingly vulnerable. Further serious deterioration in water quality will impact negatively on the biodiversity of the aquatic invertebrate and bird fauna.

A series of recommendations for management is an important outcome of this research. These recommendations recognise the need for a multiple use framework for the Park but place conservation and rehabilitation as objectives of the highest priority.

The Yellagonga Regional Park wetlands have high conservation, recreational and aesthetic value. There is a need for the community to develop a shared vision for the Park which recognises these different values and uses. Such a vision should provide the basis for long term action to establish a unique wildlife area that fulfils conservation requirements and adds recreational and aesthetic value to the community as well as potential economic benefits from tourism to the City of Wanneroo.

In managing the Park there needs to be recognition of its interrelated ecological components, including upland and fringing vegetation, vegetated and open aquatic habitats, and the interdependence of the various fauna within the Park. For these reasons, a management plan needs to focus on the conservation and rehabilitation of all ecological components and on the complete range of habitats within the Park. Such a plan should go beyond short-term maintenance to prevent further degradation of the wetlands and extend to long-term restoration of riparian and upland communities and their fauna.

6.4 RECOMMENDATIONS

Recommendations from the study are grouped, for ease of consideration, under relevant headings. It is recommended that:

Water quality

1. The source(s) of nutrients flowing into Beenyup Swamp be identified as a matter of urgency and strategies be put in place for reducing these inputs;

2. Surface inputs of nutrients into the Park wetlands be monitored on a regular basis, including stormwater drains, and strategies for reducing these inputs be implemented (eg. nutrient stripping basins);

3. Nutrient levels and the trophic status of the wetlands be monitored regularly and opportunities for maintaining sustainable levels of nutrients be investigated;

Aquatic fauna

4. Regular monitoring of biotic diversity be undertaken to inform and guide management strategies;

5. The benthic fauna be considered for study, particularly in terms of the potential impact of the removal and degradation of riparian;

Seasonal hydrological cycle

6. Trends in the water levels in Lake Joondalup and Lake Goollelal be monitored as well as their potential effects on the sustainability of the wetland system (including protection of the full range of habitats for aquatic and avian fauna).

Fringing vegetation

This is important in providing habitat, food, pathways for nutrient uptake, colour and temperature amelioration. It is recommended that:

7. The conservation of all remaining areas of natural fringing vegetation be given a high priority in Lake Joondalup, Beenyup Swamp and Lake Goollelal. In this context, the conservation of vegetation within Beenyup Swamp and restoration of an effective vegetation buffer zone around it is particularly important, given the role that this small waterbody appears to play in modifying the algal response to enrichment;

8. The rehabilitation of degraded fringing and riparian vegetation, and restoration where appropriate, should be considered in areas where this is likely to improve water quality and re-establish natural habitats (particularly in South Lake Joondalup). Strategies such as these which increase the options for plant nutrient uptake may also be significant for reducing the potential internal nutrient loading from sediments. Such sediment release of nutrients is likely to slow or even prevent restoration as external loadings are reduced;

Waterbirds

9. The mudflats and littoral habitats of the eastern shoreline north of Ocean Reef Road be protected as an important feeding ground for a wide diversity of waterbird species, including trans-equatorial waders;

10. The protective seclusion of the important roosting site for ibis on the north-west shoreline of Lake Joondalup be maintained.

Upland vegetation

This is an important component of the Park and interfaces with the fringing vegetation. While this region was not part of the study it is recommended that:

11. An intensive survey of remaining terrestrial fauna be undertaken;

12. The conservation of high quality areas of terrestrial vegetation be given a high priority;

13. Strategies for rehabilitation and restoration of degraded areas be implemented;

14. In the longer term, strategies for the exclusion of feral predators be considered to allow for the reintroduction of indigenous fauna;

Land use & provision of recreational facilities

15. Educational and recreational facilities such as viewing areas and walkways be planned with conservation as the major priority;

16. Access nodes to the lake for educational and recreational purposes be planned using already degraded sites;

17. Activities inconsistent with the conservation of the wetland system eg. agriculture, market gardening and horse agistment be phased out;

18. Long-term strategies for the design and implementation of educational programmes be developed. Such programmes would provide educational platforms for developing a community understanding of the importance of reducing nutrient inputs to the wetlands and of the strategies implemented. In the longer term they would develop an appreciation in the local community for this resource and encourage the community to own, share and contribute to the vision for the Park.

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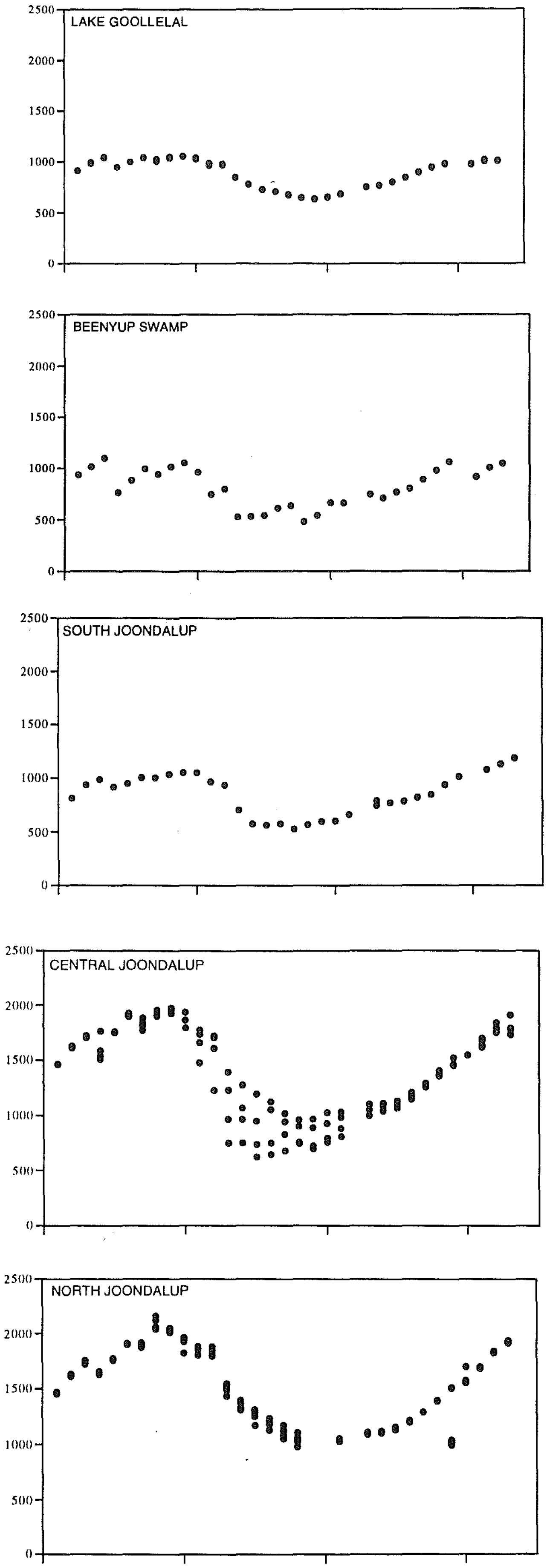
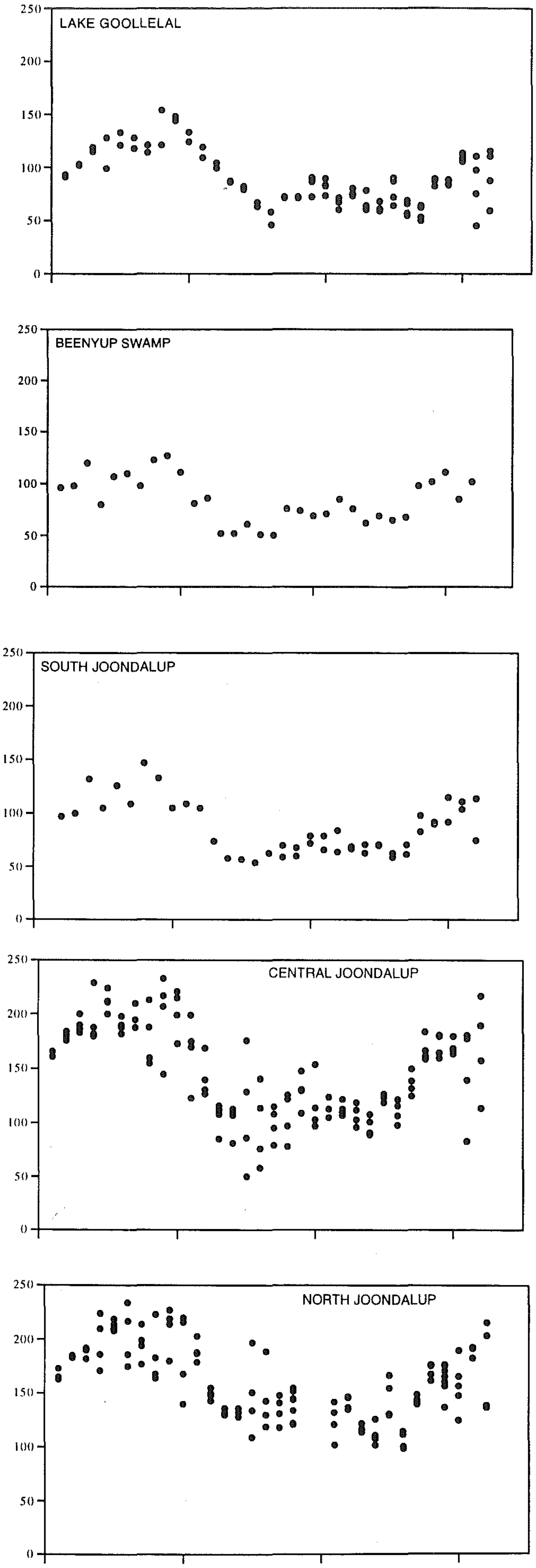
APPENDIX A

Water chemistry values displayed as scatter graphs
for each of the sampled wetland sites

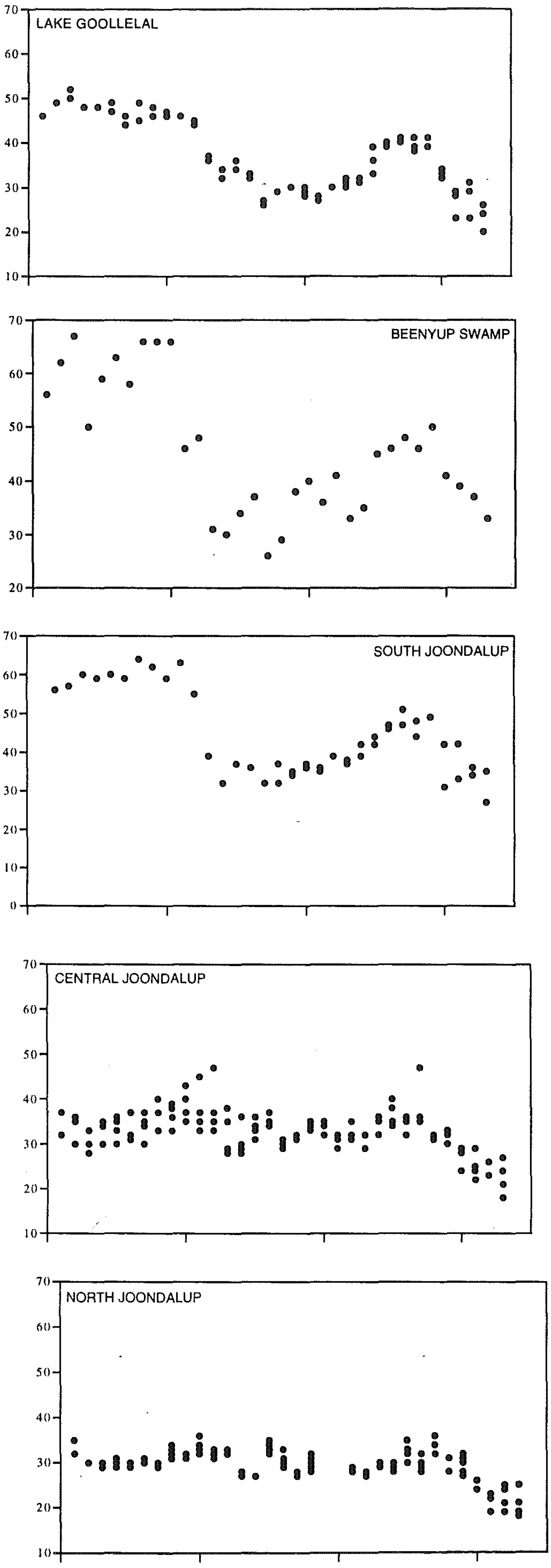
A1: CONDUCTIVITY (mS cm^{-1})



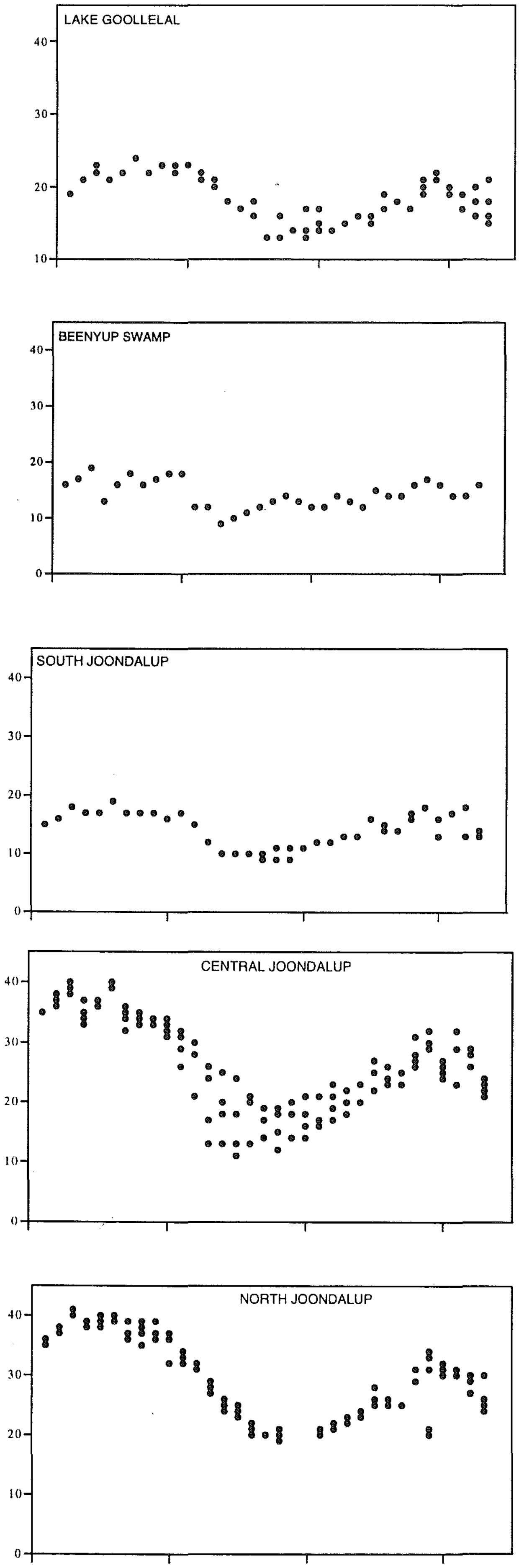
A2: SODIUM (mg L^{-1})



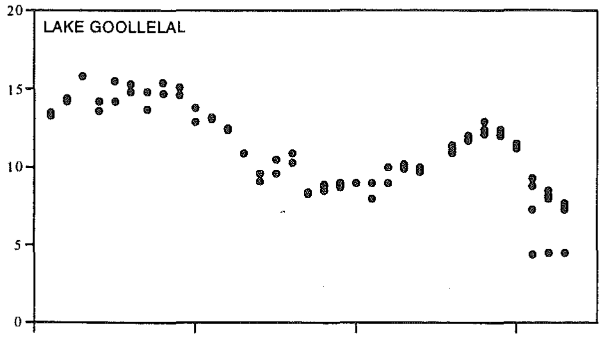
A3: CALCIUM (mg L^{-1})

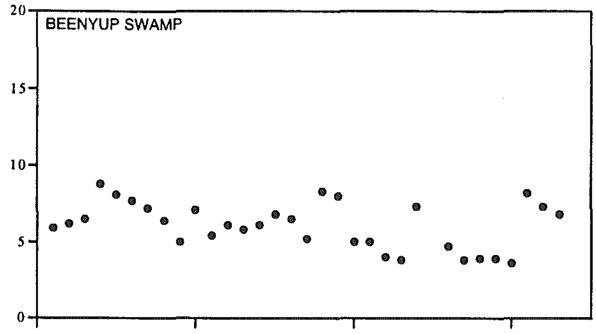


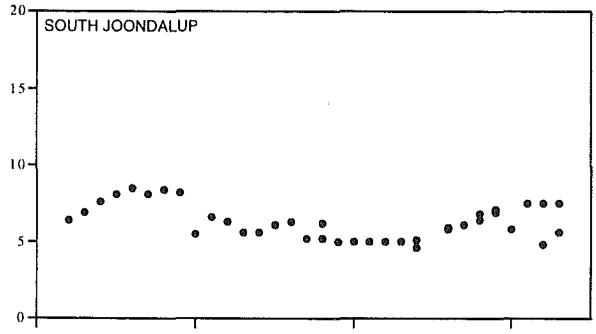
A4:MAGNESIUM (mg L^{-1})

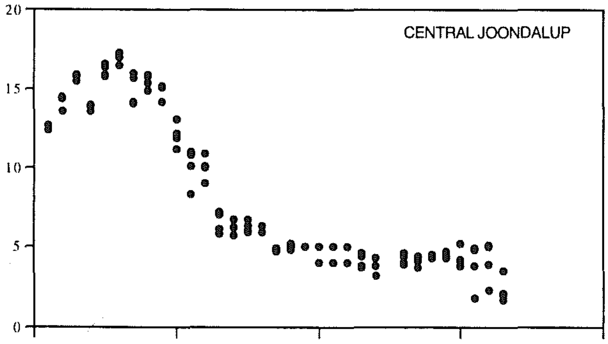


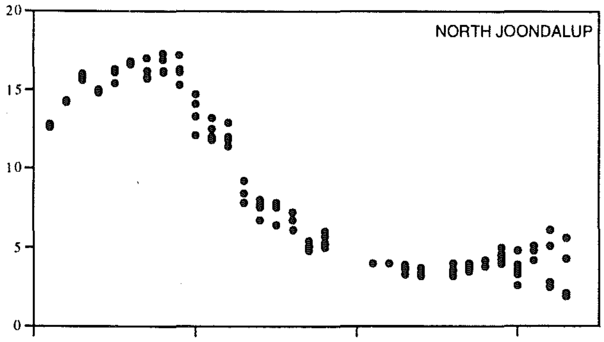
A5: POTASSIUM (mg L^{-1})



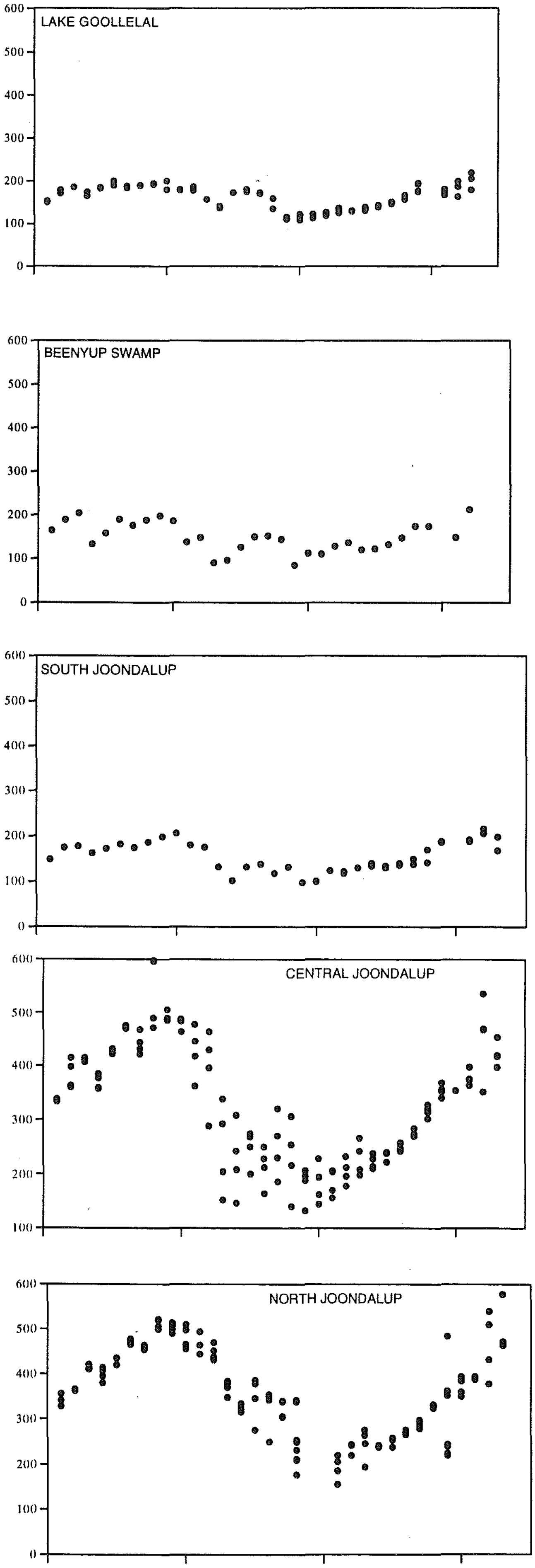


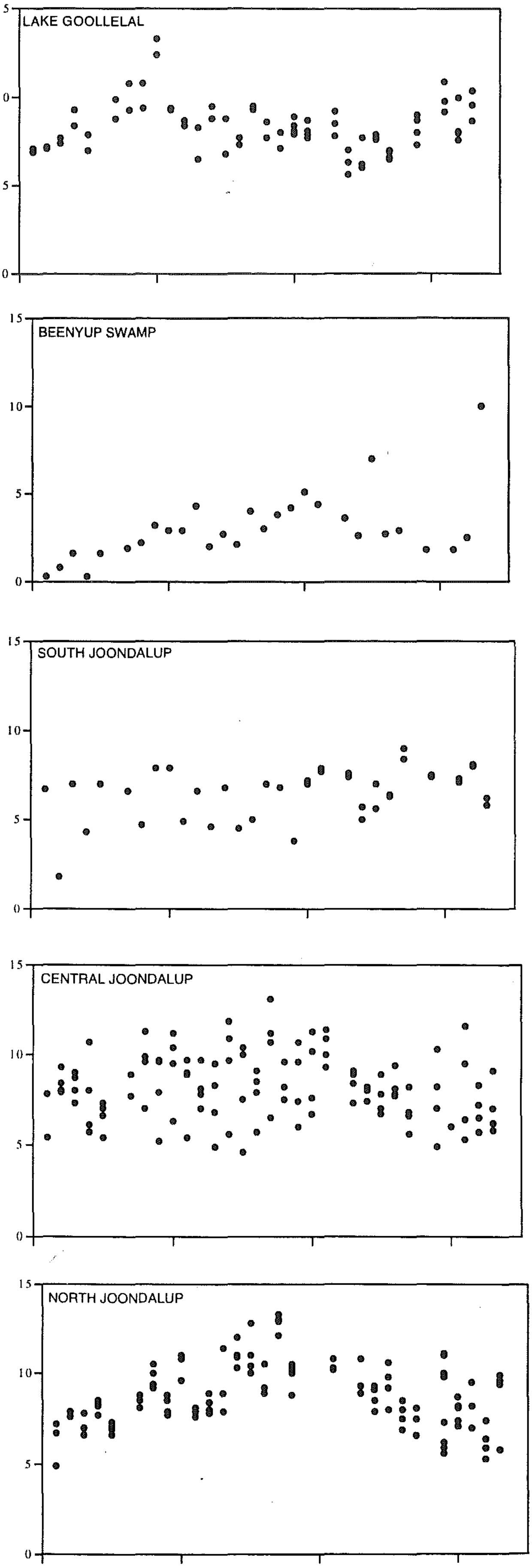






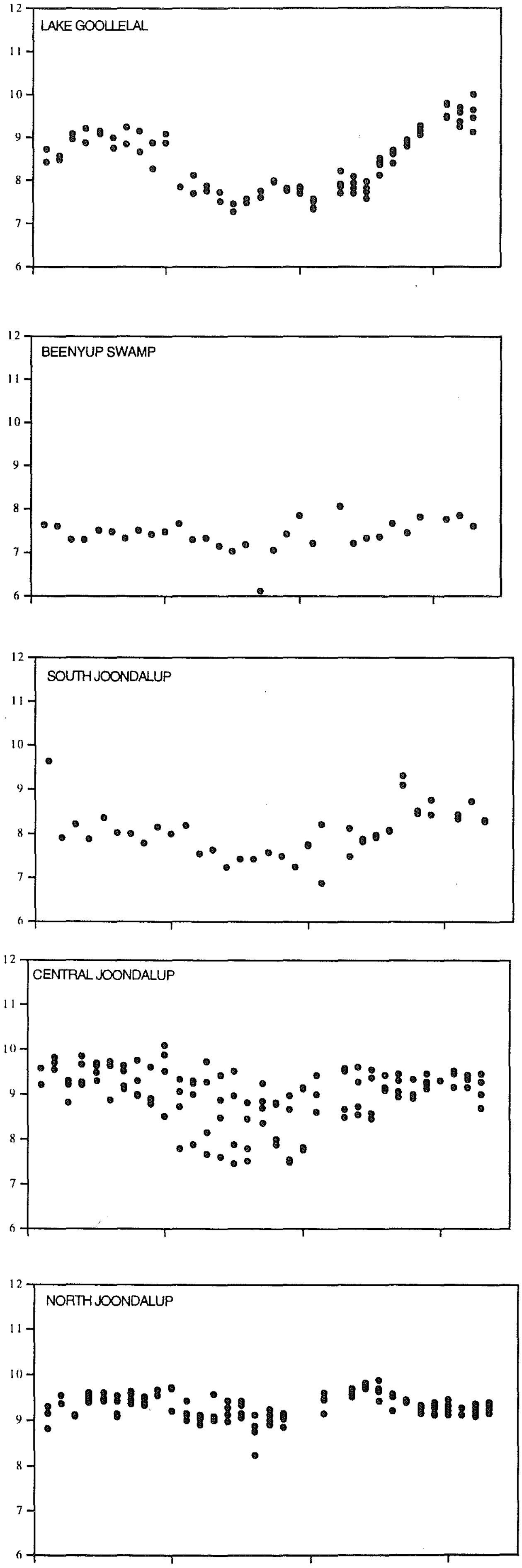
A6:CHLORIDE (mg L^{-1})



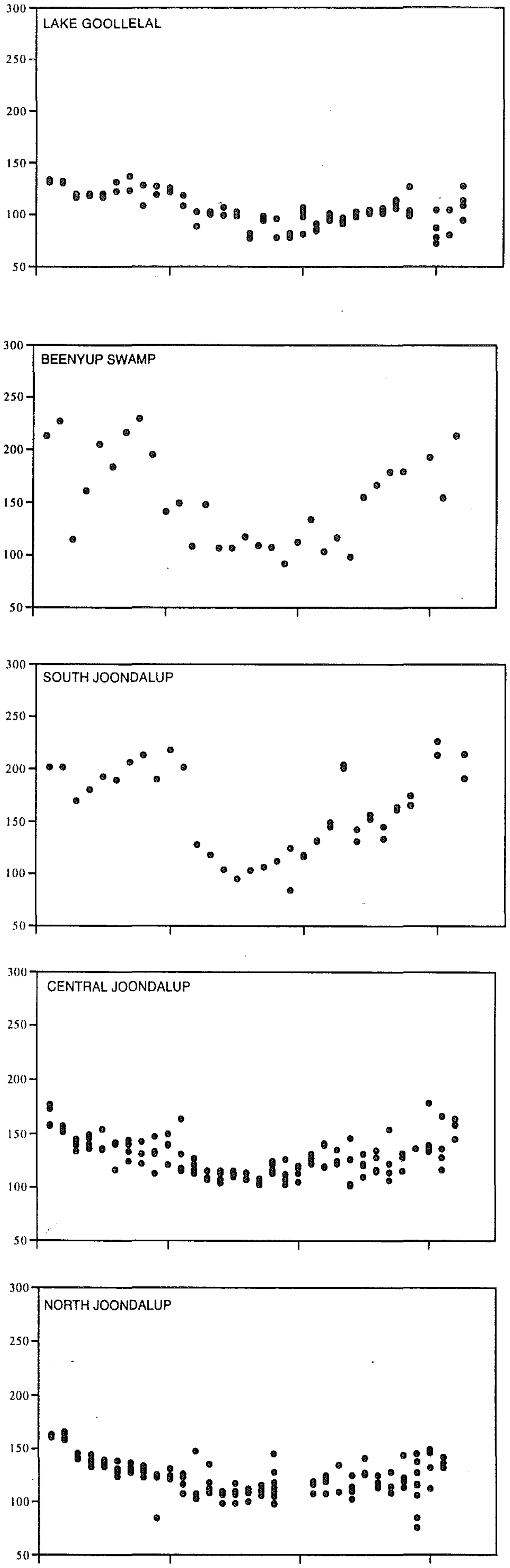


A7: DISSOLVED OXYGEN (mg L^{-1})

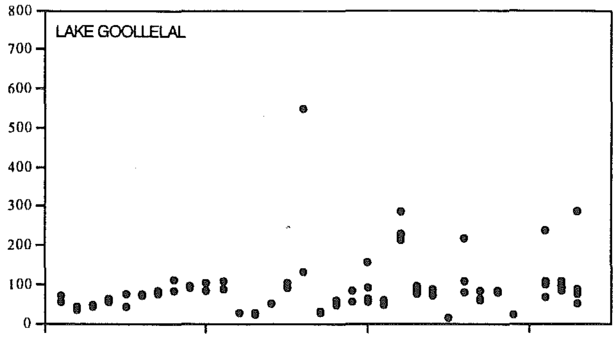
A8: pH

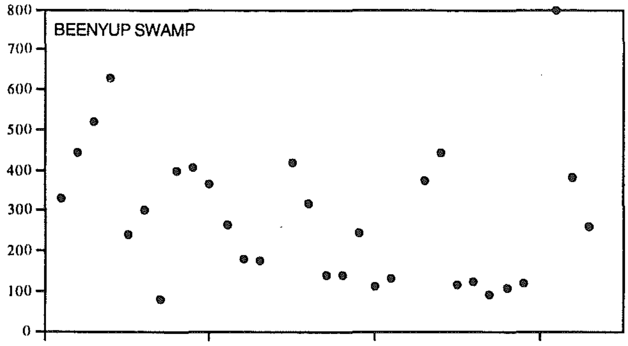

LAKE GOOLLELAL
BEENYUP SWAMP
SOUTH JOONDALUP
CENTRAL JOONDALUP
NORTH JOONDALUP
12
11
10
9
8
7
6

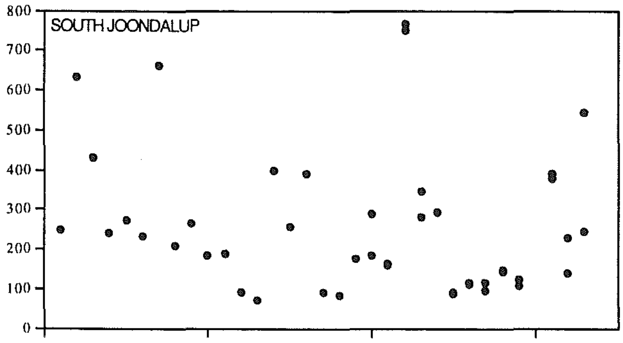
A9: ALKALINITY (mg L^{-1} $CaCO_3$)

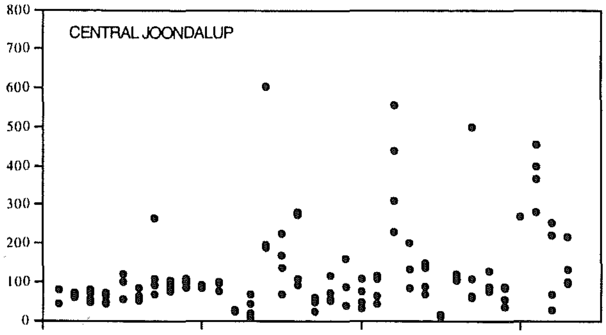


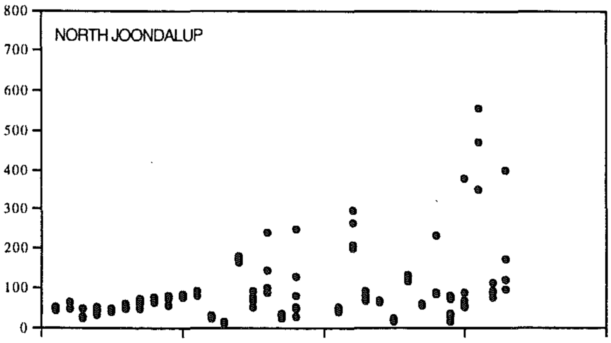
A10: TOTAL PHOSPHORUS (μg L^{-1})



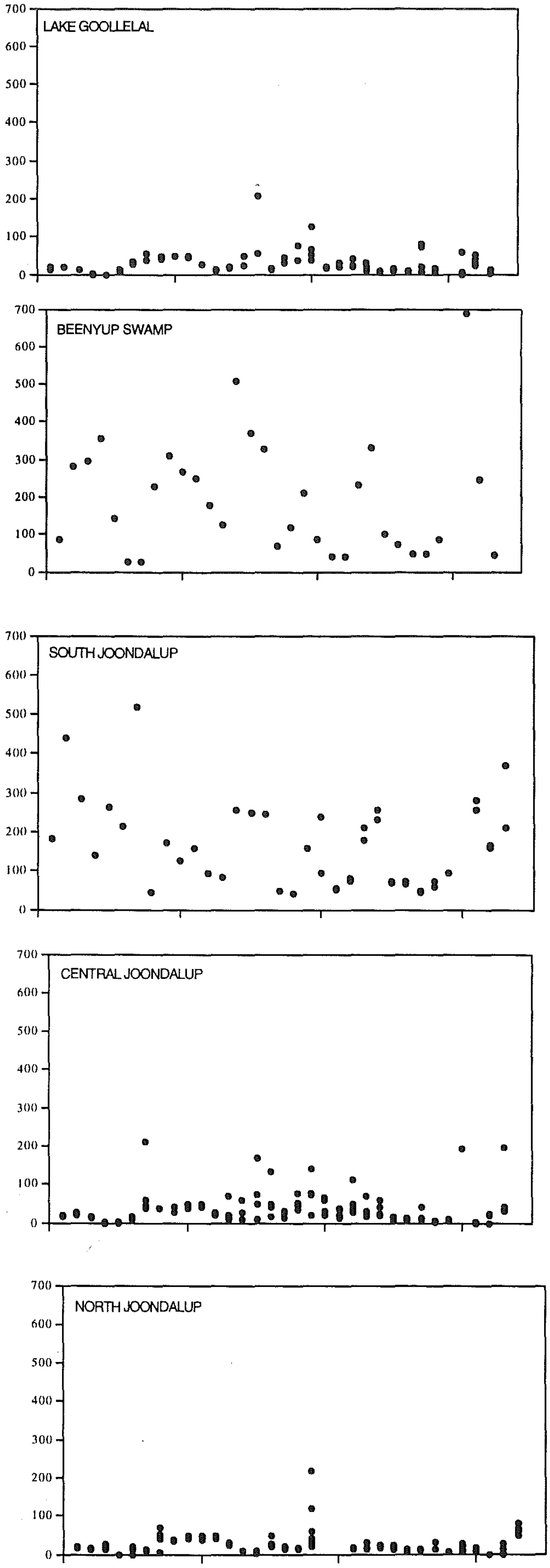




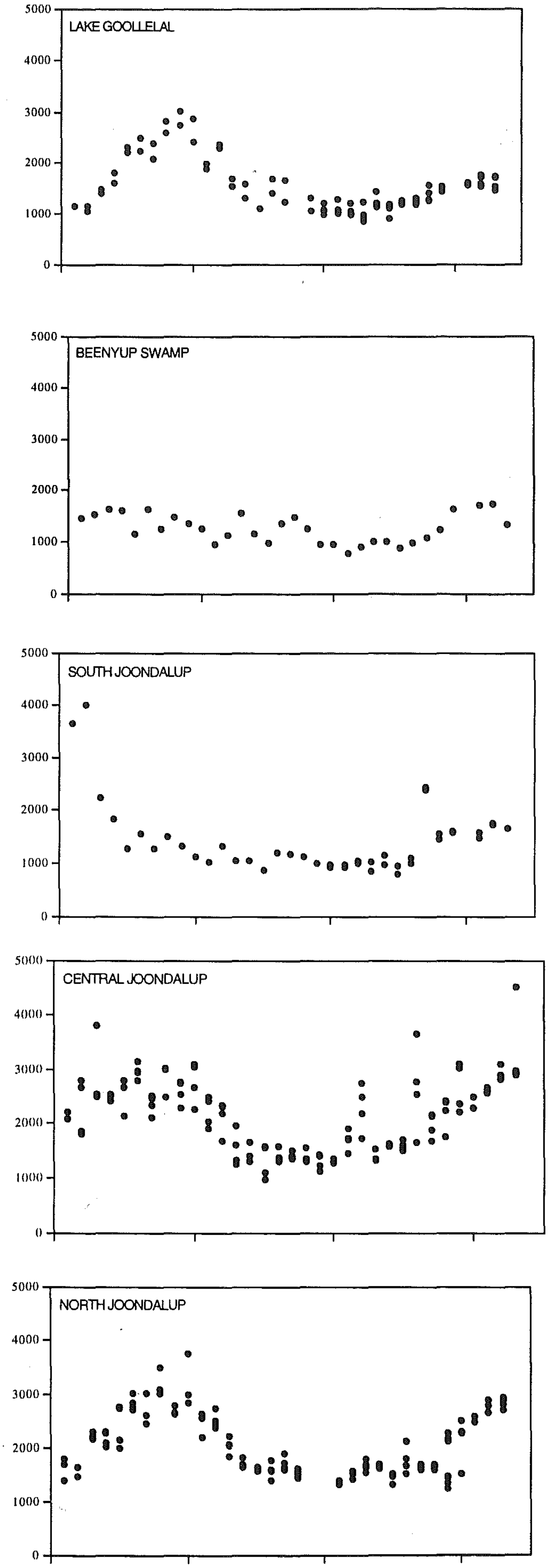




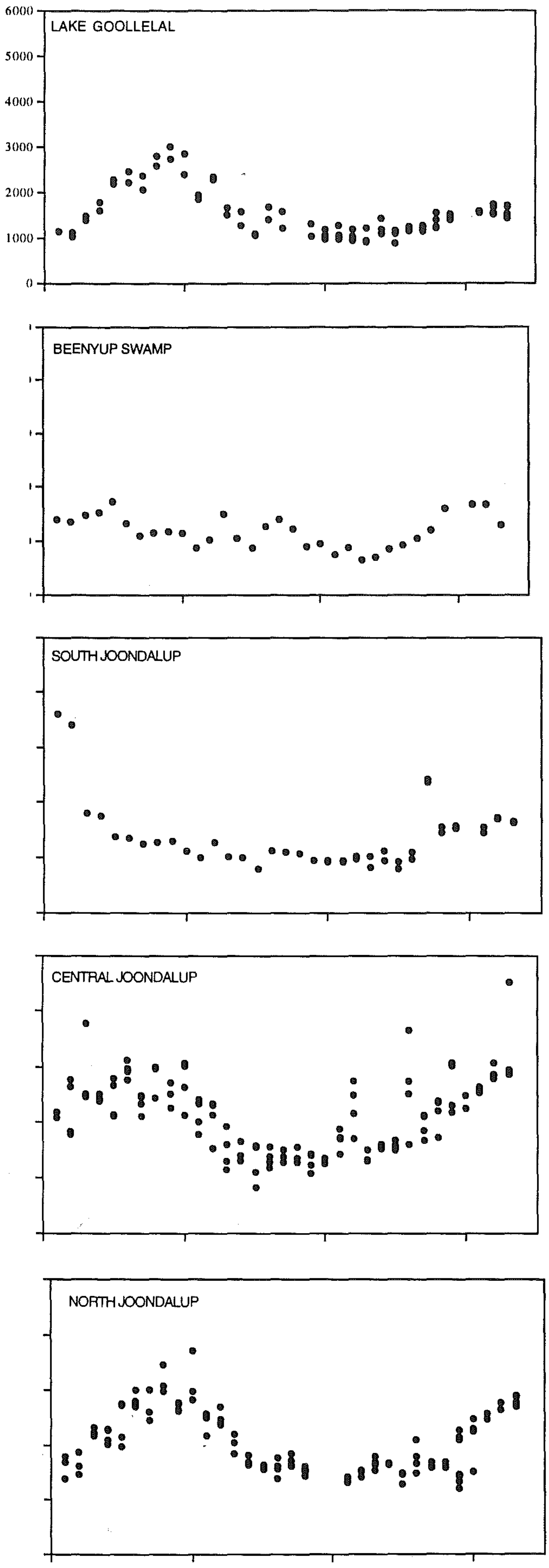
A11: REACTIVE PHOSPHORUS (μg L^{-1})



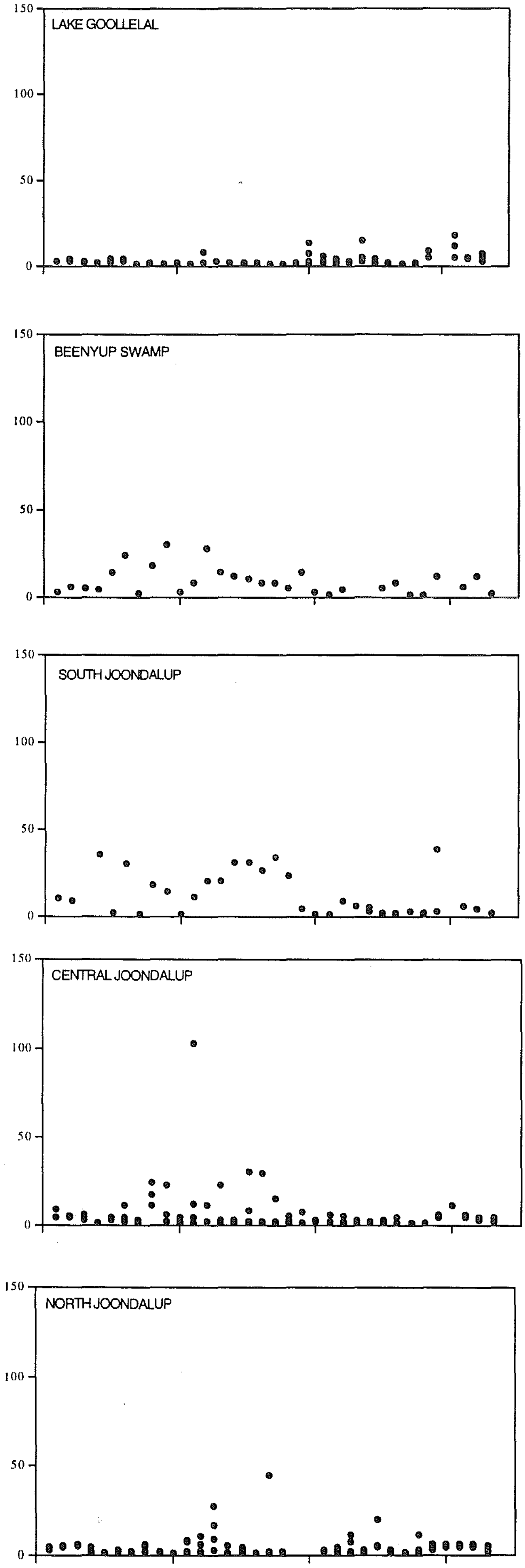
A12: TOTAL NITROGEN ($\mu g\ L^{-1}$)



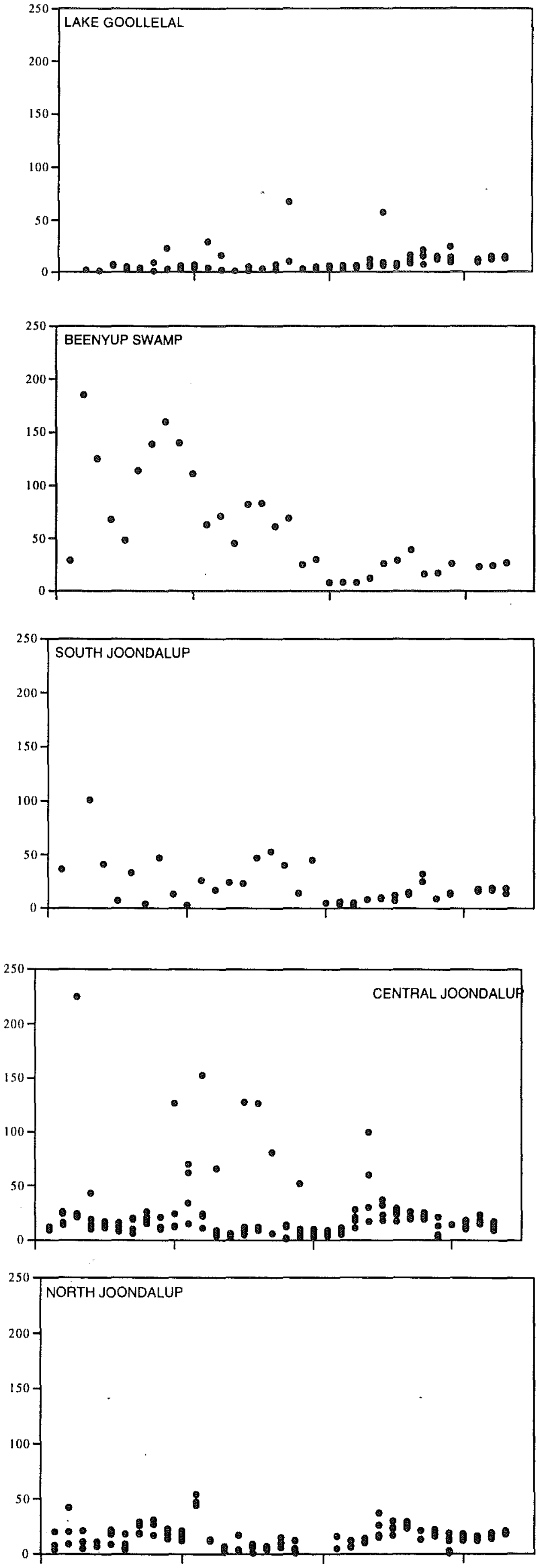
A13: ORGANIC NITROGEN ($\mu g\ L^{-1}$)



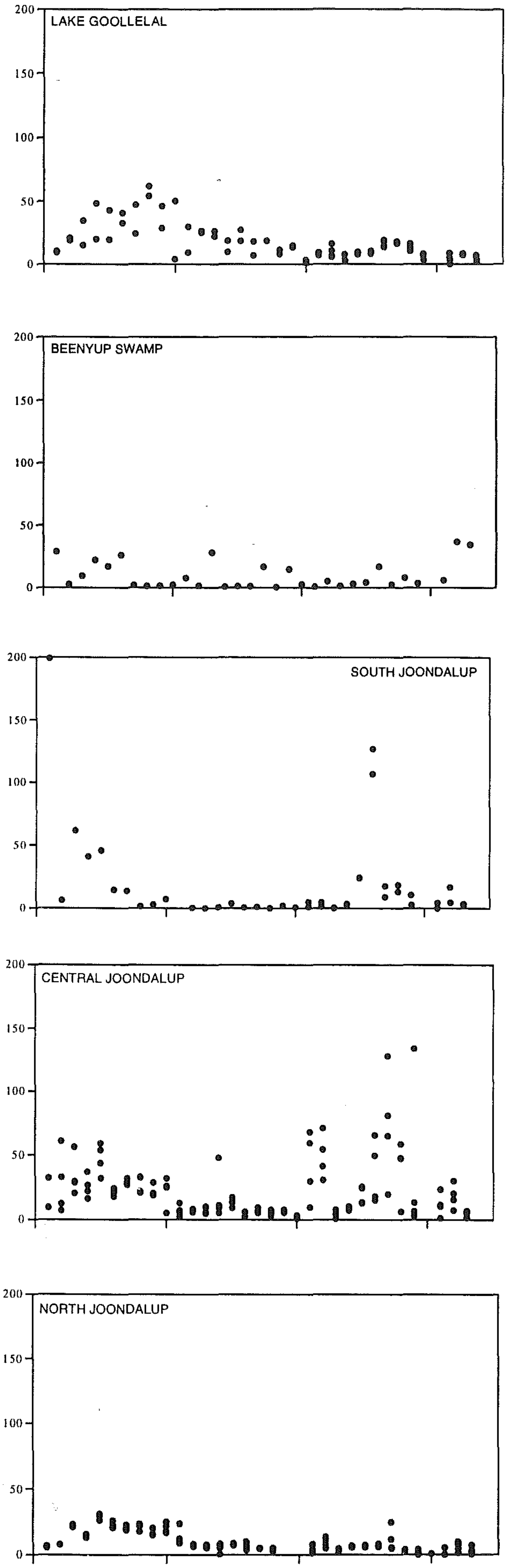
A14: NITRATE/NITRITE NITROGEN ($\mu g\ L^{-1}$)



A15: AMMONIUM NITROGEN ($\mu g\ L^{-1}$)



A16: CHLOROPHYLL *a* (µg L^{-1})



APPENDIX B

Aquatic invertebrate species list

YELLAGONGA REGIONAL PARK
AQUATIC INVERTEBRATES SPECIES LIST

J=Lake Joondalup, **B**=Beenyup Swamp, **G**=Lake Goollelal

(* denotes higher-order taxa present, including two vertebrate groups sampled, but unclassified; unknown species of orders are generally not included)

VERTEBRATA	PISCES*	GOBIIDAE	*Pseudoglobius olorum*	J,B,G
		POECILIDAE	*Gambusia holbrooki*	J,B,G
	AMPHIBIA*			J
ANNELIDA	OLIGOCHAETA*			J,B,G
	HIRUDINEA*			J,B,G
MOLLUSCA	GASTROPODA	PLANORBIDAE	Unknown species	J,G
		PLANORBIDAE	*Helisoma duryi?*	G
		PLANORBIDAE	*Glyptophysa* sp.	J
		PLANORBIDAE	*Isidorella hainesii*	J,G
		PHYSIDAE	*Physa acuta*	J,B,G
		PHYSIDAE	*Physa* sp.	J,G
		ANCYLIDAE	*Ferrissia* sp.	J,G
			Amerianna carinata	G
	BIVALVA	SPHAERIIDAE	*Sphaerium* species A	J,B
			Sphaerium Species B	J
ARTHROPODA	INSECTA: TRICHOPTERA	HYDROPTILIDAE	*Acritoptila globosa*	J,B,G
			Species A	J,G
			Species B	G
		LEPTOCERIDAE	*Oecetis* species A	J,G
			Oecetis species B	G
			Species A	J
			Species C	J
			Species D	J
			Species E	J
			Triplectides australis	J,B,G
		ECNOMIDAE	*Ecnomus* sp.	J

INSECTA:EPHEMEROPTERA	BAETIDAE	*Cloeon* sp.	J,G
		Baetis sp.	J,B
	CAENIDAE	*Tasmanocoenis* sp.	J,G
	LEPTOPHREOIDAE?	Unknown species A	B
INSECTA: NEUROPTERA		Unknown larva	J,B
INSECTA: ODONATA	CORDULIDAE	*Hemicordulia tau*	J,B
	AESHNIDAE	*Anax papuensis*	J,B
		Aeshna brevistyla	B
	LESTIDAE	*Austrolestes annulosus*	J,B,G
	COENAGRIONIDAE	*Ischnura heterostricta*	J,B
		Ischnura aurora	J,G
		Xanthagrion erythroneurum	J,B
		Austroagrion coeruleum	J,G
INSECTA: DIPTERA	CHIRONOMIDAE	*Chironomus alternans*	J,B,G
		Chironomus occidentalis	J,B,G
		Chironomus tepperi?	B
		Dicrotendipes conjunctus	J,B,G
		Dicrotendipes sp.	J,B,G
		Cladopelma curtivalva	J,B,G
		Tanytarsus fuscithorax	J,B,G
		Tanytarsus sp.	B
		Polypedilum nubifer	J,B,G
		Pentaneura levidensis	J
		Procladius villosimanus	J,B,G
		Coelopynia pruinosa	J,B
		Cryptochironomus griseidorsum	J,B
		Paralymnophyes pullulus	J,B,G
		Kiefferulus martini	J,B,G
		Kiefferulus intertinctus	J,B,G
		Paratanytarsus grimmii	J,B,G
		Orthocladiin species A	B
		Cricotopus sp.	J
	STRATIOMYIDAE	Species A	J,B

	TANYPODINAE	*Pentaneura levidensis*	J,B
		Species A (P)	J
	TABANIDAE	Species A	B
		Species B	J,G
		Species C	B
	CERATOPOGINDAE	*Culicoides* sp. A	J
		Culicoides sp.B	J,B,G
INSECTA: HEMIPTERA	CORIXIDAE	*Micronecta robusta*	J,B,G
		Agraptocorixa eurynome	J,B
		Sigara sp. A	J,B
	NOTONECTIDAE	*Anisops* sp.A	J,B,G
		Paranisops sp. A?	J,B,G
INSECTA: COLEOPTERA	DYTISCIDAE	*Hyphdrus elegans* (L)	J
		Lancetes lanceolatus	J
		Megasporus sp. A (L)	J
		Cybister sp. A (A)	J
		Sternopriscus multimaculatis	J
	HYDROPHILIDAE	*Berosus* sp.A	J
	CHRYSOMELIDAE	Species A	J
ARACHNIDA: ACARINA	PIONIDAE	*Piona cumberlandensis*	J,B
		Piona sp. A	J,B
		Acercella falcipes	J,B
	LIMNESIIDAE	*Limnesia* sp. A	J
		Limnesia sp. B	J
	ARRENURIDAE	*Arrenurus balladoniensis*	J
CRUSTACEA: OSTRACODA	CYPRIDIDAE	*Alboa wooroa*	J
		Candonocypris novaezelandiae	J,B,G
		Cypretta baylyi	J,B
		Sarcypridopsis aculeata	J
CRUSTACEA: CLADOCERA	DAPHINIIDAE	*Daphnia carinata*	J,B,G

CRUSTACEA: COPEPODS	CALANOIDEA	*151Calamoecia attenuata*	J,B,G
		Calamoecia tasmanica subattenuata	J,B,G
		Boekella sp.	J,B
		Harpacticoida sp.	J,B
	CYCLOPOIDEA	*Cyclopoida mesocyclops*	J,B,G
		Eucyclops sp.	J
		Cyclopoida macrocyclops	J,G
CRUSTACEA: AMPHIPODA	CEINIDAE	*Austrochiltonia subtenuis*	J,G
CRUSTACEA: ISOPODA	AMPHISOPIDAE	*Paramphisopus palustris*	J,B,G
CRUSTACEA: DECAPODA	PALAEMONIDAE	*Palaemonetes australis*	J,G
	PARASTACIDAE	*Cherax quinquecarinatus*	J,G

APPENDIX C

Waterbirds species list

WATERBIRDS RECORDED IN THE YELLAGONGA REGIONAL PARK

September 1991 - March 1993

In the following list, the waterbirds are arranged in family groupings in the order of listing in the 1994 RAOU Monograph 2. Names in the left-hand column are the recommended English names (Schodde *et al.*, 1978; Christidis and Boles, 1994) and those in the right-hand column are the scientific names according to Christidis and Boles (1994).

Family ANATIDAE

Blue-billed Duck	*Oxyura australis*
Musk Duck	*Biziura lobata*
Black Swan	*Cygnus atratus*
Australian Shelduck	*Tadorna tadornoides*
Australian Wood Duck	*Chenonetta jubata*
Pink-eared Duck	*Malacorhynchus membranaceus*
Grey Teal	*Anas gibberifrons*
Mallard	*Anas platyrhynchos*
Pacific Black Duck	*Anas superciliosa*
Australasian Shoveler	*Anas rhynchotis*
Hardhead	*Aythya australis*

Family PODICIPEDIDAE

Australasian Grebe	*Tachybaptus novaehollandiae*
Hoary-headed Grebe	*Poliocephalus poliocephalus*
Great Crested Grebe	*Podiceps cristatus*

Family ANHINGIDAE

Darter	*Anhinga melanogaster*

Family PHALACROCORACIDAE

Little Pied Cormorant	*Phalacrocorax melanoleucos*
Pied Cormorant	*Phalacrocorax varius*
Little Black Cormorant	*Phalacrocorax sulcirostris*

Family PELECANIDAE

Australian Pelican	*Pelecanus conspicillatus*

Family ARDEIDAE

Great Egret	*Egretta alba*
White-faced Heron	*Ardea novaehollandiae*
Cattle Egret	*Ardea ibis*
Rufous Night Heron	*Nycticorax caledonicus*
Little Bittern	*Ixobrychus minutus*

Family PLATALEIDAE

Glossy Ibis	*Plegadis falcinellus*
Australian White Ibis	*Threskiornis molucca*
Straw-necked Ibis	*Threskiornis spinicollis*
Yellow-billed Spoonbill	*Platalea flavipes*

Family RALLIDAE

Purple Swamphen	*Porphyrio porphyrio*
Dusky Moorhen	*Gallinula tenebrosa*
Black-tailed Native-hen	*Gallinula ventralis*
Eurasian Coot	*Fulica atra*

Family SCOLOPACIDEA

Common Greenshank	*Tringa nebularia*
Common Sandpiper	*Tringa hypoleucos*

Family RECURVIROSTRIDAE

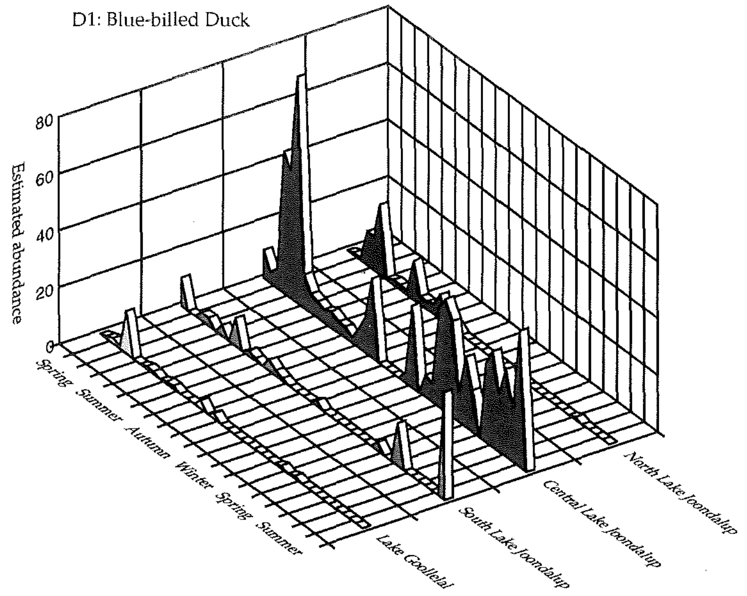
Black-winged Stilt	*Himantopus himantopus*
Red-necked Avocet	*Recurvirostra novaehollandiae*

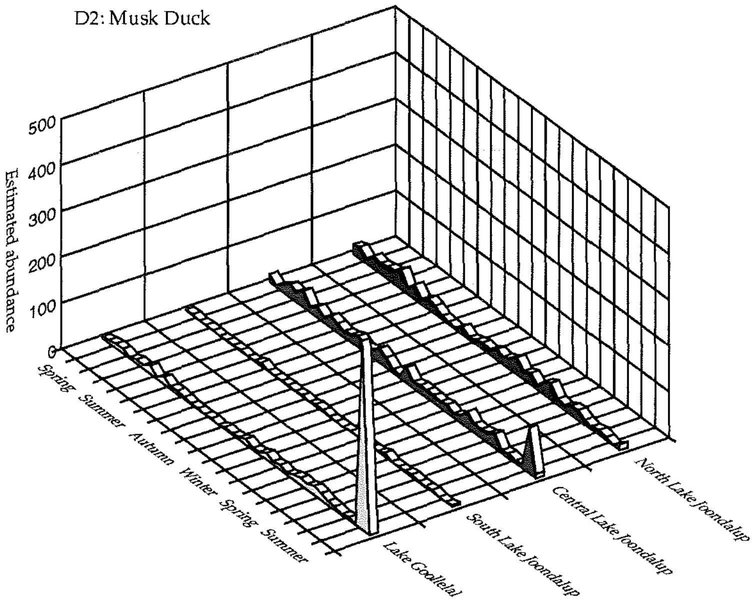
Family CHARADRIIDAE

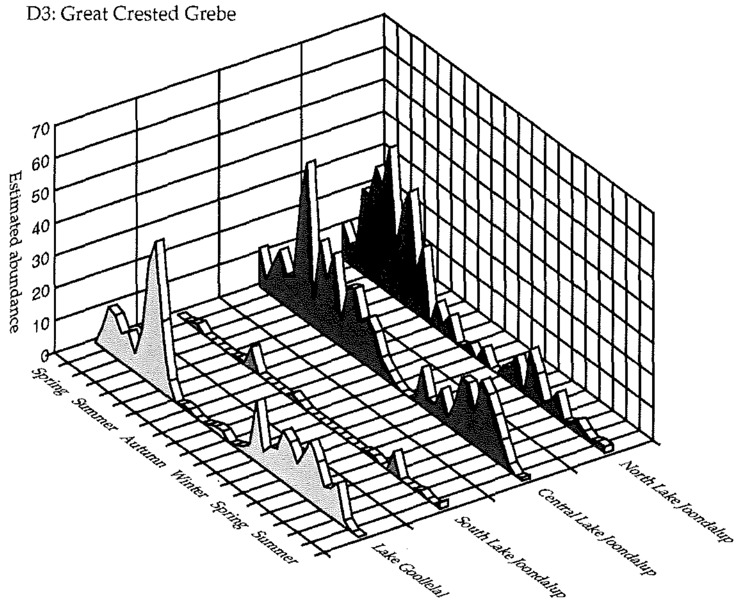
Black-fronted Dotterel	*Charadrius melanops*

APPENDIX D

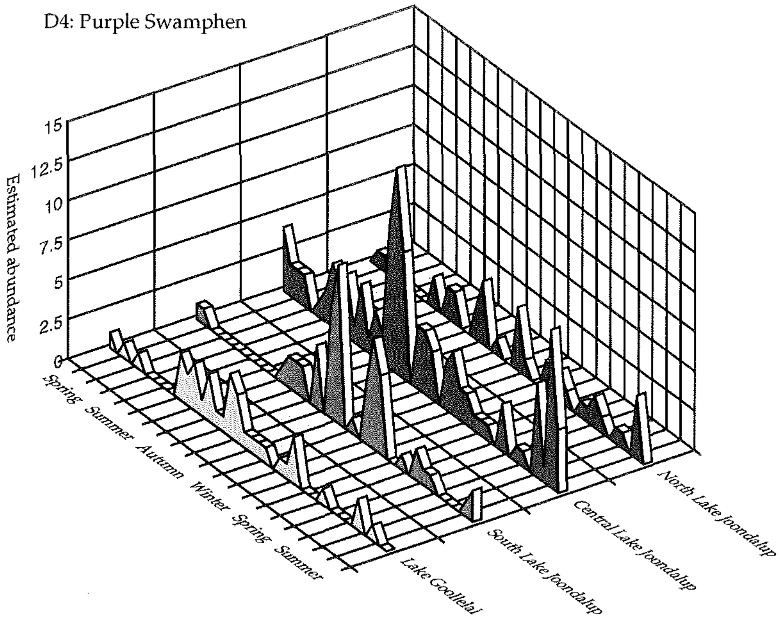
Spatial and seasonal patterns of abundance of selected bird species.


D1: Blue-billed Duck

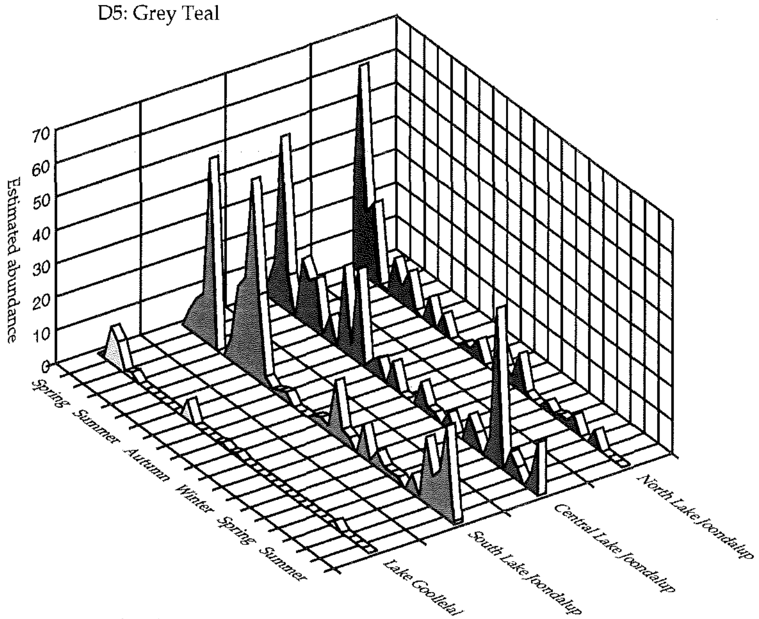

D2: Musk Duck


D3: Great Crested Grebe

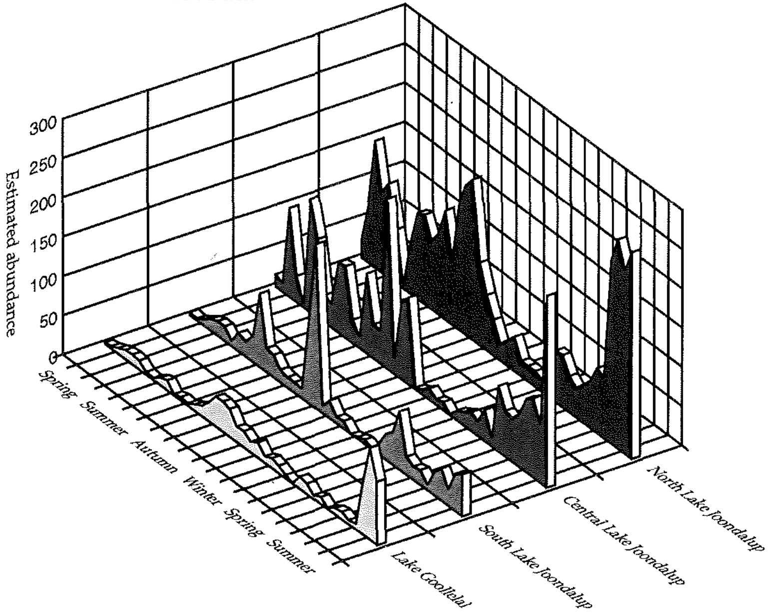
D4: Purple Swamphen



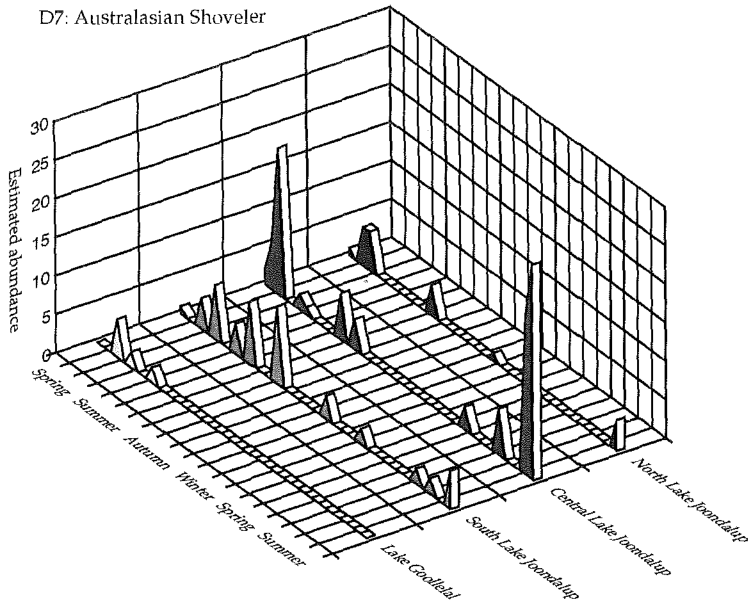
D5: Grey Teal



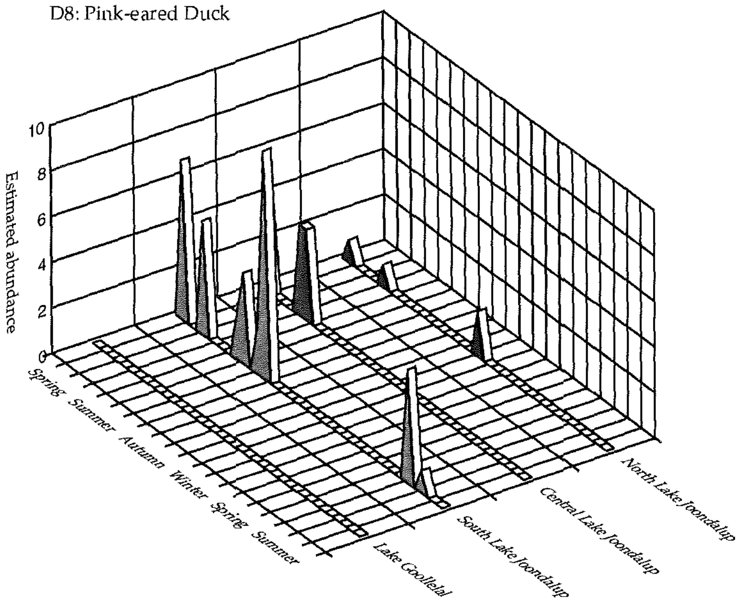
D6: Pacific Black Duck



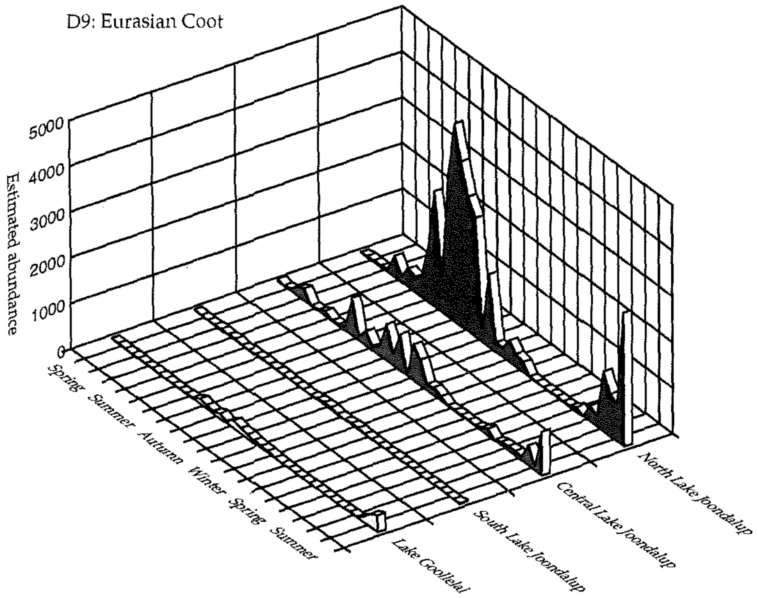
D7: Australasian Shoveler



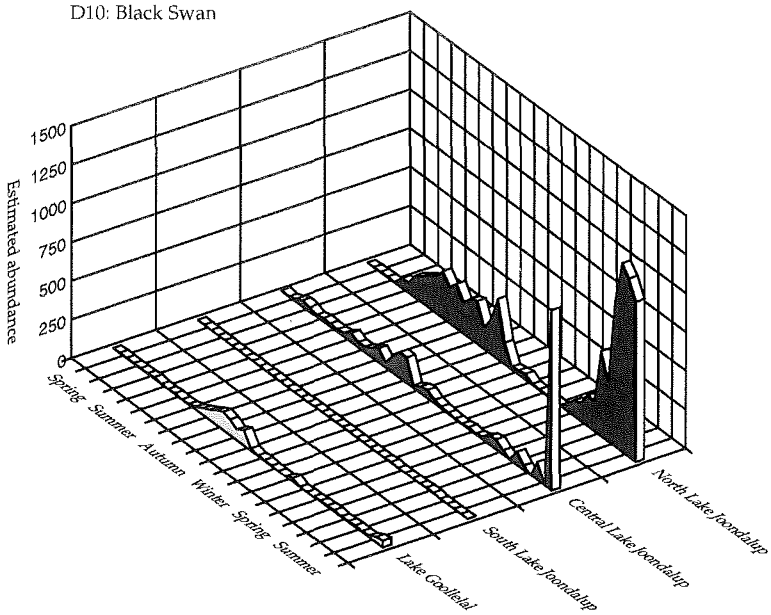
D8: Pink-eared Duck



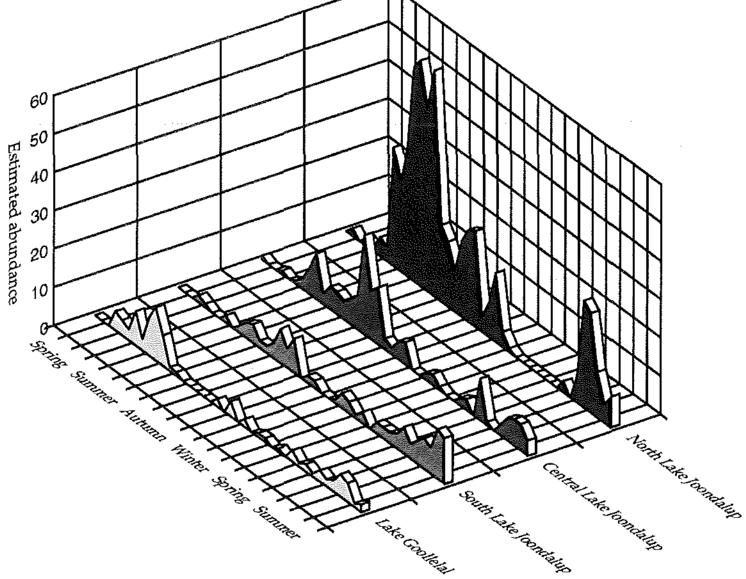
D9: Eurasian Coot



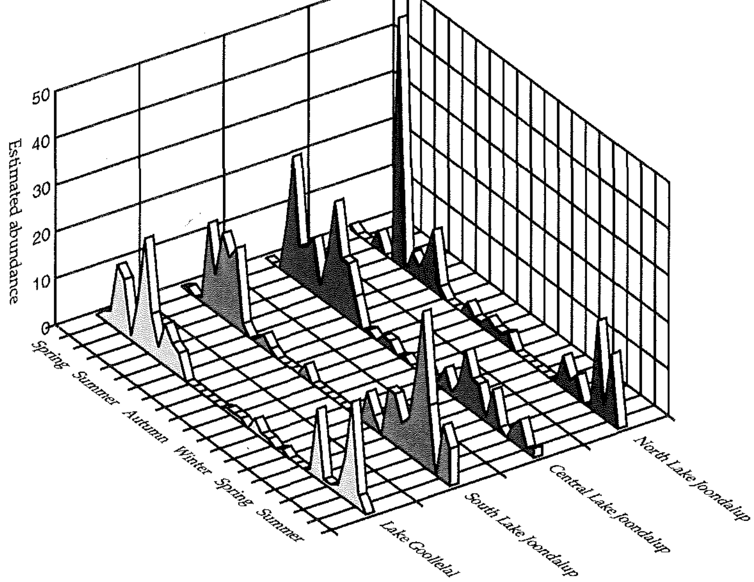
D10: Black Swan



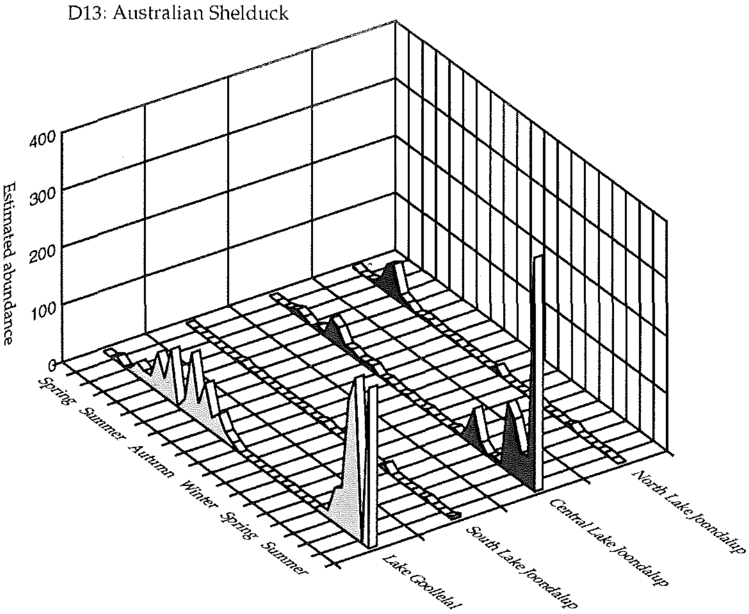
D11: Little Pied Cormorant



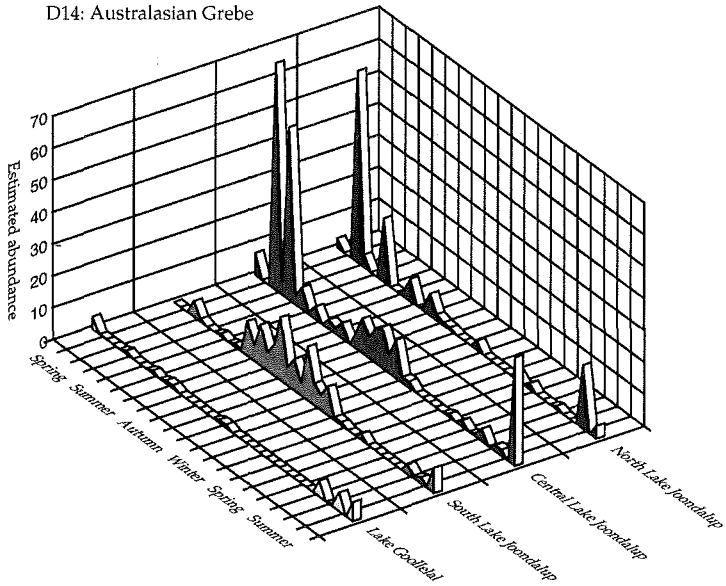
D12: Little Black Cormorant



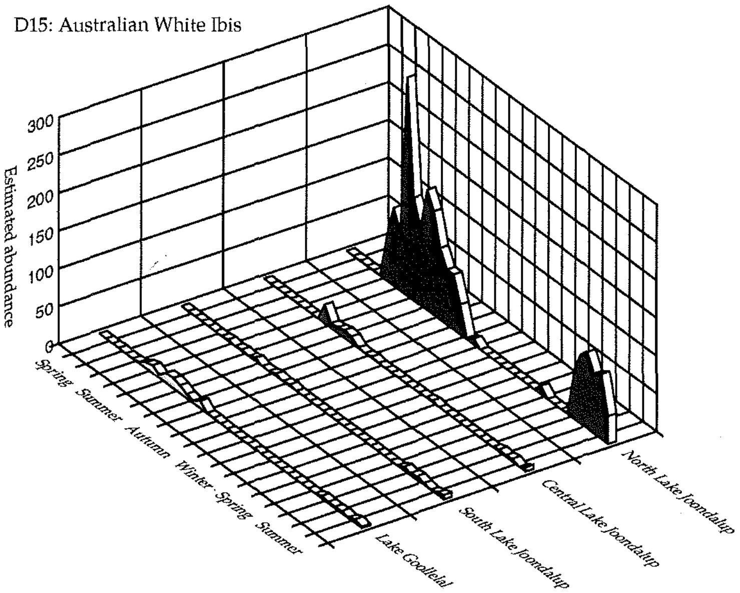
D13: Australian Shelduck



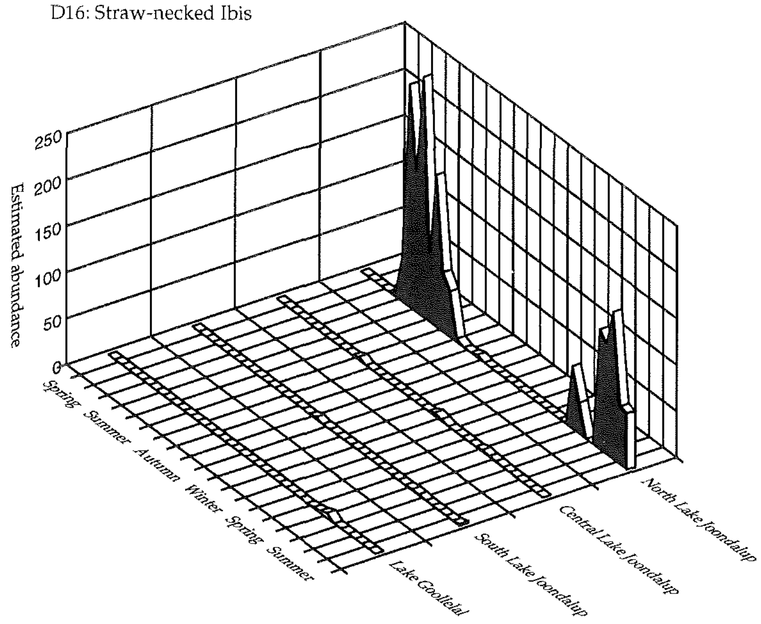
D14: Australasian Grebe



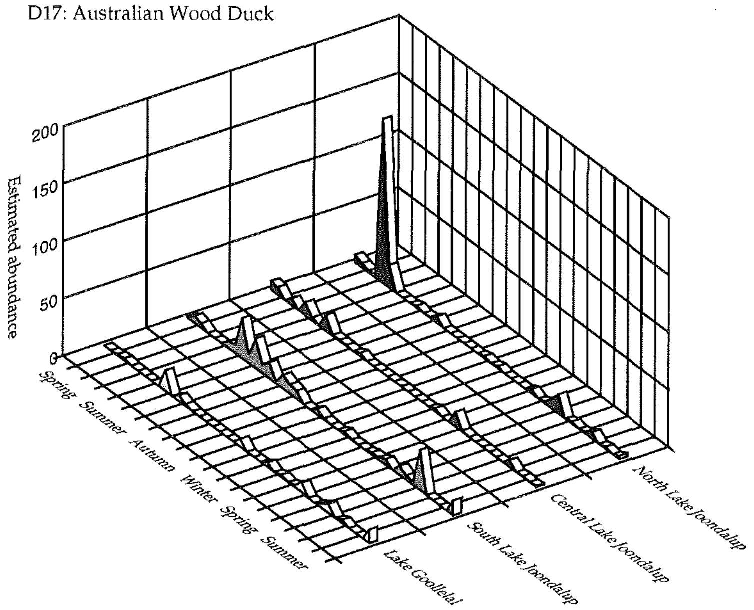
D15: Australian White Ibis



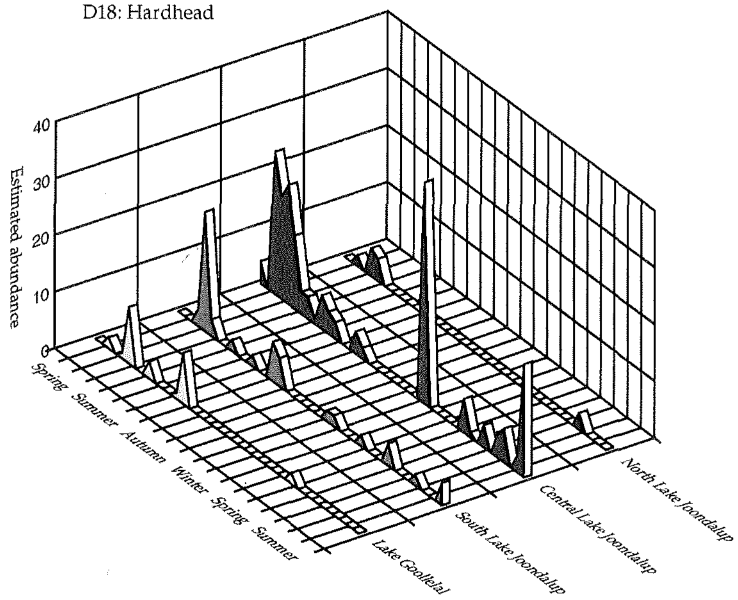
D16: Straw-necked Ibis



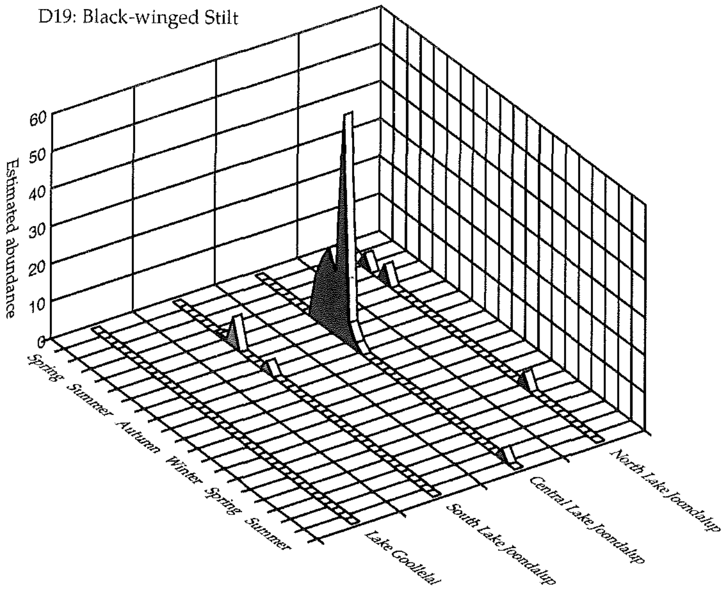
D17: Australian Wood Duck



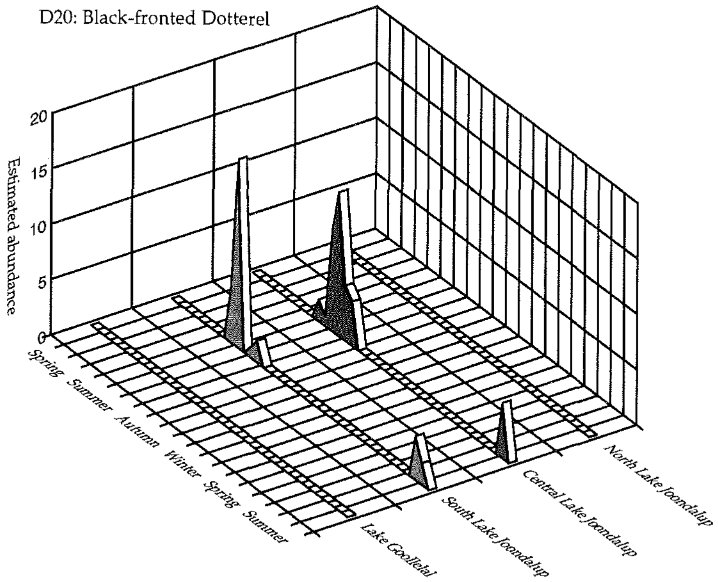
D18: Hardhead



D19: Black-winged Stilt



D20: Black-fronted Dotterel



D21: White-faced Heron