PLANKTON OF THE MURRAY-DARLING RIVER SYSTEM, WITH PARTICULAR REFERENCE TO THE ZOOPLANKTON

by

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A thesis submitted to the University of
Adelaide in fulfilment of the requirements
for the degree of Doctor of Philosophy.

awarded August 1981

January 1981

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university and, to the best of my knowledge, contains no material previously published or written by another person, except where due reference is made in the text.

SUMMARY

The Murray-Darling river system drains one-seventh of the Australian continent (>1 x 10^6 km^2), yet carries only 2% of the annual runoff (21 mm yr^{-1}). The two rivers have distinctly different hydrology, geology and geomorphology, which reflect in physical, chemical and biological differences. The Darling has peak flows resulting from summer monsoons in the north of the basin, the Murray has peak flows in winter and spring following winter rains and spring snow melt in the south of the basin. Contrasts have been enhanced by successive impoundment of the Murray and tributaries. The Darling is relatively unimpounded.

This study investigated the plankton of the two river systems; the limnoplankton of headwater reservoirs, plankton of lentic habitats on the floodplain (billabongs), and the potamoplankton of the lower Murray below the Murray-Darling confluence.

More than 400 taxa of Rotifera, Cladocera, Copepoda and Ostracoda were recorded from Murray-Darling waters. Half of these were new records from the continent, with 22 taxa new to science. Common rotifer genera were cosmopolitan (e.g. *Asplanchna, Brachionus, Keratella, Filinia, Polyarthra, Synchaeta*), with endemic species in several genera. 90% of rotifers recorded were cosmopolitan. Common cladocerans included the genera *Alona, Chydorus, Bosmina, Ceriodaphnia, Daphnia* (35% endemism). Copepods (e.g. *Boeckella, Calamoecia, Mesocyclops*) consisted of predominantly endemic or Australasian calanoids, and cosmopolitan cyclopoids.

Physico-chemical features of habitats investigated are given. Discrete plankton assemblages were recorded for each of 23 reservoirs and 38 billabongs studied. Fluctuations in limnoplankton composition were related to physico-chemical variables, storage depth and retention time. Long retention time reservoirs (e.g. Eildon, Hume) had a stable limnoplankton dominated by microcrustacea (dominants *Bosmina, Diaphanosoma, Boeckella, Calamoecia*). Short retention time storages (e.g. Goulburn Weir, Mulwala) had an unstable plankton dominated by rotifers.

Limnoplankton densities were lowest in oligotrophic reservoirs (e.g. Eucumbene, $\bar{x}$ zooplankton 13.0 ℓ^{-1}), highest in seasonally eutrophic storages, (e.g. Burrinjuck, $\bar{x}$ 567 ℓ^{-1}). Species diversity was lowest in the latter storages during dense algal blooms, highest in shallow impoundments with marginal hydrophyte growth, i.e. a result of pseudoplanktonic incursions (e.g. Goulburn Weir). Although a small group of eurytopic and widely distributed zooplankters was recorded from most reservoirs, on any sampling date there were different species dominants, density and diversity in even adjacent habitats, i.e. responses to local environmental variables.

With few exceptions (e.g. Rocky Valley Dam), reservoirs supplied plankton to downstream rivers. There was evidence of avoidance of outflows by microcrustacea; rotifers dominated upstream and middle reaches of the Murray and Darling tributaries. Dominant phytoplankters were, seasonally, detached epibenthic diatoms, with *Volvox* and blue-green algae most common in slower flows of summer.

Inoculation from fringing hydrophytes and billabongs occurred downstream. Billabong plankton and littoral microfaunal communities were the richest yet recorded (>100 rotifer and microcustacean taxa from a single Goulburn billabong). Murray billabongs had less diverse communities. Differences were related to man's interference. Plankton densities in billabongs were invariably higher than in the nearby river or upstream reservoirs. Dominant species generally were not those of either habitat.

Shallow meso- to eutrophic impoundments on middle reaches of the Murray had features of both billabongs and lakes. From these, seasonal algal blooms accompanied by a lacustrine plankton moved downstream. The predominant zooplankters were microcrustaceans (*Alona*, *Chydorus*, *Bosmina*, *Ceriodaphnia*, *Daphnia*, *Simocephalus*, *Boeckella*, *Calamoecia*).

In contrast, the Darling, unimpounded for 2700 km,had a distinctive rotifer potamoplankton dominated by tropical species of *Brachionus*, *Keratella*, *Filinia*, with up to 35 rotifer species present on any date. Phytoplankters

were sparse, possibly due to characteristic high abiogenic turbidity. Although continuously inoculated into the lower Murray, most pronounced pulses of Darling potamoplankton occurred in autumn, i.e. floods from summer rains in the north of the catchment took several months to reach the Murray.

Seasonal fluctuations in plankton composition in the lower Murray reflected the disproportionate contributions from the two rivers, i.e. a predominantly microcrustacean limnoplankton from Murray flows, with blooms of blue-green algae (*Anabaena/Anacystis*) in summer, and diatoms (*Cyclotella/ Melosira*) in winter and spring, and a plankton dominated by typically warm stenothermal pantropical rotifers from the Darling with, seasonally, waters of high abiogenic turbidity and low algal biomass.

One hundred and thirty-three taxa were recorded from the lower river zooplankton; half of these were pseudoplanktonic or littoral incursion species flushed in by floods, or accompanying algal blooms. Of the dominant potamoplankters, approximately half were endemic or Australasian in distribution, i.e. a characteristic and autochthonous Murray potamoplankton assemblage. Plankton density and diversity was markedly contagious both across the river and longitudinally, with localised pulses in response to point source nutrient inflows. Both density and diversity increased downstream. Mean zooplankton density recorded at Mannum, S.A., was $119\ \ell^{-1}$, average momentary species composition was 14.4 rotifers, 6.0 cladocerans and 2.4 copepods. Correlation coefficients derived by linear regressions of plankton density and diversity on measured environmental variables indicated that temperature, salinity and turbidity significantly influenced some of the predominant taxa. Most common taxa were eurytopic, recorded over a wide range of water quality across the basin. Most of the cosmopolitan taxa, particularly Rotifera, are regarded elsewhere as indicators of eutrophy.

ACKNOWLEDGEMENTS

For their supervision and encouragement during this project I thank my supervisors, Professor W. D. Williams and Dr. K. F. Walker, the former also for stimulating my interest in limnology while he was teaching undergraduate courses at Monash University, and for the subsequent offer of a place in the Zoology Department at Adelaide, and the latter for invaluable guidance during preparation of the thesis.

Direct contributions were made by several people. Dr. T. J. Hillman of the Albury-Wodonga Development Corporation made available physico-chemical data and collections, and with Messrs. J. Hawking and W. Embury assisted in field work or made collections specifically for this project. Mr. R. Coghill analysed water samples at the AWDC labs.
Ms. I. J. Powling (State Rivers & Water Supply Commission, Victoria) identified algae, made available physico-chemical data from Commission storages, assisted in field work at Dartmouth and Eildon dams, and made collections when circumstances prevented me from so doing. Dr. D. Garman (N.S.W. Water Resources Commission) supplied physico-chemical data from Commission storages. Access to data also was provided by officers of the River Murray Commission, Canberra, A.C.T., the Engineering and Water Supply Department, S.A., the State Electricity Commission of Victoria, and the Snowy Mountains Hydro-Electric Authority, Cooma, N.S.W.

Taxonomic expertise was provided by Dr. I. A. E. Bayly, Monash University (Calanoida), Mr. P. De Deckker, University of Adelaide (Ostracoda) Dr. R. Hamond, University of Melbourne (Harpacticoida), Dr. V. Korinek, Charles University, Prague (*Bosmina*), Mr. W. Koste, Quakenbruck, F.R.G. (Rotifera), Mr. D. W. Morton, Monash University (Cyclopoida), Mr. A. Neboiss, National Museum of Victoria (Trichoptera), Dr. N. N. Smirnov, Academy of Science, Moscow (Cladocera), Dr. B. J. Smith, National Museum of Victoria (Mollusca), Dr. P. J. Suter, National Museum of Victoria (Ephemeroptera), Dr. K. O. Viets, Wilhelmshaven, F.R.G. (Hydracarina) and Ms. A. Wells, University of Adelaide (Trichoptera). All are sincerely thanked for their interest and assistance.

Appreciation of help also is given to Ms. S. Humphries, Australian National University, Mrs. V. Jones, National Herbarium, Sydney, Dr. K. G. McKenzie, Riverina C.A.E., Wagga Wagga, Dr. S. Lake, Monash University, and Dr. B. V. Timms, Avondale College, Cooranbong, N.S.W. Particular thanks are due to the Hillman family of Albury, who provided a hospitable 'half-way house' on long field trips and a base from which to work the upper Murray catchment.

Drafts of chapters were read critically by Dr. N. A. Locket, Prof. T. Reynoldson, Dr. K. F. Walker and Prof. W. D. Williams. All are thanked for their constructive comments and improvements to the MS.

Chapters 1-3 were typed by Ms. A. Sebastyan. Errors and inconsistencies in the remaining chapters are my own. Ms. H. Allan, Mrs. J. Francis and particularly Mrs. R. Hughes, University of Adelaide, are thanked for improving my rough sketches and figures. Mr. P. G. Kempster advised on photography, and Ms. J. Pointon kindly checked the references.

Financial support for the project came from a Commonwealth Postgraduate Research Award, from the Albury-Wodonga Development Corporation, and from a short term Research Grant from the University of Adelaide. These funds are gratefully acknowledged.

For their understanding, hospitality and provision of a quiet place in their home in which to write the final chapters, I thank the Locket family, and most of all, I am grateful to my mother, Mrs. H. E. Shiel, of Broadford, Victoria, for her care and support along the way.

"...for the amount of work that has been published on the ecology of Australian rivers and streams, limnologists outside Australia might well be forgiven for thinking that no running waters exist in Australia at all !"

Bayly & Williams (1973:135)

Top : Headwaters at Tom Groggin, Mt. Kosciusko National Park.

FRONTISPIECE : THE RIVER MURRAY

Bottom : Lower Murray, South Australia.

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1. INTRODUCTION

Man's dependence on rivers is documented from 3000 BC, when the success or failure of settlement in the Nile Valley was determined by the flood regime of the river. The Egyptian calendar revolved around the cycle of inundation and flood recession, and the Nile was an integral part of secular and religious life. The first record of management of river water for irrigation is from this period (Emery, 1967), and the Nile has continued to meet the needs of an increasing population for more than five thousand years. The river has been progressively regulated by impoundments, so that by the 1970's it was fully controlled and utilized (Hammerton, 1972).

Similarly, other major rivers have been progressively exploited by rapidly increasing populations, particularly following the "technological revolution" of the mid-nineteenth century. Although most present demands on water supplies are not fundamentally different to those of agrarian societies, it is in the intensity of use that contrasts are seen. Rivers are used for abstraction, effluent disposal, flood mitigation, power generation, transport, biological exploitation, recreation, controls for hygiene and catchment utilization - to name only the most important. The impact of these often conflicting uses and their deleterious effect on water quality, particularly on biotic communities, was neglected by ecologists for the first half of this century (Whitton, 1975). The attention of ecologists has mostly been on lakes and only in the last twenty years has river ecology become a rapidly expanding field of study.

In the first major review of ecological studies on running waters, Hynes (1970) stressed the increasing interest in rivers and streams, noting that half the literature had been published in the preceding decade. Subsequent to Hynes' review, more than 650 publications on running waters appeared during 1970-1975 (Oglesby, Carlson & McCann, 1972; Whitton, 1975). Evidence that this growth of lotic studies continues is given by the result of a search of the literature during the present project. A file search (Lockheed, Los Angeles, Sept., 1979) retrieved more than 5100 river-study citations for the decade 1969-1979 - more than twice the reported works from the preceding century.

The intensification of research stems from increasing awareness that flowing waters are finite resources, and that poor management, both of water quality and flow, has repercussions beyond the predictive capabilities of engineers. With increased population growth, continued multi-purpose use of already stressed rivers has necessitated a systems ecology (holistic) approach, particularly with the increasing awareness of possible ramifications of stream disposal of biologically toxic chemicals and, in some countries, radionuclide contamination (Nelson *et al.*, 1972).

At the same time, it should be stated logistic difficulties of sampling flowing waters often preclude application of holistic methods to river systems. This is not to say that they do not conform to the concept of an "ecosystem" (cf. Rzoska, 1978, 1979) as the concept is presently used. Taken as a unit area, i.e. the catchment and standing waters associated with the flowing component, any particular river can be seen to cycle matter and energy between biotic and abiotic compartments, and to have a longitudinal and therefore temporal increase in diversity towards a dynamic equilibrium with a definite trophic structure. The changes imposed on a riverine ecosystem by variability of flow, or by impoundment, produce compensatory adjustments within the system leading to a different stage of maturity or development. This is not necessarily a more mature configuration (Krebs, 1972).

Despite the difficulties of lotic ecosystem studies, there is, nevertheless, considerable information on the major rivers of most continents. Of particular interest is the nature, derivation and dynamics of the plankton, the suspended plant (phytoplankton) and animal (zooplankton) components of the riverine biota, and their response to interference with the riverine regime by, for example, nutrient enrichment, thermal pollution or impoundment.

A distinction has been made between limnoplankton (e.g. Hutchinson, 1967) and potamoplankton (e.g. Zacharias, 1898), the pelagic faunal and floral components of, respectively, lakes and rivers. The composition of the potamoplankton differs both qualitatively and quantitatively from that of the limnoplankton, even when the water derives from a lake source or reservoir in which a typical limnoplankton is present; there is selective elimination of some components of the lacustrine plankton such that the dominant phytoplankters of flowing waters are diatoms, particularly *Melosira*, *Cyclotella* and *Asterionella*, with seasonal occurrences of blue-green algae (particularly *Anabaena*, *Anacystis* and *Microcystis*) and green algae (e.g. *Scenedesmus*). Hynes (1970) noted the frequent occurrence of ostensibly benthic algae displaced from the substratum into open water.

The zooplankton component of the potamoplankton is generally dominated by Rotifera (e.g. *Asplanchna*, *Brachionus*, *Filinia*, *Keratella*, *Notholca*, *Synchaeta*) with Cladocera (*Bosmina*, *Chydorus* and, seasonally, *Moina*) and copepods (*Cyclops*, *Diaptomus* in the northern hemisphere, *Mesocyclops* and *Boeckella* in the southern hemisphere) occurring less commonly. As with lacustrine species assemblages, zoogeographical differences in potamoplankton assemblages are evident when remote localities are compared.

It is appropriate here to review briefly the major potamoplankton studies. Detailed reviews of some of these studies are given by Shadin (1956), Hynes (1970) and Whitton (1975) amongst others. A number of recent studies on running waters are noted by Sladacek (1978). Relevant studies on impoundments and lake sources of major rivers are also mentioned briefly, as are the sparse references to floodplain ecology (e.g. Welcomme, 1979).

Most potamoplankton studies are from North America and Europe. They began in the late nineteenth century. Early studies in the United States found that the travel time of water was important to development of the plankton community (Kofoid, 1903, 1908), and that temperature, current velocity and plankton development were correlated (Allen, 1920). In a three-month study of the upper Mississippi, Galtsoff (1923) established that density and production of plankton fluctuated both horizontally and vertically in different parts of the river, and confirmed Kofoid's finding that lakes added to the plankton volume. Galtsoff also observed that the river fauna occurred in tributaries, stagnant waters, lakes and ponds, but the proportions of plankton groups differed in the river. Also on the Mississippi, Reinhard's (1931) study emphasized the plankton stability of impounded and older waters. As in the earlier studies, the dominant phytoplankters were diatoms (*Melosira, Cyclotella, Asterionella*) and the dominant zooplankters rotifers (*Keratella, Brachionus*).

Early use of potamoplankton as indicators of pollution was discussed by Eddy (1934), who noted that the continuous progression of species was not a "succession" in terms of lacustrine or terrestrial ecology, but was more comparable to invasion and colonization of barren terrestrial areas, with continual production and replacement of plankton as the water mass moved downstream. The deleterious effects of high turbidity and increased water velocity were also noted.

A decrease in plankton downstream of lakes was noted by Chandler (1937), who attributed this to non-selective straining by vegetation and settlement of the plankton in association with detritus. The plankton composition of a later study (Chandler, 1939) on the Huron River did not differ significantly from that of upstream lakes, although quantitatively the river plankton had a significantly lower density.

An early suggestion of a detritus-based food chain came from a report on the Missouri River (Berner, 1951), where phytoplankton production was limited by high turbidities (Secchi readings of 1 cm). A consequence of this was low plankton densities and a predominance of zooplankton over phytoplantkon.

Beach (1960), in the first whole-system study, examined the planktonic Rotifera of the small (100 km^2) Ocqueoc River in Michigan, and noted the deleterious effect of current upon lacustrine forms, many of which did not survive downstream of impoundments. The slow-flowing and lake-like conditions of the Montreal River system (Cushing, 1964) and the Sacramento River (Greenberg, 1964) were found, in contrast to Beach's study, to be conducive to downstream plankton production.

Similar increased production in slowly-flowing reaches of the River Canard, Ontario, was reported by Winner & Hartt (1969) and Hodgkinson (1970). Succession of the planktonic Rotifera was associated with temperature and nutrient-availability in particular.

A number of rotifer species were implicated as indicative of eutrophic conditions. Other studies in which particular aquatic organisms have been considered in relation to the trophic status of given systems are reviewed by Sladacek (1973).

Of European rivers, the Danube is one of the best studied limnologically (Liepolt, 1967). Its 1888 km drain 805,000 km^2 of twelve countries (Liepolt, 1972). Thirty-two studies referring to the Danube zooplankton are cited by Enaceanu (1967), who recorded 413 taxa (18.9% Protozoa, 47.5% Rotifera, 12.8% Copepoda and 20.8% Cladocera). Longitudinal variation in plankton species composition and biomass was noted, in particular increased plankton density in spring in response to increased nutrient input. Sixty per cent of the biota recorded in the Danube studies were considered to be incursions from the littoral and benthic communities, and were termed pseudoplankton.

A similar planktonic composition was reported from the Rhine by Brehm (1911). He observed the contribution of lakes and still waters to the riverine biota, and questioned the validity of the term potamoplankton.

Studies of longitudinal and seasonal variation in the zooplankton of rivers of the U.S.S.R. include those by Pirozhnikov & Shulga (1957) on the Yenisey and Lena, Romadina (1959) and Dzyuban (1979) on the Volga, Monakov (1964) on the Oka, a tributary of the Volga, and Petrova (1976) on the Irgiz and Turgay Rivers in Kazakhstan. Construction of a series of impoundments along the Volga has profoundly affected the biology of the river (Mordukhai-Boltovskoi, 1979). Whereas the plankton of the other rivers was generally dominated by rotifers, the rheophilic zooplankton of the Volga has been replaced by a crustacean limnoplankton.

Of African rivers, the Nile is hydrologically the best known, but no comprehensive ecological study exists. The zooplankton of the headwater lakes was examined by Green (1967, 1971) and that of river tracts associated with the impoundment of the White Nile by the Jebel Aulia Dam and of the Blue Nile by the Sennar and Roseires Dams (Brook & Rzoska, 1954; Rzoska, Brook & Prowse, 1955; Rzoska, 1961, 1968, 1974, 1976, 1978; Klimowicz, 1961; Abu Gideiri, 1969; Hammerton, 1972; Ward & Stanford, 1979). These studies established that the construction of the Jebel Aulia Dam provided conditions suitable for the development of a limnoplankton (i.e. reduction of current and turbidity, and reduction of level fluctuations). A typical lacustrine phytoplankton dominated by blue-green algae and diatoms (*Anabaena, Lyngbya, Melosira)*, and a zooplankton dominated by Cladocera (*Daphnia, Ceriodaphnia*) developed. Below the dam, the zooplankton assemblage was dominated by Rotifera. Similarly, the pre-impoundment zooplankton of the Blue Nile was rotifer-dominated, but with construction of Sennar and Rosseires Dams a seasonal 100-200-fold increase in zooplankton was recorded which was more typical of lacustrine conditions. Below the junction of the Blue and White Nile the plankton assemblage is maintained for more than 2,000·km. The rotifer component of this assemblage resembles that of eutrophic lakes elsewhere, and moderately saline water forms predominate (Klimowicz, 1961).

A similar increase in zooplankton development following impoundment of the Niger River was described by Clarke (1978) from Lake Kainji. Species of *Brachionus* (Rotifera) dominated the riverine zooplankton, and cladocerans, particularly *Bosmina* dominated in the lake. The dilution by floodwaters and low nutrient status of the Sokoto River were considered by Holden & Green (1962) to account for the low density and diversity of plankton. Standing waters adjacent to the river were more productive.

Few studies have been reported from other continents. Lemmerman (1906) reported phytoplankton dominated by blue-green and green algae from the Yangtze-Kiang. The absence of diatoms was noted, as was the poor development of rotifers and predominance of Crustacea, i.e. a plankton indicative of eutrophic, lacustrine conditions. The Yamuna River near Delhi was examined by Rai (1974), who found changes in the potamoplankton inversely related to changes in turbidity and discharge. Nutrient input from sewage pollution was responsible for greater plankton development.

Elsewhere, Gessner (1955) recorded a diatom/rotifer plankton from the Orinoco, Venezuela. Hauer (1965) and Koste (1972, 1974) described rotifer assemblages from the Amazon plankton, and Paggi & Jose de Paggi (1974) and Jose de Paggi (1978) have made preliminary studies on the plankton of the Parana River, Argentina. As with the other South American studies, turbidity was found to be limiting for plankton development.

It is clear from these studies on the potamoplankton of the major rivers of the world that although individual rivers may differ in response to local environmental conditions, the following general statements apply. Rivers have self-sustaining plankton with a species dominated by diatoms and rotifers. The phytoplankton is usually numerically dominant over zooplankton, although the converse may be true where high turbidity is limiting. The potamoplankton assemblage is derived from headwater lakes and impoundments, backwaters and tributaries, standing waters adjacent to the river, and has an autochthonous component (developing within the river). No single factor appears to control development and maintenance of the potamoplankton, but temperature, turbidity, flow rate, nutrient-availability and water chemistry are implicated. Horizontal and vertical development of the plankton is not homogeneous, and "clouds" of differing density move downstream. Plankton production increases downstream and in regions of slower flow. Impoundment produces conditions more or less resembling those of a lake, so that a plankton develops which resembles a true lacustrine assemblage. The response of the plankton to alterations in water quality may be useful in the assessment of environmental impact.

It is notable that Australia's rivers are absent from the lists of lotic studies given in the reviews cited earlier. Invertebrates generally, and plankton particularly, have been neglected in those few riverine studies which have been made. Only Playfair (1914) studied specifically the plankton of the Richmond River in N.S.W. Potter, Cannon & Moore(1975), however, did include the phytoplankton in their study on the Moruya River, N.S.W., and Jolly & Chapman (1966) mentioned zooplankton in their study of pollution in Farmer's Creek and Cox's River, N.S.W. Incidental mention of riverine zooplankton is made in the essentially estuarine studies of Arnott & Hussainy (1972) and Kennedy (1975, 1978). Shiel (1979) has reported on the species composition and seasonality of rotifers from the lower River Murray at Mannum, S.A.

Australian lacustrine and impoundment studies which include information on the plankton are likewise few (e.g. Jolly, 1966; Thomasson, 1973; Timms, 1968, 1969, 1970; May, 1978, 1979; Walker & Hillman, 1977), as are studies on standing waters of the floodplain. The latter, colloquially termed "billabongs" in Australia (see Ch 6; Shiel, 1976, 1980) are generally shallow, densely-vegetated (i.e. littoral) habitats closely associated with the river. They are important breeding and refuge areas for a complex assemblage of organisms. Information on the microfaunal composition of billabong communities is given by Shiel (1974, 1976) and Walker & Hillman (1977). Similar communities elsewhere are ox-bows, meander scrolls in the U.S.A., Altwasser, lônes, bras morts in Europe, meander lakes, varzea in South America (Hutchinson, 1957; Green, 1972; Welcomme, 1979). The importance of these floodplain habitats to the river ecosystem is discussed by Welcomme (1979).

This paucity of fundamental biological information on the Australian riverine biota is particularly surprising in view of the importance of some Australian rivers to man. This applies particularly to the Murray-Darling river system, the waters of which are used for domestic and agricultural supplies, fish production, recreation, waste transport and purification, and wildfowl production. It was against this background of poor knowledge of an important regional river system, and the interest of comparing the nature of Australian river communities with those in rivers on other continents that the present study was undertaken.

Constraints of time and resources did not permit comprehensive study of the total biota, and the present study is restricted to a comparative study of the plankton, particularly the zooplankton, of the two most important rivers of eastern Australia, the Darling and the Murray, including major impoundments and selected billabongs of the Murray and a large tributary of it, the Goulburn River. Data on species composition and seasonal variation in the plankton of major impoundments and rivers of the Murray-Darling system were collected to provide a basis for comparison with other rivers.

Selected impoundments, two billabong areas and certain river stations above and below the confluence of the two rivers were sampled regularly. Data on physicochemical factors known from other studies to influence significantly the plankton were also collected. These included water temperature, pH, dissolved oxygen, turbidity and ionic composition.

In summary, then, the specific aims of the present study were:

1. to provide a systematic account of the limno- and potamoplankton of representative reservoirs and rivers of the Murray-Darling system;
2. to compare the plankton assemblages of the two rivers and relate dissimilarities, if any, to physical or chemical differences, including those resulting from latitude or altitude;
3. to assess the contribution of the limnoplankton to the downstream plankton;
4. to characterize species assemblages of impoundments of known nutrient status and thereby enable comparisons with work elsewhere on biological indicators;
5. to provide information on the plankton of billabong communities and investigate its contribution, if any, to the potamoplankton.
6. to collect synecological (community) data on the plankton of the lower river, including species diversity, density, seasonality and derivation, and also autecological information on the dominant species of the lower river plankton.
7. to compare the potamoplankton of the Murray-Darling system as a whole with that of large river systems elsewhere.

2. THE STUDY AREA

2.1 Introduction

Australia is a flat, dry land. More than half of the continent's 8,000,000 km^2 is less than 300 m in elevation, and only 6 per cent exceeds 600 m. Mt. Kosciusko, the highest point of the Eastern Highlands, reaches 2,251 m. Average rainfall is 420 mm, with a third of the continent receiving less than 250 mm (Fig.2.1). Rainfall also is variable (Fig.2.2); the climate is characterized by long periods of subnormal rainfall or drought, with occasionally exceptional falls and flooding. Due to high evaporation rates only 13 per cent of rainfall runs off as stream flow. Two thirds of the continent has less than 25 mm annual runoff (AWRC, 1976).

Of the 12 principal drainage divisions (Fig.2.3), only four (I-IV) have perennial streams. High rainfalls on the eastern side of the highlands (average $>$ 4,300 mm in Qld, 2,500 mm in the Snowy Mountains of N.S.W., and 3,500 mm in Tasmania) result from summer monsoons in the north and prevailing westerlies in the south. Rivers flowing east to the Pacific across the narrow (< 200 km wide) coastal plain carry 98% of the runoff (1,050 mm/yr). There is a rain-shadow on the western side of the highlands; the remaining 2 per cent of runoff (21 mm/yr) is carried by the westward-draining rivers of Division IV, the Murray-Darling system (see Fig.2.3).

2.2 The Murray-Darling system

The Murray-Darling Basin (Fig.2.4), with an area of 1,072,905 km^2, spans 13° of latitude (24°S-37°S) and 13° of longitude (138°E-151°E), with an altitudinal range of 0-2,251 m. The basin is therefore subject to considerable climatic variations, particularly of annual precipitation

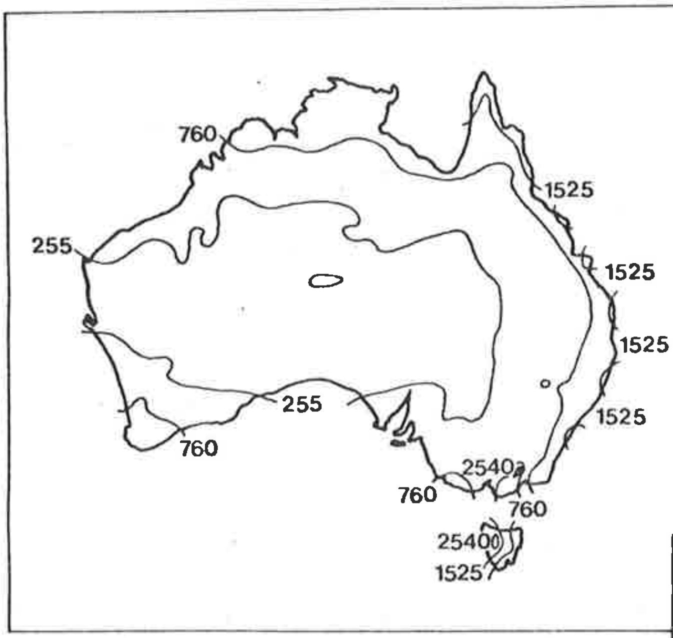


FIG. 2.1 Average annual rainfall (mm) patterns in Australia (E.B 1978)

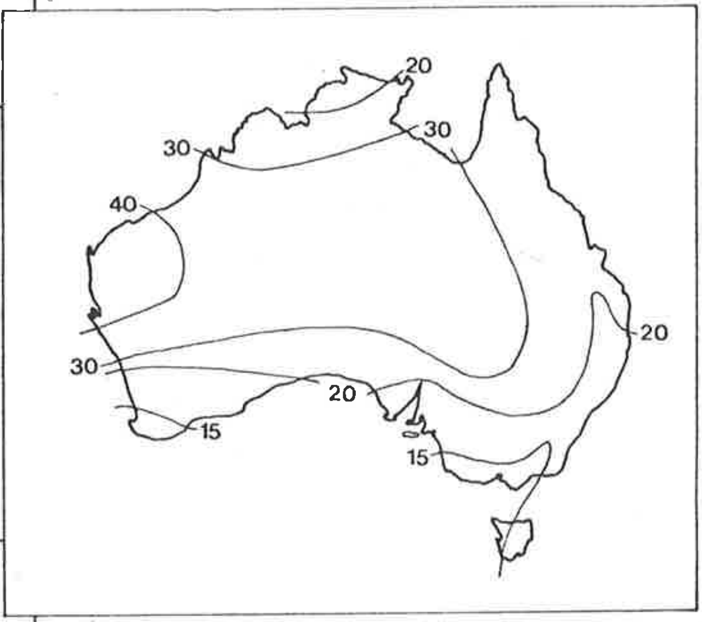


FIG. 2.2 % mean variability from annual mean rainfall. (Leeper 1970)

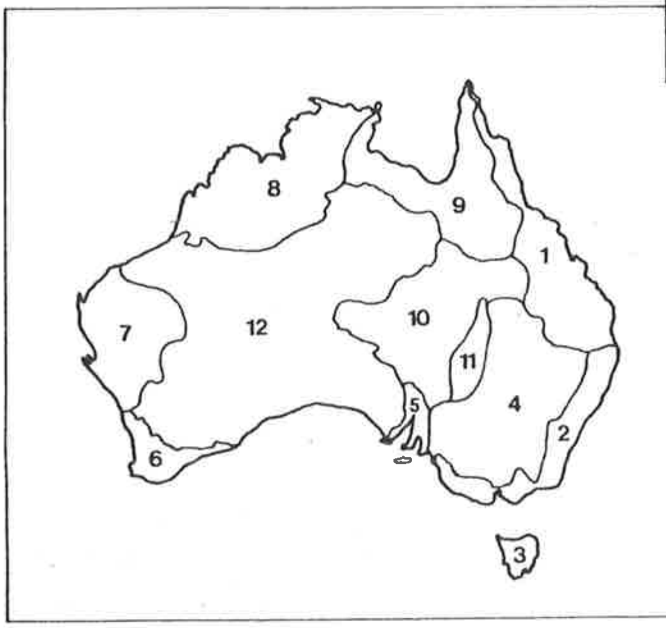


FIG 2.3 Principal drainage divisions of Australia (AWRC 1976)

1 North-east coast
2 South-east coast
3 Tasmanian
4 Murray-Darling
5 South Australian gulf
6 South-west coast
7 Indian Ocean
8 Timor Sea
9 Gulf of Carpentaria
10 Lake Eyre
11 Bulloo-Bancannia
12 Western plateau

(Fig.2.5) and evaporation (Fig.2.6). Evaporation exceeds precipitation over almost all of the basin; less than 2 per cent of the basin (the upper Murray catchment) supplies more than 25 per cent of the runoff. Seasonality and unreliability of rainfall is more pronounced in the north of the basin, drained by the Darling, where the predominant influence is summer monsoons. The south of the basin is influenced by winter low pressure systems; peak runoff derives from winter rains and spring snow melt (AWRC, 1976). Peak flows in the two systems do not, as a rule, coincide.

The Murray and the Darling rivers, with distinct hydrologic regimes, are also geomorphologically and geologically different. These differences are reflected in other physical and chemical features and, as will be shown later, biological features. Human settlement and development have enhanced the contrasts, particularly by impoundment of the major tributaries of the Murray and by urban and agricultural development. Of Australia's 342 principal reservoirs, 104 are located in the Murray-Darling catchment: 87 for water supply and irrigation, 15 for hydro-electricity and two for recreational use (AWRC, 1976).

The two rivers above their confluence and the river below the confluence are treated separately in the following resumé of their characteristics. This separation is also used in later discussion of biological features.

Federal and several State governments control allocation of the Murray waters (The River Murray Waters Agreement), and although considerable information on the hydrology and water quality of the system exists, there is no fully comprehensive report. Many data are included in internal reports and are not readily accessible.

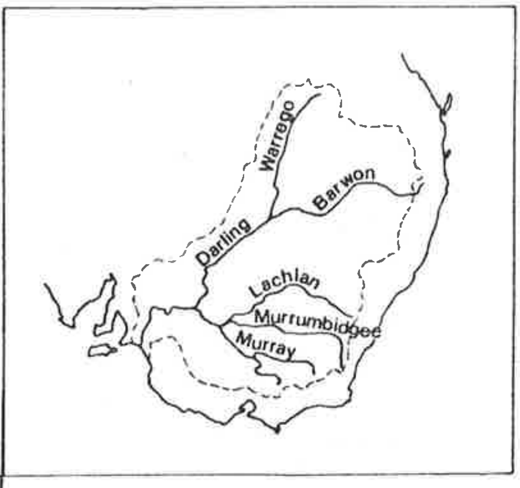


FIG. 2.4 Major rivers of the Murray-Darling Basin

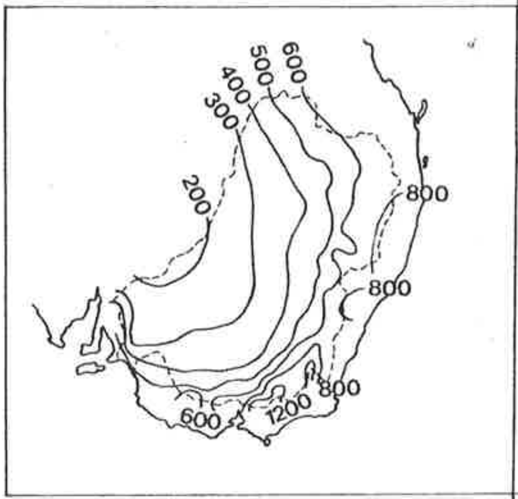


FIG. 2.5 Median annual rainfall (mm)
(After Baker and Wright 1978)

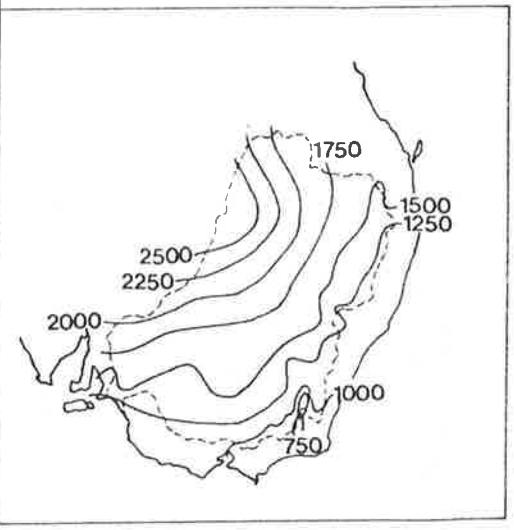


FIG. 2.6 Average annual evaporation (mm)
(Modified after Baker and Wright 1978)

The most comprehensive study to date is that of Walker & Hillman (1977) on the River Murray in relation to urban development at Albury-Wodonga. A concise review of the extent and effects of impoundment on the Murray waters is given by Walker (1979). Early studies are reviewed by Frith & Sawer (1974), and aspects of the geomorphology, hydrology, water quality and biology of the Murray-Darling system are described in the proceedings of a recent symposium (e.g. Dexter, 1978). Additionally, there are several popular accounts (e.g. Colwell & Finch, 1978; Davis, 1978).

The following brief description of the two rivers includes data from unpublished reports by the Albury-Wodonga Development Corporation (hereafter AWDC), the Engineering and Water Supply Department of South Australia (E&WS), the N.S.W. Water Conservation and Irrigation Commission, later the Water Resources Commission (WRCN), the River Murray Commission (RMC), the Snowy Mountains Hydro-Electric Authority (SMA), the State Electricity Commission of Victoria (SEC) and the State Rivers and Water Supply Commission of Victoria (WSCV). Much of the data in these unpublished reports is in the form of computer printout with no further analysis. Part of the description below therefore represents an original analysis of considerable amounts of raw data.

2.2 The Murray and its tributaries

The Murray rises in the Eastern Highlands near Mt. Kosciusko (2251 m) and with its tributaries has a catchment area of some 310,000 km^2. Major tributaries (see Fig.2.7) are the Murrumbidgee, Mitta Mitta, Ovens, Loddon, Goulburn and Campaspe Rivers. Average annual runoff is approximately 29 mm, part of which is contributed by snow melt during spring. Average annual runoff from the upper

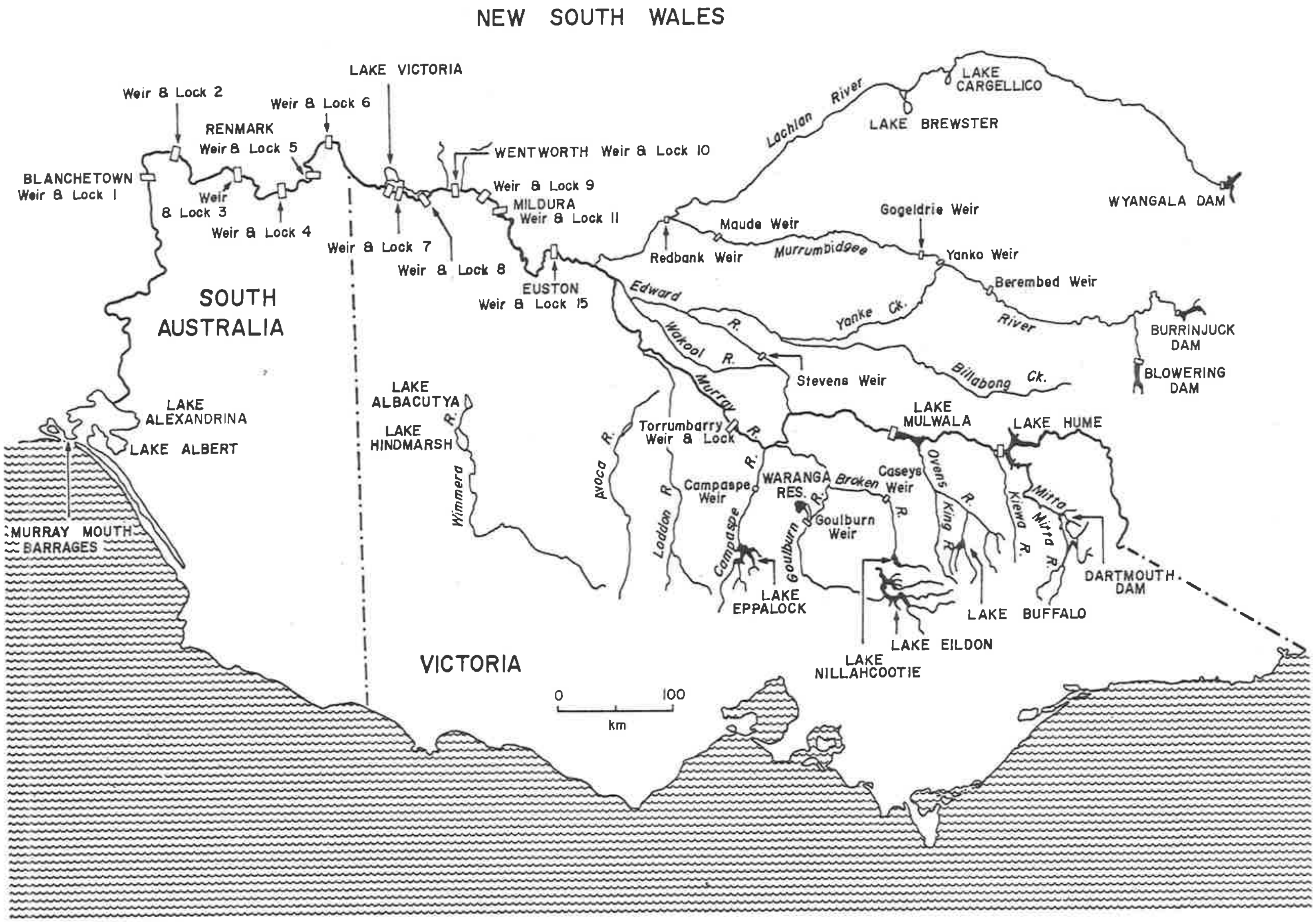


FIG. 2·7 Major tributaries of the River Murray, including the River Murray in South Australia.

Murray catchment in the Snowy Mountains ranges from 400 mm (Murray) to 1450 mm (Tooma). Average runoff from the principal contributing river, the Murrumbidgee, is 1375 mm. Maximum flows range from around twice average annual discharge (Kiewa) to 5.5 times (Lachlan).

Whilst the Murray, like the Darling, also is subject to the vagaries of climate, flows are more reliable than those of the Darling. The river has ceased to flow only four times since gauging commenced in 1909 (Hills, 1974). The inherent seasonal variability of discharge, however, discouraged irrigated agriculture, so that large storages have been constructed on several of the upper tributaries (see Table 2.1). Additionally, the Snowy Mountains Hydroelectric Scheme, completed in 1958, provides for diversion of flows from the eastward-flowing Snowy River into the Murray catchment. During 1976-1979 this diversion supplied 10-26 per cent of total inflow into the Hume storage (RMC, 1976, 1977, 1978, 1979).

It is interesting to note that the Murray, which is the boundary between N.S.W. and Victoria, was not partitioned equally between the two States, as is usual when a river forms a political boundary. In this case the State border of Victoria is the south bank of the river, which consequently flows in N.S.W.

River gradients in the Murray above the Murray-Darling confluence decrease from 1 m/km in the headwater streams to 14 cm/km near Albury, with gradually decreasing gradients for some 1500 km to the confluence. Downstream of Albury, the meandering Murray has left anabranches, abandoned channels and billabongs on the floodplain. Similar, but less extensive, billabong tracts occur on the Goulburn, Murrumbidgee, Ovens and Mitta Mitta Rivers (see Ch. 6, also Dept. Nat. Dev. 1974; Shiel, 1976, 1979; RMC, 1977; Walker & Hillman, 1977). A profile of the River Murray is shown in Fig. 2.8.

Table 2.1: Major storages (> 1×10^6 m^3) in the Murray-Darling basin. Darling storages (*) are small, with retention times of only several months. The larger Murray storages have retention times of up to 2 years.

Sources: AWRC (1976); Baker & Wright (1978); Powling (1978); WRCN (1978).

Name	River	Capacity ($m^3 \times 10^6$)	Purpose
Dartmouth	Mitta Mitta	4000	Irrigation and hydro-electricity
Eildon	Goulburn	3390	Irrigation and hydro-electricity
Hume	Murray	3038	Irrigation and hydro-electricity
Menindee Lakes	Darling*	1794	Irrigation and water supply
Burrendong	Macquarie*	1680	Irrigation and flood control
Blowering	Tumut	1628	Irrigation and hydro-electricity
Copeton	Gwydir*	1364	Irrigation
Wyangala	Lachlan	1220	Irrigation
Burrinjuck	Murrumbidgee	1026	Irrigation

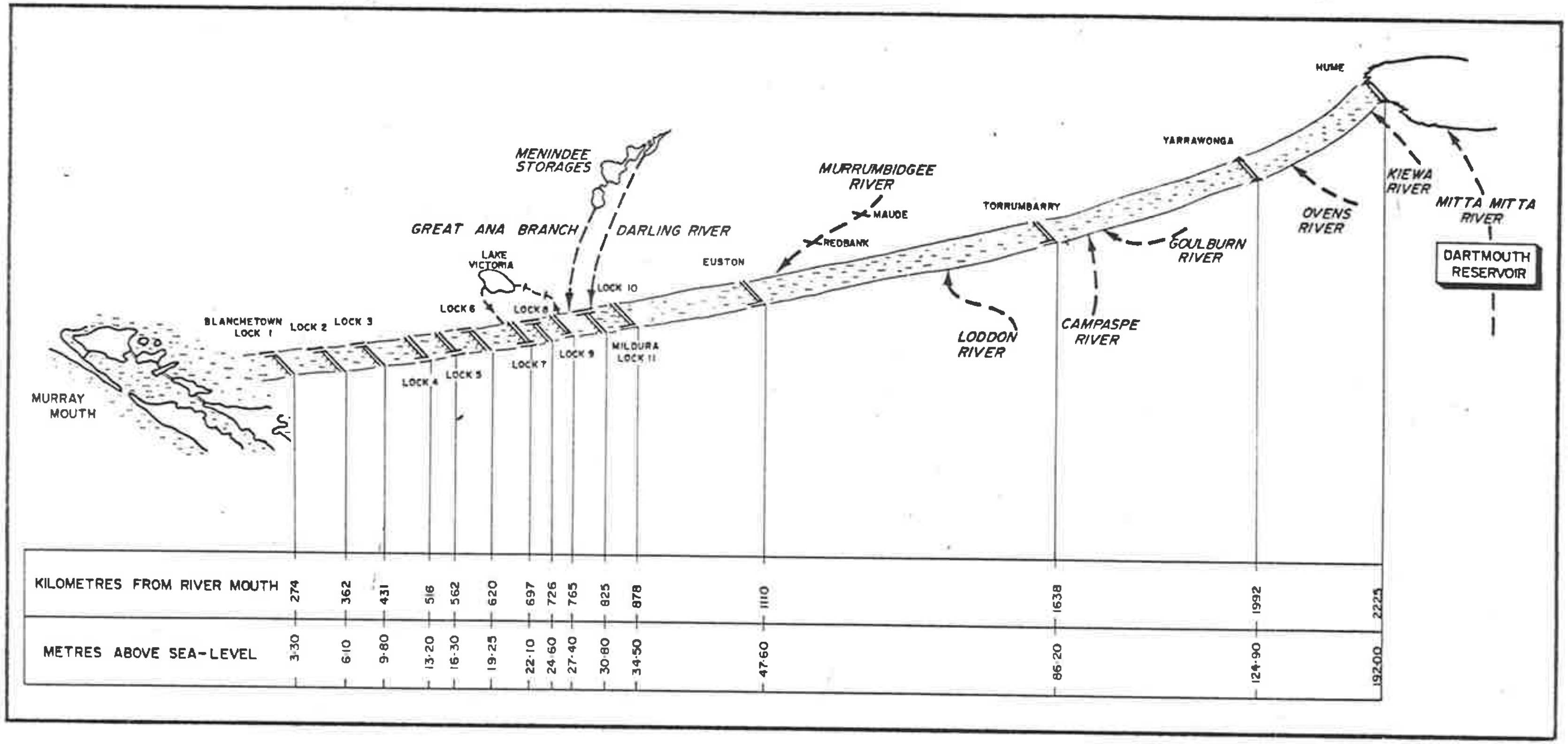


Fig. 2.8: PROFILE OF THE RIVER MURRAY

(R.M.C., 1976)

As in the Darling waters, ionic dominances in the Murray catchment are Na > Mg $\gtrless$ Ca > K and HCO_3 > Cl > SO_4 (Walker & Hillman, 1977; Powling, 1978). Most tributaries have a pH range of 7.0-8.0, with regional exceptions (e.g. 5.5 has been recorded from the Mitta Mitta, 9.9 from the upper Murrumbidgee (SMA, 1971; Graham *et al*., 1978)). Total dissolved solids (TDS) of the upper rivers (with some regional and seasonal exceptions) generally is less than 100 ppm, and conductivities generally are less than 100 µS cm^{-1}. Temperature ranges of 5.5-24.9 °C (Mitta-Mitta) and 6.7-26.4 °C (Murray) are recorded by Walker & Hillman (1977).

Ranges of water quality characteristics in the Murray catchment are smaller than those of the Darling. The most significant differences between the systems result from the construction of the large storages on the Murray and tributaries. Some effects of these dams on the hydrology, water quality and biology of the rivers have been described by Walker & Hillman (1977), Baker & Wright (1978), Cadwallader (1978), Walker, Hillman & Williams (1978) and Walker (1979).

High flows of winter and spring are stored for release over summer and autumn, thereby reducing the incidence of flooding and also flood peaks, but reversing the natural flow regime. Due to increased evaporative loss from impoundments and increased availability of water for abstraction, total runoff is decreased. Hypolimnetic release from dams depresses downstream summer temperatures and released water may be seasonally anoxic (Walker, Hillman & Williams, 1978; I.J. Powling, WSCV, pers. comm.). Lacustrine conditions with abundant nutrients may promote nuisance algal blooms, particularly of blue-green algae (May, 1978) which, because of reduction of downstream flow by weirs and locks, persist into the lower Murray. Turbidity may be limiting to algae in the lower river (Falter, 1978).

One feature of the impoundment of Murray-Darling waters given considerable attention is the effect on river salinities of increased availability of water for irrigation. Salinity increases downstream, a result of saline groundwater release from underlying marine sediments. Although the river has long been subject to seasonal influxes of moderately saline groundwater during flood recession (cf. Collett, 1978), the problem has been exacerbated by some irrigation practices. With extensive irrigation contributing to elevated water tables in floodplain areas along, for example, the Murrumbidgee, Goulburn and Riverland/Riverina reaches of the Murray, saline loads frequently exceed 500 ppm or the 800 EC (conductivity) unit maximum recommended by the WHO (Collett, 1978). In the lower river particularly, salinities may exceed the maximum recommended for much of the year e.g. the average for August, 1977 - April, 1978 was 826 EC units, with 1220 EC units recorded in March, 1978 (RMC, 1978).

2.2.2 The Darling and its tributaries

The Darling River (Fig.2.9), with a catchment of some 650,000 km^2, rises near 1600 m altitude in the Eastern Highlands of N.S.W. and Qld. Initially the Severn River, it joins the Macintyre, the Barwon and the Darling. Tributaries include the Culgoa, Warrego, Paroo, Gwydir, Moonie and Namoi Rivers. Average annual runoff over the eastern tributaries varies from 30.0 mm (Gwydir) to 9.5 mm (Moonie) and of the northern tributaries from 6.0 mm (Warrego) to 3.7 mm (Paroo). Average annual flow of the Darling at Menindee is 5.6 mm (Woodyer, 1978).

The headwater streams of the Darling are in the highlands of south-east Qld and north-east N.S.W. South of the Qld-N.S.W. border the Darling flows south-west for c. 2700 km across flat plains with

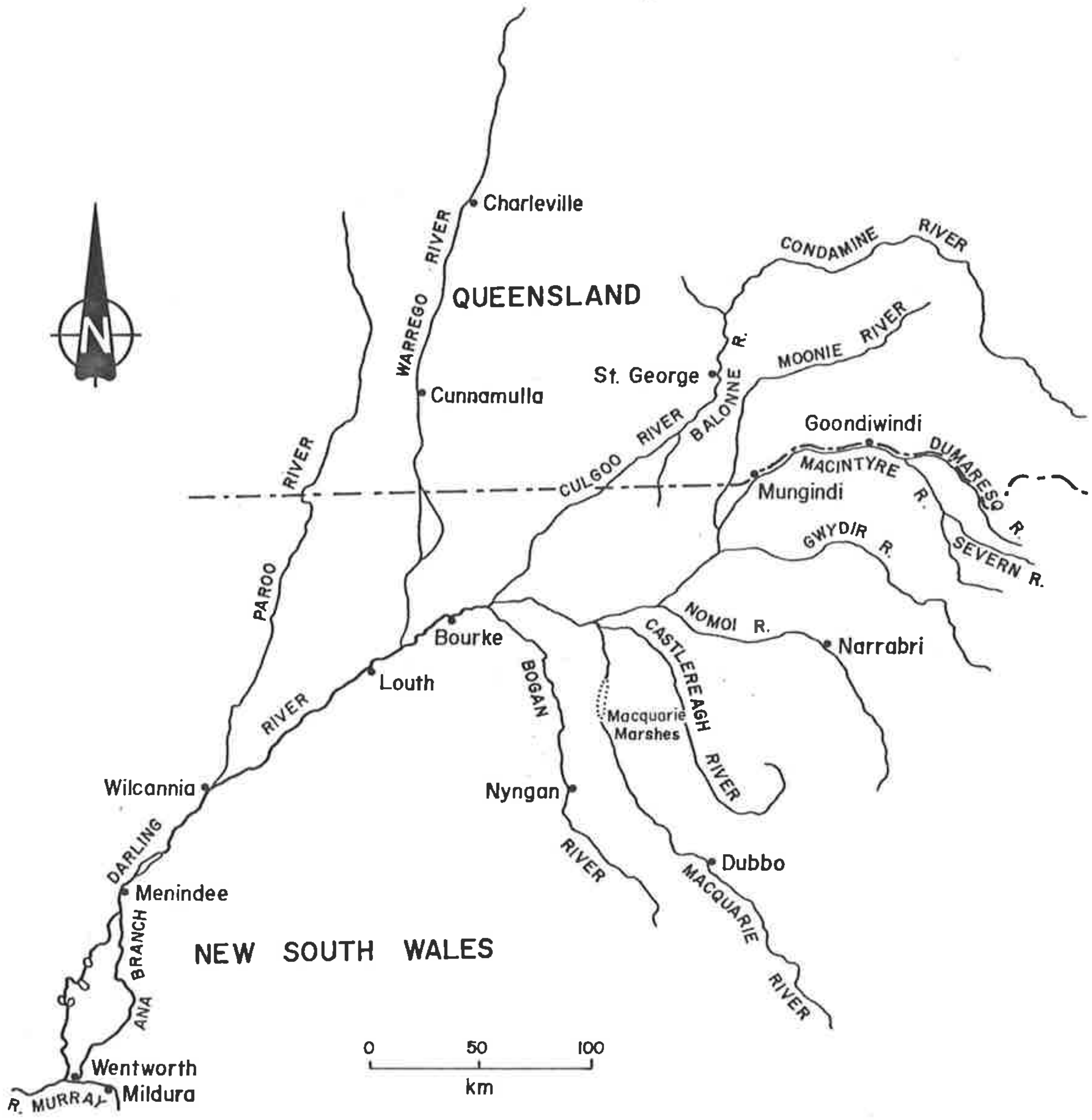


FIG. 2·9 Major tributaries of the Darling River.

no significant tributaries. Prior to completion of barrages at Menindee Lakes in 1960, the river was entirely free of impoundments. Several have since been constructed, e.g. at Keepit on the Namoi (1960), at Burrendong on the Macquarie (1967), at Pindari on the Severn (1969) and at Copeton on the Gwydir (1976) (WRCN, 1978). These have significantly modified the flow regime of the Darling, but not to the extent that the larger dams on the Murray system have regulated that river. Most of the Darling storages are small, with short retention times. Comparative figures for the major Murray-Darling storages are given in Table 2.1.

Evidence of the variability of the Darling is provided by records kept at Menindee. Here the river often has ceased to flow, with the longest period without flows being 362 days (Woodyer, 1978). At the other extreme, flows in excess of 9 times the annual average have been recorded (AWRC, 1976). Flow rate is notably low, a result of the low declivity of the basin (<5 cm/km for more than 2,000 km (Gill, 1970)). Floodwaters may take several months to peak, the floodplain may be inundated for a similar time, and travel-time of floodwaters to the Murray-Darling junction at Wentworth may be three months or more. There is thus a lag between rainfall in the north of the catchment (summer) and peak flows in the lower Murray resulting from this input (autumn).

The characteristic turbidity of waters in the Darling results from sparse vegetative cover in the catchment, extreme variability of runoff, and the nature of the weathered substrate through which the rivers flow. It is a suspended-load stream, carrying suspensions of silts and kaolinite/montmorillonite clays, 80-95 per cent of which are finer than 2 μm (Woodyer, 1978). Further details of the geomorphology and hydrologic features of the Darling catchment are provided by

Bowler *et al.*, (1978), Butler & Hubble (1978), Riley & Taylor (1978) and Woodyer (1978).

Chemically, the Darling has sodium bicarbonate dominated waters, with cation dominance generally Na > Ca > Mg > K (rarely Na > Mg > Ca > K). Anions are typically HCO_3 > Cl > SO_4 > CO_3 (rarely HCO_3 > SO_4 > Cl > CO) (Williams, Walker & Brand, 1970; WRCN, 1976). While the order of cations is typical for Australian fresh waters (Williams, 1967; Williams & Buckney, 1976), it is notable that anionic dominance differs in that Cl is never dominant in waters of the Darling, suggesting a geologic rather than oceanic origin. The same ionic dominance prevails in waters of the Great Artesian Basin, over which the Darling flows (WRCN, 1976).

pH is variable. Extremes of 4.8 (at Louth, 10.ix.65) and 9.2 (at Burtundy, 07.xi.67) have been recorded from the Darling (WRCN, 1976). pH of the lower river usually is between 7.5-8.5, while the headwater streams reflect geological differences in their catchments. There are some slightly acid waters (e.g. Severn River, pH 6.5) but most tributaries are alkaline.

Total dissolved solids (TDS) of the upper streams is commonly between 80-200 ppm, with some regional and seasonal exceptions reflecting different land-use practices (e.g. in the Namoi, where cotton is grown, the range is usually 200-400 ppm TDS). The Darling below Menindee typically has 200-300 ppm (WRCN, 1976). An average of 273 ppm was recorded from four stations on the Darling by Williams, Walker & Brand (1970), which is considerably higher than the value of 59 ppm given by Livingstone (1963) as the mean salinity of Australian rivers. A conductivity range of 50-4200 $\mu S\ cm^{-1}$, representing a salinity range of 30-2520 ppm, was reported from waters of the Darling by Lake (1967).

River temperatures generally are in the range 4.0-31.0°C (Lake, 1967), and higher temperatures have been recorded from the Darling than from rivers east of the Highlands. Although air temperatures may exceed 50°C in summer, river temperatures rarely exceed 30°C (Weatherley, 1967). This has been attributed to the cooling effect of a high evaporation rate as a consequence of low atmospheric humidity (Weatherley, 1963).

Intensive agriculture, made possible by irrigation from headwater storages, is found only on the north-eastern tributaries, particularly along the Namoi and Gwydir Rivers. Irrigated areas are small compared to the longer-established Murrumbidgee Irrigation Area (MIA) and areas of the Goulburn and the Riverland irrigation districts of the Murray Valley. The Darling downstream of the tributaries flows through the most arid parts of the basin, where small and scattered settlements (population densities 2-5/km^2) draw water for domestic and stock supply. The principal land use is stock grazing.

2.2.3 The lower Murray

The lower River Murray in South Australia (Fig.2·7) has two distinctive tracts. Flowing westward into S.A. from the junction of the two rivers, the Murray has a floodplain characterized by scroll plains and abandoned river loops. Extensive irrigation occurs, with significant effects on water quality. At North West Bend the river abruptly changes course, flowing south towards its outlet at Lake Alexandrina through a gorge 30-40 m deep and 600-1400 m wide (Twidale *et al.*, 1978). Geomorphological evidence suggests that the pre-Pleistocene Murray extended further west to a delta in Spencer Gulf, and was diverted by geologic faulting in the Quaternary Period (Williams & Goode, 1978).

Gentle gradients (1-2 cm/km) are a feature of the lower river, with consequent low flow rates. A mere 1.8 mm of runoff is acquired from the lower catchment, which is 5.5% of the entire basin. Average annual flow of the lower Murray is 21 mm (AWRC, 1976). There are no significant tributaries and no reservoirs, although a series of nine locked weirs installed for navigation greatly impede the natural flow. Flows in the lower Murray reflect disproportionate contributions from the Darling and Murray (see Fig.2.10), and while these inputs are not usually coincident, exceptions occur, as in 1956, when the river level at Mannum, S.A. rose 7.2 m. The Murray has been in flood throughout its length in 1870, 1914-15, 1956 and 1973-75 (Currey & Dole, 1978; Twidale, Lindsay & Bourne, 1978).

Physico-chemical characteristics also show seasonal variations according to the relative contributions of the two rivers. Most distinctive is turbidity, which increases markedly (>120 NTU) during peak flows from the Darling, and the river has a characteristic "chalky-white" colour due to fine clay particles in suspension. When Murray flows predominate, algal blooms (diatoms or blue-green algae) may contribute significantly to turbidity, creating problems for water users.

In the upper reaches, cation dominance is generally Na > Ca > Mg > K. Anions show some seasonal variation, with higher chloride than bicarbonate levels over summer corresponding with increased use of water for irrigation. At other times anions are $HCO_3 > Cl > SO_4$ (E&WS, 1975, 1979). Salinity peaks in excess of 1,000 ppm are not uncommon. Prior to erection of barrages at Goolwa on the Murray mouth (completed in 1940) marine incursions into the Murray during periods of low flow were recorded several hundred km upstream. A record 9,460 ppm was measured at Murray Bridge in 1915 (E&WS, 1975).

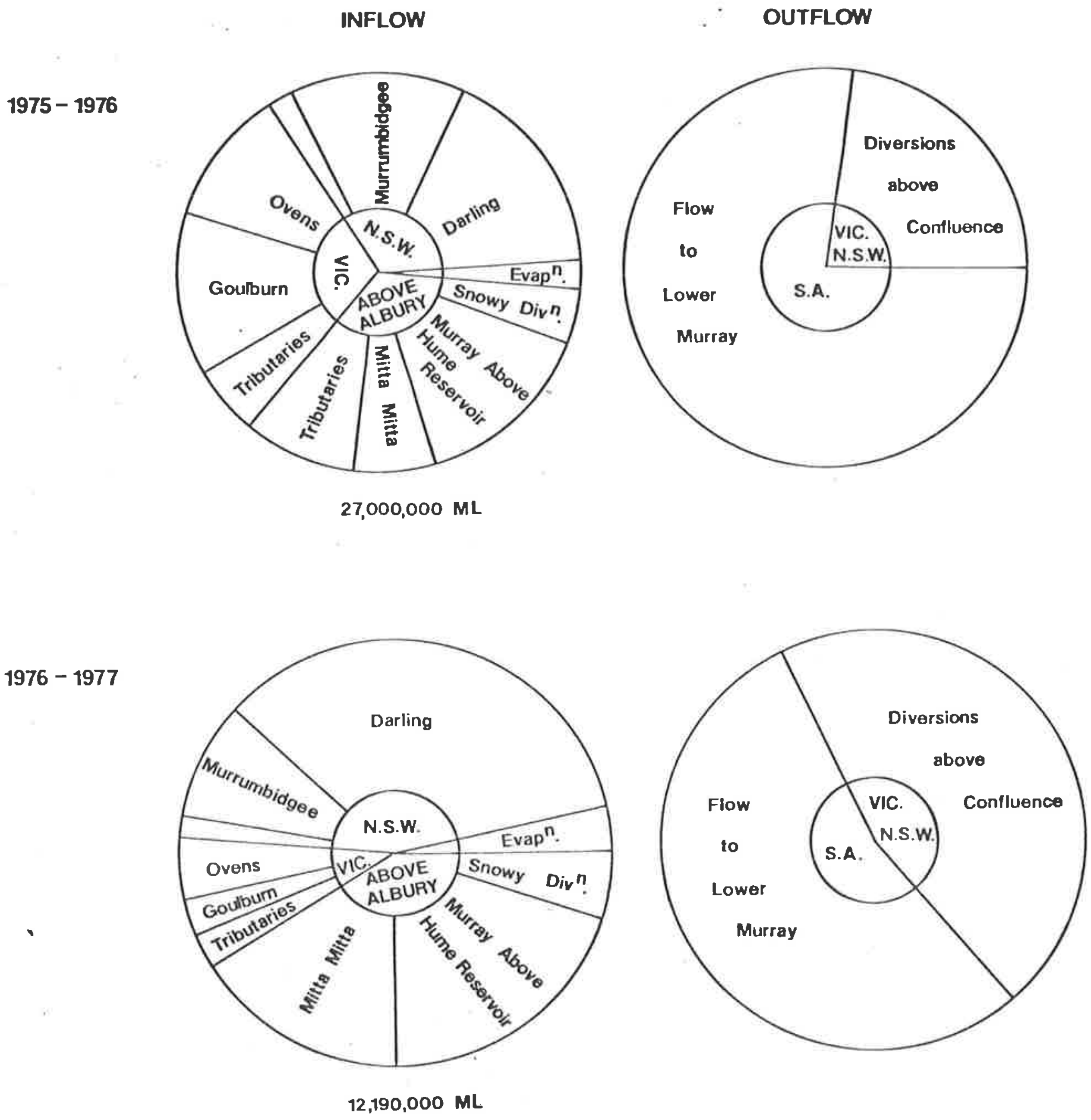


Fig. 2.10 Flows and volume discharged, Murray-Darling system, 1976-79 (from River Murray Commission annual reports).

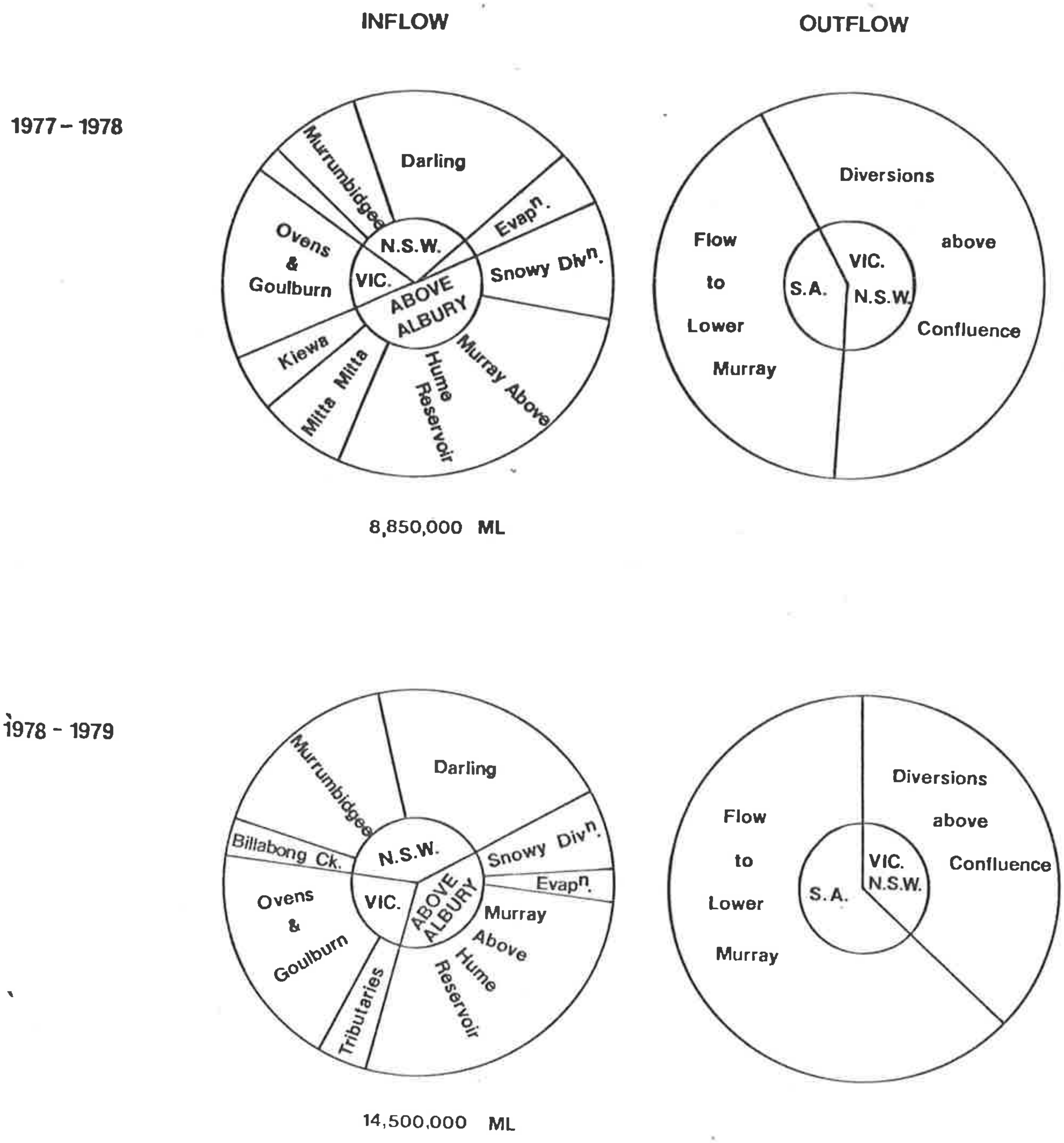

INFLOW
OUTFLOW
1977 – 1978
Murrumbidgee
Darling
Evapn.
Snowy Divn.
Ovens
&
Goulburn
N.S.W.
VIC.
ABOVE ALBURY
Kiewa
Mitta Mitta
Hume Reservoir
Murray Above
Flow to Lower Murray
Diversions above Confluence
S.A.
VIC.
N.S.W.
8,850,000 ML
1978 - 1979
Murrumbidgee
Darling
Billabong Ck.
Snowy Divn.
Evapn.
N.S.W.
VIC.
ABOVE ALBURY
Ovens
&
Goulburn
Tributaries
Murray Above Hume Reservoir
Flow to Lower Murray
Diversions above Confluence
S.A.
VIC.
N.S.W.
14,500,000 ML

Fig. 2.10 (cont.).

Salinity increases in the lower Murray (about 6 EC units/year, equivalent to river acquisition of 25,000 tonne/year (Collett, 1978)) pose problems for domestic and agricultural use, particularly in the lower reaches. Adelaide, for example, with a population of almost one million, abstracts 40-80 per cent of its water supply from the lower Murray (E&WS, 1978). Reports on salinity levels are given by Gutteridge, Haskins and Davey (1970, 1976), E&WS (1976) and Collett (1978).

Temperature ranges are less extreme in the lower river than in the Darling. Water temperatures rarely exceed 28°C, and air temperatures rarely exceed 40°C.

The consequences of the fluctuations in flow and water quality on the biota are little studied. The effects of saline diversions on the phytoplankton are mentioned by Falter (1978). Some information on fish in the lower river is given by Reynolds (1976), and the salinity tolerance of the introduced European carp is discussed by Geddes (1979). Invertebrate groups studied in the lower river include the River Murray crayfish (*Euastacus armatus*) (Kaires, 1979), the yabbie (*Cherax destructor*) and freshwater mussels (*Alathryia jacksoni* and *Velesunio ambiguus*) (Jones & Walker, 1979 ; Walker, 1979). The environmental management of the River Murray in South Australia is discussed by Maynard (1979).

2.3 Sampling stations

It was not feasible to sample all selected rivers, impoundments and associated waters with the same intensity. Accordingly, several surveys were made during early 1976 to establish regular sampling sites and determine possible sampling frequency. Sites were selected to (1) enable latitudinal, longitudinal and altitudinal comparisons of species assemblages, (2) permit comparative sampling of the downstream Murray at at least monthly intervals, and (3) permit seasonal collections from large impoundments for which there was considerable information on water quality and hydrologic data already available, particularly Hume, a meso-eutrophic storage (Gutteridge, Haskins & Davey, 1974; Walker & Hillman, 1977), and Eildon, an oligotrophic storage (Powling, 1978). A unique opportunity was provided to study plankton changes in the deepest Australian storage, then under construction (Dartmouth, 170 m deep), and altitudinal comparisons were made possible by including Rocky Valley Dam (elevation 1599 m).

A series of billabongs on the Goulburn was included, one of which had been studied during 1974 (Shiel, 1974, 1976). A series on the Murray which was under study by, and close to the facilities of the AWDC Ecology Laboratory at Wodonga was included for comparative purposes, as were billabongs on the Mitta Mitta and Ovens Rivers. Several other standing waters of small size and associated with the floodplains were also sampled, as were a few localities outside the Murray-Darling drainage basin but supplying water by diversion. The latter included the Snowy Mountains Hydroelectric Authority storages at Jindabyne and Eucumbene. Finally, comparative samples were collected from some basins with intermittent drainage to the Murray. These included fresh-saline lakes near Kerang, Victoria, and the Loddon and Richardson Rivers of western Victoria.

All localities studied are shown in Fig.2.11 and listed in Table 2.2. In total, collections were made from 23 impoundments, 38 billabongs, 67 river sites and 42 other localities. However, intensity of sampling varied from weekly-monthly at the closest river stations, depending on flow conditions, to seasonally at the furthest areas of the catchment. Sampling dates are indicated in the relevant chapters.

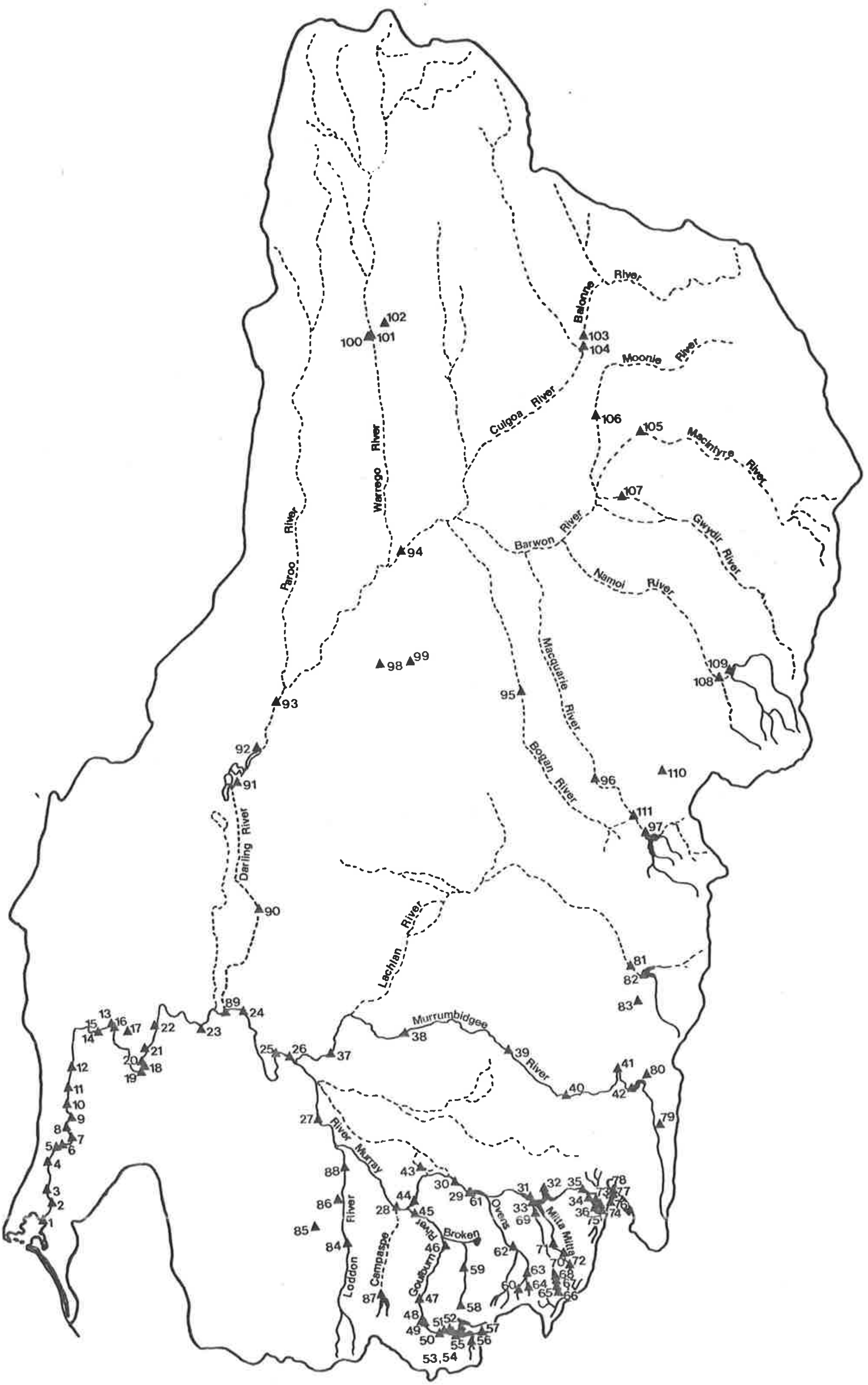


Fig. 2.11 Sampling sites in the Murray-Darling basin.

Table 2·2: Sampling stations, with map coordinates and predominant habitat type (see fig. 11). Where several stations were sampled at a locality, only the central station is given. Habitats are coded R (river or stream), L (impoundment), Bb (billabong) and O (other standing waters associated with the floodplain, or ephemeral pools). Coordinates from Dept.Nat.Devt.(Canberra) 1:100,000 and 1:250,000 topographic maps.

#	LOCALITY	COORDINATES	HABITAT
1	Wellington, S.A.	35°20'S/139°23'E	R
2	Tailem Bend, S.A.	35°15'S/139 28'E	R
3	White Sands, S.A.	35°10'S/139°19'E	R
4	Mannum, S.A.	34°55'S/139°18'E	R
5	Mannum-Teal Flat, S.A.	34°54'S/139°26'E	Bb
6	Teal Flat, S.A.	34°53'S/139°31'E	R
7	Purnong Landing, S.A.	34°51'S/139°38'E	R
8	Walker Flat, S.A.	34°36'S/139°34'E	R
9	Walker Flat, S.A.	as above	Bb
10	Greenways Landing,S.A.	34°41'S/139°39'E	R
11	Swan Reach, S.A.	34°34'S/139°36'E	R
12	Blanchetown, S.A.	34°21'S/139°27'E	R
13	Overland Corner, S.A.	34°09'S/140°20'E	R
14	Waikerie, S.A.	34°11'S/139°56'E	Bb
15	Waikerie, S.A.	34°11'S/139°59'E	R
16	Kingston, S.A.	34°14'S/140°21'E	R
17	Barmera, S.A.	34°15'S/140°28'E	L
18	Katarapko Creek, S.A.	34°25'S/140°40'E	R
19	Loxton, S.A.	34°27'S/140°34'E	R
20	Salt Creek, S.A.	34°19'S/140°34'E	O
21	Berri S.A.	34°17'S/140°36'E	R
22	Renmark, S.A.	34°10'S/140°45'E	R
23	Cullulleraine, Vic.	34°16'S/141°35'E	L
24	Mildura, Vic.	34°11'S/142°10'E	R
25	Euston, N.S.W.	34°35'S/142°44'E	R
26	Boundary Bend, Vic.	34°43'S/143°09'E	R
27	Swan Hill, Vic.	35°20'S/143°33'E	R
28	Echuca, Vic.	36°08'S/144°45'E	R
29	Yarrawonga, Vic.	36°01'S/146°00'E	L
30	Cobram, Vic.	35°55'S/145°39'E	R
31	Albury/Wodonga, Vic.	36°07'S/146°53'E	Bb
32	Hume, N.S.W.	35°59'S/147°03'E	L
33	Bandiana, Vic.	36°09'S/146°56'E	Bb
34	Corryong, Vic.	36°12'S/147°54'E	R
35	Tintaldra, Vic.	36°03'S/147°56'E	R
36	Tom Groggin, N.S.W.	36°33'S/148°09'E	R
37	Balranald, N.S.W.	34°38'S/143°34'E	R
38	Hay, N.S.W.	34°30'S/144°51'E	R
39	Narrandera, N.S.W.	35°45'S/146°33'E	R
40	Wagga Wagga, N.S.W.	35°07'S/147°22'E	R
41	Jugiong, N.S.W	34°50'S/148°19'E	R
42	Burrinjuck, N.S.W.	34°58'S/148°42'E	L
43	Mathoura, N.S.W.	35°42'S/144°53'E	R
44	Barmah, N.S.W.	36°01'S/144°57'E	R
45	McCoy's Bridge, Vic.	36°12'S/145°08'E	R
46	Shepparton, Vic.	36°23'S/145°24'E	L
47	Nagambie, Vic.	36°47'S/145°10'E	L
48	Seymour, Vic.	37°02'S/145°09'E	R
49	Seymour, Vic.	37°00'S/145°10'E	Bb
50	Yea, Vic.	37°13'S/145°26'E	Bb
51	Molesworth, Vic.	37°10'S/145°33'E	R
52	Alexandra, Vic.	37°13'S/145°44'E	Bb
53	Thornton, Vic.	37°15'S/145°48'E	R
54	Thornton, Vic.	37°15'S/145°49'E	Bb
55	Eildon, Vic.	37°07'S/145°58'E	L
56	Jamieson, Vic.	37°18'S/146°08'E	R
57	Howqua, Vic.	37°12'S/146°29'E	R
58	Nillahcootie, Vic.	36°53'S/146°01'E	L
59	Benalla, Vic.	36°33'S/145°59'E	R
60	Buffalo, Vic.	36°43'S/146°39'E	L
61	Yarrawonga, Vic.	36°01'S/146°00'E	R
62	Wangaratta, Vic.	36°21'S/146°19'E	R
63	Myrtleford, Vic.	36°34'S/146°44'E	R
64	Bright, Vic.	36°44'S/146°58'E	R
65	Rocky Valley,Vic.	36°53'S/147°18'E	L
66	Pretty Valley, Vic.	36°54'S/147°16'E	L
67	Junction Dam, Vic.	36°48'S/147°13'E	L
68	Mt. Beauty, Vic.	36°45'S/147°10'E	O
69	Kiewa, Vic.	36°15'S/147°00'E	R
70	Mitta Mitta, Vic.	36°32'S/147°22'E	R
71	Eskdale, Vic.	36°28'S/147°15'E	Bb
72	Dartmouth, Vic.	36°34'S/147°32'E	L
73	Bogong Creek, Vic.	36°22'S/148°10'E	R
74	Swampy Plains, N.S.W.	36°26'S/148°09'E	R
75	Thredbo, N.S.W.	36°30'S/148°19'E	R
76	Jindabyne, N.S.W.	36°23'S/148°38'E	L
77	Eucumbene, N.S.W.	35°58'S/148°38'E	L
78	Eumerella Ck. N.S.W.	35°57'S/149°09'E	R
79	Burley-Griffin, A.C.T.	35°17'S/149°13'E	L
80	Yass, N.S.W.	34°51'S/148°55'E	R
81	Cowra, N.S.W.	33°50'S/148°41'E	R
82	Wyangala, N.S.W.	33°58'S/148°57'E	L
83	Boorowa, N.S.W.	34°18'S/148°47'E	R
84	Bridgewater, Vic.	36°36'S/143°57'E	R
85	Donald, Vic.	36°22'S/142°59'E	R
86	Boort, Vic.	36°08'S/143°45'E	L
87	Eppalock, Vic.	36°52'S/144°34'E	L
88	Kerang, Vic.	35°56'S/143°49'E	L
89	Wentworth, N.S.W.	34°06'S/141°55'E	R
90	Pooncarrie, N.S.W.	33°24'S/142°34'E	R
91	Menindee, N.S.W.	32°20'S/142°20'E	L
92	Black Gate, N.S.W.	32°08'S/142°43'E	L
93	Wilcannia, N.S.W.	31°34'S/143°22'E	R
94	Bourke, N.S.W.	30°05'S/145°56'E	R
95	Nyngan, N.S.W.	31°34'S/147°12'E	R
96	Dubbo, N.S.W.	32°15'S/148°37'E	R
97	Burrendong, N.S.W.	32°40'S/149°09'E	L
98	Barrier Highway,N.S.W.	31°36'S/145°00'E	O
99	Cobar, N.S.W.	31°30'S/145°50'E	O
100	Cunnamulla, Qld.	28°04'S/145°41'E	R
101	Cunnamulla, Qld.	28°02'S/145°56'E	O
102	Widgeegoarra Ck.,Qld.	27°57'S/147°09'E	O
103	Balonne Highway, Qld.	27°40'S/147°45'E	O
104	St. George, Qld.	28°03'S/148°35'E	R
105	Goondiwindi, Qld.	28°33'S/150°18'E	R
106	Sawpit Lagoon, Qld.	28°35'S/148°51'E	Bb
107	Moree, N.S.W.	29°28'S/149°51'E	R
108	Gunnedah, N.S.W.	30°59'S/150°15'E	O
109	Keepit, N.S.W.	30°50'S/150°30'E	L
110	Gilgandra, N.S.W.	31°43'S/148°39'E	R
111	Wellington, N.S.W.	32°33'S/148°57'E	R

3. METHODS AND MATERIALS

In view of the wide range of aquatic habitats in the study area, uniform methods were necessary for effective comparison. Sampling sites established at each locality were maintained throughout the study. Single sites were sampled at lotic stations, with the exception of the lower Murray at Mannum, where a cross-river ferry operated by the S.A. Highways Department was used on occasions to obtain multiple samples. Several sampling sites were selected at lentic stations, particularly the larger reservoirs.

During the first year of study a rubber dinghy was used to sample from deep water at both riverine and lacustrine sites, but a power boat was later used at several impoundments. At all other sites collections were made from approximately 1 m depth, although some billabongs were seasonally less than 1 m deep.

The lower river sites were sampled at approximately the same time on each visit (see Ch. 7). In view of the variability of physicochemical characteristics of fresh waters generally and flowing waters particularly (Hynes, 1970; Whitton, 1975; Welcomme, 1979), as well as the possibility of deriving misleading interpretations from regular sampling (Montgomery & Hartt, 1974; Hellawell, 1978), comparative samples were also collected earlier and later in the day. Distant field stations generally were visited within daylight hours.

3.1 Physico-chemical methods

Surface water samples were collected in 1 ℓ polyethylene bottles and analysed in Adelaide. Analysis of water samples from the most frequently sampled Mannum site was generally within two hours of collection. Initially, water samples from distant field areas were preserved by acidification with H_2SO_4 (APHA, 1975) and returned to Adelaide. Later, facilities were provided by the AWDC, and water samples from the floodplain and upper catchment sites were analysed at Wodonga within two-three hours of collection.

Water quality characteristics known to influence the plankton and measured in the field or a laboratory are discussed below.

3.1.1 Temperature

Ambient and surface (i.e. 10 cm) water temperatures at all stations were measured with a YSI oxygen meter thermistor and a mercury thermometer. The former was used to take vertical temperature profiles in the lower Murray, billabongs on the Goulburn and Murray, and in several impoundments (Hume, Eildon and Dartmouth).

3.1.2 Dissolved oxygen (DO)

All DO measurements were made with a YSI 51B oxygen meter at a depth of 1 m (or the deepest point in the case of shallow billabongs). Oxygen profiles were recorded in the lower Murray in two impoundments (Hume, Dartmouth).

3.1.3 Conductivity

Conductivity was measured from water samples with a Radiometer CDM2e conductivity meter.

3.1.4 Total dissolved solids (TDS)

TDS were estimated by evaporation to dryness of a 100 or 200 ml water sample at 103°C.

3.1.5 pH

Field measurements were made with a Metrohm E 488 portable pH meter. Laboratory measurements at Wodonga were made with a Townson & Mercer PT 75 meter within an hour of collection.

3.1.6 Turbidity

Water transparency was estimated during the first field surveys by Secchi disc. Later measurements of suspended particulate matter in water samples were made with a Hach 2100A turbidimeter.

3.1.7 Major ion chemistry

Cation proportions were determined by atomic absorption spectrophotometry (Varian Techtron model 1250 A.A.S). Chloride analyses were made using a Radiometer ABU 12 autoburette/TTT 60 automatic titrator. Other anions were not measured. Analysis of major ions (of typologic value only) was not continued beyond the first year of the study because of the availability of comprehensive data for many of the more-frequently sampled localities (e.g. AWRC, 1976; E&WS, 1976; RMC, 1976, 1977; Walker & Hillman, 1977).

3.2 Biological methods

A feature of the plankton community which makes data collection difficult is its spatial and temporal patchiness. Few lotic plankton studies include information on sampling techniques and the methodological problems associated with the heterogeneity. Rarely adequately treated, they may be simply stated in procedures, with no consideration of implications for, or constraints on, later conclusions. No comprehensive review of the subject has been made, although some problems of plankton studies in general are described by Tonolli (1971), UNESCO (1974), Bottrell *et al.*,(1976), White (1977) and Hellawell (1978).

3.2.1 Sampling

The aim of the sampling program was to obtain reliable estimates of density and diversity of the plankton. Techniques involving more than a single operator, or complicated sampling gear with increased likelihood of failure in the field could not be considered, and therefore several collecting methods were tried during the first field surveys . Several nets and two volume samplers were tested in a lake (Jindabyne), a billabong (Goulburn View, Alexandra) and a river (the Murray at Mannum). The nets were cone nets of 18 cm and 30 cm aperture, with mesh sizes of 23, 53 and 180 µm. Volume samplers were a 5 ℓ van Dorn sampler and a 30 ℓ Patalas/Schindler perspex trap (Fig. 3.1). Additionally, 30 ℓ of water was collected by hand in a 10 ℓ polyethylene bottle and poured through 12 µm mesh. Table 3.1 gives representative results.

The 20 µm phytoplankton net clogged rapidly, particularly in the turbid waters of the river, and was discounted from further use. All nets clogged in the billabong, due to indiscriminate sampling of the tops of submerged *Myriophyllum/Triglochin* beds, so that detritus, macroinvertebrate and fish were collected. However, fitting a Birge cone of 6 mm mesh stainless steel partly overcame this problem, although it introduced further resistance to throughflow. Hand-poured samples and perspex trap samples underestimated copepods, which evidently were able to avoid the containers. Nets undersampled nauplii, copepodites and rotifers – small forms which may pass through the mesh under pressure, or not enter the net as a result of turbulence. All small forms were lost through the 180 µm mesh, which was not used further. The 53 µm nets were used throughout the study.

The van Dorn sampler was less reliable in closing than the perspex

Fig. 3.1: Volume sampler; 30 ℓ perspex trap (modified after Schindler, 1969).

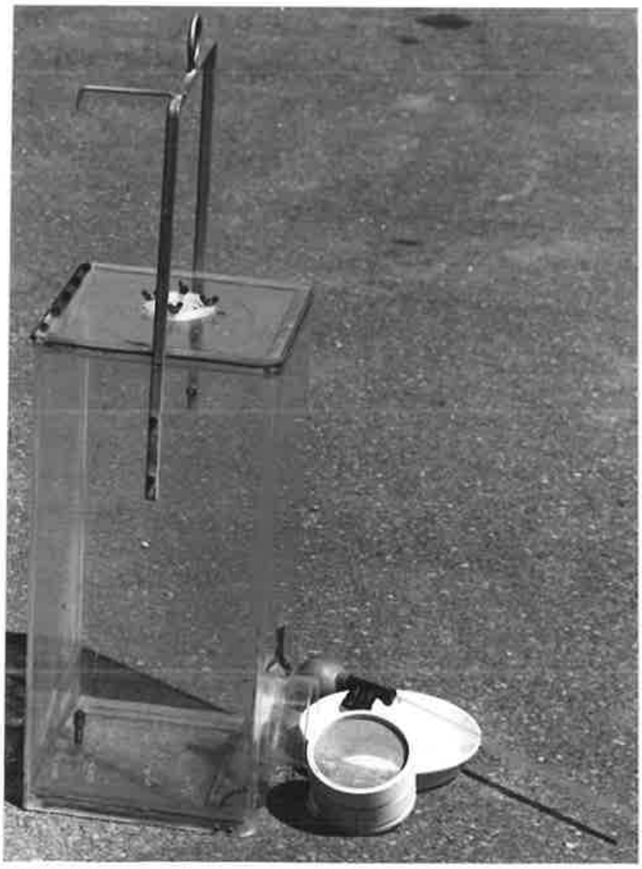


Fig. 3.2 : Interchangeable mesh net (20 μm, 53 μm) enabled more convenient handling of samples.

Table 3.1: Comparative efficiencies (per cent capture) of several sampling methods. All net tows 5 x 6 m, except cross-river tow (300 m). 10 ml aliquot subsamples counted. Trap sample total count.

Taxa	Method											
	30 ℓ poured		30 cm cone 53 µm		30 cm cone 180 µm		16 cm cone 53 µm		30 cm CRT 180 µm		30 ℓ trap 53 µm	
	n	%	n	%	n	%	n	%	n	%	n	%
Rotifera	76	26.3	130	9.6	40	6.9	196	21.4	1104	14.2	411	22.7
Cladocera	63	21.5	514	37.9	308	53.3	294	32.2	4080	52.3	549	30.4
Copepoda	48	16.6	442	32.6	230	39.8	306	33.5	2613	33.5	280	15.5
nauplii &c	103	35.6	270	19.9	-	-	118	12.9	-	-	567	31.4
Σ	290		1356		578		914		7797		1807	
n species	13		18		12		26		12		23	

trap, was more awkward to handle than the trap, and was not subsequently used. The latter was reliable in the river and lake, but less so in the billabong, due to submerged vegetation. Filtration rate was slow, due to clogging of the initial 20 μm mesh cone net. This was replaced with a 53 μm cone with a threaded PVC attachment to take a 120 ml pomade jar (Fig.3.2) Some loss of plankters through the coarser mesh was unavoidable. Fig.3.2 shows the filtering arrangement made for the subsequently modified trap. The net could be removed, rinsed down with distilled H_2O from a wash-bottle, and the catch removed by pipette. The problem of adherence to the net was minimised, and handling reduced, as the smaller volume could be counted in its entirety.

For qualitative comparisons, at each station 5 x 6 m net tows were made, and the samples pooled. Short tows were made to decrease the clogging effect (cf. Comita & Comita, 1957). Formalin (4%) was added to make the total volume up to 120 ml, a data card showing date, place, time and method of collection included, and the outside of the sample bottle labelled. On occasions, tows for phytoplankton were made. These were treated with Lugol's iodine (Vollenweider, 1974). Replicate tows specifically for ostracods were collected from some billabongs. These were preserved with 70% ethanol.

To minimise cross-contamination between sampling localities all nets were washed down with distilled water after collections were made. Later in the study, nets were soaked in a modified 10 ℓ polyethylene bottle containing 70% alcohol prior to use at the next locality.

To determine the efficiency of the trap sampler, and thereby establish the collecting effort required to produce reliable estimates of population density, multiple trap samples were collected at a river station (Fig.3.3) and a lake station (Fig.3.4). Means and variances are shown. The formula $n = \{\frac{tS}{D\bar{x}}\}^2$ (Elliott, 1971) was used to

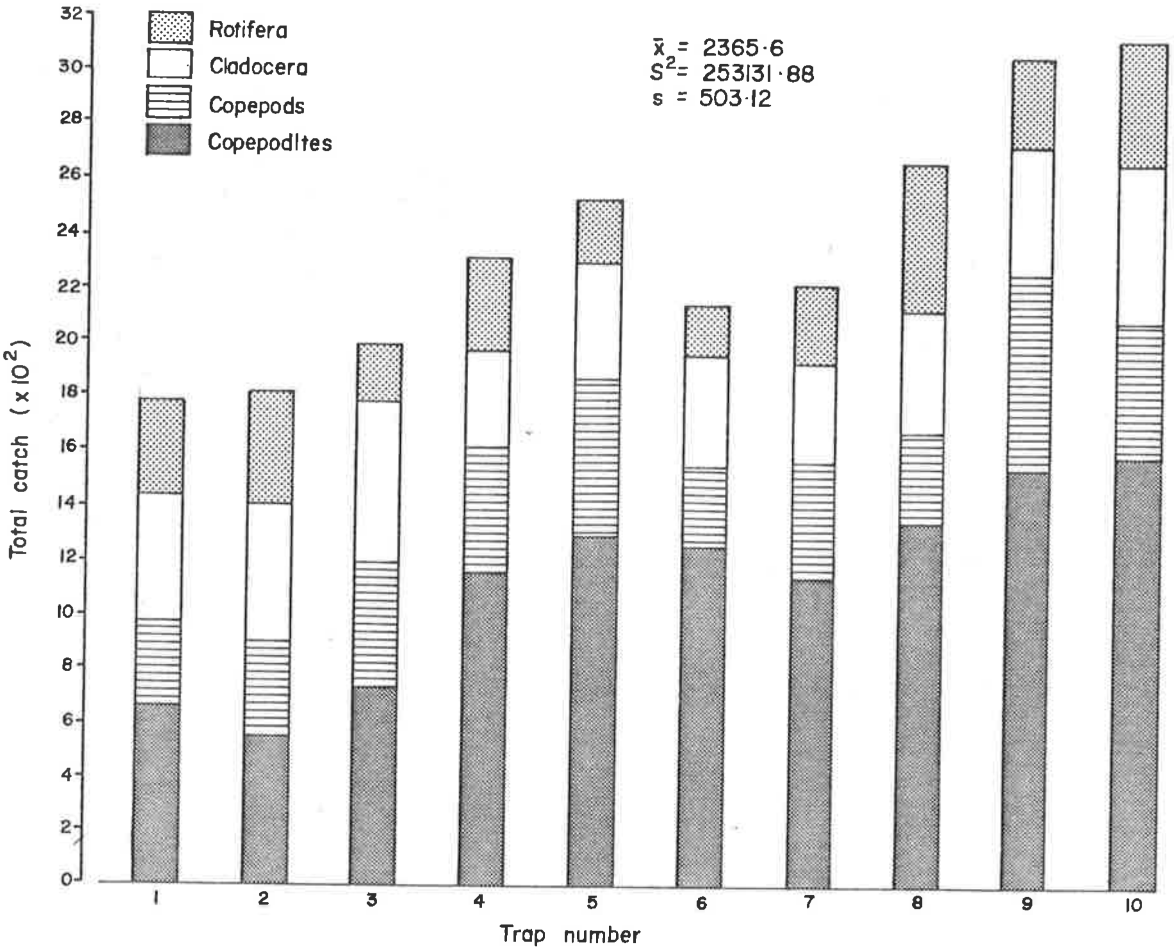


FIG. 3·3 Ten 30 litre trap samples (collected within 30 minutes). Mannum (7·i·77)

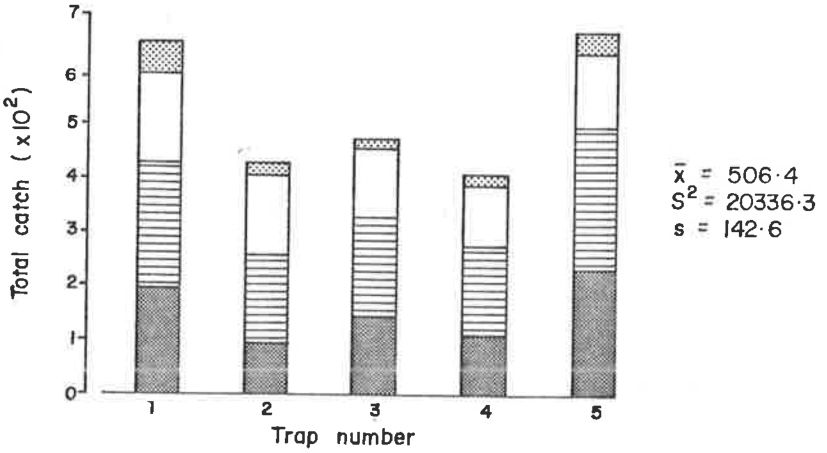


FIG. 3·4 Five 30 litre trap samples (collected within 10 minutes). Lake Jindabyne (8·i·77) calculate the number of sample units (n) required for a given relative error (D) of the mean ($\bar{x}$). A tolerated level of precision of 10-40% is given by Cummins (1975) for lotic macroinvertebrate studies (i.e. D = 0.10-0.40). Substitution of these values into the above formula, using the multiple trap data from Mannum and Jindabyne, showed that, for greater precision, considerably more samples were required than could be processed. For an error of 10% (D = 0.10) with a probability of 95% (t = 2) for the Mannum series, for example ($\bar{x}$ = 2365.6, S = 503.12), $\underline{n = 18.1}$. However, for a D = 0.40, $\underline{n = 1.1}$.

In view of the contagious distribution of plankton in all localities compared (variance > mean), acceptance of the higher level of precision was not considered warranted, and for the duration of the study 1-2 trap samples were collected at each site, with the exception of vertical and horizontal series noted earlier, and a 24-hour series at Mannum (Ch. 7).

To determine the significance of the differences between the multiple samples, and therefore if one or two traps could be considered representative, the non-parametric Kruskal-Wallis one-way analysis by ranks was applied to the data (Table 6) (Siegel, 1956). The null hypothesis (H_0) was that all samples came from the same population, and therefore there was no difference in mean level between samples. As k is distributed approximately as χ^2 with n-1 degrees of freedom (d.f.), 7.7 and 3.0 are below the respective 5% points (Sokal & Rohlf, 1973), therefore H_0 was accepted.

When the cumulative number of species is plotted against number of samples for the Mannum trap data, an approximate exponential curve is generated (cf. Chutter & Noble, 1966; Hellawell, 1978). Of the 27 planktonic species (excluding copepodites) collected in the ten traps, 20 (74%) were present in the first trap. Only one or two species were added for each of the following traps (Fig.3.5). Twenty-six of the 27

Table 3.2: Kruskal-Wallis one-way ranking of Mannum trap series (Fig. 3.3).

Raw data

Trap #	Rotifera	Cladocera	Copepoda	Copepodites	Σ
1	340	471	314	658	1783
2	421	549	280	569	1819
3	207	585	463	735	1990
4	340	480	335	1160	2315
5	242	446	581	1267	2536
6	197	396	317	1238	2148
7	285	340	430	1135	2190
8	553	458	315	1350	2676
9	342	486	699	1536	3063
10	680	390	476	1590	3136

Ranked data

								$\frac{R_i^2}{n_i}$
1	11	21	6	30	n=4	R_i	68	1156
2	16	25	4	47	"		72	1296
3	2	29	30	33			94	2209
4	11	23	9	35			78	1521
5	3	18	28	37			86	1849
6	1	15	8	36			60	900
7	5	11	17	34			67	1172.3
8	26	19	7	38			90	2025
9	13	24	32	39			108	2916
10	31	14	22	40			107	2862.3

$N = 40$

$$\Sigma \frac{R_i^2}{n_i} = \underline{17856.6}$$

$$k = \frac{12}{40(41)}(17856.6) - 3(41)$$

$$= \underline{7.7}$$

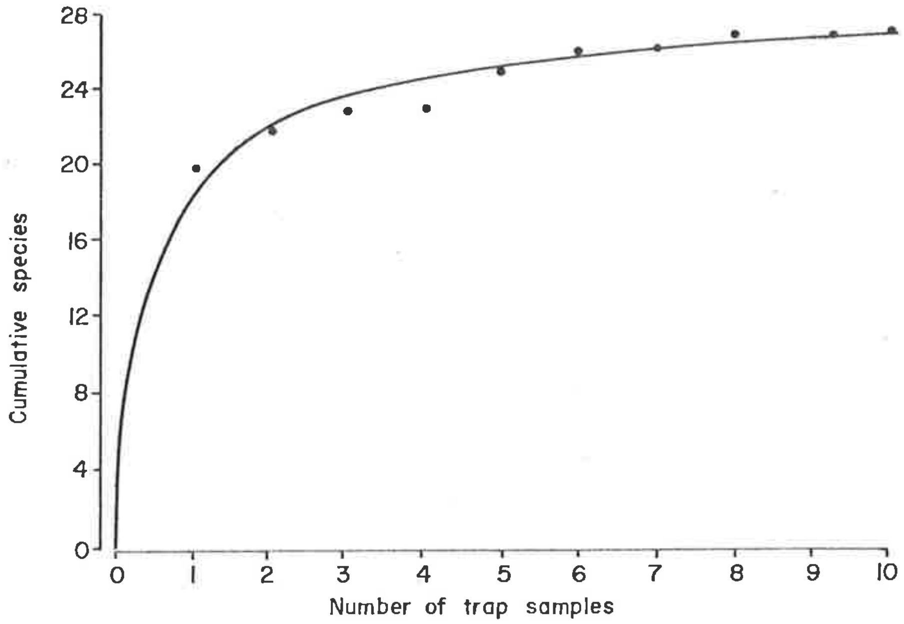


FIG. 3.5 Cumulative species vs. number of trap samples.

species were collected in a net sample taken at the same time, i.e. rare taxa missed by trap sampling were collected in larger volume net tows.

Throughout the study, the volume samples were regarded as adequate measures of population density at the point sampled (within the accepted level of accuracy). The net samples were taken in a consistent manner and therefore assumed to be qualitatively comparable. Some 1200 samples were collected by all methods during the study.

3.2.2 Sorting

Because of the high density of plankters in many samples, or the presence of detritus or algae, counting of the entire catch was rarely practical, and then only in the case of trap samples. Subsampling was therefore necessary. Methods of subsampling which provide reliable population estimates are described, for example, by Edmonson & Winberg (1971), Venrick (1971) and Bottrell *et al.*, (1976).

Qualitative samples were subsampled by agitating the sample bottle to disperse the contents and withdrawing a 10 ml aliquot. The aliquot was run into a milled perspex counting tray (20 ml volume) which was scanned sequentially. Plankters were identified *in situ* or removed by micropipette or tungsten needles for later identification. A minimum of 200 plankters was counted for each sample, and the remaining part of the tray scanned for additional species. Usually one or two additional species only were recorded (noted as less than 1 per cent), but in billabong communities 8-10 additional species were not unusual.

Plankters adhering to the surface-film, particularly *Bosmina* and chydorid cladocerans, were enumerated separately.

Quantitative samples were counted in their entirety where the sample volume was less than 20 ml. Otherwise, it was transferred to a measuring cylinder and the volume recorded. Ten ml aliquots were withdrawn from the sample after agitation and enumerated as above. The total count was then multiplied by the aliquot fraction of the original volume. Up to five aliquots were taken from test samples, and the χ^2 statistic used to compare aliquots. No significant difference was recorded at the 5% level. Throughout the study, 2-6 aliquots were taken from each sample. Subsamples were taken also early and late in the study to cross-check identifications, obtain individuals for measurements or to check breeding seasonality. In each case the check-count was pooled with the initial count.

Phytoplankton counts from the Mannum samples were made on 1 ml aliquots from trap samples. A Sedgwick-Rafter cell or a Lund cell (Lund, 1959) were used on a compound microscope, and the algae in 5-10 field areas counted by means of a Whipple ocular grid.

Plankton were tallied on a bank of counters. Vital staining (cf. Seepersad & Crippen, 1978) was not necessary to distinguish zooplankton live or dead on collection. During sorting and counting, plankters which were dead on collection could usually be distinguished by structural damage, loss of body contents, air bubbles trapped within the carapace, etc.

After counting, the contents of the counting tray were returned to the sample bottle by pipette. To minimise cross-contamination of samples, all pipettes were kept in a measuring cylinder of distilled water to which several drops of detergent were added and were rinsed several times before and after use in an adjacent 1 ℓ beaker of water. Contamination of samples occurred early in the study when tap water from the city reticulated supply which was used for rinsing pipettes was found to contain plankton, and dead plankters were subsequently collected in a plankton net placed under the supply tap. All water for rinsing and dilution was thereafter from a distilled supply.

3.2.3 Species

A major difficulty in working with multiple samples containing large numbers of species is that of accurate identification. Confusion of species and failure to recognize taxa is a common problem (Bullock, 1971). Taxonomic aspects, therefore, occupied a considerable amount of time, particularly since specific keys to many of the representative taxa in the plankton of Australian waters do not exist.

Treatments for each taxonomic group and the literature used in identification are given below. In all cases microscopic identifications were carried out on an Olympus binocular dissecting microscope (<40x) and an Olympus binocular compound microscope (model FHT) using phase-contrast condenser and objectives (10-1000x).

(a) Phytoplankton:

Algae for identification were removed from samples by micropipette and mounted on a slide in glycerine or PVA (polyvinylalcohol-lacto-phenol) mountant. Identifications were made to generic level using the keys of Drouet (1959), Thompson (1959), Patrick (1959) and Prescott (1976). Some specific identifications were made using descriptions and figures by Viyakornvilas (1974), Bowles (1978) and Powling (unpublished).

(b) Zooplankton:

i. Protozoa. Whilst collecting and preserving techniques used generally precluded sampling Protozoa, some taxa, particularly Rhizopoda, were occasionally collected. As far as possible these were identified to generic level using the keys of Jahn (1949), Pennak (1953) and Deflandre (1959).

ii. Rotifera. Individuals for identification were withdrawn from samples by micropipette. Species in which the lorica morphology is of taxonomic significance were placed directly into a drop of glycerine on a slide (or PVA if a permanent mount was to be made) and a #1 coverslip added. On occasions, to prevent distortion of fragile specimens, small pieces of broken coverslip were placed in the PVA prior to addition of the top coverslip, and the edges later sealed with lacquer. Where necessary, rotifers were treated for 10 minutes in NaOCl in a well-slide to clear the gut, rendering the trophi and mastax more visible (Donner, 1956), and mounted as above.

Identifications were made at 400x and 1000x using the keys of Hyman (1951), Pennak (1953), Donner (1956), Voigt (1956/57), Edmondson(1959), Sudzuki (1964), Kutikova (1972), Ruttner-Kolisko (1974), and Koste (1978). All measurements of lorica, body and bristles were made with a Leitz ocular micrometer calibrated against a microslide-mounted 100 µm scale. A photographic head and 35 mm camera (Olympus OM-1) were used for comparative taxonomy. Dark-field phase contrast was found to be most efficient for transparent rotifers.

iii. Cladocera. Individuals were removed from samples by pipette, or entomological forceps in the case of large taxa. Where disarticulation was necessary, fine tungsten needles sharpened by dipping in boiling $NaNO_2$ were used. Initially, smaller species (e.g. Chydoridae) were disarticulated in KOH (Megard, 1964). This technique was found to be time-consuming and capable of handling only small numbers concurrently. By placing a thin smear of PVA (to which a small amount of chlorazol black was added for contrast) on a slide, up to 40 specimens could be ranked. The PVA was allowed to dry slightly, further PVA was added, then a coverslip. By rotating the coverslip it was possible to roll the specimens to give a dorsal view of the taxonomically-significant head pores. Bosminids were also treated in this way. Taxonomic works used include those of Pennak (1953), Brooks (1959), Frey (1962), Bayly, Bishop & Hiscock (1967), Fryer (1968, 1971), Goulden (1968), Korinek (1971), Smirnov (1971, 1976, 1977) and Smirnov & Timms (in press).

iv. Copepoda. *Cyclopoida* (♀♀) were dissected and the appendages ranked sequentially in a thin line of PVA run onto a slide with a dissecting needle (Hamond, 1969). Antennae and antennules (AI and AII), thoracic appendages (PI, PII, PIII and PIV) and the urosome and furca with PV and PVI intact were treated in this way. The preparation was allowed to air dry, further PVA was added, and a coverslip. Initially, keys by Rylov (1958), Pennak (1953) and Yeatman (1959) were used for generic identifications. Later, specific identifications were possible using keys by Morton (1977). *Calanoida*. The taxonomically significant fifth leg (PV) of male calanoids was removed with dissecting needles and mounted as above. Identifications were made using the keys of Bayly (1961, 1962, 1963a, b). *Harpacticoida*. These were treated as for cyclopoids (Hamond, 1969).

v. Ostracoda. These, if not preserved in 75% ethanol in the field, were so treated as soon as possible after return to the laboratory. They were sent for expert identification.

vi. Macroinvertebrates. The drift component of flowing waters and macroinvertebrates collected during billabong surveys are treated separately (Chs.6 & 7). Collecting methods precluded catching larger macroinvertebrates; those commonly collected were nymphal stages of insects, particularly Ephemeroptera, and glochidia of the River Murray mussel. In billabongs, small molluscs, hydroids and a diverse assemblage of arthropods frequently were present in net tows. Molluscs, mayfly nymphs and hydracarinid mites were sent for expert identification; other taxa were identified as far as possible (usually to family) using keys by C.S.I.R.O. (1970), Hynes (1978), Williams (1980).

3.2.4 Statistics

Plankton studies rarely have included statistical treatment of the data. On occasions, inappropriate measures have been used, e.g. early investigators assumed normal distributions, and those few studies which do report statistical treatment used parametric statistics based on assumptions which were not measured (cf. Siegel, 1956). Negative binomial distributions, i.e. contagious or patchy, were reported by Comita & Comita (1957) and Colebrook (1960), among others. Such patchiness in multi-species assemblages renders difficult effective comparisons between samples (cf. Bullock, 1971). In the present study, habitat heterogeneity compounded this problem; analyses suitable for lake samples may not be suitable for river samples.

Comparative statistical treatments were given, for example, by Elliott (1971), Sokal & Rohlf (1973), Heck (1976) and Hellawall (1978). Nonparametric tests and diversity indices which do not assume normality were used in this study. On occasions log transformations were necessary (Elliott, 1971). In general, simple statistical procedures were followed; the nature of the data did not justify more complex treatments. Several treatments were compared on early data, e.g. Eildon reservoir samples. Subsequently, single coefficients or indices were used.

The standard χ^2 statistic and Kruskal-Wallis' analysis by ranks were used to determine the extent of contagion in the plankton. Two "community coefficients" were used; that of Jaccard (1912) ($CC = \frac{c}{a + b - c}$), where a is the number of species in the first sample, b the number of specie in the second sample, and c the species common to both, and that of Czekanowski (1913) ($C = \frac{2w}{a + b}$), where w is the sum of the lower of the two quantitative values for shared species, a is the sum of all values for the first community, and b the sum of all values for the second. The Jaccard coefficient compares species composition only, the Czekanowski coefficient emphasizes numerical disparities.

Two diversity indices were compared; Simpson's (1949) ($I = \frac{1}{\sum p_i^2}$)

and the Shannon-Wiener information theory function (Shannon, 1948) ($H' = -\sum_{i=1}^{S}(p_i)(\log_2 p_i)$), where I and H' are indices of species diversity, S = number of species and p_i = the proportion of individuals belonging to the ith species.

Despite some criticism of the use of H', indeed of "species diversity" (cf. Hurlbert, 1971), H' was convenient to calculate and provided a consistent comparative measure. Species diversity was used in the context of species numbers or richness, and the apportionment of individuals among the species (evenness) (cf. Lloyd & Ghelardi, 1964). The inherent problems of the use of such indices must be taken into account i.e. ambiguity of measurement, nonrandom distribution, overestimation of evenness, or differences in species number resulting from sample size or stochastic variation (Goodman, 1975; Peet, 1975). Analyses of diversity are considered further by Southwood (1966), Peet (1974), May (1975), Hellawell (1978) and Krebs (1978).

Correlation coefficients, which must also be interpreted with caution, were derived by linear regression of log species density on measured environmental variables or by Spearman's rank method ($\rho = 1 - \frac{6\Sigma d^2}{n^3 - n}$ where d = difference in magnitude of the rank of each species for the pairs of stations, and n = total number of species in the comparison. The F-test (Elliott, 1971) was used as a test of significance.

Problems in interpretation of test statistics are considered later where appropriate. All calculations were performed on programmed Hewlett-Packard calculators (HP-41C and HP-67).

4. BIOTA

4.1 General Introduction

Although interest is directed mainly at the zooplankton, phytoplankton, protozoans and macroinvertebrates are discussed briefly later. Taxa considered pseudoplankters (i.e. incursions from the benthic or littoral zones) in other studies also were frequently collected, particularly as a result of flushing from billabongs or accompanying algal blooms in rivers, and also are discussed briefly. All taxa noted in the planktonic microfauna are listed here; they are considered further in Chapters 5, 6 and 7, which deal with community structure.

To ease discussion, the study area is classified as follows: lakes and impoundments of the Darling River system (DL), billabongs and associated standing waters of the Darling River (DB), the Darling River (DR), lakes and impoundments of the River Murray system (ML), billabongs of the River Murray (MB), the River Murray above the Darling confluence (MR) and the lower Murray below the confluence (LM). These codes apply throughout the thesis. In some instances, localities not readily categorized are included with the habitat type they most closely approximate. Lake Cullulleraine, in north-western Victoria, for example, is filled from the Murray below the Darling confluence, and the biota resembles that of the river, as does the water quality. Lake Cullulleraine therefore is included in the lower Murray (LM) category.

Ranges of water quality characteristics are given for each taxon, with the exception of several rotifer species which occurred in incidental collections by the AWDC or WSCV for which water quality information is not available.

4.2 Rotifera

4.2.1 Introduction

Apart from comments on isolated collections (e.g. Berzins, 1953, 1960, 1963; Russell, 1957, 1961) and single-species descriptions (e.g. Sudzuki & Timms, 1977), the study of Australia's rotifer fauna has lapsed for more than fifty years. Early workers (e.g. Thorpe, 1887, 1889; Shephard, 1889, 1896, 1897; Colledge, 1909, 1911, 1914, 1924) sampled near Brisbane, Sydney and Melbourne on the east coast; otherwise little information exists. Most early reports were simply species lists (e.g. Whitelegge, 1889; Shephard, 1911) with little or no ecological information.

Recent advances in taxonomy, particularly with the recognition of morphological variability within species, enabled synonymies to be established for many of the early records. Of more than 450 rotifer "species" recorded from the continent, only 282 are now considered valid (Appendix 1). Several new taxa have been described by Koste (1979) and Koste & Shiel (1980a, b), synecological information on the lower River Murray Rotifera has been given by Shiel (1978, 1979), and a checklist of the Australian Rotifera was given by Shiel & Koste (1979). Williams (1980) includes a short account of the ecology of the rotifers of Australia's inland waters.

An additional 134 species and subspecies of rotifers were recorded from Murray-Darling waters during this study. (Koste, 1979, 1980a, b; Koste & Shiel, in press). Of these, twenty are new to science. A further twenty-one taxa from waters outside the Murray-Darling basin has brought to 437 the number of recorded rotifer taxa from the continent (Koste & Shiel, 1980c).

4.2.2 Taxonomy and ecology

Table 4.1, which lists the Rotifera recorded from the Murray-Darling waters, follows the systematics of Koste's (1978) revision of Voigt (1956/57). Some nomenclatural confusion persists among authors (e.g. Kutikova, 1972; Ruttner-Kolisko, 1974; Koste, 1978), although electrophoretic and SEM studies (e.g. Gilbert & Wurdak, 1978) are resolving uncertainties.

TABLE 4.1: Rotifera recorded from the zooplankton and littoral microfauna of :

DL : lakes/impoundments of the Darling River and tributaries,

DB : billabongs and associated waters of the Darling River system,

DR : rivers and streams of the Darling River system,

ML : lakes/impoundments of the River Murray above the Darling confluence,

MB : billabongs and associated waters of the River Murray and tributaries above the confluence,

MR : rivers and streams of the River Murray system above the confluence,

LM : the lower River Murray below the Darling confluence.

Note that all taxa are listed systematically, including varietal and form differences below subspecific rank. Roman characters indicate undescribed taxa. An asterisk (*) denotes the first record of a taxon from the Australian continent. Ranges of measured water quality characteristics are given for localities from which taxa were collected.

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (oC)	pH	DO (ppm)	Cond. (μS)	Turb. (NTU)
	ORDER BDELLOIDA FAM. PHILODINIDAE												
1	*Philodina megalotrocha* Ehrenberg, 1832					●			15.0 – 20.0	7.1 – 7.3	6.2 – 9.0	<100	–
2	*Philodina* sp.					●			16.5	7.3	8.6	75	2
3	*Dissotrocha macrostyla* (Ehrenberg) 1838			●					13.5	8.4	8.0	–	–
4	**D.* sp.							●	12.0	7.9	10.4	950	15
5	*Rotaria macrura* (Ehrenberg) 1832	●				●			13.5	7.5	10.2	–	–
6	*R. neptunia* (Ehrenberg) 1832		●	●		●		●	12.0 – 24.0	7.2 – 8.2	8.4 – 10.4	850 – 1000	10 – 88
7	*Macrotrachella multispinosa* Thompson, 1892			●					13.5	8.0	8.4	–	–
8	Unidentified bdelloid				●	●		●	18.0	8.2	8.6	850	10
	ORDER PLOIMA FAM. EPIPHANIDAE												
9	**Liliferotrocha subtilis* (Rodewald) 1940					●			17.8	7.1	8.9	28	<5
10	*Epiphanes brachionus* (Ehrenberg) 1837					●			8.0 – 15.2	7.2 – 7.9	9.0 – 11.0	137 – 230	10 – 17.5
11	*E. clavulata* (Ehrenberg) 1832		●			●	●	●	13.0 – 24.0	7.0 – 8.3	4.5 – 10.2	31 – 1000	<5 – 120
12	*E. senta* (Müller) 1773		●						16.5	7.5	6.6	–	–
13	**Rhinoglena frontalis* Ehrenberg, 1853					●			14.5	8.2	12.5	74	18
	FAM. BRACHIONIDAE												
14	*Platyias quadricornis* (Ehrenberg) 1832				●	●		●	16.5 – 27.0	7.6 – 7.7	7.0 – 9.0	150 – 255	27 – 65
15	*Brachionus angularis* Gosse, 1851	●	●	●	●	●	●	●	9.0 – 29.0	7.0 – 8.7	6.0 12.0	64 – 1500	75 – 220

TABLE 4.1 (cont.):

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (°C)	pH	DO (ppm)	Cond. (µS)	Turb. (NTU)
16	*_B. angularis bidens_ Plate, 1886				●		●		25.3	7.9	11.3	55	24
17	*_B. bidentata bidentata_ Anderson, 1889				●			●	16.5 - 23.5	7.9 - 8.1	6.0 - 9.0	650 - 750	67 - 100
18	*_B. bidentata_ f. _jirovci_ Bartos, 1947				●				23.5	7.9	6.0	750	67
19	*_B. bidentata_ f. _testudinarius_ Jakubski, 1912				●				23.5 - 25.3	7.9	6.0 - 11.3	55 - 750	24 - 67
20	*_B. bidentata_ "dwarf"							●	17.0	8.2	9.7	1000	88
21	*_B. budapestinensis_ (Daday) 1885	●	●	●	●	●	●	●	10.5 - 29.0	7.5 - 9.0	8.5 - 10.0	602 - 1000	10 - 65
22	_B. calyciflorus calyciflorus_ Pallas, 1766		●	●		●		●	16.5 - 29.0	7.5 - 8.2	8.6 - 9.0	140 - 850	10 - 95
23	_B. calyciflorus_ f. _amphiceros_ Ehrenberg, 1838			●	●	●	●	●	10.5 - 25.0	7.1 - 8.7	6.4 - 12.0	92 - 1250	10 - 65
24	*_B. calyciflorus_ f. _anuraeiformis_ Brehm, 1909			●	●	●	●	●	10.0 - 29.0	7.3 - 9.0	6.4 - 10.3	60 - 1250	9 - 115
25	*_B. calyciflorus_ "Darling form"	●	●	●				●	10.0 - 19.0	7.3 - 8.5	10.0 - 10.2	300 - 1000	9 - 220
26	_B. caudatus_ Barrois & Daday, 1894				●	●			22.0	7.2	8.7	-	-
27	*_B. caudatus_ f. _austrogenitus_ Ahlstrom, 1940							●	23.0	8.0	8.3	602	65
28	_B. dichotomus_ Shephard, 1911		●		●	●			17.0 - 29.0	7.5 - 7.7	6.4 - 9.0	60 - 115	<.5- 22
29	*_B. dichotomus reductus_ Koste & Shiel, 1980		●		●	●			24.2 - 29.2	7.5 - 7.7	7.6 - 8.6	60 - 85	6 - 22
30	*_B. dimidiatus_ (Bryce) 1931					●			15.9	7.4	9.0	680	4
31	_B. diversicornis_ (Daday) 1883			●	●		●	●	15.0 - 25.0	7.2 - 8.7	6.4 - 10.5	500 - 1000	10 - 130
32	_B. falcatus_ Zacharias, 1898	●	●	●		●	●	●	16.5 - 24.0	7.1 - 8.7	8.2 - 9.2	92 - 1000	8 - 50
33	*_B. keikoa_ Koste, 1979	●	●	●				●	8.5 - 25.0	7.0 - 8.7	6.4 - 12.0	290 - 1950	20 - 220
34	*_B. leydigi_ var. _rotundus_ (Rousselet) 1907				●	●	●		11.0	7.5	11.2	257	-
35	_B. lyratus_ Shephard, 1911					●	●	●	19.5 - 29.0	7.5 - 7.7	9.4	620	37
36	*_B. novaezealandia_ (Morris) 1912	●	●	●		●		●	8.5 - 21.5	7.8 - 8.7	8.2 - 12.0	330 - 1350	32 - 250
37	_B. patulus_ (Müller) 1786				●	●			20.2 - 25.0	6.2 - 7.6	6.5 - 8.4	145 - 250	45

TABLE 4.1 (cont.):

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (°C)	pH	DO (ppm)	Cond. (µS)	Turb. (NTU)
38	*B. plicatilis* Müller, 1786					●	●	●	14.0	8.0	9.8	875	95
39	**B. quadridentatus quadridentatus* Hermann, 1783	●	●	●			●		13.0 - 23.0	7.1 - 8.7	8.6 - 10.0	270 - 1000	20 - 110
40	**B. quadridentatus melheni* Barrois & Daday, 1894				●	●	●	●	15.5 - 29.0	7.0 - 9.0	8.4 - 9.6	120 - 145	<1 - 10
41	**B. quadridentatus f. brevispinus* (Ehrenberg) 1832				●	●			23.5	7.9	6.0	750	67
42	**B. quadridentatus f. cluniorbicularis* (Skorikov) 1894					●							
43	*B. urceolaris urceolaris* (Müller) 1773			●	●	●	●	●	13.0 - 17.0	7.0 - 8.1	8.4 - 10.2	365 - 380	120 - 135
44	**B. urceolaris bennini* (Leissling) 1924				●	●		●	14.0 - 24.0	7.6 - 8.5	8.0 - 9.8	290 - 1250	23 - 120
45	**B. urceolaris nilsoni* (Ahlstrom) 1940		●	●				●	13.6 - 17.0	7.6 - 8.1	8.3 - 10.2	380	120
46	*B. urceolaris* var. *rubens* (Ehrenberg) 1838			●	●	●	●		10.0 - 25.3	7.2 - 8.4	10.0 - 11.3	55	24
47	**B. variabilis* (Hempel) 1896					●	●		8.0 - 10.0	7.0 - 7.2	10.3 - 11.2	65 - 137	10 - 65
48	*Keratella australis* (Berzins) 1963	●	●	●	●	●	●	●	2.0 - 29.0	6.7 - 8.7	3.3 - 12.0	22 - 1350	2.5 - 275
49	*K. cochlearis* (Gosse) 1851	●	●	●	●	●	●	●	8.0 - 25.0	7.0 - 8.4	6.1 - 11.3	8 - 835	1.5 - 135
50	*K. cochlearis* var. *hispida* (Lauterborn) 1900						●		14.5	7.7	9.2	47	5
51	*K. lenzi* Hauer, 1953				●				24.2	7.2	8.6	60	22
52	*K. procurva* (Thorpe) 1891	●	●	●	●	●	●	●	2.0 - 27.0	6.2 - 8.5	3.3 - 12.0	2 - 1250	<.5 - 135
53	*K. procurva* "robusta"	●	●	●	●			●	10.5 - 25.0	7.4 - 8.7	6.4 - 10.8	270 - 1000	15 - 115
54	*K. quadrata* (Müller) 1786				●	●	●	●	8.5 - 23.0	7.0 - 8.3	6.3 - 12.0	27 - 875	.7 - 130
55	**K. shieli* Koste, 1979							●	13.0 - 23.5	7.0 - 8.7	7.4 - 10.2	290 - 1950	20 - 135
56	*K. slacki* (Berzins) 1963	●	●	●	●	●	●	●	8.5 - 24.0	7.0 - 8.4	3.3 - 11.0	38 - 875	7.5 - 130
57	*K. tropica* (Apstein) 1907	●	●	●	●	●	●	●	8.2 - 29.0	6.0 - 8.7	7.5 - 12.0	8 - 1950	.5 - 130
58	*K. valga* (Ehrenberg) 1834	●			●	●	●	●	14.5 - 27.0	6.2 - 8.4	6.5 - 10.0	60 - 900	.5 - 40
59	**Notholca squamula* (Müller) 1786						●		11.0	7.8	10.4	-	-
60	*Anuraeopsis fissa* (Gosse) 1851				●	●			24.2 - 29.0	7.5 - 7.7	8.6	60	22

TABLE 4.1 (cont.):

#	Taxon	DL	DB	DR	ML	Mℓ	MR	LM	Temp. (°C)	pH	DO (ppm)	Cond. (μS)	Turb. (NTU)
61	**A. navicula* Rousselet, 1910					●			10.5 - 17.8	7.1 - 7.4	8.4 - 10.2	-	-
	FAM. EUCHLANIDAE												
62	*Euchlanis deflexa* (Gosse) 1851					●			17.5 - 19.6	7.2 - 7.3	8.6	14.5	4
63	*E. dilatata dilatata* Ehrenberg, 1832	●	●	●	●	●	●	●	10.0 - 25.4	7.2 - 8.5	6.1 - 10.3	52 - 1250	2.0 - 235
64	**E. dilatata f. larga* (Kutikova) 1959				●	●			22.0 - 22.5	7.1 - 7.3	8.3 - 8.6	-	-
65	**E. dilatata f. lucksiana* (Hauer) 1930			●	●	●	●	●	9.0 - 23.5	7.2 - 8.4	6.2 - 13.0	65 - 1080	:8 - 23.5
66	**E. dilatata f.unisetata* (Leydig) 1854					●			10.0	7.2	11.6	330	62
67	**E. incisa* Carlin, 1939				●	●			13.5 - 17.5	7.1 - 7.3	2.7 - 7.8	180 - 240	5.0 - 22
68	*E. lyra* Hudson, 1886				●				12.0	7.5	10.7	46	17.5
69	*E. meneta* Myers, 1930			●	●	●			13.0 - 24.2	7.5 - 7.7	8.6 - 10.0	60 - 110	<1 - 22
70	*E. oropha* Gosse, 1887			●			●	●	10.5 - 17.0	7.0 - 8.4	8.4 - 10.0	290 - 365	120 - 135
71	**E. parva* Rousselet, 1892					●			13.2	7.0	6.3	-	-
72	*E. triquetra* Ehrenberg, 1838			●					15.5	7.3	9.8	-	-
73	**Dipleuchlanis propatula* (Gosse) 1886		●						25.5	6.2	2.9	62	-
	FAM. MYTILINIDAE												
74	**Mytilina macracantha* (Gosse) 1886					●			20.0	7.4	8.8	1500	-
75	**M. mucronata* (Müller) 1773					●			14.7	7.1	4.1	240	5
76	*M. ventralis* (Ehrenberg) 1832				●	●		●	19.5 - 22.5	7.1 - 7.9	6.0 - 9.4	620 - 1500	37 - 67
77	*Lophocharis salpina* (Ehrenberg) 1834				●	●		●	10.5 - 23.5	7.1 - 8.4	4.1 - 11.0	38 - 750	5 - 67
	FAM. TRICHOTRIDAE												
78	**Wolga spinifera* (Western) 1894			●					10.5	8.4	10.0	675	250
79	*Trichotria tetractis* (Ehrenberg) 1830	●		●	●	●		●	8.0 - 29.0	6.2 - 8.4	4.1 - 11.6	46 - 700	5 - 80
80	**T. tetractis var. similis* (Stenroos) 1898					●			8.0 - 22.0	7.0 - 7.2	9.1 - 11.1	60 - 135	5 - 15
81	*T. tetractis var. truncata* (Whitelegge) 1889				●	●			12.0 - 25.0	7.5 - 7.7	8.6 - 10.7	46 - 145	17.5

TABLE 4.1 (cont.):

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (^{o}C)	pH	DO (ppm)	Cond. (uS)	Turb. (NTU)
82	_Macrochaetus subquadratus_ (Perty) 1850					●			23.5 - 29.0	7.5 - 7.9	6.0 - 7.0	750	67
83	FAM. COLURELLIDAE *_Colurella adriatica_ Ehrenberg, 1831				●		●		8.5 - 23.5	7.0 - 7.9	6.0 - 11.2	575 - 750	21 - 67
84	_C. obtusa_ (Gosse) 1886					●			8.0	7.0	11.2	135	15
85	_C. uncinata_ (Müller) 1773			●		●	●		8.5 - 22.5	7.2 - 8.0	7.8 - 11.2	135 - 1080	3 - 21
86	*_Squatinella mutica_ (Ehrenberg) 1832				●	●			13.5 - 19.9	7.2 - 8.0	8.4 - 8.5	85	10
87	_Lepadella acuminata_ (Ehrenberg) 1834			●	●	●			8.0 - 17.8	7.0 - 8.0	8.4 - 11.2	135	15
88	*_L. apsicora_ Myers, 1934				●				23.5	7.9	6.0	750	67
89	*_L. benjamini_ Harring, 1916				●				2.0	7.4	8.8	-	-
90	*_L. chengalathi_ Koste, 1980				●				23.5	7.9	6.0	750	67
91	*_L. dactyliseta_ (Stenroos) 1898				●				8.5 – 27.0	7.0	7.6 - 11.2	575	21
92	*_L. elliptica_ Wulfert, 1939				●				27.0	7.0	7.6	-	-
93	*_L. heterodactyla_ Fadeew, 1925				●				20.0	7.4	8.8	-	-
94	_L. heterostyla_ (Murray) 1913				●				23.5	7.9	6.0	750	67
95	*_L. latusinus videniformis_ Koste & Shiel, 1980				●				27.0	7.6	7.0	-	-
96	*_L. monodactyla_ Berzins, 1960		●						25.5	6.2	2.9	62	-
97	_L. patella_ (Müller) 1773				●	●		●	10.0 - 23.0	7.2 - 8.3	7.8 - 11.6	320 - 1080	3 - 62
98	_L. rhomboides_ (Gosse) 1886				●				23.5	7.9	6.0	750	67
99	*_L. rhomboides_ f. _carinata_ (Donner) 1943						●		27.0	7.6	7.0	-	-
100	*_Heterolepadella ehrenbergi_ (Perty) 1850					●			29.2	7.5	8.0	48	-
101	FAM. LECANIDAE *_Lecane acronycha_ Harring & Myers, 1926		●						25.0	6.2	3.0	48	-
102	*_L. aculeata_ (Jakubski) 1912				●				27.0	7.5	7.4	245	5
103	_L. arcuata_ (Bryce) 1891					●			10.5 - 23.5	7.2 - 7.4	6.0 - 10.4	750	67

TABLE 4.1 (cont.):

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (°C)	pH	DO (ppm)	Cond. (μS)	Turb. (NTU)
104	*L. bulla* (Gosse) 1851				●	●		●	10.2 - 29.0	7.0 - 8.5	1.5 - 11.3	2 - 1250	0.75 - 120
105	*L. closterocerca* (Schmarda) 1895			●		●			15.5 - 27.0	4.9 - 7.9	6.0 - 10.3	750 - 1500	3.0 - 67
106	*L. crenata* (Harring) 1913					●			22.5	7.5	7.8	1080	3
107	**L. crepida* Harring, 1914				●				24.2	7.7	8.6	60	22
108	**L. elsa* Hauer, 1931					●			20.0	7.2	9.1	-	-
109	**L. flexilis* (Gosse) 1886			●	●	●		●	10.5 - 22.0	7.5 - 8.4	8.6 - 10.7	46 - 550	17.5 - 40
110	*L. hamata* (Stokes) 1896			●		●			10.5 - 20.0	4.9 - 8.4	1.5 - 13.0	65 - 1500	4 - 23.5
111	**L. hamata victoriensis* Koste & Shiel, 1980					●			20.0	7.2	9.1	-	-
112	**L. hornemanni* (Ehrenberg) 1834					●			19.9 - 29.0	7.2 - 7.9	6.0 - 9.2	85 - 750	<1 - 67
113	**L. inopinata* (Harring & Myers) 1926				●	●			18.0 - 27.0	7.0 - 7.5	7.4 - 11.0	70 - 245	1 - 5
114	*L. luna* (Müller) 1776	●	●	●	●	●	●	●	10.5 - 29.0	7.0 - 8.4	7.4 - 10.8	60 - 100	.5 - 135
115	*L. lunaris* (Ehrenberg) 1832			●	●	●	●	●	6.0 - 18.5	4.2 - 8.4	6.3 - 11.0	31 - 1100	.5 - 25
116	**L. lunaris crenata* (Harring) 1913				●				24.2	7.7	8.6	60	22
117	*L. ohioensis* (Herrick) 1885			●				●	10.2 - 16.0	8.4 - 8.2	9.0 - 9.4	650	-
118	*L papuana* (Murray) 1913						●	●	17.0 - 22.5	7.1 - 8.2	6.4 - 9.7	500 - 1000	37 - 88
119	**L. pyriformis* (Daday) 1905					●			14.7	7.1	4.1	24	5
120	**L ruttneri* Hauer, 1937				●				20.0	7.4	8.8	-	-
121	**L. signifera* (Jennings) 1896		●		●				11.0 - 17.0	7.5 - 7.7	9.0 - 10.4	-	-
122	**L. signifera ploenensis* (Voigt) 1902			●	●				14.0 - 24.2	7.7 - 8.1	8.5 - 8.6	60	22
123	*L. stenroosi* (Meissner) 1908			●				●	13.5 - 21.0	7.5 - 8.1	8.0 - 9.2	575 - 700	50 - 90
124	**L. stichaea* Harring, 1913							●	11.0	8.4	10.8	575	40
125	**L. ungulata australiensis* Koste, 1979					●			10.0 - 28.0	7.1 - 7.3	9.8 - 13.8	65 - 250	23.5- 85
	FAM. PROALIDAE												
126	**Proales daphnicola* Thompson, 1892					●			14.5	7.6	10.2	78	39

TABLE 4.1 (cont.):

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (oC)	pH	DO (ppm)	Cond. (µS)	Turb. (NTU)
127	*P. decipiens* (Ehrenberg) 1831					●	●		10.0 - 13.5	7.2 - 7.6	10.3 - 10.7	64	7.5
128	**P. fallaciosa* Wulfert, 1937						●		12.0	7.2	10.4	-	-
129	*P. wernecki* (Ehrenberg) 1834			●									
	FAM. LINDIIDAE												
130	**Lindia deridderi* Koste, 1979					●			10.2	7.2	9.0	154	4
131	**L. torulosa* Dujardin, 1841					●			10.0 - 17.8	7.1 - 7.2	6.1 - 8.9	17 - 28	170
	FAM. NOTOMMATIDAE												
132	**Scaridium longicaudum* (Müller) 1786					●			8.0 - 24.0	7.2 - 7.5	9.2 - 12.0	60	5
133	**Monommata arndti* Remane, 1933					●			20.0	7.2	9.1	-	-
134	**M.* cf.*grandis* Tessin, 1890					●			22.0	7.2	9.2	60	5
135	**Eothinia elongata* Ehrenberg, 1832					●			14.7	7.1	4.1	240	5
136	*Eosphora najas* Ehrenberg, 1830			●					13.5	8.0	8.4	-	-
137	*Notommata collaris* Ehrenberg, 1832				●								
138	*N. copeus* Ehrenberg, 1834					●			17.8	7.1	8.9	28	-
139	*N. cyrtopus* Gosse, 1886					●			10.2	7.2	9.0	-	-
140	**N. glyphura* Wulfert, 1935					●			17.8	7.1	8.9	28	-
141	*N. pachyura* (Gosse) 1886					●			20.	7.1-7.5	9.0	575	50
142	*Notommata sp. 1*					●			19.0	7.4	8.7	130	-
143	*Notommata sp. 2*		●	●					24.0	7.7	9.1	-	-
144	**Itura myersi* Wulfert, 1935					●			14.7	7.1	4.1	240	5
145	*Pleurotrocha petromyzon* Ehrenberg, 1830					●	●		12.0	7.2	10.4	-	-
146	**Cephalodella biungulata* Wulfert, 1937				●				10.5	7.1	11.0	38	32
147 (a)	**C. eva* (Gosse) 1886					●			17.9	7.1	9.2	87	.5
147 (b)	*C. forficula* (Ehrenberg) 1832					●			15.0 - 19.9	7.1 - 7.3	8.5 - 10.6	65 - 85	5 - 92
148	*C. gibba* (Ehrenberg) 1832		●	●	●	●	●	●	6.0 - 24.0	4.2 - 8.4	8.4 - 10.0	575 - 1000	10 - 90
149	*C. gisleni* Berzins, 1953						●		18.0	7.8	9.4	220	45

TABLE 4.1 (cont.):

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (°C)	pH	DO (ppm)	Cond. (µS)	Turb. (NTU)
150	*C. mucronata Myers, 1924			●	●				12.2 - 16.0	7.5 - 8.2	6.1 - 9.0	52	2
151	*C. tinca Wulfert, 1937					●			15.0	4.9	10.3	455	12
	FAM. TRICHOCERCIDAE												
152	*Trichocerca agnatha Wulfert, 1939						●		15.0	7.6	9.0	-	-
153	T. bicristata Harring, 1913					●	●	●	8.0 - 11.0	7.3 - 8.4	9.0 - 13.0	65 - 630	23.5 - 43
154	*T. bidens (Lucks) 1912					●			22.0	7.2	9.2	6.0	5
155	T. capucina Wierzejski & Zacharias 1893					●	●		8.5 - 29.0	7.0 - 7.5	6.1 - 11.2	575	21
156	*T. cavia (Gosse) 1886					●			18.0	7.0	11.0	70	<1
157	*T. chattoni (De Beauchamp) 1907				●	●			17.5 - 29.2	7.0 - 7.5	7.1 - 8.9	31 - 120	<1
158	T. elongata (Gosse) 1886					●			20.0 - 22.0	7.2	9.2	60	5
159	*T. insignis (Herrick) 1885		●		●		●		14.5 - 25.2	7.6 - 7.8	7.4 - 8.4	146 - 180	-
160	T. longiseta (Schrank) 1802				●	●			8.0 - 27.5	7.2 - 9.0	8.1 - 11.2	50 - 575	8 - 21
161	*T. mus Hauer, 1937/38				●				15.0	7.5	8.9	-	-
162	T. porcellus (Gosse) 1886					●			8.0 - 22.0	7.0 - 7.2	6.1 - 11.2	60 - 170	5 - 17
163	T. pusilla (Jennings) 1903			●	●	●	●	●	10.0 - 25.0	7.6 - 8.4	8.4 - 12.0	60 - 145	22 - 100
164	T. rattus (Müller) 1776			●		●			8.0 - 22.0	7.0 - 8.4	6.2 - 11.2	65 - 135	15 - 23.5
165	*T. rattus f.carinata (Ehrenberg) 1830				●	●			8.0 - 23.5	7.0 - 8.4	6.0 - 11.2	135 - 1080	3 - 67
166	*T. rousseleti (Voigt) 1902					●	●	●	8.5 - 17.9	7.0 - 8.3	8.1 - 12.0	28 - 600	<1 - 135
167	T. similis (Wierzejski) 1893		●	●	●	●	●		7.2 - 26.0	6.2 - 8.1	6.5 - 11.6	23 - 310	.5 - 220
168	*T. similis grandis (Hauer) 1965					●							
169	*T. similis var. Koste & Shiel, in press					●			29.2	7.5	6.0	85	8
170	T. stylata (Gosse) 1851			●	●	●	●	●	10.0 - 29.0	7.5 - 8.4	8.2 - 10.0	23 - 440	54 - 68
171	T. tenuior (Gosse) 1886					●			8.0 - 11.5	7.0 - 7.3	10.0 - 11.2	135	-
172	T. tigris (Müller) 1786					●	●	●	14.0 - 15.0	7.3 - 7.6	9.6 - 9.8	290 - 325	115 - 120

TABLE 4.1 (cont.):

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (°C)	pH	DO (ppm)	Cond. (μS)	Turb. (NTU)
173	_T. weberi_ (Jennings) 1903					●			10.0 - 20.0	7.2 - 7.3	9.6 - 13.0	65	23.5
174	*_Ascomorphella volvocicola_ (Plate) 1886				●	●			11.0 - 12.4	7.1	8.6 - 10.2	115	2.5
	FAM. GASTROPODIDAE												
175	_Gastropus hyptopus_ (Ehrenberg) 1838					●			14.0	7.0	9.4	75	120
176	_G. minor_ (Rousselet) 1892					●			22.0	7.2	9.2	60	5
177	_G. stylifer_ Imhof, 1891				●	●	●		9.0 - 13.5	7.6 - 7.7	3.3 - 10.9	64 - 75	1.5 - 7.5
178	_Ascomorpha ecaudis_ (Perty) 1850					●		●	15.4 - 22.0	7.0 - 7.8	8.6 - 10.6	50 - 550	6.8 - 40
179	*_A. ovalis_ (Carlin) 1943				●	●	●		13.5 - 14.0	7.0 - 7.6	8.8 - 9.4	75	120
180	*_A. saltans_ Bartsch, 1870				●	●			26.0	7.6	8.0	190	1
	FAM. SYNCHAETIDAE												
181	*_Synchaeta litoralis_ Rousselet, 1902			●		●			10.2 - 20.0	7.2 - 7.4	9.0 - 9.2	154	4
182	*_S. longipes_ Gosse, 1887	●		●	●	●	●	●	8.5 - 27.0	6.2 - 8.5	6.3 - 10.4	27 - 270	.5 - .8
183	*_S. oblonga_ Ehrenberg, 1831			●	●	●	●		9.0 - 14.0	7.1 - 8.5	6.2 - 12.0	38 - 600	32 - 130
184	_S. pectinata_ Ehrenberg, 1832				●	●	●	●	7.0 - 29.0	6.7 - 8.7	3.3 - 10.6	58 - 1000	18 - 23
185	_S. stylata_ Wierzejski, 1893	●	●	●	●	●	●	●	8.0 - 27.0	7.0 - 8.5	7.0 - 11.8	60 - 1100	1.5- 110
186	*_S. tavina_ Hood, 1893				●			●	23.0	8.0	8.3	602	65
187	_S. tremula_ (Müller) 1786			●					10.5 - 16.0	8.1 - 8.4	9.2 - 10.0	355	40
188	*_Polyarthra dolichoptera_ (Idelson) 1925		●	●	●	●	●	●	7.0 - 26.0	6.2 - 8.2	6.5 - 11.0	58 - 440	1 - 120
189	_P. longiremis_ Carlin, 1943						●		17.5	7.0	8.9	31	.45
190	_P. remata_ (Skorikow) 1896					●			21.4	7.2	4.5		
191	_P. vulgaris_ Carlin, 1943	●		●	●	●	●	●	7.2 - 29.0	6.0 - 8.7	1.5 - 12.0	23 - 1100	.5 - 110
	FAM. ASPLANCHNIDAE												
192	*_Asplanchnopus hyalinus_ Harring, 1913	●			●	●			15.0 - 17.0	7.8	9.6 - 9.8	-	-
193	_A. multiceps_ (Schrank) 1793					●			10.0 - 28.0	6.9 - 7.3	7.1 - 13.8	65 - 250	4 - 23.5

TABLE 4.1 (cont.):

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (°C)	pH	DO (ppm)	Cond. (µS)	Turb. (NTU)
194	*Asplanchna brightwelli* Gosse, 1850		●	●	●	●	●	●	8.5 - 26.2	7.0 - 8.7	6.4 - 12.0	55 - 1100	.5 - 130
195	**A. girodi* (De Guerre) 1888				●	●			9.0 - 15.0	7.1 - 7.6	10.0 - 11.4	65	92
196	*A. priodonta* Gosse, 1850	●	●	●	●	●	●	●	9.0 - 29.0	7.4 - 8.2	7.2 - 11.2	46 - 1000	.5 - 80
197	*A. sieboldi* (Leydig) 1854	●	●	●	●	●	●	●	7.0 - 29.0	6.0 - 9.0	1.5 - 11.3	2 - 850	1 - 50
	FAM. DICRANOPHORIDAE												
198	**Dicranophorus aquilus* (Gosse) 1887			●			●		16.0	8.1	9.2	-	-
199	*D. caudatus* (Ehrenberg) 1834				●				23.5	7.9	6.0	750	67
200	**D. epicharis* Harring & Myers, 1928					●			20.0	7.2	9.1	-	-
201	*D. forcipatus* (Müller) 1786				●				12.0	7.5	10.7	46	17.5
202	**D. haueriensis* Wisniewski, 1939			●			●		15.5 - 19.5	7.3 - 7.7	8.5 - 9.8	31 - 361	.45
203	**D. lutkeni* (Bergendal) 1892					●			22.5	7.5	7.8	1080	3
204	**D. uncinatus* (Milne) 1886					●							
205	**Dicranophorus* sp.nov. Shiel & Koste, in prep.			●				●	13.5 - 22.0	8.0 - 8.1	8.4 - 8.8	370 - 420	80 - 90
206	**Aspelta psitta* Harring & Myers, 1928					●			10.2	7.2	9.0	-	-
207	**Encentrum gibbosum* Wulfert, 1936						●		12.0	7.7	10.0	-	-
208	**E. grande* (Western) 1891				●				12.0	7.5	10.7	46	17.5
209	**E. putorius* Wulfert, 1936						●		12.0	7.2	10.4	400	160
	ORDER GNESIOTROCHA FAM. TESTUDINELLIDAE												
210	**Testudinella emarginula* (Stenroos) 1898					●	●		12.0 - 27.0	7.3 - 7.6	7.0 - 9.8	-	-
211	**T. parva* (Ternetz) 1892					●			20.0	7.2	9.1	-	-
212	*T. patina* (Hermann) 1783					●		●	13.5 - 23.5	7.1 - 7.9	1.4 - 13.0	65 - 1500	23.5 - 67
213	**T. tridentata* Smirnov, 1931				●				24.2	7.7	8.6	160	22
214	*Pompholyx complanata* Gosse, 1851	●		●	●	●	●	●	8.5 - 27.0	7.0 - 8.7	6.4 - 12.0	75 - 1950	.5 - 135

TABLE 4.1 (cont.):

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (^{o}C)	pH	DO (ppm)	Cond. (μS)	Turb. (NTU)
215	**P. sulcata* (Hudson) 1885				●	●		●	9.0 - 25.3	7.5 - 8.2	9.4 - 11.3	55 - 1000	.5 - 135
	FAM. FLOSCULARIIDAE												
216	*Beauchampia crucigera* (Dutrochet) 1812				●	●			8.0 - 24.2	7.0 - 7.7	8.5 - 10.8	60 - 95	8 - 25
217	*Limnias ceratophylli* Schrank, 1803			●	●	●		●	8.0 - 23.5	7.0 - 8.1	6.0 - 11.2	85 - 750	8 - 67
218	*L. melicerta* Wiesse, 1848					●			11.0 - 16.5	6.9 - 7.2	1.4 - 10.2	95 - 220	2.5- 12
219	*Floscularia janus* (Hudson) 1881				●				24.2	7.7	8.6	60	22
220	*F. ringens* (Linnaeus) 1758				●	●	●	●	8.0 - 24.2	7.0 - 8.5	8.2 - 11.2	60 - 600	15 - 50
221	*Ptygura brachiata* (Hudson) 1886					●			11.9 - 17.8	7.1	8.5 - 8.9	85	28
222	*P. crystallina* (Ehrenberg) 1834				●	●			8.0 - 20.3	7.0 - 7.4	8.2 - 11.2	135	15
223	**P. furcillata* (Kellicott) 1889				●				23.5	7.9	6.0	750	67
224	**P. melicerta* var. *mucicola* (Kellicott) 1889					●							
225	**P. tacita* Edmonson, 1940					●			19.9	7.1	8.5	85	< 1
226	**P. velata* (Gosse) 1851					●			22.0	7.2	9.2	60	4
227	*Ptygura* sp.				●	●			15.0	7.8	9.6	-	-
228	*Sinantherina semibullata* (Thorpe) 1889				●				24.2	7.7	8.6	60	22
229	*Lacinularia elliptica* Shephard, 1897	●			●	●		●	2.0 - 29.0	7.3 - 8.1	9.0 - 9.6	280 - 700	3 - 22
230	*L. flosculosa* (Müller) 1758				●	●			24.2	7.7	8.6	60	22
231	**L. ismaeloviensis* (Poggenpol) 1872				●	●			12.0 - 27.5	7.6 - 7.8	7.2 - 9.6	60 - 145	2
	FAM. CONOCHILIDAE												
232	*Conochilus dossuarius* (Hudson) 1885	●	●	●	●	●	●	●	8.5 - 27.5	4.9 - 8.7	1.5 - 12.4	125 - 1350	.5 - 275
233	*C. hippocrepis* (Schrank) 1830	●				●	●	●	13.5 - 18.9	7.5 - 8.2	9.7 - 10.2	850 - 1000	10 - 80
234	*C. natans* (Seligo) 1900				●	●	●	●	11.0 - 24.2	7.7 - 8.2	8.4 - 11.2	60 - 1350	22 - 100
235	*C. unicornis* Rousselet, 1892	●			●	●		●	8.5 - 27.0	6.0 - 8.5	1.5 - 11.8	52 - 1250	.5 - 235
	FAM. HEXARTHRIDAE												
236	**Hexarthra intermedia* (Wisniewski) 1929	●		●	●	●		●	10.0 - 29.0	7.1 - 8.4	6.4 - 10.2	270 - 830	37 - 110

TABLE 4.1 (cont.):

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (°C)	pH	DO (ppm)	Cond. (μS)	Turb. (NTU)
237	*Hexarthra mira* (Hudson) 1871	●	●	●	●	●		●	9.0 - 29.0	7.3 - 8.5	6.0 - 10.4	27 - 1950	.5 - 220
	FAM. FILINIIDAE												
238	*Filinia longiseta* (Ehrenberg) 1834	●	●	●	●	●		●	10.0 - 29.0	7.3 - 8.7	7.6 - 10.7	280 - 1950	2 - 125
239	**F. australiensis* Koste, 1980	●		●	●	●		●	8.5 - 29.0	7.0 - 8.5	6.1 - 12.0	52 - 1350	2 - 275
240	**F. longiseta v.passa* (Müller) 1786	●	●	●	●	●	●	●	13.0 - 22.0	7.6 - 8.1	8.5 - 10.2	380 - 700	1 - 12
241	*F. opoliensis* (Zacharias) 1898	●	●	●	●			●	10.5 - 25.0	7.5 - 8.7	6.4 - 10.2	290 - 1980	20 - 130
242	**F. pejleri* Hutchinson, 1964	●		●	●	●		●	8.5 - 25.0	7.0 - 8.4	6.4 - 12.0	300 - 1010	22 - 135
243	**F. pejleri grandis* Koste, 1979	●	●	●	●			●	8.5 - 25.0	7.0 - 8.5	6.4 - 12.0	290 - 1100	10 - 135
244	**F. terminalis* (Plate) 1886				●	●	●	●	8.5 - 25.0	7.0 - 8.7	6.1 - 11.8	52 - 1950	2 - 135
	FAM TROCHOSPHAERIDAE												
245	**Horaella brehmi* Donner, 1949							●	13.0 - 23.0	7.6 - 8.3	8.6 - 10.2	380 - 1000	90 - 120
	FAM. COLLOTHECIDAE												
246	*Collotheca campanulata* (Dobie) 1849					●			11.0	7.1	10.2	115	2.5
247	*C. coronetta* (Cubitt) 1869				●	●			13.5	7.4	10.2	-	-
248	**C. mutabilis* (Hudson) 1885	●		●	●		●	●	14.0 - 27.0	7.5 - 8.3	7.4 - 10.0	60 - 350	.5 - 110
249	*C. ornata* (Ehrenberg) 1832				●	●			24.2	7.7	8.6	60	22
250	**C. pelagica* (Rousselet) 1893			●	●				8.5 - 16.0	7.4 - 8.4	9.8 - 11.0	-	-
251	*Stephanoceros fimbriatus* (Goldfuss) 1820					●			14.0	7.4	10.4	458	-
	FAM. ATROCHIDAE												
252	**Cupelopagis vorax* (Leidy) 1857					●			14.5 - 20.0	7.0 - 7.4	9.4 - 9.6	1500	-

The following taxa were identified after completion of Table 4.1.

All were from Goulburn billabongs. They are not in taxonomic order.

253	*Cephalodella catellina* (O.F.M.,1796)
254	*Dicranophorus robustus* Harring & Myers, 1928
255	*Eosphora* sp. nov.
256	*Euchlanis calpida* Myers, 1930
257	*E. phryne* Myers, 1930
258	*Hexarthra polyodonta* (Hauer, 1957)
259	*Resticula melandocus* (Gosse, 1887)

Of the 252 taxa in 24 families and 60 genera listed, 103 (41 per cent) were recorded only once (cf. 45 per cent of the Rotifera of Europe recorded only once (Berzins, 1967)). 176 taxa (70 per cent) were of restricted distribution, i.e. confined to one or two of the habitats. Of the remaining 76 taxa, 58 (23 per cent) were widely distributed throughout the study area. Thirteen species (5 per cent) occurred only in the River Murray waters and five species (2 per cent) were collected only from Darling waters. Aspects of rotifer taxonomy and distribution, and where relevant a brief discussion of ecological information from Table 4.1, are included in the following resumé of the Murray-Darling Rotifera. Species collected once only are not discussed further. Data on breeding and seasonality are given later in the discussion of species assemblages and communities (Ch,5,6,7) and also in the appendices.

ORDER BDELLOIDA

The bdelloid rotifers are adapted to a benthic or littoral habit in close association with the substrate, occur infrequently in open water (Hyman, 1951; Donner, 1956), and hence were collected rarely during this study. In the absence of narcotization those which were collected usually were contracted and unidentifiable.

All bdelloids identified were of the family Philodinidae and, with the exception of *Rotaria neptunia*, were collected near submerged and emergent macrophytes, particularly in billabongs. *R. neptunia* was the most widely collected of the bdelloids, from a range of habitats. Its appearance in the lower river usually coincided with summer turbidity peaks (Ch.7). The genus is reported elsewhere (e.g. Allen, 1920; Eddy, 1934) as a seasonal component of the potamoplankton.

Bdelloids are not considered further here. The group has remained unstudied in Australia since the 1900's (e.g. Murray, 1911). Bdelloida recorded from Australia are listed in Appendix 1.

ORDER PLOIMA

Ploimate rotifers were collected throughout the basin, except in seasonally anoxic billabongs (Ch.6). Taxa are treated on a family basis.

Fam. Epiphanidae

Four of the five species collected occurred only in billabongs, and are considered littoral species (Koste, 1978). *E. clavulata*, considered by Koste as a semipelagic warm stenotherm, was facultatively planktonic throughout the basin, occurring in clear, neutral waters of low conductivity (e.g. Murray billabongs) and highly turbid alkaline and moderately saline waters of the lower Murray.

Fam. Brachionidae

Brachionids, typical of alkaline waters (Hutchinson, 1967), were the most widespread family, with the greatest number of morphological variants and apparently endemic species. Three genera (*Platyias, Notholca* and *Anuraeopsis*) were represented by only four species from widely separated localities. *Notholca squamula*, a common potamoplankter elsewhere (Whitton, 1975), was not recorded from the major Murray-Darling rivers, but was present in isolated collections from the predominantly internal drainage areas of the Kerang Lakes and Richardson River at Donald, Victoria (see Fig.2.11). Two other genera, *Brachionus* and *Keratella*, with 44 species and subspecies, comprised 18 per cent of all Rotifera collected. Aspects of the taxonomy and ecology of the Australian representatives of these genera are described briefly.

Brachionus: Of the 33 taxa collected, only two (*B. angularis, B. falcatus*) occurred in billabongs, lakes and rivers. *B. angularis* (Fig.4.1a) was collected seasonally in floodplain areas and perennially in the lower river. A single variant, *B. angularis bidens* (Fig.4.1b) was recorded from L. Mulwala. *B. falcatus* (Fig.4.1c,d,e) occurred seasonally (autumn). Soft-water forms of this species (Fig.4.1c) lacked the thickened and ornamented lorica of the lower river (bicarbonate water) forms. *B. budapestinensis* (Fig. 4.1f), three of the four forms of *B. calyciflorus* (Fig. 4.1g,h,i), *B. diversicornis* (Fig. 4.1k), *B. urceolaris rubens* (Fig. 4.1l) and *B. novaezealandia* (Fig.4.1m) probably are more widely distributed than indicated by Table 4.1, a reflection of variation in sampling intensity. All above species are described by Koste (1978) as thermophile or summer forms, widely distributed in tropical and subtropical alkaline waters.

Other taxa of *Brachionus* were more or less restricted in distribution to either the Murray or Darling basin, to a particular type of habitat, or to single localities. *B. bidentata* occurred in L. Boort, a moderately saline lake on the Loddon River floodplain. The typical form (Fig. 4.2a), f. *testudinarius* (Fig. 4.2b) and f. *jirovci* (Fig. 4.2c) co-occurred. Another morph similar to f. *testudinarius* but with an unstructured dorsal lorica and without forked marginal spines (Fig. 4.2d) was recorded from Lake Nillahcootie, Vic.(27.ii.78). The typical form occurred also in the River Murray at Mannum (30.xi.78). A dwarf form of *B. bidentata* (120-156 μm cf. f. typ. 153-578 μm) also was collected from the R. Murray at Mannum (28.xii.77). This was regarded as a genetically distinct population (*B. bidentata minor* Koste & Shiel, 1980)(Fig. 4.2e). Such dwarfing, in response to ionic composition or salinity, has been reported in the rotifers of crater lakes (Green, 1977).

An undescribed variant of *B. calyciflorus* ("Darling form", Fig. 4.1j) was collected from L. Cawndilla (Menindee Lakes), from the Darling River, and from the lower Murray. It was subsequently reported from the Macquarie marshes (F. C. Crome, CSIRO Canberra, pers. comm.) and may be more widespread in the Darling basin. Its exceptional size (≃750 μm), the largest lorica measurement of any *Brachionus* to date, and its unusually transparent lorica distinguish this morph from others of the species.

B. caudatus (Fig. 4.2f), *B. dimidiatus* (Fig. 4.2g), *B. leydigii* (Fig. 4.2h), *B. lyratus* (Fig. 4.2i), *B. patulus* (Fig. 4.2j), *B. plicatilis*

(Fig. 4.2k), three of the four recorded morphs of *B. quadridentatus* (Fig. 4.2l,m,n), *B. urceolaris bennini* (Fig.4.3a) and *B. variabilis* (Fig. 4.3b) were recorded seasonally, generally in small numbers, from billabongs and slow-flowing reaches of the Murray. A bloom of *B. caudatus* f. *austrogenitus* (Fig. 4.3c)(>200 ℓ^{-1}), a pantropical thermophile typical of standing acid waters (Koste, 1978), was recorded from the Murray at Mannum (pH 8.0, 17.xii. 76).

B. lyratus, described by Shephard (1911) from Victoria, but accorded synonymy with *B. angularis* by subsequent authors (Harring, 1913; Ahlstrom, 1940; Koste, 1978), was recorded from the Goulburn floodplain at Thornton, Vic., the first record since that of Shephard. *B. dichotomus* (Fig. 4.3d), also described by Shephard and relegated to synonymy with *B. falcatus* (Voigt, 1956/57; Koste, 1978), was collected from billabongs of the Mitta Mitta and Gwydir Rivers. A dwarf form, *B. dichotomus reductus* (Fig. 4.3e) occurred in billabongs of the Mitta Mitta River. Both the f. typ. and the dwarf were collected from L. Mulwala. *B. dichotomus* is probably widely distributed in Australia; Sudzuki & Timms (1980) report the species from eastern N.S.W., and it occurs in billabongs of the Magela Creek, N.T. (Shiel, unpublished).

B. keikoa (Fig. 4.3f) was collected from the Darling and downstream of the Darling confluence. Isolated occurrences in material from the Macquarie River indicate that this distinctive species probably is widespread in the north of the Murray-Darling basin. It occurred in dense populations in extremely turbid waters (>250 NTU) of small dams near Cunnamulla, Qld.

Records of *Brachionus* outside the study area are given in Appendix 1. Apparently endemic species are *B. dichotomus, B. keikoa* and *B. lyratus* (cf. Pejler, 1978; Koste, 1978).

Keratella: This genus was noted by Hutchinson (1967) as more widespread and from a greater variety of habitats than *Brachionus*. This was also the case in the Murray-Darling basin. Seven of the eleven species of *Keratella* recorded were widely distributed over the basin; *K. australis* (Fig. 4.4a), *K. cochlearis* (Fig. 4.4b), *K. procurva* (Fig. 4.4c), *K. quadrata* (Fig. 4.4d), *K. slacki* (Fig. 4.4e), *K. tropica* (Fig. 4.4f)and *K. valga* (Fig. 4.4g). *K. cochlearis* var. *hispida* (Fig. 4.4h) and *K. lenzi* (Fig. 4.4i) were recorded only once, from the Goulburn River at Molesworth, Vic., and L. Mulwala respectively. *K. shieli* (Fig. 4.4j) occurred seasonally (summer) in the lower Murray, but was not recorded elsewhere; Koste (1979) suggested that this species is endemic to the lower river.

A species of *Keratella* initially identified as *K. serrulata* (Shiel, 1978; Koste, 1979), which was reported from Australia by Russell (1957), was collected from waters in the Darling catchment (pH 7.4-8.7). As this range is not in accord with the published information on the acid water preference of the species (Koste, 1978), collections containing *K.*"serrulata" were re-examined. The taxon was found to be a small variant of *K procurva* (≃150 µm) and sufficiently different in form (Table 4·1) and facettation of the lorica (Fig. 4.4k,l) to be considered a new subspecies (Koste & Shiel 1980c). The two individuals figured show the range of variation seen in different habitats. Although *K. procurva robusta* did not co-occur with the typical form in reservoirs (e.g. Keepit Dam), both were collected seasonally in the plankton of the lower Murray (Ch.7).

K. serrulata, although recorded by Russell (1957) from Qld, was not collected during this study. Russell's record may be valid, but is probably a misidentification of the variant of *K. procurva,* which it resembles.

Marked seasonal variations in spine development were noted for several species. Examples of such cyclomorphic variation from different localities are discussed further in section 4.2.3.

K. australis, K. procurva robusta, K. shieli and *K. slacki* probably are endemic. *K. cochlearis* is cosmopolitan. The other species probably are pantropical or pansubtropical, although records for the Southern Hemisphere are sparse. Previous records of *Keratella* in Australia are given in Appendix 1.

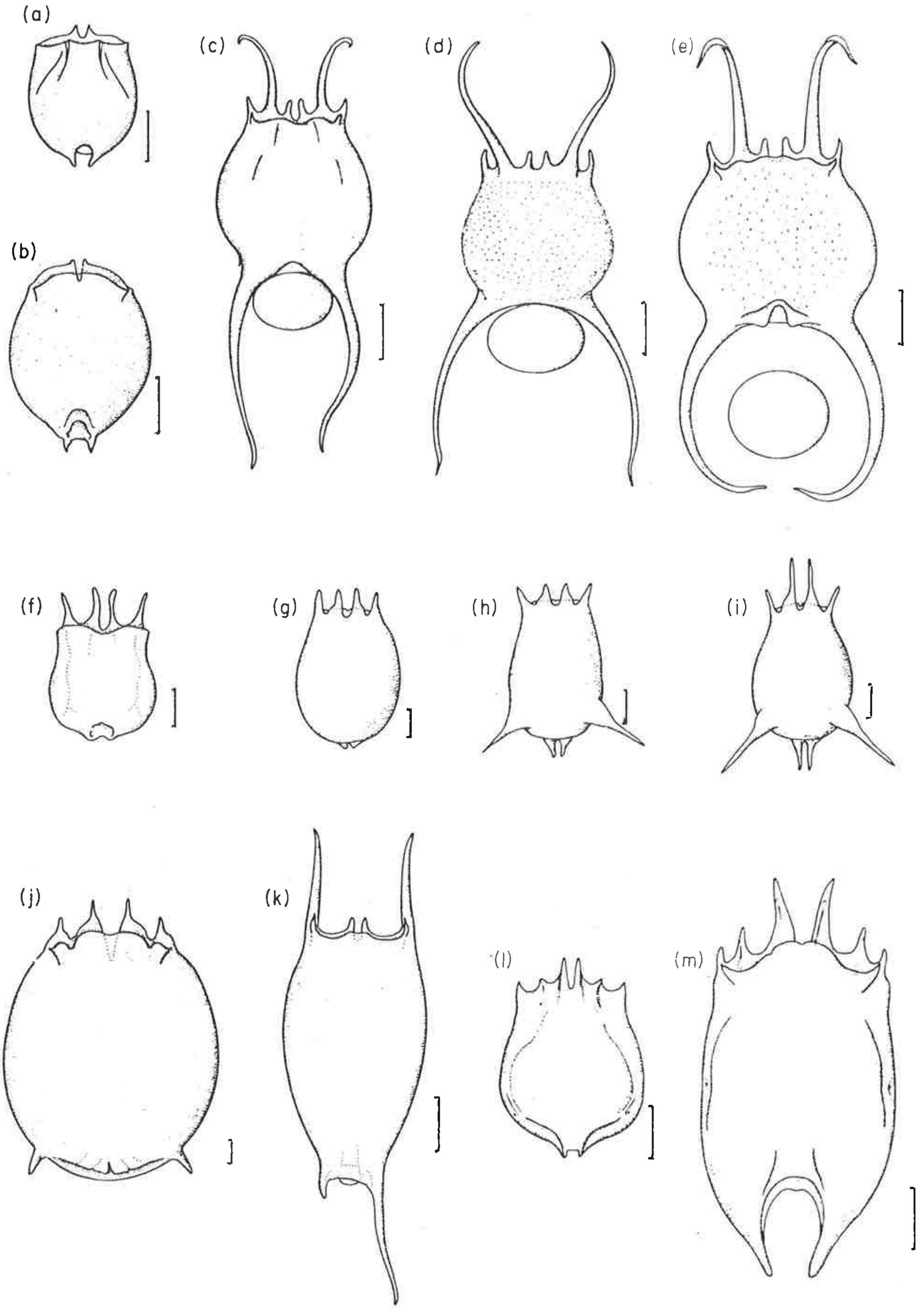


FIG. 4·1 Brachionus spp. from Murray-Darling waters
(a) *B. angularis* (b) *B. angularis bidens* (c) (d) & (e) morphs of *B. falcatus*
(f) *B. budapestinensis* (g) (h) (i) & (j) *B. calyciflorís* ((g) f. typ (h) f. *anuraeiformis* (i) f. *amp*
(j) Darling River form, (k) *B. diversicornis* (l) *B. urceolaris rubens*
(m) *B. novaezealandia* (modified after Koste 1978, 1979; Koste & Shiel 1980)

Scalar = 50 µm

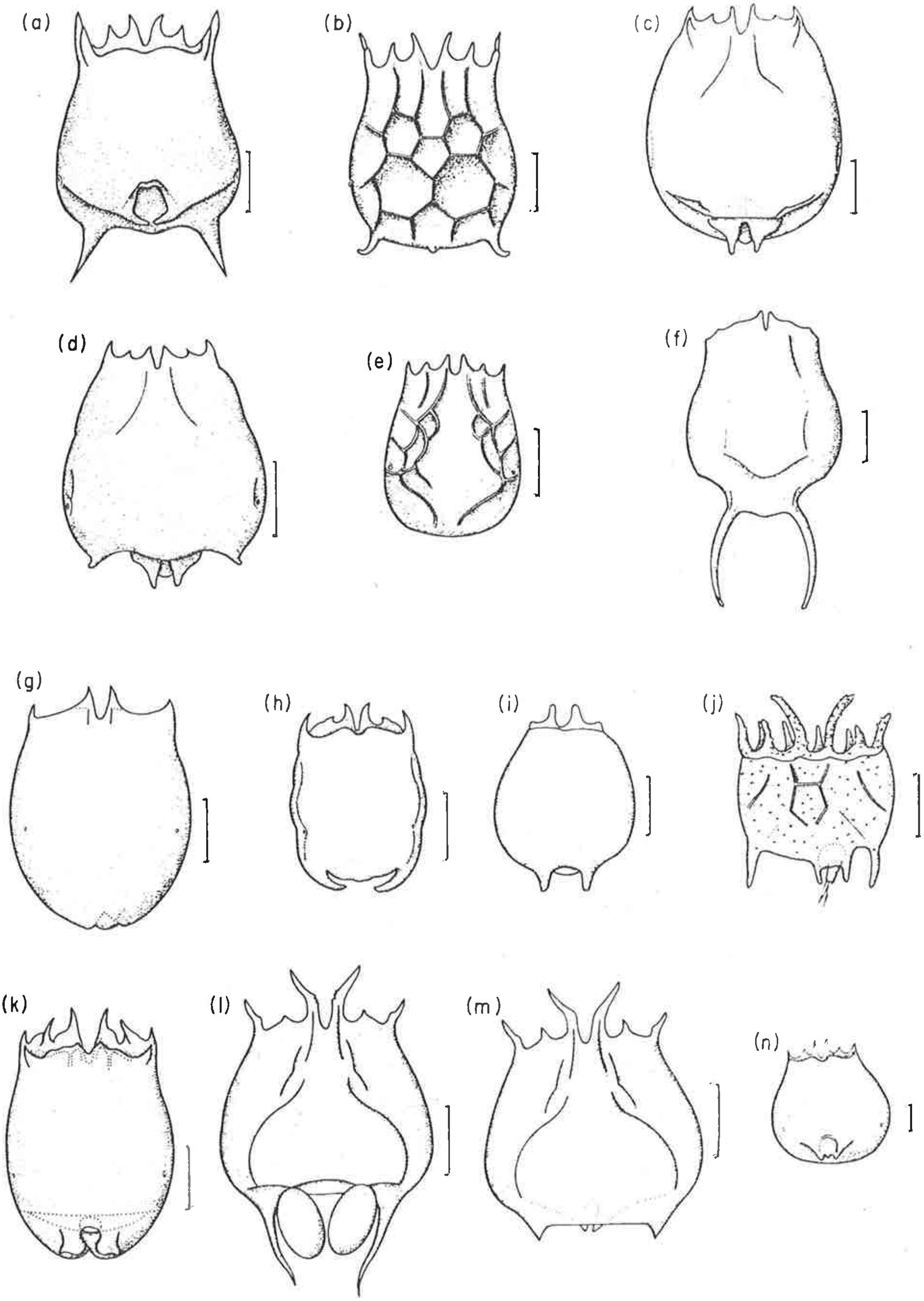


FIG. 4·2 *Brachionus* spp. of restricted distribution.
(a) *B. bidentata* f. typ. (b) f. *testudinarius* (c) f. *jirovci* (d) f. *testudinarius* (L. Nillahcootie) (e) *B. bidentata minor* (Lower Murray) (f) *B. caudatus* (g) *B. dimidiatus* (h) *B. leydigi* (i) *B. lyratus* (j) *B. patulus* (k) *B. plicatilis* (l) *B. quadridentatus melheni* (m) f. *brevispina* (n) f. *cluniorbicularis*

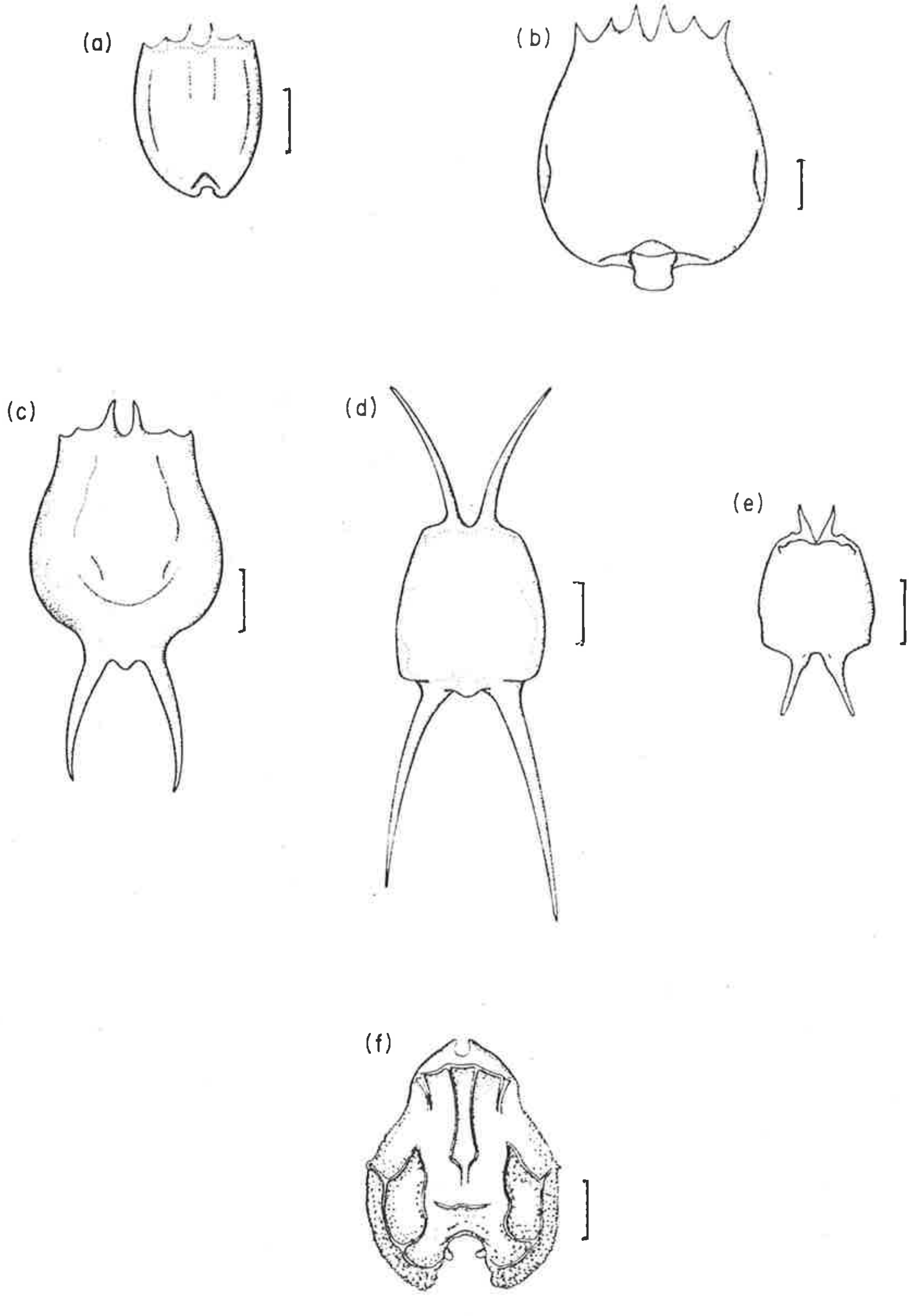


FIG. 4·3 *Brachionus* spp. (continued)
(a) *B. urceolaris bennini* (b) *B. variabilis* (c) *B. caudatus* f *austrogenitus*
(d) *B. dichotomus* (e) *B dichotomus reductus* (f) *B keikoa*

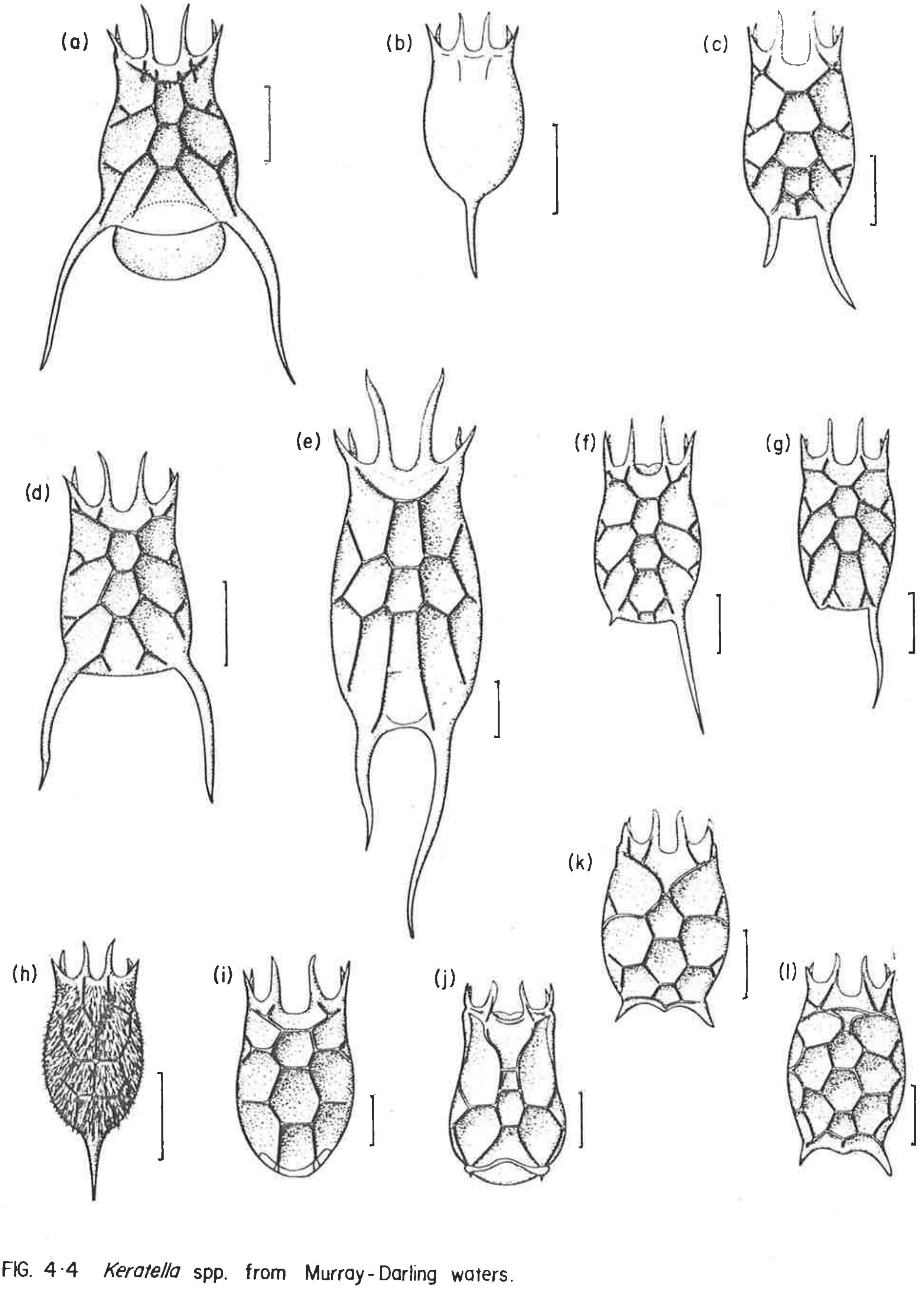


FIG. 4·4 *Keratella* spp. from Murray-Darling waters.
(a) *K. australis*, (b) *K. cochlearis*, (c) *K. procurva*, (d) *K. quadrata*, (e) *K. slacki*
(f) *K. tropica*, (g) *K. valga*, (h) *K. cochlearis f. hispida*, (i) *K. lenzi*,
(j) *K. shieli*, (k) *K. procurva robusta*, (l) *K. procurva robusta*.

Table 4.2 : Comparative morphology of *K. procurva* f. typ. and *K. procurva robusta* (measurements in µm) (Modified after Koste & Shiel, 1980).

	Lorica length	Lorica width	Lorica morphology	Anterior spines	Posterior spines
f. typ.	155 - 220	67 - 80	smooth or weakly granulated	19 - 20 17 - 22 30 - 40	22-24 left 27-64 right
K. procurva robusta	148 - 150	82 - 90	strongly studded	15 - 17 10 - 15 22 - 23	14-15 left 20-23 right

Fam. Euchlanidae

Of the 13 species recorded, *E. dilatata* f. typ. and f. *lucksiana* were widespread. Other species generally were confined to standing waters and billabongs. The euchlanids are predominantly littoral in habit, and are associated with macrophytes in standing and flowing waters. *E. dilatata* f. *lucksiana* is recorded as a pelagic form (Koste, 1978).

Fam. Mytilinidae

Mytilinids, also littoral with rare incursions into the plankton, were collected on occasions from billabongs. Seasonal appearances (summer) also were recorded in the lower Murray.

Fam. Trichotridae

T. tetractis occurred seasonally throughout the study area. Other taxa were confined to billabongs or associated with the Aufwuchs community of lake margins.

Fam. Colurellidae

Predominantly inhabiting impoundments or billabongs, 14 of the 18 colurellids recorded occurred only once, and were evidently seasonal.

Fam. Lecanidiae

The second most abundant group after Brachionidae, the lecanids were represented by 25 species in the Murray-Darling system. Seventeen were from single collections, generally from the sheltered waters of billabongs. Four species were collected regularly from flowing waters: *L. bulla, L. flexilis, L. luna* and *L. lunaris*. Of these, only *L. bulla* occurred during algal blooms. All were seasonal in occurrence.

Fam. Proalidae, Fam. Lindiidae, Fam. Notommatidae

Twenty-three of the 27 species recorded from these three littoral families were collected from billabongs, usually in small numbers. *Proales daphnicola* occurred as an epizoite on the lorica of *B. urceolaris rubens* (cf. Koste, 1978:276). A single species, *Cephalodella gibba*, noted as cosmopolitan, tolerant of a wide range of conditions (Koste, 1978), was widely distributed.

Fam. Trichocercidae

Most of the 23 taxa recorded from this family occurred in billabongs. Only two species were widely distributed (*T. similis, T. stylata*); both were common in the lower Murray, particularly during algal blooms. Also abundant during algal blooms (*Volvox)* in standing waters was the parasitic species *Ascomorphella volvocicola*.

Fam. Gastropodidae

Recorded in isolated collections from standing waters, with a single genus (*Ascomorpha*) accompanying algal blooms in the lower Murray. This genus is reported as planktonic in the littoral of lakes and ponds at the time of *Ceratium* maxima (Ruttner-Kolisko, 1974).

Fam. Synchaetidae

Of the five species of *Synchaeta* occurring widely in the study area, *S. oblonga* was collected only below 14.0^{0}C (cf. De Ridder, 1972). *S. pectinata* occurred only in low turbidity waters. The other species occurred in a broad range of temperature and water quality. All five are noted as cosmopolitan in the pelagic of lakes (Ruttner-Kolisko, 1974). Two additional species, *S. tavina* and *S. tremula* were restricted to isolated collections from the Darling and Murray respectively. *S. tremula* is a cold stenotherm from the littoral (Kutikova, 1972; Ruttner-Kolisko, 1974). *S. tavina* is recorded from brackish water plankton in the Northern Hemisphere (Koste, 1978).

Two species of *Polyarthra* (*P. dolichoptera* and *P. vulgaris*) were widely distributed. *P. vulgaris* is cosmopolitan, eurythermal and tolerant of a wide salinity range. *P. dolichoptera* is a cold stenotherm mainly collected at low O_2 concentrations (Ruttner-Kolisko, 1974). Neither of these conditions was met during this study. *P. longiremis* and *P. remata* were collected only from the littoral of single localities on the Murray floodplain.

Fam. Asplanchnidae

Asplanchnopus species were confined to Murray lakes and billabongs, as was *Asplanchna girodi*. *A. brightwelli*, *A. priodonta* and *A. sieboldi* were widely distributed. On occasions two, and rarely, three species coexisted. A distinct size separation of co-occurring species usually was evident, with *A. priodonta* the smallest (≃400 μm), *A. brightwelli* (≃700 μm) and *A. sieboldi* (≃1600 μm). Ruttner-Kolisko (1974) noted the variability and overlap of all features used to distinguish the various forms of what she called the *girodi-brightwelli* group, however SEM studies, particularly of resting eggs and trophi of *Asplanchna* have shown species-specific morphological differences (Gilbert & Wurdak, 1978; Gilbert, Birky & Wurdak, 1979). In this study, species could usually be distinguished by trophi structure.

Extremely large Reisenforms ("travelling forms") of *A. sieboldi* were collected on occasions from the turbid waters of the Darling, and were the largest zooplankters present (2,000-2,500 μm).

Fam. Dicranophoridae

This family, benthic in habit, was represented by 12 species, usually from single and widely separated localities.

ORDER GNESIOTROCHA

Fam. Testudinellidae

All four species of *Testudinella* were of isolated seasonal occurrence. *Pompholyx sulcata* occurred only in the Murray; *P. complanata* perennially across the study area.

Fam. Flosculariidae

Members of the six genera of Flosculariidae collected were generally confined to standing waters of the Murray system. Rare seasonal occurrences (summer) of *Limnias ceratophylli*, *Floscularia ringens* and *Lacinularia elliptica* were recorded from flowing waters, particularly the lower Murray.

Fam. Conochilidae

C. dossuarius was distributed throughout the basin, although it was replaced in Murray billabongs by *C. unicornis*. *C. hippocrepis* and *C. natans* were collected only from the Murray catchment. All four species occurred seasonally in a broad range of conditions in the lower Murray.

Fam. Hexarthridae

Both known species of *Hexarthra* occurred throughout the system, and were occasionally collected together from the lower river. Although not present in faster-flowing upstream reaches, both species were present in billabongs of the Murray and Goulburn Rivers.

Fam. Filiniidae

Recorded as common components of the limno- and potamoplankton elsewhere (Hutchinson, 1967; Winner , 1975), the genus *Filinia* was represented by at least seven taxa in the study area. *F. longiseta* and a large form resembling f. *limnetica* occurred most widely. The latter was found to be a new species on the basis of trophi structure (28 pairs of uncus teeth ≃ 19 µm long vs. *limnetica*'s 22 pairs 32 µm long)(Koste, 1980 c).*F. longiseta* and *F. australiensis* are shown in Fig. 4.5a,b. The short-spined f. *passa* (Fig. 4.5c) occurred in standing waters, and seasonally in slow-flowing rivers, across the basin, as did the pantropical *F. pejleri* (Fig. 4.5d). A large, typically spindle shaped species (cf. Hutchinson, 1964) was identified as a new subspecies of *F. pejleri* (Koste, 1979)(Fig. 4.5e). *F. pejleri grandis* was collected only from Darling waters, as was the pantropical *F. opoliensis* (Fig. 4.5f). *F. australiensis* and *F. pejleri grandis* were characterised by the exceptional length of bristles.

A species resembling the cold stenotherm *F. terminalis* (Fig. 4.5g) was commonly recorded from the Murray catchment, although at temperatures up to 25 °C (cf. Ruttner-Kolisko, 1974). Comparative measurements of body length and depth and bristle lengths were made (Table 4.3). In general morphology this taxon resembles *F. terminalis*, but is distinguished from it, and also

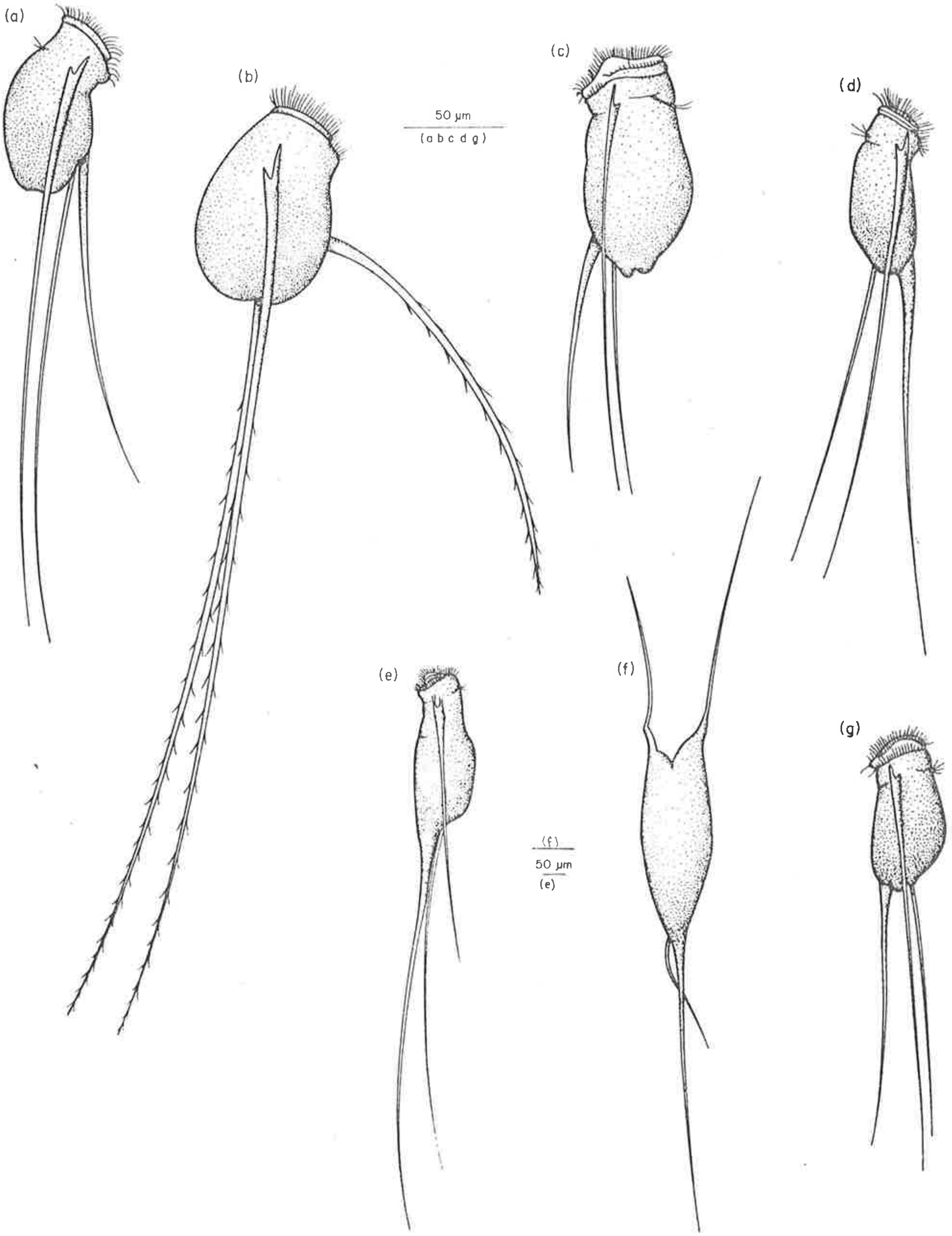


FIG. 4·5 Species of *Filinia* from Murray - Darling waters
(a) *F. longiseta*; (b) *F. australiensis*; (c) *F. longiseta* var *passa*; (d) *F. pejleri*; (e) *F. pejleri grandis*; (f) *F. opoliensis*; (g) *F. terminalis*

Table 4.3: Comparative measurements of *Filinia terminalis* and an unidentified species (measurements in µm).

F. terminalis Locality	n	Body length	Body depth	length/depth	Right bristle	Left bristle	Caudal bristle
Ryan's billabong	5	144	64	2.25	364	352	305
R. Murray, Mannum	16	146	68	2.10	369	358	268
R. Murray, Mildura	14	113	56	2.01	212	296	222
Lake Mulwala	7	119	57	2.23	315	305	251
Darling R.Bourke	5	98	45	2.18	353	321	201
Sheepwash Lagoon	6	123	59	2.10	385	342	299
Filinia sp.							
Wise's billabong	15	187	83	2.24	433	416	336
R. Murray, Mannum	22	179	81	2.20	395	389	320

Table 4.4 Comparative measurements of seven taxa of *Filinia* from Murray-Darling waters (measurements in µm).

Species	n	Body length	Body depth	length/depth	Right bristle	Left Bristle	Caudal bristle
F. australiensis	37	197	144	1.40	763	758	394
F. longiseta	65	154	119	1.30	690	668	364
F. longiseta passa	12	189	109	1.72	457	421	299
F pejleri	41	207	71	3.00	415	346	281
F. pejleri grandis	25	286	87	3.20	723	617	641
F. terminalis	53	124	58	2.15	350	329	253
Filinia sp.	25	183	82	2.22	414	402	328

from *F. pejleri* by the insertion of the caudal bristle and by the gibbous, ventrally flattened body shape. It is possibly a morph of *F. longiseta*, such as described from Darling waters by Koste (1980*c*). Comparative measurements are given in Table 4.4 and are discussed in section 4.2.3. Clearly, further taxonomic work on this genus in Australian waters is necessary.

Fam. Trochosphaeridae, Fam. Collothecidae,
Fam. Atrochidae

Of the eight species in four genera representing these families, only a single species, *Collotheca mutabilis*, was collected widely from lakes and rivers of the system. *C. pelagica* occurred in Murray waters. Neither pelagic form was recorded from billabongs, but three other species occurred in isolated collections from standing waters.

4.2.3 DISCUSSION

Discussion here is concerned with taxonomic/morphological features of individual genera, with comments on factors controlling their distribution. In this regard, comments are restricted to a consideration of polymorphism, the influence of abiotic and biotic factors, lotic adaptations and endemicity. Quantitative data on seasonality, species associations and community structure are given later.

With few exceptions, representatives of the 56 genera of ploimate rotifers recorded were collected from habitats in accord with their autecological preferences noted elsewhere (cf. Ahlstrom, 1940,1943; Hutchinson, 1957; Green, 1960, 1967; Pejler, 1974; Ruttner-Kolisko, 1974; Koste, 1978). Broad habitat preferences of the 40 genera collected more than once, or from other than single localities, are summarised in Table 4.5.

There is a notable preponderance of cosmopolitan eurytopic species, i.e. tolerant of wide ranges in water temperature, salinity, alkalinity and pH, with warm-water species dominating. A similar trend is seen in the endemic species, with eurytopic forms (*B. keikoa, K. australis, K. procurva robusta, K. shieli* and *K. slacki*), and stenotopic warm-water species (e.g.

Table 4.5: Habitat preferences and autecological information on predominant rotifer genera from Murray-Darling waters as recorded elsewhere (from various sources). Codes: C=cosmopolitan; PT=Pantropical or pansubtropical; E^t=eurythermal; WS^t= warm stenotherm; CS^t= cold stenotherm; T= thermophile; E^h=euryhaline; E^p=pH tolerant; B= brackish water forms. Note that codes refer only to local species of each genus.

Genus	Comments	Habitat type		
		Benthic	Littoral	Pelagic
Epiphanes	ws^t		*	*E. clavulata*
Platyias	C, E^h		*	
Brachionus	C, T, B(alkaline)		*	*
Keratella	C, ws^t			*
Anuraeopsis	ws^t			*
Euchlanis	C		*	*E. dilatata*
Mytilina	B, eutrophic	*	*	
Lophocharis	fresh- B	*		
Trichotria	E^t,E^h,E^p		*	
Macrochaetus	T		*	
Colurella	C, E^h, E^t	*		
Squatinella			*	
Lepadella	C, E^t, E^h, E^p	*	*	
Lecane	E^t, E^h, E^p	*	*	
Proales	C, some parasitic	*	*	
Lindia	eutrophic		*	
Scaridium	C, ws^t, E^p		*	
Monommata	C, E^p	*	*	
Notommata	C		*	
Cephalodella	C, PT, alkaline	*		
Trichocerca	C		*	*
Gastropus	summer		*	*
Ascomorpha	C		*	*
Synchaeta	C, E^t, E^h, E^p			*
Polyarthra	C, E^t, E^h, E^p			*
Asplanchnopus	C, ws^t			*
Asplanchna	C, ws^t			*
Dicranophorus	C		*	
Encentrum	cs^t		*	
Testudinella	E^t,E^h, E^p, C	*	*	*
Pompholyx	E^t, E^h, E^p			*
Limnias	C, sessile		*	
Floscularia	C, sessile		*	
Ptygura	C, T, E^h		*	
Lacinularia	C, colonial			*
Conochilus	C. colonial, T			*
Hexarthra	C, E^h,B			*
Filinia	T,ws^t(most), PT			*
Horaella	Sthn hemisphere ?ws^t			*
Collotheca	PT		*	*C. mutabilis*

B. dichotomus, B. lyratus).

Sixty per cent of the genera listed in Table 4.5 are considered elsewhere as inhabitants of shallow astatic or permanent ponds and lakes, or littoral zones of the latter, and occur infrequently as pseudoplankters in open water. In this study, several of these genera (e.g. *Euchlanis, Colurella, Lepadella*) occurred frequently in open waters of deep reservoirs, and in rivers, apparently in response to algal blooms. These facultative plankters are not considered further here; where possible, pelagic species, particularly endemics, are given as examples in consideration of rotifer morphology from this study. Brief comparisons are drawn from studies elsewhere.

POLYMORPHISM

Spatial differences in morphology within a species, i.e. polymorphism, and the seasonal or cyclic expression of such differences, i.e. cyclomorphism, are not differentiated in this study. Assuming that phenotype is the expression of the genotype in interaction with environmental determinants, both expressions refer to the same phenomenon, with a temporal component implicit in the latter (cf. Hutchinson, 1967; Sheppard, 1967).

Morphological variability within rotifer species was noted by early authors (e.g. Lauterborn, 1898; Wesenberg-Lund, 1900) and later studied in detail by taxonomists and ecologists (e.g. Ahlstrom, 1940; Carlin, 1943). Spatially separated populations, or those from the same locality but temporally separated, showed cyclic variations in, for example, lorica morphology, spine development, body length and overall size. This undoubtedly contributed to the ensuing taxonomic confusion, with morphs of a single species named as "form", variety, subspecies or given specific status (cf. Kutikova, 1972). Early studies on cyclomorphosis are reviewed by Hutchinson (1967), and recent studies (e.g. Gilbert, 1967, 1977, 1978; Pourriot, 1974) have elucidated some of the stimuli for and adaptive significance of such polymorphism.

Asplanchna, Brachionus and *Keratella* are the most intensively studied polymorphic genera. Cyclomorphic phenomena observed in successive generations include:

- decrease in size with increasing temperature;
- di- and trimorphic populations;
- changes in lorica lengths, spine lengths and facettation of the dorsal lorica (*Brachionus, Keratella*) in response to temperature-related allometric growth or turbidity;
- spine development in *Brachionus* in response to secretions by its predator, *Asplanchna;*
- the production of spined individuals from resting eggs of unspined specimens and vice versa - a response of genetically diverse populations to indeterminate environmental factors (Hutchinson, 1967).

While cyclomorphic changes in direct response to single environmental characteristics such as water temperature or pH are not always clear-cut (cf. Halbach, 1970), and while the degree and combination of factors may be important in determining form (Ruttner-Kolisko, 1974), recent studies have shown some direct relationships to biotic influences. Thus, body size may be controlled by diet (Pourriot, 1965; Gilbert, 1975), particularly the presence of tocopherol (vitamin E) and prey type (Gilbert, 1977). Several studies report spine induction in *Brachionus* by *Asplanchna* (Gilbert, 1967; Halbach, 1970; Green & Lan, 1974). The induction of a giant morphotype, an adaptive response to larger prey, also is reported (Hurlburt *et al.* 1972; Gilbert, 1973; Pourriot, 1977). Other studies are given in King (1977). Apart from the *Brachionus-Asplanchna* pair, there is little information on other predator-prey relationships. Green (1980) suggests that *Keratella tropica* may exhibit similar adaptive spine elongation in the presence of predatory diaptomid copepods.

Polymorphic forms were recorded in several genera of Murray-Darling Rotifera, notably *Brachionus, Keratella, Asplanchna* and *Filinia*, exemplifying the morphological variability which led to the profusion of synonyms in the early literature. As well as morphs of polytypic species documented elsewhere (see Table 4.1),local variants were recorded. These are described below.

Three recognized forms of *B. bidentata* (f. typica, f. *testudinarius* and f. *jirovci*) from L. Boort and a fourth from L. Nillahcootie are morphs of a little studied variable species restricted to alkaline waters (7.9-8.2). The dwarf form from the R. Murray (*B. bidentata minor*) may be a response to high salinity, high temperature or low food supply, all of which prevail in the Murray in summer, and all of which may be implicated in rotifer dwarfing (Green, 1977). Salinity is implicated in this case. The dwarf form was recorded only once (28.xii.77); in the following summer (30.xi.78) the typical form occurred in waters of similar temperature, pH, DO and turbidity, but markedly lower conductivity (370 vs. 1,000 μS).

Morphs of *B. calyciflorus* commonly collected included both spined and spineless individuals. The giant morph recorded from turbid waters of the Darling R. shows a possible alternative strategy to spine production in the presence of the predator, i.e. increased body size, precluding handling by the trophi of the latter. The unusually transparent lorica of the giant form also is distinctive. While increased size is a useful foil to tactile predation, e.g. by *Asplanchna*, extreme transparency is not. This may be a response to visual predation (cf. O'Brien, Kettle & Riessen, 1979).

Little is known of planktivory in Australian waters. Zooplankton communities differ from those elsewhere; some common predators (*Leptodora*, *Mesocyclops edax*) do not occur in Australia, *Diaptomus* is absent from Murray-Darling waters and predatory cyclopoids are rare in lotic habitats of the system. Notably, the largest zooplankton predator in most samples during this study was *Asplanchna*, and the largest forms, campanulate *A. sieboldi* (≃2500 μm) (cf. Gilbert, 1973, 1976) were from turbid Darling waters, cohabitant with the giant *Brachionus*. Size-induction in both predator and prey is suggested. Evidence for the handling of larger prey is provided by trophi measurements for the large *Asplanchna* (220-340 µm cf. 80-90 µm for the species elsewhere).

Other species of *Brachionus* in which variations in lorica/spine morphology were noted include the endemic *B. dichotomus*, with a dwarf summer-autumn billabong form (Koste & Shiel, 1980a), *B. falcatus* and *B keikoa*, both with heavily ornamented loricas in turbid, higher salinity waters of the lower Murray, and *B. quadridentatus*, with variable posterior spine development.

Because of the marked seasonality, or isolated occurrence in low numbers, of the polytypic *Brachionus* species, variation was not analysed. The more abundant species of *Keratella*, some of which were perennial in all habitats, were more amenable to measurement and analysis, particularly the endemics *K. australis* and *K. slacki*, and the pantropical *K. procurva*. These species, and to a lesser extent *K. cochlearis* and *K. tropica*, showed seasonal variations in lorica and spine length. *K. quadrata, K. shieli* and *K. valga* were of sporadic occurrence; only a few specimens were measured for comparative purposes. *K. lenzi* was collected only once, from L. Mulwala, and is not discussed further.

Individuals for measurement were drawn from collections from widely separated areas of the basin, both temporally separated samples from the same locality, and geographically separated localities on the same sampling date. For each species present, lorica and spine measurements were taken as shown in Fig. 4.6 (n=10-60). Table 4.6 shows frequency of occurrence of each of the eight species in 317 samples which contained *Keratella*, representative measurements of mean lorica and spine lengths, standard deviation and coefficient of variation. Size variation in the five common species is shown in Fig. 4.7. Seasonal variation is discussed in more detail later.

Least variability is seen in the endemic *K. shieli*; however, this species is of infrequent occurrence, and is represented by few specimens.

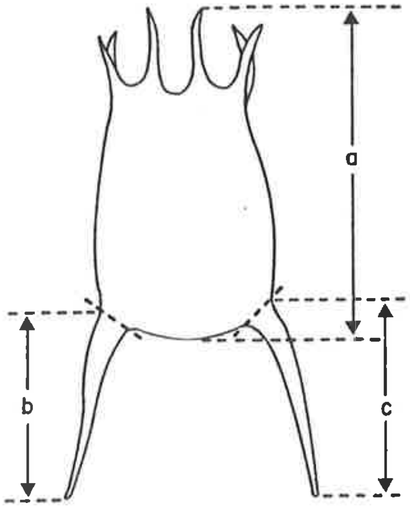


FIG. 4·6 Measurements of *Keratella* species :

a. lorica length from caudal rim to anterior spines

b. left spine from lorica margin to tip (LS)

c.. right spine as above (RS)

Species	Occurrence (per cent)	n	Lorica µm	s	CV	Left spine	s	CV	Right spine	s	CV
K. australis	55	73	182.6	14.3	7.8	116.0	17.9	15.4	117.0	21.7	18.5
K. cochlearis	41	58	119.9	7.4	6.7	48.7	7.8	16.0	-	-	-
K. procurva	41	100	155.4	13.3	8.6	21.4	10.4	48.6	47.8	16.2	33.9
K. quadrata	4	21	154.0	10.7	6.9	88.2	13.4	15.2	94.3	14.1	15.0
K. shieli	9	43	164.5	7.7	4.7	-	-	-	-	-	-
K. slacki	22	184	233.2	27.5	11.8	68.5	16.5	24.0	134.0	32.5	24.3
K. tropica	42	87	143.6	10.8	7.5	37.7	21.0	55.7	103.6	15.5	15.0
K. valga	3	18	121.6	9.5	7.8	2.4	5.6	233.3	55.0	9.8	17.8

Table 4.6: Frequency of occurrence and representative measurements of eight species of *Keratella* from Murray-Darling waters. n=specimens measured, s=standard deviation, CV=coefficient of variation (per cent). Note that *K. cochlearis*' single caudal spine is tabulated as left spine, and *K. shieli* does not have caudal spines (see Fig. 4.8).

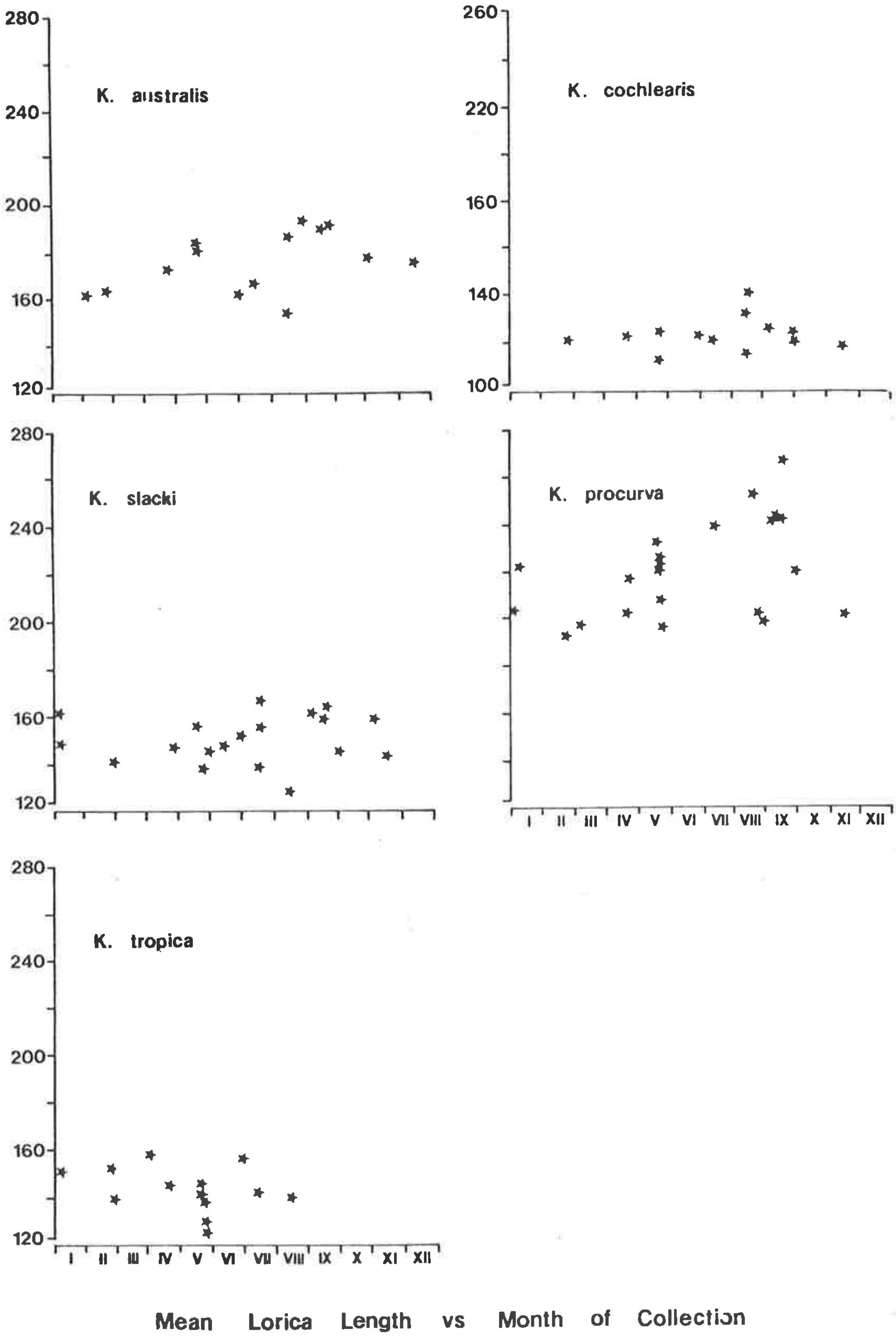


Fig. 4.7 Seasonal variation in lorica length in five widely distributed species of *Keratella*.

Notably, all specimens lacked posterior spines. In the type description "short, very sharp caudal spines seated on a button- to cone-shaped base" are noted (Koste, 1979:247). Fig. 4.8 shows the interfacet sutures between the trapezoid posteromedian facet or panel and each posterior lateral panel are sufficiently raised to give the impression of spines.
Despite the infrequent occurrence of this species in the lower Murray, it shows wide tolerance of water quality, with marked spring-summer seasonality (i.e. is a warm stenotherm). Occasional winter collections of ovigerous ♀♀ suggests it may be distributed in the tropical north of the basin and is transported by Darling flows; however *K.shieli* was not collected elsewhere.

Of the five common species, the cosmopolitan plankter *K. cochlearis*, perhaps the most common and widely distributed of the Rotifera (Ahlstrom, 1943), is least variable in the study area with respect to lorica and spine length, although a greater degree of variation in lorica morphology was noted. Forms with rudimentary foundation patterns (Fig. 4.4b) were collected from the lower Murray, and extremely granulated *hispida* forms (Fig. 4.4h) occurred in the Goulburn River. The latter are regarded as typical of shallow turbulent waters; the strong, granulated and/or spinulated lorica reduces bouyancy (Ruttner-Kolisko, 1974).

K. australis, K. quadrata and *K. slacki* are forms which have consistently two posterior spines of similar variability (Table 4.6). *K. procurva, K. tropica* and *K. valga* show variability in both spines, but considerably more for the left, which is sometimes even absent. *K. valga* was of rare occurrence, and was collected in insufficient numbers for further discussion.

Polymorphism in *K. tropica* is well known (e.g. Ahlstrom, 1943; Green, 1960, 1980), and also in *K. quadrata* (e.g. Hutchinson, 1967). In Green's study of *K. tropica* in the Sokoto River, Nigeria, right spine and lorica length were positively correlated, but the left spine showed no consistent

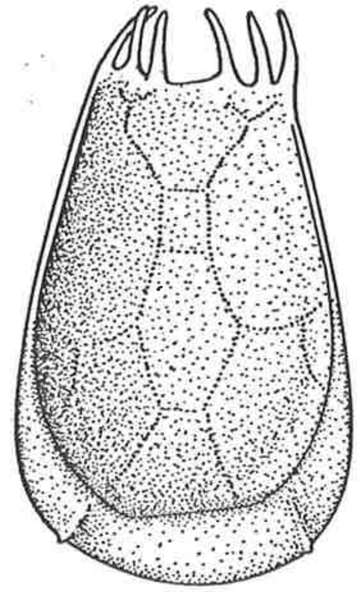


FIG. 4·8 *Keratella shieli* : ventral, showing caudal interfacet ridges.

correlation. No correlations with environmental variables could be determined.

Little is known of variability in *K. procurva.* Apart from the typical form described by Thorpe (1891), the only evidence of variation in this species is in the Parana River, Argentina, where there is a series showing reduction of the left spine (Paggi, 1973). Similarly, little is known of variability in the endemics *K. slacki* and *K. australis* (cf. Koste & Shiel, 1980c). The former showed greatest variation in lorica morphology, and is given here as an example of cyclomorphic variation. Brief comparisons are made with *K. australis* and *K. procurva* populations.

In Fig. 4.10 lorica length is plotted against mean spine length for 25 *K. slacki* populations from widely separated collections. Spearman's rank correlation coefficient $r_s = 1 - \frac{6 \Sigma d^2}{n(n^2 - 1)}$ (Elliott, 1971) was used to determine significance of both spine lengths against lorica length, with the null hypothesis (H_o) that the two variables are independent. r_s in both cases was tested by the F-test ($F = \frac{(n-2) r_s^2}{1 - r_s^2}$) (Sokal & Rohlf, 1973). H_o was rejected (P<.05) (Table 5A, Yamane, 1967); left and right spines show positive correlation with lorica length; i.e. allometric growth is involved (cf. Pejler, 1962).

The mean lorica length rankings were then correlated with ranked temperature, DO, pH, conductivity and turbidity data by Spearman's coefficient and F-test. H_o was accepted for temperature, DO, pH and turbidity, but rejected (P<.05) for conductivity. *K. slacki* occurs as significantly smaller individuals in summer collections from habitats with higher salinity than at other times of the year. The species, although collected from all habitat types (Table 4.1) is characteristically a "billabong form", particularly of the Murray floodplain above the Goulburn confluence, where it is a perennial breeder. Its life cycle is an effective adaptive strategy for the variable habitat conditions of billabongs (Ch. 6).

Within any single habitat, *K. slacki* varies as shown in Fig. 4.11,

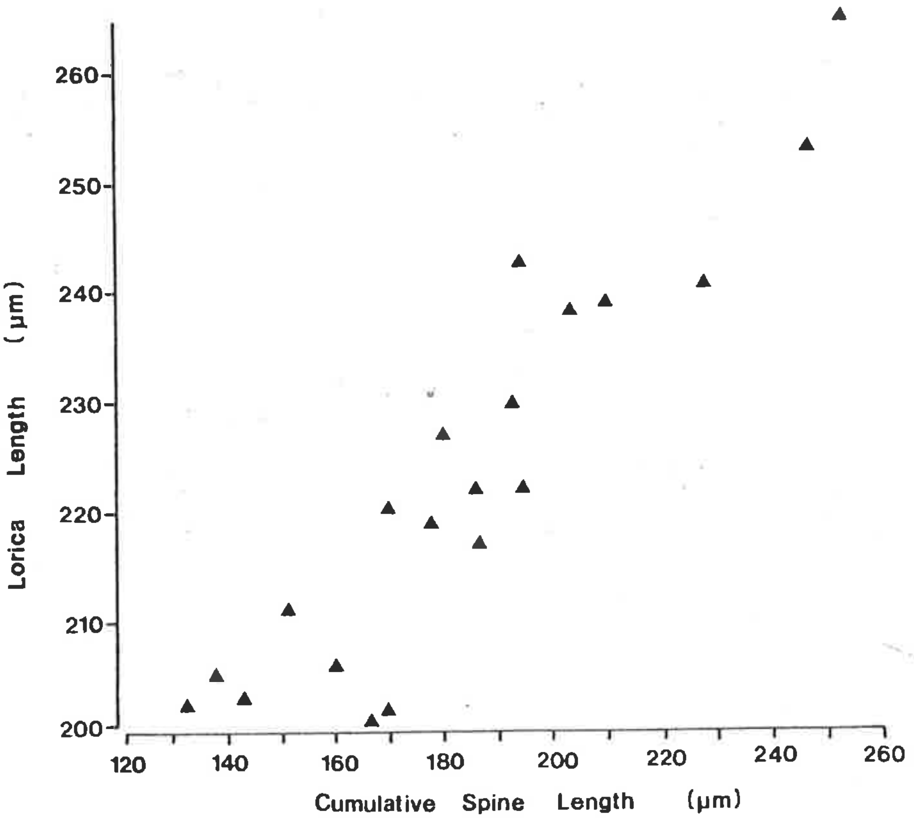


FIG. 4·10 Spine length vs. lorica length for 25 widely separated *K. slacki* populations although a temporal shift may occur with latitude (i.e. depending on climatic conditions). Comparison by t-test of the lorica data for each pair of localities in which the species was collected indicates that significant differences may exist between populations in close geographical proximity, and that a lag in the developmental cycle occurs in the north of the basin, where the dwarf "summer" form persists until May, and probably into winter, depending on the timing of seasonal rainfall and filling of the billabongs.

In spring populations, distinct size classes appeared in some billabongs (Fig. 4.11d). Both amictic (parthenogenetic) and mictic (sexually reproducing) individuals were present, the latter significantly larger in lorica and spine measurements. Fig. 4.12a shows an amictic summer dwarf, and Fig. 4.12b an amictic individual from the same habitat (a billabong at Wodonga, Vic.) the following spring. The posterior lorica of the mictic individual (Fig. 4.12c), also in spring, carries three smaller (n) resting eggs. Lorica length data for this population are plotted as a scatter diagram (Fig. 4.13).

The significance of mictic egg production in spring during high water levels and adundant food production is clear when the life cycle of a ploimate rotifer is considered. Resting eggs produced from mictic eggs are resistant to adverse conditions. In the northern hemisphere many species overwinter in the resting egg stage (Pennak, 1978). Under drought conditions, on the other hand, such a resting egg would survive desiccation of the habitat until the following wet season.

Intraspecific temporal variation as seen in *K. slacki* is reported elsewhere for *Keratella* (Ahlstrom, 1943; Carlin, 1943), *Brachionus* (Gilbert, 1963), *Trichocerca* (Pourriot, 1965), *Notommata* (Clement & Pourriot, 1976) and *Asplanchna* (Birky, 1969; Gilbert, 1975). A succession of genetically distinct clones, i.e. temporal genetic polymorphism, is described in *Euchlanis dilatata* (King, 1972). King suggests that a large genetic

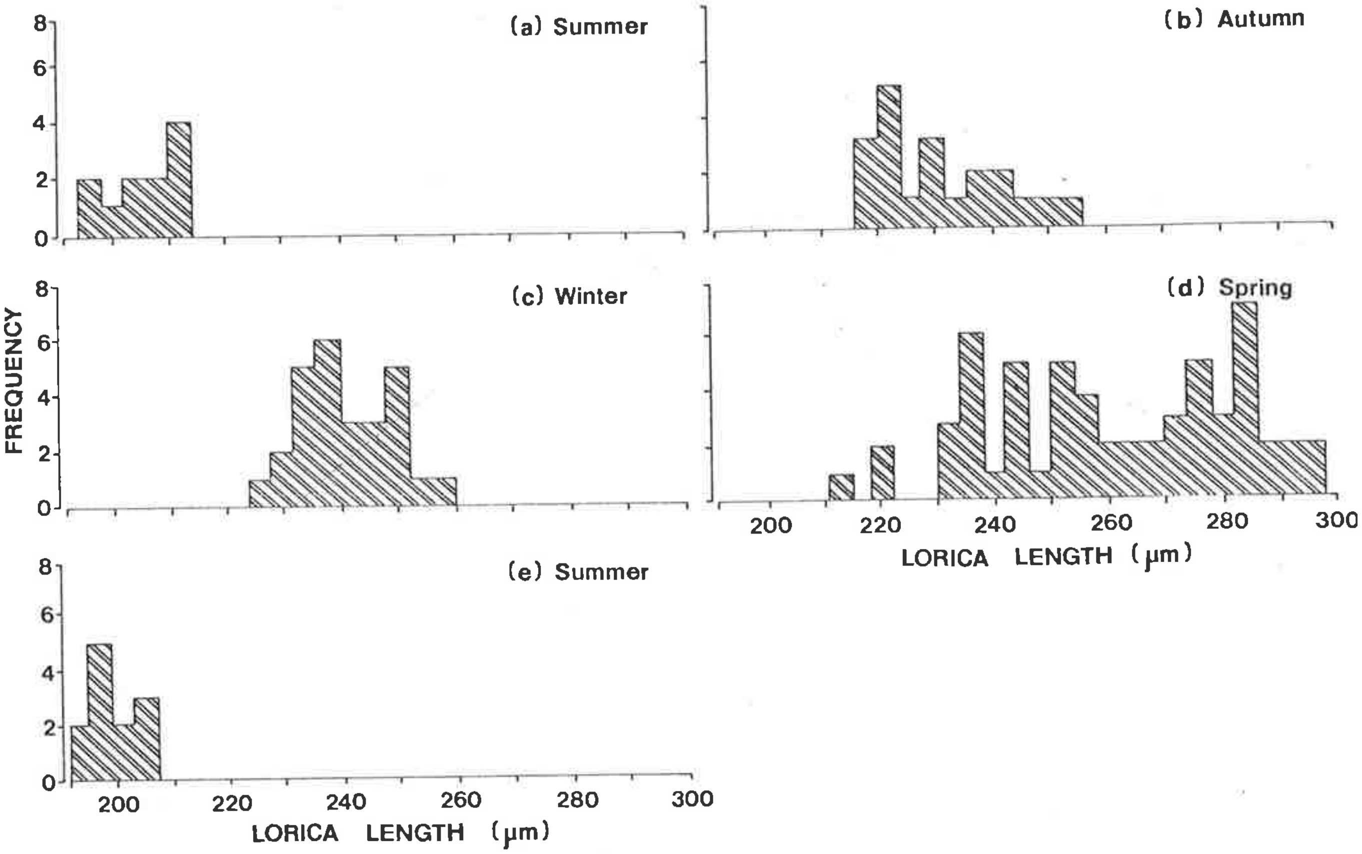


Fig. 4.11 Seasonal variation of lorica length in *K. slacki* (Snowdon's billabong, Wodonga).

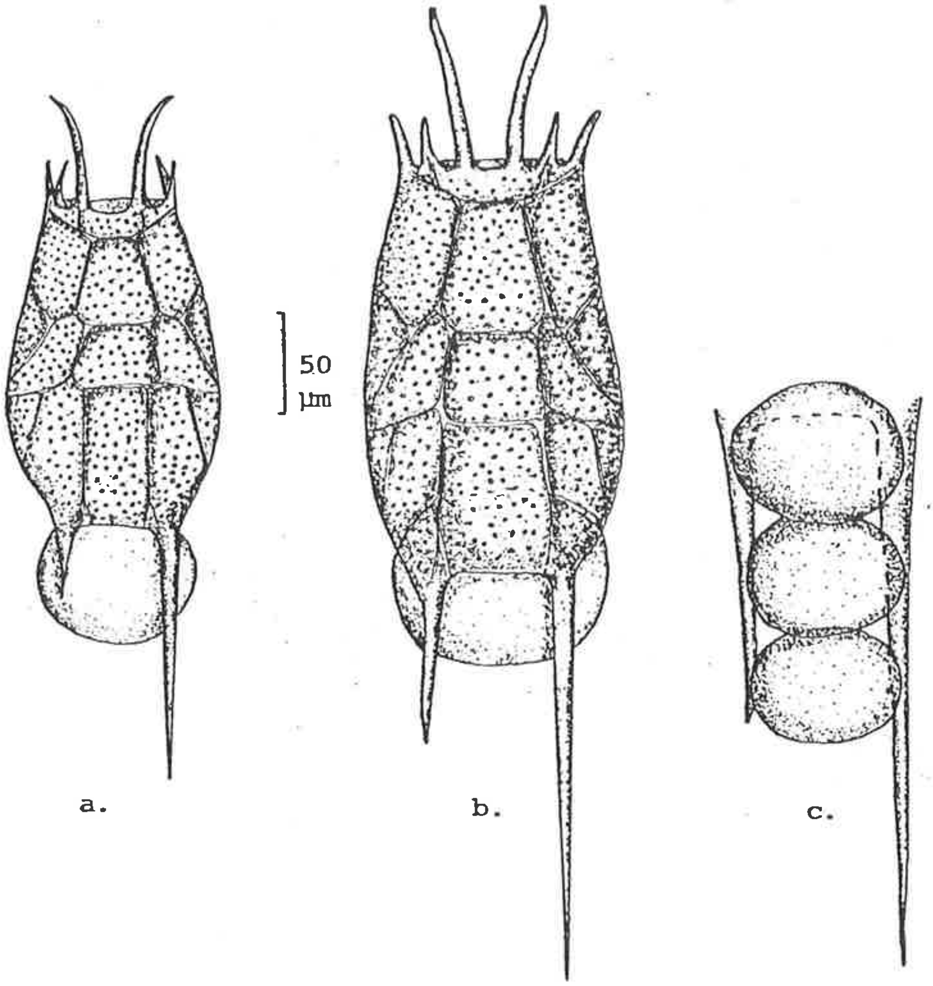


Fig. 4.12: Temporal variation in *K. slacki* (Snowdon's billabong, Wodonga, Vic.), a. summer "dwarf", amictic individual, b. spring form, c. mictic individual, spring.

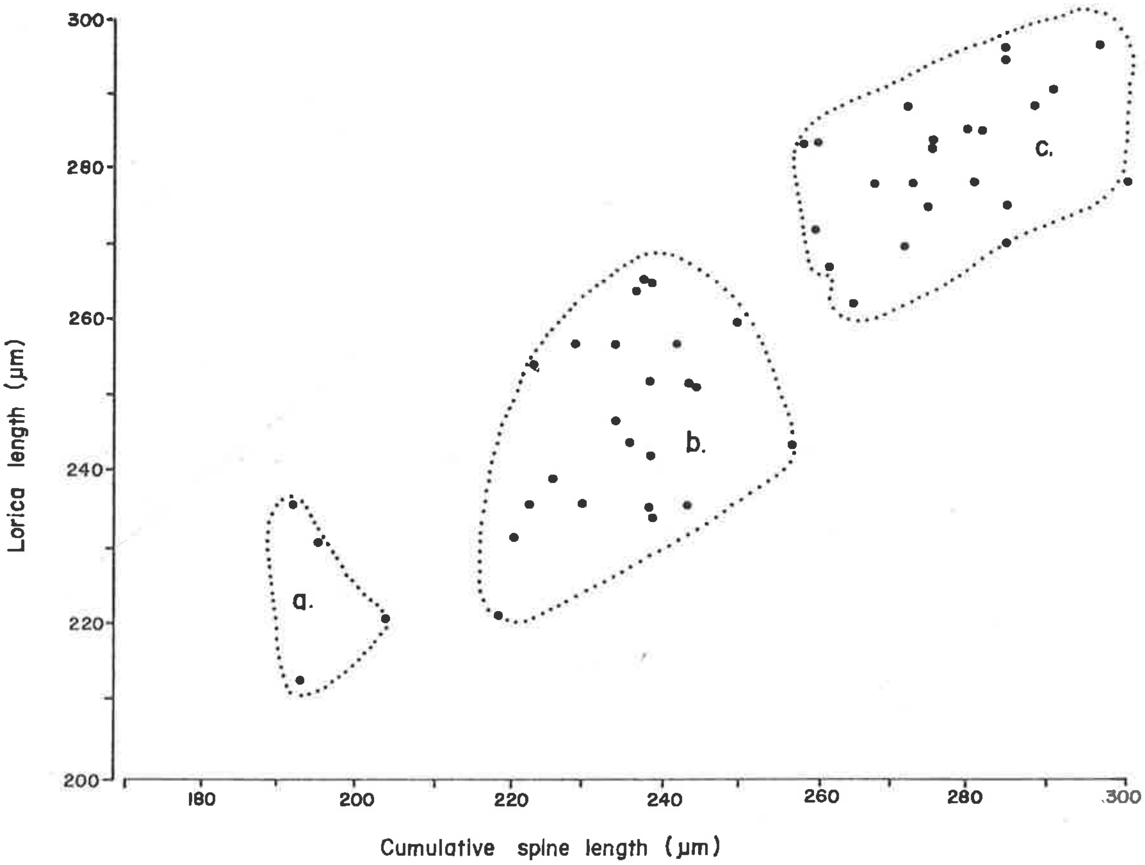


FIG. 4·13 Envelopes enclosing two populations of *K. slacki* (bimodal distribution) (Snowdon's billabong 7·ix·78)
a - juveniles; b - amictic females; c - mictic females.

component is necessary to explain the adaptation of the species to seasonal variation. Different clones may respond differently to changing environmental characteristics. The form or clonal type within a polytypic species which is best adapted to existing conditions is rapidly fixed by virtue of short life cycles and parthenogenetic reproduction (Ruttner-Kolisko, 1974; Gilbert, 1977). On the basis of electrophoretic studies in which clones from the same collection demonstrated a large degree of heterogeneity, King (1977:199) suggested that " rotifer populations are highly inbred and structured in temporally restricted demes".

These concepts applied to the widely separated *K. slacki* populations provide an explanation of the parallel but temporally displaced clonal succession observed in isolated billabongs, but do not clarify the environmental cues which initiate such succession. Billabongs, even those in close proximity which may be continuous in times of flood, are heterogeneous habitats in terms of both floral and faunal associations (Shiel, 1976, 1980; Walker & Hillman, 1977) and physico-chemical fluctuations (Ch.6). While increasing salinity is implicated as a cue, other environmental variables, both abiotic, e.g. throughflow of river water in winter-spring, and biotic, e.g. predator population density, also may be significant. Interestingly, maximum spine production in *K. slacki* coincided with the appearance of *Asplanchna* in billabongs in spring. The effect on the predator of ingestion of long-spined forms is indicated in Fig. 4.14; integumental penetration would probably be lethal.

The correlation with water quality seen for *K. slacki* was not detected in the more widely dispersed *K. australis* and *K. procurva* populations. Lorica length data for both species were analysed in the same manner. H_0 was accepted at the 5% level for all measured water quality characteristics. The two species are eurytopic, occurring in a wide range of waters; *K. australis* predominantly in lakes and rivers, rarely in billabongs, and *K. procurva* ubiquitous throughout the study area. A greater

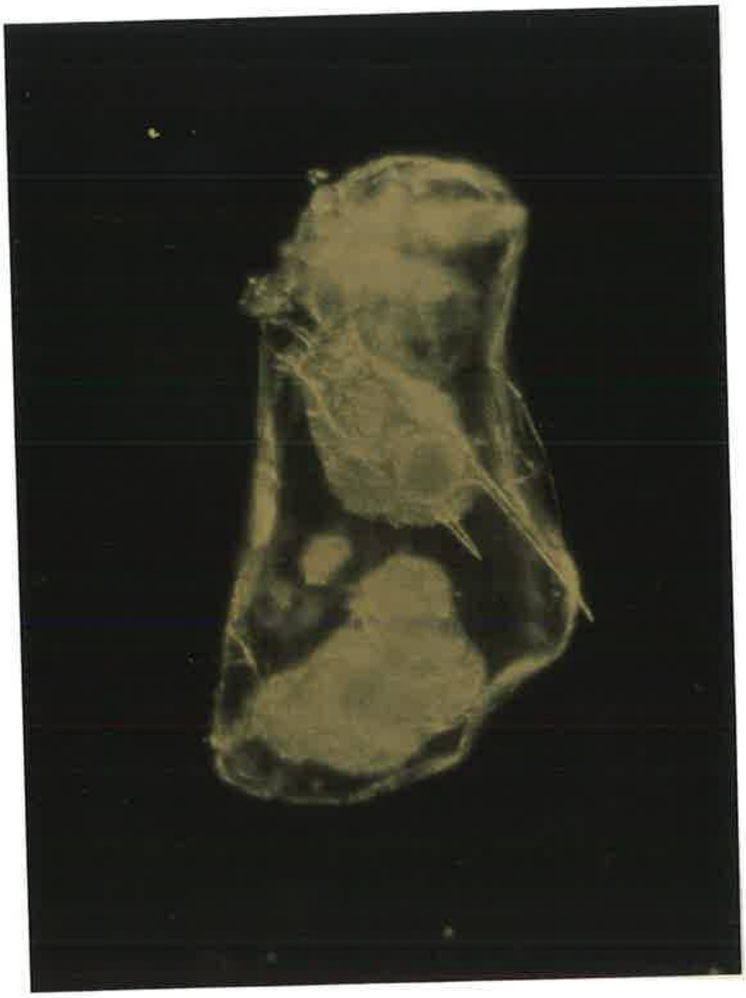


Fig. 4.14: Long-spined *K. slacki* ingested by the predator, *A. sieboldi* (Wise's billabong, 07.ix.78).

degree of polymorphism was noted for the latter species, with a wide variety of forms similar to those described elsewhere for *K. tropica.* At opposite extremes are the exhuberant and spineless forms shown in Fig. 4.15. Dumont (1980) notes that *K. procurva* occurs in small numbers, always in the tropics (neither of which is strictly true in the present study), and that when *tropica* and *procurva* are co-occurrent, *tropica* is abundant, *procurva* not. The converse was found in Murray-Darling waters, and also has been observed in African waters (H. J. Dumont, pers. comm.).

Polymorphic variation in other genera (e.g. *Asplanchna* and *Filinia*) is considered in more detail in later chapters on community structure, as the variations noted were subjectively correlated with habitat differences. In the case of *Asplanchna* seasonal variations were noted in food type and availability within discrete habitats (based on gut content examination during progressive digestion with NaOCl).

In *Filinia* (Table 4.4), morphological variants, particularly of bristle lengths, are characteristic of particular habitat types. Two species with the greatest bristle lengths yet recorded (*F. australiensis* and *F. pejleri grandis*) occur only in the river plankton. Bristles are an adaptation to a planktonic existence (Ruttner-Kolisko, 1974), and their extreme development in these species possibly reflects a genetic response to slow flow conditions of the river system. Intermediate in bristle length, *F. longiseta* and the undescribed species are limnoplankters, with seasonal appearances in the river plankton. The smallest species, *F. terminalis* and the short-spined *F. longiseta passa* occurred in billabongs and smaller standing waters.

Log-log plots of caudal bristle length vs. mean anterior bristle length for all species (with the exception of the distinctive *F. opoliensis*) are given in Fig. 4.16, which also gives comparative envelopes for European representatives of the genus. While separation of populations by this method is used frequently (cf. Hutchinson, 1964, 1967) overlap in populations makes suspect the taxonomic use of bristle length measurements, even body

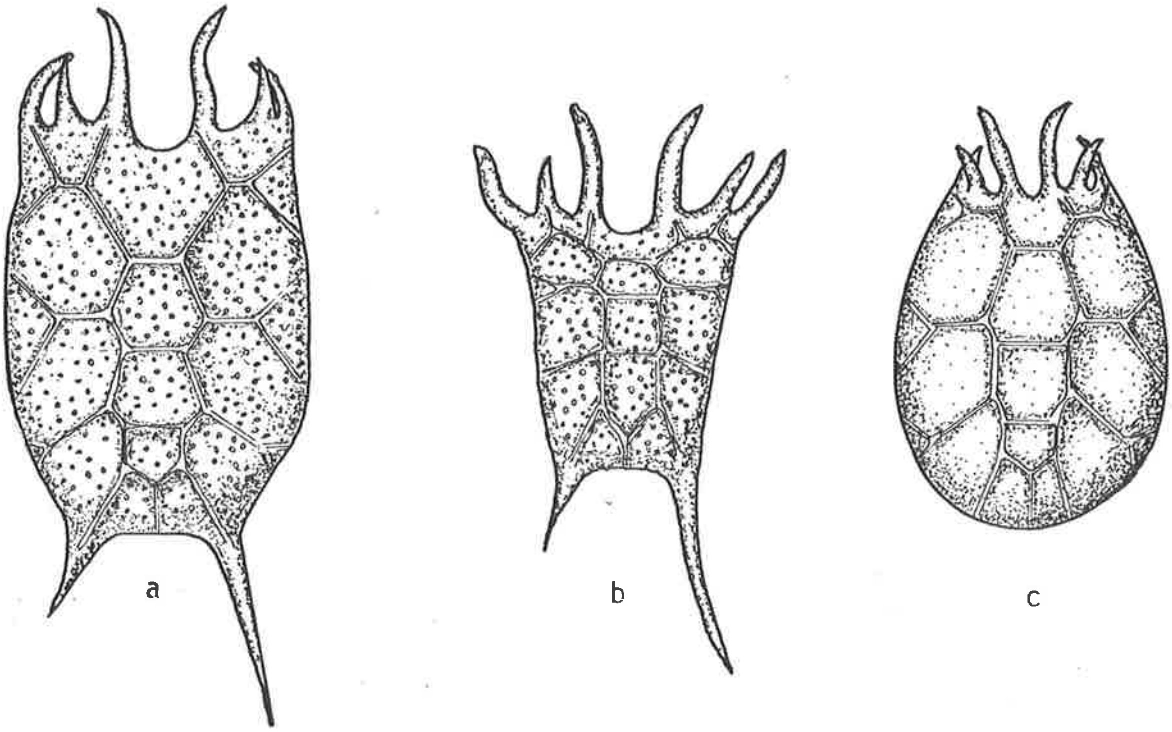


Fig. 4.15: *Keratella procurva* variants from Murray-Darling waters. a. f. typ., b. exhuberant form, L. Victoria, Shepparton, Vic., c. spineless saline water form, Richardson River, Donald, Vic.

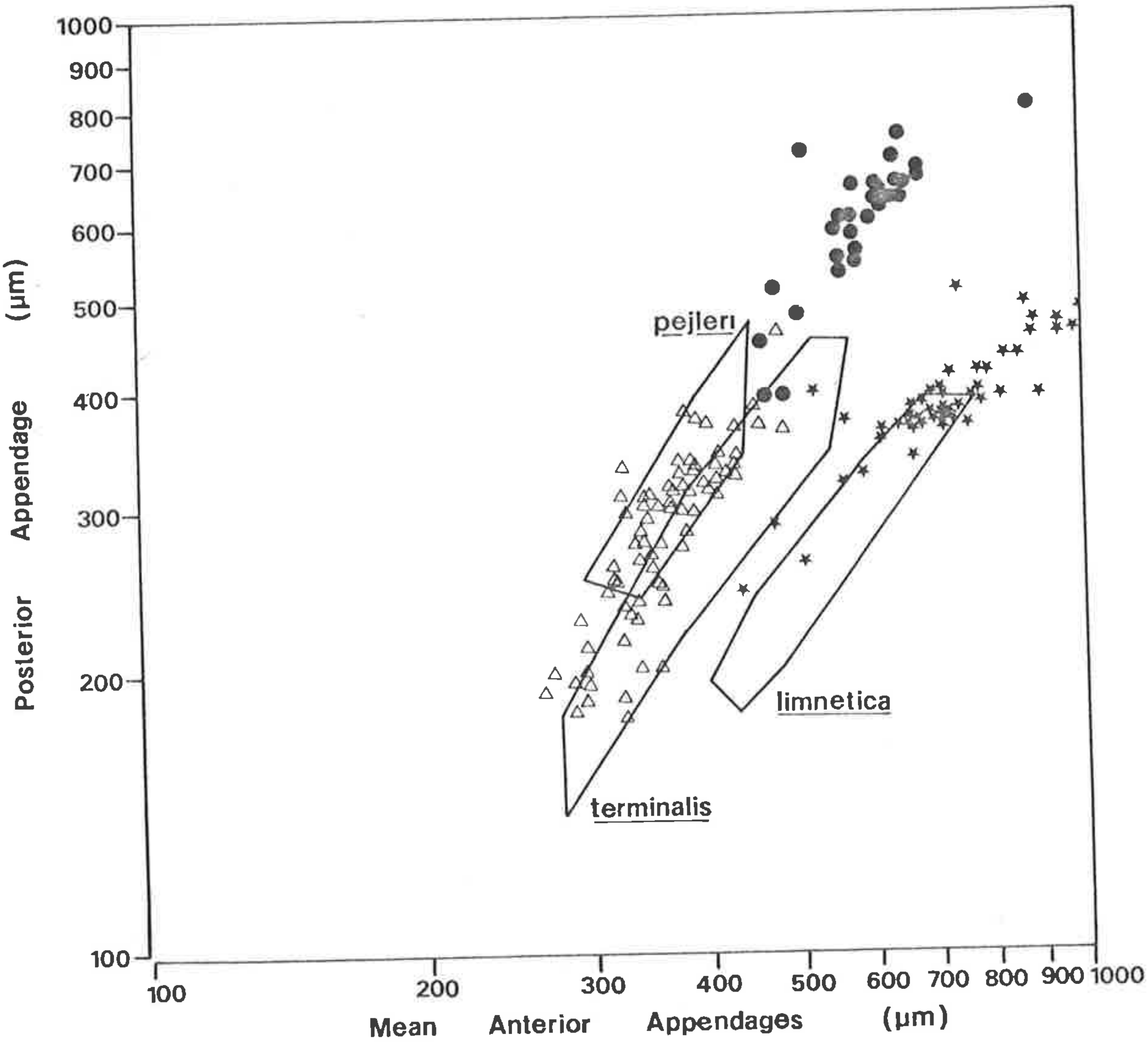


Fig. 4.16 Variation in *Filinia* populations. Envelopes enclose comparative ranges for European forms. ● *F. pejleri grandis;* ✫ *F. australiensis / F. longiseta;* △ *F. terminalis, F. pejleri* and an undescribed species.

length/depth ratios as in Table 4.4. The only satisfactory method appears to be detailed study of trophi structure (Koste, 1980b). For this reason the taxonomic status of several *Filinia* populations collected during this study is not yet successfully resolved. In particular, the undescribed species overlaps the niches of both *F. pejleri* and *F. terminalis*, and was not readily separated from them. Confusion of small individuals of this taxon with *F. terminalis* accounts for records of the latter in waters up to 25.0 °C. *F. terminalis* positively identified from Murray reservoirs and billabongs was collected at temperatures below 15.0 °C, in keeping with its cold stenothermal characteristics noted elsewhere (Ruttner-Kolisko, 1974). The undescribed species apparently is eurytopic, occurring in a wide range of habitats, and is widely dispersed across the study area. Further comments on the extent of morphological variation in Murray-Darling *Filinia* taxa are given by Koste (1980b).

This brief discussion of polymorphism in four genera of Murray-Darling Rotifera exemplifies the range of variation seen in most widely dispersed genera. Billabong forms in particular showed most variation from the types at the subspecific or infrasubspecific level (cf. Koste, 1979; 1980a,b; Koste & Shiel, 1980 , in press). These are mentioned, where appropriate, in Ch. 6.

THE INFLUENCE OF ABIOTIC FACTORS

Correlations between rotifers and water quality rarely are fully documented. The difficulty of attributing morphological changes to single factors is seen in the preceding discussion of polymorphism; a similar situation is seen with regard to species distribution and population dynamics. Pourriot (1965) showed that species distribution is not closely related to existing values of single factors, e.g. temperature, pH. Hofmann (1977) noted that single factor theories are unsuitable in evaluating population dynamics, which are governed by both abiotic and biotic factors. As will be shown in later chapters, abiotic and biotic factors were not readily separable in this study. Nevertheless, some general comments here serve as introduction to later discussion of succession in the limno- and potamoplankton.

Rotifers, with life cycles of less than 20 days (Ruttner-Kolisko, 1974), face the problem of temporal heterogeneity in the habitat; each generation may be in a different environment. Other organisms of longer generation time may physiologically regulate in a changing environment, or they may diapause at some stage of the life cycle (King, 1972; Chapman & Lewis, 1978). As noted earlier, rotifers apparently carry sufficient genetic information from generation to generation to cope with any marked environmental change. Such a change in temperature, dissolved oxygen, ionic concentration etc., may stimulate resting egg production (Whitney, 1914; cf. Gilbert, 1977a,b).

The influence of temperature, probably the single most important determinant of occurrence, is well known (e.g. Edmondson, 1946; Pejler, 1962). By influencing biochemical reaction rates, temperature affects all aspects of development, feeding and reproduction. Species-specific temperature tolerance accounts for the seasonal succession of rotifers in rivers and lakes (e.g. Carlin, 1943; Pejler, 1962; Byars, 1960; Hofmann, 1977), or the restriction of some species to particular habitats (cf. Hofmann, 1975). In the latter study, vertical migration of *K. cochlearis* and *F. terminalis* occurred from the epilimnion to the hypolimnion in response to changing temperature/oxygen conditions.

Extreme changes in habitat as a result of water utilization, i.e. thermal effects or eutrophication, may eliminate rotifer species (cf. Horton, Gallup & Nursall, 1977) or allow colonization by species with different tolerances. In the Loire River, for example, where abstraction for cooling nuclear reactors has raised temperatures in stretches of the river, tropical rotifer species have been collected (Lair, 1980).

A review of the influence of other abiotic factors on the dynamics of rotifer populations is given by Hofmann (1977); suffice to note here that temperature is regarded as the only factor operating directly on embryonic development time and thereby directly influencing population densities (Hofmann, p. 81). Dissolved oxygen, light, pH, ionic composition, metabolites or other chemicals produced by biotic components of the environment also may be important.

THE INFLUENCE OF BIOTIC FACTORS

Reviews of studies on biotic influences on rotifer populations include those of Edmondson (1946, 1957), Hutchinson (1957) and Dumont (1977). Recent studies include those of Halbach (1970), Green & Lan (1974), Anderson (1977), Gilbert (1977, 1978, 1980), Gilbert & Litton (1978), Miracle (1977), Ruttner-Kolisko (1977), Clement (1980) and Starkweather (1980, in press) on features of feeding behaviour, predation on and by rotifers, and parasitism.

In this study, food preferences were recorded for the predator *Asplanchna*. Gut contents of approximately 120 specimens of the three abundant species (*A. brightwelli, A.priodonta, A. sieboldi*) were examined, either during hypochlorite digestion to clear trophi, or after clearing in PVA. Food items recorded included fragments of filamentous and colonial chlorophytes (including *Eudorina* and entire *Volvox* colonies), diatoms, dinoflagellates, various species of *Brachionus, Keratella, Synchaeta, Polyarthra, Asplanchna, Filinia,* copepod nauplii and copepodites, and *Bosmina*. Food items are similar to those recorded elsewhere (e.g. Pejler, 1957, 1965; Green & Lan, 1974; Guiset, 1977; Salt, 1977; Salt, Sabadini & Commins, 1978), and were correlated in this study with food availability. *Asplanchna*, for example, is predatory by preference (J. J. Gilbert, pers. comm.), but will take algal material. In billabongs with low prey densities *Asplanchna* species fed on algae. *A. brightwelli* and *A. priodonta* were more frequently recorded with algal material in the gut (25% and 17% respectively) than was *A. sieboldi* (4%).

As noted earlier, where all three species occurred together, a marked size separation was evident, suggesting a reduction of competition by selection of different prey size. This also was seen for most other genera in which congeneric associations were noted e.g. Table 4.7 gives congeneric associations of *Keratella* in 317 collections in which the genus occurred, and Fig. 4.17 a representative plot of frequency vs. lorica length for a billabong community in which four species co-occurred. Small forms of *Keratella* are unable to handle large particles, large forms feed less efficiently on small particles (Gilbert, 1980); in this way the habitat is effectively partitioned.

The only other notable record of food preference is that of *Lindia torulosa*, collected from a Goulburn billabong (Sheepwash, Yea, 22.viii.78). Fragments of *Oscillatoria* were present in the gut; this was the only record of a plankter feeding on blue-green algae. Starkweather (in press) reports *Brachionus calyciflorus* feeding on *Anabaena*. Other planktonic rotifers were assumed to have similar feeding habits to those recorded elsewhere, i.e. predominantly herbivorous, taking in algal material, bacteria and/or detritus. Only a few species are noted elsewhere as predacious (e.g. *Dicranophorus*, *Trichocerca*) (Ruttner-Kolisko, 1974; Pourriot, 1977; Starkweather, 1977, 1980, in press; Koste, 1978; Gilbert, 1980).

Predation on Rotifera was recorded only for *Asplanchna*, but it is probable, in billabongs at least, that carnivorous cyclopoid copepods are significant predators, particularly *Mesocyclops*. Elsewhere, rotifers are preyed upon by Cyclopidae, Cladocera (*Leptodora*), dipteran larvae (*Chaoborus*), and Calanoida (*Diaptomus*) (Anderson, 1972; Comita, 1972; Hilbricht-Ilkowska, 1975). Of these, cladoceran and calanoid predators are absent from Murray-Darling waters, and dipteran larvae are not commonly collected in the potamoplankton (Ch. 7). *Chaoborus* is widespread in Australia (Williams, 1966) and is common in billabongs, but its preferred food is microcrustacea, particularly cyclopoids (Swift & Fedorenko, 1975). Considering the low population densities of plankton in Murray-Darling waters generally, it is likely that predation

Table 4.7: Congeneric associations of *Keratella* sp. (n=317).

	No. of species in collection					
	1	2	3	4	5	6
n	137	90	60	20	7	3

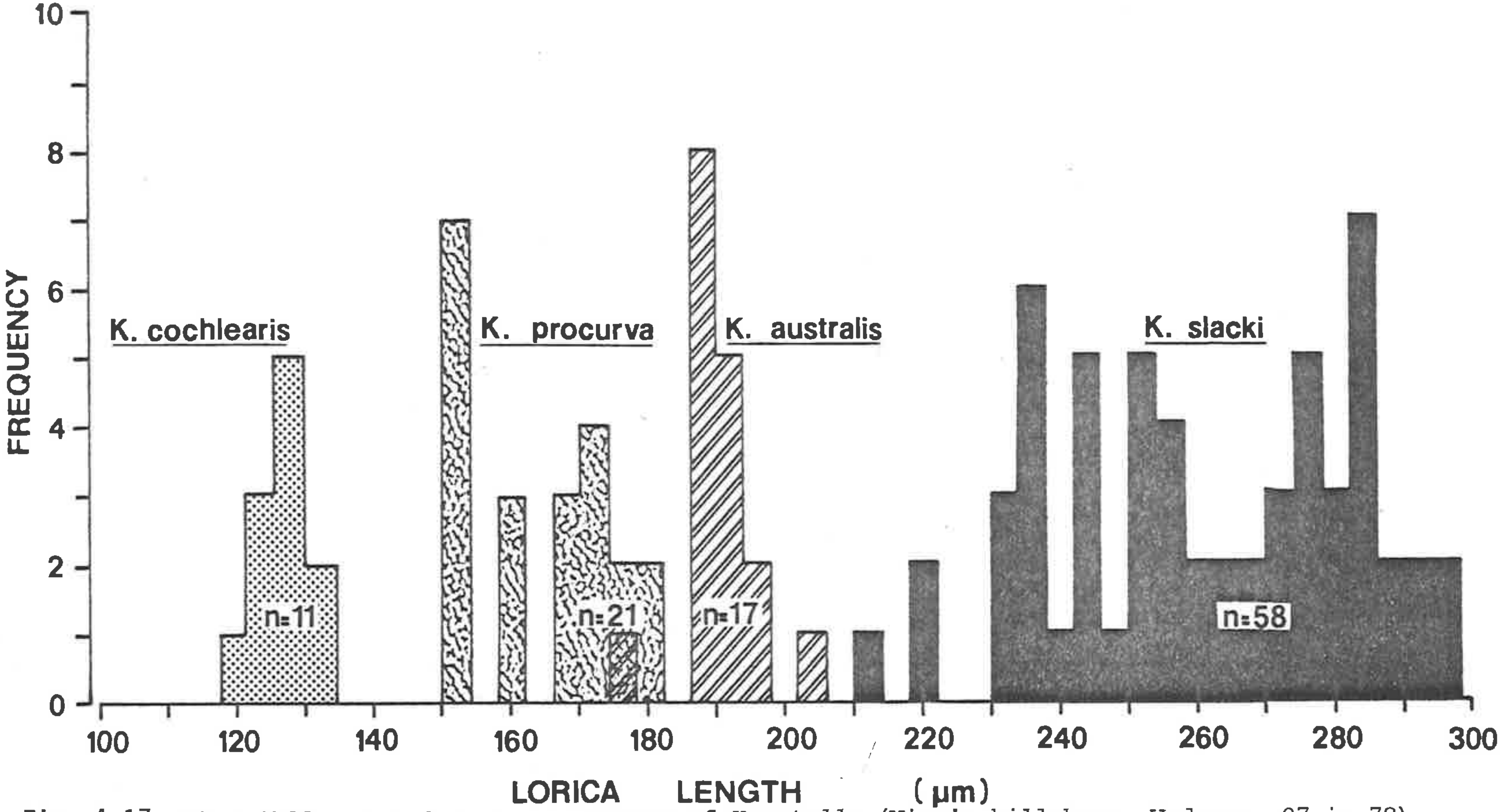


Fig. 4.17 Size differences between congeners of *Keratella* (Wise's billabong, Wodonga, 07.ix.78).

pressure on rotifers is low (cf. Dumont, 1977).

Parasitism on Rotifera is reported elsewhere (Edmonson, 1965; Miracle, 1976, 1977; Ruttner-Kolisko, 1974, 1977; Pennak, 1978) but was not observed during this study. Populations of rotifers parasitic on colonial volvocales (*Ascomorphella volvocicola*) were recorded from Burrinjuck Dam (Ch.5) and Murray billabongs (Ch.6). They were the most abundant zooplankters during *Volvox* blooms.

The influence of other biotic factors on rotifer populations, e.g. fish, algal blooms, particularly blue-green algae, is discussed by Dumont (1977). Fish predation effects on community structure, i.e. selective removal of larger Cladocera and Copepoda, allowing increases in smaller species and rotifers, were only inferred in isolated cases in this study (Ch. 6). Frequent algal blooms and accompanying increases in species richness are a feature of some Murray-Darling waters. Algal blooms may allow littoral or periphytic species into the pelagic (cf. Carlin, 1943) by their use of filaments or mats of algae as substrates. If not feeding directly on the algae, e.g. blue-greens, rotifers may be using a decomposer shunt (Dumont, 1977) in that products of bacterial decomposition and bacteria within a bloom may provide abundant food and thereby account for increases of rotifer population density and diversity. This phenomenon is discussed later (Ch.7) in reference to *Oscillatoria*, *Anabaena* and *Melosira* blooms in the lower Murray.

ADAPTATIONS TO A LOTIC HABIT

Few of the plankters collected from Murray-Darling waters occurred only in the rivers, with morphologically different forms occurring in the headwater lakes (cf. *Filinia australiensis, F. longiseta)*. Most planktonic forms from the reservoirs and rivers of the basin are adapted to a planktonic mode as elsewhere, and readily distinguished from true benthic, epiphytic or littoral species. The adaptations of these true plankters are summarised briefly; taxa in which the adaptation is most pronounced in Murray-Darling waters are given in parentheses.

Reduction of lorica thickness (e.g. *B. calyciflorus* and "Darling form") decreases specific weight, as does inflated volume (e.g. *B. calyciflorus* "Darling form", *Synchaeta, Asplanchnopus, Asplanchna*) and the production of an enveloping gelatinous matrix (*Conochilus*). Reduction or total loss of foot and toes (*Filinia, Synchaeta, Pompholyx, Asplanchna*) and the development of long spines and bristles (*Filinia*) aid in flotation. Eggs may remain attached to the female (*Brachionus, Keratella, Pompholyx, Filinia*), have oil droplets or increased surface area (*Polyarthra, Synchaeta*) or vivipary may reduce chances of egg loss (*Asplanchna*)(Ruttner-Kolisko, 1974). As noted, the development of some of these adaptations in Murray-Darling rotifers exceeds any described elsewhere (i.e. bristle length, lorica reduction, increased volume).

ENDEMICITY

Rotifers inhabit most fresh waters, and have long been regarded as at least potentially cosmopolitan. However, recent studies (e.g. Pejler, 1977) suggest that only some are cosmopolitan. Although this study considerably extends the known distribution of most species recorded, it shows also that rotifers with specific requirements or dispersal limitations may have restricted distributions.

Pejler's (1977) review of brachionid distribution listed four taxa endemic to Australia. Two, *K. ahlstromi* and *K. sancta*, are in fact New Zealand species, but *K. australis* and *K. slacki* are Australian endemics. With the rediscovery of *B. dichotomus* and *B. lyratus* and the description of several other taxa (*B. baylyi* Sudzuki & Timms; *B. bidentata minor* Koste & Shiel; *B. dichotomus reductus* Koste & Shiel; *B. keikoa* Koste; *B. plicatilis colongulaciensis* Koste; *K. shieli* Koste and *K. procurva robusta* Koste & Shiel), the Australian endemics of this family increase to 11. With the exception of *B. bidentata minor* and *K. shieli*, known only from the lower River Murray, all were recorded from small, isolated lentic habitats.

From the literature at least 34 taxa in other families apparently are endemic. While endemicity is low (10%) compared with the microcrustacea, i.e. calanoids >90%, cyclopoids 60%, cladocerans 35% (Bayly, 1964, 1979; Bayly & Morton, 1978; Smirnov & Timms, in press), only a fraction of Australia has yet been studied. Early collections were made near Melbourne, Sydney and Brisbane, and the present study was confined to the Murray-Darling basin. Probably even more edemicity will become apparent after further work (e.g. Koste & Shiel, in press), so that the Rotifera are not excepted from the distinctively Australian freshwater fauna (cf. Williams, 1980).

In summary, then, the rotifer fauna of the Murray-Darling system consists of predominantly cosmopolitan, pantropical or pancontinental eurytopic forms, i.e. tolerant of extremes of water quality (although alkaline forms predominate), with a small group of less widely distributed stenotopic species of more stringent ecological requirements. On the basis of the rotifer material described here, it is likely that a greater degree of endemicity, species richness and community complexity than previously considered exists for the zoogeographical region of Notogaea (Australia and Tasmania).

4.3 CLADOCERA

4.3.1 Introduction

The Cladocera is one of the most frequently collected groups from Australia's inland waters (Williams, 1966), but their taxonomy and ecology is not well studied. Much of the available taxonomic work on the Cladocera was published last century (e.g. Brady, 1850; King, 1853, 1854; Sars, 1885, 1888, 1889, 1896) with very little work over the following 50 years (e.g. Serventy, 1929). More recently, several small taxonomic works have been published (e.g. Brehm, 1953; Petkovski, 1973a, b; Hebert, 1977; Smirnov, 1977) but as yet no comprehensive review of Australian Cladocera exists. Taxonomic confusion persists in some families, e.g. the Daphniidae (cf. Hebert, 1977; Mitchell, 1978).

Ecological studies including information on Cladocera also are few, and restricted to lentic habitats (e.g. Jolly, 1966; Timms, 1969, 1970, 1972; Bayly & Williams, 1973; Shiel, 1976). Little information is available on the cladoceran potamofauna. Playfair (1914) included the crustacean plankton in his study of the Richmond River, N.S.W., as did Jolly & Chapman (1966) on tributaries of Cox's River, N.S.W. Brief mention is made of the freshwater cladoceran component of the Fitzroy River estuary (Qld) by Kennedy (1978), and a species list and brief ecological information on the Murray-Darling zooplankton was given by Shiel (1978).

More than 125 species of Cladocera have been recorded from the continent, with 44 species apparently endemic. This represents the highest number of endemics from any comparable area (B. V. Timms, pers. comm.). Seventy-five species were collected from Murray-Darling waters during this study. Ten of these are new or new records, at least 16 are endemic to Australasia. The known distribution of most species is considerably extended (N. N. Smirnov, Academy of Sciences, Moscow, pers. comm.).

4.3.2 Taxonomy and Ecology

The Cladocera recorded from the Murray-Darling basin are tabulated according to the systematics of Smirnov (1974, 1976) (Table 4.8). Of the 75 species in 6 families and 26 genera, 44 (59%) were of restricted distribution, i.e. single collections or one or two habitat types. Of these, 37 occurred only in Murray waters, 7 occurred in Darling waters or were associated with Darling floodwaters below the confluence. Twelve species (16%) were collected widely across the Murray catchment, and 19 species (25%) were common in a wide range of water quality across the study area.

Brief notes are given below on taxonomic and ecological features of the recorded families of Cladocera.

Fam. Sididae

Of the two genera recorded, *Latonopsis* was noted as a rare component of the littoral microfauna of lakes and billabongs. *L. australis* was a summer

TABLE 4.8 : Cladocera recorded from the zooplankton and littoral microfauna of the Murray-Darling waters.

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (°C)	pH	DO (ppm)	Cond. (μS)	Turb. (NTU)
	FAM. SIDIDAE												
1	*Latonopsis australis* Sars, 1888				●	●			24.2 - 25.0	7.6 - 7.7	8.4 - 8.6	60 - 145	1 - 22
2	*L. ? brehmi* Petkovski, 1973					●			12.0 - 18.0	7.2 - 7.3	6.2 - 9.4	-220	120
3	*Diaphanosoma excisum* Sars, 1886	●	●	●	●	●	●	●	14.5 - 27.5	7.3 - 9.0	4.0 - 9.4	18 - 720	6 - 120
4	*D. unguiculatum* Gurney, 1927	●	●	●	●	●	●	●	6.2 - 29.0	7.0 - 8.7	6.2 - 12.5	121 - 1350	.5- 275
	FAM. CHYDORIDAE												
5	*Pleuroxus aduncus* (Jurine) 1820				●	●	●	●	8.5 - 24.0	6.9 - 8.7	1.0 - 12.0	145 - 1000	5 - 135
6	**P. inermis* Sars, 1896			●				●	10.5 - 21.0	8.0 - 8.5	9.0 - 10.6	420 - 1250	23 - 130
7	*P. jugosus* (Henry) 1919							●	10.5 - 17.0	8.2 - 8.3	9.7 - 11.8	630 - 1000	43 - 88
8	*Alonella clathratula* Sars, 1896							●	15.0	4.9	9.8	160	12.5
9	*A. excisa* (Lilljeborg) 1853				●	●		●	10.5 - 29.4	7.1 - 8.2	1.2 - 11.0	38 - 1000	2 - 88
10	*Chydorus barroisi* (Richard) 1894				●	●			10.0 - 15.0	4.9 - 7.4	9.8 - 13.0	52 - 160	12.5 - 23.5
11	*C. eurynotus* Sars, 1901				●	●			11.0 - 15.0	7.7 - 7.8	7.2 - 9.6	392	-
12	*C. herrmanni* Brehm, 1933					●			16.0	7.2	9.6	-	-
13	*C. sphaericus* (Müller) 1785	●	●	●	●	●	●	●	4.0 - 29.4	4.2 - 8.5	1.2 - 13.0	58 - 1950	1.0 - 350
14	*Chydorid n.gen. n.sp.					●			12.9	7.4	7.6	166	15
15	*Dunhevedia crassa* King, 1853		●		●	●			7.8 - 25.0	7.0 - 7.8	1.4 - 11.6	95 - 1080	2.6 - 350
16	*Pseudochydorus globosus* (Baird) 1843				●	●			6.2 - 29.4	6.9 - 8.4	1.6 - 13.0	73 - 1080	1.0 - 350
17	*Alona cambouei* Guerne/Rich.1893					●			8.5 - 20.0	7.1 - 8.3	1.4 - 12.0	145 - 600	27 - 350
18	*A. clathrata* Sars, 1888							●	23.0	8.4	7.2	530	47
19	*A. costata* Sars, 1862					●			16.5	7.2	9.1	95	35
20	*A. davidi davidi* Richard, 1895					●	●	●	9.0 - 17.0	7.2 - 7.7	9.2 - 11.0	142	5
21	*A. davidi iheringi* Richard, 1897				●	●		●	8.5 - 29.4	6.9 - 8.3	1.2 - 12.0	50 - 1100	1.0 - 130
22	*A. davidi punctata* Daday, 1898					●			22.0	7.3	8.0	155	10

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (°C)	pH	DO (ppm)	Cond. (μS)	Turb. (NTU)
23	_A. guttata_ Sars, 1862			●	●	●	●	●	8.5 - 29.4	7.4 - 8.4	1.2 - 12.0	130 - 1000	0.5 - 130
24	*_A. cf.inreticulata_ Shen Chia-jui,1964					●			14.0	7.3	9.6	500	4.5
25	*_A. poppei_ Richard, 1897				●				10.7	7.9	9.4	650	-
26	_A. pulchella_ King, 1853				●	●			12.0 - 16.0	7.0 - 7.9	2.7 - 10.2	220 - 460	25 - 350
27	_A. rectangula_ Sars, 1862	●	●	●	●	●	●	●	7.8 - 29.4	7.0 - 8.7	1.2 - 12.0	37 - 1135	2 - 350
28	*_Alona_ n.sp.1 unpublished				●				15.0	7.8	9.6	445	67
29	*_Alona_ n.sp.2 unpublished	●							13.5	7.5	10.2	-	-
30	_Graptoleberis testudinaria occidentalis_ Sars, 1901				●	●			10.0 - 26.6	7.1 - 7.8	1.2 - 9.8	140 - 1080	5 - 350
31	_Kurzia latissima_ (Kurz) 1895					●			11.0	7.2	7.2	392	2
32	_K. longirostris_ (Daday) 1898			●					20.0	7.4	9.2	110	120
33	_Camptocercus australis_ Sars, 1896				●	●	●		10.0 - 20.0	7.1 - 7.4	2.7 - 13.0	57 - 660	5 - 350
34	_Leydigia australis_ Sars, 1885		●			●		●	14.0 - 17.0	7.7 - 7.8	7.6 - 9.0	520	125
35	_L. ciliata_ Gauthier, 1939					●			16.8	8.1	12.2	137	16
36	_L. cf.leavis_ Gurney, 1927						●		16.0	7.6	8.6	-	-
37	_L. leydigi_ (Schoedler) 1863				●				10.2	7.9 - 8.4	9.4 - 10.0	650	12.5
38	_Biapertura affinis_ (Leydig) 1860				●	●	●	●	10.2 - 26.6	6.2 - 8.4	1.2 - 10.0	95 - 700	4.5 - 90
39	_B. intermedia_ (Sars) 1862						●		17.0	7.6	9.3	178	-
40	_B. karua_ (Sars) 1862			●		●	●		10.0 - 29.4	7.1 - 8.3	1.0 - 10.8	64 - 245	2.5 - 17
41	_B. kendallensis_ (Henry) 1919			●	●	●	●		6.0 - 22.5	4.2 - 7.8	1.4 - 11.6	60 - 1080	2.0 - 62
42	_B. longigua_ Smirnov, 1971					●			16.5	7.2	9.1	95	-
43	_B. macrocopa_ (Sars) 1895					●			10.0	7.3	13.0	52	23.5
44	_B. rigidicaudis_ Smirnov, 1971	●		●	●	●		●	10.2 - 29.4	7.1 - 8.4	1.2 - 11.2	125 - 650	2.5 - 27
45	_B. setigera_ (Brehm) 1931					●	●	●	10.0 - 21.0	7.0 - 8.5	1.4 - 11.6	85 - 1250	2.0 - 130
46	*_Monospilus_ n.sp.1 unpublished	●		●				●	8.5 - 22.0	7.5 - 8.3	8.2 - 12.0	365 - 590	43 - 135
47	*_Monospilus_ n.sp.2 unpublished							●	8.5 - 20.0	8.2 - 8.3	9.0 - 12.0	530 - 575	43 - 130

TABLE [illegible] (cont.).

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (°C)	pH	DO (ppm)	Cond. (µS)	Turb. (NTU)
	FAM. MACROTHRICIDAE												
48	**Ilyocryptus brevidentatus* Sars, 1909					●			16.8	8.0	12.2	137	16
49	*I. sordidus* (Lieven) 1848	●		●	●	●	●	●	6.5 - 23.0	6.9 - 8.5	2.7 - 11.0	110 - 603	35 - 50
50	*I. spinifer* Herrick, 1882				●	●	●	●	8.0 - 25.4	4.9 - 8.3	1.4 - 12.0	85 - 600	2.0 - 350
51	*Macrothrix hirsuticornis* Norman&Brady,1867							●	12.0 - 18.0	8.0 - 8.2	8.6 - 10.6	42 - 850	10 - 130
52	*M. spinosa* King, 1853	●	●	●	●	●	●	●	7.8 - 28.0	7.0 - 8.4	2.7 - 13.8	85 - 750	2.0 - 350
53	*M. breviseta* Smirnov, 1976					●			16.0 - 28.0	7.1 - 7.4	9.2 - 13.8	155 - 250	12.5
54	*Echinisca capensis* Sars, 1916		●										
55	*E. hardingi* (Petkovski) 1973			●									
56	*Echinisca sp.*		●						14.0	8.1	8.5	-	-
57	*Pseudomoina lemnae* (King) 1853				●	●			12.0 - 17.0	4.9 - 7.5	9.8 - 10.0	227 - 415	<10
58	*Neothrix armata* Gurney, 1927				●		●	●	8.5 - 20.0	7.0 - 8.3	5.5 - 12.0	548 - 600	130
	FAM. MOINIDAE												
59	*Moina australiensis* Sars, 1896					●			16.8	8.1	12.2	137	16
60	*M. micrura* Kurz, 1874	●	●	●	●	●	●	●	9.0 - 29.4	7.1 - 8.7	1.2 - 10.9	27 - 1950	0.5 - 350
61	*M. tenuicornis* Sars, 1896		●	●	●	●		●	12.5 - 27.5	6.0 - 9.0	1.7 - 11.2	135 - 827	5 - 49
	FAM.BOSMINIDAE												
62	*Bosmina meridionalis* Sars, 1904	●		●	●	●	●	●	5.0 - 29.4	6.2 - 8.7	1.2 - 12.5	2 - 1950	0.5 - 350
	FAM. DAPHNIIDAE												
63	*Daphnia carinata* s.l. King, 1853	●		●	●	●	●	●	5.0 - 29.0	6.0 - 8.5	1.5 - 12.0	40 - 1135	0.4 - 275
64	*D. lumholtzi* Sars, 1885	●		●	●	●	●	●	7.8 - 31.0	7.0 - 8.7	4.1 - 12.0	31 - 1100	0.5 - 130
65	*Simocephalus acutirostris* (King) 1853					●			14.5 - 15.4	7.0	9.4 - 10.6	50 - 260	6.8 - 220
66	*S. exspinosus* (Koch) 1841					●			10.0 - 29.4	4.9 - 7.4	1.2 - 13.0	52 - 245	2.5 - 35
67	*S. vetulus* (Müller) 1776				●	●	●	●	8.0 - 29.4	7.0 - 8.5	1.2 - 13.0	38 - 1080	1.0 - 220
68	*Simocephalus* n.sp. unpublished					●			10.0 - 13.5	7.2 - 7.5	10.2- 11.6	330 - 435	62

TABLE 4.8 (cont.):

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (°C)	pH	DO (ppm)	Cond. (µS)	Turb. (NTU)
69	*Scapholeberis kingi* Sars, 1903			●		●			11.0 - 20.0	7.1 - 8.3	6.6 - 10.0	90 - 435	5 - 75
70	*Ceriodaphnia cornuta* Sars, 1885	●	●	●	●	●	●	●	9.0 - 28.0	6.0 - 8.7	1.4 - 11.3	8 - 1250	1.5 - 320
71	*C. dubia* Richard, 1894					●			11.0 - 29.4	7.1 - 7.2	1.2 - 8.2	130 - 245	2.5 - 27
72	**C. laticaudata* (Müller) 1785					●			8.0 - 22.0	7.1 - 7.7	8.0 - 10.4	85 - 155	0.4 - 10
73	*C. quadrangula* (Müller) 1785	●	●		●	●	●	●	5.0 - 29.4	4.9 - 8.5	1.2 - 13.0	2 - 1950	0.5 - 350
74	*C. rotunda* Sars, 1862				●	●			6.5 - 21.3	7.0 - 7.8	8.0 - 10.3	58	3.5
75	*Ceriodaphnia* sp.				●				15.0	7.8	9.6	105	2.5

plankter in L. Mulwala. This species is recorded as a summer form from Qld (Timms, 1967; Timms & Midgley, 1969) and the present record apparently is the southernmost limit of its range. *L. brehmi*, reported by Petkovski (1973) from W.A. and N.S.W., was collected in billabongs of the Goulburn River in spring and autumn. Two species of *Diaphanosoma* were recorded widely from the study area; *D. unguiculatum* frequently as a limno- and potamoplankter, *D. excisum* commonly from shallow, weeded areas, a converse ecological preference to that noted by Smirnov & Timms (in press). *D. unguiculatum* was a seasonal (summer) form in the lower Murray.

Fam. Chydoridae

The most abundant family of cladocerans recorded from Murray-Darling waters, chydorids were represented by 43 species. Only four of these were widely distributed across the basin and were perennially or seasonally planktonic (*C. sphaericus, A. rectangula, A. guttata, B. rigidicaudis*). The remaining species were collected, often in large numbers, from billabongs and lake littorals, with occasional seasonal incursions of some pseudo-planktonic species into the potamoplankton (e.g. *A. davidi, B. affinis*). Notably, two new species of *Monospilus* were recorded from waters of the Darling River (Smirnov & Timms, in press). This genus was previously considered monospecific, with *M. dispar* recorded predominantly from the Northern Hemisphere (Smirnov, 1971). Of the 68 chydorid species recorded from Australia, 25 are endemic (Smirnov & Timms, in press).

Fam. Macrothricidae

Eleven species of macrothricids in five genera were recorded. Although all are regarded as littoral in habit (Smirnov, 1976), *I. sordidus* and *M. spinosa* frequently were noted in the potamoplankton, the latter particularly during algal blooms in the lower Murray (Ch. 7). Four of the eleven species are endemic (*M. breviseta, E. capensis, P. lemnae, N. armata*).

Fam. Moinidae

Species of *Moina* commonly are recorded from small, temporary bodies of water (Goulden, 1968). All three species recorded in this study occurred in billabongs, but *M. australiensis* was the only one confined to this habitat. *M. tenuicornis* was more widely distributed in billabongs and lakes, and *M. micrura* occurred across the basin, frequently in large numbers in the lower Murray. This species showed marked seasonality (November-March), with peak breeding in summer (cf. Geddes, 1968; Timms, 1970). It is reported elsewhere as the most widely distributed species of the genus (Goulden, 1968).

Fam. Bosminidae

A single species of *Bosmina, B. meridionalis*, is recognized from the continent (V. Korinek, Charles University, Prague, pers. comm.). It was collected from all habitat types across the basin, and was noted as a perennial breeder in the lower Murray.

Fam. Daphniidae

The nomenclatural uncertainty of several genera of daphniids in Australia is not yet resolved, and it is possible that more species are involved than are listed in Table 4.8.

The variability of *Daphnia carinata* was documented by Sars (1914) and subsequently reported by Jolly (1966) and Bayly & Williams (1973). This seasonal polymorphism or cyclomorphosis is noted to a lesser extent in *D. lumholtzi*. With publication of a taxonomic revision of the southeastern Australian representatives of the genus, Hebert (1977) elevated several apparently cyclomorphic forms to specific status on the basis of unpublished electrophoretic studies. Polymorphism and cyclomorphosis in a single population subsequently were reported (Mitchell, 1978). In the present study it was not possible to separate possible congeners of the *D. carinata* "complex" on the basis of morphological differences, and for the duration of the study only two taxa were differentiated, *D. carinata* s.l. and *D. lumholtzi*. Both species were widely distributed and often were collected together. The observation that *D. lumholtzi* is a clear-water species and *D. carinata* a turbid-water species (Jolly, 1966) is supported. Although both species were collected from lakes and billabongs (clear) and the lower Murray (turbid), *D. lumholtzi* occurred in large numbers and breeding populations only in the former habitats.

Notably, *D. carinata* was not collected from billabongs over summer (cf. Jolly, 1952; Timms, 1970; Mitchell, 1978) but was present in breeding populations at higher altitudes in Lakes Eucumbene and Jindabyne, also in deep waters of Dartmouth Dam (Ch.5). Summer temperatures in billabongs (up to 40 ^{0}C) probably exceed *D. carinata*'s thermal tolerance. The species was collected from waters up to 29^{0}C (cf. *D. lumholtzi* to 31^{0}C).

Simocephalus is under review (H.J. Dumont, Ghent, Belgium, pers. comm.). Four species were distinguished during this study. With the exception of two subspecies of *S. vetulus*, which occurred in the plankton as littoral strays during floods, all were littoral in habit, predominantly in billabongs.

A single species of *Scapholeberis* , *S. kingi,* also was collected from billabongs. A specimen from the Richardson River at Donald, Vic., had long antennules characteristic of *S. mucronata.* A specimen identified as *S. mucronata* from a Goulburn billabong (N. N. Smirnov, pers. comm.) may have been a variant of *S. kingi*; subsequent examination of the collection produced individuals with the short, wide antennules characteristics of the latter (Sars, 1903).

Five species of *Ceriodaphnia* were identified from the study area. *C. cornuta* and *C. quadrangula* frequently were collected together and were ubiquitous throughout the basin. *C. cornuta* is reported as most common in summer (Timms, 1970) and to prefer warmer waters (Smirnov & Timms, in press). Both observations were supported in this study. Two other species, *C. dubia* and *C. laticaudata* were confined to billabongs and shallow lake margins. A taxon identified as *C. rotunda* was recorded seasonally (autumn-winter) from L. Mulwala. This species lacks the characteristic spines on the vertex (Sars, 1862; cf. Pennak, 1978:371 Fig. 269J), a feature which is not mentioned in the description by Smirnov & Timms (in press). The latter description could well be applied to *C. pulchella*, which is not recorded from the continent. Individuals resembling this species were collected from billabongs of the Goulburn River and from L. Mulawala . In head and postabdomen development (Sars, 1862; cf. Pennak, 1977:371) the species more resembles *C. pulchella* than *C. rotunda*. Similarly, *C. dubia* could not consistently be distinguished from *C. quadrangula* ; the spinule row at the base of the postabdominal claw of the former often was not present. It is possible that these two taxa are conspecific. Clearly, a thorough taxonomic revision of the genus is necessary.

4.3.3 DISCUSSION

As for the Rotifera, general comments only are given on representative genera of Cladocera, i.e. on morphological variability and distributional features, and correlations with biotic and abiotic factors recorded during the study. Quantitative data are discussed in Chs.5, 6 and 7.

POLYMORPHISM

Cyclomorphism is more conspicuous and better studied in the Cladocera than any other group. *Bosmina, Ceriodaphnia, Chydorus* and *Daphnia* have been studied in particular. The phenomenon is extensively reviewed by Hutchinson (1967). In *Daphnia*, in which cyclomorphism is most distinct, inter- and intraspecific expression of expansion of the anterior part of the head is variable under different habitat conditions. Most strikingly cyclomorphic forms appear in localities where there is a great temperature change between summer and winter. Cyclomorphism is less pronounced in ponds and shallow lakes, where the degree of development is consistent from one individual to another. Much more variability is seen in large deep lakes. Increased temperature is regarded as a primary stimulus; light intensity, day length, food supply and turbulence also have been implicated. Recently, the selective value of increased development of less visible peripheral structures has been related to planktivory by visual predators (Hrbacek, 1959; Brooks, 1965, 1966; Jacobs, 1961, 1962, 1966; Hutchinson, 1967; Zaret, 1972; Wetzel, 1975;

Kerfoot, 1977).

Zaret (1972) distinguished two types of polymorphism; a temporal succession of temperate zone populations in which all members have similar morphology, and a spatial polymorphism as seen in tropical regions in which all morphs are present at the same time. Both types are reported simultaneously for populations of *D. carinata* in South Australia (Mitchell, 1978). In Murray-Darling waters polymorphism was noted in *Bosmina, Ceriodaphnia* and *Daphnia*.

Daphnia: In *D. carinata* s.l. (Fig. 4.18a), the most commonly recorded species of the genus in this study, cyclomorphosis involved elongation of the rostrum, expansion of the anterodorsal carina and variation in the length of the posterior carapace spine (cf. Bayly & Williams, 1973; Mitchell, 1978). In *D. lumholtzi* (Fig. 4.18b) variation was noted in the anterior carapace spine, the lateral spines of the fornices, and the posterior spine (cf. Green, 1967).

Individuals for measurement were removed from spatially and temporally separated collections. Length and width were measured as shown in Fig. 4.18. The posterior spine also was measured, but as this often was broken, did not provide consistent data. Approximately 200 ovigerous and ephippial adults of each species were measured. Means (±1SD) are shown in Fig. 4.19.

In both species, morphological variation often was asynchronous in adjacent habitats, and did not occur at the same time in successive years. Considerably more variation is seen in *D. carinata* (Fig. 4.19a) than in the smaller *D. lumholtzi* (Fig. 4.19b)(cf. Bayly & Williams, 1973). In the latter, the greatest development occurred in late winter-spring in both lake and billabong populations, and was primarily due to production of larger individuals with corresponding elongation of the anterior spine. All forms were "helmeted", i.e. f. typica (Sars, 1885). They were significantly larger in all seasons than the helmeted form reported from Lake Albert (Green, 1967: 190, Fig. 4).

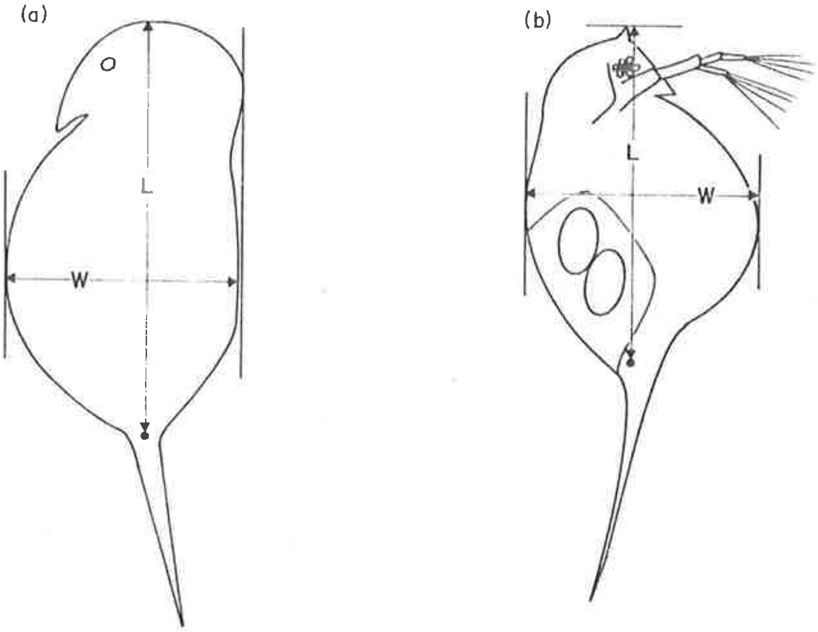


FIG 4.18 Measurements of (a) *D. carinata* and (b) *D. lumholtzi* were taken on the longitudinal axis (L) to the base of the spine, and across the carapace (W).

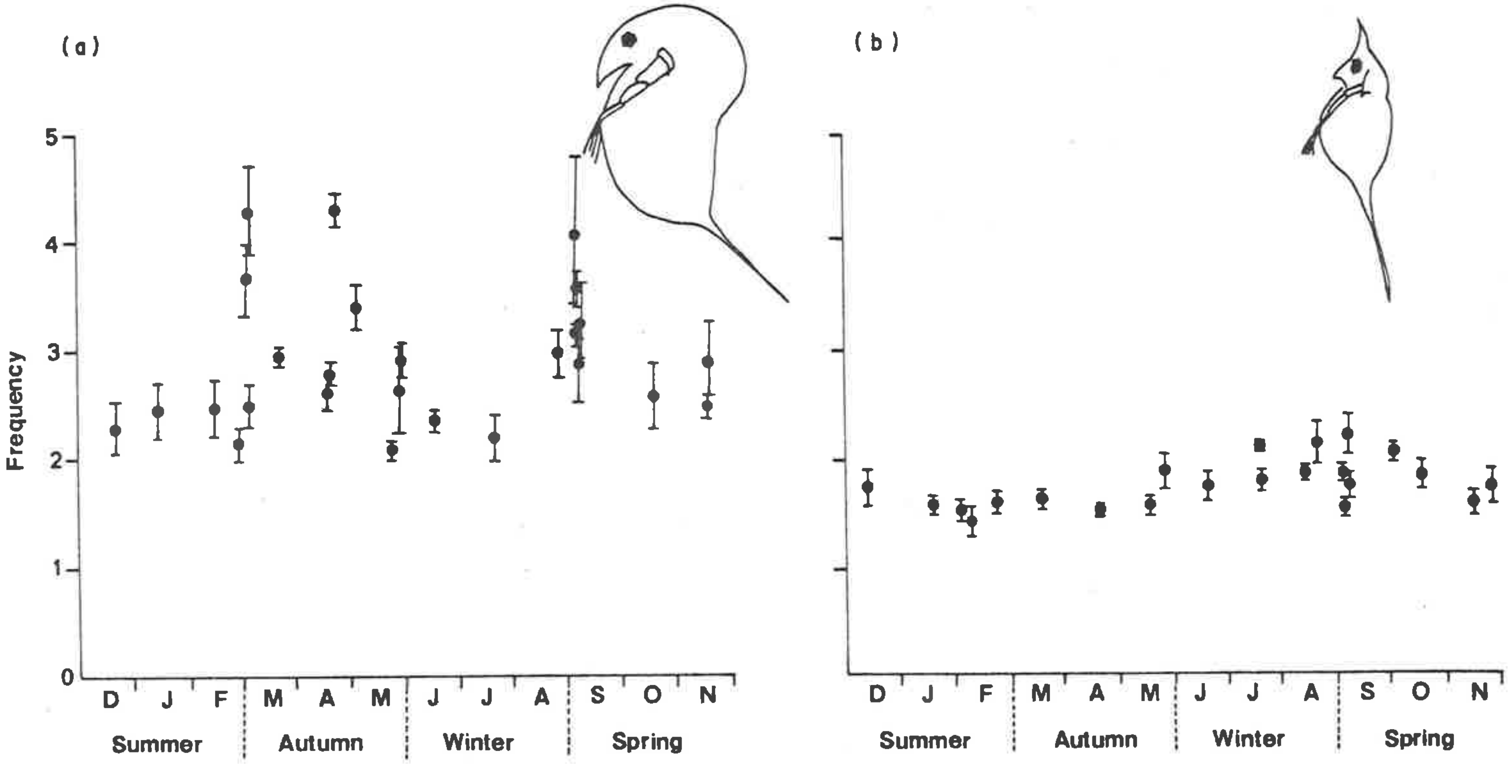


FIG 4 19 Seasonal variations in carapace length of (a) *D. carinata* and (b) *D. lumholtzi* ($\bar{x} \pm$ 1SD)

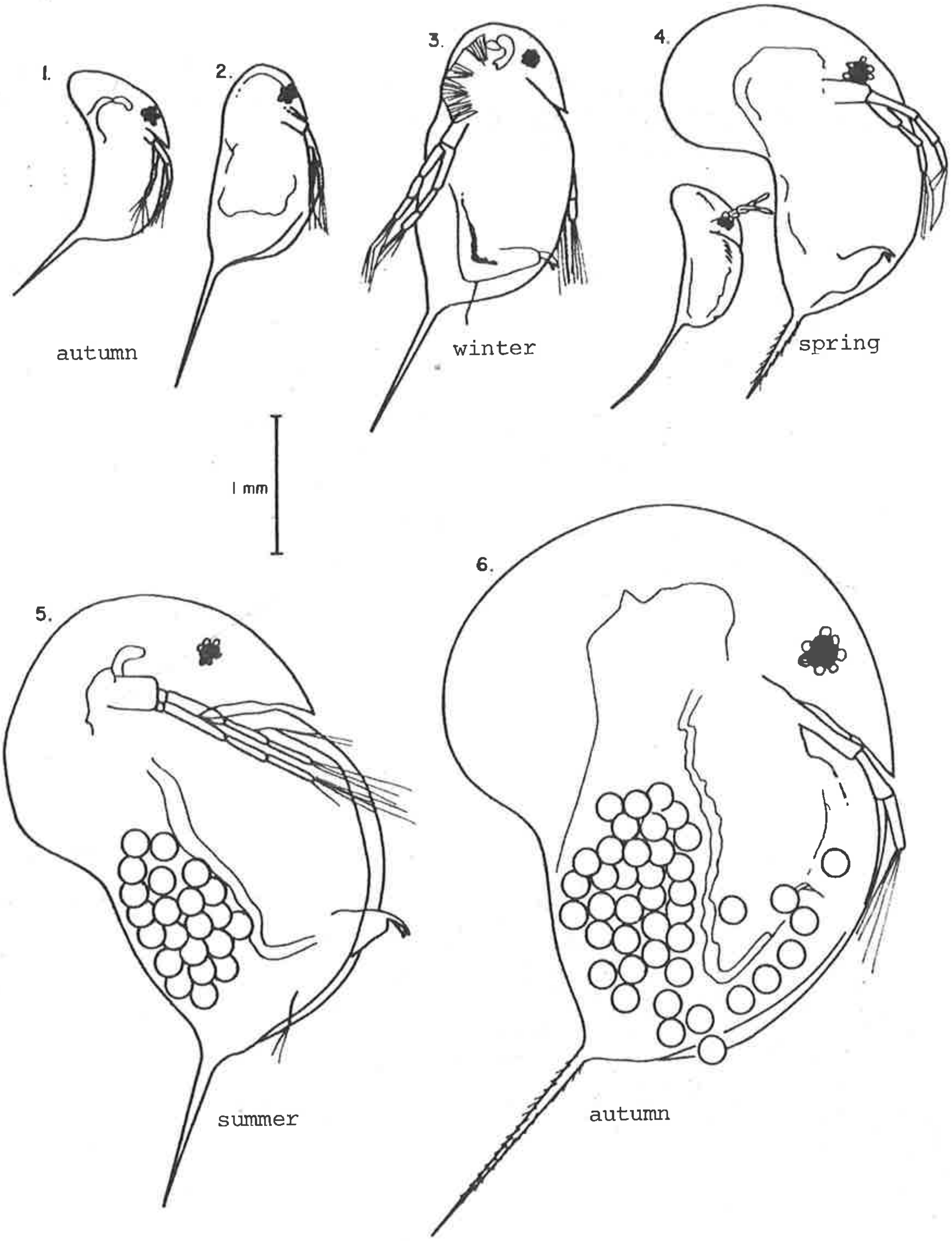
In its cyclomorphic development *D. carinata* exhibits several contrasts to northern hemisphere species. Unlike the cephalic development recorded in Holarctic *Daphnia* (Hutchinson, 1967), in this study cyclomorphosis in *D. carinata* involved expansion of the anterodorsal carina (cf. Sars (1904) var. *cephalata*). In contrast, the populations described from South Australia by Mitchell (1978) produced broad carapace "humps" (cf. Sars var. *magniceps*) in animals over 2 mm in length. In this study all instars of cyclomorphic populations had anterodorsal carapace expansion. A seasonal sequence showing morphological variability in a single habitat is given in Fig. 4.20.

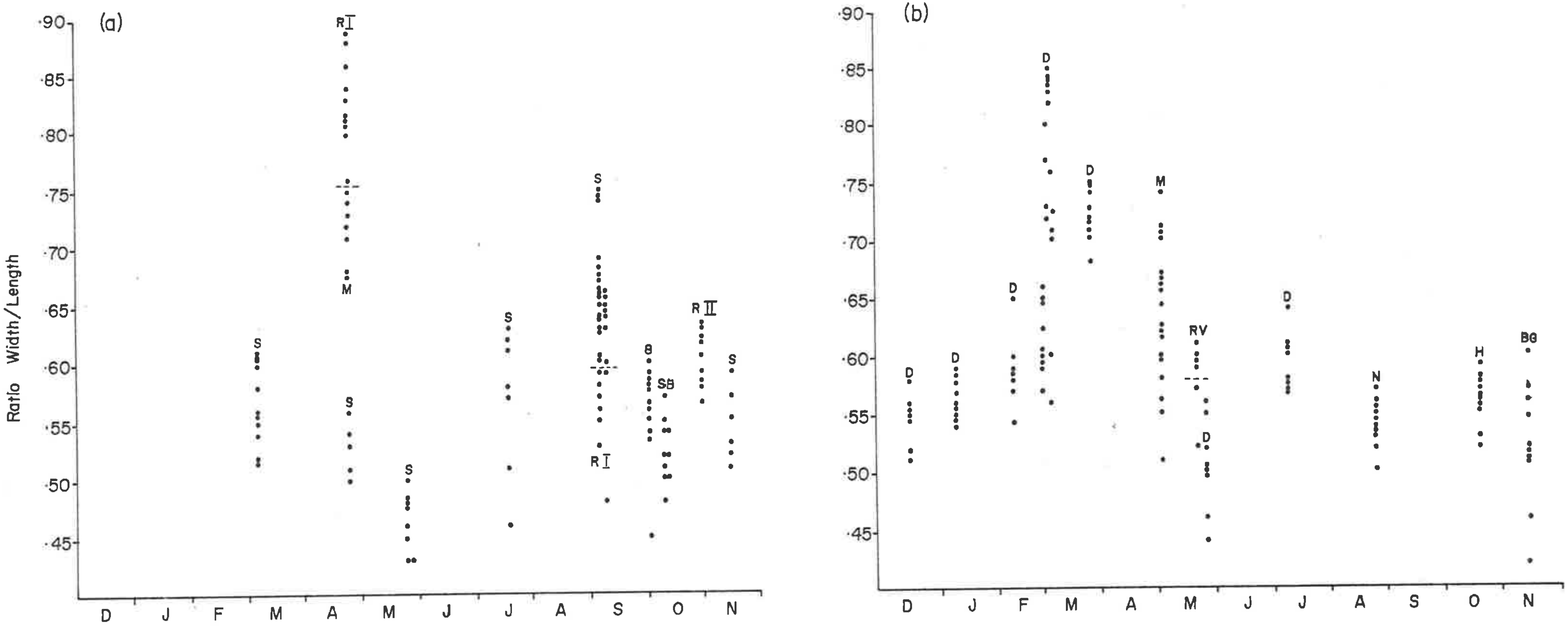
Width/length ratios for billabong and lake populations are plotted against season in Fig. 4.21. Maximum carapace length and anterodorsal carina expansion occurred simultaneously in the autumn. A second peak was noted in billabong forms during spring, but was not seen in lake populations. Northern hemisphere species undergo greatest development over summer (Hutchinson, 1967). Billabong populations were, in general, more extreme in carina development than those of lakes, again in contrast to northern hemisphere species (cf. Bayly & Williams, 1973). A single exception occurred in Dartmouth Dam, which was atypical of lacustrine habitats during filling (see Ch. 5). Morphological variability in the Dartmouth population was probably due to inoculation from a variety of discrete floodplain habitats which were submerged as the reservoir filled.

The greatest variation in a single *D. carinata* collection ($\bar{x}$ = 4.06 mm, Sx = 0.71, S$\bar{x}$ = 0.22; Fig. 4.19a, September) was recorded from a billabong at Wodonga which was receiving effluent as a waste stabilization pond. Several morphs occurred concurrently, as was reported in Mitchell's (1978) study; this may be characteristic of waste stabilization ponds in general. Similar co-occurrence was not noted for adjacent "natural" billabongs.

Ceriodaphnia: Morphological variants of several species were recorded. With the exception of a single population of *C. cornuta* in which all individuals

FIG 4·20 Morphological variability in *D. carinata* s.l. from Snowdon's billabong, Wodonga





LOCALITY CODE

M : Mildren's billabong
RI : Ryan's I billabong
RII : Ryan's II billabong
S : Snowdon's billabong
SB : Seymour's billabong
8 : 8-mile Creek

LOCALITY CODE

BG : Lake Burley-Griffin
D : Dartmouth Dam
H : Hume Reservoir
M : Lake Mulwala
N : Lake Nillahcootie
RV : Rocky Valley Dam

FIG. 4·21 Temporal variation in *D. carinata* width/length ratios
(a) billabong populations
(b) lake populations

were of the "horned" variety (Fig. 4.22a,b; cf. Rzoska, 1956; Zaret, 1972), variation was in size. Several populations were recorded with considerable reduction in eye size. This is considered later in relation to biotic influences. Because of taxonomic difficulties encountered with some species of the genus, comparative measurements were made only of the two readily identifiable species, *C. quadrangula* and *C. cornuta* (Fig. 4.23). Both species occurred as larger individuals over the colder months.

Bosmina, Chydorus: Isolated polymorphic populations of these plankters were collected. Variation involved dorsal expansion of the carapace over winter to produce a pronounced hump in *B. meridionalis*, with a less pronounced dorsal bulge in *C. sphaericus*.

THE INFLUENCE OF ABIOTIC FACTORS

While environmental variables such as temperature and salinity clearly may limit the distribution of species, their influence on morphological variability of the species may be indistinct. Mitchell (1978: 573) notes that high temperatures seem to play a role in cyclomorphosis in *D. carinata*, although the correlation is not clear from his study. In both *D. lumholtzi* and *D. carinata* in this study there was no significant correlatio between any measured water quality characteristic and cyclomorphosis (Spearman rank, F-test). The apparent inverse relationship between temperature and body size in *Ceriodaphnia*, with larger individuals over winter and in higher altitude waters in summer, was not significant.

THE INFLUENCE OF BIOTIC FACTORS

Following Brooks' (1965) hypothesis of the influence of planktivorous fish on helmet size in *Daphnia*, i.e. increased helmet size affords protection from predation, considerable information from field and laboratory studies has extended the predator-pressure hypothesis to include invertebrate planktivores and prey genera other than *Daphnia* (e.g. Dodson, 1974).

The influence of predators on Cladocera is little studied in Australi Mitchell's (1979) waste stabilization pond study suggested invertebrate

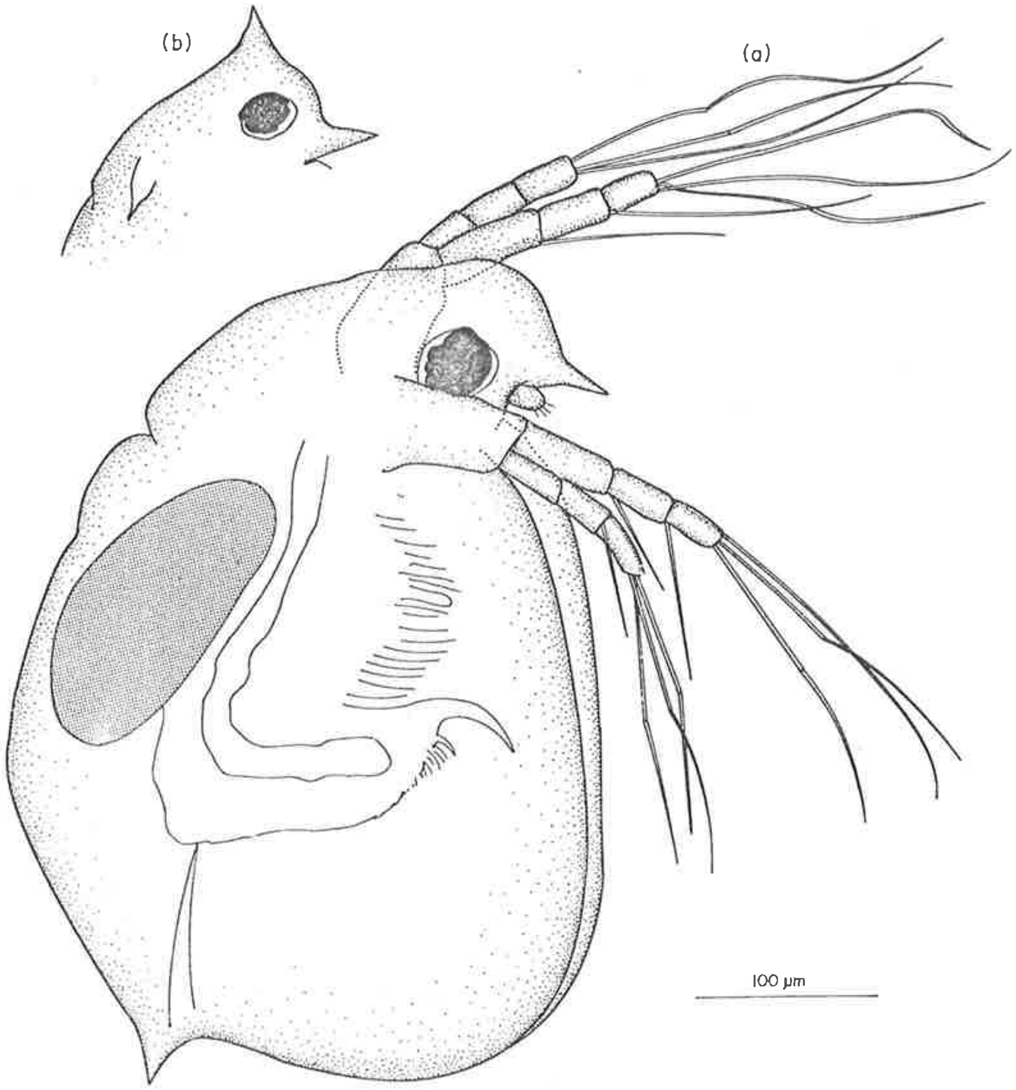
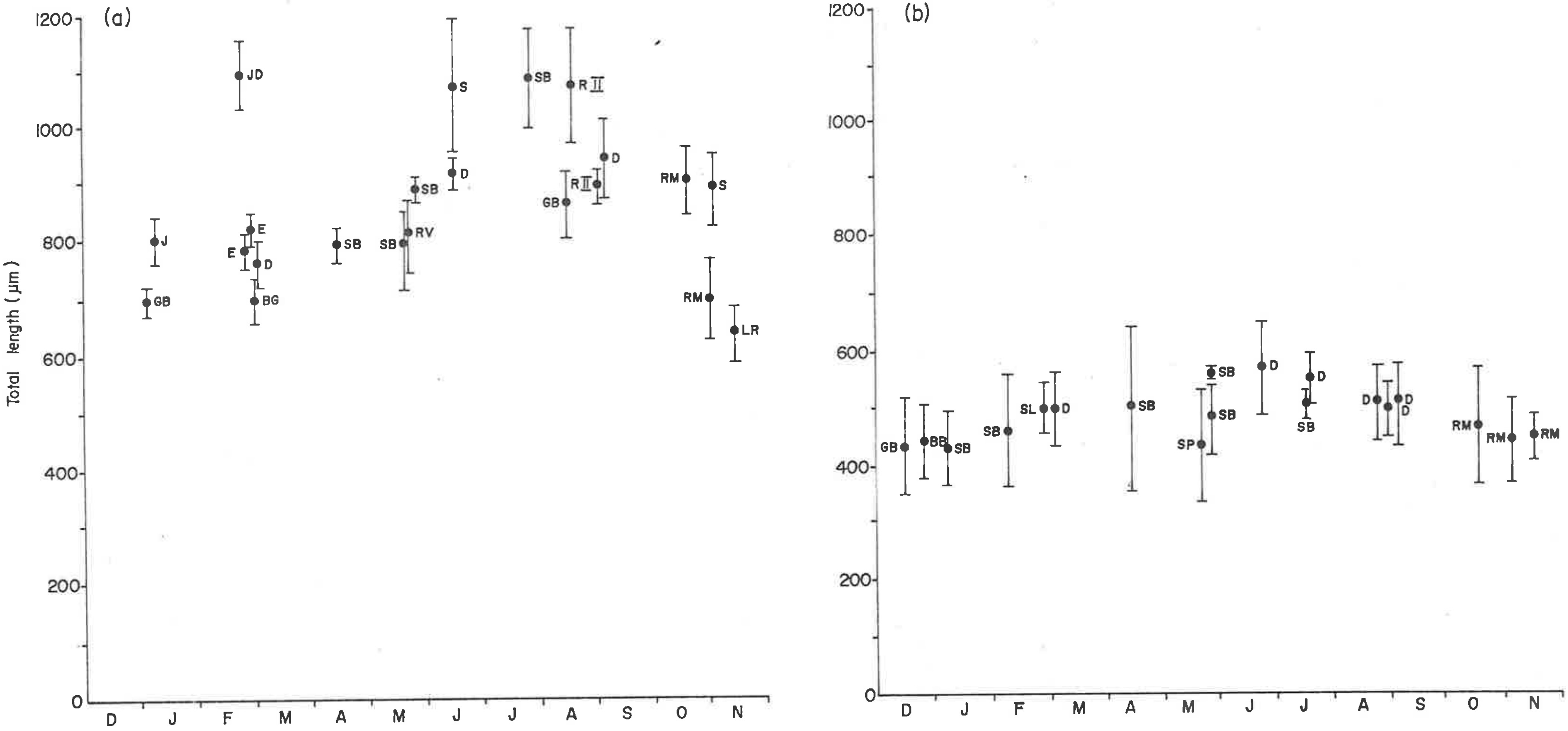


FIG. 4·22 *C. cornuta* (a) common 'hornless' form (Seymour billabong)
(b) horned form (billabong near Mungindi, N.S.W.)



LOCALITY CODE:

BG : Lake Burley-Griffin
D : Dartmouth Dam
E : Lake Eucumbene
GB : Goulburn View billabong
J : Lake Jindabyne
JD : Junction Dam
LR : Loddon River, Bridgewater
R II : Ryan's II billabong
RM : River Murray Mannum
RV : Rocky Valley Dam
S : Snowdon's billabong
SB : Seymour billabong
SL : Sheepwash Lagoon
SP : Sawpit Lagoon

FIG. 4·23 Temporal size variation in *Ceriodaphnia quadrangula*. (a); and *C. cornuta* (b) predators such as aquatic insects and raptorial cyclopoids may affect *D. carinata* populations, but the intensity of such predation was not determined. Correlations between the abundance of crested *D. carinata* populations and notonectid predators was reported from South Australia by Reynolds (1980), who also demonstrated the induction of cephalic crests in laboratory populations of *Daphnia* in the presence of *Anisops deani*. Similar cephalic induction was reported in pond populations of *D. carinata* var. *cephalata* subject to notonectid predation (O'Brien & Vinyard, 1978).

In the same variety of *D. carinata* in Murray-Darling waters, maximum carapace development (spring) corresponded with the greatest density of macroinvertebrates, particularly predatory dytiscids, notonectids and odonates (see Ch. 6), and, in some billabongs, with dense populations of mosquito fish (*Gambusia affinis*). Incidental observations on billabong *G. affinis* maintained in a laboratory aquarium during 1976 exemplify the selective value of increased carapace size to the cladoceran - live *D. carinata* returned to the laboratory over an 8-month period were selectively preyed upon by the fish, which took juvenile instars and left larger (> 3.0 mm) adults.

Such size selective predation accounts for the removal of size classes from billabong communities in the presence of *Gambusia* (and presumably the fry of other fish). Alteration of community structure in this way is described in Ch. 6; suffice to note here that under temperate Australian conditions predation pressure is less seasonal than is recorded for Holarctic studies (e.g. Hutchinson, 1967), and may, in part, account for the contrasts seen in cyclomorphic variation.

Variants also were recorded in *Ceriodaphnia*. The horned variety of *C. cornuta* recorded from a billabong of the Barwon River near Mungindi, N.S.W. co-occurred with *Gambusia*. Polymorphism in *C. cornuta* in response to fish predation is described by Zaret (1969, 1971, 1972), who notes that the species is able to decrease its visibility to predators by reducing the heavily pigmented area of the compound eye. Fig. 4.24 shows comparable eye

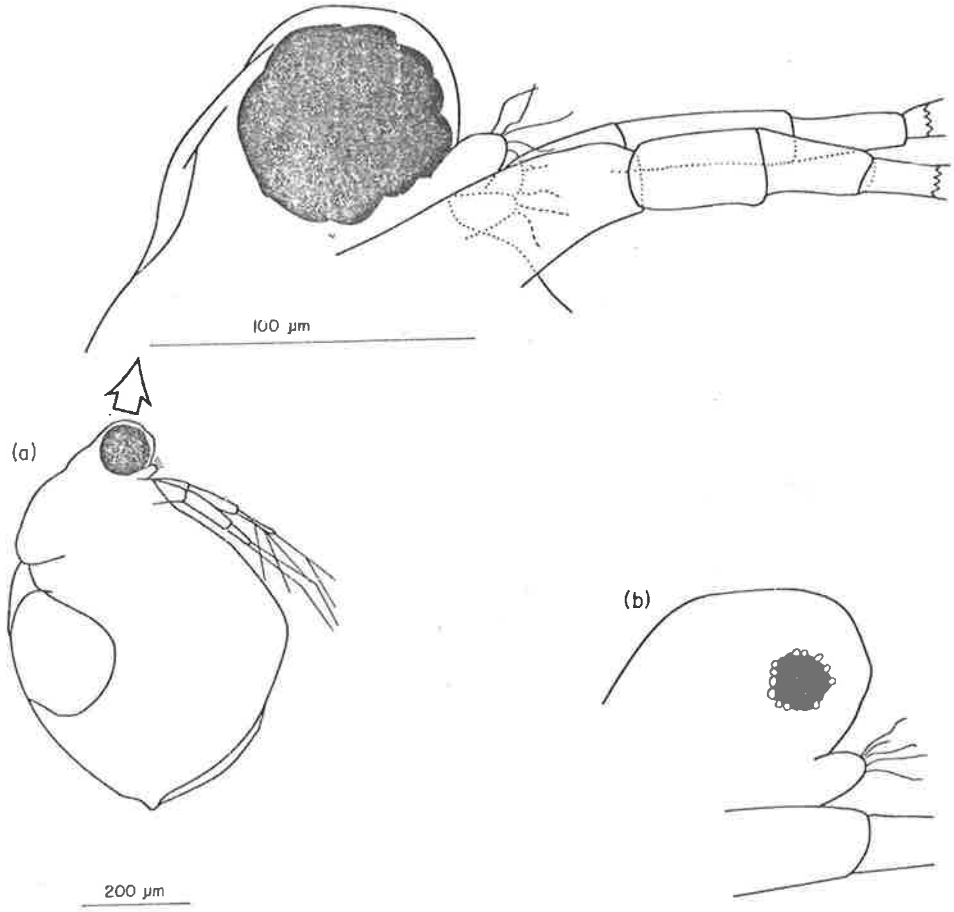


FIG 4 24 Variation in eye size in *C. quadrangula*
(a) from a billabong without *Gambusia* (b) from a billabong with the predator.

reduction in some billabong forms of *C. quadrangula*. The small-eyed form occurred only with dense populations of fish fry (*G. affinis* and unidentified spp.). Adaptations in prey species to foil visual and tactile predators are considered further by Dodson (1974), Zaret & Kerfoot (1975) and O'Brien, Kettle & Riessen (1979).

As in the Rotifera, where several species of a genus co-occurred, there normally was marked size separation. Congeneric associations were common in *Daphnia* (*D. carinata* > *D. lumholtzi*), *Ceriodaphnia* (commonly *C. quadrangula* > *C. cornuta*, although in Goulburn billabongs *C. laticaudata* > *C. cornuta* occurred, and rarely *C. laticaudata* > *C. quadrangula* > *C. cornuta* or *C. quadrangula* > *C.?pulchella* > *C. cornuta*. The latter congeners are shown in Fig. 4.25), *Biapertura* (commonly 4-5 species; *B. kendallensis* > *B. setigera* > *B. affinis* > *B. karua*) and *Alona* (*A. davidi* > *A. rectangula* > *A. guttata*). Such size differences effectively reduce competition for resources, and, as will be described in Chapter 6, the extent of such resource partitioning in Goulburn billabongs is greater than yet recorded from any freshwater habitat (cf. Shiel, 1976).

Food preferences and feeding behaviour of the cladoceran plankton were not assessed. Food was not considered to be limiting in most Murray-Darling habitats; only in oligotrophic headwater reservoirs were low algal densities recorded. Elsewhere, algae and organic detritus were abundant, zooplankton densities were low. These features, in relation to trophic status of the reservoirs, are considered later. The influence of food type and density on zooplankton communities was reviewed by Hutchinson (1967).

4.4 Copepoda

4.4.1 Introduction

Of the three orders of Copepoda, the Calanoida has been most intensively studied in Australia. Taxonomically, the group is reasonably well known (Bayly, 1961, 1962, 1963, 1966, 1967, 1979), but less so ecologically (cf. Williams, 1966; Bayly & Williams, 1973; Timms, 1979;

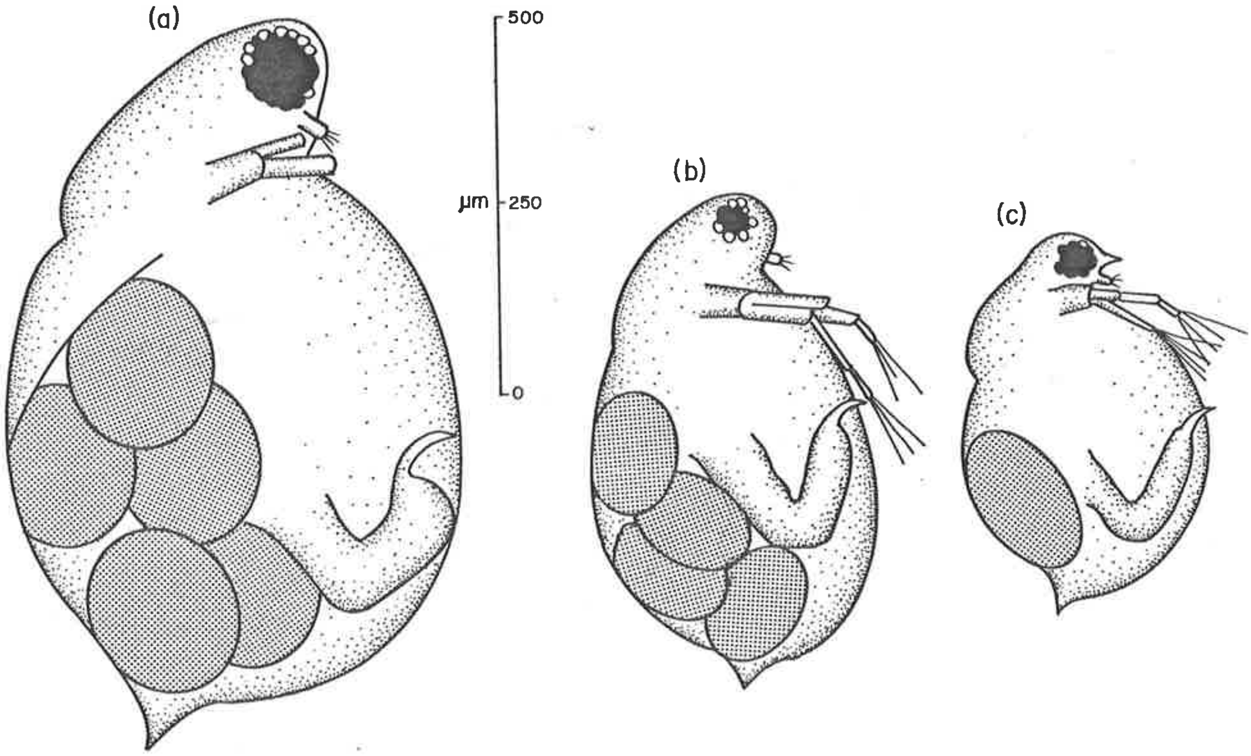


FIG. 4·25 Congeneric association of *Ceriodaphnia* (a) *rectangula* (b)? *pulchella* (c) *cornuta* (Goulburn billabong, Seymour Victoria)

Williams, 1980). Thirty-five species in three main genera (*Boeckella*, *Hemiboeckella* and *Calamoecia*) are known from Australian inland waters (Bayly, 1979). Two species of *Diaptomus* also are recorded, and one or two species of *Gladioferens* are known from coastal freshwaters (Timms, 1977; Bayly, 1979).

With the exception of *Diaptomus*, the Australian freshwater calanoids are of the family Centropagidae, and most genera are restricted to the Southern Hemisphere or Australasia (Bayly, 1963, 1966). Most species are endemi

Until recently (Morton, 1977), the Australian Cyclopoida were less well known. As yet, no comprehensive taxonomic work has been published, although isolated single-species descriptions exist,(e.g. Nicholls, 1944 ; Bayly, 1971). The cyclopoids also are neglected ecologically; only brief mention is made of the group in several recent studies,(e.g. Jolly & Chapman, 1966 ; Timms, 1970 ; Shiel, 1976 ; Morton & Bayly, 1977). Forty-four species of Cyclopidae are known from Australia, 60% of which are endemic (Bayly & Morton, 1978).

The least known of the copepods from Australia, the Harpacticoida, has been the subject of isolated taxonomic descriptions (e.g. Henry, 1919, 1922; Brehm, 1953; Hamond, 1971, 1972, 1973) but little ecological informatio is available. A forthcoming revision (R. Hamond, University of Melbourne, pers. comm.) should clarify both taxonomic and ecological features of the Australian fauna.

4.4.2 Taxonomy and ecology

4.4.2.1 Calanoida

Sixteen species of calanoid were recorded during this study (seven of *Boeckella*, one of *Hemiboeckella*, six of *Calamoecia* and two of *Gladioferens*). Of these, only one, *B. triarticulata*, was ubiquitous across the basin. Three others, *B. fluvialis, C. ampulla* and *C. lucasi* were relatively widely distributed, while the remaining species occurred only from single collections or one or two habitats. Taxa, and the ranges of water quality in which they was recorded, are listed in Table 4.9 and discussed briefly below. General observations on taxonomic and distributional features are given here; further information on ecological features, including quantitative data, is given in later chapters. Taxa are considered in the sequence of Table 4.9.

Genus : *Boeckella*

B. delicata: The single Australian record for this species given by Bayly (1964) was from Lake Eucumbene, also the only habitat from which breeding populations were collected in the present study, although isolated individuals occurred downstream in the Murrumbidgee and Burrinjuck Dam. *B. delicata* probably is perennial in Eucumbene. It also is reported from L. Wyuna, near Cooma, N.S.W.(Timms, 1979). This population has morphological differences indicative of a pond-like habitat , i.e. stouter body, shorter antennules than populations in the limnetic zone of deeper lakes.

B. fluvialis: Bayly (1964) noted that this species was absent from most of Victoria, but was distributed widely through Queensland and N.S.W. A record from Seymour billabongs during this study is the southernmost to date (I.A.E. Bayly, Monash University, pers. comm.). *B. fluvialis* was widely distributed across the basin, in a wide range of water quality. It was, however, a rare component of the reservoir limnoplankton, occurring in autumn each year in, for example, Hume, Burrinjuck and Eildon reservoirs. The species was more common in the limnetic region of small lentic habitats, and was the predominant and perennial calanoid in Murray billabongs. It also was perennial in small numbers in Goulburn Weir, but was notably rare in upstream Goulburn billabongs. The occurrence of *B. fluvialis* in reservoirs coincided with high autumn flows; the species possibly was washed in from floodplain habitats. Isolated records, generally from small, shallow reservoirs, are given by Jolly (1966) and Timms (1970a, b, 1973).

B. major: This large species (>3.0 mm) was recorded only once, from a billabong near Wodonga. Previous records are from small bodies of water in southern Victoria and Tasmania (Bayly, 1964).

B. minuta: Predominantly from floodplain habitats, *B. minuta* was a common

Table 4.9 : Copepoda recorded from the zooplankton and littoral microfauna of the Murray-Darling waters.

#	Taxon	DL	DB	DR	ML	MR	MR	LM	Temp. (°C)	pH	DO (ppm)	Cond. (µS)	Turb. (NTU)
	Ord. CALANOIDA												
	FAM.CENTROPAGIDAE												
1	*Boeckella delicata* Percival, 1937				●		●		7.2 - 18.0	7.0 - 7.7	8.2 - 9.6	23 - 31	0.5 - 5.4
2	*B. fluvialis* Henry, 1922	●	●	●	●	●	●		7.8 - 28.0	4.9 - 8.1	3.1 - 11.6	45 - 800	0.5 - 350
3	*B. major* Searle, 1938					●			16.7	7.4	9.8	236	2.0
4	*B. minuta* Sars, 1896				●	●		●	6.5 - 29.4	4.8 - 8.2	1.0 - 13.8	52 - 827	2.0 - 350
5	*B. pseudochaele* Searle, 1912				●				7.0 - 14.0	6.4 - 6.7	8.0 - 9.8	39 - 58	0.2 - 1.0
6	*B. symmetrica* Sars, 1908					●			15.3	6.9	7.1	170	4.0
7	*B. triarticulata* Thompson, 1883	●	●	●	●	●	●	●	5.0 - 29.0	6.2 - 8.7	1.5 - 12.5	55 - 1950	0.5 - 350
8	*Hemiboeckella searli* Sars, 1912					●			10.0 - 29.4	7.1 - 7.3	1.2 - 13.8	52 - 250	2.5 - 23.5
9	*Calamoecia ampulla* (Searle) 1911	●		●	●		●	●	8.0 - 31.0	6.2 - 8.5	6.5 - 11.8	60 - 1950	1.2 - 115
10	*C. australica* Sars, 1908				●				15.0	7.4	9.2	250	12.5
11	*C. canberra* Bayly, 1962		●						24.0	7.2	9.1	-	-
12	*C. clitellata* Bayly, 1962				●						n/a		
13	*C. expansa* Sars, 1912				●	●			8.4 - 22.0	7.0 - 7.5	8.4 - 11.0	55 - 230	0.5 - 27
14	*C. lucasi* Brady, 1906	●	●	●	●	●	●	●	6.2 - 27.4	7.0 - 8.7	2.7 - 12.5	45 - 1100	0.5 - 350
15	*Gladioferens pectinatus* (Brady) 1899							●	14.0 - 22.0	8.0 - 8.1	8.7 - 10.0	608 - 1010	23 - 38
16	*G. spinosus* Henry, 1919			●	●		●	●	11.0 - 21.0	7.7 - 8.7	8.3 - 10.8	290 - 1100	90 - 120
	Ord.CYCLOPOIDA												
	FAM. CYCLOPIDAE												
17	*Microcyclops dengizicus* Lepeshkin, 1900		●		●		●		6.0 - 19.1	4.2 - 7.8	9.1 - 10.0	65 - 275	0.2 - 24
18	*M. varicans* Sars, 1863				●	●	●	●	10.5 - 29.4	4.9 - 8.3	1.0 - 12.4	110 - 900	0.5 - 130
19	*Ectocyclops medius* Kiefer, 1930					●		●	11.0 - 29.4	7.1 - 7.8	1.4 - 9.4	125 - 520	2.5 - 125
20	*Macrocyclops albidus* (Jurine) 1820				●	●		●	5.0 - 26.6	6.2 - 8.0	1.2 - 10.3	31 - 500	0.5 - 350
21	*Mesocyclops decipiens* Kiefer, 1929				●	●	●	●	10.0 - 24.9	6.0 - 8.5	1.7 - 11.6	55 - 660	0.5 - 350

Table 4.9 (cont):

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (°C)	pH	DO (ppm)	Cond. (μS)	Turb. (NTU)
22	*M. hyalinus* (Rehberg) 1880	●			●				20.0 - 23.0	6.5 - 7.6	8.6 - 9.1	45 - 54	2.0 - 5.0
23	*M. leuckarti* (Claus) 1857	●	●		●	●	●	●	7.8 - 29.4	4.9 - 8.5	1.2 - 13.8	55 - 1950	0.5 - 275
24	*Acanthocyclops vernalis* (Fischer) 1853				●	●	●		7.0 - 26.6	7.1 - 7.5	1.2 - 9.7	95 - 460	5.0 - 350
25	*Tropocyclops* n.sp.1 unpublished	●	●		●	●			8.0 - 29.4	7.1 - 8.0	1.2 - 13.8	60 - 1080	0.5 - 60
26	*T.*n.sp.2 unpublished				●	●			15.0 - 29.4	6.2 - 7.2	1.2 - 8.2	164 - 245	2.5 - 27
27	*T.*n.sp.3 unpublished					●			12.4	7.3	6.6	435	7.5
28	*T.*n.sp.4 unpublished			●					17.0	8.3	9.0	430	350
29	*Eucyclops agilis* (Koch) 1838		●	●	●	●		●	10.0 - 26.4	7.1 - 8.4	1.2 - 12.0	142 - 555	2.5 - 135
30	*E.*n.sp. unpublished				●	●	●	●	8.0 - 29.4	6.9 - 8.0	1.4 - 13.8	60 - 508	1.0 - 120
31	*Paracyclops chiltoni* (Thompson) 1883				●	●		●	8.5 - 29.4	7.0 - 8.3	9.2 - 12.0	164 - 500	2.4 - 220
32	n.gen.n.spp. unpublished		●		●	●		●	15.0 - 25.0	7.2 - 8.1	6.3 - 9.0	55 - 700	0.5 - 90
	Ord. HARPACTICOIDA												
	FAM.CLETODIDAE												
33	*Cletocamptus* cf. *dietersi* (Richard) 1897							●	12.0	8.1	11.0	460	95
	FAM.CANTHOCAMPTIDAE												
34	*Mesochra baylyi* Hamond, 1971				●						n/a		
35	*Attheyella australica*				●		●	●	15.0 - 20.2	6.2 - 8.0	6.5 - 10.0	112 - 600	0.5 - 100
36	*A.*n.sp. unpublished					●			7.8 - 19.0	6.2 - 7.4	1.4 - 13.0	52 - 450	2.6 - 35
37	*Elaphoidella* cf. *bidens* (Sars) 1904				●	●		●	11.0 - 19.0	7.0 - 7.8	1.4 - 9.8	65 - 560	2.0 - 125
38	n.gen.n.sp. unpublished					●			14.0	7.2	10.1	67	1.0
	FAM. D'ARCITHOMPSONIIDAE												
39	n.gen.n.sp. unpublished					●			9.6	7.0	12.4	55	0.5

calanoid from Goulburn billabongs. Although recorded as the most common calanoid in artificial impoundments in northeastern N.S.W., (Timms, 1970), it was rare in the large Murray-Darling storages, e.g. Eildon (spring-summer), Hume (summer), Mulwala (autumn). Only in the small Kiewa River storage, Junction Dam, were small breeding populations recorded (autumn).

B. pseudochaele : Until now characteristic of small temporary waters and occurring in late spring (Bayly, 1964 and pers. comm.), this species is restricted to isolated habitats along the Eastern Highlands. In this study it was recorded in late summer 1976-77 and spring 1977 from Rocky Valley Dam, with the congener *B. triarticulata*. Presence of large breeding populations of *B. pseudochaele* suggested that it was established in the storage rather than washed in. Rocky Valley Dam is relatively small, and possibly has features of a temporary habitat resulting from extremely rapid level fluctuations produced by drawdown for power generation.

B.symmetrica : This species was recorded only once, from Ryan's billabong at Wodonga. Bayly (1964) regarded the species as widely distributed (N.S.W., Vic.,Tas.,S.A.), and it is likely that populations of this species were missed,i.e. by the patchiness of the sampling program, or by its seasonal occurrence (spring) in small numbers, and particularly if present with the congener *B.triarticulata*, which it superficially resembles.

B.triarticulata : The most common and widely distributed of the calanoids, this polymorphic species occurred perennially in most reservoirs, and was the only calanoid to occur perennially in the lower Murray (Ch. 7). It was not common in Murray billabongs, and occurred sporadically (autumn and spring) in those of the Goulburn. It was recorded in a greater range of water quality than were other species of the genus, i.e. is eurytopic. It also was most variable in size, and in structure of the taxonomically significant ♂ P5. In a summer collection from Rocky Valley Dam, for example, mean size of ♂♂ was 1.82 mm (n=20)(05.i.77). The following autumn, mean size of ♂♂ was 1.38 mm (n=2, no other ♂♂ were present in the sample). While this 24% variation in size is close to the range reported for other species of the genus (Bayly, 1964), the diminution in size over the colder months is converse to the normal situation. Possible reasons, including the presence of two congeners, *B. minuta* and *B. pseudochaele* are considered later.

An eighth and unfamiliar species of *Boeckella* was recorded (Goulburn View billabong, Alexandra, 22.viii.78). A single ♂ was collected, and sent for expert identification. The slide was broken in transit, and part of the taxonomically significant P5 was lost. The species possibly was *B. montana* Bayly, which occurs at high altitudes in the Eastern Highlands (I. A. E. Bayly, pers. comm.). Flood transport would account for the Goulburn billabong record.

Genus: *Hemiboeckella*

Of three known species of this genus, only one, *H. searli*, was recorded in this study. It was probably perennial in small numbers in a billabong of the Goulburn River (cf. Shiel, 1974).

Genus: *Calamoecia*

Most species of this Australasian genus are small (♂ <1.0 mm) and typically occur in permanent waters (Bayly, 1961). In this study, species of *Calamoecia* were commonly the smaller member when two or more species of calanoid were associated. Four of the six recorded species were of restricted distribution; only *C. ampulla* and *C. lucasi* were eurytopic.

C. clitellata: One of two known halobiont species, *C. clitellata* was identifie from a collection taken by WSCV officers from Lake William, one of the saline Kerang Lakes, and is the only record in this study. The species occurs in saline lakes across S.E. Australia, also in Western Australia (Bayly, 1979).

C. canberra: Also from a single record, this species occurred in a temporary roadside pool (22° C, pH 8.0) near Cunnamulla Qld (see Fig. 2.2), which is within the triangle shown by Bayly & Williams (1973:114,Fig. 6.4) for the known distribution of the species. It apparently is an opportunist; rains some 6-8 days earlier had been the first in several months, yet adult calanoid were present. Other plankters present were juvenile anostracans and daphniid cladocerans.

C. australica: A small population occurred in Burrinjuck Dam (18.v.77). Slight differences from the type (Sars, 1908) and from the description by Bayly (1962) were noted, e.g. 7 spines rather than 5 on the left endopodite. This taxon may have been washed into the dam from a small floodplain habitat.

C. lucasi: The most widely distributed species of the genus, *C. lucasi* was perennial in Lake Burley-Griffin, occurring seasonally (autumn-winter) in other storages, e.g. Eildon, Goulburn Weir, and was common in Goulburn billabongs. It replaced *C. ampulla* at lower temperatures, i.e. although eurytopic, the species possibly has a slightly lower temperature tolerance.

C. expansa: Previously known from a few low Ca^{++}, acid/humic waters of S.E. Victoria and Tasmania (Knott & Lake, 1974; see also Bayly, 1962), *C. expansa* was perennial in Goulburn Weir, Nagambie, with a winter maximum. It also was recorded from upstream billabongs. While these habitats were not acid or humic, they were low in Ca^{++} (<3.0 mg ℓ^{-1}). The species occasionally was the dominant (and largest) calanoid, with smaller congeners *C. lucasi* or *C. ampulla* subdominant.

C. ampulla: Widely distributed in the basin, *C. ampulla* was common in Darling River reservoirs, and was the predominant calanoid in Burrinjuck, Eildon, Hume Nillahcootie and Lake Victoria. Maximum abundance was over spring-summer and early autumn. In Goulburn Weir there was an autumn-winter maximum. *C. ampull* was perennial in Mulwala during 1976-77, but was replaced by *C. lucasi* in autumn 1977 and was not recorded again. The species was eurytopic, tolerant o raised salinities, and occurred sporadically in the lower Murray.

Genus: *Gladioferens*

This Australasian genus was considered by Bayly (1963) to be restrict to coastal waters, i.e. less than 60 km from the sea. The occurrence of two species in Murray-Darling waters was therefore of interest, and possibly represent introductions through man's activities.

G. pectinatus: Recorded as the dominant zooplankter in the Brisbane River, and from coastal localities in Eastern Australia (Bayly, 1963), this extremely euryhaline species was collected once from the Murray at Mannum, and was possibly transported in bilgewater by power boat from coastal waters, e.g. Lake Alexandrina, some 70 river km south.

G. spinosus: Similarly, a record of this taxon from Eildon Reservoir was clearly an example of such transport. It was recorded in the Jerusalem Creek boat harbour (southern arm of the reservoir). Less clear, however, was a record from the Darling River at Pooncarrie, from the Murray below the Darling confluence, and the presence of a perennial breeding population in Lake Cullulleraine, i.e.> 500 km from the Murray mouth. *G. spinosus* subsequentl was identified from collections made in the late 1960's near the site of the proposed Chowilla Dam (Lindsay River) upstream of Renmark (I. A. E. Bayly, pers. comm.). The species possibly was introduced into these waters from coastal localities by boating, and became established there, or may have become established prior to construction of barrages and locks when marine incursions were apparent considerable distances upstream (see p.21). In any event, *G. spinosus*, regarded as a true freshwater species essentially littoral in habit and frequenting aquatic plants at the edges of lakes or sluggish rivers (Bayly, 1963), is now well established in L. Cullulleraine.

Diaptomus, two species of which occur in northern Australia, was not recorded in the north of the basin, although its distribution overlaps those of *Boeckella* and *Calamoecia*, and *D. australis* has been recorded in northern N.S.W. (Henry, 1922). The genus is considered further by Bayly (1966).

4.4.2.2 Cyclopoida

Cyclopoids were poorly represented in the plankton of lakes and rivers of the Murray-Darling system, but were common in billabongs and other small lentic habitats (cf. Hutchinson, 1967) i.e. species collected were essentially littoral and benthic in habit. Eighteen species were recorded. These are listed in Table 4.9 and discussed briefly below. Due to taxonomic difficulties, particularly lack of published keys to the Australian cyclopoids, many taxa in early collections were identified only to genus; distributions shown in Table 4.9 therefore are incomplete, and considerably more species probably were present.

Genus: *Microcyclops*

Fourteen species of *Microcyclops* are known from Australia, eleven of these apparently are endemic (Bayly & Morton, 1978). Only two species were positively identified from Murray-Darling waters, both cosmopolitan.

M. dengizicus: Widely distributed across the basin in small lentic habitats, this species is reported as restricted to moderately saline waters (D. W. Morton, pers. comm.,cf. De Deckker & Geddes, 1980). While some of the records in this study were from saline habitats (e.g. the Kerang Lakes), others were from low salinity pools and billabongs (e.g. a roadside pool, Gilgandra, N.S.W., 24.v.78, 65 µS). *M. dengizicus* was collected also from Lake Burley Griffin (15.xi.77, 280 µS).

M. varicans: Common in Goulburn billabongs (summer-autumn maxima) and some Murray billabongs, this species occurred also in the plankton of Eucumbene and Eildon, and sporadically in the lower Murray over a wide range of water quality. It was not recorded from Darling waters.

Genus: *Ectocyclops*

A single species, *E. medius*, a typically benthic form (Rylov, 1948), was common, although in small numbers, in Goulburn and Murray billabongs.

Genus: *Macrocyclops*

M. albidus, a eurytopic littoral species, was common and perennial in billabongs, and was collected sporadically as a littoral stray from lake margins, e.g. Eucumbene, Eildon.

Genus: *Mesocyclops*

Two of the three recorded species were restricted in distribution; *M. decipiens* probably was perennial in Goulburn billabongs (autumn maxima) and some Murray billabongs. It was limnetic in some reservoirs, e.g. Dartmouth (summer), Mulwala (summer-autumn). It was eurytopic, notably tolerant of very low dissolved oxygen concentrations in billabongs over summer.

M. hyalinus: Recorded over a narrow range of water quality in the limnoplankton of Burrendong (autumn 1977) and Dartmouth (summer 1977-78).

M. leuckarti: The most widely distributed of the cyclopoids, this eurytopic cosmopolitan species was perennial in small numbers in Mulwala and Eildon, and seasonal in other storages, e.g. Dartmouth, Hume. It was present in all Darling River storages, was perennial in most billabongs, and seasonal (spring -summer 1976, summer-autumn 1977) in the lower Murray.

Genus: *Acanthocyclops*

A. vernalis, another cosmopolitan taxon, was common in billabongs, and occasionally pseudoplanktonic in Goulburn Weir and Dartmouth.

Genus: *Tropocyclops*

Four taxa were recorded, all new species (D. W. Morton, pers. comm.). One was limnetic, eurytopic and widely distributed in lakes and billabongs of the Darling and Murray. The remaining species were restricted to one or two small lentic habitats, e.g. Rocky Valley Dam.

Genus: *Eucyclops*

Two species were identified; *E. agilis*, a cosmopolitan and eurytopic limnoplankter recorded occasionally in some reservoirs, e.g. Eucumbene, and in several rivers, including the lower Murray, and a new species. The latter was widely collected in Murray waters, but not from the Darling. It apparently was eurytopic.

Genus: *Paracyclops*

Two species of this typically benthonic form were collected; *P. affinis* (cosmopolitan) and *P. chiltoni* occurred in plankton tows from billabongs and lake margins in the Murray catchment, *P. chiltoni* sporadically in the lower Murray.

Genus: nov.

A preliminary report on a new cyclopoid genus containing two species was given by Bayly & Morton (1978). Both species were widely distributed in the basin, and occasionally were co-occurrent (e.g. Eildon). One species was perennial in the Eildon limnoplankton, possibly also in Dartmouth, and both species were recorded from the lower Murray. The large size of the taxa (i.e. > *Macrocyclops*) suggests that they may be carnivorous.

4.4.2.3 Harpacticoida

Essentially benthic in habit, harpacticoids were recorded in samples from billabongs and lake margins. Seven taxa were identified; several others, collected as single individuals, were not. One halobiont species, *Mesochra baylyi*, occurred in Lake Charm (Kerang Lakes area) and the Richardson River at Donald. *Cletocamptus* cf. *dietersi*, recorded from the River Murray at Mannum, apparently also is a halobiont (cf. Hamond, 1973). The most widely recorded taxa were *Attheyella australica* and the cosmopolitan *Elaphoidella* cf. *bidens*, both of which apparently are eurytopic.

4.4.3 Discussion

Because considerable information was available on morphological variability in the Australian Calanoida, and because the taxonomically difficult Cyclopoida and Harpacticoida were under revision, less attention was given to quantitative assessment of morphological variability in these groups. Nevertheless, some general comparative observations are possible prior to consideration of community structure in the following chapters.

With few exceptions, copepods were recorded from similar habitats to those in other Australian studies. Within each group only one or two species were widely distributed and eurytopic (e.g. *B. triarticulata, B. fluvialis, C. ampulla, C. lucasi, M. leuckarti, M. varicans, A. australica, E.*cf. *b idens*). All the calanoids were limnoplankters, most more commonly found in billabongs and small lentic habitats. Only the polymorphic *B. triarticulata* persisted in breeding populations into the extremely variable habitat of the lower Murray. Cyclopoids generally were minor components of the limnoplankton of reservoirs, but as will be shown in Ch. 6, were extremely important in billabong communities. Only a single species, the cosmopolitan *M. leuckarti*, was ubiquitous. Harpacticoids were collected only as strays from littoral areas.

POLYMORPHISM

There usually are marked differences in size between closely related calanoid species occurring in the same habitat (cf. Hutchinson, 1951, 1967). Some species have strong sexual dimorphism (cf. Bayly, 1964, 1967). This is more pronounced in temporary waters, and may enhance particle size separation in feeding (Bayly, 1978). Intraspecific morphological variation may be seasonal, or a response to habitat type (cf. Timms, 1979).

In the present study, intraspecific variation in the few populations of which measurements were made generally was within ranges reported in other studies, i.e. 3-4% mean coefficient of variation between sexes, to ≃20% temporal variation (cf. Bayly, 1962; Timms, 1967; Geddes, 1968). The unusuall small population of *B. triarticulata* in Rocky Valley Dam (p.77) may have been a response to competetive pressure, i.e. *B. minuta* and *B. pseudochaele* were co-occurrent, and the small *B. triarticulata* was intermediate between these two in size, although there was some overlap in ♀♀ of the three species. Ther may have been a selective pressure for small size exerted by some visual predator.

While co-occurring calanoid species commonly were different in size, records of similar sized congeners or coexisting genera were not unusual. These included *B. fluvialis/B. triarticulata*, *B. triarticulata/B. symmetrica*, *C. lucasi/C. ampulla* and *B. minuta/C. lucasi*. Co-occurring calanoid species were more common in lakes than in billabongs. In 82 collections from Goulburn billabongs, for example, 40 contained one calanoid species, 10 contained two species, three had three species, one had four species and a single collection contained five coexisting calanoid taxa. Common associations were: *B. fluvial* > *B. minuta*, *C. expansa* > *B. minuta*, *H. searli* > *B. minuta*, *B. fluvialis* > *C. lucasi*, *B. fluvialis* > *B. triarticulata* (note that billabong populations of *B. fluvialis* usually were larger in body size than coexisting *B. triarticulata*); less common were *B. fluvialis* > *B. triarticulata* > *C. lucasi*, *B. fluvialis* > *B. minuta* > *C. lucasi*, *C. expansa* > *C. lucasi* > *C. ampulla*, *B. fluvialis* > *C. expansa* > *C. lucasi* and rarely *B. fluvialis* > *C. expansa* > *C. lucasi* > *C. ampulla* and *B. fluvialis* > *B. triarticulata* > *C. expansa* > *C. lucasi* > *C. ampulla*. Calanoid associations from Australia and New Zealand are listed by Bayly & Williams (1973:106, Table 6.3) and considered further in later chapters. Also considered later are the influences of abiotic and biotic factors on individual taxa.

4.5 Ostracoda

Ostracods are predominantly benthic or littoral in habit. They were collected infrequently in this study, generally from billabongs or lake margins in close proximity to vegetation. Only a single genus occurred in the limnetic region of lakes (*Cypretta* spp.) or occasionally in the potamoplankton. Characteristically, ostracods from open water had elongated swimming appendages and were adapted to a planktonic habit. Taxa, and the ranges of water quality from which they were collected, are listed in Table 4.10, and considered in more detail in Ch. 6.

4.6 Conclusions

The first aim of the study was to provide a comparative account of the limno- and potamoplankton of representative reservoirs and rivers of the Murray-Darling system. The extent to which this has been realized will be more apparent from later chapters. The large area of the basin and diversity of habitats precluded an exhaustive treatment; indeed, in view of the extreme habitat diversity, it is doubtful if any of the reservoirs or rivers could be considered representative.

Clearly, from the systematic account given here, the paucity of information on the plankton of Australian waters reflects a lack of workers rather than a lack of material. Also, many of the published studies represent single collections or a few visits to a particular habitat, so

Table 4.10 Ostracoda recorded from the zooplankton and littoral microfauna of the Murray-Darling waters.

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (°C)	pH	DO (ppm)	Cond. (µS)	Turb. (NTU)
	FAM.LIMNOCYTHERIDAE												
1	*Limnocythere* sp. Brady, 1868					●			14.0	7.3	9.6	500	4.5
	FAM.ILYOCYPRIDIDAE												
2	?*Ilyocypris* sp. Brady&Norman,1889							●	17.5	8.7	9.1	1100	20
	FAM.CANDONIDAE												
3	*Candona stobarti* (King) 1855				●		●		17.0	7.4	9.5	193	2.0
4	**C.*n.sp. unpublished				●	●			17.0	7.4	9.0	125	5.0
5	*Paracypria minuta* McKenzie, 1968					●			17.0 - 29.4	7.1 - 7.2	1.5 - 8.2	164 - 245	2.5 - 10.0
	FAM.CYPRIDIDAE												
6	*Newnhamia fenestrata* King, 1855				●				14.0	7.3	9.8	125	1.0
7	*Newnhamia* sp. King, 1855				●	●			14.0 - 17.0	6.9 - 7.4	8.4 - 9.1	140 - 325	2.5 - 12.5
8	*Platycypris baueri* Herbst, 1957				●				20.0	7.2	8.3	235	5.0
9	*Heterocypris leana* (Sars) 1896					●			10.0 - 17.0	7.2 - 7.3	9.8 - 13.0	52 - 227	1.0 - 23.5
10	**H.* n.sp. unpublished					●			16.0	7.2	9.8	187	4.5
11	*Strandesia* n.sp. unpublished				●	●			10.0 - 17.0	7.2 - 7.4	9.0 - 13.0	52 - 227	0.5 - 23.5
12	**Cypricercus* n.sp. unpublished					●			10.0	7.3	13.0	52	23.5
13	*Eucypris virens* (Jurine) 1820					●			12.6	7.1	12.2	66	2.5
14	*Herpetocypris* sp. Brady & Norman,1889					●			17.2	7.2	9.8	210	2.5
15	*Ilyodromus ellipticus* Sars, 1896					●			17.0	7.2	9.8	227	-
16	*I. smaragdinus* Sars, 1895					●			11.0	7.1	10.2	115	2.5
17	*Ilyodromus* sp. Sars, 1895					●			14.2 - 16.4	7.2 - 7.5	2.7 - 6.4	450 - 660	0.5 - 350
18	"*Cypris*"*bennelong* King, 1855					●			14.0	7.2	8.6	124	3.0
19	"*Cypris*"aff. *lateraria* King, 1855					●			19.5	7.3	8.4	115	5.0
20	"*Cypris*" sp. Müller, 1776					●			19.5	7.3	8.4	115	5.0
21	*Mytilocypris splendida* (Chapman) 1966				●						n/a		

Table 4.10:(cont):

#	Taxon	DL	DB	DR	ML	MB	MR	LM	Temp. (^{o}C)	pH	DO (ppm)	Cond. (µS)	Turb. (NTU)
22	*Candonocypris candonoides* (King) 1855					●			18.0	7.5	8.4	1400	10
23	*Diacypris* n.sp. unpublished					●			20.5	7.5	1.5	245	10
24	*Reticypris* sp. McKenzie, 1978				●						n/a		
	FAM.CYPRIDOPSIDAE												
25	*Potamocypris* sp.1 Brady, 1870					●			15.0	7.2	1.4	220	27
26	*P.* sp.2 Brady, 1870					●			15.2	7.4	10.2	208	12.5
27	*Cypridopsis funebris* Brady, 1867					●		●	14.0 - 19.0	6.9 - 7.8	2.7 - 8.8	110 - 520	35 - 350
28	*Cypretta minna* (King) 1855					●			7.8 - 29.4	7.1 - 7.4	1.2 - 11.6	164 - 500	2.5 - 7.5
29	*Cypretta* cf. *globula* (King) 1855					●			8.0 - 29.4	7.1 - 7.5	1.2 - 13.0	52 - 245	2.5 - 23.5
30	*Cypretta baylyi* McKenzie, 1966				●	●		●	10.0 - 23.0	7.1 - 8.3	2.7 - 10.8	130 - 660	3.0 - 350
31	n.gen.n.sp. unpublished				●				17.0	7.4	9.0	193	-
32	*Stenocypris* n.sp. unpublished					●			20.5 - 29.4	7.1 - 7.2	1.2 - 1.6	164 - 245	2.5 - 10.0

that a large proportion of seasonally occurring species were missed. This also was a problem in the present study, in part overcome by more intensive sampling of some habitats, and by extending the sampling time over several years.

Of 409 taxa recorded (260 rotifer taxa, 76 Cladocera, 41 Copepoda and 32 Ostracoda),≃170 (42%) were new species or new records from Australia. Many of these were from small lentic habitats, predominantly isolated billabongs. As relatively few billabongs were sampled, it is likely that a considerable proportion of the littoral and planktonic microfauna of these habitats is unknown. The greatest morphological variation within species, particularly Rotifera, was recorded in billabongs. Less variability was observed in lacustrine and river plankters.

In summary, the plankton of Murray-Darling waters consists of a small group of cosmopolitan eurytopic species, a small group of pantropical warm water taxa, a block of endemic eurytopic forms, and a large proportion of taxa of more restricted distribution and specific requirements. There was evidence of tropical forms confined to the north of the basin, i.e. the Darling River and nothern Murray tributaries, with a mixture of tropical and temperate forms in the southern (Murray) catchment. Approximately 10% of the Rotifera are endemic, as are some 28% of the Cladocera, ≃90% of the Calanoida, 60% of the Cyclopoida, and (probably) most of the Harpacticoida and Ostracoda. The contribution of each of these groups to the plankton assemblages in particular habitats is considered in subsequent chapters.

5. PLANKTON COMMUNITY COMPOSITION ABOVE THE MURRAY-DARLING CONFLUENCE

5.1 General Introduction

In discussing the plankton communities of the study area, the separation of the two discrete rivers is continued. For convenience, the limnoplankton of reservoirs and the potamoplankton of downstream river stations are treated sequentially. This permits assessment of the effects of impoundment on the riverine biota, and of the influence of each reservoir on the river below the dam. For logistic reasons, considerably more attention was given to the Murray system: 20 of the 23 impoundments sampled are on that system, as are most of the river stations. Discussion of plankton community structure and changes in response to water quality is based on data from Murray waters.

Introductory sections for reservoirs include pertinent information on morphometry and physico-chemical limnology. Biological observations largely are confined to the zooplankton. The species composition of the limno- and potamoplankton of each locality is described, as are spatial and temporal changes in community structure. Responses to fluctuations in water quality are considered. Comparison of community structure between impoundments and rivers of the basin is made in the final section of the chapter.

5.2 The River Murray system

The River Murray and tributaries above Yarrawonga weir (i.e. Lake Mulwala) are regarded as the upper Murray. The river between the weir and the Darling confluence is considered here as the middle reaches, and below the Darling confluence, the lower Murray. Plankton assemblages are considered in the following sequence: headwater storages and river reaches above Hume reservoir, limnoplankton of Hume, and that of storages and river reaches below the dam.

5.2.1 The upper Murray

Ten impoundments and 15 river stations were sampled in the upper

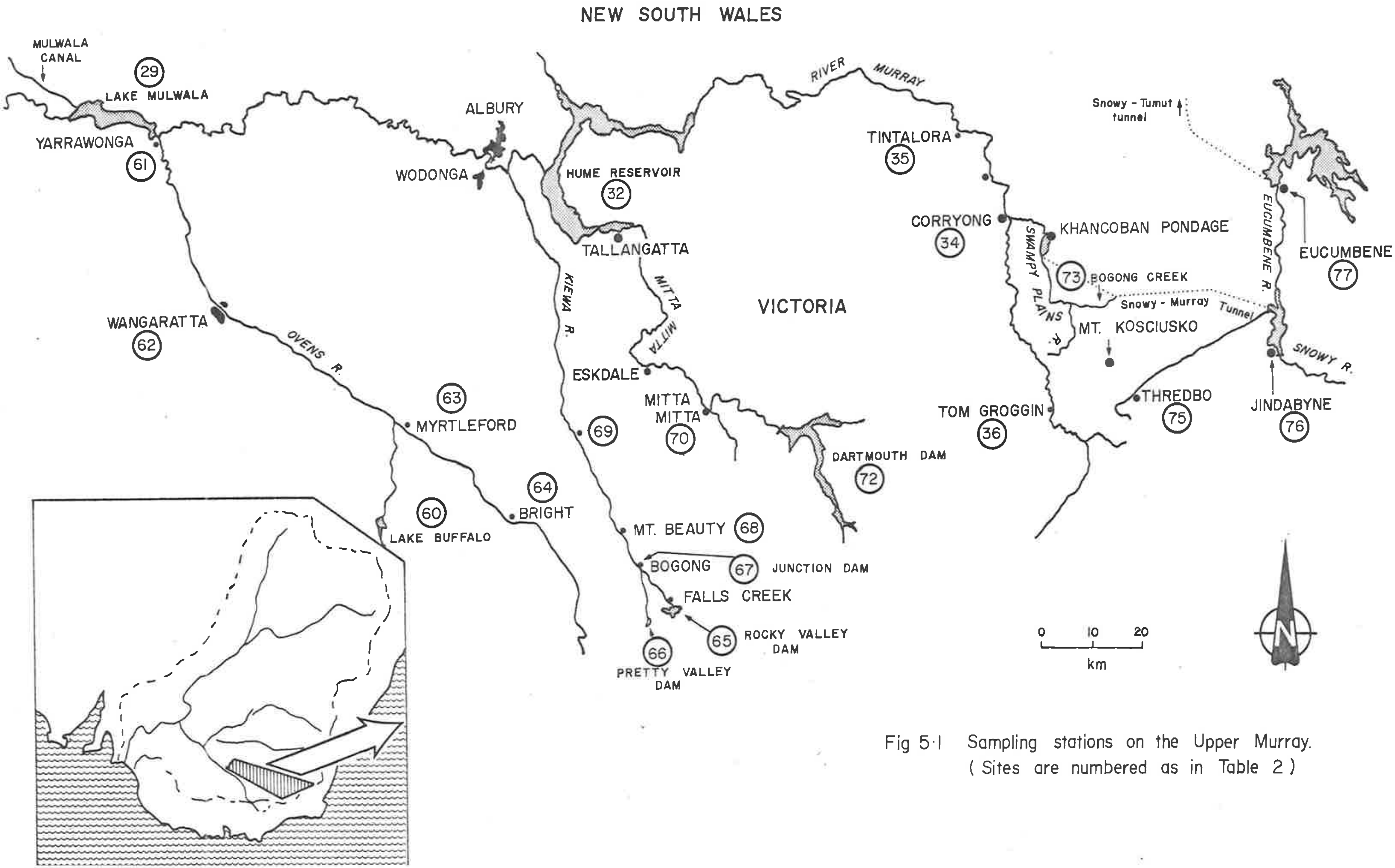


Fig 5·1 Sampling stations on the Upper Murray.
(Sites are numbered as in Table 2)

catchment. Regular sampling stations are shown in Fig. 5.1. Two SMA storages on the Eucumbene and Snowy Rivers, i.e. outside the Murray-Darling watershed (Lakes Eucumbene and Jindabyne), supply up to 40% of flows by diversion to Hume reservoir, and were included to determine their contribution to the upper Murray plankton.

5.2.1.1 Lakes Eucumbene and Jindabyne (Fig. 5.2).

Eucumbene, completed in 1957 with the construction of a 116 m dam on the Eucumbene and upper Murrumbidgee Rivers, permits diversion of water by tunnel into the Tumut River, a tributary of the Murrumbidgee. Diversions also can be made from Eucumbene to Jindabyne. Jindabyne, completed in 1967 with a 72 m dam on the Snowy River, allows diversion of Snowy waters by tunnel into the Swampy Plain River, a tributary of the upper Murray. Generation of hydro power and supply of irrigation water into the Murray-Darling basin are the principal uses of the diversions. Details of the Snowy Mountains Scheme and diversions are given in the annual reports of the Snowy Mountains Hydro-ELectric Authority (1952-), and by the River Murray Commission. In the present study, each reservoir was visited six times.

Physico-chemical features:

Ranges and means of some physico-chemical features measured by the SMA are given in Table 5.1. Measurements made during this study are in Table 5.2. Waters of both reservoirs generally were of high transparency (Secchi readings 3-6 m), low conductivity sodium bicarbonate type, similar in all measured characteristics, and reflecting high rainfall (>1500 mm) and snow melt on the Kosciusko catchment.

Biological features:

Phytoplankton. In the Eucumbene samples, only in the winter 1978 collection was there an appreciable number of phytoplankters. At other times phytoplankton was sparse. Predominant genera throughout the study were *Micrasterias* (*M. hardyi*), *Staurastrum* and other desmids, i.e. a phytoplankton assemblage

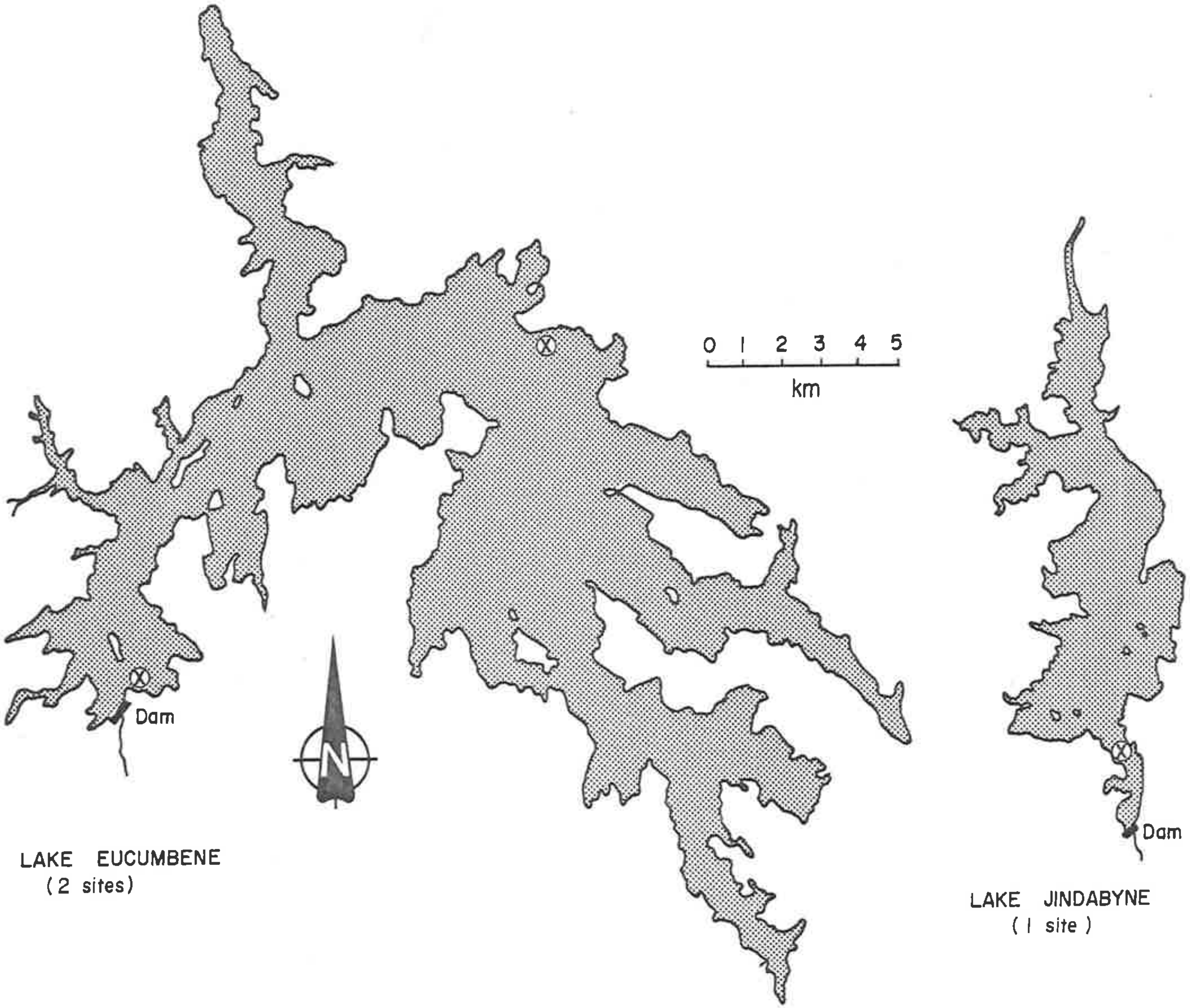


FIG. 5·2 Lakes Eucumbene and Jindabyne : sampling sites (⊗)

Table 5.1: Physico-chemical features of Eucumbene Dam and the Snowy River at Jindabyne (SMA, 1960-67).

Eucumbene Capacity 4,799 x 10^6 m^3 Elevation 1169 m			Snowy at Jindabyne (Dam capacity 690 x 10^6 m^3) Elevation 868 m	
Characteristic	mean	range	mean	range
Temperature (°C)	12.3	5.5-18.3	10.7	2.5-20.4
pH	6.9	6.6-8.0	6.9	6.6-7.8
Colour (Hazen)	17.7	5 - 50	14.5	4.5- 45
Turbidity (NTU)	12.1	2 - 35	8.2	0 - 80
Hardness ($CaCO_3$) (mg ℓ^{-1})	17.2	14.0-30.0	15.2	5.4-30.0
Total alkalinity	19.9	12.0-23.0	19.4	4.0-45.0
Chlorides	0.84	0 - 2.4	2.29	0-10.0
Nitrate-N	0.15	0 - 2.0	0.08	0-0.51

Fig. 5.2b: View of Lake Eucumbene (facing north), Snowy Mountains, N.S.W. (1 km east of dam, above site 1).

	EUCUMBENE						JINDABYNE					
	1977			1978		1979	1977			1978		1979
Date	08.i	18.v	15.xi	28.ii	24 viii	2.iii	08.i	18.v	15.xi	28.ii	24 viii	2.iii
Water temp. °C	18.0	12.0	11.0	18.0	7.2	23.0	20.0	12.0	10.0	18.2	9.0	23.0
DO (ppm)	8.2	9.6	9.4	7.0	9.2	8.6	7.4	9.6	9.0	7.4	9.5	8.4
pH	7.0	7.0	7.1	7.2	7.4	7.4	7.3	7.0	7.3	7.1	7.5	7.4
Conductivity (uS)	35	25	18	31	23	110	37	44	30	53	45	120
Turbidity (NTU)	0.5	0.2	0.1	0.5	5.4	0.5	1.0	0.6	1.0	2.0	2.0	1.0
Dominant phytoplankters (*et al.*)		*Micrasterias*	*Micrasterias* *Staurastrum*	*Micrasterias* *Staurastrum*	*Micrasterias* *Staurastrum*	*Ceratium*	*St./Micr.* 40/1 $\simeq$ 400ℓ^{-1}	*St./Micr.* 3/1, $\simeq$200ℓ^{-1}	*Staurastrum* *Micrasterias* *Volvox*	-	*Micrasterias*	*Micrasterias* *Ceratium*
Zooplankton ℓ^{-1}	23	21	8	15	4	9	13	24	7	16	3	5
Rotifer spp. (R)	-	2	1	3	3	3	5	3	3	1	1	5
Cladoceran spp. (Cl)	2	5	1	3	2	4	5	2	4	4	3	3
Copepod spp. (Co)	$\frac{3}{5}$	$\frac{6}{13}$	$\frac{1}{3}$	$\frac{3}{9}$	$\frac{2}{7}$	$\frac{3}{10}$	$\frac{3}{13}$	$\frac{3}{8}$	$\frac{3}{10}$	$\frac{3}{8}$	$\frac{3}{7}$	$\frac{5}{13}$
% composition R/Cl/Co	0/90/10	6/25/96	0/6/94	10/12/88	9/9/82	2/27/71	2/28/60	22/2/76	2/21/77	5/37/58	8/10/82	8/42/50
Diversity I/H'	.19/ .59	.97/ 2.6	.11/ .37	.74/ 2.2	.49/ 1.5	.73/ 2.2	.72/ 2.1	.67/ 1.9	.60/ 1.8	.74/ 2.2	.53/ 1.5	.82/ 2.7

Table 5.2: Physico-chemical features and plankton composition of Lakes Eucumbene and Jindabyne (1977-79).

indicative of oligotrophy (cf. Hutchinson, 1967). These genera also were dominant in Jindabyne, with peaks noted in summer. Colonies of *Volvox* also occurred in summer. Representative densities from aliquot subsamples (1 ml) counted in a Lund cell under high power are included in Table 5.2.

Zooplankton. Twenty-two zooplankton taxa were identified from each reservoir (9 Rotifera, 6 Cladocera and 7 Copepoda from Eucumbene, 11 Rotifera, 5 Cladocera and 6 Copepoda from Jindabyne). The number of species, percentage of each group, zooplankton density ℓ^{-1} and community diversity for each sampling date are included in Table 5.2. Temporal variation in community composition is shown in Fig. 5.3.

On any sampling date, the zooplankton of both impoundments was dominated by microcrustacea, although the same species were not dominant in both storages. In Eucumbene, rotifers comprised less than 10% of the limnoplankton. Only two species, *T. similis* (summer) and *L. ismaeloviensis* (spring-autumn) were collected more than once. Cladocera were subdominant to calanoid copepods; in only a single collection (summer 1977) did *B. meridionalis* predominate. Other subdominant cladocerans were *D. unguiculatum, D. carinata* and *C. quadrangula* (summer-autumn). Calanoid copepods made up 70-94 % of the other collections, with up to three species present. The most common calanoid was *B. delicata*. The similar sized congener, *B. triarticulata* and the smaller *C. lucasi* were co-occurrent. Cyclopoids were rare.

In Jindabyne, a higher proportion of rotifers was noted. Several occurred more than once, i.e. probably were perennial, e.g. *C. dossuarius*, *P. dolichoptera* had an autumn maximum, and *H. mira* occurred in spring-summer. The same cladoceran species as in Eucumbene were present, although at any time they made up a greater proportion of the plankton, and apparently were perennial. Calanoids also were perennial in the smaller storage, but notably *B. delicata* was absent. *B. triarticulata, C. lucasi* and an unidentified harpacticoid copepod were perennial.

Temporal variations in zooplankton density were similar in both storages, with highest densities in summer-autumn, lowest in winter-spring. Densities

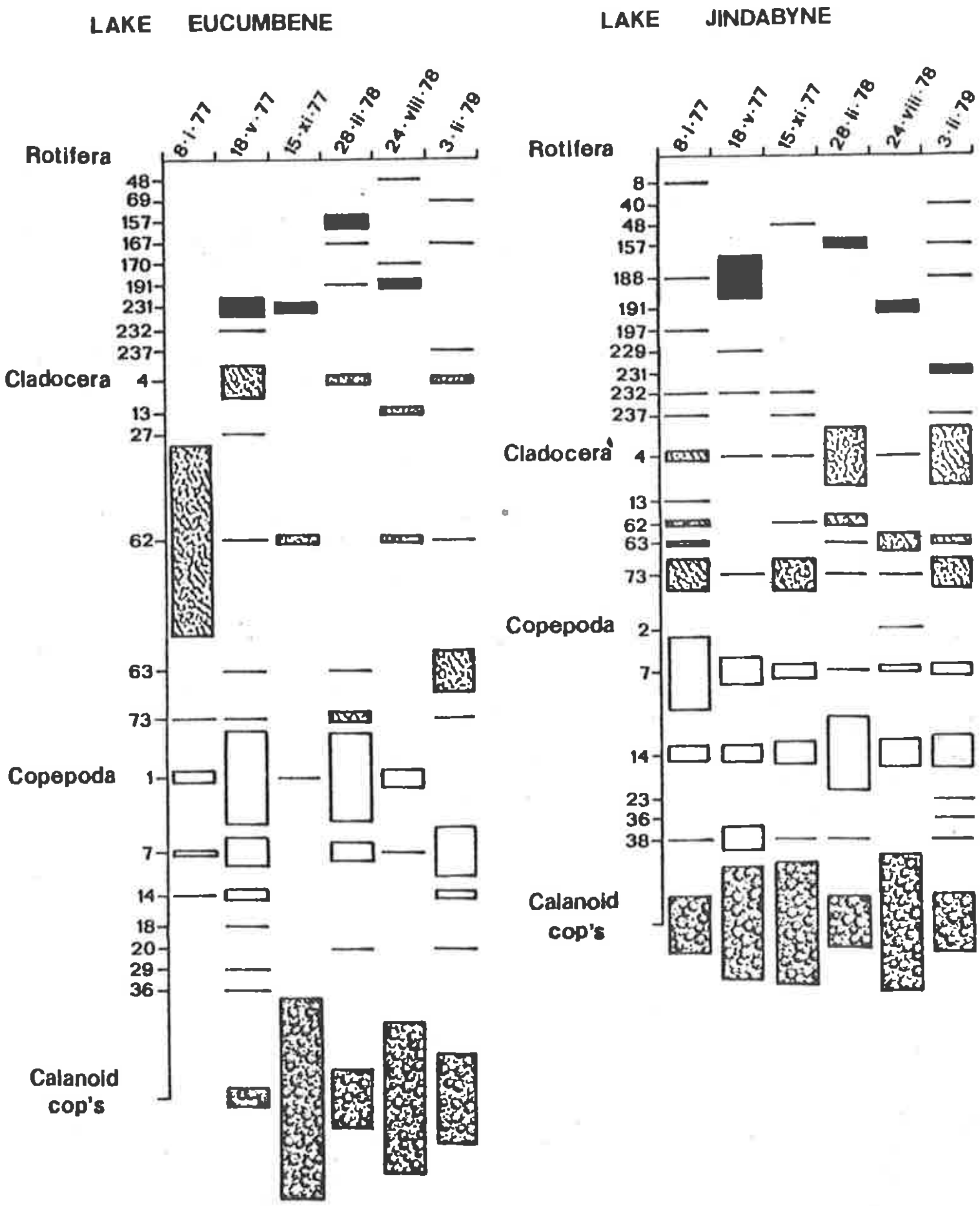


FIG. 5·3 Temporal variation in limnoplankton composition, Lake Eucumbene & Lake Jindabyne

indicates the presence of ovigerous individuals in this and subsequent similar figures.

a. Jindabyne:

	1977			1978		1979
	8.i.	18.v.	15.xi.	28.ii.	24.viii.	2.iii.
8.i.77		.40	.64	.50	.33	.44
18.v.77	.31		.38	.33	.25	.31
15.xi.77	.47	.52		.64	.42	.44
28.ii.78	.42	.31	.40		.50	.50
24.viii.78	.36	.59	.60	.40		.33
2.iii.79	.35	.35	.43	.69	.44	

b. Eucumbene:

	1977			1978		1979
	8.i.	18.v.	15.xi.	28.ii.	24.viii.	2.iii.
8.i.77		.38	.60	.27	.33	.36
18.v.77	.11		.23	.22	.18	.35
15.xi.77	.04	.14		.20	.43	.18
28.ii.78	.14	.42	.29		.23	.46
24.viii.78	.04	.19	.45	.49		.13
2.iii.79	.06	.37	.46	.39	.37	

c. The two storages compared:

Eucumbene

1977			1978		1979	Jindabyne
8.i.	18.v.	15.xi.	28.ii.	24.viii	2.iii.	
.29	.37	.14	.22	.18	.44	8.i.77
	.24	.10	.21	.07	.29	18.v.77
		.18	.27	.21	.54	15.xi.77
			.42	.15	.50	28.ii.78
				.17	.42	24.viii.78
					.35	2.iii.79

$$CC = \frac{c}{a + b - c}$$

$$C = \frac{2w}{a + b}$$

Table 5.3 Temporal changes in the species composition of Lakes Eucumbene and Jindabyne expressed as community coefficients.

were lower than in any other Murray-Darling impoundment ($<30\ \ell^{-1}$). Community diversity generally was highest in summer-autumn, lowest in winter-spring in both impoundments. Mean diversity was higher in Jindabyne than in Eucumbene ($\bar{x}$ H' 2.0 vs. 1.59).

Temporal changes in the limnetic zooplankton communities of each storage were compared by two community coefficients (Table 5.3). There was greater disparity in species composition between samples from Eucumbene than between those from Jindabyne. Most similar assemblages were in spring-summer collections from Jindabyne. Czekanowski's coefficient emphasized the numerical disparities; there was little similarity in population peaks or species composition. Average momentary species composition was 2.0 rotifers, 2.8 cladocerans and 3.0 copepods in Eucumbene, and 3.0 rotifers, 3.5 cladocerans and 3.3 copepods in Jindabyne, cf. Timms (1968, 1970) figures of 1.1 and 2.0 Cladocera, 2.3 and 2.2 Copepoda for lentic habitats also on the eastern side of the Highlands.

Environmental factors:

The influence of measured environmental factors on population density of the dominant plankters was investigated by linear regressions of species density on each variable. As population density values could not be assumed to be normally distributed, densities were transformed to logarithms (Elliott, 1971). Correlation coefficients (r^2), i.e. the proportion of variance accounted for by variations in temperature, DO, pH, conductivity and turbidity are given in Table 5.4. Spearman rank (ρ) and F values also are shown.

Variations in measured environmental variables generally accounted for little of the variance in density of the dominant species in the impoundments. Of only five r^2 values exceeding 0.40, i.e. accounting for more than 40% of the variation in density, three were not significant ($P>.05$). The abundance of *D. unguiculatum* was positively correlated with temperature. A significant correlation was found between *D. carinata* and pH.

The plankton data from these storages must be interpreted with caution

Taxon		°C			pH			DO			µS			NTU	
	a	b	r^2	a	b	r^2	a	b	r^2	a	b	r^2	a	b	r^2
Eucumbene															
B. meridionalis	14.54	0.58	0.01	7.24	-0.10	0.25	8.73	-0.10	0.07	44.59	-7.42	0.04	1.42	-0.25	0.01
B. delicata	15.27	-0.53	0.01	7.33	-0.16 ρ: -0.57, F: 3.03 P > .05	0.46	8.92	-0.26	0.05	50.17	-20.95	0.24	1.88	-0.73	0.08
B. triarticulata	9.87	5.61	0.38	7.22	-0.04	0.02	8.89	-0.25	0.03	13.95	29.64	0.30	2.38	-1.34	0.17
Copepodites	17.35	-1.83	0.05	7.02	0.12	0.23	8.09	0.42	0.10	31.72	6.34	0.02	-3.17	24.75	0.18
Jindabyne															
D. unguiculatum	8.88	7.88 ρ: .81,F: 7.71 P < .05	0.89	7.30	-0.04	0.02	9.61	-1.29 ρ: .74, F:4.87 P >.05	0.82	35.91	22.99	0.24	1.23	0.05	0.00
D. carinata	15.71	-0.67	0.0	7.10	0.31 ρ: 0.81,F:13.79 P<.05	0.67	8.58	-0.06	0.0	59.50	-8.98	0.02	1.16	0.21	0.03
C. quadrangula	13.13	2.80	0.15	7.22	0.06	0.08	9.02	-0.58	0.23	55.27	-0.55	0.00	1.50	-0.30	0.17
B. triarticulata	10.99	3.75	0.16	7.40	-0.12	0.14	9.60	-0.90	0.31	73.66	-16.14	0.09	1.89	-0.53	0.31
C. lucasi	11.56	3.17	0.13	7.11	0.13	0.21	9.92	-1.14 ρ:-0.79,F:6.58 P>.05	0.56	60.22	-4.49	0.01	0.72	0.45	0.25
Copepodites	17.35	-1.83	0.05	7.02	0.12	0.23	8.09	0.42	0.10	31.72	6.34	0.02	-3.17	24.75	0.18

Table 5.4 : Regression of log population density of dominant limnoplankters in Eucumbene and Jindabyne on water temperature, dissolved oxygen, pH, conductivity and turbidity. a: intercept, b: slope of regression line, r^2: regression coefficient, ρ: Spearman's Rank correlation coefficient, F: F value and level of significance.

in view of the low sampling frequency and lack of comprehensive data on environmental variables. More frequent sampling would be necessary to detect significant changes in those variables which were measured; such changes were effectively missed by the timing of sampling. Even for reservoirs from which monthly data were available, e.g. Hume and Dartmouth, fluctuations in the zooplankton could not readily be attributed to single factors.

Other important determinants of zooplankton composition, e.g. predation, were not assessed in this study. Tilzey (1972 and pers. comm.), for example, reported that Cladocera (*Daphnia* sp.) in Eucumbene were heavily cropped by rainbow trout, while copepods were not. He noted that smaller fish were caught as food became limiting, a result of increasing fish populations and a stable food supply. If this trend continued after Tilzey's 1970-71 study, trout predation could account, in part, for the temporal variation in the Eucumbene limnoplankton, and for the disparity between Eucumbene and Jindabyne populations.

Unfortunately, no accurate comparison of plankton densities can be made between the present study and that of Tilzey. He noted densities of the order of 40,000-125,000/m^2 of lake surface. Depth was not specified. The present samples expressed in the same units give a range of 4,000-46,000 individuals/m^2 at site 1 near the dam, however it is doubtful, in view of the extreme contagion of the plankton in all reservoirs sampled, if a single measurement of density/m^2 is meaningful.

While similarity of species composition was higher than for any other connected reservoirs (64% of all species shared), it is the dissimilarities which are notable, particularly since the storages are less than 30 km apart. The absence of *B. delicata* from Jindabyne is of interest. Bayly (1964) noted that the known distribution of the species was remarkably discontinuous; it was recorded from two New Zealand lakes, with the only Australian record from Eucumbene. As the latter storage had only recently filled at the time of collection (1960), Bayly suggested that the species probably inhabited small bodies of water in the vicinity. This has been verified by Timms (1979). In the present study, records of *B. delicata* downstream and in Burrinjuck Dam probably resulted from flood transport from higher altitudes. It is likely that the species does not survive transit through the tunnels of the Snowy Scheme , e.g. into Jindabyne, although it may be more widespread in the Eastern Highlands. Its distribution probably is temperature related (Bayly, 1964).

A similar disjunct distribution is seen in other plankton species, e.g. the new cyclopoid genus, recorded also from Eildon, on the Goulburn River, occurred perenially in Jindabyne, but was not recorded from Eucumbene. Several Rotifera occurred also in one reservoir, but not in the other.

When the community composition of both storages is compared to that of other impoundments (described later), an explanation for some of the temporal variation is suggested. Those impoundments which are less frequently drawn down for irrigation or other purposes tend to have a more stable plankton, with greater similarity between sampling dates. This is seen in Jindabyne, but not in Eucumbene. The latter is used more intensively for irrigation supply into the Murrumbidgee River than is Jindabyne, which is maintained at a more stable level (RMC weekly reports, 1976-79).

In summary, the two SMA storages were more similar in water quality and in zooplankton species composition than any other pair of Murray-Darling reservoirs. With the exception of a single high-altitude species, the predominant zooplankters were of wide ecological tolerance and distribution. Population densities were lower and in general more variable than in other storages. Fish predation was possibly a significant influence on the Eucumbene plankton, less so in Jindabyne. Diversions for irrigation along the Murrumbidgee were possibly of greater influence on the stability of the Eucumbene plankton than were those into the upper Murray on the plankton of Jindabyne.

Plankton assemblages downstream from each dam are discussed separately; that of the upper Murray is summarised below, that of Eucumbene diversions with the Murrumbidgee R. (5.2.6).

The Swampy Plain River (Station 73, Fig. 5.1)

Dates of sampling were as for Jindabyne. In only a single sample (07.i.77) were live plankters recorded (*K. australis, B. meridionalis, Tropocyclops* sp.). Of these, only *B. meridionalis* was recorded from the reservoirs above. Exoskeletal material was present in all collections, as were nymphal stages of macroinvertebrates (Chironomidae, Plecoptera, Ephemeroptera). On all sampling dates, velocity (>1 m s^{-1}) and turbulence were inhibitory to plankton.

Khancoban pondage (Fig. 5.1)

A shallow weir at Khancoban regulates flows in the Swampy Plain River. Comparative collections only were taken during summer, autumn and winter 1978. Twelve plankton species were recorded from the pondage (7 Rotifera and 5 Cladocera). Densities in all collections were less than 10 ℓ^{-1}. Greatest diversity was in the summer collection (H'=2.35), least in the winter (H'=1.56). Rotifera dominated the summer plankton (*A. brightwelli, P.* cf. *longiremis, K. cochlearis, K. tropica*). None of these was recorded from the SMA storages. *B. meridionalis* and *C. quadrangula* occurred in Khancoban pondage and Jindabyne concurrently. The plankton of the autumn collection consisted largely of calanoid nauplii and copepodites, that of the winter collection a few chydorids flushed into open water from fringing reedbeds (*B.kendallensis, C. australis, C. sphaericus*). The plankton of the pondage persisted in the river below the weir in the summer samples, but no live plankters were collected in autumn and winter. Velocity and turbulence were inhibiting.

River Murray, Tom Groggin (Station 36, Fig.5.1, Frontispiece)

Four seasonal samples (07.i.77, 18.iv.77, 15.xi.77 and 24.viii.78) were taken from the Murray at Tom Groggin, on the western slopes of Mt. Kosciusko. The following physico-chemical ranges were recorded: water temperature 8.0-18.0 °C, pH 6.9-7.5, DO 9.6-11.0, µS 38-100 and turbidity (NTU) 0.2-1.7. All collections contained exoskeletal material and detritus, but only in the summer 1977 collection were live plankters recorded. Seven zooplankton species were present; three rotifers (an unidentified bdelloid, *K. tropica* and *A. brightwelli*), two cladocerans (*B. meridionalis, C. dubia*) and two copepods (*B. triarticulata, Tropocyclops* sp.). Densities were low ($<1\ \ell^{-1}$). As in the nearby Swampy Plain River, plankters were collected only during low summer flows. At other times, flows were greater than 1 m s^{-1}, and turbulence in the shallow stream would have been deleterious to any planktonic microfauna.

River Murray, Corryong (Station 34, Fig. 5.1)

A single collection was made at Corryong in summer (28.ii.78) immediately below the Swampy Plain River confluence to compare the species composition with that of the Khancoban pondage. Few phytoplankters were present (*Micrasterias, Staurodesmus, Cosmarium*). Nine species of rotifers were recorded, including all four present in Khancoban pondage (additionally *E. clavulata, L. lunaris, Synchaeta* sp., *P. vulgaris* and *T. similis*, i.e. several littoral species as well as true plankters). Microcrustacea were absent.

River Murray, Tintaldra (Station 35, Fig. 5.1)

Thirty km downstream from the Swampy Plain confluence, the Murray is approximately 20 m wide, and, during the study, 1.6-2.0 m deep. Sampling dates were as for station 36. On each visit flow rates were lower than at the upstream station (0.6-0.9 m s^{-1}) and a greater density and diversity of zooplankton was present. Nineteen species were collected, of which 6 (32%) were recorded upstream. Table 5.5 shows physico-chemical features and plankton present on each sampling date. Only in summer were sufficient plankters present to record per cent composition.

Dominant river plankters were rotifers, notably species of *Brachionus* planktonic in still waters of billabongs adjacent to the upper Murray tributaries (Ch.6) and species of *Keratella* recorded from Khancoban pondage. Other rotifers were littoral in habit. Only in summer were microcrustacea

Table 5.5: Physico-chemical features and plankton of the upper Murray at Tintaldra, Vic. (Zooplankton as per cent composition or presence only (+)).

	Date			
	7.i.77	18.iv.77	15.xi.77	24.viii.78
Water temp.(^{o}C)	23.0	10.0	8.0	7.0
DO (ppm)	8.2	10.3	11.0	9.8
pH	7.1	7.2	7.0	7.5
Conductivity (μS)	33	80	37	430
Turbidity (NTU)	1.2	2.0	2.5	3.5
Phytoplankters	*Micrasterias* *Oedogonium*	*Micrasterias* *Staurodesmus* *Staurasrtrum* *Volvox*	*Micrasterias*	
Zooplankton ℓ^{-1}	12	<1	<1	<1
Rotifera				
B. calyciflorus	5			
B. falcatus	50			
B. quadridentatus	+			
B. rubens		+		
B. variabilis		+		
K. australis		+		
K. cochlearis	+		+	
K. tropica			+	
E. dilatata		+		
Synchaeta sp.		+		
P. vulgaris		+	+	
Proales sp.		+		
P. complanata		+		
Cladocera				
A. rectangula			+	
B. meridionalis	8	+		
D. lumholtzi	+		+	
C. dubia	1			
Copepoda				
B. minuta	1			
Tropocyclops	34			
copepodites	+	+	+	+

abundant; the ubiquitous *B. meridionalis* and a species of *Tropocyclops* were dominant. In the other collections, plankton density was low, a result of dilution and turbulence in high flow conditions. Seasonality was evident with the replacement of species.

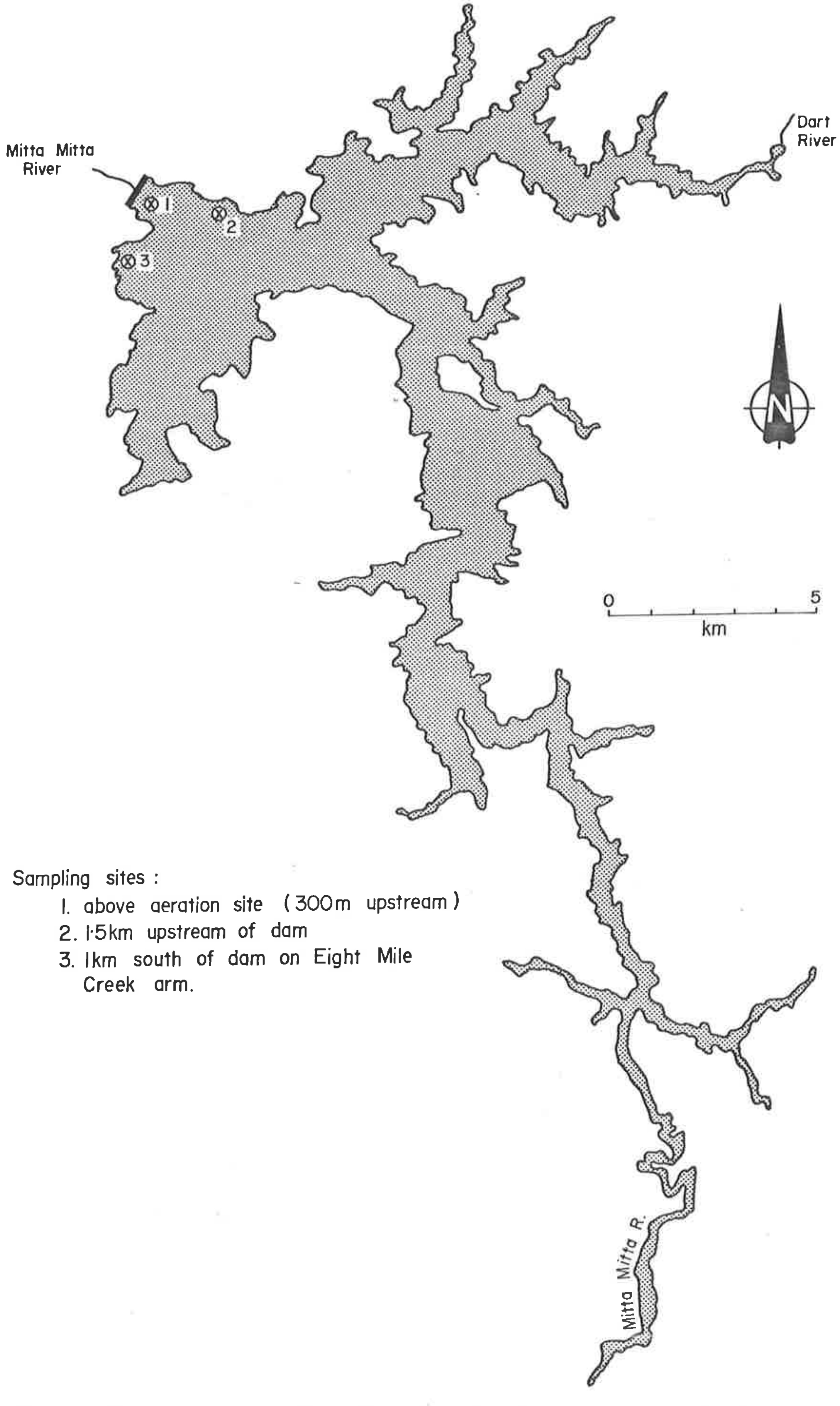
This seasonal variability in the plankton of the upper Murray probably is characteristic, and is reflected in compositional changes in the limnoplankton of the northern arm of Hume Reservoir, into which the Murray flows some 100 km downstream from Tintaldra.

5.2.1.2 Dartmouth Dam (station 72, Fig. 5.1)

Dartmouth Dam (Fig. 5.4), completed in 1978 below the confluence of the Dart and Mitta Mitta Rivers, will be Australia's deepest reservoir when filled (171 m). The dam was built to provide greater reliability of flows for irrigation in the Murray Valley.

Features of the dam and catchment are described in an environmental study report (S.R.& W.S.C.,1978) and by Powling (1980). Pertinent information is included in Table 5.6. In summary, the catchment drains the western slopes of the Bogong High Plains (ca. 2300 m) in north-eastern Victoria. Precipitation exceeds 1,000 mm yr^{-1} over most of the catchment, with >2400 mm yr^{-1} at Mt. Bogong, 25 km south west of the dam. Highest falls are in spring. Average annual runoff from the Mitta Mitta River is 325 mm. Average monthly temperatures at Mitta Mitta range from 6.0 °C(July) to 20.0 °C (January). Geology is largely granitic, geomorphology that of narrow, V-shaped valleys. Both of these features are important in determining the chemistry and behaviour of the water mass. Vegetation is native eucalypt forest, little of which was cleared from the area of submergence. Land use is predominantly forest grazing and logging, with agriculture on the floodplain below the damsite.

In the present study, to provide basic information on the microfauna of the filling reservoir and of lentic habitats on the Mitta Mitta floodplain, Dartmouth was regularly sampled during construction, as were the river and several billabongs below the damsite (Ch. 6). Collections also were taken by



Sampling sites :

1. above aeration site (300m upstream)
2. 1·5km upstream of dam
3. 1km south of dam on Eight Mile Creek arm.

FIG. 5·4 Dartmouth Dam, Mitta Mitta River. Sampling sites are numbered.

officers of the WSCV.

Sampling stations:

Three sites were sampled during the study (Fig. 5.4). Sites 1 and 2 (Fig. 5.5) were in open water approximately 150 m and 1.5 km upstream of the dam. Depth at these stations increased from <10 m to 120 m during 1977-80 as the storage filled. Site 3, 2 km southwest of the dam on Eight Mile Creek inlet, was a shallow area below the borrow pits, from which clay was extracted for the dam. WSCV samples generally were taken in the vicinity of sites 1 and 2. The two open water sites were sampled to compare the plankton above aeration facilities (site 1), which were installed when the reservoir became anoxic, with that of the upstream station.

Physico-chemical features:

Ranges and means of measured characteristics are included in Table 5.6 and Fig. 5.7 for the period 1977-80. Most distinct changes were those in turbidity, pH and dissolved oxygen, largely due to submergence of the native vegetation. Several weeks after filling commenced, the water was highly coloured due to released pigments and organic acids, particularly tannic acids from eucalypts. Decomposition of the submerged vegetation resulted in anoxia, and H_2S was detected three weeks after dam closure (Powling, 1980). By early March, 1978, the reservoir was anoxic to the surface (then 33 m deep). Aeration was commenced above the outlet to improve water quality to the township of Dartmouth, below the dam. In this study, DO levels of 0.6 mg ℓ^{-1} were recorded below the riparian outlet (03.iii.78). H_2S was evident. Thirty metres downstream 2.8 mg ℓ^{-1} was recorded, and by 2 km downstream, turbulence had increased DO levels to approximately 80% (7.6 mg ℓ^{-1}). In the first hundred metres below the outlet fish were seen leaping from the water, possibly in response to the low DO levels.

Anoxia recorded in the first summer did not subsequently reoccur, although depressed winter DO levels followed increased nutrient inflows. Turbidity also increased with the first winter rains (1978) as runoff from the borrow pits and construction area carried in clays and suspended particles.

Fig. 5.5 : Dartmouth Dam, Mitta Mitta River. View west from site 2 to site 1, just upstream of the retaining wall.

Table 5.6 Hydrologic, morphometric and physico-chemical features of Dartmouth Dam (from Powling, 1980 and pers. comm.).

Latitude & longitude	$147^{\circ}31'$E $36^{\circ}35'$S
Elevation (m)	494.00
Catchment area (km^2)	3,613
Shoreline (km)	275
Capacity (Ml)	3,700,000
Max. depth (m)	171
$\bar{x}$ depth (m)	58.8
Retention time	4-32 years
	$\bar{x}$ (n=32)
pH	6.1
TDS	39.6
Colour	10
Turbidity (JTU)	4
Chlorophyll ($\mu g\ \ell^{-1}$)	12.8
total P ($mg\ \ell^{-1}$)	0.06
nitrate-N ($mg\ \ell^{-1}$)	0.04

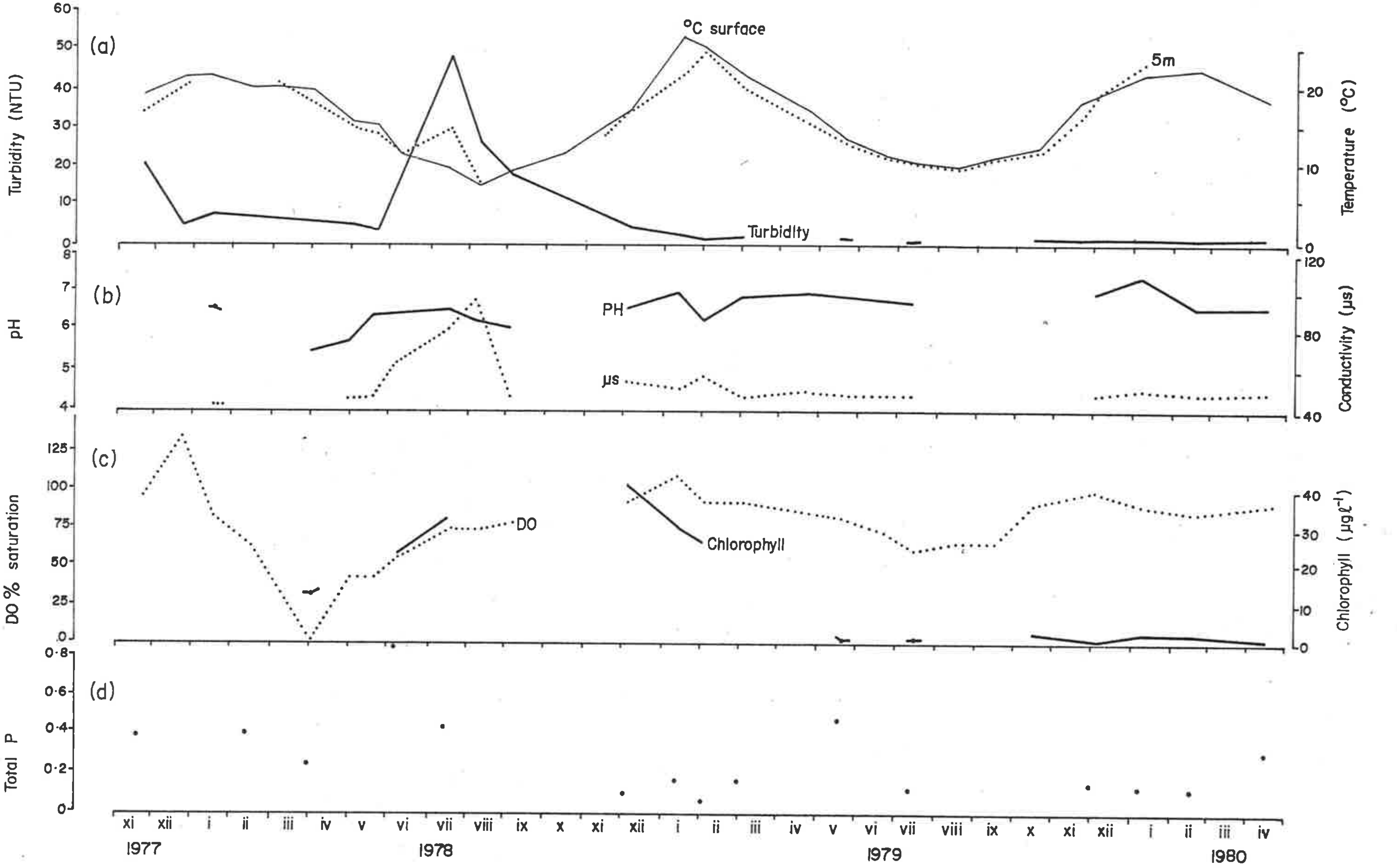


FIG. 5·7 Fluctuations in physico-chemical features in Dartmouth Dam, November 1977 - April 1980
(a) Water temperature and turbidity
(b) Conductivity and pH
(c) DO and chlorophyll
(d) Total P

(Composite of records from the present study and those supplied by I. J. Powling, WSCV)

The reservoir was still filling (120 m deep) and had not stabilized when sampling for this study ended in April, 1980. It was subsequently noted (I. J. Powling, WSCV, pers. comm.) that the dam did not overturn after summer stratification, a result of deep basin morphometry. Other features of the filling stage were the initially high nutrient levels, i.e. eutrophy, and the concomitant algal blooms, and increasing turbidity with depth, as suspended particles settled out.

Biological features:

Phytoplankton. Unlike the relatively stable, seasonally cyclic phytoplankton populations of other large storages, e.g. Hume, Eildon, those of Dartmouth reflected the instability of the reservoir. Following the appearance of the colonial flagellate *Synura* late in 1977, several other flagellate and blue-green algal genera appeared in the dam. Predominant of these was *Volvox*, which appeared briefly in the autumn 1977 collections, and occurred in bloom proportions through autumn 1979. Up to 220 colonies ℓ^{-1} were recorded at this time, with significant vertical differences in density. Although chlorophyll levels were not consistently measured, it is apparent that algal biomass increased through 1978, particularly after winter nutrient inflows, to a peak in summer-autumn 1978-79. A chlorophyll maximum of 42 $\mu g\ \ell^{-1}$ was recorded in summer, but probably was higher during the *Volvox* bloom. Bloom conditions did not occur the following summer, presumably as a result of nutrient depletion, i.e. by algae and sedimentation. It is likely that the phytoplankton composition of the dam will remain unstable as filling continues and the vast amount of submerged organic material decomposes. When the dam eventually stabilizes it is probable that a desmid-diatom plankton similar to that of Eildon, i.e. an oligotrophic assemblage, will develop.

Zooplankton.

Community Composition: Sixty-one zooplankton species were identified from Dartmouth (38 species of rotifer, 15 Cladocera, 7 Copepoda and one ostracod). The number of species in each group, per cent composition and diversity for each sampling date are shown in Fig. 5.8. Density is shown only for samples

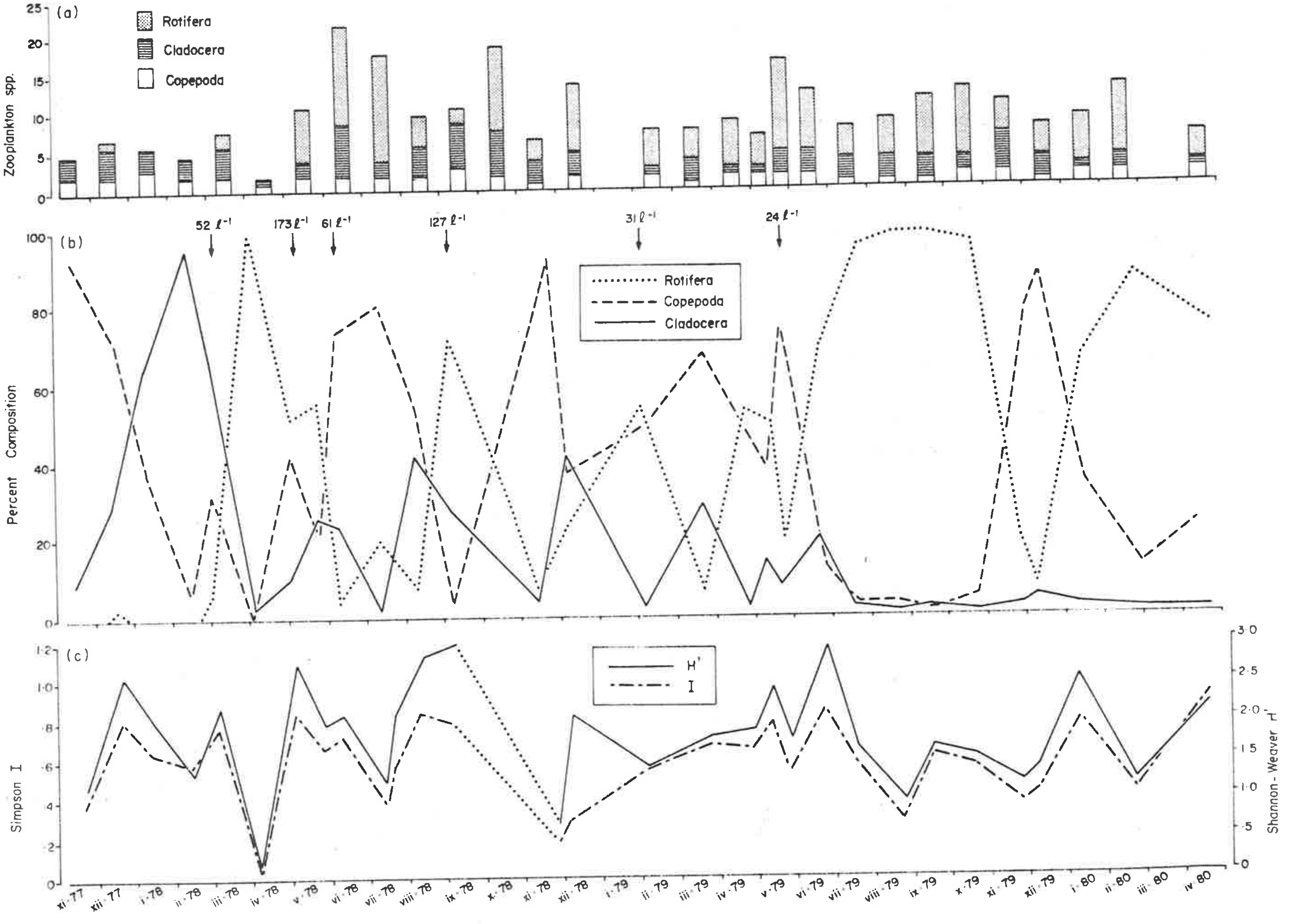


FIG. 5·8 Dartmouth Dam. Seasonal fluctuations in limnoplankton composition collected by Schindler trap. Most of the WSCV samples were vertical hauls, i.e. qualitative rather than quantitative, and density could not be calculated. Temporal variation in community composition is shown in Fig. 5.9.

The most obvious feature of the Dartmouth zooplankton distinguishing it from that of other reservoirs was the change in community composition as the impoundment filled. As in the phytoplankton, rapid changes occurred in zooplankton species composition in response to environmental fluctuations. The microcrustacean community which developed after closure of the dam was replaced by a rotifer assemblage, with seasonal pulses of copepods. In autumn and spring each year nauplii and copepodites of *B. triarticulata* were numerically abundant.

Despite the variability imposed upon the plankton community by the instability of the limnetic environment, distinct seasonality was apparent in both limnetic species and in the high proportion of non-limnetic incursions from standing waters. Forty-two per cent of Dartmouth zooplankters (more than for any other reservoir) were considered to be littoral or epibenthic in habit. Of the true limnoplankters, only a single species was perennial (*D. carinata*). This cladoceran is more typically an inhabitant of shallow lentic habitats such as billabongs. The initial similarity of the developing plankton fauna in the dam to that of a billabong assemblage is not surprising in view of the wide range of habitats submerged by the filling reservoir, and from which it was colonized.

The relative rapidity of compositional changes in the zooplankton community make difficult any generalizations across the study period. For comparative purposes, however, trends are considered for each group in the same sequence as for other reservoirs.

Of the 38 rotifer species recorded, 16 (42 per cent) were of littoral origin. These appeared in isolated collections or seasonally in small numbers, e.g. *Lecane* spp. The true limnetic rotifers were dominated initially by *L. ismaeloviensis* and *C. unicornis*, both colonial forms which occurred in

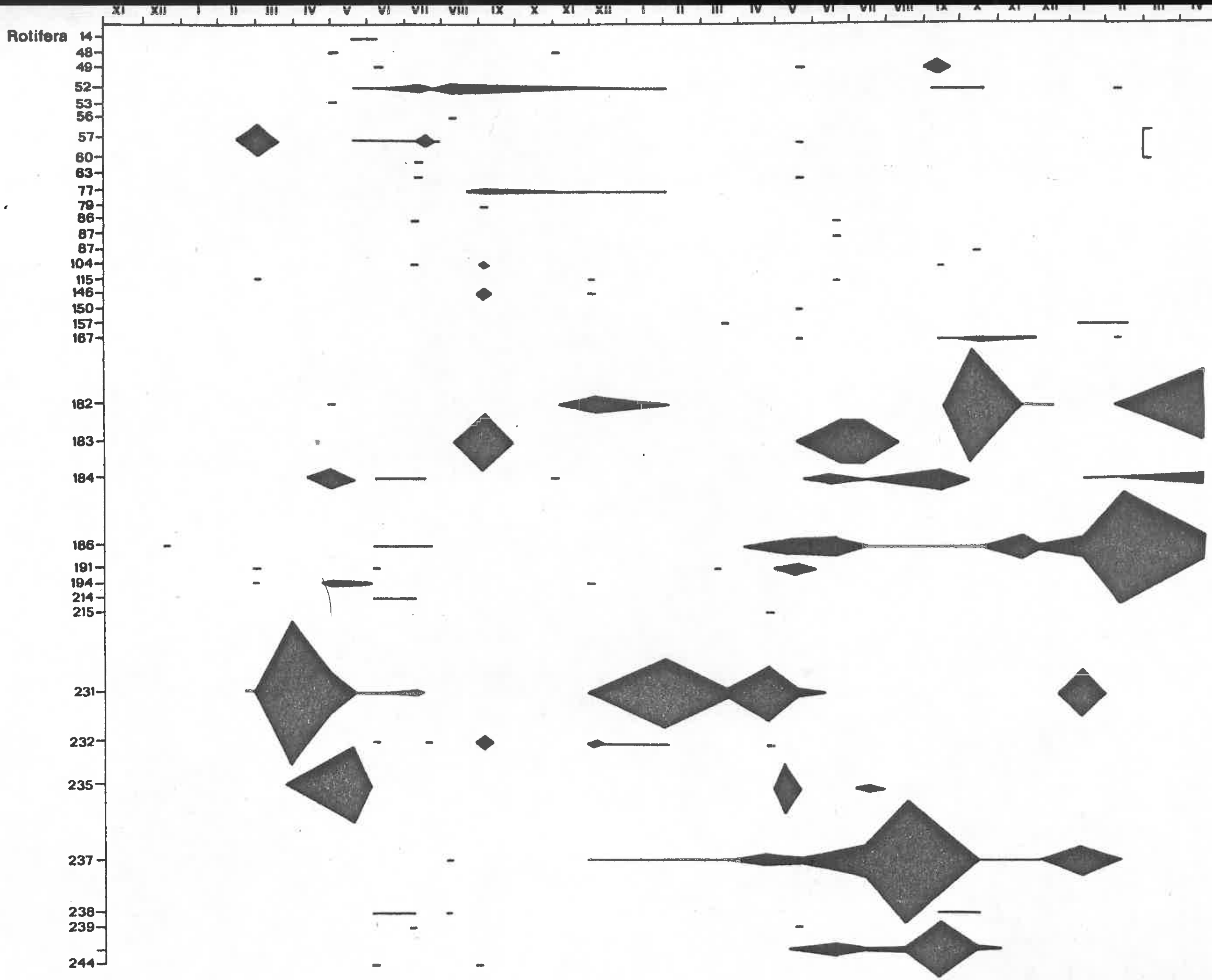


FIG. 5·9 Temporal variation in limnoplankton composition, Dartmouth Dam

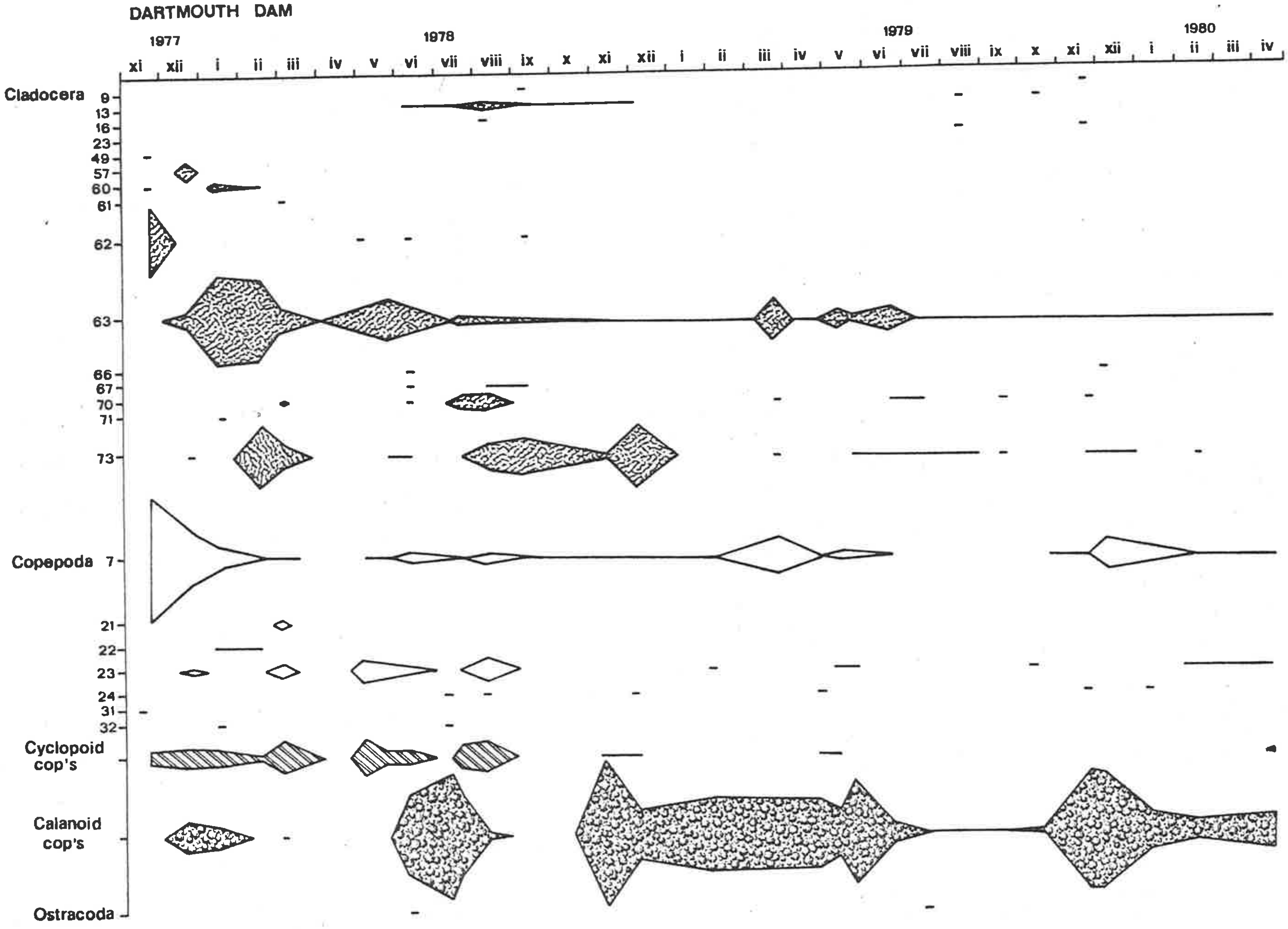


FIG. 5·9 (Continued)

summer and autumn. Species of *Synchaeta* and *Polyarthra* later predominated. *Hexarthra mira* was perennial during 1979, with a winter maximum. Seasonality was evident in the three species of *Synchaeta* which occurred; *S. pectinata* appeared in autumn, the cold-adapted *S. oblonga* in winter, and *S. longipes* in spring.

The contribution of the Rotifera to the Dartmouth plankton was variable. Rotifers were sparse in early collections; even in the autumn 1978 samples when large numbers of individuals were present, few colonies were represented. Each colony of *L. ismaeloviensis* contained from 60-170 individual In general, only single species were numerically dominant in any collection, although up to 14 species occurred in single samples. The greatest number of species and also dominance by rotifers occurred in winter-spring 1978-79 and summer 1980.

Fifty-three per cent of the Cladocera recorded (8 spp.) were littoral in habit. The common limnoplankter of other Murray storages, *B. meridionalis*, was abundant in the first collection, but was sparse thereafter. *D. carinata* was numerically abundant the first summer, and persisted in low numbers throughout the study, with peaks in summer-autumn. Exceptionally large specimens (-4.5 mm) were collected from all depths during the period of anoxia in summer 1977-78. They were bright red in colour, and had bubbles beneath the carapace. The production of haemoglobin under low oxygen conditions has been recorded elsewhere (e.g. Hoshi *et al.*,1978). After the summer 1978 peak of *D. carinata*, cladocerans rarely comprised more than 30% of the plankton; from mid-winter 1979, less than 5%. *C. quadrangula* was the only other cladoceran of frequent occurrence.

Copepods were poorly represented in Dartmouth. *B. triarticulata* was the only calanoid recorded, and was probably perennial. Adults were not collected during winter-spring 1979. Several littoral cyclopoids were of rare occurrence. *M. leuckarti* appeared in autumn each year, coinciding with population peaks in nearby billabongs. This species, as *D. carinata*, was not commonly present in the limnoplankton of other reservoirs.

Temporal variation as measured by the coefficient of community is shown in Table 5.7. Only the Jaccard coefficient (CC) was used, as collections and counts from WSCV samples were made on a qualitative rather than quantitative basis, and use of the Czekanowski coefficient was not justified.

The rapid changes in species composition between sampling dates are clear; low CC values reflect replacement of species. Most similar assemblages were from consecutive or temporally close samples. Some evidence of seasonality is given by higher values in the same season each year; in some cases this was asynchronous , reflecting community instability. In general, greater disparity in species composition existed between the Dartmouth samples than between those from other large impoundments. A noticeable trend towards the end of sampling (spring-summer 1979-80) was increasing similarity of species composition as rotifers became predominant and persistent.

Average momentary species composition was 5.3 rotifers, 2.9 cladocerans and 1.8 copepods. Species diversity maxima (Fig. 5.8c) were less clear-cut in Dartmouth than in other reservoirs. Greatest diversity occurred in summer 1977, autumn and spring 1978, 1979 and again in summer 1980, with a probable autumn 1980 peak. Although less distinct, the bimodal spring-autumn increases in diversity followed the pattern in other storages, e.g. Hume, Eildon. Lowest diversity in Dartmouth occurred during the summer 1980 anoxia. Mean diversity (H'=1.8) was lower than for other large storages. Only Burrinjuck (p.   ) had a more simple plankton assemblage.

Maximum species numbers occurred also in spring and autumn, as did maximum population densities, coincident with seasonal breeding of most plankters. Densities ranged from 24-173 ℓ^{-1} ($\bar{x}$ 73 ℓ^{-1}) (Fig. 5.8b), although these values represent only surface samples (n=7) and provide little evidence of vertical or horizontal variability in limnoplankton density. Population densities probably were considerably higher during the rotifer pulses in winter 1979 and summer 1980.

		1977		1978											1979												1980	
		20.xi.	20.xii	13.i.	14.ii.	1.iii.	4.iv.	3.v.	24.v.	8.vi.	18.vii	9.viii	6.ix.	14.xi.	5.xii.	2.ii.	20.iii	27.iv.	9.v.	24.v.	22.vi.	13.vii	17.viii	14.ix.	16.x.	23.xi.	4.xii.	10.i.	19.ii.
1980	15.iv.	.09	.40	.18	.30	.25	.25	.38	.44	.20	.23	.19	.14	.27	.24	.36	.25	.25	.40	.20	.19	.25	.15	.20	.43	.29	.36	.36	.36
	19.ii.	.06	.27	.13	.20	.19	.15	.21	.38	.21	.32	.26	.16	.36	.37	.33	.33	.33	.27	.26	.26	.33	.18	.44	.47	.53	.54	.54	
	10.i.	.08	.36	.17	.17	.24	.25	.27	.40	.19	.27	.18	.09	.15	.38	.33	.45	.45	.50	.32	.25	.33	.23	.36	.40	.46	.45		
1979	4.xii.	.08	.36	.18	.27	.24	.22	.19	.27	.19	.22	.18	.14	.36	.29	.33	.45	.33	.36	.25	.33	.33	.14	.36	.40	.58			
	23.xi.	.07	.29	.13	.21	.26	.17	.10	.21	.17	.29	.35	.12	.29	.32	.27	.46	.36	.29	.22	.35	.36	.19	.38	.33				
	16.x.	.06	.25	.12	.19	.18	.14	.26	.36	.31	.38	.32	.25	.33	.29	.40	.24	.24	.33	.30	.25	.31	.31	.50					
	14.ix.	.00	.20	.06	.13	.20	.17	.10	.21	.21	.35	.28	.17	.13	.25	.19	.36	.19	.20	.27	.26	.58	.27						
	17.viii.	.00	.07	.08	.08	.17	.25	.27	.27	.19	.22	.11	.09	.15	.29	.23	.23	.23	.36	.32	.18	.33							
	13.vii.	.00	.25	.08	.17	.24	.22	.12	.27	.19	.27	.18	.14	.15	.22	.14	.45	.23	.25	.25	.54								
	22.vi.	.06	.27	.20	.29	.32	.15	.10	.20	.17	.23	.20	.21	.19	.30	.18	.25	.25	.27	.21									
	24.v.	.10	.20	.10	.21	.30	.12	.27	.44	.38	.37	.16	.17	.14	.19	.25	.25	.19	.33										
	9.v.	.09	.40	.18	.30	.43	.29	.38	.44	.25	.29	.19	.14	.17	.24	.50	.50	.50											
	27.iv.	.08	.25	.17	.17	.24	.25	.19	.27	.19	.33	.18	.14	.15	.38	.33	.45												
	20.iii.	.08	.36	.08	.27	.40	.25	.19	.40	.24	.33	.25	.14	.15	.29	.33													
	2.ii.	.08	.25	.17	.27	.24	.25	.36	.56	.24	.33	.25	.25	.36	.38														
1978	5.xii.	.07	.17	.11	.18	.23	.14	.32	.43	.23	.36	.24	.29	.40															
	14.xi.	.09	.27	.18	.30	.18	.25	.20	.44	.20	.23	.36	.33																
	6.ix.	.10	.20	.10	.21	.15	.11	.17	.28	.38	.31	.38																	
	9.viii.	.06	.27	.13	.29	.25	.15	.15	.38	.35	.39																		
	18.vii.	.04	.23	.08	.18	.32	.10	.19	.44	.48																			
	8.vi.	.08	.20	.07	.16	.33	.09	.26	.45																				
	24.v.	.10	.44	.20	.50	.58	.33	.55																					
	3.v.	.14	.20	.12	.19	.55	.18																						
	4.iv.	.00	.13	.14	.14	.25																							
	1.iii.	.06	.33	.19	.36																								
	14.ii.	.25	.63	.50																									
	13.i.	.38	.18																										
1977	20.xii.	.33																											

Table 5.7: Temporal changes in species composition of the Dartmouth plankton (Jaccard's CC values).

During the period of oxygen depletion in summer 1978 and again in mid-winter 1978, several vertical trap samples were taken to compare plankton density and diversity at depths in the storage. A comparison also was made between the plankton above the aeration facility (site 1, 36 m deep) and the upstream station (site 2, 25 m deep) during the summer series. Trap samples were taken at 1 m intervals to 10 m, at 15 m and at 20 m at both sites during summer (Fig. 5.10). During the winter series only two samples were collected (15 m and 20 m); a door was lost from the trap during 10 m sampling. Several vertical hauls were taken to permit at least qualitative comparisons.

In the summer samples, plankton densities decreased with depth at site 1. Mean zooplankton density over the water column was 34.6 ℓ^{-1}. Mean *Volvox* density was 41.5 ℓ^{-1}, with a maximum at 2-3 m. The zooplankton was most abundant (52 ℓ^{-1})at 1 m, most diverse at 2 m (12 spp.,H'=1.95). Most abundant plankters were *K. tropica* and copepodite stages of *M. leuckarti*. The same taxa predominated at site 2, but other zooplankton were depauperate, with few species in each trap, and a mean density of only 12 ℓ^{-1}. Greatest density and diversity was at 2 m (7 spp., 21 ℓ^{-1}, H'=1.91). *Volvox* was considerably more abundant at site 2, again with a maximum at 2 m (183 ℓ^{-1}) and a mean density of 80 ℓ^{-1}. Biomass decreased to 10 m, then increased steadily to 20 m.

Light inhibition is probable in the upper 2 m of the water column (cf. Eildon). Differences in species composition were attributed to low oxygen levels at site 2 inhibiting the zooplankton, and turbulence at site 1 (a result of aeration) depressing the algal population. Increased algal densities with depth at site 2 probably resulted from passive sinking. Maxima of diversity and density around 2 m at both stations is possibly a trophic effect; phytoplankters grazed by the herbivorous zooplankton occurring maximally at this depth, or may reflect diurnal vertical migration.

Failure of the volume sampler prevents comparisons other than those of qualitative features as in Figs. 5.8 and 5.9. The two traps which were collected in winter contained 61 plankters ℓ^{-1}(15m) and 18 ℓ^{-1}(20 m). These

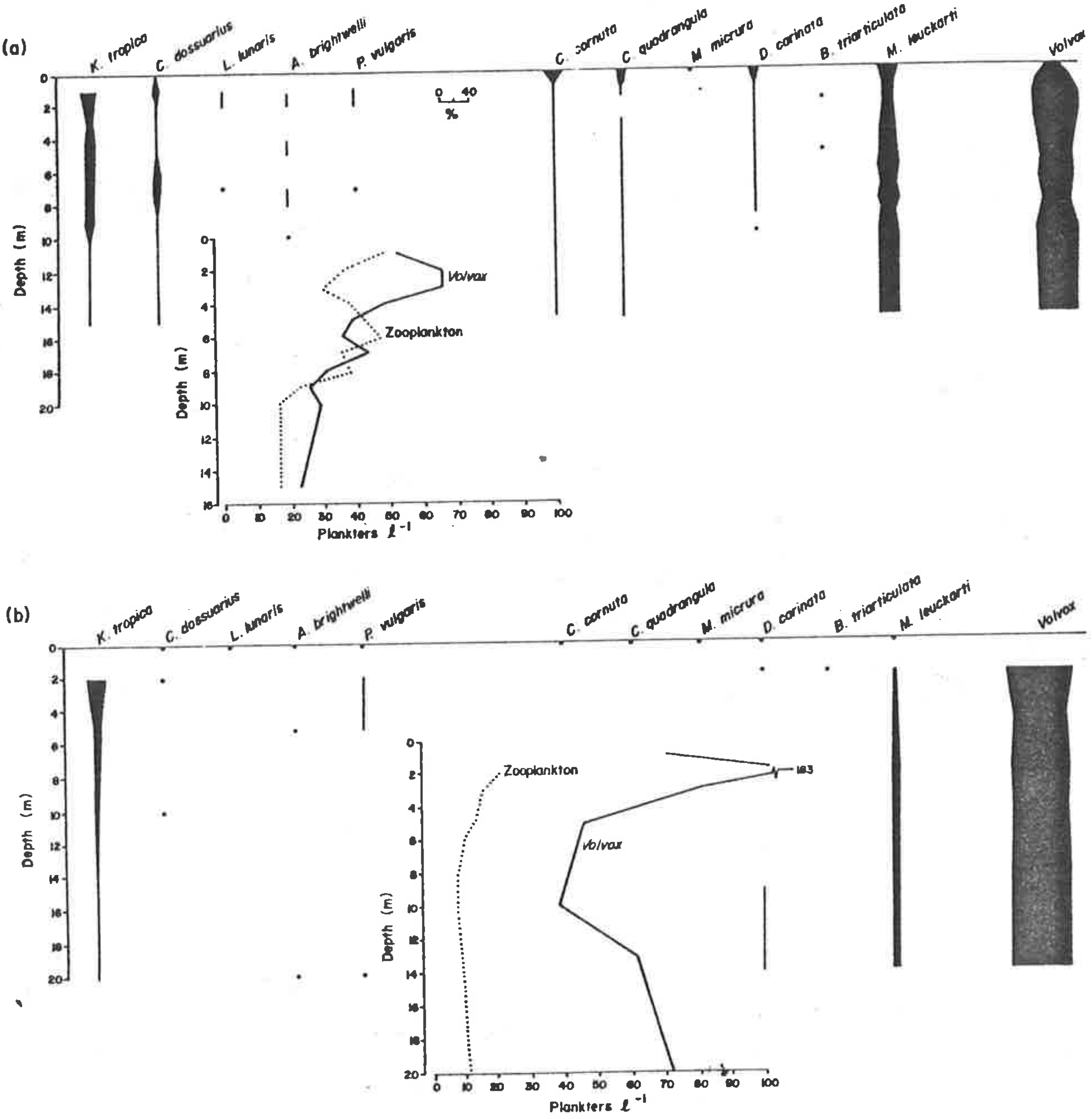


FIG. 5·10 Plankton density vs. depth in Dartmouth Dam (2·iii·78)
(a) above aeration facility
(b) no aeration

samples, and those collected by vertical hauls from several depths, were dominated by calanoid copepodites, i.e. despite a greater number of species and greater density than in the summer samples, very low H' values were recorded.

Environmental factors:

Sixteen taxa were collected frequently enough for regression analysis. Table 5.8 shows only those taxa for which more than 40% of the variance in log density could be attributed to variations in measured environmental characteristics. For only seven taxa were linear relationships suggested. Of these, four were significant ($P<.05$). *H. mira* and *M.leuckarti* were negatively correlated with DO levels, while copepodite stages of *B. triarticulata* were positively correlated with DO. A negative correlation also existed between *L. ismaeloviensis* and conductivity. Apparent relationships between log density of several species and temperature and pH were non-significant. There were no significant correlations (all $r^2<0.10$) between overall community diversity (H') and any water quality characteristic, including PO_4, NO_3-N and chlorophyll.

Although correlations may be interpreted in terms of individual species' habitat preferences, some caution is necessary, e.g. *L. ismaeloviensis* is regarded as cosmopolitan (Koste, 1978). It was found over a very restricted salinity range in the study area, and may have a low tolerance to changes in salinity. The ecology of the species is little known. The inherent problems of suggesting causal relationships on the basis of a few correlations are clear. Many more environmental determinants than those measured may influence significantly the dynamics of the plankton, particularly so in Dartmouth, where a rapidly fluctuating and complex environment resulted from interactions between the water mass and the submerged basin. Patchy knowledge of such interactions may produce quite misleading interpretations of apparent correlations (cf. Dumont, 1977). Clearly, habitat complexity and relative infrequency of sampling preclude a more than superficial treatment of the plankton of this unique storage.

Table 5.8 : Regression of log population density of dominant limnoplankters in Dartmouth on measured water quality characteristics($r^2 > 0.40$ only are shown).

Taxon	°C	pH	DO	µS	NTU
	a b r^2	a b r^2	a b r^2	a b r^2	a b r^2
S. oblonga					-3.47 7.70 0.40 ρ:-0.35, F: 1.59 P>.05
P.dolichoptera	11.27 5.10 0.63 ρ:0.49,F:1.19 P >.05		72.27 10.01 0.46 ρ:0.22,F:2.11 P > .05		
L.ismaeloviensis				71.71 -11.59 0.49 ρ:-0.89,F:22.48 P<.05	
H. mira	21.24 -6.01 0.42 ρ:-0.43,F:2.51 P>.05		94.32 -11.35 0.70 ρ:-0.75,F:14.58 P<.05		
C. quadrangula		6.87 -0.30 0.41 ρ:-0.35,F:1.59 P>.05			
M. leuckarti		6.70 -0.34 0.53 ρ:-0.59,F:3.77 P>.05	96.79 -29.46 0.46 ρ:-0.68,F:7.94 P< .05		
Cyclopoid copepodites	22.71 -5.20 0.45 ρ:-0.32,F:0.94 P > .05				
Calanoid copepodites			69.30 11.96 0.50 ρ:0.69,F:11.02 P < .05		

In summary, the Dartmouth plankton was a mixed community of true limnoplankters and billabong species. Rapid environmental fluctuations in the filling storage enabled rapid replacement of plankters by species of different ecological tolerance. There was evidence of increasing stability towards the end of sampling, however the species dominants at that time (rotifers) were a transitory assemblage, i.e. indicative (in other storages) of low retention time and unstable habitat. It is unlikely that a micro-crustacean dominated limnoplankton will develop in Dartmouth for several years. Even when the reservoir fills the plankton may take years to stabilize.

The Mitta Mitta River below Dartmouth

Collections were taken at several sites between the dam and Eskdale, some 40 km downstream. The effects of construction activity were apparent on each sampling date (07.i.77, 20.v.77, 15.xi.77, 2.iii.78). For several km below the damsite extreme turbidity resulted from silt and larger particles in suspension, particularly after increased runoff from the spillway construction area. Settling of this material on the gravel and stony substratum of the stream had promoted dense algal growth (*Melosira*, *Oscillatoria*, ?*Lyngbya*), which persisted for 15 km below the dam. Deposition of the suspended load resulted in decreased turbidity by Eskdale.

The effect of the substrate change on the benthic fauna of the river was described by Blyth & St. Clair (1978) and Blyth (1980). There was a considerably greater impact on the downstream biota than originally predicted, with complete eradication of most major groups, reduction of diversity and dominance by a few species capable of utilizing the new substrate and algal mats. Of these species, only chironomid larvae were collected during the present study, and then only one or two individuals in summer 1977. No plankters were collected, although exoskeletal material was present. Survival of plankters probably was prevented by turbidity, i.e. abrasion by large particles, and by turbulence.

There was, however, a complex plankton in billabongs downstream from

Mitta Mitta, where the river meanders across a narrow (1-2 km wide) floodplain. The billabong communities are described in chapter 6. Suffice to note here that under normal seasonal (spring and early summer) flooding these communities would provide an inoculum of limnetic and littoral species into the river and thence into Hume, 50 km downstream of Eskdale. High flow conditions were not recorded in the river in this study, however some indication of the seasonal contribution from the floodplain community is seen in the compositional fluctuations in the southern arm of Hume Reservoir, described later. Construction of Dartmouth Dam, by reducing seasonal flood peaks and thereby limiting water (and nutrient) replenishment of the swamps and billabongs, will undoubtedly have a devastating effect on the biology of the Mitta Mitta floodplain. Even in peak flows the cold water regime imposed by the dam will disrupt the environmental cues necessary for breeding in aquatic invertebrate and vertebrate populations in the Mitta Mitta valley (cf. Smith *et al.* 1978).

5.2.1.3 Hume Reservoir (station 32, Fig. 5.1)

The original dam, at the confluence of the upper Murray and Mitta Mitta rivers, was begun in 1919, and the first stage was sealed in 1936. The dam was enlarged in 1961 to form the present Hume reservoir. The storage is used to regulate flows for irrigation in the Murray valley, also for domestic and industrial supplies to the nearby cities of Albury and Wodonga (population 52,000).

During 1973-1976 Hume and the Murray for 230 km downstream to and including Yarrawonga Weir (L. Mulwala) were the subject of an intensive ecological study. The principal objective of the study, which was reported by Walker & Hillman (1977), was to determine possible impacts on the ecology of the nearby R. Murray of urban development in the two cities. Baseline ecological information so collected would provide a foundation for future comparative environmental monitoring.

Comprehensive background information is given in the report. Simply stated, the study was primarily concerned with physico-chemical features, particularly nutrient loadings, and their effect on phytoplankton development. Secondarily, invertebrate and fish fauna were surveyed, and biological monitoring studies were carried out. Due to time constraints and taxonomic problems, study of the zooplankton was less comprehensive than that of the phytoplankton. A preliminary species list and estimates of microcrustacean zooplankton densities were provided in the report.

In the present study, the expertise of the AWDC Peter Till Environmental Laboratory staff was made freely available, and invaluable assistance was provided in sampling. All plankton collections from the early study were made available for comparative purposes. In addition, a large number of collections made from the AWDC survey area during 1976-79 were specifically for the present study; their analysis here represents original work.

The AWDC sampling stations are shown in Fig. 5.11. Although only Hume Reservoir is considered here (i.e. stations 3, 4 and 5), the same numbering also serves in later discussion. Several of the AWDC sites were sampled in the present study, in addition to the sites shown in Fig. 5.1. Hydrologic and morphometric data for the reservoir are given in Table 5.9. Compared to the other large storages, Hume is relatively shallow, with a shorter retention time.

Physico-chemical features:

Water quality data for the three reservoir sites are summarised in Table 5.10. Hume water, as for other upper Murray storages, was of low salinity, sodium bicarbonate type. With the exception of NO_3-N, ranges of measured characteristics were similar at the three stations, although there were significant differences between stations on some sampling dates (Walker & Hillman, 1977). The extreme range of NO_3-N at station 4 possibly resulted from the more intensive land use of the Mitta Mitta floodplain.

On the basis of annual nutrient loadings, which were variable, Walker & Hillman noted that Hume could be classified as meso-eutrophic, i.e. the

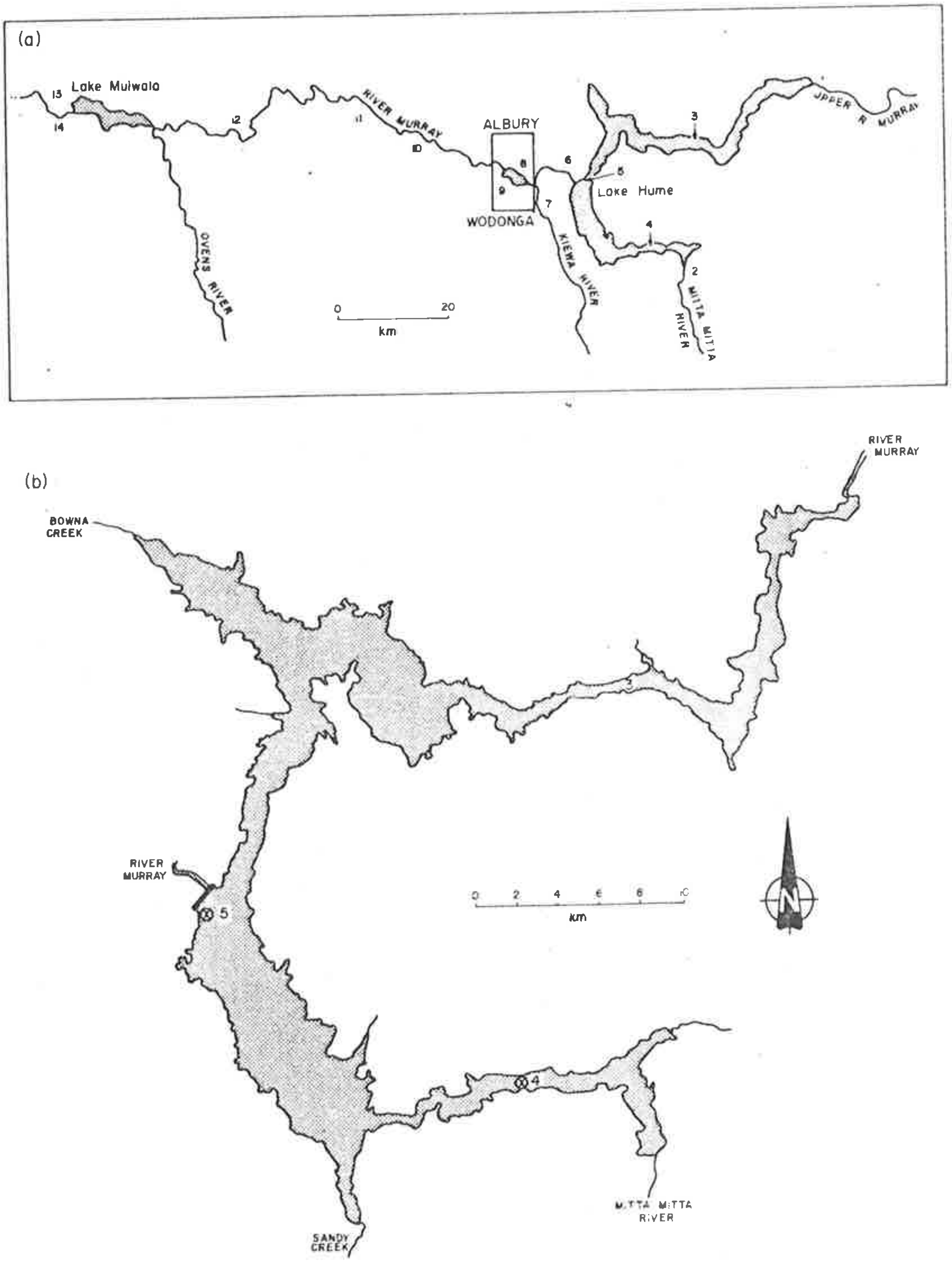


FIG. 5.11 (a) AWDC sampling sites between Hume and Mulwala
(b) Lake Hume sites sampled in this study ⊗

Table 5.9: Hydrologic and morphometric features of Hume Reservoir (from Walker & Hillman, 1977; Croome, 1980).

Latitude and longitude	$147^{\circ}07'$E $36^{\circ}01'$S
Catchment area (km^2)	15,275
Elevation (m)	193.8
Shoreline (km)	250
Capacity (Ml)	3.07×10^6
Max. depth (m)	15.2
$\bar{x}$ depth (m)	14.2
Retention time ($\bar{x}$ yr)	0.75

Table 5.10: Ranges of some water quality characteristics for three stations in Hume Reservoir (abstracted from Walker & Hillman, 1977, Appendix 12.3).

	Station 3 Murray arm	Station 4 Mitta arm	Station 5 behind dam
Temperature ($^{\circ}$C)	7.2-26.0	7.4-26.2	8.9-26.4
Dissolved oxygen (% saturation)	72-121	83-118	78-120
pH	6.8-8.05	6.5-8.05	6.8-8.5
Turbidity (NTU)	1.3-57.0	1.8-51.0	1.2-14.0
Conductivity (µS)	34.2-53.8	30.1-75.0	40.8-61.0
Colour (Hazen)	<5 - 60	<5 - 60	<5 - 60
TDS	20-35	18-45	24-36
Alkalinity (mg ℓ$^{-1}$ CaCO$_3$)	10.8-18.6	10.0-27.0	17.0-23.0
NO$_3$- N	.002-.330	.002-185.0	.002-.140
Orthophosphate	.005-.024	.005-.020	.005-.021

reservoir frequently had a total-P concentration above 20 mg m^3.

Biological features:

Phytoplankton.

The phytoplankton of Hume was studied by Viyakornvilas (1974) and reported by Walker & Hillman (1977), who listed 142 species from the impoundment (cf. Eildon, p.   ). During the AWDC study, and during the present study, the dominant algae were diatoms (*Melosira, Asterionella*), with subdominants including *Volvox, Trachelomonas, Anabaena* and *Anacystis*. There were marked differences in relative abundance and peaks of algal species at the three sites during 1974-76, the reasons for which were not clear. Similarly, there were complex fluctuations in algal biomass and chlorophyll which were not readily correlated with environmental factors. Mean biomass (mm^3/m^3) and chlorophyll (mg/m^3) for the three stations were as follows: station 3, 742/7.08; station 4, 1418/10.15; station 5, 855/4.55. Differences at station 4 probably relate, as was noted above, to land use practices in the Mitta Mitta valley.

Zooplankton.

Community composition: Identifications and density estimates of the Hume microcrustacean zooplankton were given by Walker & Hillman (1977). The dominant plankters during the AWDC study were copepods (*B. triarticulata, C. ampulla* and *M. leuckarti*), with cladocerans subdominant (*B. meridionalis, C. quadrangula, D. unguiculatum* and *Daphnia* spp.). Quantitative variations in the zooplankton during 1974-75 are shown in Fig. 5.12. Although rotifer density was not estimated in the AWDC survey, data on the microcrustacea provide a basis for comparison with data from the present study, and enable a more comprehensive treatment of temporal diversity in community structure.

In this study 44 species of zooplankton were recorded from the reservoir (26 Rotifera, 10 Cladocera, 8 Copepoda). Compositional data are summarised in Figs. 5.13 and 5.14; breeding seasonality is included in the latter. Predominance of copepods is evident in Fig. 5.13b. On most occasions the Hume limnoplankton was dominated by the perennial *C. ampulla*.

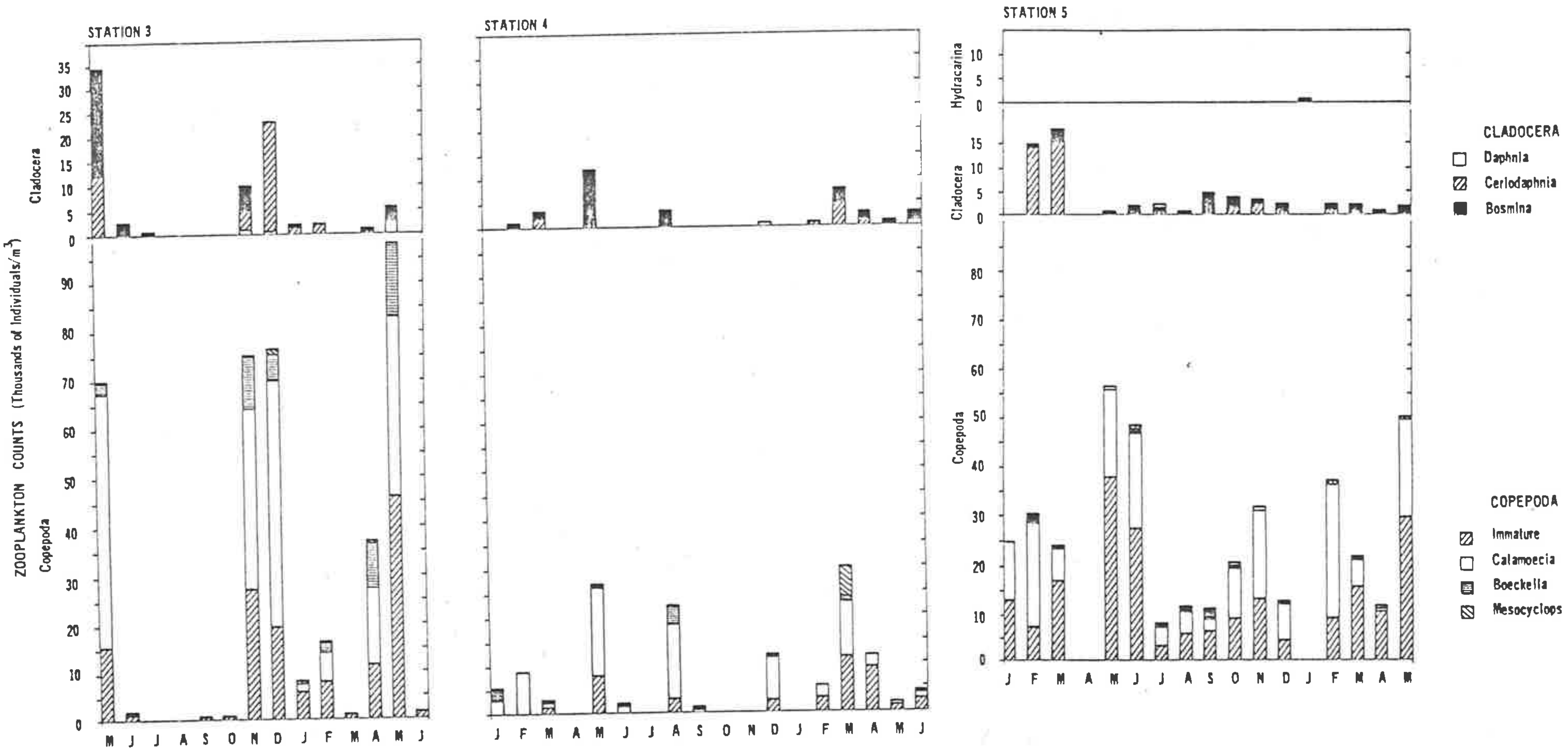


FIG. 5·12 Zooplankton counts (individuals/m³) at Stations 3 4 and 5 (Lake Hume) 1974-5.

(from Walker & Hillman 1977)

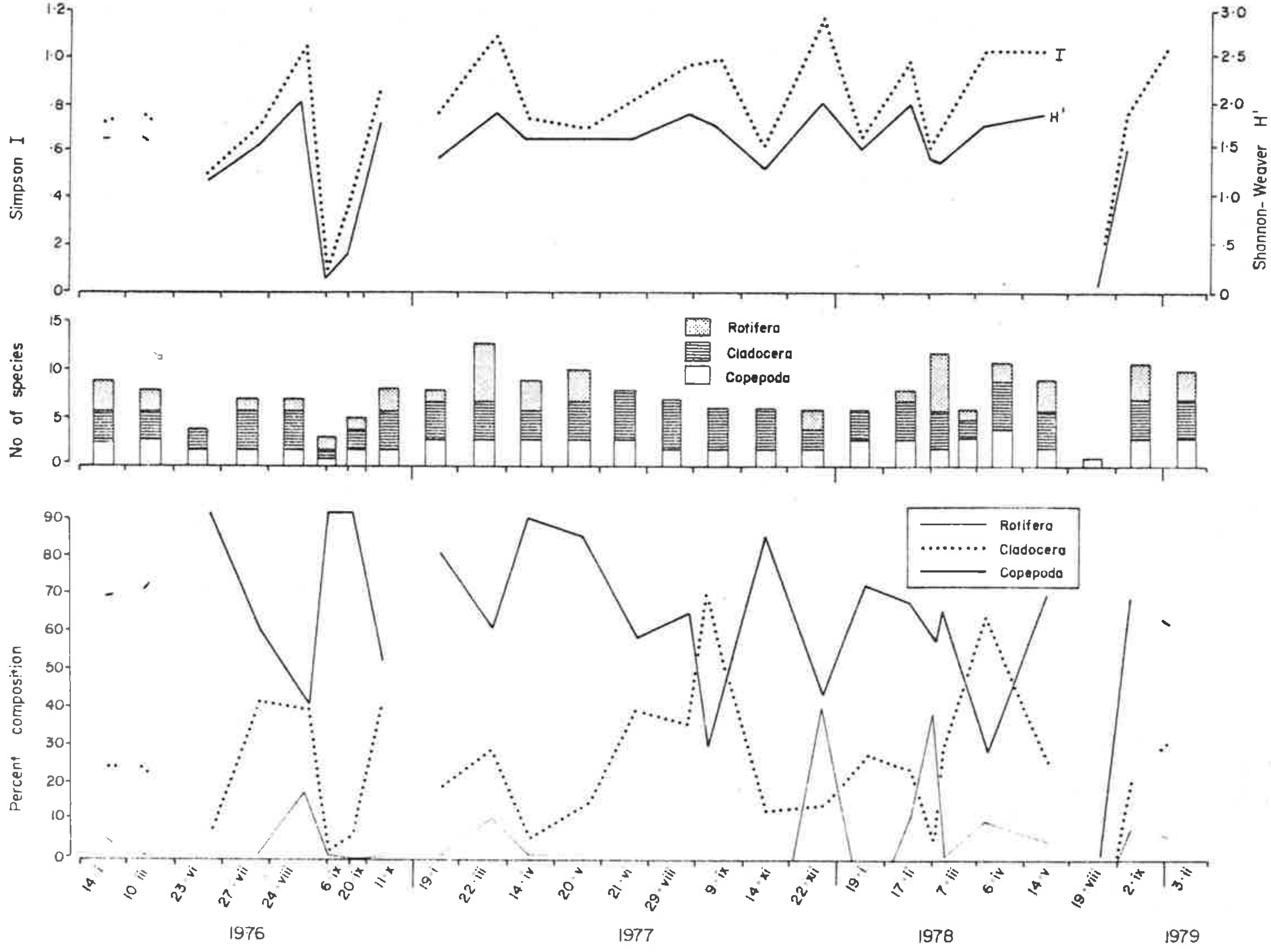


FIG 5 13 Fluctuations in species composition and diversity of limnoplankton in Hume Reservoir

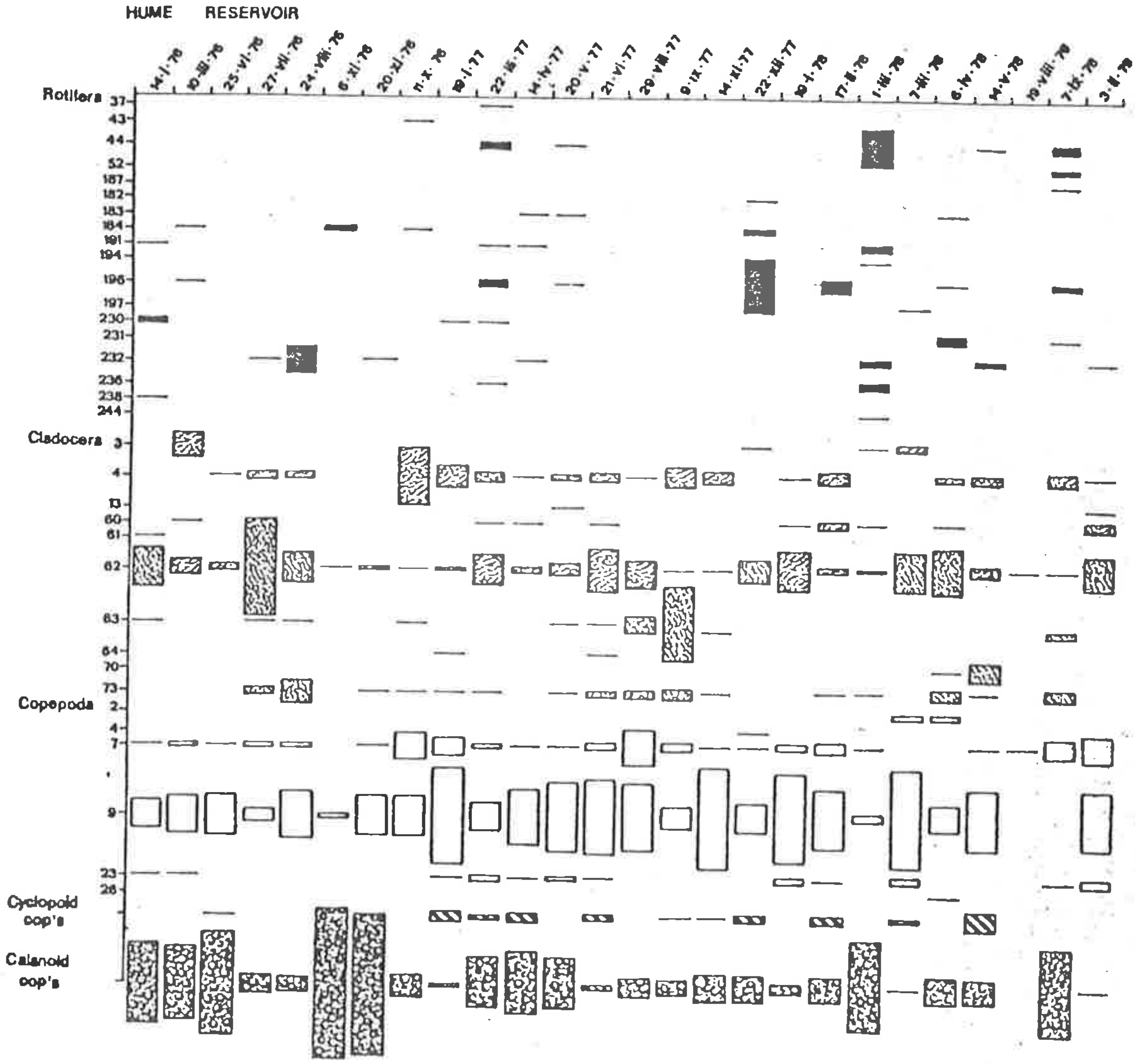


FIG. 5·14 Temporal variation in limnoplankton composition, Hume Reservoir

B. triarticulata also was perennial, with the cyclopoid *M. leuckarti* seasonal (summer-autumn). Of the Cladocera, *B. meridionalis* was perennial. *D. unguiculatum* probably also was perennial. *C. quadrangula* was absent over summer. Other cladocerans were seasonal, e.g. *M.micrura*(summer), *D. carinata* winter-spring). Rotifers were notably depauperate; on only two occasions did they comprise more than 20% of the limnoplankton. In summer 1977-78 there were successional 'blooms' of *A. priodonta* and *K. cochlearis*. Seasonality was evident in several species, e.g. *K. cochlearis, P. vulgaris* (summer-autumn), *S. oblonga* (autumn), *C. dossuarius* (autumn-winter). The absence of rotifers from winter-spring collections is possibly due to dilution.

A single species (*C. ampulla* and copepodite stages) comprised from 50-90% of the plankton on most sampling dates, with generally ony two or three species making up more than 90% of the plankton. Average momentary species composition was 1.8 rotifers, 3.3 cladocerans and 2.4 copepods, i.e. fewer rotifers and more microcrustacea than in Dartmouth.

Species diversity (Fig. 5.13c) was more stable than that of Dartmouth. Very low diversities recorded in spring 1976 and 1978 are attributed to dilution and reduction of plankton density. Diversity, as in Eildon, was greatest in winter. Mean H' (1.99) was greater than in either Eildon or Dartmouth. Maximum species numbers (Fig. 5.13a) occurred in summer, with maximum population densities in autumn. Excluding the dinoflagellate, *Ceratium,* which on occasions was the numerically dominant plankter, with densities in excess of 200 ℓ^{-1}, plankton densities were low (range 4-123 ℓ^{-1}, $\bar{x}$ 44.4 ℓ^{-1}). Densities of the same order of magnitude are given for station 5 during the AWDC study (Fig. 5.12).

In contrast to the variability of the Dartmouth plankton, in which pseudoplankters and littoral incursions were frequent, that of the mid-reservoir station in Hume (station 5) was relatively stable during 1976-79, and comprised true plankters. Non-planktonic incursions were, however, frequent in collections from the two arms of the reservoir. Differences in community composition noted ~~f~~during the AWDC study also were apparent during the present study.

Comparative data for the three stations are given in Fig. 5.15. Station 4, on the Mitta Mitta arm, had a lower average biomass than either station 3 or 5, but the species diversity was higher, with more billabong species represented, e.g. *Brachionus* spp., *K. slacki*.

Evidence of the relative stability of the Hume limnoplankton is given by the CC values in Table 5.11. Species composition generally was more similar between collections than for any other reservoir, and distinct seasonality also was more apparent, with synchronous occurrences of major species at approximately the same time each year. Bimodality was evident in some species, i.e. autumn-spring maxima. Low species numbers in winter-spring collections accounted for low CC values at these times.

Environmental factors:

During the AWDC study, little correlation was found between measured environmental characteristics and trends of phytoplankton biomass. Zooplankton biomass tended to be highest at stations with the lowest phytoplankton biomass (Walker & Hillman, 1977), suggesting a trophic relationship. In this study there was little correlation between log population density of any species, or overall species diversity, and environmental factors (all r^2 values <0.30). Fluctuations in nutrient status probably account for the differences in plankton composition in the north and south arms of Hume (cf. Eildon), however no relationship was detected in this study.

As will be discussed in more detail later, the lack of correlations make doubtful the value of zooplankton species as biological indicators. In Hume, at least, the generalization that eutrophy leads to a decrease in diversity but an increase of tolerant species does not hold. Although Hume was at times eutrophic in terms of nutrient load, expected algal responses to these loads were inhibited by adverse environmental conditions. This inhibition appears to follow through to the grazing zooplankton, resulting in generally low population densities and greater community diversity than otherwise would be expected. In some cases, however, the predicted sequence

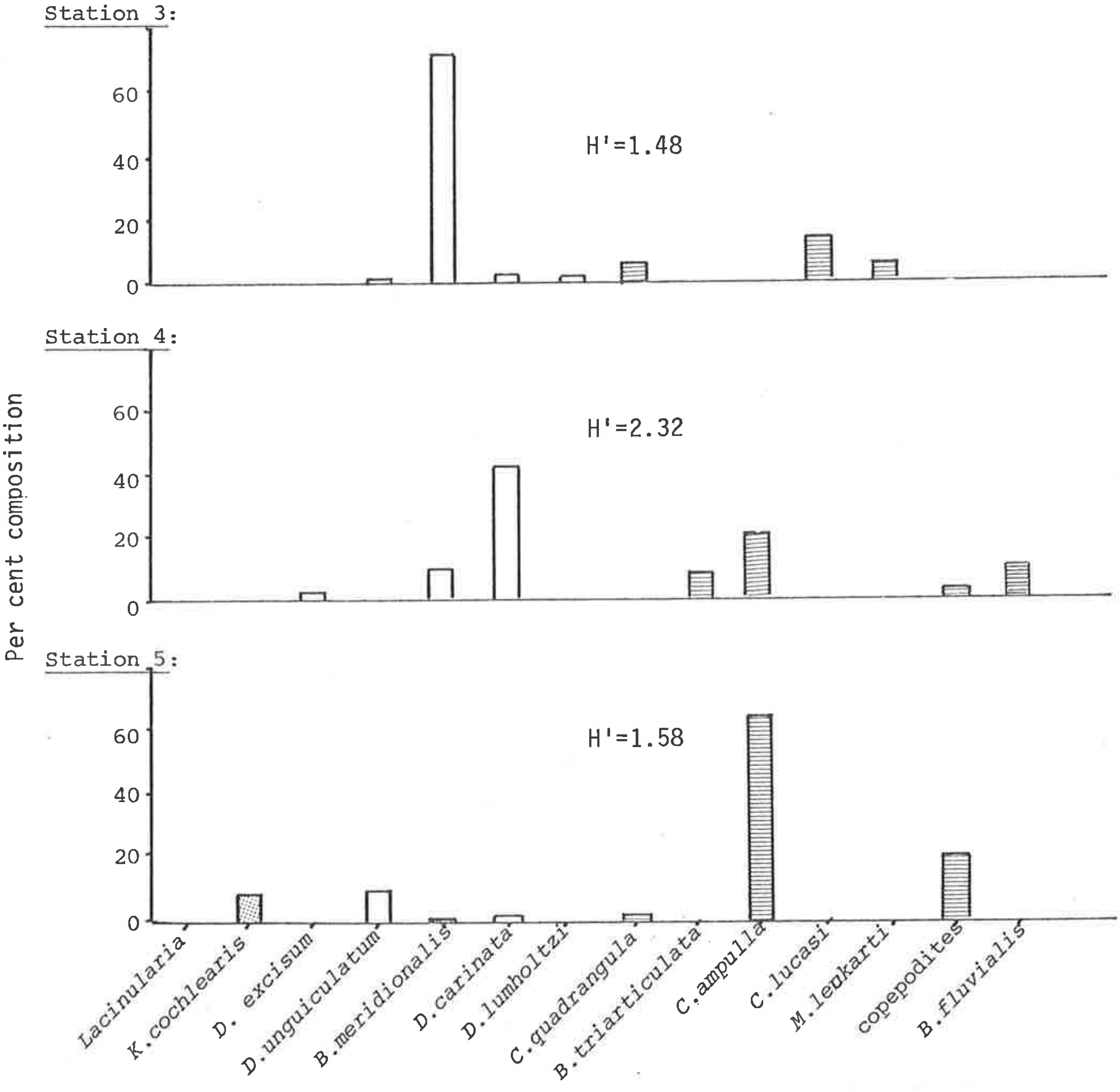


Fig. 5.15: Comparative species composition at stations 3, 4 and 5, Hume reservoir, 18.x.77.

1976						1977									1978								1979		
10 iii	23 vi	27 vii	24 viii	06 ix	11 x	19 i	22 iii	14 iv	20 v	21 vi	29 viii	09 ix	14 xi	22 xii	19 i	17 ii	01 iii	07 iii	06 iv	14 v	09 viii	07 x	03 ii		
.31	.30	.33	.33	.10	.31	.31	.38	.38	.36	.42	.33	.36	.36	.15	.33	.31	.17	.25	.25	.20	.11	.43	.27	14.i.	1976
	.33	.25	.25	.25	.33	.33	.40	.42	.38	.33	.25	.27	.27	.56	.56	.60	.25	.40	.36	.31	.13	.27	.50	10.iii.	
		.57	.57	.20	.50	.31	.44	.40	.50	.57	.67	.67	.25	.67	.50	.14	.25	.25	.44	.25	.36	.40	.50	23.vi.	
			1.0	.13	.67	.50	.33	.50	.55	.67	.75	.86	.86	.18	.44	.50	.27	.18	.29	.60	.14	.50	.42	27.vii.	
				.13	.67	.50	.33	.50	.55	.67	.75	.86	.86	.18	.44	.50	.27	.18	.29	.60	.14	.50	.42	24.viii	
					.25	.11	.07	.10	.09	.11	.13	.14	.14	.33	.14	.11	.08	.14	.08	.10	0	.08	.09	06.ix.	
						.45	.31	.31	.50	.60	.67	.75	.75	.27	.40	.45	.18	.17	.27	.42	.13	.46	.29	11.x.	
							.40	.42	.50	.60	.67	.56	.56	.17	.56	.60	.18	.27	.36	.42	.13	.46	.50	19.i.	1977
								.47	.53	.50	.33	.36	.36	.19	.46	.62	.39	.19	.50	.38	.08	.50	.44	22.iii.	
									.46	.55	.33	.36	.36	.15	.67	.55	.31	.25	.33	.50	.11	.54	.58	14.v.	
										.64	.55	.60	.60	.23	.45	.64	.22	.23	.40	.58	.10	.62	.43	20.v.	
											.67	.75	.75	.17	.75	.78	.25	.27	.46	.42	.13	.58	.50	21.vi.	
												.86	.86	.18	.44	.50	.19	.18	.29	.45	.14	.50	.31	29.viii	
													1.0	.20	.50	.56	.20	.20	.31	.50	.17	.55	.33	09.ix.	
														.20	.50	.56	.20	.20	.31	.50	.17	.55	.33	14.xi.	
															.20	.27	.20	.33	.21	.15	0	.13	.23	22.xii.	
																.75	.20	.33	.42	.36	.17	.42	.60	19.i.	1978
																	.18	.27	.58	.42	.13	.46	.64	17.ii.	
																		.20	.21	.31	0	.28	.22	01.iii.	
																			.31	.15	0	.21	.23	07.iii.	
																				.33	0	.29	.24	06.iv.	
																					.11	.43	.36	14.v.	
																						.09	.10	09.viii	
																							.31	07.x.	

Table 5.11 : CC values, Hume Reservoir samples, 1976-79.

accompanying eutrophy does occur, e.g. Buurinjuck Dam.

The composition of the species assemblage, can, however, be a useful indicator of localised or point source eutrophication. In both Hume and Eildon the influence of seasonal nutrient enrichment from camping areas resulted in blooms of particular "indicator" species, particularly protozoans, dinoflagellates and small rotifers. Thus, these marginal areas had a zooplankton numerically dominated by rotifers, while the mid-lake plankton in both reservoirs was characteristically a microcrustacean assemblage (see p. 129).

In brief, the Hume limnoplankton, predominantly microcrustacea, showed greater stability and community diversity than the limnoplankton of other large storages. The effects on the plankton of fluctuations in nutrient status were suggested, although no linear relationship could be detected. Such changes of plankton composition were more marked in the shallow arms of the storage, and were ascribed to pseudoplanktonic incursions and littoral taxa flushed in by influent streams. These inocula did not persist into the mid-lake plankton, which provided the major source of plankters into the Murray downstream of the dam. Two other sources, the Kiewa and Ovens Rivers, are considered below.

5.2.1.4 Rocky Valley, Pretty Valley and Junction Dams, Kiewa River (Figs. 5.1, 5.16)

The Kiewa River rises a few km from the Mitta Mitta headwaters in the Bogong High Plains, N.E. Victoria, and flows north to join the Murray some ten km downstream from the Hume Dam. The upper catchment, much of which is above 1500 m, receives >2,000 mm precipitation annually, largely as snow. The area is snow covered for 4-5 months of the year, limiting land use to grazing. Snow grass and sparse snow gums are the principal vegetation.

To utilize the high runoff for hydroelectricity production, the Kiewa Hydroelectric Development was constructed during the 1940's and 1950's.

The project was described by Rufenacht (1961). A system of aqueducts and pipelines diverts water from 300 km^2 of the catchment through three power stations. Rocky Valley Dam is the major storage; Pretty Valley, Junction and Clover Dams (Fig. 5.16) are regulating pondages. Following greater use of the High Plains for skiing, domestic water supply is of increasing importance. Falls Creek Ski Village is supplied from the hypolimnion of Rocky Valley Dam. Pertinent information on the upper dams is included in Table 5.12.

Downstream of Mt. Beauty there is intensive horticulture (tobacco, hops, nuts), dairying and beef cattle grazing (Land Cons. Council, Vic.,1974). The floodplain widens to several km, and is more intensively utilized than that of the nearby Mitta Mitta River. In the last 50 km extensive meandering has produced numerous anabranches and billabongs (Walker & Hillman, 1977).

In the present study, seasonal samples were collected from Rocky Valley and Pretty Valley Dams, Junction Dam at Bogong Village, Mt. Beauty pondage, and at several river sites between Mt. Beauty and the Murray at Bandiana. Collections made from several billabongs are described in Ch. 6.

Rocky Valley Dam (Fig. 5.16 c,d)

No published information exists on water quality or biological features of this storage. Some incidental information collected by the WSCV and SECV is contained in internal reports.

Physico-chemical features:

Only six visits were made to the dam. Sampling dates are given in Fig. 5.17. Ranges were as follows: Water temperature 0.0-23.0 ^{o}C, pH 6.9-7.9, DO 8.0-9.8, conductivity 2-58 uS, turbidity 0.5-1.0 NTU. Nutrient levels were checked from the summer 1978 sample (orthophosphate .014 mg ℓ^{-1}, Total-P .028 mg ℓ^{-1}, NO_3-N .021 mg ℓ^{-1}). Nutrient input into the reservoir derives from grazing in the catchment, indirectly from runoff and directly by cattle defecating into the aqueducts. Otherwise the high quality dilute water, on occasions of lower conductivity than lab-distilled water, reflects snow melt

FIG. 5.16a KIEWA RIVER DAMS

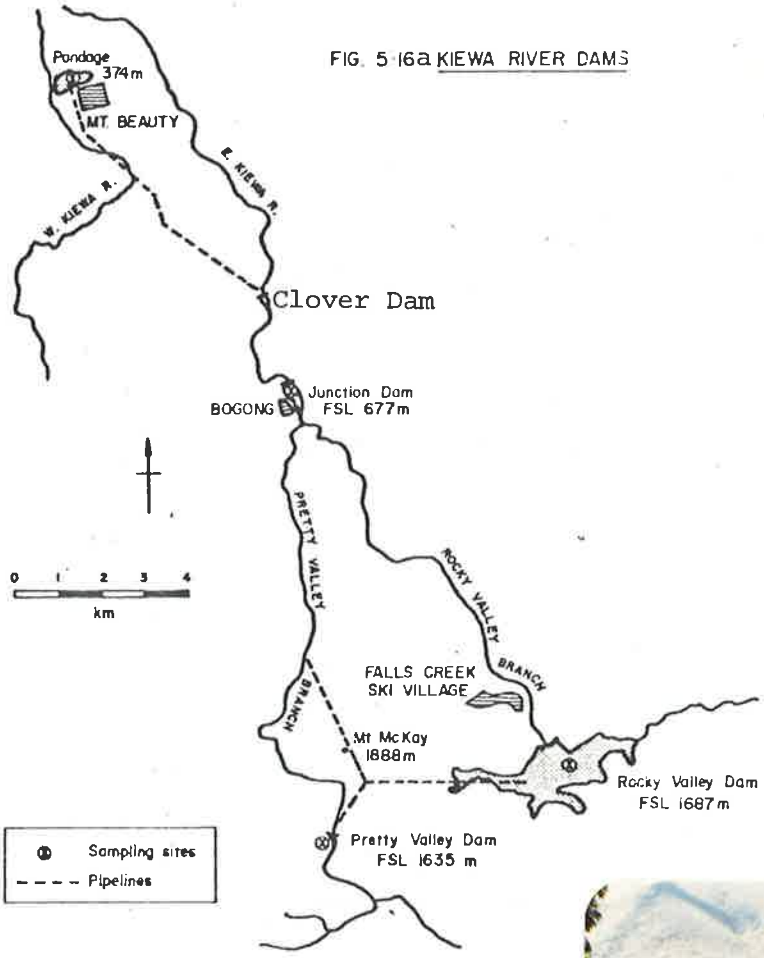


Fig. 5.16 b Station 67, Junction Dam, Kiewa River, Bogong Village.

Fig. 5. 16 c (top) Rocky Valley Dam, Falls Creek, summer.

d (bottom) winter.

Table 5.12: Comparative features of Rocky Valley and Pretty Valley Dams. Temperature ranges are given only for the former.

	Rocky Valley	Pretty Valley
Latitude and longitude	36°53'S 147°18'E	36°55'S 147°15'E
Elevation (m)	1599	1635
Catchment (km^2)	33.5	27.5
Capacity (Ml)	28,370	-
Depth (m)	23	5
Draw-down (m)	17	4
Temp. range (°C)		
Air	-5.0-40.0	
Water	0 - 20.0	

and rainfall on the catchment.

Rocky Valley is dimictic, stratifying during summer and under thick ice (to 1 m) in winter. It is probably the only dimictic lake on the Australian mainland, although several are known from Tasmania (P.A. Tyler, University of Tasmania, pers. comm.). Winter ice cover and prolonged stratification produce anoxic conditions and problems of water quality in the Falls Creek Ski Village supply. Destratification of the hypolimnion was carried out by the WSCV during 1976-77 (WSCV unpublished report). Ice cover prevented effective sampling during this period, however a winter sample was obtained the following year when ice cover was not as thick.

Biological features:

Phytoplankton: A typical oligotrophic desmid-dominated assemblage was present in all collections, although plankters were sparse. The major genera were : *Docidium, Hyalotheca, Spondylosium, Staurastrum, Staurodesmus* (desmids); *Eunotia, Fragilaria, Surirella, Synedra, Tabellaria* (diatoms). Additionally, *Sphaerocystis* (chlorophyte), *Peridinium* (dinoflagellate) and *Oscillatoria* (blue green alga) occurred in summer, possibly in response to increased nutrient levels.

Zooplankton: Excluding protozoans, 20 species of zooplankton were recorded from the dam (11 Rotifera, 5 Cladocera and 4 Copepoda). Species composition, density and diversity for each sampling date are shown in Fig. 5.17. With the exception of the spring 1977 assemblage, the plankton was dominated by the calanoid *B. triarticulata* (66-100%), with a larger congener, *B. pseudochaele* co-occurrent in summer and spring 1977, and a third species, *B. minuta*, present in spring. The only plankters present in the winter sample were calanoid nauplii and copepodite stages. Rotifera dominated the plankton only in spring (*A. sieboldi, K. procurva, S. pectinata, P. dolichoptera*). At other times Cladocera comprised 11-30% of the plankton and several species apparently were perennial (*B. meridionalis, C. quadrangula, D. carinata*). *C. sphaericus* apparently was seasonal (autumn and spring).

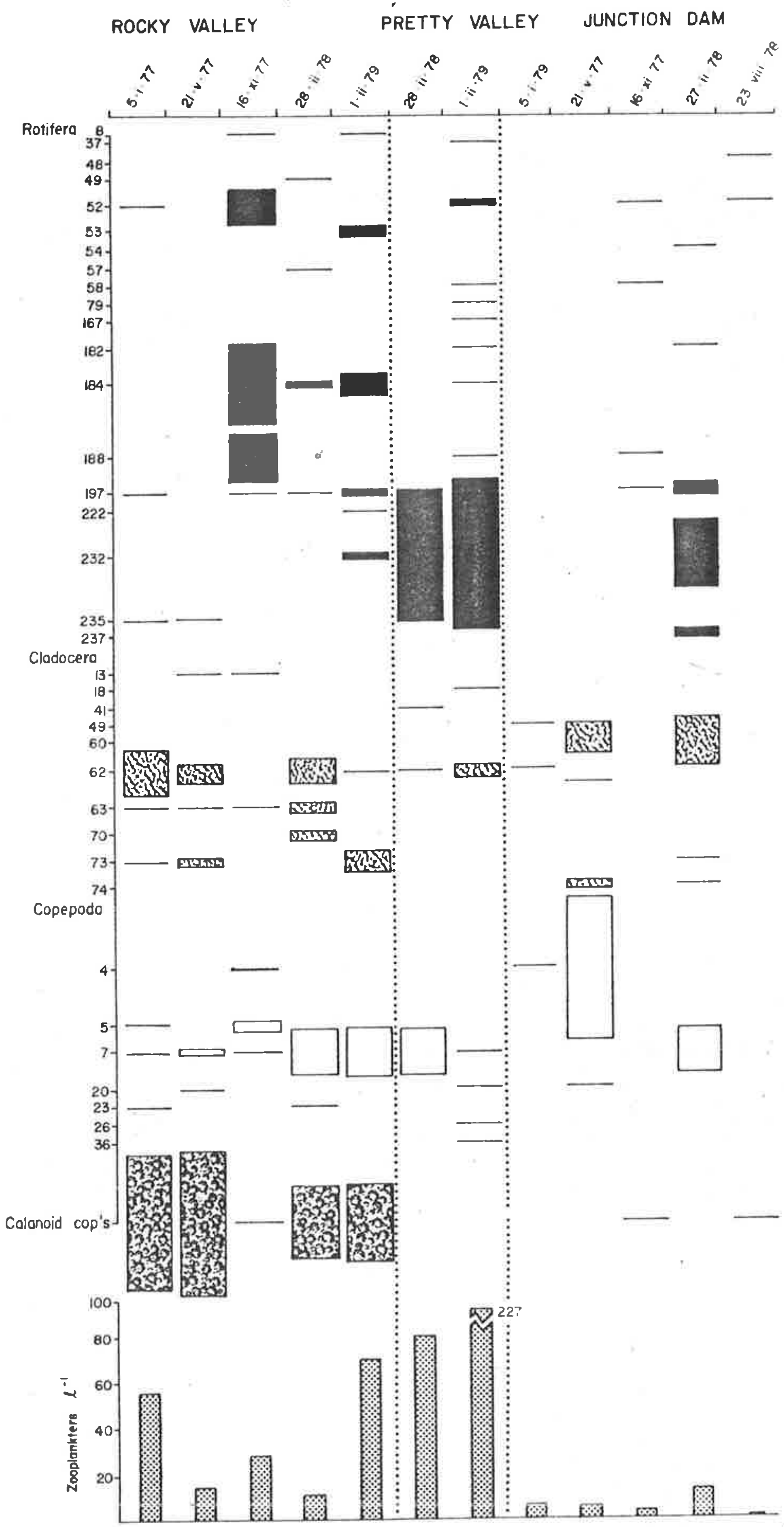


FIG. 5·17 Temporal variations in limnoplankton composition, Kiewa River dams

The small block of perennial species accounted for the generally low similarity in species composition between sampling dates (Table 5.13). Most similar assemblages were those closest in time. Dissimilarities resulted from single occurrences of several species, some of which were littoral incursions e.g. *Ptygura* sp., *Macrocyclops* . Mean species diversity was low (H'=1.52), with spring 1977 and summer 1979 maxima. Density also was lower than for most other storages (10.0-71.7 plankters ℓ^{-1}), with maximum density recorded from the summer 1979 collection. Momentary species composition was 3.2 rotifers, 2.3 cladocerans and 1.7 copepods.

Pretty Valley Dam (station 66, Fig. 5.16a)

Unlike the larger dam, which frequently is drawn down for power generation, the small pondage at Pretty Valley, some 3 km from Rocky Valley, is maintained at full supply level. Although only two comparative samples were taken from the pondage, in summer 1978 and 1979, contrasts with the plankton of Rocky Valley were clear.

Physico-chemical features:

Temperature, DO, pH and turbidity on both visits were similar to those in Rocky Valley Dam. Conductivity was slightly higher (12.5 µS vs. 8.0 µS in 1978, 21.0 µS vs. 10.5 µS in 1979). Nutrient levels also were slightly different in the single summer 1978 sample (orthophosphate .020 mg P ℓ^{-1}, total P .024 mg ℓ^{-1} and NO_3-N .007 mg N ℓ^{-1}).

Biological features:

Phytoplankton: There was a more complex phytoplankton than in Rocky Valley Dam. In addition to all genera listed for that storage, the following were recorded: *Closterium, Closteridium, Dinobryon, Euastrum, Pediastrum, Melosira,* several species of *Staurastrum,* and *Triplocerca* (I. J. Powling, pers. comm.). Phytoplankton also were more abundant in Pretty Valley than Rocky Valley, possibly a response to higher nutrient levels.

Zooplankton:

Community composition: Data are summarized in Fig. 5.17. Sixteen plankton

Table 5.13: CC values, Rocky Valley Dam.

21.v.77	16.xi.77	18.ii.78	24.viii.78	1.ii.79	
.50	.31	.42	.13	.31	05.i.77
	.23	.23	.14	.23	21.v.77
		.29	.11	.29	16.xi.77
			.11	.29	28.ii.78
				.11	24.viii.78

species were present (9 Rotifera, 3 Cladocera, 4 Copepoda). The zooplankton of Pretty Valley was more complex than that of Rocky Valley in the summer 1979 collection. Diversity was lower in both years due to predominance of a single species (*C. dossuarius*, 70% and 82% respectively). Rotifers were quantitatively most abundant in both years, with a single species in 1978 and nine species in 1979. Several of these were pseudoplanktonic, indicative elsewhere in the basin of small lentic habitats, e.g. *B. patulus*, *T. similis*, *T. tetractis*. *B. triarticulata* was subdominant in 1978 (38%), but was sparse in 1979. Non-planktonic Cladocera and Copepoda also were recorded (*Biapertura*, *Macrocyclops* and *Attheyella*), reflecting the greater littoral influence in the smaller dam. Zooplankton densities, as for the phytoplankton, were considerably higher in Pretty Valley than in Rocky Valley Dam (79 ℓ^{-1} vs. 10 ℓ^{-1} in 1978, 227 ℓ^{-1} vs. 72 ℓ^{-1} in 1979).

Environmental factors: Sampling of the high altitude dams was inadequate for other than subjective comments on environmental influences. The most significant factors probably are perturbation of Rocky Valley due to drawdown, low winter temperatures, and the seasonal effect of nutrient influx due to cattle grazing activities. Catchment area and storage volume would be expected to influence the latter, e.g. the summer 1978 nitrate level in Pretty Valley was one-third that of Rocky Valley. Whether this difference was due to a lower input, or depletion by algae, is not clear, although the latter is likely. A trophic effect would account for the significantly higher zooplankton densities recorded from Pretty Valley. Also, the predominance of small rotifer species may reflect nutrient differences, or alternatively, a short retention time in the smaller storage, i.e. predominance of short life cycle species, with insufficient time for the development of a microcrustacean assemblage.

As noted earlier, the occurrence of *B. pseudochaele* is of interest. Although considered a temporary pool species, it was not found in pools adjacent to Rocky Valley, or in Pretty Valley. Breeding populations were present during 1977, possibly also in summer 1978, when a single ♀ of a large species was collected. The species is possibly established in the dam, rather than flushed in from the catchment, and its persistence may be related to the rapid fluctuations in storage level, i.e. ephemeral nature of the habitat. Drawdown, up to 17 m, may be extremely rapid (SECV, Mt. Beauty, pers. comm.). No distinction could be made between naupliar stages of the two coexisting calanoid species; overwintering nauplii may have been one or both species. No adults were collected. The strategy of overwintering under ice cover is reported for diaptomids (Hutchinson, 1967).

With the exception of *B. pseudochaele*, all plankters were relatively widely distributed in the study area; in terms of species composition there was little to distinguish the two high altitude dams from other storages. Population densities in Rocky Valley Dam were, however, appreciably lower.

Junction Dam, Bogong Village (station 67, Fig. 5.16b)

Some fourteen km downstream and > 1,000 m lower in altitude, Junction Dam is a small regulating pondage below the confluence of the Rocky Valley and Pretty Valley branches of the East Kiewa River. Its purpose is to provide a head for Clover Power Station and to supply domestic water to Bogong Village. Five collections were made from the pondage to determine if plankters survived from the upstream storages. Sampling dates are given in Fig. 5.17.

Physico-chemical features:

Ranges recorded were as follows : Temperature 2.0-21.0 °C, pH 6.9-7.7, DO 8.0-11.0, conductivity 20-40 µS, turbidity 0.5-1.0 NTU, i.e. similar water quality to the dams.

Biological features:

Phytoplankton: In only one collection (Jan. 1977) was there any algal material. This consisted of shredded, unidentifiable cells, with some indeterminate organic matter.

Zooplankton: Species composition, density, diversity and temporal changes in the Junction Dam plankton are included in Fig. 5.17. Seventeen zooplankton taxa were recorded (9 Rotifera, 4 CLadocera, 4 Copepoda). Of these, ten (59%) were present in the upstream dams. All collections were depauperate in live plankton, and, with the exception of the summer 1978 sample, contained large amounts of carapace and other exoskeletal material. Only 2-5 species were present in the 1977 collections. *B. minuta* and *B. meridionalis* predominated, with littoral strays also present (*Ilyocryptus, Macrocyclops*). Densities were less than 1 ℓ^{-1}. In the summer 1978 sample, rotifers predominated. Five species made up 50% of the plankton, with *C. dossuarius* most abundant, coincident with the same species peak in Pretty Valley Dam. Subdominants were *M. micrura* and *B. triarticulata*. Density was $\simeq$ 10 ℓ^{-1}. Few plankters occurred in winter 1978. In the summer of 1978-79 the pondage was drained; no collection could be taken.

Environmental factors: The pincipal influence on the plankton of this impoundment is the regulation and use of water for power generation. Pressures of 53 kg cm^2 and velocities of $\simeq$380 km hr^{-1} are reached in the pressure tunnels leading to McKay Creek Power Station (SECV, McKay Creek, pers. comm.). Explosive decompression would account for the exoskeletal material found in the downstream pondages. Survival of the plankton downstream of the headwater reservoirs would be similarly low in the streams, where velocities would be inhibitory.

Downstream of Junction Dam, water is impounded in Clover Dam for further power generation prior to ponding at Mt. Beauty to regulate release into the Kiewa River. Three seasonal collections were taken during 1977 from the pondage and from the Kiewa River at Mongan's Bridge (station 69, Fig. 5.1)(dates as for Junction Dam). No live plankters were collected from the pondage in January or May. Exoskeletal material was present. Live plankters occurred in spring (*S. pectinata* (4%), *B. meridionalis* (25%), *C. sphaericus* (49%), *S. vetulus* (2%) and calanoid copepodites (20%). Density was low (17 ℓ^{-1}). A depauperate plankton, with low density and diversity, probably results from extreme habitat fluctuations. Similarly, velocity and turbulence in the river downstream precluded plankton development. Plankters were absent from the summer and spring collections, and in the autumn a single *Bosmina*, an unidentified rotifer and three copepodites were recorded from a five minute tow. Macroinvertebrates were present in all collections.

It seems likely that the contribution of the limnoplankton of the Kiewa system to the Murray plankton was negligible during the study. The upper reservoir plankton was self-sustaining, and with few exceptions, composed of widely distributed, eurytopic species. Survival of this fauna into the downstream river was low. On the floodplain, at times of overbank flow, inoculation from a diverse plankton assemblage from the billabongs would be expected. During the study, however, flooding was not recorded along the Kiewa River.

Downstream of the Kiewa confluence, the Murray floodplain widens to several km, and extensive anabranches and billabongs occur. Some of these are described in Ch. 6. During the study these areas were, on occasions, flooded by releases from Hume, and typical billabong plankters were recorded from the river and downstream L. Mulwala. Water quality in the river reflected the influence of Hume (cf. Walker, Hillman & Williams, 1978). The river stations were sampled for comparison with nearby billabong plankton assemblages, and are considered in more detail in Ch. 6. Suffice to note here that seasonal collections during 1977 and 1978 from the Murray at Wodonga, Wahgunyah and between Corowa and L. Mulwala were numerically dominated by rotifers. At Wodonga the species all were present in Hume (e.g. *K. cochlearis*, *K. procurva*), while downstream stations had an increasing proportion of species associated with fringing weedbeds (and billabongs). Similarly, microcrustacea in the river at Wodonga all were found in Hume (*Bosmina*, *Boeckella*, *Mesocyclops*) while billabong species were more frequent downstream (e.g. *Biapertura*, *Daphnia*) Densities were low ($< 20\ \ell^{-1}$). Species diversity increased downstream, a result of the higher proportion of pseudoplanktonic incursions.

Clearly, the Hume limnoplankton constitutes a major, but seasonally variable proportion of the input to the L. Mulwala plankton. The only other major input to the plankton of the impoundment is from the Ovens River, which enters L. Mulwala at the eastern end.

5.2.1.5 Lake Buffalo (station 60, Fig. 5.1)and the Ovens River

The Ovens River was not systematically sampled, although incidental collections were taken during 1977. These were from L. Buffalo, an impoundment on the Buffalo River, a tributary of the Ovens, and from river sites at Bright, Myrtleford, Wangaratta and just before L. Mulwala. General observations on these collections are pertinent to later discussion of the Mulwala plankton assemblage.

The small headwater storage (24,000 Ml, 29 m deep) was sampled in summer, autumn and spring 1977. Phytoplankton was predominantly a desmid-diatom assemblage, with some *Volvox* and filamentous chlorophytes in summer. The zooplankton in summer and autumn was dominated by microcrustacea, with the numerically abundant plankter *B. meridionalis*. Other cladocerans were sparse (e.g. *Chydorus, Macrothrix*). *M. leuckarti* was the only copepod present, and *A. sieboldi* the only rotifer. In spring, a diverse rotifer fauna (9 spp.) was present, with *B. meridionalis* and cyclopoid copepodites the only microcrustacea. As in Rocky Valley Dam at the same time, the dominant rotifer was *P. dolichoptera,* with *P. vulgaris* co-occurrent. *K.cochleari* also was abundant. Other rotifers were common species elsewhere (*E. dilatata, T. longiseta, T. stylata, S. longipes, A. priodonta, A. sieboldi*). A dense population of unidentified protozoans also was present in spring. Density of plankters was low (4-28 ℓ^{-1}). Diversity was highest in spring (H'=2.48).

The seasonal compositional changes observed suggest the influence of low retention time (several days). Throughflow is greatest in winter-spring. The spring rotifer-dominated plankton consisted largely of species of short life cycle.

Below the dam, samples from the Buffalo River contained plankters only in the slow flow conditions of summer 1977 (*B. meridionalis* and *E. dilatata*).

Larvae of *Baetis* and chironomids also were present. Similarly, only in low flows were plankters collected from the Ovens below the Buffalo confluence (littoral rotifer taxa, e.g. *Lecane, Euchlanis* and the ubiquitous *B. meridionalis*). At other times plankters probably were limited by flow conditions at the upstream Ovens stations. At Wangaratta, plankters were few. In addition to *P. dolichoptera* and *B. meridionalis*, a few littoral taxa were recorded (e.g. *Encentrum, Dicranophorus, Alona, Neothrix*).

Below Wangaratta, a town of 15,000 which discharges treated sewage into the Ovens (Walker & Hillman, 1977), the river was sampled only at the inflow to Mulwala. The respective influences of nutrient input, lacustrine conditions such as flow reduction, and the presence of beds of *Vallisneria* combined to produce an extremely complex rotifer-dominated plankton. Up to 32 species were present in some collections. This lower Ovens plankton assemblage is described with the L. Mulwala plankton. Notably, the predominant limnoplankters were not those of the other major input, the Murray.

5.2.1.6 Lake Mulwala (station 29, Fig. 5.1)

This shallow impoundment provides a head for irrigation canals. Table 5.14 gives morphometric data. Features of the storage and some details of its biology are given by Walker & Hillman (1977). During the AWDC study, fluctuations in the water quality of L. Mulwala were monitored, and estimates were made of phytoplankton production. A preliminary list of zooplankton was provided, and similarities with the Hume zooplankton noted.

In this study, two stations were sampled seasonally (Fig. 5.18); one near the Yarrawonga Yacht Club (AWDC station 13) and one at the Ovens arm near the Goulburn Valley Highway bridge. Additionally, AWDC collections, some made specifically for this study, were made available.

Physico-chemical features:

Ranges of water quality characteristics were as follows: Temperature 8.5-25.0 ^{o}C, pH 6.9-8.4, dissolved oxygen 8.4-11.2 ppm, conductivity 57 -145 μS, turbidity 0.4-30 NTU. With the exception of the conductivity of 145 μS

Table 5.14: Hydrologic and morphometric features of Lake Mulwala (from Walker & Hillman, 1977; WSCV pers. comm.).

Latitude & longitude	36°01'S 146°05'E
Catchment area (km^2)	27,300
Elevation (m)	108
Shoreline (km)	48
Capacity (Ml)	117 x 10^3
Max. depth (m)	13.7
Mean depth (m)	2.6
Retention time (range 1974-76, days)	2.9-13.8

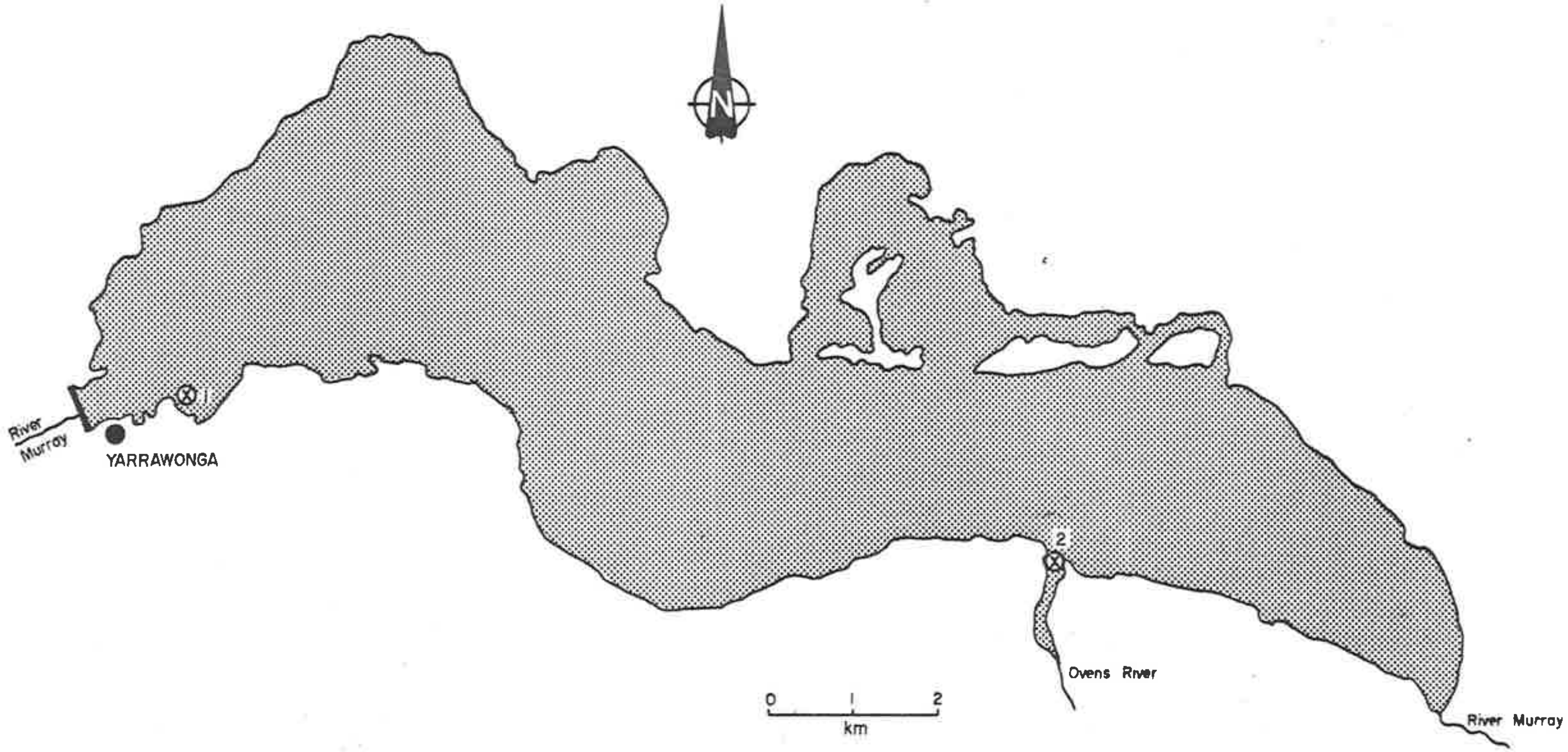


FIG. 5·18 Lake Mulwala showing sampling sites.

(4.ii.79) all measurements were within the ranges reported by Walker & Hillman (1977). The AWDC study gives comprehensive information on fluctuations of water quality in Mulwala, particularly nutrient loadings. The lake was considered to be eutrophic, however problem algal blooms were prevented by high turbidity levels.

Phytoplankton: One hundred and twelve phytoplankton taxa are known from Mulwala, of which 84% also are known from Hume, which strongly influences the downstream plankton (Walker & Hillman, 1977). During the present study, the dominant algae in L. Mulwala were diatoms (*Melosira* spp.) with subdominants from the genera *Anabaena, Anacystis, Asterionella, Cryptomonas, Micrasterias, Trachelomonas* and *Volvox*. A mean algal biomass of 1584 mm^3/m^3 was recorded during the AWDC study (1974-76), higher than for Hume (station 5, 5,855 mm^3/m^3) and a mean chlorophyll level of 9.61 mg/m^3 (cf. station 5, 4.55 mg/m^3). Seasonal fluctuations in community composition and biomass were complex, and could not be correlated with any of the measured environmental characteristics. In the present study no quantitative assessment of phytoplankton density was made. Predominant genera were recorded, and bloom conditions noted.

Zooplankton:

Community composition: Ninety-eight taxa were recorded from Mulwala (67 of Rotifera, 21 of Cladocera and 8 of Copepoda), more than from any other impoundment. Fig. 5.19 shows species present, relative proportions of each group, density and diversity on each sampling date, Fig.5.20 the percentages of each taxon and temporal variations in community composition. Breeding seasonality also is shown for each taxon.

Seasonal trends were apparent, but less clear than in other reservoirs due to Mulwala's short retention time and rapid level fluctuations. The influence of extensive beds of *Vallisneria* and shallow morphology tended also to mask population changes in the open water plankton. Non-planktonic incursions comprised 59% of the taxa recorded, a higher proportion than for any other storage.

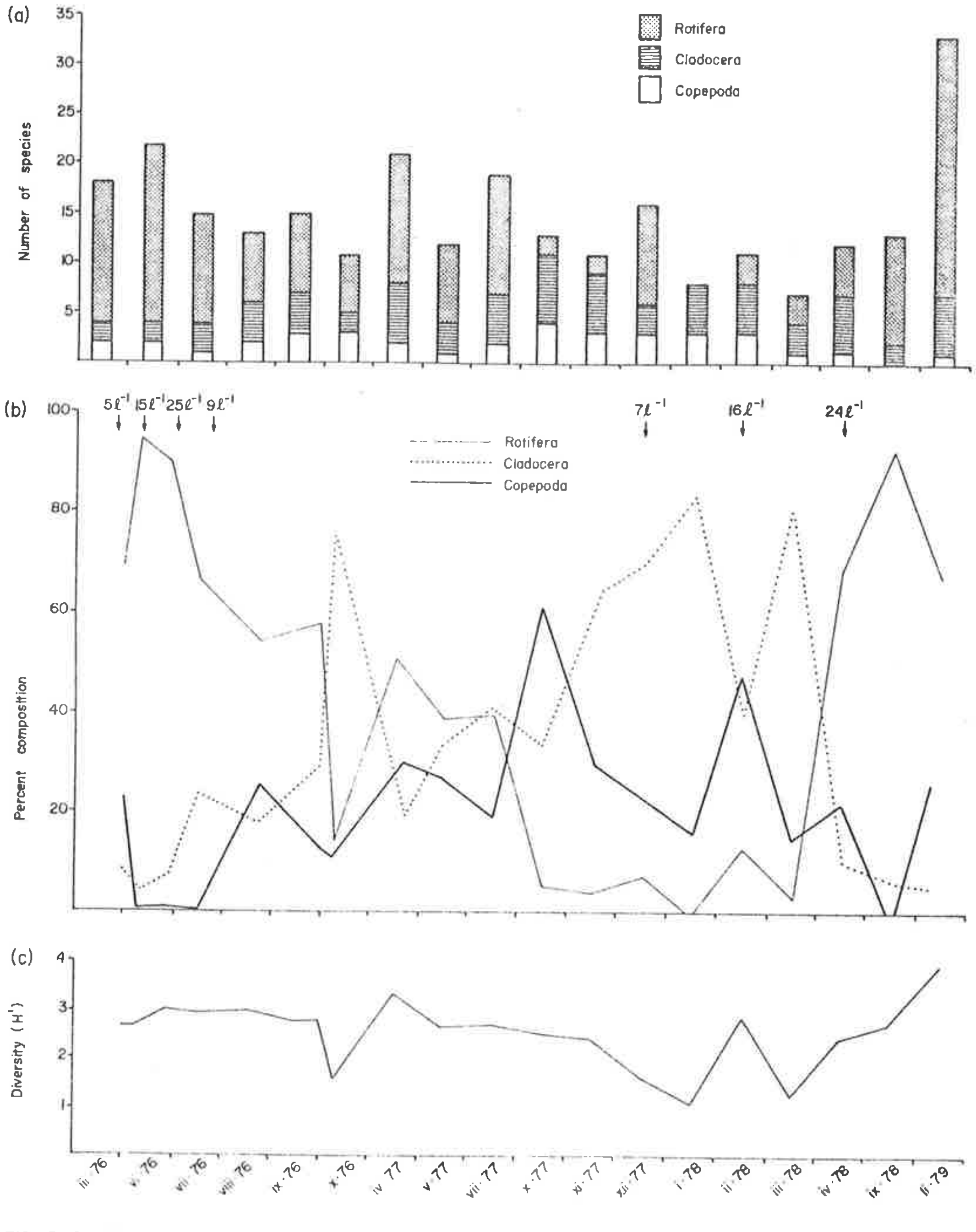


FIG. 5·19 Fluctuations in limnoplankton composition, Lake Mulwala
(a) species composition, (b) percent composition (c) diversity

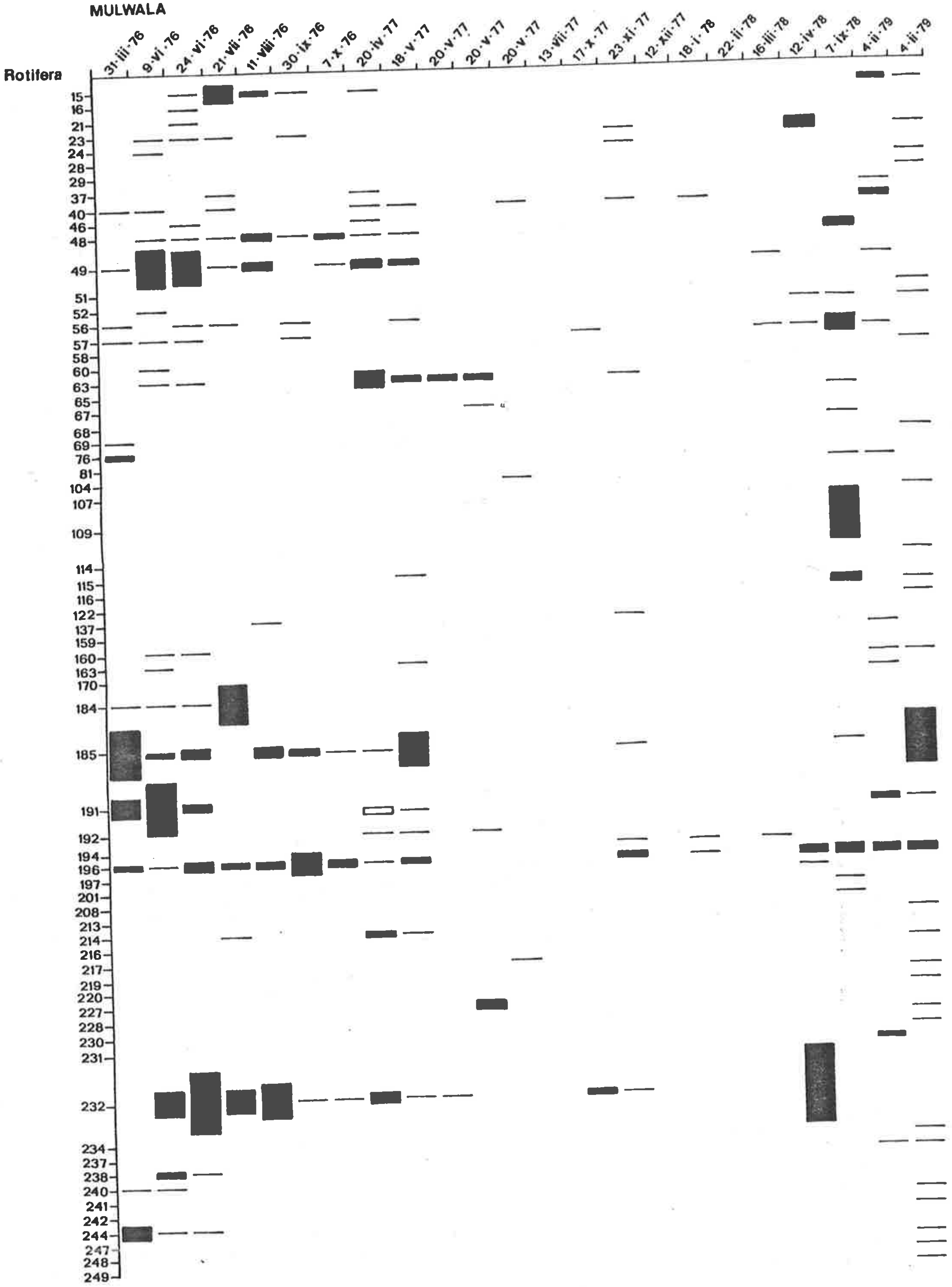


FIG. 5·20 Temporal variation in plankton composition, Lake Mulwala

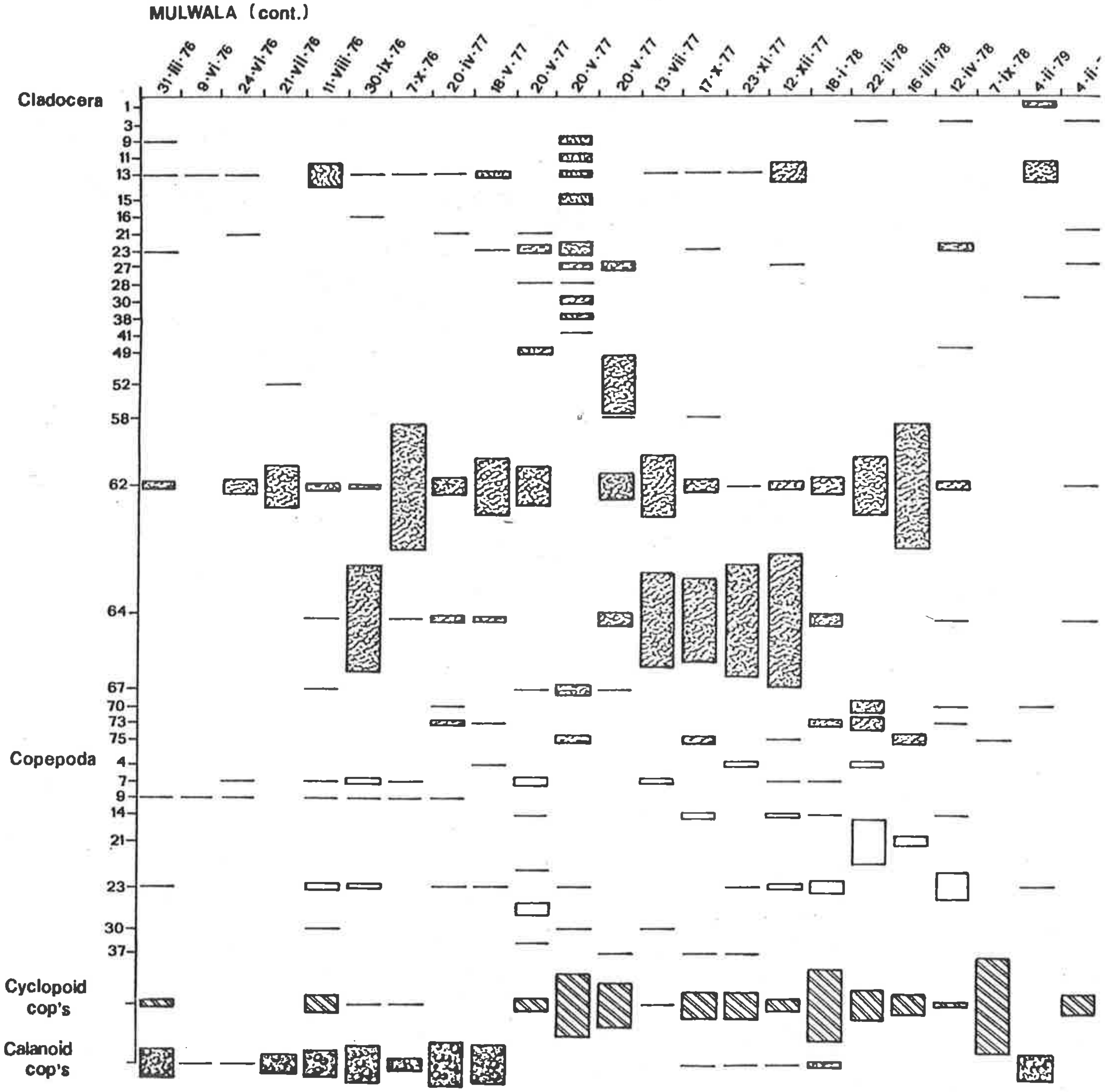


FIG. 5·20 (Continued)

Of the Rotifera, less than half (30 spp.) were true plankters. Of these typically limnetic species, only nine occurred in more than two or three collections over the study and apparently were established in the storage (*B. angularis, K. australis, K. cochlearis, S. pectinata, S. stylata, P. vulgaris, A priodonta* and *C. dossuarius*). Notably, with the exception of *K. australis*, all are cosmopolitan eurytopic species, tolerant of extremes of water quality. All probably were perennial in Mulwala. The remaining 21 taxa of limnetic forms occurred in single collections, in several collections with no apparent seasonality, or were rare seasonal components of the plankton, e.g. *A. brightwelli* (spring-summer), *P. complanata* (autumn-winter). Other rotifers were ostensibly billabong forms, littoral or epibenthic species, or, as *K. slacki*, limnetic in shallow waters of billabongs.

The high proportion of these taxa, 55% of recorded rotifers, exemplifies the strong littoral influence. While collections in proximity to hydrophytes would be expected to contain littoral strays, several species occurred commonly in open water. *B. quadridentatus, K. slacki* and *E. dilatata* were facultatively planktonic in Mulwala, the latter predominantly in autumn. Other non-planktonic taxa were distinctly seasonal in occurrence, apparently dislodged from macrophytes, e.g. *E. meneta, M. ventralis* (summer), *N. collaris* (winter).

A similar trend is seen in the cladoceran assemblage. Five of the 23 species recorded (22%) were considered limnoplankters, with only two of these probably perennial; *C. sphaericus*, which is reported elsewhere as facultatively planktonic accompanying algal blooms (Hutchinson, 1967), and *B. meridionalis*, the predominant cladoceran in Hume. *D. lumholtzi* occurred in large numbers in winter-spring 1977 and 1978, *D. unguiculatum* in summer 1978 and 1979, and *C. quadrangula* in autumn 1977 and summer 1978. A further 18 cladoceran taxa were of sporadic or seasonal occurrence, generally in small numbers, e.g. chydorids.

Six of the eight copepod taxa recorded are limnetic in habit. *B. triarticulata* and *C. ampulla* were collected most frequently, but in low numbers. During the AWDC study, *C. ampulla* was dominant. *B. minuta* and *C. lucasi* were rare. *M. leuckarti*, common in billabongs, was common in the plankton, but was absent in winter. A single pulse of *M. decipiens* occurred in summer 1978.

Temporal variation in plankton assemblages was more pronounced than in other storages. During 1976, rotifers dominated all except the spring collection, with one or two species numerically abundant, comprising 40-60% of any sample. Succession was evident in changing species dominants. Early in 1977 an abrupt change in composition was evident, with complete loss of all limnetic species during late autumn, and only sporadic occurrences until the following autumn. A coincident increase in cyclopoids (adults and copepodites) was noted. The latter were subdominant during late 1977 to *D. lumholtzi* and *B. meridionalis*, which made up 60-90% of the plankton. Rotifers again predominated in spring 1978 and summer 1978-79.

Low similarities between the species composition of successive collections and between collections made in the same season in successive years (Table 5.15) emphasize the instability of the Mulwala zooplankton assemblage. The greatest community similarity was between collections from the same point closely approximated in time, with a suggestion of autumn-spring pulses in some species. In general, however, the Mulwala community assemblages were less similar temporally than in any other storage.

Spatial heterogeneity also was more extreme than in any other impoundment, e.g. an AWDC sample from station 13 (18.v.77) and samples from three other sites collected during the present study (20.v.77) are compared in Table 5.15, as are two summer samples (4.11.79). There was a greater disparity in species composition between spatially separated than between temporally separated samples, emphasizing the strong littoral influence and habitat heterogeneity.

Population densities were low during the study (5-25 plankters ℓ^{-1}), lower than for any other storage. Maximum densities were 25 ℓ^{-1} in June

	1976						1977									1978					1979			
31 iii	09 vi	24 vi	21 vii	11 viii	30 ix	07 x	20 iv	18 v	20* v	20* v*	20** v*	13 vii	17 x	23 xi	12 xii	13 i	22 ii	16 iii	12 iv	07 ix	04† ii	04†† ii		
	.39	.32	.24	.24	.40	.18	.45	.36	.11	.09	.03	.10	.15	.21	.13	.11	.10	.13	.19	.11	.32	.11	31.iii	
		.52	.26	.22	.35	.20	.39	.28	.06	.05	.03	.09	.06	.32	.04	.06	.00	.07	.17	.17	.18	.10	09.iv.	
			.33	.32	.57	.26	.62	.30	.17	.05	.06	.13	.17	.22	.11	.09	.04	.19	.16	.14	.13	.12	24.vi.	
				.24	.44	.17	.50	.32	.09	.00	.13	.06	.14	.21	.05	.14	.06	.11	.18	.08	.14	.13	21.vii	1976
					.64	.34	.61	.31	.25	.12	.11	.29	.15	.26	.24	.20	.05	.08	.19	.11	.16	.14	11.vii	
						.41	.91	.43	.16	.07	.10	.27	.29	.44	.38	.29	.07	.13	.44	.12	.16	.17	30.ix.	
							.39	.24	.06	.03	.06	.19	.14	.19	.16	.14	.04	.04	.13	.17	.08	.10	07.x.	
								.94	.21	.15	.14	.25	.21	.50	.27	.35	.23	.13	.41	.14	.22	.19	20.iv	
									.19	.15	.10	.14	.19	.33	.17	.23	.14	.08	.32	.14	.22	.13	18.v.	
										.24	.09	.14	.20	.17	.25	.20	.06	.05	.32	.00	.03	.05	20.v.*	
											.07	.10	.11	.09	.17	.03	.00	.04	.07	.03	.09	.04	20.v.*	
												.13	.14	.12	.17	.14	.06	.05	.08	.00	.03	.07	20.v**	1977
													.25	.18	.50	.23	.13	.09	.13	.13	.05	.09	13.vii	
														.22	.33	.14	.06	.18	.32	.25	.08	.05	17.x.	
															.20	.27	.11	.09	.21	.07	.18	.09	23.xi.	
																.45	.08	.14	.24	.05	.08	.08	12.xii	
																	.13	.11	.32	.04	.11	.07	13.i.	
																		.18	.29	.00	.04	.03	22.ii.	
																			.11	.11	.08	.03	16.iii	
																				.13	.14	.16	12.iv	1978
																					.10	.07	07.ix.	
																						.09	04.ii	1979

Table 5.15: Jaccard CC values, Lake Mulwala, 1976-79.(* and + = same day collections).

1976, and 24 ℓ^{-1} in April 1978. Similar densities during 1974-75 were reported by Walker & Hillman (1977), who related the low biomass to Mulwala's low retention time. Biomass was an order of magnitude less than in Hume (cf. Fig. 5.12 and 5.21).

Environmental factors: Linear regressions of log density of ten common zooplankton species on temperature, pH, dissolved oxygen, conductivity, turbidity, total-P and nitrate nitrogen indicated only two linear relationships: the density of *S. stylata* was negatively correlated with dissolved oxygen (r^2=0.49), and the density of *K. cochlearis* varied according to pH (r^2=0.57). While the correlation with pH was significant (ρ=0.76, F=7.98, P< .05), that with dissolved oxygen was not (ρ=-0.25, P>.05). All other r^2 values were less than 0.30; little of the variance in log density of the plankters could be attributed to variation in measured physico-chemical factors.

A biotic influence was suggested, i.e. the autumn increase of raptorial cyclopoid copepodites, which persisted through 1977 and 1978. During this time rotifers were notably depauperate in the plankton. Direct predation was likely, however regression analysis of log density of predominant rotifer species on log density of cyclopoids indicated little correlation (r^2=0.11, ρ=-0.36, F=3.13 (F 5%=4.32),n=32). There was little fluctuation in the storage level during autumn 1977, i.e. it was not drawn down, and no physico-chemical or biotic stimulus was apparent which could account for the loss of rotifers from the plankton.

Unlike the phytoplankton, the zooplankton of Mulwala did not closely resemble that of Hume. While 50% of species recorded from Hume occurred also in the downstream storage, they represented only ≃20% of the Mulwala assemblage; species dominants largely were dissimilar and there was a higher proportion of non-limnetic species in Mulwala. In effect, Mulwala acts as a "biological sink" for disparate inputs, particularly the Ovens and Murray, the zooplankton assemblages of which are quite distinct. That of the Ovens has a species-rich, largely pseudoplanktonic community, a result of nutrient and other

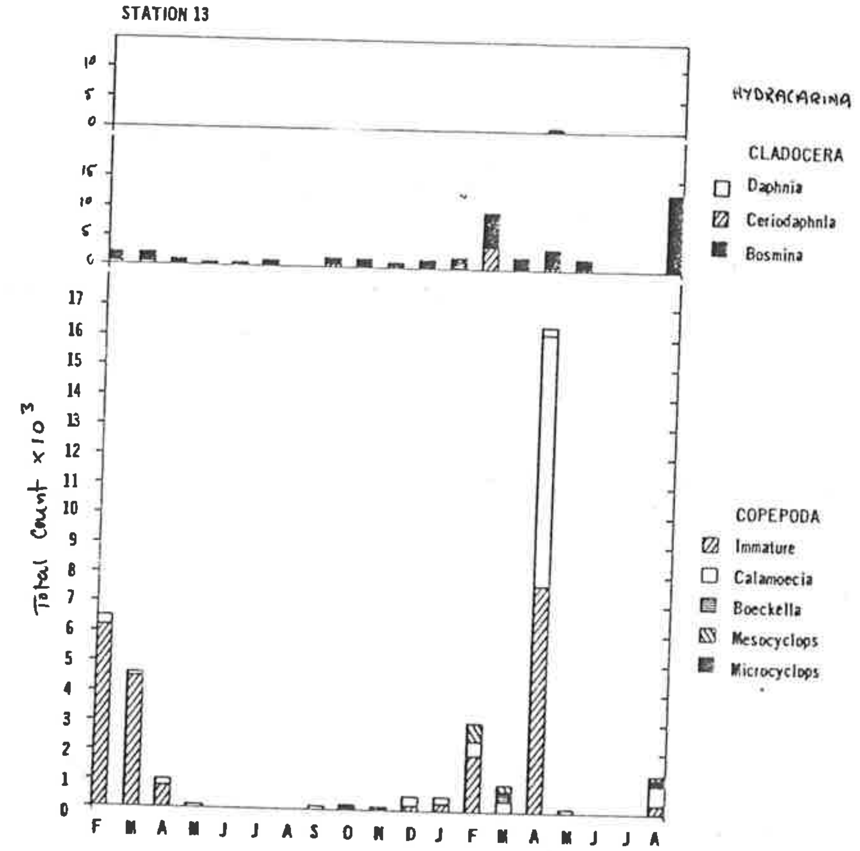


FIG. 5·21 **Zooplankton counts (individuals/m^3) at Station 13 (Lake Mulwala) 1974-5.**
(from Walker & Hillman 1977)

water quality differences, slower flows, and more extensive marginal hydrophyte communities, while the Murray has a relatively depauperate zooplankton consisting of Hume limnoplankton and inocula from billabongs and marginal habitats. The latter tend to predominate in Mulwala, i.e. the combined influences of shallow morphometry, a wide littoral zone, submerged trees etc. have produced a habitat essentially more "billabong" in terms of microfauna, with a flowing component introducing potamoplankton. Because of its short retention time, a stable limnoplankton is not able to develop in the impoundment.

5.2.2 The River Murray below Mulwala: the middle reaches

The only major tributaries between Mulwala and the Darling confluence are the Goulburn and Murrumbidgee Rivers. Of these, the Goulburn was sampled more intensively in the course of a billabong survey (Shiel, 1980). Comparative collections were taken from the Murray at Cobram (below Mulwala), Echuca and Swan Hill (below the Goulburn) and Mildura (below the Murrumbidgee). Logistics precluded comprehensive sampling of these stations, nevertheless some seasonal comparisons are possible.

R. Murray, Cobram (station 30, Fig. 2.11)

Water quality on each of three visits (11.viii.76, 30.ix.76, 20.v.77) closely approximated that of Mulwala. Phytoplankters were sparse in all collections. Fluctuations in the R. Murray phytoplankton at Cobram were described by Bowles (1978), who noted the following seasonal succession: *Asterionella, Nitzschia* (spring), *Melosira, Cryptomonas* (late spring), centric diatoms and *Anabaena* (summer), *Melosira* (late summer-early autumn), *Rhizosolenia* and *Attheya* (late autumn) and small centric diatoms (winter). The persistence of these group into the lower Murray will be considered in Ch. 7.

Zooplankton at Cobram consisted almost entirely of microcrustacea, with *Asplanchna* the only rotifer also in Mulwala to occur in the river on the sampling dates. The species composition otherwise resembled that of the Mulwala microcrustacea. Predominant taxa were *B. triarticulata, C. ampulla,* *M. leuckarti*, *B. meridionalis*, *C. sphaericus* and *D. lumholtzi*, with littoral strays (e.g. *I. sordidus*) in winter. Low densities were noted (<5 ℓ^{-1}) in each sample. Diversity was not calculated.

The Goulburn River (Fig. 5.22)

The Goulburn River flows west from the Eastern Highlands. It is impounded at Eildon (hydro-electricity and irrigation supply). Abstraction for domestic supply occurs at several towns. Diversions for irrigation are controlled from Goulburn Weir, a shallow impoundment at Nagambie. From the nearby Waranga storage basin some 400 km of channels carry water to semi-arid western Victoria. From Goulburn Weir, the river flows north through Shepparton, where a small impoundment, "Lake" Victoria, is used seasonally for recreation. The Goulburn enters the Murray just upstream from Echuca.

During this study, samples were collected from Eildon, Goulburn Weir, Lake Victoria and five river stations. Additionally, Lake Nillahcootie, a small impoundment on the Broken River, a tributary of the Goulburn, and the Broken River at Benalla were sampled.

5.2.2.1 Eildon Reservoir (station 55, Fig.5.22)

Sugarloaf reservoir was constructed in 1927 below the confluence of the Delatite and Goulburn Rivers. The present Eildon dam was constructed just downstream from the original weir, which was submerged when the storage filled in 1956. The southern (Goulburn) arm of the catchment provides 90% of the inflow to the reservoir; major flows are from the Goulburn and Big Rivers, principally from winter rains and spring snow melt. The remaining inflows are from the undulating northern (Delatite) catchment, much of which has been cleared for grazing. Most recent recreational development, i.e. holiday homes, houseboating facilities and camping grounds, has been on the northern arm of the reservoir, with concomitant problems of water quality with more intensive use.

A bacteriological and limnological study commence in 1969 by the WSCV

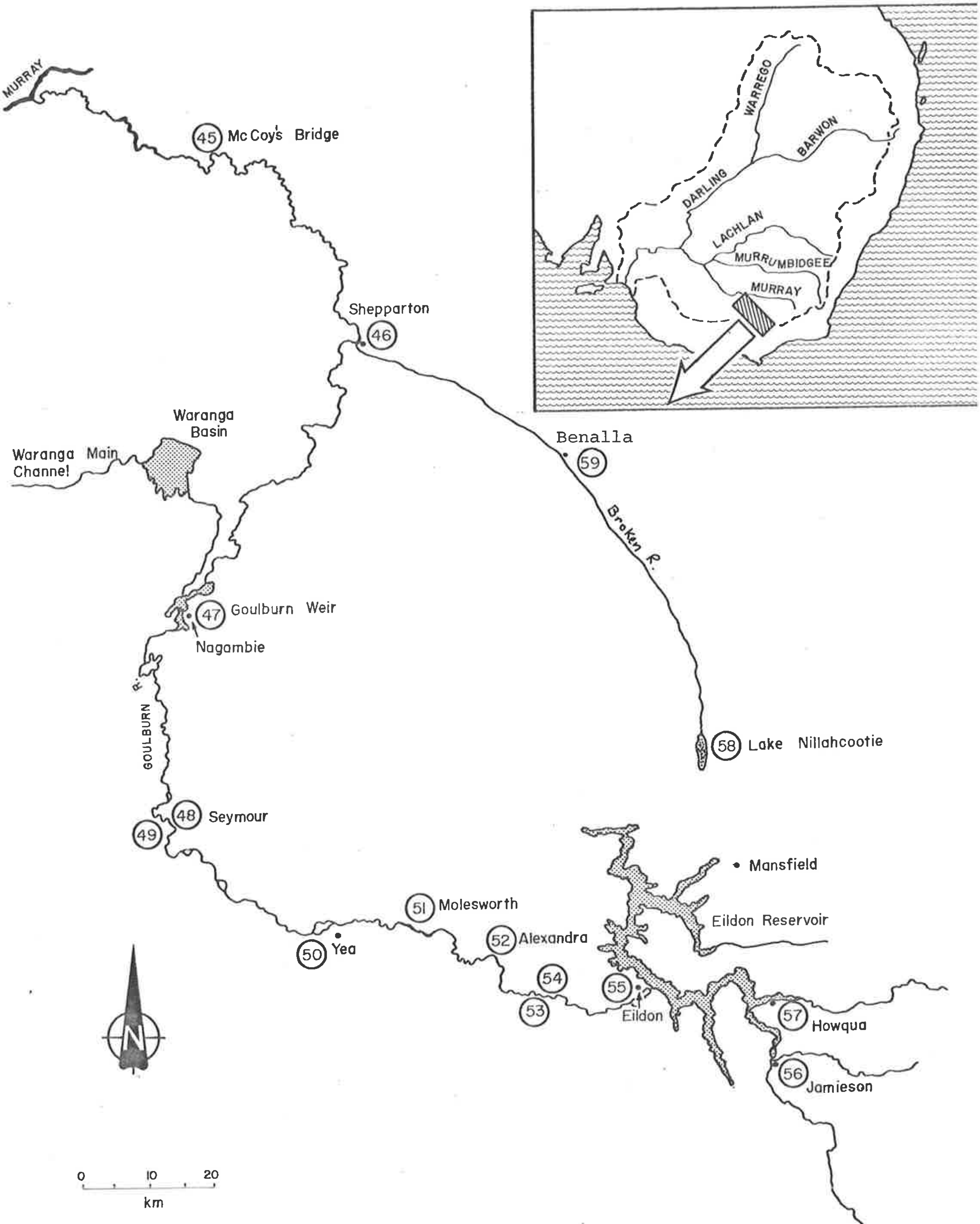


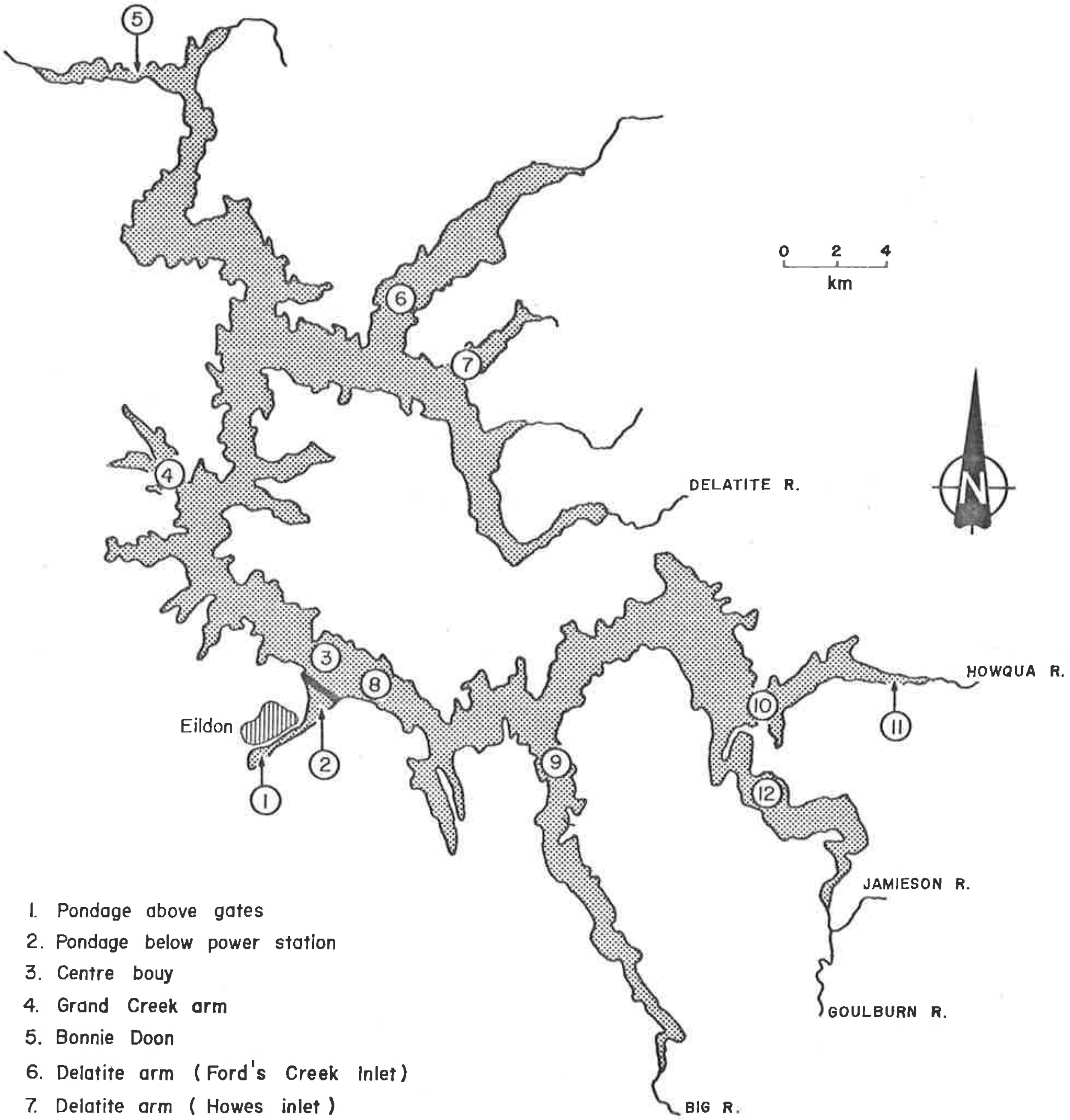
FIG. 5·22 Goulburn River : Stations 45-59 (from Table 2·2) culminated in restrictions on houseboating and development in the catchment. As a result of this study there is considerable information on the chemical and physical limnology of the reservoir, and on phytoplankton composition. Little is known of the composition or dynamics of the zooplankton.

Sampling sites (Fig. 5.23): Early in 1976 a powerboat was used for collections from ten sites in the reservoir, five along each arm to include the deepest point, major inlets and nutrient inflow point sources, e.g. Bonnie Doon Caravan Park. Subsequent sampling generally was from a single station adjacent to the retaining wall (≃10 m deep), with incidental comparative collections from the Delatite arm at Bonnie Doon. Additionally, two sites were sampled in the pondage below the power station, and seasonal collections were made from inflowing streams at Howqua and Jamieson.

Physico-chemical features:

A summary of the morphometric, physical and chemical features of Eildon is given in Table 5.16. All means and ranges refer to the 1969-76 WSCV study period (Powling, 1972, 1978, 1980). Measurements made on each sampling date are given in Table 5.17. With the exception of a low temperature of 6.2 °C all are within the ranges reported by the WSCV.

Eildon is a warm monomictic reservoir which stratifies in September-October (spring). Stratification breaks down in June-July (winter). The hypolimnion does not become anoxic due to instability caused by summer release of hypolimnetic water, nevertheless, oxygen levels below the power station outlet may fall below 50% saturation for several months over summer. Surface water temperatures range from 10.0-26.0 °C. Bottom temperature, and that of released water, usually is 10.0-12.0 °C. Transparency generally is high, with Secchi readings of 3-5 m. Turbidity after rains is highest in the northern arm of the storage. Salinity is low ($\bar{x}$ 37.0 mg ℓ^{-1}), with higher TDS in the northern arm. NH_3-N generally is less than 0.10 mg ℓ^{-1} in the southern arm, up to 0.23 mg ℓ^{-1} in the north. Total-P ($\bar{x}$ 0.03 mg ℓ^{-1}) is slightly higher in the northern arm.



1. Pondage above gates
2. Pondage below power station
3. Centre bouy
4. Grand Creek arm
5. Bonnie Doon
6. Delatite arm (Ford's Creek Inlet)
7. Delatite arm (Howes inlet)
8. Spillway
9. Goulburn arm (Big River inlet)
10. Goulburn arm (Howqua inlet)
11. Goulburn arm (Howqua inlet)
12. Goulburn arm

FIG. 5·23 Eildon Reservoir sampling sites

Fig. 5.23b: Eildon Reservoir, N.W. along Delatite arm, station 3 to left behind retaining wall.

Table 5.16: Morphometric, hydrologic and physico-chemical features of Eildon Reservoir (from Powling, 1980).

Latitude and longitude	37°11' S 145°54'E
Elevation (m)	292
Catchment area (km^2)	3,885
Shoreline (km)	466
Capacity (Ml)	3.4×10^6
Max. depth (m)	76.2
$\bar{x}$ depth (m)	23.9
Retention time (yr)	2
Cation dominance	Na>Mg>Ca
Anion dominance	HCO_3=Cl>SO_4
pH ($\bar{x}$ and range)	6.9,6.6-7.5
TDS (mg ℓ^{-1})	42, 34-54
Colour (Pt-Co)	15, 5-50
Turbidity (JTU)	4 , 1-12
Alkalinity ($CaCO_3$)	18, 16-22
NO_3-N (mg ℓ^{-1}) ($\bar{x}$)	0.03
Total-P (mg ℓ^{-1}) ($\bar{x}$)	0.025

	1976	1977				1978			1979	1980
	18.ii.	03.i.	04.i.	12.iv.	14.x.	07.i.	27.ii.	22.viii.	21.v.	16.iv.
Temperature (°C)										
Air	26.0	24.0	21.0	17.0	15.0	23.0	30.5	6.0	15.0	20.0
Water	22.0	20.0	22.0	20.0	19.0	17.0	25.5	6.0	13.0	18.4
Dissolved oxygen (ppm)	8.9	8.7	8.6	8.6	8.8	9.1	8.9	12.5	9.9	9.2
pH	7.2	7.1	7.3	7.2	7.3	7.1	7.2	7.0	7.0	7.0
Conductivity (μS)	37	50	61	21	40	56	61	73	105	56
NTU	0.5	1.0	27.5	2.5	2.0	3.2	4.0	36	11	1.4

Table 5.17: Physico-chemical measurements taken from Eildon during 1976-80.

Biological features:

The WSCV study investigated sources of faecal contamination and, following a massive *Microcystis* bloom in 1969, possible factors stimulating such blooms. Faecal coliform counts were correlated with areas of intensive recreational activity over summer, and high counts after winter rains in the northern arm of the reservoir were attributed to animal origin. Little information is available on the cause of the 1969 algal bloom, however the drowning of subterranean clover which grew on land exposed during a drought in 1967-68 is implicated.

Phytoplankton: Some 150 taxa of phytoplankters from the reservoir are listed by Powling (1978), including 70 species of desmids, 24 of diatoms, 27 of flagellates and three of blue-green algae. On the basis of the desmid dominated phytoplankton and low nutrient levels, the reservoir is described as oligotrophic. There is a summer maximum standing crop (green algae) with a period of diatom dominance in winter-spring. Predominant green algal genera are *Sphaerocystis, Staurastrum, Staurodesmus* and *Cosmarium* over summer. *Dinobryon* is perennial with a winter maximum. Dominant diatoms are *Melosira, Synedra, Rhizosolenia, Attheya* and *Cyclotella*. Surprisingly, there has been no interpretation or analysis of the algal data base collected by the WSCV, so little is known of stimuli for changes in phytoplankton composition in Eildon.

In view of the low densities of phytoplankters in early collections from the mid-lake station, no counts were made. Only a single mid-lake collection (07.i.78) was numerically dominated by phytoplankters, predominantly green algae (*Staurastrum pingue, Eudorina elegans, Attheya zachariasi* and *Melosira granulata*). Most common genera on all sampling dates are given in Table 5.18. Greater densities of phytoplankters were present in summer collections from both Bonnie Doon and Howqua inlets, principally *Volvox* and *Spirogyra*.

Zooplankton: Zooplankton were neglected in the WSCV study, although the superabundance over summer of a purple ciliated protozoan (cf. *Climacostomum*) was noted, particularly in northern bays, where density of the organisms

Table 5.18: Principal genera of phytoplankton recorded in samples from Eildon, 1976-80.

Taxon	18.ii.76	03.i.77	04.i.77	12.iv.77	14.x.77	07.i.78	27.ii.78	22.viii.78	21.v.79	16.iv.80
Eudorina	●					●				
Volvox			●							
Micrasterias				●						
Staurastrum					●	●				
unid. desmids	●									
Spirogyra			●							
Ulothrix					●		●			
Dinobryon	●	●								
Melosira				●						●
Attheya					●					
Fragilaria			●		●		●			
Ceratium	●		●		●	●			●	
?Climacostomum			●							

coloured the water black. Similar blooms are reported from Hume (Walker & Hillman, 1977). The summer appearance of medusae of *Craspedacusta sowerbyi* also was recorded (cf. Hume).

Analysis of epilimnetic collections early in this study showed minor percentage composition changes along each arm of the storage, with greater densities of the dinoflagellate *Ceratium* and the rotifer *K. cochlearis* f. *tecta* at shallower stations 5 and 11. Differences, however, were not significant ($P>.05$).

Community composition: Excluding testate Rhizopoda, other protozoans and dinoflagellates, a total of 48 zooplankton taxa were identified from the reservoir (22 Rotifera, 13 Cladocera, 11 Copepoda and 2 Ostracoda). Zooplankters ℓ^{-1}, number of species in each group, percentage composition and community diversity for each sampling date are given in Fig. 5.24. Temporal variation in community composition is shown in Fig. 5.25. Presence of ovigerous ♀♀ in each taxon also is included.

The limnetic zooplankton of Eildon was dominated by microcrustacea (77-100%), predominantly a block of perennial multivoltine species, e.g. *B. meridionalis, B. triarticulata, C. ampulla, M. leuckarti*, with other species perennial and univoltine (*D. unguiculatum*) or markedly seasonal in occurrence, e.g. *M. micrura, D. carinata, D. lumholtzi, C. cornuta* (summer). Other microcrustacean species probably also were perennial, but were of low density and not collected in some samples, e.g. *C. sphaericus* and the new cyclopoid.

Rotifera made up 0-23% of mid-lake collections. Perennial species included *K. cochlearis, P. dolichoptera, C. dossuarius, A. brightwelli*, others were seasonal, e.g. *L. elliptica, T. similis* (summer-autumn), *K. procurva* (spring-summer). Only in collections from northern inlets did rotifers numerically dominate samples. Two such samples are included for comparison in Fig. 5.25 (4.i.77, Howqua inlet, and 21.v.79, Bonnie Doon inlet). Notably, the rotifers of the shallow inlets were occasionally of different species to those in mid-lake, e.g. *P. vulgaris* and *P. sulcata* in inlets, *P. dolichoptera* and *P. complanata* in mid-lake.

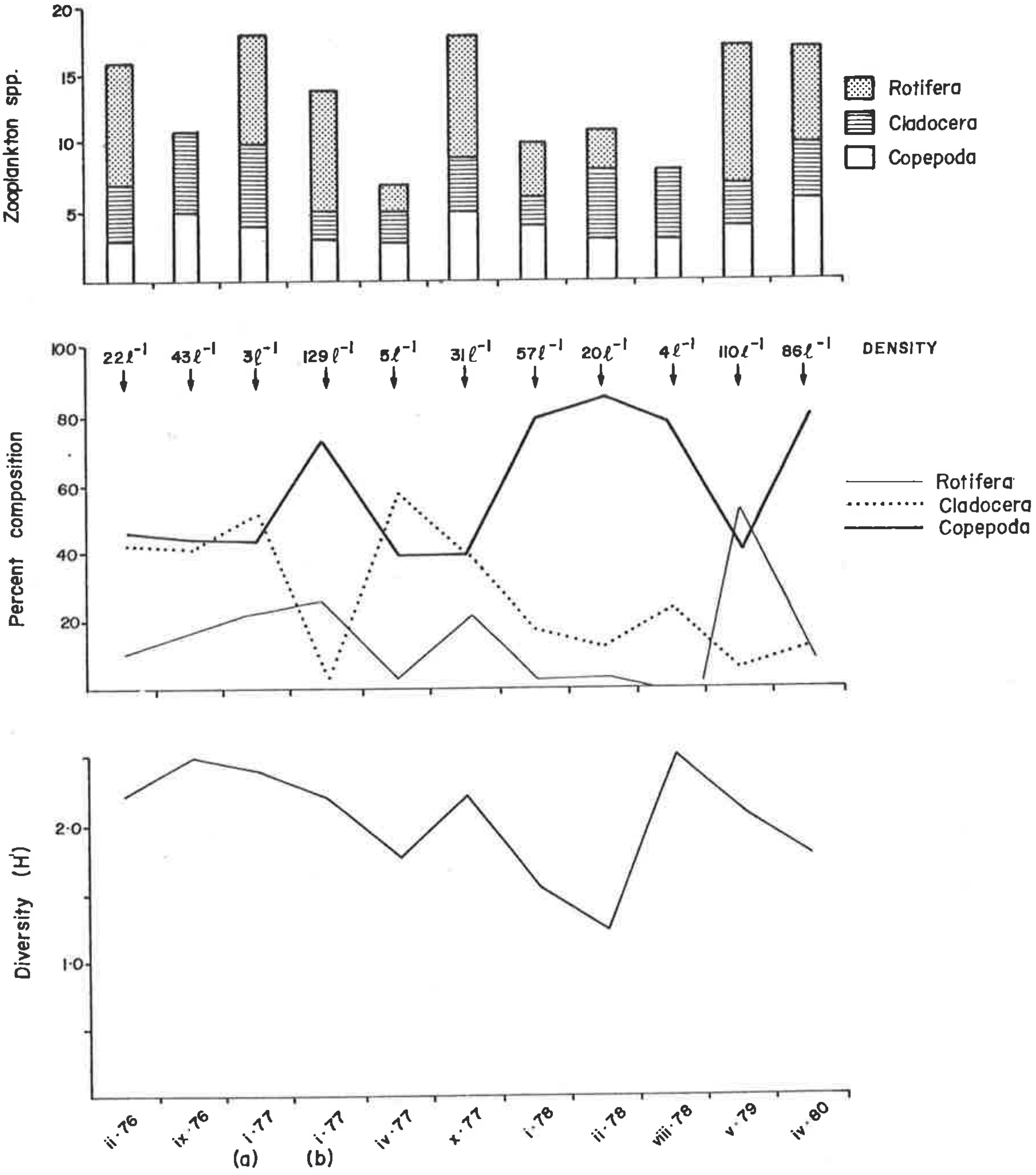


FIG. 5·24 Temporal fluctuations in species number, percent composition and diversity of Eildon limnoplankton. Note that data are not continuous.

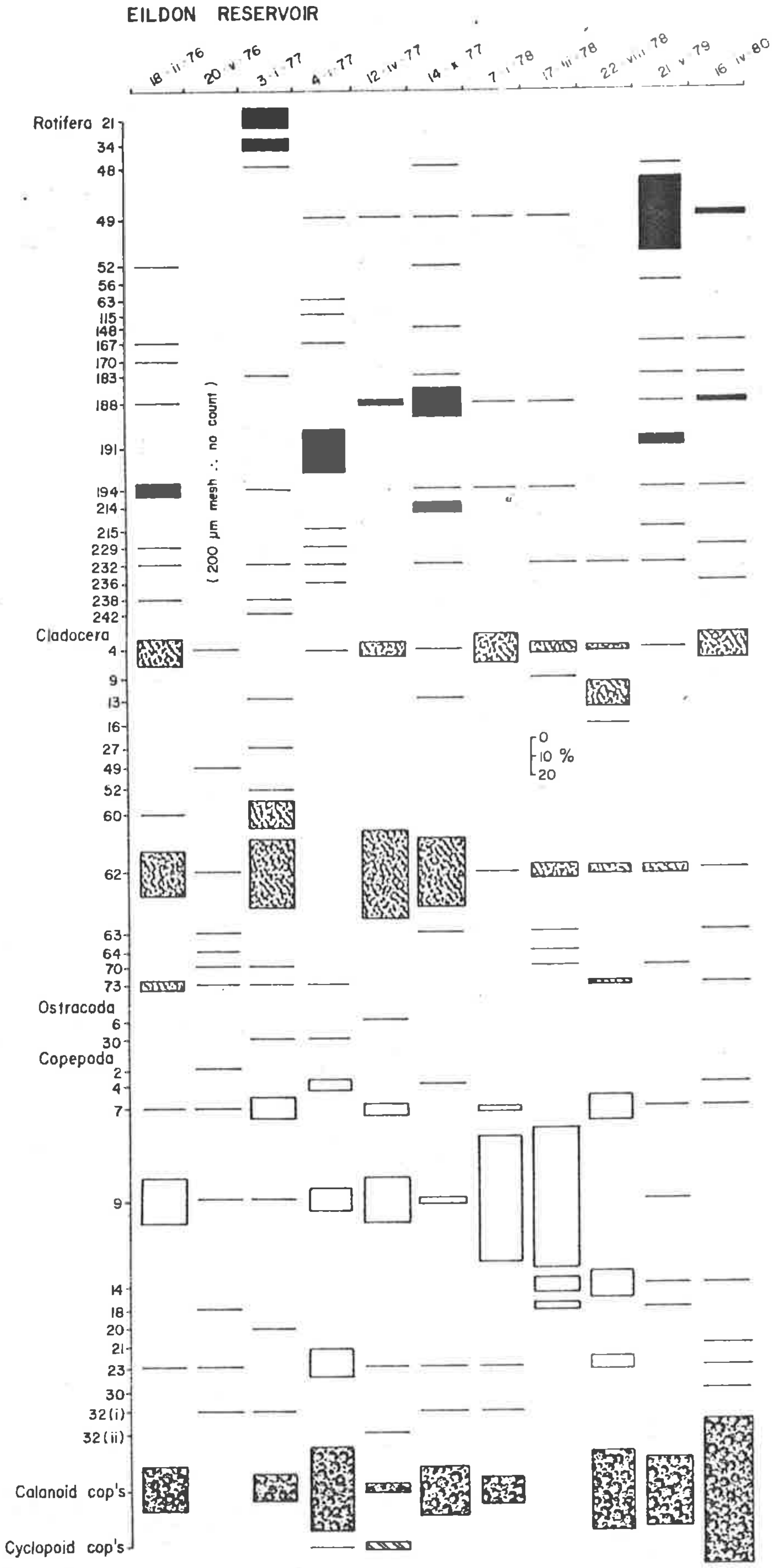


FIG. 5·25 Temporal variation in limnoplankton composition, Eildon Reservoir.

CC values for the Eildon samples are shown in Fig. 5.19. The block of perennial microcrustacean species was stable over the study, occurring in nearly all samples. Seasonal succession, e.g. the replacement of *C. ampulla* by the colder water species *C. lucasi*, rare seasonal species, e.g. *B. calyciflorus, B. diversicornis, B. fluvialis, B. minuta*, and pseudoplanktonic incursions accounted for the generally low similarities in species composition over time. Greatest differences were seen in collections from marginal bays and mid-lake, or from collections widely separated in time.

Diversity generally was higher in mid-lake than in inlets, with greatest diversity over winter 1978, lowest in summer 1978 and autumn 1980. On any sampling date two or three species comprised 60-80% of the zooplankton. Average momentary species composition during the study was 4.8 rotifers, 3.9 cladocerans and 3.9 copepods. Zooplankton densities were lower ($<60\ \ell^{-1}$) in mid-lake than in inlets (110-$274\ \ell^{-1}$). Most abundant plankters in these shallow waters were *Ceratium* ($200+\ \ell^{-1}$ in summer, 1978) and the unidentified ciliate, estimated to be in excess of $2{,}000\ \ell^{-1}$ at the same time, although no count was made of the latter.

Hydracarinid mites (*Piona* sp.) were recorded from mid-lake samples in summer-autumn, and freshwater mussel glochidia were noted in the summer 1978 collection.

Environmental factors: Little of the variance in density of dominant species could be attributed to variations in measured physico-chemical characteristics. Values obtained by linear regression of species density on each variable are given in Table 5.20. All factors accounted for less than 36% of the variance. A single significant negative correlation between *B. meridionalis* and conductivity is possibly an artefact due to the small number of data points; as shown in Table 4.8, this taxon occurred over a wider salinity range than any other plankter, and was eurytopic.

The above observations on the Eildon limnoplankton apply only to the epilimnetic plankton community. Vertical samples were not taken. Powling

1977				1978			1979	1980		
03.i.	04.i.	12.iv.	14.x.	07.i.	27.ii.	22.viii.	21.v.	16.iv.		
.25	.35	.44	.35	.47	.29	.26	.38	.42	18.ii.	1976
	.12	.17	.27	.28	.25	.16	.29	.14	03.i.	1977
		.22	.21	.20	.13	.15	.28	.18	04.i.	
			.30	.78	.29	.36	.37	.50	12.iv.	
				.40	.30	.17	.29	.30	14.x.	
					.33	.31	.37	.54	07.i.	1978
						.19	.47	.38	27.ii.	
							.19	.36	22.viii.	
								.33	21.v.	1979

Table 5.19: CC values, Eildon Reservoir, 1976-1980.

Taxon	Temp.			DO			pH			µS			NTU		
	a	b	r^2	a	b	r^2	a	b	r^2	a	b	r^2	a	b	r^2
D.unguiculatum	16.98	2.21	0.03	9.53	-0.35	0.02	7.4	0.0	0.0	71.06	-25.12	0.25	14.29	-8.96	0.11
ρ/F											-0.33/.98 P>.05				
B.meridionalis	17.22	1.26	0.02	9.62	-0.35	0.04	7.09	0.06	0.10	71.94	-18.29	0.28	15.97	-8.10	0.18
ρ /F											-0.64/5.55 P<.05				
C. ampulla	14.97	4.18	0.36	9.93	-0.68	0.17	7.7	0.10	0.32	66.10	-12.61	0.19	12.51	-4.49	0.08
ρ/F		0.61/4.7 P>o.5						0.60/4.5 P>0.5							
copepodites	25.22	5.46	0.29	8.45	0.69	0.10	7.23	0.07	0.10	42.08	10.99	0.07	-1.61	8.30	0.13
ρ/F		0.44/1.92 P>.05													

Table 5.20: Regressions of log population density of dominant limnoplankters in Eildon on water temperature, dissolved oxygen, pH, conductivity and turbidity. a: intercept; b: slope of regression line; r^2: regression coefficient; ρ: Spearman's rank correlation coefficient; F: F value and significance.

(1978) noted that maximum phytoplankton populations occurred at 2.5 m depth (cf. Dartmouth), and suggested photoinhibition as the cause. It is likely that the limnoplankton of deeper waters may be different in both density and diversity to that of the epilimnion. Vertical species stratification is reported elsewhere (e.g. Berzins, 1958; Nilssen, 1976). Inferences about the hypolimnetic community from collections taken immediately below the power station are discussed later.

The phytoplankton component of the Eildon limnoplankton, while not readily categorized into Hutchinson's (1967) classification , clearly is an oligotrophic desmid-diatom assemblage (cf. Bayly & Williams, 1973). Seasonal changes in trophic status of the northern bays are suggested by summer blooms of protozoans and dinoflagellates. Large populations of small rotifers, the diet of which is largely bacteria, organic particles and small algae, accompany these blooms, e.g. *K. cochlearis* f. *tecta, P. sulcata, P. vulgaris.* Elsewhere, these species are considered to be indicators of eutrophy (Sladacek, 1973; Ruttner-Kolisko, 1974). Notably, *E. coli* counts of up to 3100/100 ml were recorded in summer samples from Bonnie Doon inlet (Powling, 1978).

The microcrustacean mid-lake plankton is less readily categorized as an oligotrophic assemblage, due to the dominance of ubiquitous *B. meridionalis, D. unguiculatum, B. triarticulata* and *C. ampulla.* As in oligotrophic reservoirs elsewhere, however, population densities were exceptionally low. Calanoid copepods, some of which are more efficient feeders in dilute food conditions than are cladocerans (McNaught, 1975), generally were predominant. Several of the mid-lake rotifers, e.g. *P. dolichoptera* and the long-spined form of *K. cochlearis,* are reported elsewhere as cold-stenotherms indicative of oligotrophy (Wetzel, 1975). In Eildon, these species had maxima in spring and autumn respectively, at temperatures around 15°C.

Although sampling frequency was inadequate for detailed discussion of population dynamics of the reservoir limnoplankton, several trends were clear. Maximum breeding of mid-lake microcrustacea was in spring and summer, with maximum population densities in summer accompanying green algal peaks.

Several pseudoplanktonic species occurred also in open water at this time, e.g. *E. dilatata, L. lunaris, A. rectangula, M. spinosa, M. albidus*. Greatest population densities of the predatory cyclopoid, *M. leuckarti*, occurred during summer, as did density of the new cyclopoid genus, which probably also is predatory.

Synchronous population peaks each, year, possibly a trophic effect, and synchronous seasonal breeding suggests a more stable plankton assemblage than in other storages. The Eildon assemblage was a "true" limnoplankton, i.e. relatively few pseudoplanktonic taxa were recorded compared to other dams. The establishment of a littoral microfauna in Eildon is precluded by the absence of fringing macrophytes (except in shallow northern bays), a result of great fluctuations in level. It is likely that species richness of the Eildon limnoplankton was greater than recorded here; seasonal species of short life cycle possibly were missed. Sampling infrequency also prevented adequate assessment of the influence of changes in water quality.

Downstream of Eildon

The plankton of the downstream river was of interest following and earlier study of a Goulburn billabong (Shiel, 1974). Only 5% of the billabong microcrustacea were present in Eildon, cf. 60% of the pond zooplankton derived from an upstream lake reported by Elgmork (1966). As 1974 was an exceptional flood year, the apparently low survival of plankters below the dam may have been simply due to dilution.

Background information: A shallow pondage (3 m deep) extends for 4 km below the dam. The pondage gates regulate variable flows from the power station, thus controlling the flow of the river. Hypolimnetic release (offtake at 52 m) of uniformly cold water (9-11 °C, annual range only 2 °C in the pondage) depresses summer temperatures for more than 150 km downstream. Above the dam, stream temperatures range from 3-27 °C (Powling, 1978). Only on rare occasions has epilimnetic water been released from the spillway, e.g. during floods in 1974-75, when surface water temperature (7.5 °C) was colder than hypolimnetic water (9.0 °C), water temperature in flooded billabongs 30 km downstream reached only 8.0 °C (Shiel, 1974). The plankton of the pondage and river below the dam is subject, therefore, to low temperatures, some seasonal oxygen depression, and, importantly, extreme and rapid variations in flow rate and volume.

Sampling sites: Seasonal collections were made from the pondage and three river stations between Eildon and Nagambie (Fig. 5.22), *viz.* Thornton, 15 km downstream, Molesworth, 55 km downstream and Seymour, 130 km downstream.
Results and Discussion: Physico-chemical and biological features for each site on each sampling date are given in Table 5.21. The influence of the reservoir is clear, with depressed temperatures as far as Seymour, and uniformly low conductivity and turbidity. Plankton composition also was influenced by the dam; the most significant factor appeared to be discharge volume. Only in low-flow conditions (summer autumn) were plankters present in appreciable numbers. Phytoplankton densities were low, and diatoms predominated. The most common of these was *Diatoma elongatum* a benthic form, which occurred in relatively large numbers only in summer 1978. Other plankters, generally also benthic species, were sparse.

Zooplankton density and diversity were low, with a maximum (spring 1976) of less than 20 ℓ^{-1} recorded from the pondage. Seventy per cent of the plankters in this collection were not present in the reservoir, but were pseduoplankters from the more stable communities of fringing hydrophytes in the pondage. Few zooplankters were collected during high flows, a result of dilution and also high mortality due to turbulence, i.e. exoskeletal material was more abundant during winter and spring. The more diverse zooplankton collected during low flows, e.g. summer 1978, was dominated by pseudoplanktonic taxa. Less than 40 per cent of reservoir limnoplankton persisted downstream of the dam, and densities generally were less than 1 ℓ^{-1}. Rotifers notably were absent. The only Rotifera recorded (e.g. 12.iv.77) were incursions from standing waters adjacent to the river (see Ch. 6).

In summary, the contribution of the reservoir to the downstream

Table 5.21(next page): Physico-chemical and biological features recorded from four Goulburn River stations downstream of Eildon Reservoir, 1976-79.

Physico-chemical features:	Eildon pondage				Thornton					Molesworth					Seymour				
	30.ix.76	04.i.77	12.iv.77	22.viii.78	04.i.77	12.iv.77	14.x.77	27.ii.78	22.viii.78	12.iv.77	22.v.77	14.x.77	27.ii.78	22.viii.78	22.v.77	14.x.77	27.ii.78	22.viii.78	01.ii.79
Surface temperature	12.5	13.0	12.1	8.0	14.5	15.0	14.5	15.2	9.0	14.5	9.0	14.0	14.5	8.5	11.0	14.5	15.0	9.0	18.0
Dissolved oxygen (ppm)	10.4	7.4	9.0	12.0	9.9	9.4	9.8	6.9	12.1	9.2	11.0	10.2	9.7	11.2	10.3	10.4	9.8	11.6	9.7
pH	7.2	7.1	7.2	7.0	7.2	7.0	7.3	7.0	7.0	7.7	7.4	7.3	7.1	6.9	7.3	7.3	7.3	7.2	7.5
Conductivity (uS)	85	60	49	55	62	41	49	54	58	47	47	40	53	52	110	75	82	70	95
Turbidity (NTU)	1.0	2.5	2.5	5.0	5.0	2.0	1.0	0.4	4.0	5.0	6.0	7.5	0.6	15.0	4.5	5.0	2.5	6.0	1.0
Biological features: Phytoplankters	few	few	-	*Diatoma*	-	*Ulothrix* *Diatoma*	-	*Diatoma* *Synedra*	-	*Melosira*	*Diatoma* *Closterium*	-	*Diatoma* *Oedogonium* *Synedra*	"	*Diatoma*	*Diatoma*	*Diatoma*	-	-
Zooplankters (code as tabulated in Ch.4)																			
Rotifera																			
8								●				●							
32										●									
35										●									
39										●									
50										●									
63	2											●							
166										●									
185										●									
188												●	●						
220										●									
Cladocera																			
4								●											
13	7			●										●	●			●	
23	1																		
27	13																		
30	1																		
33								●									●		
39								●											
52		●																	
58																			●
60																			●
62	26			●				●	●			●	●	●	●		●	●	
63	1	●						●									●		
64		●																	
67		●		●				●											●
73	9														●				●
Copepoda																			
4								●									●		●
7		●						●	●										●
9	16	●			●			●							●		●		
14				●													●		
23	30	●						●							●		●		●
36								●											
nauplii	●										●	●				●			
S_T	10	8	–	4	1	–	–	12	2	7	–	4	2	2	6	1	6	2	7
Density ℓ^{-1}	16	5	–	<1	<1	–	–	7	–	<1	–	<1	<1	<1	<1	–	<1	<1	<1
Exoskeletal & organic material	✓	✓	✓✓	✓	✓	✓	✓	✓	✓✓	✓	✓	✓	✓	✓✓	✓	✓	✓	✓✓	✓
Species also present in reservoir /%	4/31	5/39	–	3/38	1/5	–	–	4/36	2/25	–	–	2/11	2/18	2/25	–	–	4/36	2/25	–

plankton was low during the study. Plankters survived passage through the power station or, following earlier epilimnetic releases, were established in the pondage, where hydrophyte beds provided some shelter from the effects of variable discharge. Limnetic plankters and pseudoplankters from marginal habitats and billabongs contributed a greater diversity of species to the Goulburn plankton than did the reservoir. Contributions from all sources, while variable, appeared to be greatest over summer-autumn. This assemblage constituted the major input into Goulburn Weir, some 165 km downstream from Eildon.

5.2.2.2. Goulburn Weir, Nagambie (station 47, Fig. 5.26).

This small (25,500 Ml) shallow (14.3 m) impoundment provides a head for irrigation supply to western Victoria and domestic water to several towns. Nagambie is the largest of these, and a centre for seasonal recreation on the storage. The impoundment has a short retention time (2½-25 days) and is drawn down seasonally for irrigation. Extensive areas of hydrophytes are present, particularly on the western margin. Collections were made with the aim of comparing the plankton of a shallow storage subject to great seasonal perturbations with that of a large storage of long retention time (Eildon).

Sampling sites: Open water collections were taken from a jetty adjacent to Nagambie Caravan Park, in approximately 4 m depth. A second site on the western margin was sampled in spring 1976 to compare the littoral and limnetic plankton of the storage.

Physico-chemical features:

Ranges of all measured characteristics are shown in Table 5. 22. With the exception of temperature, all ranges were greater than those in Eildon. Greater ranges reflect morphometric and catchment differences, i.e. shallow, exposed to wind action, intensive agricultural land use, higher turbidity runoff. Measurements made in the present study are given in Table 5.23.

Biological features:

Phytoplankton: A greater variety of desmids and diatoms occurs in Goulburn

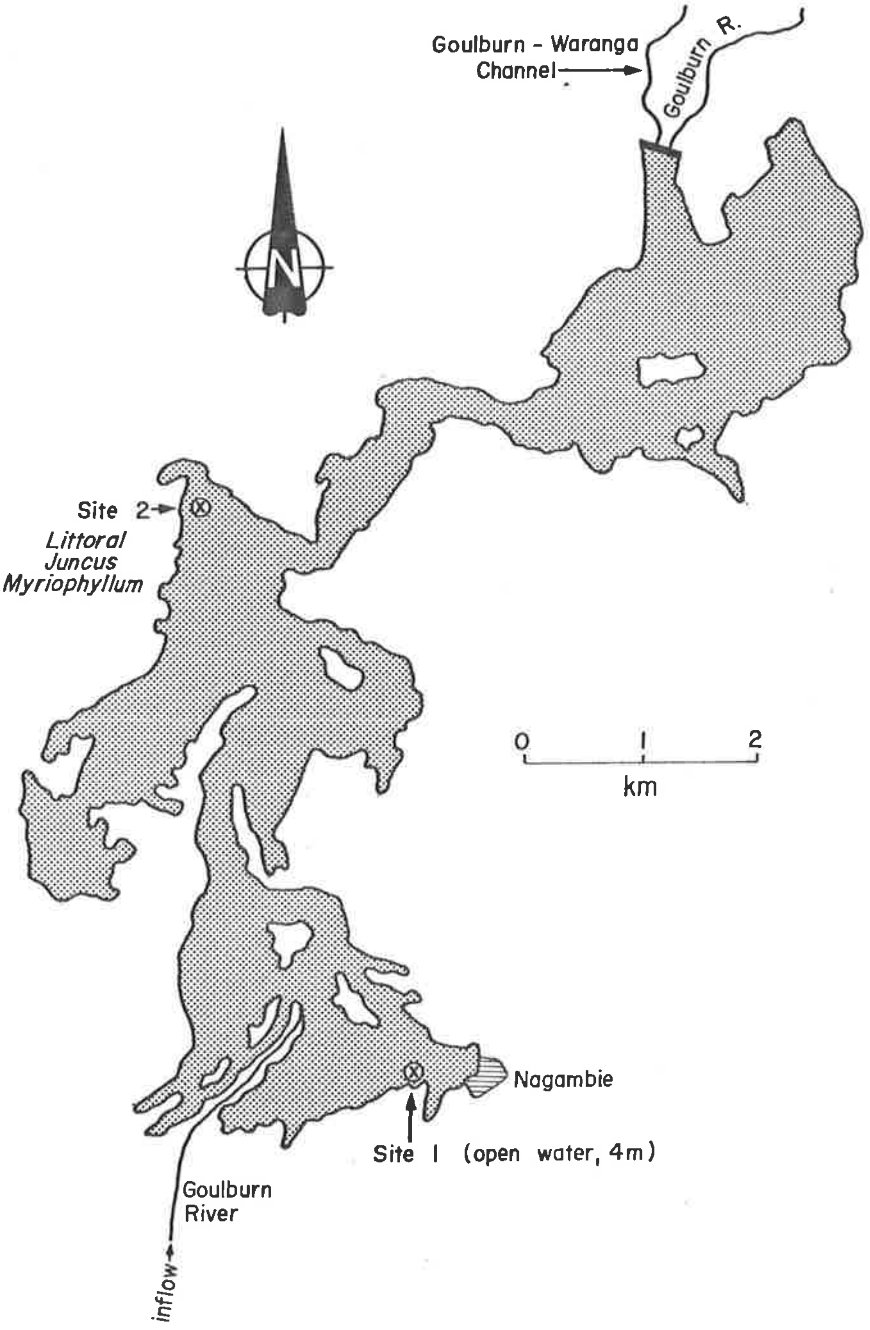


FIG. 5·26 Goulburn Weir, Nagambie, showing sampling sites.

Table 5.22: Ranges of some physico-chemical features measured in Goulburn Weir (WSCV unpublished data).

Characteristic	Range
pH	6.7-7.4
Conductivity(μS)	57-309
TDS (mg ℓ^{-1})	36-190
Colour (Pt)	10-160
Turbidity (NTU)	1-80
Alkalinity ($CaCO_3$)	15.4-93
Chloride (mg ℓ^{-1})	7.8-74.7

Table 5.23: Records from each sampling date, 1976-79

	Sampling date									
	1976			1977		1978			1979	
	25.v.	11.viii.	29.ix.	13.iv.	15.x.	08.ii.	26.ii.	22.viii.	01.ii.	25.v.
Surface temperature (°C)	18.0	15.0	17.1	16.5	18.0	15.0	21.3	10.0	25.0	8.5
pH	7.3	7.4	7.4	7.4	7.5	7.5	7.0	7.3	7.4	7.4
Dissolved oxygen (ppm)	8.7	9.1	9.0	8.0	8.4	8.9	8.8	8.7	7.0	11.0
Conductivity (μS)	110	65	70	75	-	65	55	85	112	67
Turbidity (NTU)	12	90	30	53	-	4	3.5	100	17.5	10

Weir than in Eildon (I. J. Powling, pers. comm.). A representative list, from a collection in May 1976, is given in Appendix 2. During the present study, few phytoplankters were found in open water collections. Most common were a few colonies of *Volvox* (<5 ℓ^{-1}) or filaments of *Spirogyra*. Small species (*Cosmarium, Eudorina, Staurodesmus*) occurred in a spring 1976 collection, but density was low. In view of the high zooplankton densities in spring and summer collections, grazing pressure probably was high; only large, not readily assimilable phytoplankters remained.

Zooplankton:

Community composition: Sixty-five species of zooplankters were recorded (28 of Rotifera, 24 of Cladocera, 11 Copepoda and 3 Ostracoda). Of these, 33 species were present in Eildon [50% of rotifers (14 spp.), 50% of cladocerans (12 spp.) and 73% of copepods (8 spp.)]. Species composition, density and diversity of zooplankton on each sampling date are shown in Fig. 5.27. Temporal variation in community composition is shown in Fig. 5.28. A single littoral sample (29.ix.76) is shown for comparison, but was not included in calculation of $\bar{x}$ H'.

On most sampling dates, rotifers were the predominant limnoplankters; in only four collections were microcrustacea numerically abundant. At other times, up to 15 rotifer species comprised 56-95 per cent of the limnoplankton, with different species dominants in successive collections, e.g. in spring 1976, *P. vulgaris* (112 ℓ^{-1}) and *C. dossuarius* (160 ℓ^{-1}) comprised almost 70 per cent of the plankton. The following autumn they were replaced by small numbers of *P. dolichoptera* and *C. unicornis*, with *K. cochlearis* (42 ℓ^{-1}) numerically dominant. The spring 1977 assemblage was dominated by *K. cochlearis S. longipes* and *P. dolichoptera*. Although no single species was present in all collections, several probably were perennial, e.g. *K. cochlearis, K. procurva, S. longipes, C. dossuarius*. Other species were seasonal, but not necessarily at the same time each year, or showed no distinct seasonality, occurring in small numbers in several consecutive collections. The influence of marginal macrophyte growth is seen when species composition of littoral and open water

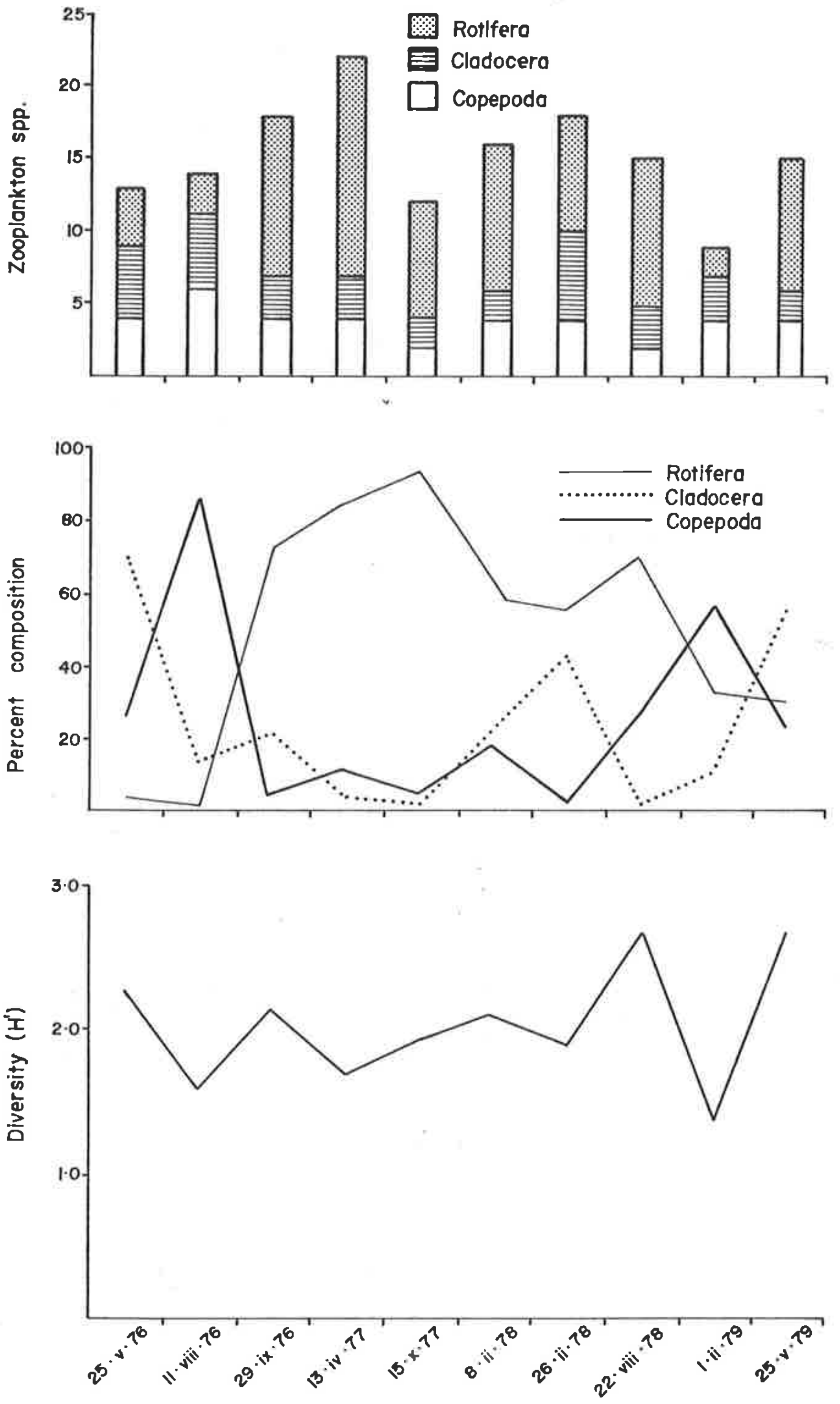


FIG. 5·27 Temporal fluctuations in species numbers percent composition and diversity of Goulburn Weir limnoplankton. Note that data are not continuous.

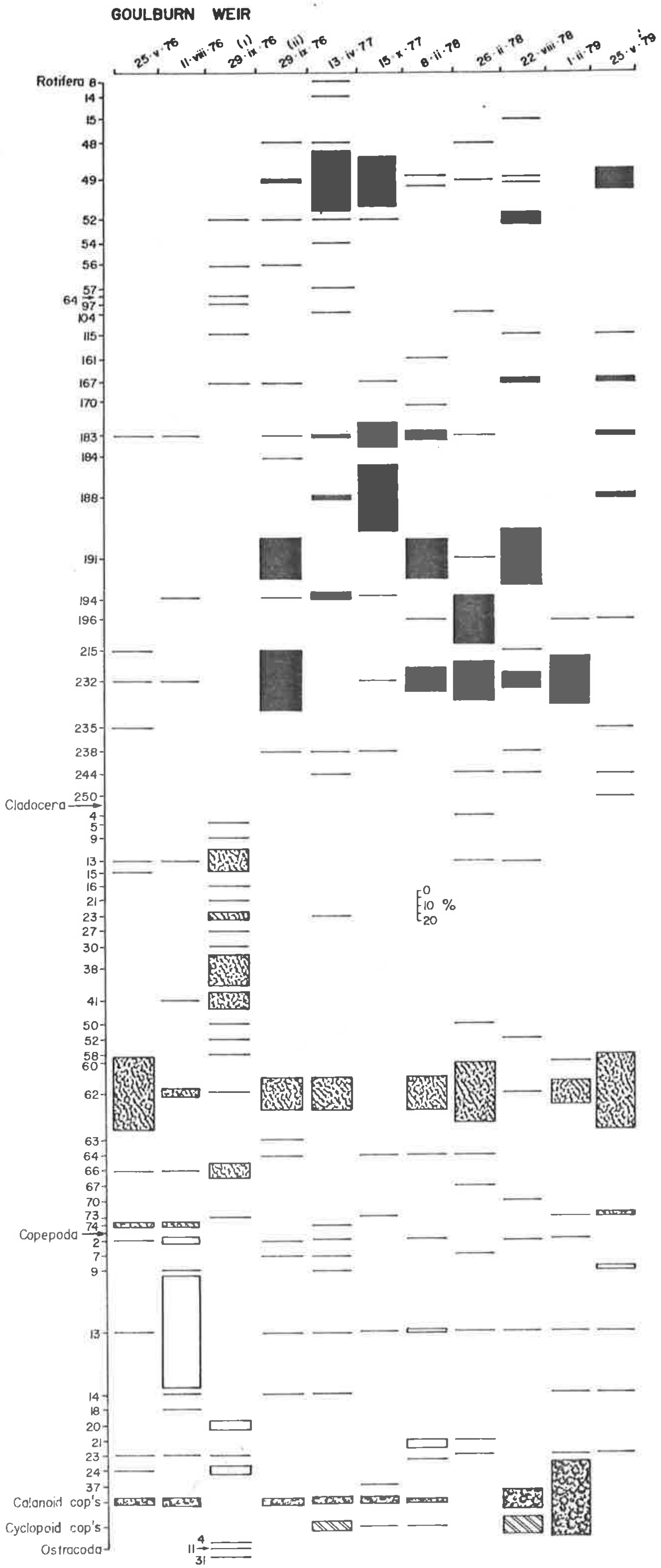


FIG 5·28 Temporal variations in limnoplankton composition, Goulburn Weir samples are compared (Fig. 5.28, 29.ix.76). Although more species were collected from Goulburn Weir than Eildon, a greater proportion of them (32% vs. 14%) were pseudoplankters, i.e. epibenthic in habit.

Of the Cladocera, only a single species was of frequent occurrence. As in Eildon, *B. meridionalis* was perennial, although it was not collected in the spring 1977 sample. Examination of the gut contents of one of several small (<1 cm) fish fry which were collected suggests predation as the cause. Identifiable exoskeletal fragments of *Bosmina* (i.e. mucrones) and a lorica of *K. cochlearis* were distinguished. Other cladocerans were neither abundant nor frequently collected in open water; no other species occurred in more than 50% of collections. For this reason, seasonality was less distinct in the limnoplankton than in Eildon. Excluding the spring 1976 littoral collection, in which several littoral cladoceran species were abundant, seasonality was apparent only in *D. lumholtzi* (spring-summer) and *C. rotunda* (autumn-winter). *C. quadrangula* apparently had spring and autumn maxima.

Up to five calanoid and three cyclopoid taxa were present in single samples. Only two, *B. fluvialis* and *C. expansa* probably were perennial. The unusual occurrence of the latter species in the low Ca^{++} waters of Goulburn Weir is discussed on page 79. The coexistence of more than three species of calanoids is rare in Australian waters (Bayly & Williams, 1973). On two occasions in 1976, four species coexisted in Goulburn Weir, and five species (three *Calamoecia* and two *Boeckella*) were collected in autumn 1977. Non-equilibrium conditions at the end of a seasonal succession cycle are the likely reason for such co-occurrence. As noted earlier, a marked size difference was apparent between congeners and between genera, i.e. *B. fluvialis* > *B. triarticulata* > *C. expansa* > *C. lucasi* > *C. ampulla*, which suggests particle size separation in feeding, permitting niche partitioning by closely related taxa.

Cyclopoids were not abundant. The most common was the cosmopolitan *M. leuckarti*, with a single summer appearance of *M. decipiens*.

Table 5.24 shows CC values for Goulburn Weir samples. Temporal changes in community composition were greater than those in Eildon, reflecting instability of community structure. As in Eildon, the greatest disparity was between littoral and open water collections. Greatest similarity in community structure was between the spring 1976 and summer 1978 plankton.

Mean species diversity was greater than for Eildon ($\bar{x}$H' 2.02 vs. 1.96). Greatest diversity was recorded from the littoral sample (H' 3.45), the species assemblage of which resembled the chydorid dominated browser community of billabongs (cf. Shiel, 1976). Species diversity in open water was greatest in autumn and winter, while maximim population densities were in spring and summer. Population peaks of over 400 ℓ^{-1} were due to "blooms" of small rotifer species,e.g. *K. cochlearis, P. vulgaris, P. dolichoptera* and *C. dossuarius*. Average momentary species composition was 8.0 rotifers, 3.4 cladocerans and 3.8 copepods; more Rotifera and fewer microcrustacea than in Eildon. Average density ℓ^{-1} (n=10) was 209.7 (cf. Eildon 42.3).

Environmental factors: Regressions of log population density on water temperature, dissolved oxygen, pH, conductivity and turbidity were calculated for the six most frequently collected plankters (Table 5.25). These factors accounted for little of the variation in density of the dominant plankters. *B. meridionalis* and turbidity were negatively correlated.

Shallowness, the presence of marginal reedbeds and the short retention time of Goulburn Weir (cf. Mulwala) are the major influences on plankton development. The reedbeds provide abundant habitats for a diverse littoral plankton and, to some extent, protection from throughflow. Strays from the littoral account for the higher proportion of pseudoplankters than were found in Eildon waters. Relatively rapid changes in species composition resulted from seasonal drawdown for flood mitigation or irrigation. This is clearly seen in the winter-spring collections of 1976, when, over a six week period, the composition of the plankton community changed from a microcrustacean to a rotifer limnoplankton. A predominantly microcrustacean community was not recorded again until summer 1979. Fluctuations in water quality did not

Table 5.24; CC values for Goulburn Weir, 1976-79. a=littoral sample, b= open water.

1976			1977		1978			1979			
21.viii.	29.ix.a	29.ix.b	13.iv.	15.x.	8.ii.	26.ii.	22.viii.	1.ii.	25.v.		
.43	.02	.23	.24	.03	.23	.29	.03	.09	.54	25.v.	
	.01	.13	.16	.05	.10	.17	.04	.10	.15	21.viii.	1976
		.02	.05	.09	.06	.07	.07	.02	.06	29.ix.a	
			.26	.08	.64	.48	.24	.37	.25	29.ix.b	
				.32	.30	.30	.10	.25	.38	13.iv.	1977
					.14	.03	.09	.03	.23	15.x.	
						.50	.33	.37	.32	08.ii.	1978
							.13	.37	.32	26.ii	
								.31	.06	22.viii.	
									.10	01.ii.	1979

Taxon	oC			DO			pH			µS			NTU		
	a	b	r^2	a	b	r^2	a	b	r^2	a	b	r^2	a	b	r^2
K. cochlearis	16.42	0.02	0.0	8.41	0.44	0.12	7.34	0.02	0.01	86.75	-8.54	0.11	58.21	-29.76	0.43
ρ/F													ρ -0.52/2.96 $P>.05$		
S. longipes	16.74	-0.04	0.01	8.66	0.02	0.02	7.30	0.01	0.22	78.39	-0,20	0.01	47.17	-1.92	0.20
C. dossuarius	17.39	-1.13	0.04	8.7	0.07	0.0	7.42	-0.07	0.16	78.07	-1.27	0.0	31.93	3.29	0.01
B. meridionalis	15.34	0.78	0.02	8.45	0.23	0.0	7.37	-0.01	0.0	77.77	-0.56	0.03	72.42	-27.57	0.39
ρ/F													ρ -0.76/10.94 $P<.05$		
C. expansa	16.82	-0.60	0.01	8.51	0.39	0.10	7.35	0.02	0.02	80.24	19.25	0.17	30.24	7.66	0.03
copepodites	18.18	-0.17	0.32	8.23	0.05	0.69	7.35	0.0	0.02	78.31	-0.13	0.01	38.61	-0.39	0.03
ρ/F				ρ 0.23/0.44 $P>.05$											

Table 5.25: Regression of log population density of dominant zooplankters in Goulburn Weir on water temperature, DO, pH, conductivity and turbidity. a: intercept; b: slope of regression line; r^2: regression coefficient; ρ: Spearman's rank correlation coefficient; F: F test value and significance.

account for these changes.

Records of Goulburn Weir openings kept by the WSCV showed that during the week ended 25.ix.76 local flooding caused an increase in outflow from 1,000 Ml day^{-1} to 13,734 Ml day^{-1} (I. J. Powling, WSCV pers. comm.). The susceptibility of plankton to water movement through the impoundment, i.e. to loss by flushing, would account for the observed compositional changes. Short life-cycle opportunist species survived in the modified conditions, with successional changes in response to the instability of the habitat. Low population densities suggested by Bayly & Williams (1973) as a feature of such impoundments clearly are not a feature of the Goulburn Weir plankton. Dilution accounts for low population densities over winter, with negative effects of high turbidity and increased flow. In other seasons zooplankton densities were higher than in any other Murray-Darling reservoir.

Although no data are available on nutrient loadings in the impoundment, it seems that relatively rapid fluctuations in trophic status would be characteristic. Variability due to inflows from Eildon or from catchment runoff is seen in measured water quality. Presumably similar fluctuations in nutrient levels occur, as in Mulwala, particularly in spring and summer with increased agricultural and recreational use of the Weir. High population densities of β-mesosaprobic rotifers (cf. Sladacek, 1973) at these times are indicative of nutrient influxes.

In summary, the limnoplankton of Goulburn Weir was more diverse and more abundant than that of the upstream reservoir. The temporal disparity in community composition between sampling dates was extreme, with more rapid replacement of species than would be expected by seasonal succession. The dissimilarity in species composition between the Weir and Eildon is a direct result of instability due to level fluctuations. Whereas the plankton of Eildon was dominated by a stable block of relatively long generation time microcrustacea, opportunists (particularly short generation time rotifers) predominated in the smaller impoundment. In this context, the perennial microcrustacea in Goulburn Weir, *B. meridionalis, B. fluvialis* and *C. exspansa* probably are acting as opportunists.

Downstream of Goulburn Weir

Approximately 60 km downstream of Goulburn Weir is a small storage filled from the Goulburn, Lake Victoria at Shepparton. For logistic reasons it was not possible to sample this impoundment as often as those upstream, nevertheless, collections which were made cover all seasons, and generally were within an hour of sampling Goulburn Weir. Some comparisons of the plankton of two distinctly different habitats are therefore possible.

5.2.2.3 Lake Victoria,Shepparton (station 46, Fig. 5.1)

This small impoundment is maintained at full supply level all year, principally for aesthetic uses, e.g. recreation over summer. A single site adjacent to a camping area in Shepparton was sampled. There was no marginal vegetation; water depth was stable at 1.5 m.

Physico-chemical features:

The following ranges were recorded: water temperature 9.0-25.0 °C, pH 7.4-7.6, DO 7.8-11.0 ppm, conductivity 120-335 µS, turbidity 200-275 NTU, (n=5). Extreme turbidities were characteristic of the storage. In summer, turbulence due to speed-boating maintains a suspension of clay and organic particles. In winter, high turbidities are due to runoff after heavy rains. Other physico-chemical differences between this storage and Goulburn Weir were due to its smaller size, lack of river through-flow, also to sampling later in the day (e.g. slightly higher temperatures on each visit).

Biological features:

Few phytoplankters were recorded. In autumn 1977 a few desmids (*Micrasterias*) and diatoms were present, also *Ceratium*. A large population of the rhizopod ?*Difflugia* was noted in summer 1978. Twenty-one zooplankton species were recorded from the impoundment (10 Rotifera, 7 Cladocera, 3 Copepoda and 1 ostracod sp.). Five of these (24%) were not recorded from Goulburn Weir. Species composition and temporal changes therein are shown in Fig. 5.29.

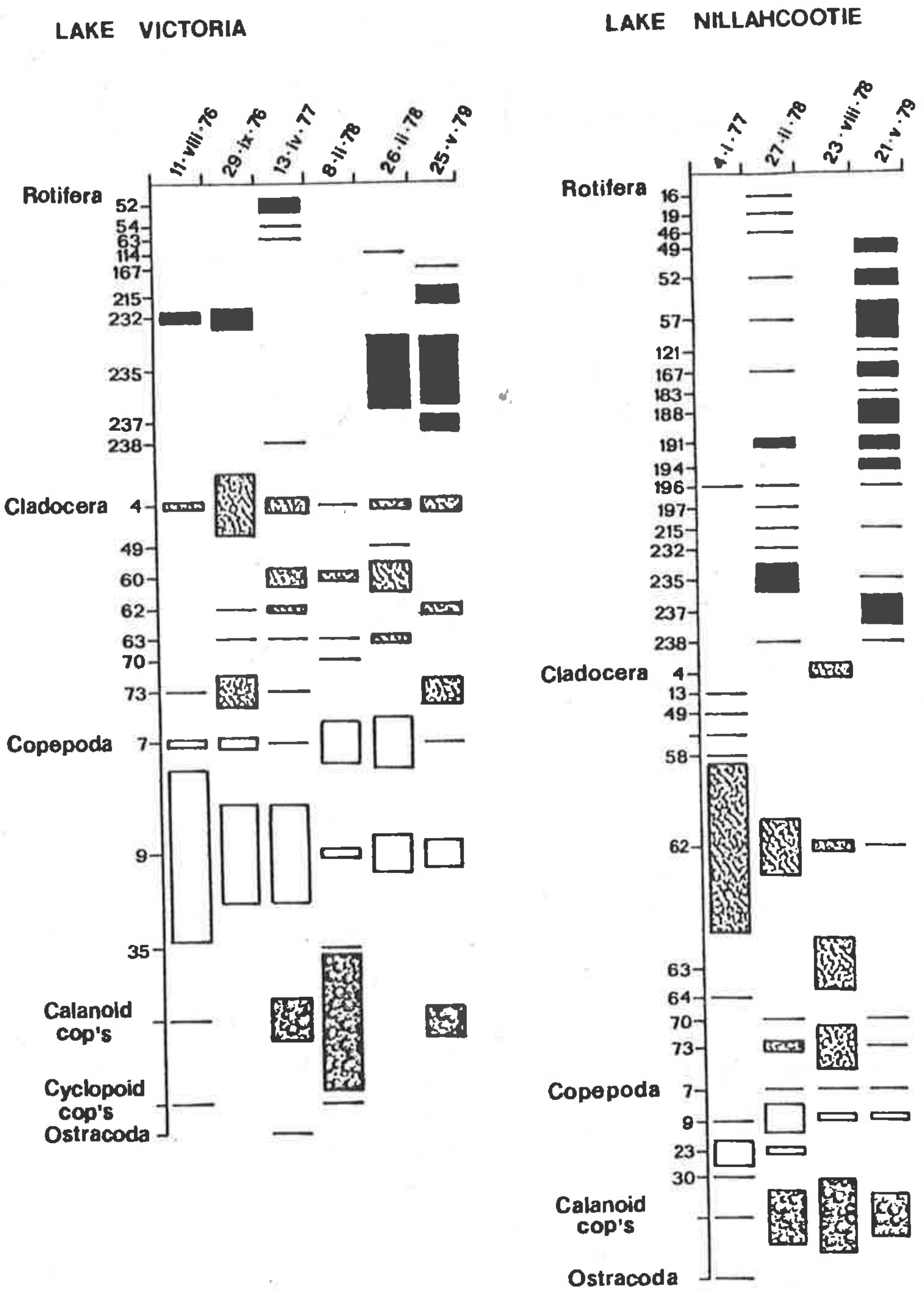


FIG. 5·29 Temporal variation in limnoplankton composition, Lake Victoria & Lake Nillahcootie

Rotifers were notably rare in all collections, including those of summer 1978 and autumn 1979 in which *C. unicornis* comprised ≃30% of the plankton. This represents individuals; only 1-2 colonies ℓ^{-1} were present. No rotifer species were perennial. Seasonality is suggested, e.g. *C. dossuarius* (winter-spring), *C. unicornis* (summer-autumn).

In all collections, a depauperate microcrustacean plankton predominated, notably the most widely tolerant and widely distributed species. Two to four species of Cladocera were present on each sampling date, but only *D. unguiculatu* was perennial. Other species apparently seasonal were *M. micrura, C. cornuta* (summer), *D. carinata* (spring-summer) and *C. quadrangula* (spring-autumn). Two species of calanoid were perennial, *B. triarticulata* and *C. ampulla*. Adult cyclopoids were not recorded.

CC values are shown in Table 5.26. Species composition was, in general, more similar between samples than in Goulburn Weir or Eildon. Greatest disparity was between samples most widely separated in time.

Mean species diversity (H' 2.0) was lower than in Goulburn Weir. As in the upstream impoundments, diversity was greatest in autumn, with the highest population density in summer. Mean population density was 32.5 ℓ^{-1}.

Environmental factors: Stable levels in this impoundment, and lack of through-flow, have favoured development of a microcrustacean limnoplankton. Low density and diversity during the study possibly were due to dilution over winter and turbulence caused by recreational activities over summer. Regression of species density and diversity on measured variables indicated a negative relationship between both parameters and turbidity (r^2=0.33), however this was not significant (P>.05). Sampling probably was inadequate to detect significant environmental stimuli.

5.2.2.4 Lake Nillahcootie, Broken R. (station 58, Fig. 5.22)

The headwaters of the Broken River are on the northern slopes of the Highlands, some 15 km from the Eildon catchment. The river flows north-west to join the Goulburn south of Shepparton. Nillahcootie Dam was constructed

Table 5.26 CC values, Lake Victoria, Shepparton

29.ix.76	13.iv.77	08.ii.78	26.ii.78	25.v.79	
.64	.53	.12	.30	.18	11.viii.76
	.56	.10	.26	.22	29.ix.76
		.36	.46	.20	13.iv.77
			.38	.18	08.ii.78
				.40	26.ii.78

in 1967 to form a small impoundment (40,000 Ml) regulating flows for irrigation in the Goulburn valley. The river also is dammed by a small weir at Benalla, ≃35 km downstream, for aesthetic purposes. Plankton samples were collected from the dam and from the river at Benalla for comparison with that of the nearby Goulburn impoundments. Comparative statistics for the dam are given in Table 5.27.

Physico-chemical features:

Ranges of some measured physico-chemical features from Lake Nillahcootie are included in Table 5.27. Ranges in this study were: water temperature 8.0-25.3 °C, pH 7.0-7.9, DO 9.6-12.4, conductivity 55-124 µS, turbidity 12-21 NTU (n=4), i.e. similar to Goulburn Weir. Ranges from the river were : water temperature 8.0-27.0, pH 7.0-7.7, DO 7.0-11.2, conductivity 110-575 µS, turbidity 20-24 NTU (n=5). Differences between the two sites were due to morphometry, time of sampling, and catchment use.

Biological features:

Phytoplankton: Algae were sparse in most collections. In the dam, the summer 1977 phytoplankton was similar to the northern bays of Eildon, and to that of Goulburn Weir, i.e. *Micrasterias, Spirogyra, Volvox*. A large population of *Ceratium* also was present.

Zooplankton: Thirty four taxa were recorded from the dam (19 Rotifera, 10 Cladocera, 4 Copepoda, 1 ostracod). Seasonal changes in the Nillahcootie plankton are shown in Fig. 5.29. Microcrustacea, principally Cladocera, were predominant in three of the collections. No rotifers were present in winter 1978. In autumn 1979, rotifers comprised 71% of the plankton; 13 of the 14 species recorded were true limnoplankters. Of the Cladocera, *B. meridionalis*, and probably also *C. quadrangula*, were perennial. The perennial copepods, *B. triarticulata* and *C. ampulla*, were common in the other impoundments.

The plankton community of Nillahcootie was more similar to Goulburn Weir (24 spp. in common, 71% of Nillahcootie plankton) and Eildon (23 spp.,68%) than to downstream Lake Victoria (14 spp., 41%). Average momentary species

Table 5.27: Ranges of some physico-chemical features measured in Lake Nillahcootie (WSCV unpublished data).

Characteristic	Range
pH	7.2-7.7
Conductivity (µS)	80-213
TDS (mg ℓ^{-1})	48-130
Colour (Pt)	40-200
Turbidity (NTU)	2.5-35
Alkalinity ($CaCO_3$)	28-46
Chloride (mg ℓ^{-1})	17-27

composition was 7.0 rotifers, 3.8 cladocerans and 2.5 copepods. Species dominants showed similar seasonality in Nillahcootie to those in Eildon and Goulburn Weir, although the smaller storage had a greater plankton diversity ($\bar{x}$ H' 2.5, max. 3.86 in autumn). No quantitative samples were taken from the dam, and no further analyses made.

Similarly, samples from the river at Benalla were qualitative. The influence of variable current flows and fringing hydrophytes was apparent in the shallow weir (3-4 m deep). Of 81 taxa collected from open water (53 rotifers, 14 cladocera and 4 copepods), more than half were littoral or epibenthic in habit, occurring as strays during low flow conditions over summer, when the weir resembled a pond, or flushed from reedbeds in high flows of autumn-winter. Plankton density and diversity were similar in the downstream weir ($\bar{x}$ H' 2.7, max. 3.09 in summer) to that of Nillahcootie (n=5). Average momentary species composition was 10.6 rotifers, 2.8 cladocerans and 0.8 copepods. There was least similarity in the rotifer component of the river station plankton to other sites, e.g. 12 spp. shared with Eildon (23%), 16 with Goulburn Weir (30%), 4 with Lake Victoria (8%) and 9 with Lake Nillahcootie (17%). A greater proportion of cladocerans were common to all sites (i.e. 43% Lakes Victoria and Nillahcootie, 71% Eildon, 95% Goulburn Weir). All of the copepods from the river site were present in Eildon and Goulburn Weir, two in Lake Victoria, and three in Nillahcootie. No further analyses of the Broken River collections were made; they serve as a comparison with collections from slow-flowing reaches of rivers in the north of the basin, e.g. the Gwydir, where a similarly rich plankton dominated by rotifers was recorded.

The R. Murray downstream of the Goulburn confluence

Below the Goulburn confluence, collections were taken from the Murray at Echuca and Swan Hill. General comments only are given.

R. Murray, Echuca (station 28, Fig. 2.11)

In spring (29.ix.76) high flows precluded development of the river plankton. A few individuals of *K. quadrata, A.priodonta, A. rectangula,* *B. meridionalis* and *B. triarticulata* were recorded. Considerable amounts of detritus and suspended organic material were present. In summer (08.ii.78) rotifers were numerically dominant (66%), predominantly *T. agnatha australiensis* and *Lecane* sp. Subdominants were *K. cochlearis, K. quadrata, Synchaeta* sp. and *Filinia* sp., i.e. a mixed assemblage of true plankters and facultative forms. *B. meridionalis* was the only cladoceran present (24%). Species diversity was high (H' 3.02), a result of a dense bloom of *Melosira* which prevailed in the river (cf. Mulwala). Large amounts of detritus trapped in clumps of algal filaments provided suitable substrates for non-planktonic taxa. Slow flow conditions over summer undoubtedly contributed to the maintenance of this assemblage. Population density was low (≃12 ℓ^{-1}).

An autumn sample (25.v.79) also had a high diversity (H' 2.78) and low density (6.7 ℓ^{-1}). Phytoplankters were sparse. Microcrustacea comprised 56% of the plankton, with a littoral species, *A. rectangula*, dominant. Large amounts of suspended organic debris possibly facilitated its survival. *B. meridionalis* was subdominant. Six taxa of rotifers occurred, predominantly *P. dolichoptera, B. angularis* and *K. cochlearis* f.*tecta*. The influence of releases from the Goulburn is suggested; the same species dominants were present in Goulburn Weir, and the form of *K. cochlearis* present was typical of Goulburn waters. It was not collected in the Murray upstream of the Goulburn confluence.

R. Murray, Swan Hill (station 27, Fig. 2.11)

As at the upstream station, a depauperate plankton assemblage was recorded in spring. Diversity also was low (H' 1.80). *B. meridionalis* was the only abundant plankter (62%). Other species were as at Echuca, with *C. sphaericus* and *Eucyclops* n.sp. also present. Low density and diversity were probably due to high spring flows. Samples in autumn (16.v.77, 25.v.79) and summer (08.ii.78) showed similar trends to those from upstream stations, although species composition was slightly different. In summary, the autumn 1977 plankton was dominated by microcrustacea (68%), with *B. meridionalis* predominant. Diversity was higher (H'2.23) than in spring. In summer 1978, rotifers were most abundant during the *Melosira* bloom (63%, *Synchaeta* predominant; H' 2.98). The autumn 1979 sample was dominated by microcrustacea, with littoral species (*N. armata, I. sordidus,* 86%) most abundant (H' 2.83). The river at this time was low, flow rate was low, and turbidity was high (Secchi reading 2.0 cm). Densities in all samples were $< 20\ \ell^{-1}$, with 10-12 species present in the plankton.

Clearly, although few samples were taken, flow rate and source of river flows were important in determining plankton composition. The greater diversity in the plankton accompanying algal blooms from Mulwala probably is characteristic, as are the seasonal compositional changes in plankton assemblages. The respective contributions from these upstream sources is reflected in community structure in the lower Murray plankton (Ch. 7).

The Murrumbidgee River (Fig. 5.30)

The Murrumbidgee River drains west from the Eastern Highlands, supplying irrigation needs in the Murrumbidgee Irrigation Area. Burrinjuck Dam regulates flows. Diversions into the river from the Snowy Scheme enter via the Tumut River downstream of Burrinjuck.

In this study, plankton samples were collected from Lake Burley Griffin, an impoundment on the Molonglo River (a tributary of the Murrumbidgee) and Burrinjuck Dam. Seasonal samples were collected from the Murrumbidgee at Jugiong, above the Tumut confluence, and Gundagai, below the confluence. Wyangala Dam, on the Lachlan River, a northern tributary of the Murrumbidgee, also was sampled.

5.2.2.5 Lake Burley Griffin (Fig. 5.30, inset)

Constructed in the early 1960's for recreation and aesthetic use in Canberra, A.C.T., this small, shallow storage impounds waters of the Molonglo River, which joins the Murrumbidgee below Canberra. Features of the storage were reported by Hillman (1974,1980) following a study of zinc pollution and primary productivity in the lake. Morphometric and other details of the lake are given in Table 5.28.

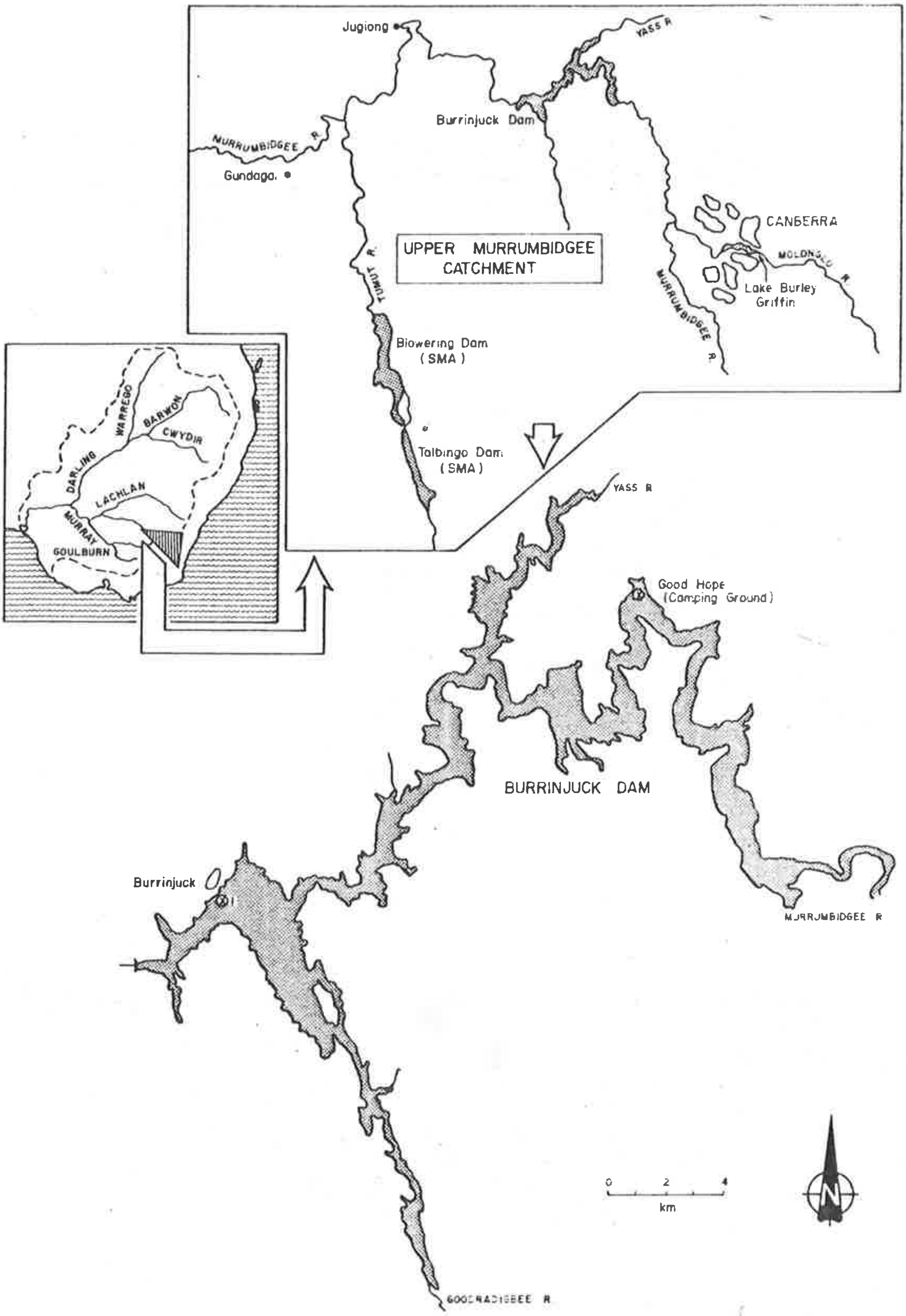


FIG. 5·30 Burrinjuck Dam showing sample sites

Table 5.28: Morphometric and other features of Lake Burley Griffin (from Hillman, 1974)

Latitude and longitude	35°17'S 149°E
Elevation (m)	556
Catchment area (ha)	183,700
Shoreline (km)	35.4
Capacity (Ml)	33,166
Max. depth (m)	17.37
$\bar{x}$ depth (m)	4.71
Retention time (yr)	0.21

Physico-chemical features:

Water quality measurements made during this study were as follows: water temperature 9.0-25.0 °C, pH 7.3-7.8, dissolved oxygen 7.9-10.0, conductivity 125-200 uS, turbidity 2-23.0 NTU. In terms of nutrient levels the lake was considered to be marginally eutrophic (Hillman, 1974), but nuisance algal blooms were prevented by the characteristically high abiogenic turbidity, i.e. shallow morphometry and exposure to wind action.

Biological features:

Only the zooplankton was examined in samples from the lake. Phytoplankton densities generally were low.

Community composition: twenty-eight taxa of zooplankton were recorded from the impoundment (15 Rotifera, 8 Cladocera, 5 Copepoda). Species composition and seasonal changes therein are shown in Fig. 5.31. On any sampling date there were 10-16 species in the plankton, with one or two dominant species comprising 40-80%, one or two species subdominant, and the remaining taxa represented by few individuals. Some seasonal trends were apparent: in spring 1977 all groups were represented equitably, and diversity was highest (H' 2.59). Rotifera predominated in summer 1978 (*Asplanchna* spp.), copepods in autumn (*B. triarticulata*), rotifers in winter (*Synchaeta* spp.) and *B. triarticulata* again the following summer. As in Hume and Mulwala, summer blooms of the dinoflagellate, *Ceratium*, were noted. It was the numerically most abundant plankter in 1978, second only to copepodites in 1979.

Species diversity was higher in Burley Griffin than in Burrinjuck ($\bar{x}$ H' 2.13 vs. 1.2) and more species were present on any date, although lower densities were recorded (7-43 ℓ^{-1} vs. 12-567 ℓ^{-1}). With the exception of *K. slacki* and *P. lemnae*, which are characteristic of shallow littoral habitats, other plankters in Burley Griffin were true limnoplankters, i.e. 93%, a greater proportion than from any other impoundment. With a few exceptions, e.g. *A. girodi*, recorded only from Burley Griffin, these taxa were the most widely distributed and eurytopic forms, ubiquitous across the study area, and exhibiting similar seasonality as in other storages, e.g. *M. micrura* (summer).

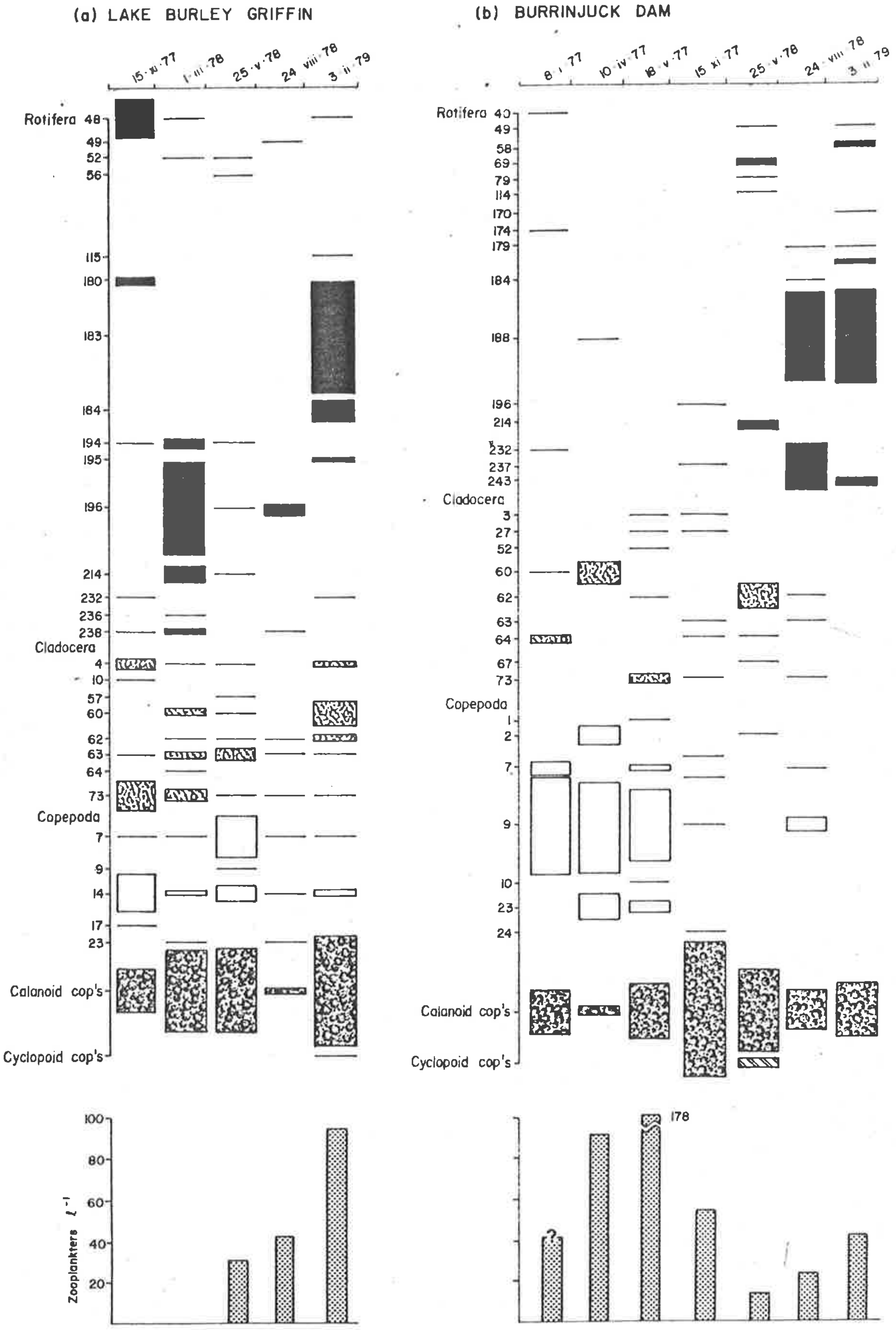


FIG. 5·31 Temporal variations in limnoplankton composition (a) Lake Burley Griffin (b) Burrinjuck Dam

CC values for Burley Griffin samples are given in Table 5.29.

Environmental factors: No correlations were found between environmental variables and density of zooplankton taxa (all r^2 values <0.20). Sampling was too infrequent. The artificial nature of the Burley Griffin basin probably has the most profound effect on plankton composition, i.e. absence of a fringing littoral zone (which is actively discouraged by weedicides), preventing littoral and pseudoplanktonic incursions which are a feature of other impoundments. Greater diversity and lower population densities, with different species dominants than were recorded from Burrinjuck possibly reflect nutrient differences. Contributing factors in Burley Griffin are the shallow morphometry and exposure to wind action, and maintenance at full level, i.e. fewer fluctuations than in an impoundment used for irrigation or generation of hydro-electricity.

5.2.2.6 Burrinjuck Dam (station 42, Fig. 5.30)

This storage has received attention in recent years due to nuisance blooms of *Anacystis* and *Anabaena* resulting from eutrophication. Nutrient enrichment occurs from the upstream Murrumbidgee and Yass Rivers, which drain populated areas around Canberra. There is little published information on physico-chemical or biological features of this large dam (1.03×10^6 Ml, < 60 m deep). May (1978) includes some data from unpublished reports, and information on water quality and biology is included in an A.C.T. water quality survey report (N.C.D.C.,1978).

Sampling sites: Site 1 (Fig. 5.30) was 1.5 km upstream from the dam, in approximately 3 m depth. Site 2 (1 m deep) was on the Murrumbidgee arm adkacent to the Good Hope caravan park. Sampling dates are included in Fig. 5.31b.

Physico-chemical features:

A surface temperature range of 11-25 °C was reported by May (1978). In the present study a range of 8.0-31.0 °C was recorded at site 1. Secchi transparencies of a few cm to 5 m were reported, with lowest transparency during spring flooding. In this study, turbidities of 1-40 NTU were recorded, with the highest turbidity during a *Volvox* bloom in summer 1977. Higher nutrient levels, lower dissolved oxygen and higher bacterial counts occurred in the northern arm of the reservoir than in the southern (May, 1978)(cf. Eildon). Other ranges recorded in this study were: pH 7.0-7.6, dissolved oxygen 7.0-10.6 ppm, conductivity 93-190 μS.

Biological features:

Phytoplankton: Thirty-one species of algae are recorded from Burrinjuck (May, 1978)(cf. Hume, Eildon). In summer 1977 a *Volvox* bloom at site 2 was estimated to have more than 5 x 10^3 colonies ℓ^{-1}, with an accompanying pulse of *Anacystis cyanea*. Both genera also were present at site 1, but in low numbers, with *Staurastrum* spp. predominant. Bloom conditions of the latter were noted in summer 1979. In other collections algae were not abundant. Most frequently encountered genera were *Cosmarium, Cyclotella, Euglena* (spring-summer), *Melosira, Micrasterias* (autumn-winter), *Sphaerocystis* and *Spirogyra* (summer). *Ceratium* was present only in the 1977 collections.

Zooplankton:

Community composition: Thirty-three taxa were identified (17 Rotifera, 9 Cladocera, 7 Copepoda). Compositional data are shown in Fig. 5.31b. Approximately 50% of these occurred also in Burley Griffin. There was no apparent synchrony of appearance. Unlike the Burley Griffin limnoplankton, non-planktonic or facultatively planktonic taxa were present in all Burrinjuck samples (9 spp.), indicating the influence of littoral areas. Strays were more frequent at site 2 than site 1, which had a rocky beach with no emergent vegetation.

The most frequently collected rotifer was *P. dolichoptera*, but the most abundant in any collection was *Ascomorphella volvocicola*, a parasite of *Volvox*. In the summer 1977 *Volvox* bloom, 60% of colonies contained single rotifers. No accurate count could be made, but from the estimate of *Volvox* density, with 60% parasitism, at least 2-3 x 10^3 individuals ℓ^{-1} were present.

This is the highest density recorded from any collection during the study. Other Rotifera were few; eleven of the species recorded were from single collections.

Similarly for the microcrustacea, few taxa occurred in consecutive, or more than one or two samples. Most common taxa were *B. meridionalis, C. quadrangula, B. triarticulata* and *C. ampulla*. The occurrence of four species of calanoid in the autumn 1977 sample was of interest. *B. delicata* may have been washed in from higher altitude. *C. australica* was co-occurrent, and was not recorded elsewhere during the study. As mentioned earlier, specimens differed slightly in morphology from the type. It is likely that an isolated population, perhaps from a billabong, was flushed into Burrinjuck with high autumn flows. Several taxa commonly found in billabong littorals also were present (e.g. *A. rectangula, M. spinosa*).

Copepoda were predominant through 1977, comprising 84-96% of the plankton (cf. Eildon). Rotifera were numerically abundant in winter 1978 and summer 1979 (67% and 71% respectively). Zooplankton density in site 1 samples is shown in Fig. 5.31b. Mean density was an order of magnitude higher at site 2 than at site 1 ($\bar{x}$ 567 ℓ^{-1}, n=4, vs. 66 ℓ^{-1}, n=6), although much of this disparity reflects the single summer pulse of *A. volvocicola* (08.i.77). Mean density for the three other collections was 90 ℓ^{-1}, i.e. the same order of magnitude as reported in the N.C.D.C (1978) study. Greatest densities occurred at both sites in summer and autumn 1977. Lowest density (12 ℓ^{-1})was recorded at site 1 during high autumn flows (25.v.78). Low densities prevailed in the winter 1978 and summer 1979 samples. With the exception of the autumn 1978 samples, densities were higher than in Burley Griffin.

Species diversity was lower than for any other storage ($\bar{x}$ H' 1.24), with lower diversity at site 1 (0.91) than at site 2 (1.87). Greatest diversity was at site 1 in autumn 1978 (2.4), lowest at site 2 during the *Volvox* bloom (0.44).

CC values for Burrinjuck and Burley Griffin samples are compared in Table 5.29. Although the plankton of both storages showed generally low

Table. 5. 29 Comparative CC values for Burley Griffin and Burrinjuck:

Burley Griffin

1.iii.78	25.v.78	24.viii.78	03.ii.79	
.40	.30	.20	.38	15.xi.77
	.58	.40	.44	1.iii.78
		.45	.41	25.v.78
			.29	24.viii.78

Burrinjuck

18.v.77	15.xi.77	25.v.78	24.viii.78	3.ii.79	
.36	.15	.27	.36	.20	10.iv.77
	.43	.12	.36	.06	18.v.77
		.12	.46	.06	15.xi.77
			.13	.14	25.v.78
				.33	24.viii.78

similarity between sampling dates, higher values for Burley Griffin reflect the greater stability of its plankton assemblage.

In summary, Burrinjuck was the only storage in which dense algal blooms were recorded. As in highly eutrophic waters elsewhere, there was a marked decrease in zooplankton diversity with maximum algal biomass, with a single zooplankton species achieving bloom proportions. While diversity was lower during such blooms than in any other storage, mean zooplankton density was the greatest recorded. The predominant influence on the Burrinjuck limnoplankton is nutrient enrichment from upstream sources into the northern arm. The habitat heterogeneity so produced has led to a heterogeneous limnoplankton assemblage. Clearly, more intensive study than was possible in the present sampling program would be necessary to clarify species and community relationships in this reservoir.

The Murrumbidgee River downstream of Burrinjuck Dam

Samples were collected from the Murrumbidgee below Burrinjuck on 10.viii.76, 08.i.77, 19.v.77, 25.v.78 and 3.ii.79. Sites were as shown in Fig. 2.11. On all occasions, plankton was sparse ($<1\ \ell^{-1}$). In winter 1976, for example, *C. sphaericus*, *B. meridionalis* and *B. triarticulata* were present in the river at Balranald. Most plankters were dead on collection, although viable eggs (*Bosmina*, *Boeckella*) hatched in a laboratory aquarium. At Hay, *B. leydigii* and cyclopoid copepodites were recorded, apparently flushed from standing waters or marginal hydrophyte beds. No live plankters were collected at Narranderah, Wagga Wagga or Gundagai. All samples contained abundant suspended silica and organic detritus. High winter flows precluded plankton development.

In lower flow conditions of summer and autumn a more diverse assemblage occurred in the Murrumbidgee plankton, although densities were low. In autumn 1977 six-nine taxa were recorded at all stations, predominantly *B. triarticulata* and *C. ampulla*, with littoral strays (*A. rectangula*, *I. sordidus*). In autumn 1978 16 taxa were recorded at Gundagai. Only three of these were present in

Burrinjuck. Rotifers dominated the river plankton (12 spp.) and most were true plankters (e.g. *K. cochlearis, S. longipes, S. oblonga, S. pectinata, F. longiseta, P. complanata*). Cladocerans were sparse (*B. meridionalis, A. rectangula*) as were copepods (*B. triarticulata, C. lucasi*).

The paucity of plankton in the Murrumbidgee during this study apparently was due to low survival in the turbulent high pressure hypolimnetic releases from Burrinjuck, and similarly low survival due to turbulence in the major tributary, the Tumut River. Only during low flows was a relatively diverse potamoplankton present, the dominant species of which were not those of the upstream reservoir. While some of these taxa were pseudoplankters, flushed from fringing vegetation, most were true limnoplankters, with breeding populations in the river. Their origin is not clear, although backwaters and sluggish reaches may allow development of an autochthonous plankton (see Ch. 7).

5.2.2.7 Wyangala Dam (station 82, Fig. 2.11)

Northernmost of the Murray basin tributaries, the Lachlan River flows south west to join the Murrumbidgee ≃100 km upstream from the Murray-Murrumbidgee confluence. Wyangala Dam was constructed in 1936 (enlarged in 1971) to regulate flows for domestic, stock and irrigation supply downstream (WRCN, 1978). In this study, samples were collected from a single site in Wyangala (Fig. 5.32), below the dam from the Lachlan at Cowra, and from a tributary, the Boorowa River at Boorowa. Morphometric and other features of the Wyangala storage are given in Table 5.30. The dam was sampled only three times; seasonal data therefore are incomplete, and are presented in summary for comparison with Burrinjuck Dam, some 100 km south.

Physico-chemical features:

The following ranges were recorded: water temperature 9.0-27.0 °C, pH 7.2-7.8, DO 7.5-9.8, conductivity 180-245 μS, turbidity 0.5-1.0 NTU. With the exception of conductivity, which was slightly higher in Wyangala, measured water quality was similar to that in Burrinjuck. On the basis of total-P levels (.016-.028 mg ℓ^{-1}, WRCN, unpublished) (cf. Hume), it is likely that

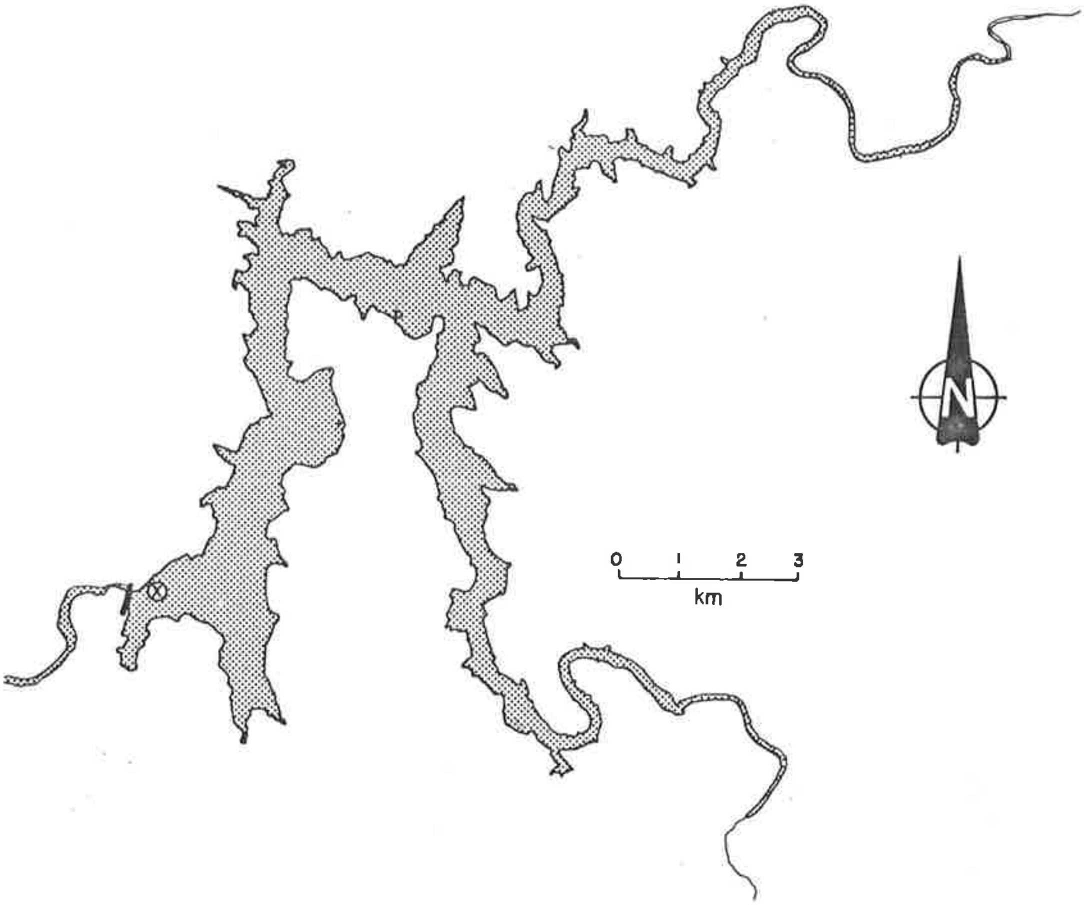


FIG. 5·32 Wyangala Dam.

Table 5.30: Morphometric and other features of Wyangala Dam (WRCN, 1978; unpublished)

Latitude and longitude	33° 58' S 148° 57'E
Elevation (m)	380
Catchment area (km^2)	8,290
Surface area (ha)	5,300
Capacity (Ml)	1.22×10^6
Max. depth (m)	72
Retention time (yr)	<1.0
Cation dominance	Na > Ca > Mg
Anion dominance	$HCO_3 > Cl > SO_4$

Wyangala is seasonally eutrophic.

Biological features:

Only in the autumn 1978 sample were phytoplankters abundant, with dense clumps of *Oscillatoria* filaments present. Zooplankton density in this bloom was low (18.2 ℓ^{-1}). Twenty-seven zooplankton taxa were recorded from all collections (16 Rotifera, 5 Cladocera, 6 Copepoda). Species composition of the limnoplankton on each sampling date is shown in Fig. 5.33. All samples were numerically dominated by calanoid copepodites (*B. triarticulata, C. ampulla*). Rotifers comprised only 5% of the autumn 1978 sample (7 spp., with *K. cochlearis, K. procurva, P. vulgaris* and *H. mira* most abundant), 24% of the spring collection (7 spp., predominantly *S. longipes, P. vulgaris, C. unicornis*), and 37% of the summer 1979 sample (11 spp., *S. longipes, P. vulgaris, A priodonta* and *H. mira* most common). Cladocera were sparse. As in other storages, *B. meridionalis* was perennial. *D. excisum*, common in billabongs, was present during the blue-green algal bloom. As in other storage *D. lumholtzi* occurred over summer.

Several congeneric associations were noted, e.g. three species of *Keratella* in autumn (*K. cochlearis, K. procurva, K. tropica*), two in summer (*K. procurva, K. valga*). Three species of *Lecane*, an ostensibly epiphytic genus, occurred in summer; *L. aculeata* and *L. inopinata*, both tropical warm stenotherms recorded from the continent for the first time (the former only in Wyangala), and *L. luna*. *C.quadrangula* and *C. cornuta* were co-occurrent in summer, and three calanoid species were present in all samples; *B. fluvialis* and *B. triarticulata*, with *C. ampulla* in autumn, and *C. lucasi* in spring and summer.

Mean zooplankton density was 57 ℓ^{-1}, mean diversity was 2.1. Both density (112 ℓ^{-1}) and diversity (H' 2.31) were highest in summer. The Wyangala species assemblage was closer in composition to the Darling storages (56% of taxa in common) than to those of the Murray (e.g. 44% of taxa shared with Burrinjuck). Predominant zooplankters were those of wide distribution,

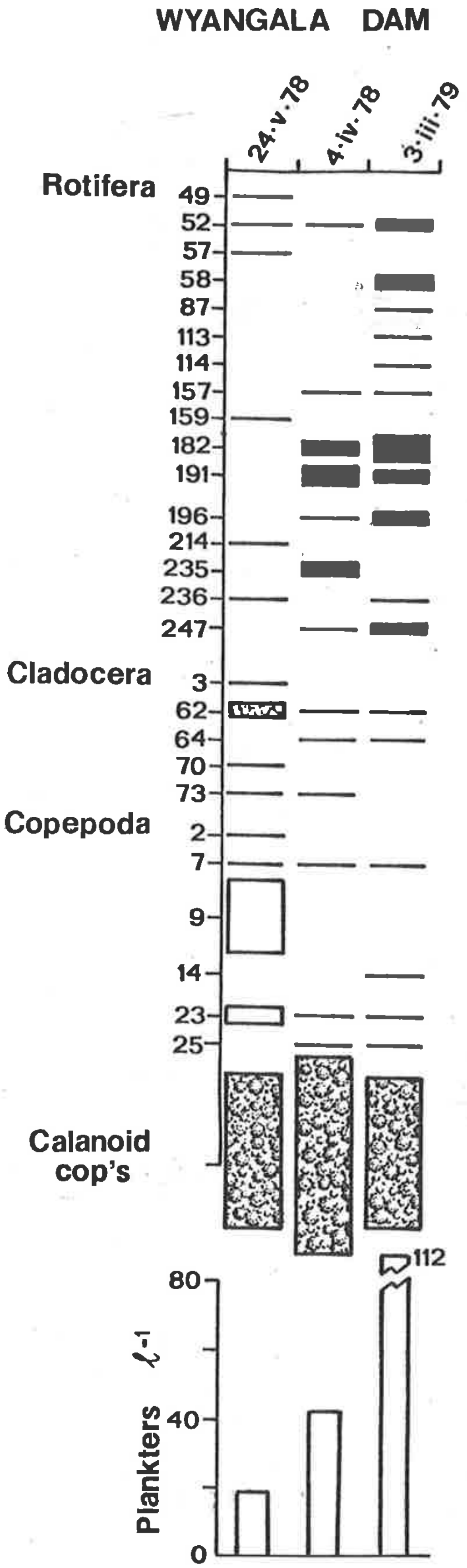


FIG. 5·33 Temporal variation in limnoplankton composition, Wyangala Dam with a small block of restricted forms (e.g. *T. chattoni*, recorded only from Wyangala and Lake Eucumbene; *L. inopinata* only from Wyangala and Lake Menindee). In view of infrequency of sampling, no further analyses were made.

The Lachlan River below Wyangala

Qualitative tows were taken from the Lachlan at Cowra to determine the contribution of the reservoir plankton to the river. Only three samples were possible, and only general observations can be given.

With the exception of temperature, which was some 10.0°C lower in spring and summer than at the surface in Wyangala, water quality was similar. Very low densities of plankters ($<5\ \ell^{-1}$) were present in all samples, with considerable amounts of organic detritus, particularly *Bosmina* exoskeletons. Only a small proportion of the dam assemblage occurred in the river, i.e. were limited by current velocity and turbulence during release. In autumn 1978, *B. meridionalis, B. fluvialis* and *C. ampulla* were present (<20 % of the dam taxa), with littoral strays *B. kendallensis* and juvenile ostracods. In spring, only copepod nauplii were recorded. As in other rivers, a more diverse assemblage was present during slow flows over summer (7 spp., 5 rotifers, 1 cladoceran, 1 copepod), however only *K. procurva* and *B. triarticulata* also were in the dam. The other taxa (70% of the river assemblage) were littoral strays (e.g. *E. proxima, D. haueriensis, L. closterocerca*). Few of the Wyangala limnoplankton survvived into the river.

Collections from a tributary, the Boorowa River, contained a plankton more similar to that of a billabong than a river, i.e. dominated by microcrustacea, with a high proportion of macroinvertebrates in open water. In autumn, for example, the plankton was dominated by *B. fluvialis* and *C. lucasi*, with *B. meridionalis, S. vetulus* and *M .leuckarti* subdominant. The influence of shallow morphometry and fringing vegetation was apparent, with 14 taxa of macroinvertebrates collected in 5 x 6m tows.

Logictics precluded sampling of the Lachlan below Cowra. It is likely that this river provides a transport corridor for species found in the north of the basin, e.g. *B. keikoa, Monospilus* spp. were recorded downstream of the Lachlan-Murrumbidgee confluence, but otherwise occurred only in Darling waters.

The River Murray downstream of the Murrumbidgee confluence

Seasonal collections were taken from the Murray at Euston and Mildura (stations 25 and 24), with incidental collections at Boundary Bend (station 26, Fig. 2.11). Similar trends were apparent to those recorded at Swan Hill, and are presented here in summary.

In winter 1976, the influence of Murrumbidgee flows into the Murray was apparent. At Euston and Mildura plankton densities were <5 ℓ^{-1}; only *A. priodonta, C. sphaericus* and *B. meridionalis* were recorded. Boeckellid exoskeletal debris was abundant, and was present in collections from several points along the Murrumbidgee, apparently due to releases from Burrinjuck. On the same day, at Barmah, on the Murray, calanoids were not recorded; *B. meridionalis* predominated. Plankton densities were low.

The spring assemblage was considerably more rich in species than at upstream stations, for example at Mildura 11 rotifer species (33%) 2 cladocerans (66%) and 1 copepod (1%) accompanied a localised *Melosira* bloom. *B. meridionalis* predominated, with *K. cochlearis, K. slacki, K. tropica* and *F. longiseta passa* subdominant. Densities were patchy, possibly a result of urban runoff and nutrient inflows at Mildura, e.g. 184 plankters ℓ^{-1} occurred at Mildura, while <5 ℓ^{-1} were collected at Euston. Some reduction of flow at Mildura due to Darling inflows also may have contributed to increased density and diversity.

Low densities prevailed over summer 1976-77 during a second pulse of *Melosira* (<20 plankters ℓ^{-1}). Rotifers predominated (72%), with four species of *Filinia* numerically abundant, i.e. different species dominants to upstream stations. *B. meridionalis* was the only cladoceran recorded.

The autumn zooplankton at Mildura was less diverse than at upstream stations (H' 1.75) although more species were recorded. A single rotifer species (*F. terminalis*) comprised 69% of the plankton. A further 14 rotifer taxa made up another 25%, with three cladocerans and two copepods making up only a small proportion of the plankton (p.141).

The plankton of the middle reaches of the Murray is influenced strongly by the shallow impoundments at Mulwala and Goulburn Weir. The species compositic of the river plankton reflected the seasonal variability of these storages. Seasonal algal blooms, particularly of *Melosira*, produced a more diverse zooplankton. At any point in the river different species dominants occurred, depending on local conditions. These longitudinal compositional changes were characteristic of most slow flowing reaches of the Murray, and as will be shown in the next section, the Darling rivers. More or less discrete slugs of water move downstream, the plankton community apparently maintaining its integrity within the water mass. Spatial and temporal variation in the potamoplankton will be considered further in Ch. 7.

5.3 The Darling River system

It is indicative of the climatic variability of the north of the basin that of five field trips along the Darling River and tributaries, one (autumn 1977) yielded little material, with no flow recorded in the river, and little standing water on the floodplain, but the following autumn-winter the river was inaccessible due to prolonged flooding. Consequently stations on the Darling rivers and reservoirs were sampled only three times, in autumn and summer. A seasonal series was possible only at Wentworth, above the Murray-Darling confluence. Data are therefore treated in summary only, with a brief consideration of the reservoirs and downstream river reaches, and general observations on the plankton assemblages recorded.

5.3.1 The reservoirs

Physico-chemical features:

Of the four major storages on the Darling R. headwaters, Burrendong Reservoir on the Macquarie R. is the largest (1.67×10^6 Ml), then Copeton on the Gwydir (1.36×10^6 Ml), Keepit on the Namoi ($.42 \times 10^6$ Ml) and Pindari on the Severn (37×10^3 Ml). All were constructed during 1960-76 for stock, domestic and irrigation supply. There are no major dams downstream, although 32 low weirs impede flows on the course of the Darling. A further series of weirs and barrages at Menindee forms four shallow ($\simeq$ 3 m deep) 'lakes' (1.79×10^6 Ml), also for stock, domestic and irrigation supply, and as a flushing supply to alleviate high salinities in the lower Murray (see Ch. 7).

Although basic water quality has been monitored (approximately bi-monthly) by the WRCN at an extensive series of riverine and lacustrine stations, not until 1979 were nutrient levels measured in the reservoirs. Little biological information is available. Features of the physico-chemical limnology of the three reservoirs sampled in this study are summarised in Table 5.31 and discussed briefly below. Retention times are based on storage capacity and annual regulated flow data, and are, at best, subjective. Data on NO_3 and total-P levels are from three dates only (early 1979).

Table 5.31: Morphometric, physico-chemical and other features of Keepit Dam, Burrendong Dam and Lake Menindee (abstracted from unpublished WRCN data).

	Keepit	Burrendong	Menindee
Latitude & longitude	30°50' S 150°30'E	32°40' S 149°09'E	32°20' S 142°20'E
Max. depth (m)	40	50	3-5
Retention time (yr)	<.5	?1-2.0	?<.5
Water temp. range	11.0-25.8	12.0-29.0	n/a
Major ions (mg ℓ^{-1}, mean only)	Ca 29.7	16.4	26.1
	Mg 15.5	10.2	11.0
	Na 21.9	19.3	32.6
	K 2.2	2.5	7.0
	CO_3 0.5	-	0.8
	$HCO_3$153.3	79.0	161.8
	$SO_4$29.3	19.9	14.4
	Cl 19.1	20.5	29.8
pH (range and mean)	7.4-8.5,8.0	5.5-8.0,7.4	7.9
Conductivity (μS)	184-478,355	180-350,237	220-603,370
TDS (mg ℓ^{-1})	100-251,193	85-200,144	120-300,196
NO_3-N "	.008-.048	0.14-22.4	n/a
Total-P	.006-.079	.016-.057	n/a
Turbiditity	1.2-1.6 FTU	1.5-22FTU	2-110 NTU
n	50	9	48

The order of ionic dominance Na $\gtrless$ Ca > Mg > K, HCO_3 > SO_4 > Cl > CO_3 is typical for Murray-Darling waters. The calcium bicarbonate waters of Keepit Dam reflect geologic origin, increasing Na levels at Menindee the influence of saline groundwater. The headwater reservoirs are commonly alkaline, of relatively low conductivity, TDS and turbidity. High turbidities in the Menindee storages result from shallowness, riverine influence, and exposure to prevailing winds. The limited nutrient data available show variable NO_3 and P levels within the ranges reported from Lakes Hume and Mulwala, i.e. indicative of meso/eutrophy (Walker & Hillman, 1977). The range of water temperature is greater than that of Hume or Mulwala, reflecting latitudinal differences.

Biological features:

Zooplankton composition of the three reservoirs (summer & autumn only) is shown in Fig. 5.34. Measured water quality, relative proportions, density and diversity of the zooplankton are shown in Table 5.32 and discussed briefly below. In view of lack of seasonal data, only general observations are possible.

5.3.1.1 Keepit Dam, Namoi River (station 109, Fig. 5.35)

All samples were dominated by rotifers, predominantly eurytopic species, and copepodites. Species of *Hexarthra, Synchaeta, Polyarthra* and *Conochilus* , true limnoplankters, were numerically abundant. Two species only, *S. longipes* and *P. vulgaris* were present in both summer and autumn collections. Several species common to shallow waters elsewhere in the basin were collected (*B. quadridentatus, K. slacki, E. dilatata*). Relatively few adult microcrustacea were present. *B. triarticulata* was present in all collections, principally as copepodites. Other microcrustacea were widely distributed eurytopic species, e.g. *C. sphaericus, M. leuckarti*.

Seasonality, even with limited sampling, was evident in the change in species composition. Although density and diversity were comparable for each sample, only three of the species collected in autumn 1977 were present in

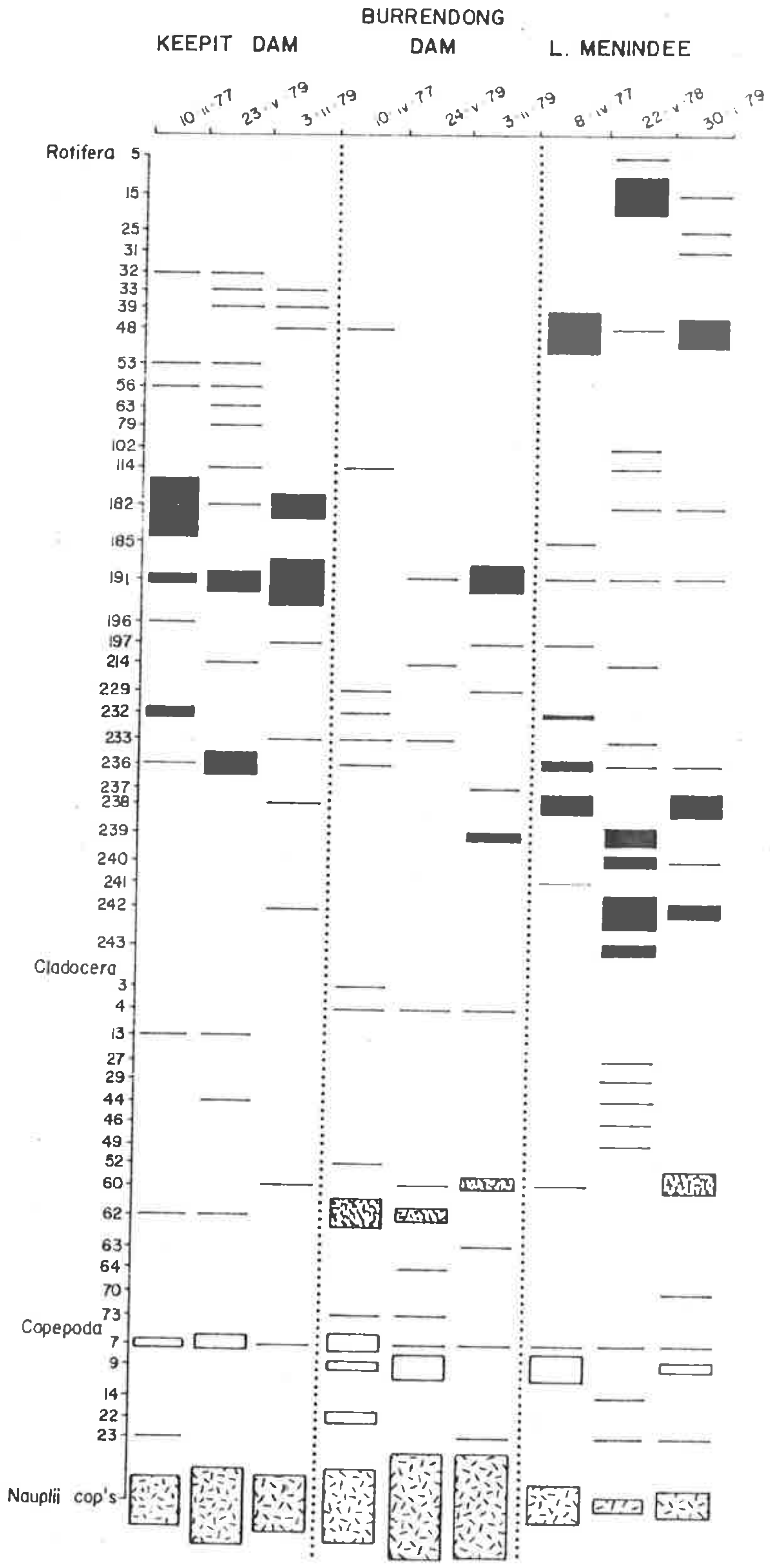


FIG 5·34 Zooplankton recorded from 3 Darling River storages

Table 5.32: Physico-chemical and biological features recorded during 1976-79, Keepit, Burrendong and Menindee storages.

	Keepit			Burrendong			Menindee		
	10iv77	24v78	03ii79	10iv77	24v78	03ii79	08iv77	22v78	30i79
Water temperature (^{o}C)	18.0	16.5	28.6	24.0	18.0	29.0	12.5	13.5	26.3
pH	8.0	7.6	7.4	7.6	7.7	7.3	8.1	7.5	8.2
Dissolved oxygen (ppm)	8.7	9.2	6.0	8.6	9.2	7.6	9.2	10.2	8.4
Conductivity (µS)	225	270	265	215	305	280	380	475	425
Turbidity (NTU)	<1	4	11	-	-	3.5	110	65	50
Zooplankton ℓ^{-1}	18	16	32	157	131	123	15	28	33
No. of species	12	16	11	14	10	10	11	22	15
% composition R / Cl / Co	61/4/35	39/1/60	55/2/43	1/56/44	2/12/86	31/7/62	45/2/53	87/9/4	63/14/23
Diversity(H')	2.45	2.05	2.46	1.94	1.42	1.70	2.56	2.77	2.95

FIG 5·35 Keepit Dam

summer 1979. Plankton densities were low, with a summer maximum of only 32 ℓ^{-1}.

The high proportion of small rotifer species and copepodite stages suggests that retention time is a major influence on the Keepit plankton, i.e. microcrustacea, with longer life cycles, are not able to develop. Those which were recorded apparently are short life cycle opportunists.

5.3.1.2 Burrendong Dam, Macquarie River (station 97, Fig.)

The limnoplankton of Burrendong, some 230 km south-west of Keepit, was markedly different in composition. Copepods (*C. ampulla, B. triarticulata*) comprised 44-86%, with cladocerans (*B. meridionalis, D. excisum* and in summer, *M. micrura*) subdominant. Rotifera were abundant only in summer (31% of zooplankton). While >70% of the rotifers in Burrendong were present also in Keepit, asynchrony of occurrence was apparent. *P. vulgaris* was the only species with coincident pulses in both dams, however low population densities suggest some taxa probably were missed. Similar asynchrony of occurrence was apparent in the microcrustacea common to both dams (4 spp., 33% of the Burrendong assemblage). Comparison of average momentary species composition emphasizes the disparity in the limnoplankton , i.e. 3.7 rotifers, 2.7 cladocerans, 1.3 copepods in Burrendong, vs. 6.3 rotifers, 1.3 cladocerans, 0.7 copepods in Keepit.

Population densities in Burrendong were considerably higher than in Keepit ($\bar{x}$ 137 vs. 22 ℓ^{-1}), but diversities were lower due to the predominance of one or two taxa ($\bar{x}$ for Burrendong was 1.69, $\bar{x}$ H' for Keepit was 2.32). Seasonality was less evident than in the smaller storage. The same taxa did not consistently appear in successive years.

Differences in water quality were not considered adequate to explain differences in plankton composition between the two storages. The most significant factor possibly is retention time. The plankton of Burrendong resembled that of the larger Murray dams (cf. Hume, Eildon) of longer retention time; short retention time favours the development of short life cycle, rapid breeding species (r strategists, cf. Miracle, 1977). In this

FIG. 5·36 Burrendong Dam.

respect the plankton of Keepit was more similar to the short retention time Lake Mulwala and Goulburn Weir assemblages, described earlier.

River reaches above the Menindee Lakes

During the early surveys of the catchment (Ch. 2), incidental collections were taken from tributaries of the Darling, e.g. the Warrego R. at Cunnamulla, Qld (station 100, Fig. 2.11), the Balonne R. at St. George, Qld (station 104), the Moonie R. near Thallon, Qld (station 106), the Macintyre R at Goondiwindi, Qld (station 105), the Gwydir at Moree, N.S.W (station 107), the Namoi R. at Gunnedah, N.S.W (station 108), the Barwon R. at Mungindi, N.S.W , the Castlereagh R. at Gilgandra, N.S.W, the Macquarie R. at Wellington, N.S.W, (station 111), and the Bogan River at Nyngan, N.S.W. (station 95). Darling R. sampling stations were at Bourke (station 94) and Wilcannia (station 93).

It was not feasible to sample all stations after the early collections; seasonal sampling thereafter was only from the river stations immediately below Keepit and Burrendong and the two Darling stations above the Menindee Lakes. It is worthwhile, however, to mention the features of these headwater reaches which promote a species rich plankton, predominantly tropical forms, which persist into the lower Murray.

Most Darling R. headwater rivers were highly turbid (80-100 NTU) when sampled, unlike those of the Murray. Water temperatures were within the range 13.5-22.0 °C, pH 7.7-8.3, dissolved oxygen 7.5-9.2 ppm and conductivity 110-450 µS. Rivers used for irrigation (e.g. Balonne, Gwydir, Barwon, Namoi) usually were most saline. Because of gentle gradients, flow rates generally were low, although spate conditions occurred in the Warrego and Balonne River in autumn 1978, with a reduction in density and diversity of the plankton. Nutrient levels were not measured, however data from the WRCN indicated that some of the headwater rivers were seasonally eutrophic, e.g. total-P ranges, 1976-78, from the Macquarie R. were .016-.060 mg ℓ^{-1}, and from the Namoi .030 .800 mg ℓ^{-1} (WRCN, unpublished data).

The combination of slow flows, nutrient enrichment and moderate physico-chemical conditions enabled development of an extremely diverse potamoplankton assemblage unlike any recorded from streams and rivers of the Murray catchment. A series of samples taken during autumn 1978 (23/24.v.) are given here as examples.

In the Gwydir R. a 5 x 6 m tow sample contained 31 taxa (H' 3.90). Twenty-seven rotifer species were present (69%), including five species of *Lecane* and three of *Synchaeta*. In the mixture of epiphytic and limnetic taxa, tropical forms predominated, e.g. *K. tropica, F. pejleri, C. cornuta*. On the same day, the plankton of the Barwon River at Mungindi contained 34 taxa [24 Rotifera (43%), 7 Cladocera (11%) and 2 Copepoda (46%)(H' 3.71)], also with several coexisting congeners, e.g. four species of *Brachionus,* four of *Keratella,* two of *Polyarthra,* two of *Cephalodella*. The species composition of the two rivers was remarkably different, although the localities were less than 100 km apart. Of 65 taxa recorded, only eight were shared (12%) by both rivers. In the Gwydir *K. australis* and *K. slacki* were abundant, with *B. urceolaris, S. oblonga* and *F. pejleri* subdominant, while the Barwon dominants were *K. tropica, K. procurva* and *K. cochlearis*, with *B. calyciflorus, S. tremula, F. australiensis* and *F. longiseta* subdominant.

Some 200 km south, on the same day, 11 taxa occurred in the Castlereagh River at Gilgandra. Rotifers predominated, and the abundant taxa were *K. procurva robusta, L. ohioensis,* with *K. slacki* and *F. longiseta* subdominant. More than half the recorded taxa did not occur in the northern rivers. Diversity was similarly high (H' 3.58). Diverse but disparate communities also were recorded from the nearby Macquarie and Bogan Rivers (H' 3.2 and 2.8 respectively).

These discrete assemblages are carried into the Darling River, where slow flows and lack of turbulence reduce loss from the plankton. Collections from the Darling at Wilcannia and Bourke invariably contained an extremely diverse (H' > 3.0) potamoplankton usually dominated by rotifers, with, seasonally, pulses of microcrustacea. Densities generally were low, possibly due, in part, to high turbidities. At Wilcannia in autumn 1977, for example, 60 plankters ℓ^{-1} were recorded. Eleven species were present (4 rotifers, 4 cladocerans and 2 copepods), with *C. cornuta* comprising 65% of the plankton. Diversity was low (H' 1.62). The river was highly turbid (125 NTU, cf. Fig. 5.37) and flow was minimal. The following autumn, with relatively high flows, rotifers predominated. Fourteen rotifer taxa made up 95% of the plankton, with *P. complanata, S. oblonga* and *B. calyciflorus* "Darling form" predominant. Nine cladoceran and one copepod species also were recorded. With the exception of *B. meridionalis*, all cladocerans were littoral in habit (*Alona, Biapertura, Monospilus, Macrothrix, Scapholeberis* spp.). Density and diversity both were low (<5 ℓ^{-1}, H' 1.26). There was a similar rotifer plankton with littoral microcrustaceans in the Darling at Bourke, although, as in other Darling rivers, there were spatial differences in species composition.

The plankton composition of Darling waters above the Menindee Lakes reflected diverse origins, with predominantly cosmotropical and cosmopolitan limnetic assemblages dominated by rotifers transported by the northern tributaries, and mixed pseudoplanktonic/true plankton communities introduced from the smaller tributaries which flow west from the Highlands. While there was a high proportion of eurytopic, widely distributed opportunist species in all headwater rivers sampled, each river contained a discrete block of taxa of restricted distribution, such that the plankton of each influent was distinctive This heterogeneous assemblage is impounded in the Menindee Lakes.

5.3.1.3 The Menindee Lakes (stations 91,92,Fig. 5.38)

Sampling sites in the Menindee Lakes area are shown in Fig. 5.38. Five of the lakes were sampled during initial surveys. Subsequent samples were taken near the Lake Menindee outlet barrier. Morphometric, physico-chemical and other information is included in Table 5.31 and zooplankton composition in Fig. 5.34.

In summary, conditions in Lake Menindee more resemble a river than a lacustrine habitat, i.e. shallow morphometry, throughflow, wind action, little emergent vegetation. In consequence, the plankton does not develop

Fig. 5.37 The Darling River at Wilcannia, N.S.W.

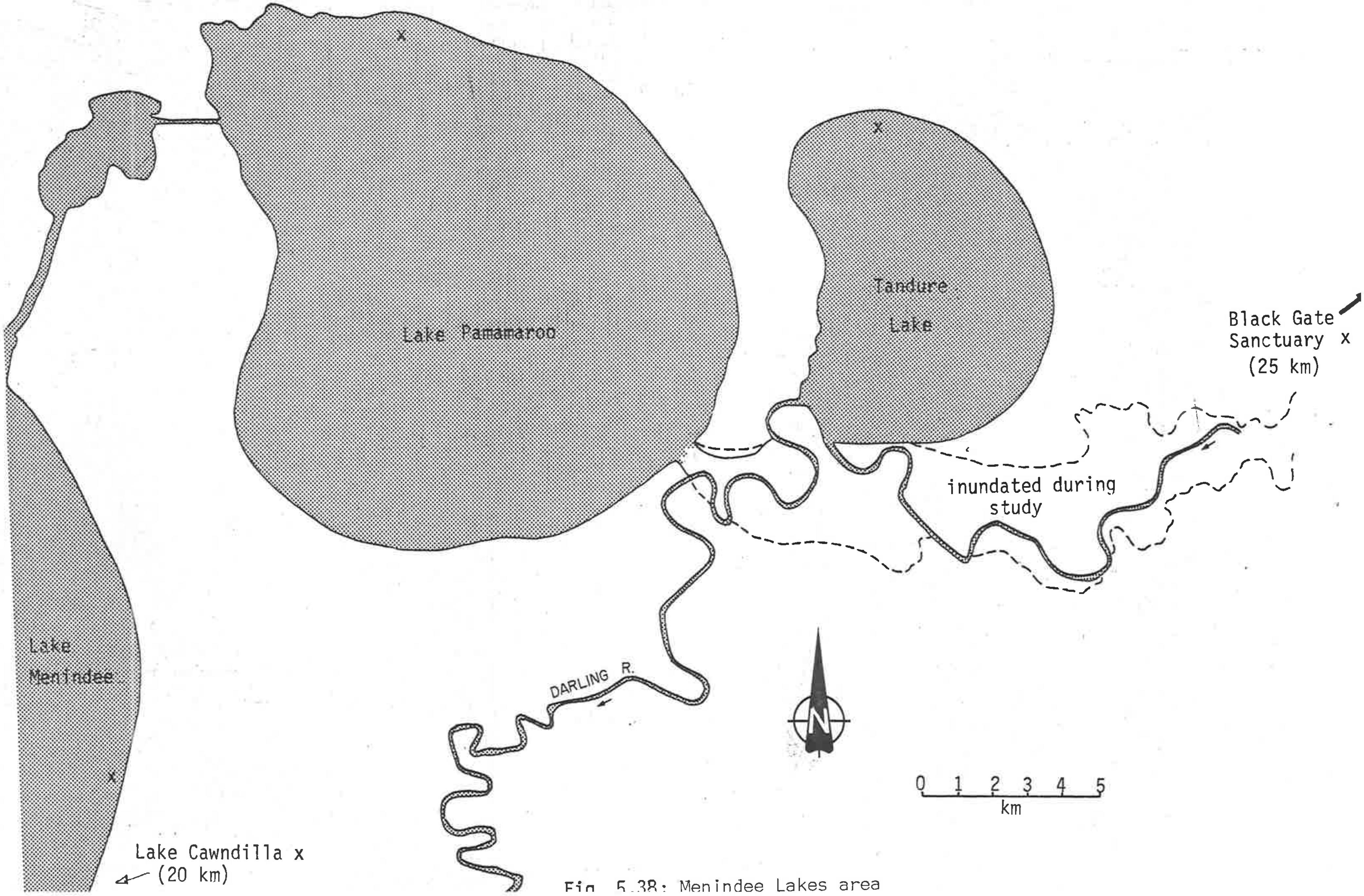


Fig. 5.38: Menindee Lakes area

into a lacustrine assemblage, but retained the features of the Darling R. community, i.e. dominated by rotifers and calanoid nauplii. In autumn 1978, for example, of 23 taxa collected, 18 were rotifers, comprising 87% of the plankton. Four species of *Filinia* were numerically abundant, with *B. angularis* and *K. australis* subdominant. As in the river, cladocerans present were littoral taxa (*Alona, Biapertura, Monospilus, Ilyocryptus*). Copepods (*B. triarticulata, C. lucasi*) were sparse. The following summer, *K. australis* and *Filinia* spp. predominated.

Diversities were uniformly high (e.g. $\bar{x}$ H' 2.76 for Lake Menindee), a result of mixing by currents and wind action. Population densities were low ($<30\ \ell^{-1}$) in collections from most lakes. A single exception was Malta Lake (Black Gate Sanctuary, Fig. 5.38), where a shallow (10 cm) pool was left when water was released on 22.v.78. A dense population of *B. calyciflorus* "Darling form" and *B. novaezealandia* tinged the water white. High turbidity (220 NTU) largely was due to the rotifers. Shallowness prevented collection of a volume sample. Neither species occurred in other nearby lakes at the same time.

The Darling River Downstream of Lake Menindee

Seasonal collections were taken from the Darling at Pooncarrie and Wentworth. The following physico-chemical ranges were recorded from Wentworth: water temperature 10.5-18.5, pH 7.8-8.4, dissolved oxygen 9.0-10.0, conductivity 190-230 µS, turbidity 220-350 NTU.

Phytoplankters were sparse in all collections, and possibly were limited by high turbidity. Zooplankton density was greater than phytoplankton density at both lower Darling stations [$\bar{x}$ zooplankton density at Pooncarrie was 45 ℓ^{-1}, and at Wentworth 62 ℓ^{-1} (n=5)]. Densities were uniformly higher than in Lake Menindee, and increased further downstream.

The species composition of the lower Darling plankton was exceptionally diverse , and resembled that of Lake Menindee and the upstream reaches, i.e. an assemblage dominated by rotifers. In spring 1976, for example, *K. australis* and *C. dossuarius* comprised 54% of the plankton. In autumn 1977, releases and high flows from the lakes decimated the plankton; only one or two individuals of *B. meridionalis, M. spinosa* and *B. triarticulata* were recorded. In the autumn of 1978, 33 taxa were collected (27 rotifers, 69%; 5 cladocerans, 5%; 1 copepod,27%) with *S. longipes, F. australiensis* and *F. longiseta* dominant, *K. australis, P. vulgaris* and copepodites subdominant (density 44.2 ℓ^{-1}, H' 3.18). In spring 1978 *K. australis* again was numerically dominant (8 spp. in plankton, 27 ℓ^{-1}, H' 1.97). Autumn 1979 collections produced 42 taxa in the Darling plankton: 32 rotifers (with 5 spp. of *Filinia*, 6 spp. of *Brachionus*, 2 of *Hexarthra* and 2 of *Synchaeta* numerically abundant) made up 74% of the plankton, copepodites made up 24%, and cladocerans were a minor component (density 80 ℓ^{-1}, H' 3.66).

In summary, the potamoplankton of the Darling River is derived from headwater reservoirs, sluggish reaches of tributary streams, and from floodplain bodies of water in time of flood (see Ch. 6). Slow flows and minimum turbulence enable this diverse assemblage to persist into the Murray. The influence of barrages, weirs and short term impoundment in the Menindee lakes apparently was minimal on the composition of the potamoplankton. Because of slow flows and moderate conditions, it is likely that several generations of plankters would occur between the headwaters and the confluence, i.e. there was an autochthonous and distinctive Darling R. zooplankton, a typically riverine assemblage dominated by Rotifera, the principal species of which were endemic eurytopic forms and cosmopolitan/cosmotropical warm water taxa. The paucity of phytoplankton was possibly due to characteristically high turbidities, which in turn could account for the absence of obligate herbivores from the river plankton, i.e. those species which persist can utilize the high levels of organic detritus in suspension which were characteristic of Darling flows. As in the Murray rivers, density and diversity of plankton increased downstream, as incursion species were flushed into the river. In general, densities in the Darling were lower, and diversities higher, than in the Murray. The selective loss of some of these taxa in the lower Murray is considered in Ch. 7.

5.4 Concluding remarks

The limnoplankton of selected impoundments, and the river plankton downstream of them, has been considered for rivers of the Murray and Darling basins. Although the size of the sampling area precluded intensive sampling of all reservoirs, the distinctive nature of each storage is apparent. The contribution of the headwater reservoir limnoplankton to the potamoplankton was variable, but generally small, depending largely on volume flows, i.e. velocity, turbulence and hypolimnetic release from deep storages were inhibitory to the potamoplankton. As elsewhere, slow flowing reaches and shallow impoundments downstream allowed the plankton to reconstitute. The plankton of the Murray tended to resemble a limnoplankton, while that of the Darling was a true riverine plankton. In both rivers, colonist species often were not those of upstream impoundments, but limnetic species from marginal lentic habitats, e.g. billabongs. These taxa persisted in downstream storages such as Mulwala and Goulburn Weir. A high proportion of these colonisers were pseudoplankters, non-limnetic taxa occurring in open water during algal blooms. These blooms, particularly of diatoms, supported a diverse zooplankton assemblage. Densities generally were low, although comparable to those reportec elsewhere (discussed further in Ch. 7). Greatest density and diversity in most habitats occurred in spring and autumn. Depending on releases from the upstream impoundments, the contribution of the Murray system to the lower Murray varied from a lacustrine plankton dominanted by microcrustacea, to a plankton dominated by Rotifera. The latter assemblage comprised true limnoplankters and facultative forms which predominated in the shallow storages. The mixing of this reservoir plankton with the riverine plankton from the Darling is considered in Ch. 7. The nature of the billabong plankton and its contribution to the river system is considered further in Ch. 6.

POSTSCRIPT: Data on L. Cullulleraine was to be included in Ch. 7. As it is more approproate to include here, the plankton assemblage of the lake is given in Fig. 5.39 for comparison only. Species dominants were those of the lower Murray, from which the storage is filled (*K. australis*, *B. meridionalis*).

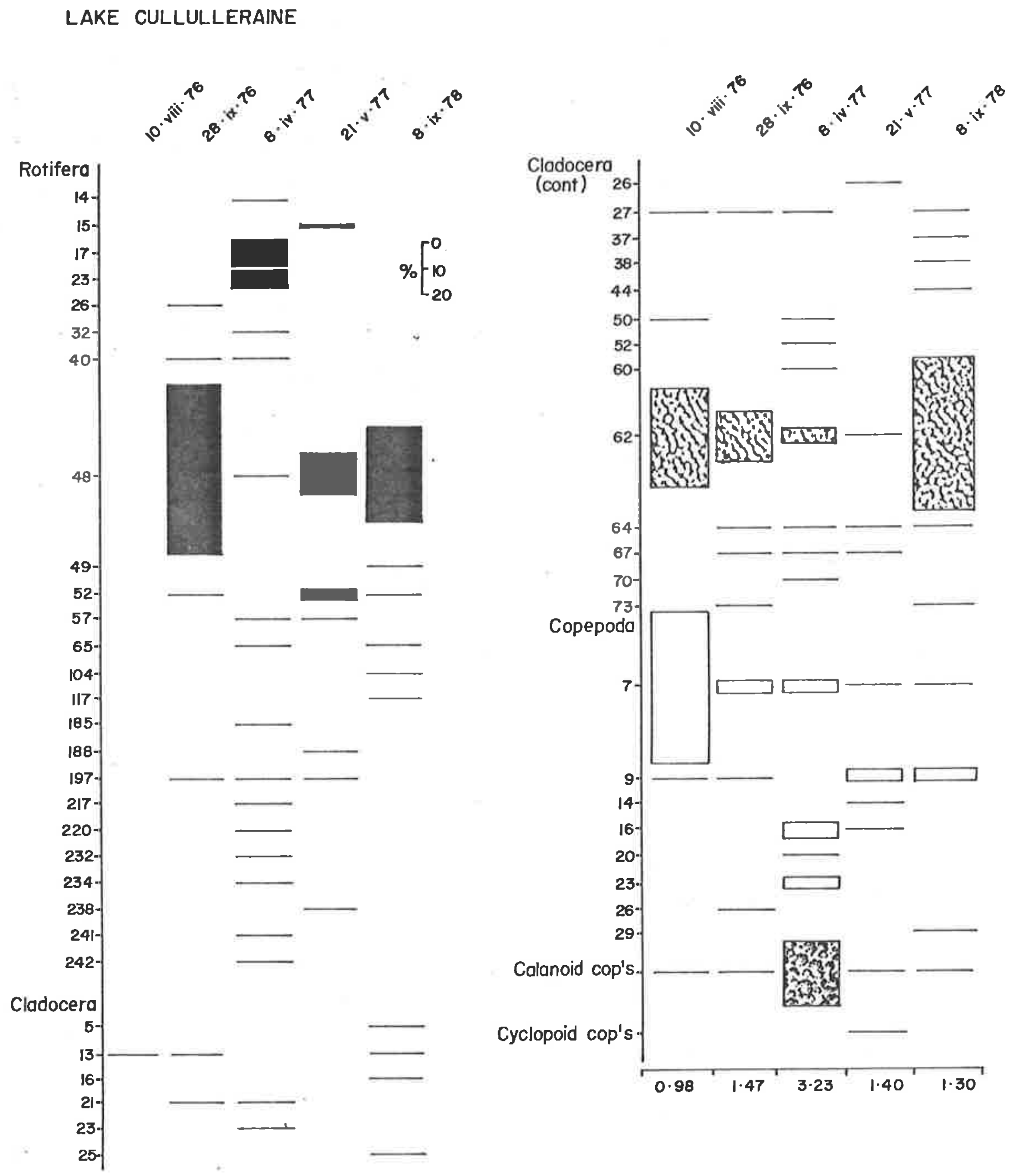


FIG. 5. 39 Lake Cullulleraine : Temporal variations in limnoplankton composition

6. FLOODPLAIN HABITATS - THE PLANKTON OF BILLABONGS

6.1 General Introduction

The first major reviews of studies on river ecology made scant reference to the importance of the floodplain to the river ecosystem (e.g. Hynes, 1970; Whitton, 1975). In a review of riverine fisheries, Welcomme (1979) summarised morphological, hydrological and biological features of floodplains. Despite the wide range of examples given, Australian rivers were not included.

Welcomme classified perennial rivers as flood or reservoir rivers, noting that many of the former had been transformed into reservoir rivers by impoundment. While few of the Murray-Darling rivers are perennial, their morphological features and hydrologic regimes are those of flood rivers. Impoundment, of the Murray particularly, has irreversibly modified these features (Walker, 1980), with concomitant effects on plants and animals adapted to a flood-drought regime.

A feature of flood rivers is their variability of flow, with seasonal submergence of the fringing floodplain and, occasionally, scouring and flushing of adjacent lentic habitats. Abrupt and extreme fluctuations in water chemistry may occur. Such variability is pronounced in the Murray rivers, where vagaries of climate limit the seasonal cycle seen in other temperate river systems. Droughts of several years may be followed by peak flows and flooding for extended periods. The exceptionally low declivity of the basin prolongs floods, decreases flow rates and thereby minimises the scouring effects of increased volume flows. Marginal lentic habitats along the Murray rivers tend, therefore, to be slowly inundated, and deleterious effects of throughflow are reduced.

Although a discussion of morphological features of floodplains is beyond the scope of this thesis, it is worthwhile noting here that the habitats studied during this project are all of one type: cut-off meanders or ox-bow lakes, colloquially termed billabongs. This term, of aboriginal derivation, includes also backwaters of perennial rivers, pools left in the bed of ephemeral streams, and natural depressions in the floodplain filled by receding floodwaters.

Such habitats adjacent to rivers are distinctive for their morphological, physico-chemical and biological heterogeneity (Walker & Hillman, 1977; cf. Welcomme, 1979; Shiel, 1980). They have in common their dependence on the flood regime for water and nutrient replenishment, although some may be below the water table, derive water from seepage, and be relatively permanent. Manipulation of the hydrologic regime by impoundment may have devastating effects; the floodplain is lost for spawning and breeding, hydraulic, temperature and flow regimes are altered, and major changes may be induced in erosion and deposition cycles and vegetation patterns (cf. Welcomme, 1979). The disruption of environmental cues to aquatic organisms may have profound effects on the ecosystem.

Prior to the AWDC study (Ch. 5), little was known of the effect of impoundment on the flood-dependent ecology of Australian rivers. Obstruction to fish movement was noted by Langtry in 1949-50 (Cadwallader, 1977). The deleterious effects of lowered temperatures and regulated flow on downstream fish populations were described by Weatherley & Lake (1967) and Lake (1967, 1971) provided evidence of the adaptations of riverine fish species to flooding, which stimulated reproductive behaviour. Spawning occurred in the billabongs and sheltered waters of the floodplain, and these were nursery areas for the developing fry (see also Butcher, 1966; Williams, 1967; Cadwallader, 1978; Dexter, 1978).

Other studies on the biology of the extensive billabongs tracts are few. There are naturalist records of frogs breeding in response to flooding along the Darling River (Russell, 1886; Fletcher, 1893). In a study on the ecology of ducks associated with Murray waters, Frith (1959) showed that plankton production in inundated areas of the floodplain was proportional to the area flooded. With reduced flooding, concomitant decreases in the density of plankton adversely affected planktivorous fish. Plankton communities of a flooded billabong on the Goulburn River were described by Shiel (1974, 1976). Density and diversity of the plankton increased in proportion to inundation, breeding apparently was triggered by flooding, and plankton communities were remarkably little affected by prolonged throughflow. Flow rates were low, and community stability was preserved by sheltering reedbeds. In contrast, high velocities in billabongs of the Magela Creek, N.T. were deleterious to the zooplankton, which was flushed out during the wet season (R. D. Tait, Pancontinental Mining Ltd.,Darwin, pers.comm.). During the AWDC study, the importance of billabongs as breeding and refuge areas, was noted (Walker & Hillman, 1977). Extant information on billabongs of the Murray-Darling system was reviewed by Shiel (1980*).

To provide comparative information on the microfauna of billabongs and its relationship to the riverine plankton, two billabong tracts of the River Murray system were sampled during this study. In addition, samples were collected from billabongs on floodplains of Darling tributaries. Several collections made outside the Murray-Darling basin permit comparisons with latitudinally separated communities. Studies on the plankton of floodplain habitats elsewhere include those of Holden & Green (1960), Green (1962, 1972a, b), Binford (1978) and Marsh, McGraw & Harrel (1978). Others are cited by Welcomme (1979).

6.2 Billabongs of the River Murray between Hume Reservoir and Yarrawonga

6.2.1 Introduction

The floodplain below Hume Reservoir near Albury-Wodonga (Fig. 6.1) has more extensive anabranches and billabongs than most other Australian floodplains. At least 190 discrete billabongs occur between Hume and Mulwala, a distance of 200 river km (Shiel, 1980). Many of these have been markedly influenced by the modified flow regime following construction of Hume Dam, and others have been subjected to a variety of stresses: draining and filling

* this paper is bound in support, Appendix 3, p.235.

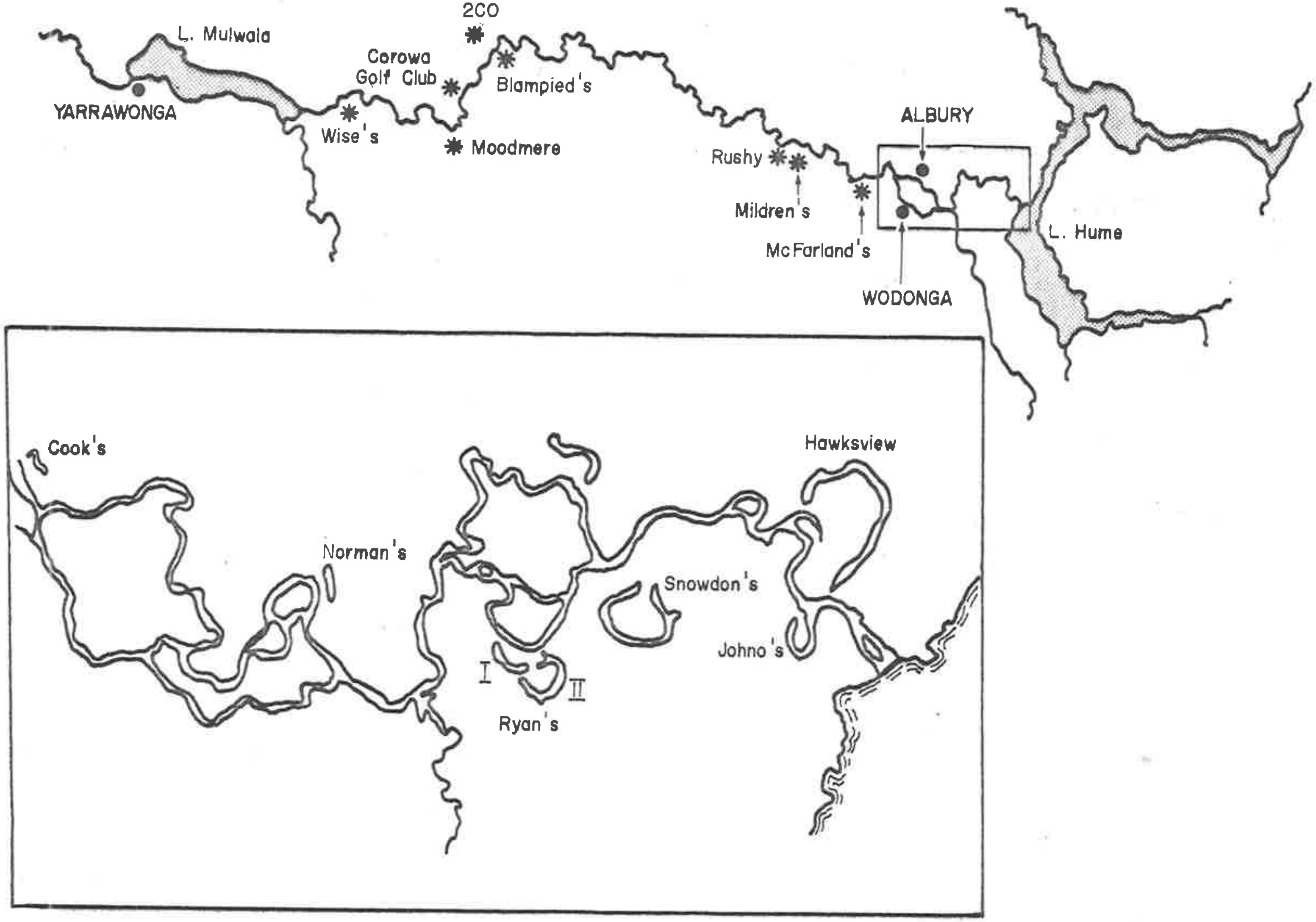


FIG. 6·1 Billabong sampling sites: River Murray floodplain between Hume and Mulwala.

Fig. 6.1b: The R. Murray floodplain below Hume Reservoir; view of area near Albury-Wodonga shown in inset, Fig. 6.1a.

for urban or agricultural use, for effluent disposal, stock, agricultural and domestic water supply, and use as waste stabilization ponds. Disruption of community ecology due to establishment of introduced species also is apparent (Walker & Hillman, 1977).

The AWDC study stressed that the billabongs are an integral part of the river ecosystem, serving as breeding refuges for most of the riverine species, and habitat for a prolific variety of organisms. Some preliminary information was reported, but there was no detailed study.

In the present study, a series of billabongs was sampled to characterize the planktonic and littoral microfauna, and to relate changes in community structure to environmental variables. Of particular interest were the interactive association with the river and the influence of habitat management. Plankton collections taken during the AWDC study were made available. Further collections and environmental measurements were made during 1977-79, enabling a more comprehensive treatment of the microfauna than was possible during the AWDC study, or would otherwise be feasible in this study. Comparison with an earlier study (Shiel, 1976), with the longer term AWDC program and with work on floodplains elsewhere would help clarify the ecological character of billabongs. Also, although interest was directed specifically towards the plankton, incidental observations were made on aspects of morphology, hydrology and biology.

Because of variation in sampling intensity it is convenient to treat the billabongs comparatively. Three relatively undisturbed billabongs monitored during the AWDC program were sampled more intensively during the present study (Ryan's I and II and Snowdon's). These are given as examples, with comparisons drawn from other billabongs to emphasize the environmental and biological heterogeneity encountered within and between individual billabongs.

6.2.2 Sampling sites

The sixteen billabongs sampled are shown in Fig. 6.1. Names are generally those of the property owner. Proximity to the AWDC laboratory facilitated sampling several billabongs in the Bandiana area between Hume Dam and the Kiewa confluence.

6.2.3 Billabong morphology and distribution

General views of some of the sites are given in Fig. 6.2, with comparative outlines shown in Fig. 6.3. Proximity to the present river course also is shown. All billabongs sampled were less than 1 km from the river. Two (Johno's Swamp and Wise's) were connected to the river at times, but there was no major flooding during 1976-79. Most have the typical elongate crescentic form of cut-off meander loops, up to several km long, but generally less than 100 m wide. Those with macrophyte growth across the bottom (e.g. Snowdon's) were less than 2 m deep. Seasonal die-off of such macrophyte growth contributes to the filling of the billabong; in some cases the bottom material consisted of 50-80 cm of black organic mud or fine silt. Eventually swamplands form, as along the Lachlan River and the eastern coastal plain (Goodrich, 1970), and the billabongs may fill completely. Their outline may, however, still be evident in aerial photographs.

Photographs were used to calculate the surface areas of billabongs and river tract in the 10 km section between Hume Dam and the Kiewa confluence. The simple expedient of tracings on squared paper was used. Some 51% of the water surface was occupied by billabongs, with a range of 35-50% for representative floodplain tracts downstream. In comparison, a range of 5-59% of the flood area of African floodplains is occupied by permanent water (Welcomme, 1979). The ecological significance of this large area of sheltered waters will be discussed later. Contrasts with Goulburn billabongs (see 6.3) relate to differences in floodplain morphology and river hydrology.

6.2.4 Physico-chemical features

As for small, shallow habitats elsewhere, there is considerable environmental variation within and between individual billabongs (Shiel, 1976; Walker & Hillman, 1977). Contributing factors include proximity to and differences in hydrologic and hydraulic effects of the parent stream, differences

Fig. 6.2: Comparative views of two of the Albury-Wodonga billabong series. Top: Ryan's I; Bottom: Snowdon's.

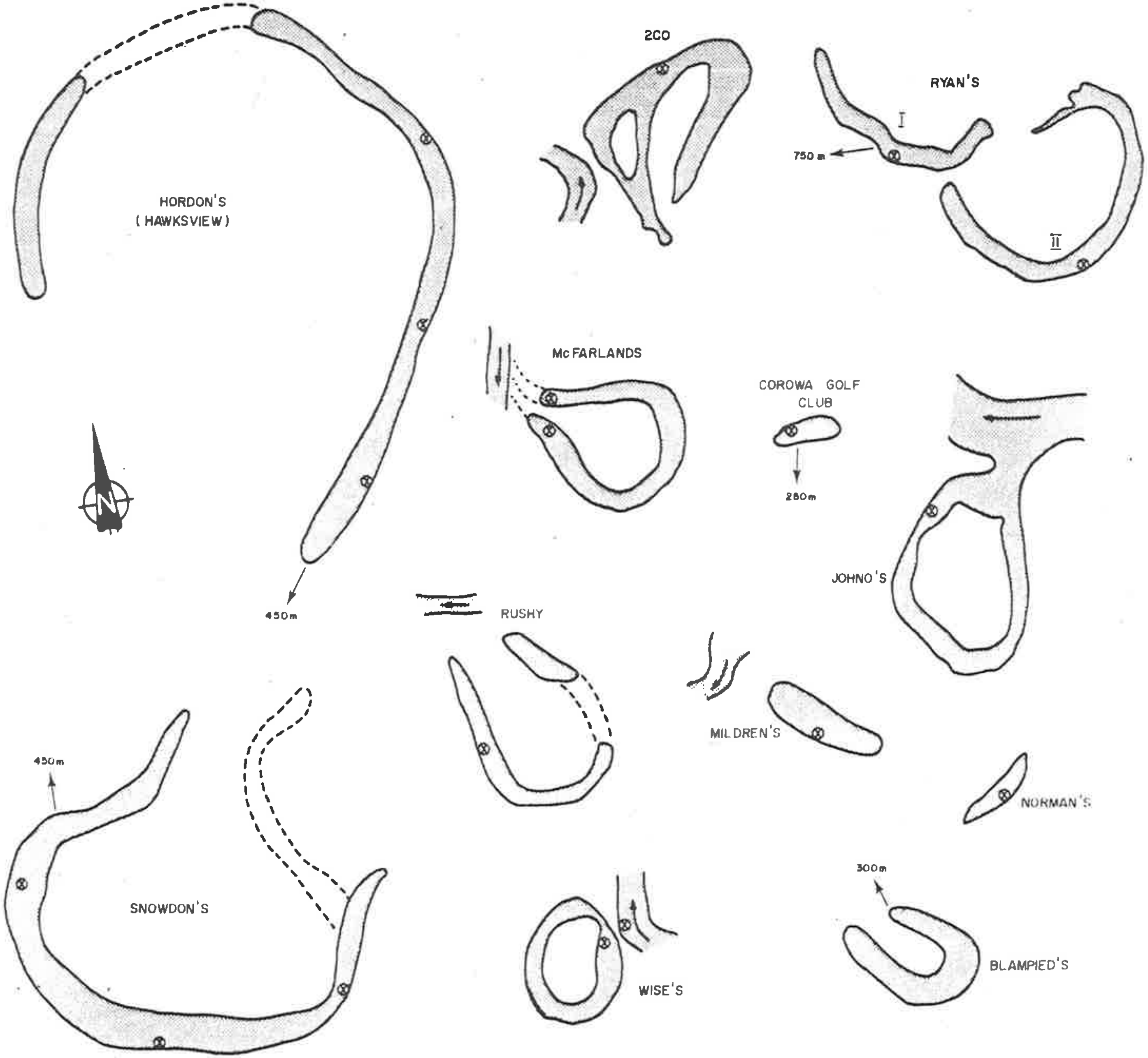


FIG. 6.3 River Murray billabongs between Hume and Yarrawonga. ==== not inundated during study

in latitude, altitude, climate, flood frequency and seasonality, catchment size, vegetation, nutrient sources and land use. Cattle grazing, for example, can provide a significant proportion of allochthonous nutrient inflow to a billabong (cf. Shiel, 1976; Welcomme, 1979). Examples of some of these influences are given in the following sections, which follow the format of Shiel (1980). A summary of water quality data from the billabongs is given in Table 6.1. Seasonal fluctuations in some physico-chemical characteristics in Snowdon's, Ryan's I and Ryan's II are shown in Fig. 6.4.

6.2.4.1 Light penetration

Billabongs are typically clear, with light penetration to the bottom, unlike farm dams, which generally have clay surrounds and are subject to high turbidities (Tait, 1976; Timms, 1977, 1980). Marginal vegetation and grassed floodplains tend to reduce particulate inflow, although floodwaters may reduce transparencies (Shiel, 1980). Considerable variation in transparency occurred between billabongs on any sampling date; in general, more exposed billabongs with little marginal vegetation or subject to stock use, e.g. Mildren's, were more turbid than sheltered billabongs with extensive macrophyte growth, e.g. Snowdon's.

Biogenic influences accounted for most seasonal increases in turbidity in the three principal study sites (Fig. 6.4a). Summer algal blooms occurred in 1976-77 and 1977-78. Blooms in Ryan's I and II were asynchronous, and consisted of the blue-green alga *Anacystis cyanea*. *Volvox* was the predominant alga in the December 1977 pulse in Snowdon's.

6.2.4.2 Temperature

Water temperatures tended to follow air temperatures. Slight differences between adjacent billabongs (cf. Fig. 6.4b) generally were attributable to differences in sampling time. Depressed temperatures resulting from river inflows were recorded from Johno's ~~s~~ Swamp, below Hume Dam, and Wise's billabong, near Mulwala. Slight horizontal temperature differences within a billabong (0.5-2.0 °C) were due to the insulating effects of vegetation. Ranges (Table 6.1)

Table 6.1: Ranges of some measured water quality characteristics from Murray billabongs (present study and AWDC unpublished).

Billabong	n	°C	pH	DO%	µS	NTU
Hawksview	19	10.1-20.1	7.2-7.9	5- 135	50-180	3.0-17.5
Ryan's I	92	7.2-27.7	6.8-9.25	15-133	62-224	3.1-44.0
Ryan's II	88	6.0-28.0	4.2-9.0	9-132	133-1978	3.4-54.0
Snowdon's	83	6.8-25.0	6.8-7.8	9-109	226-827	2.6-31.0
Mildren's	10	9.0-24.5	7-1-7.6	15-104	145-324	5.0-52.0

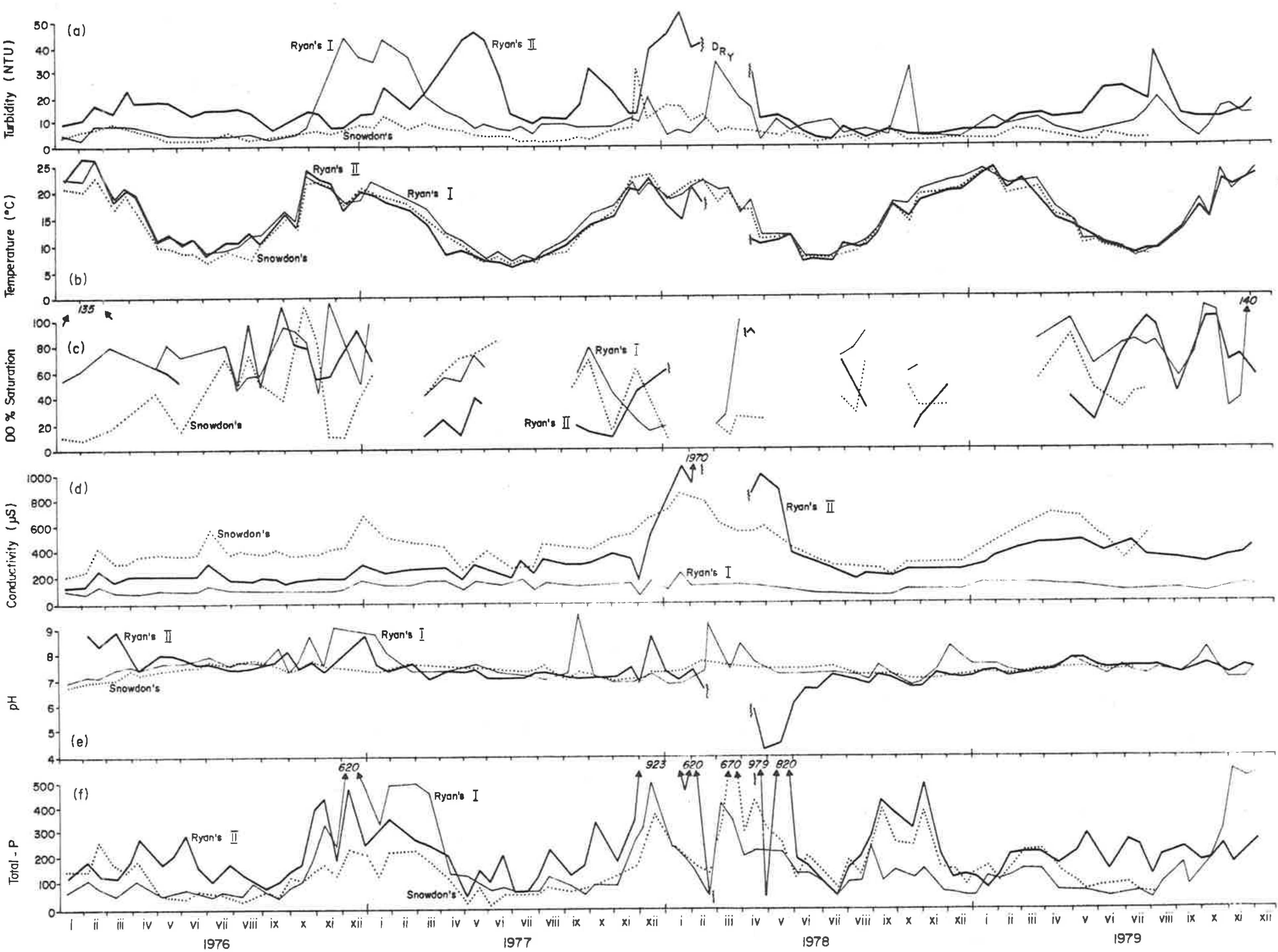


FIG. [illegible] chemical characteristics in three billabongs at Wodonga, Victoria, 1976–79 were in accord with those reported elsewhere for similar habitats (Shiel, 1976; Walker & Hillman, 1977).

6.2.4.3 Dissolved oxygen

DO levels were not consistently recorded during the AWDC study, nevertheless Fig. 6.4c shows the extreme variability of oxygen concentrations between adjacent billabongs and within a single billabong over time. Extreme local conditions may result in anoxia in one billabong, while another, less than 50 m away, may have supersaturation. Within a shallow billabong there may be anoxia at the mud/water interface, with supersaturation at the surface below a floating *Azolla/Lemna* layer (see 6.3.4.3). Algal blooms account for supersaturation levels, die-off and decomposition result in anoxia.

6.2.4.4 Conductivity

Fluctuations in salinity related to rainfall, flooding and drying out over summer. Autumn and winter rains produced small increases in salinity in most billabongs sampled. Marked increases occurred over the dry summer of 1977-78 (Fig. 6.4d) when several billabongs dried out (e.g. Ryan's II). Ryan's I was maintained at full level over this summer by pumping from the river; fluctuations were minimal. At other times localised differences in conductivity possibly resulting from land use differences, were apparent, e.g. Snowdon's was consistently the most saline (cf. Walker & Hillman, 1977).

6.2.4.5 pH

With few exceptions, pH was in the range 7.0-8.0. Only in Ryan's I and II were extremes recorded (Fig. 6.4e). During the *Anacystis* bloom in 1976-77 the pH rose to 9.0, with a lag in Ryan's II coincident with the later algal peak. Similar asynchrony occurred the following spring-summer, although somewhat earlier, with a pulse in Ryan's I followed by a pulse in Ryan's II. The latter billabong dried out over the summer of 1977-78. Following autumn rains, the pH (4.2) was the lowest recorded for any billabong in the study area. Release of organic acids from decaying macrophytes is a possible cause. The subsequent two summers were comparatively wet, blooms were less pronounced, and fluctuations in pH were less marked.

6.2.4.6 Major ions

Cations generally were in the order Na > K $\gtrless$ Ca > Mg, anions in the order HCO_3 > Cl > SO_4. Adjacent billabongs often had marked differences in ionic proportions (cf. Table 6.1). While cation dominances generally were typical for Australian waters (Williams, 1967), anions were not; bicarbonate waters were relatively common (cf. Williams & Wan, 1972).

6.2.4.7 Nutrients

Nitrate and phosphate levels were monitored in Snowdon's and Ryan's I and II during the AWDC study (Fig. 6.5). Fluctuations in total-P 1976-79 are shown in Fig. 6.4f. Nutrient levels over the four years were extremely variable, e.g. a range of <2-302 mg N/m^3 occurred in Snowdon's, with tenfold increases in summer 1976-77 and 1977-78. Corresponding values for Ryan's I and II were <2-915 and <2-529 mg N/m^3 respectively, with peaks in autumn-winter. Phosphorus levels were as follows: Snowdon's 11-678 mg P/m^3, Ryan's I 40-624 mg P/m^3 and Ryan's II 48-979 mg P/m^3 (AWDC unpublished). Maxima were in summer, with an additional peak in Ryan's II in 1978 following filling.

Nutrient levels at most times were indicative of eutrophy (Walker & Hillman, 1977). Both allochthonous factors (local rainfall, differing intensity of cattle grazing/land use, pumping from the river) and autochthonous factors (concentration by drying over summer, algal and macrophyte die-off) contributed to the high and variable nutrient levels. Similar general trends were apparent in other billabongs in which N and P levels were measured during 1979 by the AWDC, e.g. Rushy, Hawksview (AWDC, unpublished data).

Notably, no significant correlations could be found between rainfall and any measured variable.

6.2.5 Biological features

6.2.5.1 Phytoplankton

There has been no comprehensive survey of the phytoplankton of billabongs. A preliminary list of genera from a Goulburn billabong was provided by Shiel (1980). This is expanded in section 6.3.5.1. The AWDC

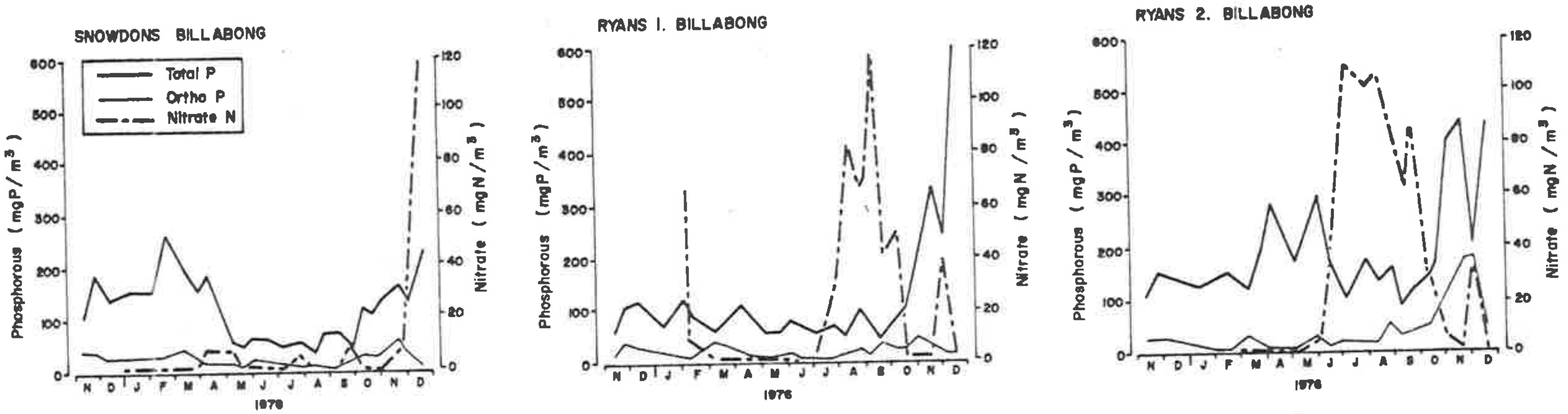


FIG. 6·5 Fluctuations in Phosphate and Nitrate levels during 1976 in Snowdons, Ryans I and Ryans 2.
(Redrawn from Walker and Hillman 1977)

study noted only the occurrence of *Anacystis* blooms in Ryan's billabongs. Similarly, in this study, the only taxa identified from Murray billabongs were those producing blooms. Algal communities of Goulburn billabongs apparently were more complex; these are discussed in more detail later.

Additional to the summer blooms of *Anacystis* in Ryan's I and II, blue-green blooms were noted in 8-Mile Creek, Norman's and Wise's (autumn, 1979). *Volvox* blooms in excess of 10^3 colonies ℓ^{-1} occurred in autumn 1976 (Ryan's I), autumn 1977 (Mildren's), spring 1978 (Snowdon's, Hawksview) and summer 1979 (Mildren's). In Hawksview, the bloom was localised near an influent from a trout hatchery; colonies were sparse elsewhere in the billabong.

Pulses of *Spirogyra* were recorded in autumn-winter 1976 in Snowdon's and Ryan's I, and a pulse of filamentous diatoms occurred in Ryan's II in spring 1977. Other phytoplankters identified were largely of the same genera as recorded from Goulburn billabongs, although species composition differed (see 6.3.5.1). Autumn pulses of the dinoflagellate *Ceratium* occurred in several billabongs, e.g. 1977,1978 (McFarland's) and 1979 (Mildren's).

6.2.5.2 Hydrophytes

The variability of hydrophyte development in billabongs is seen in Fig. 6.2. Adjacent billabongs may have different species dominants, community structure and seasonal succession. Nevertheless, there is characteristically a diverse assemblage of emergents (e.g. *Eleocharis, Juncus*), submergents (e.g. *Myriophyllum, Vallisneria*) and free-floating plants (e.g. *Azolla, Lemna, Riccia*). Contrasts in community composition are shown in Table 6.2, which lists 19 hydrophyte taxa recorded from a Goulburn billabong (Shiel, 1976) and 19 from Snowdon's and Ryan's billabongs (Walker & Hillman, 1977). Only three species were common to both areas, despite relatively close geographical proximity (≃ 160 km).

Although different in species composition, these hydrophyte communities provide similar resources of living space for micro- and macrofauna. Niche

Table 6.2 Macrophytes associated with billabongs at Wodonga and Alexandra. + present.

Species	Common name	Wodonga	Alexandra
Agrostis avenaceae	bent grass	+	
Alternanthera sp.	alligator weed	+	
Azolla filiculoides	Pacific azolla		+
A. pinnata	ferny azolla	+	+
Brasenia schreberi	water-shield	+	
Callitriche umbonata	starwort		+
C. stagnalis	common starwort		+
Ceratophyllum demersum	hornwort	+	
Chara australis	stonewort		+
Crassula helmsii	swamp Crassula	+	
Cynodon dactylon	Bermuda grass	+	
Eleocharis sphacelata	tall spike-rush	+	
Elodea canadensis	Canadian pondweed	+	
Gahnia clarkei	saw-sedge		+
Juncus ingens	rush	+	+
J. subsecundus	rush	+	
Lemna minor	common duckweed		+
Lolium rigidium	rye grass	+	
Ludwigia pepliodes	water primrose	+	
Myriophyllum propinquum	common water milfoil	+	+
M. elatinoides	coarse water milfoil		+
Nitella sp.	muskgrass	+	
Polygonum minus	—		+
P. lapathifolium	willow smartweed	+	
P. strigosum	—		+
Potamogeton ochreatus	blunt pondweed		+
P. tricarinatus	floating pondweed	+	
Ranunculus rivularis	small river buttercup		+
Riccia fluitans	liverwort		+
Ricciocarpus natans	—		+
Triglochin procera	water ribbons		+
Senecio aquaticus	marsh ragwort		+
Spirodela oligorrhiza	thin duckweed		+
Utricularia sp.	bladderwort	+	
Vallisneria gigantea	eel grass or ribbon weed	+	

(from Shiel, 1980)

specificity in such communities has been demonstrated by Quade (1968, 1971), Shiel (1976) and Walker & Hillman (1977). In the latter study, distinct microcrustacean assemblages were associated with different macrophytes in Johno's, Ryan's and Snowdon's billabongs, and were not recorded from open water. Conversely, the open water plankton did not occur in weedbeds. Limnetic species commonly occurred in flooded reedbeds during Shiel's study, i.e. were sheltered by vegetation from the effects of throughflow.

Clearly, the direct relationship with hydrophyte species diversity and abundance accounts, in part, for the contrasts between billabong zooplankton communities. In billabongs with a diverse assemblage of hydrophytes (> 20 spp.), the array of spatially discrete microhabitats available for colonization is immense. Predictably, therefore, billabongs support a diverse, if not unique, assemblage of micro- and macroinvertebrates.

6.2.5.3 Zooplankton

Collections of zooplankton from open water in billabongs invariably contained littoral species, due to the occurrence of floating and submerged vegetation. Summer collections particularly had a high proportion of "strays". At times open water was not present, and nets sampled submerged vegetation. Of necessity, therefore, littoral and pseudoplanktonic taxa were included in counts and diversity calculations from open water collections, which makes difficult generalizations about a specific limnetic community. There was, however, a readily distinguished "block" of limnoplankters in each billabong, with varying proportions of non-planktonic incursions depending on the proximity to, and community complexity of, fringing hydrophyte beds.

The discrete nature of each habitat is reflected in the structure of the zooplankton community. On any sampling date there were different species dominants, population densities and community diversity in even adjacent billabongs. In the larger billabongs, e.g. Snowdon's, such differences were apparent in different hydrophyte beds. Fig. 6.6 shows community composition of the open water plankton in 13 billabongs on the same day (05.ix.1978).

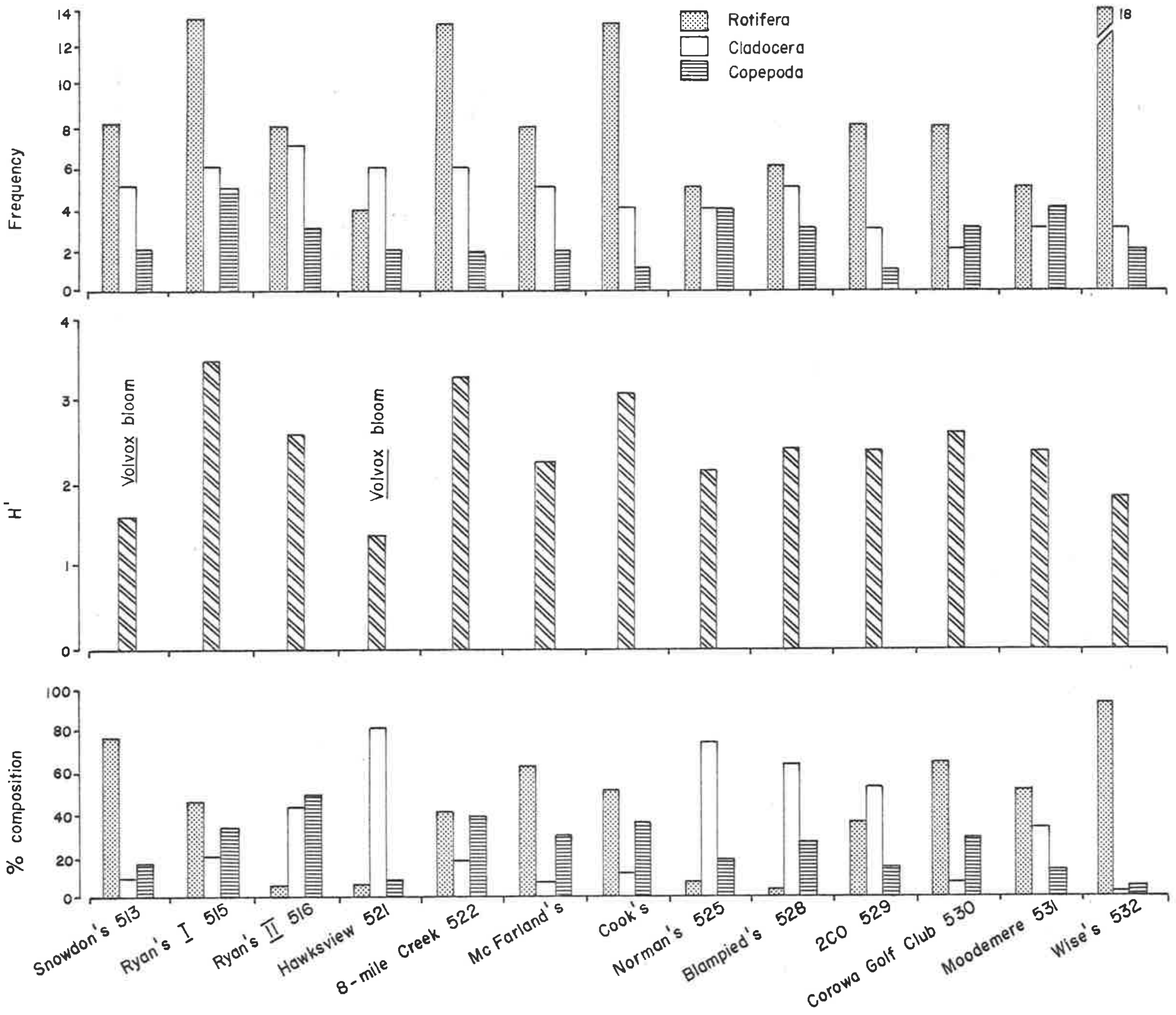


FIG. 6·6 Limnoplankton assemblages in 13 River Murray billabongs, Spring 1978

The number of species in each group, per cent composition and H' are shown. Ostracods, which occurred in small numbers in several samples, are not included. Raw data from all collections are included in appendices. Table 6.3 includes pertinent information.

Although the following observations refer specifically to the comparative data in Fig. 6.6 and Table 6.3, similar trends were apparent in most billabongs. Spatial heterogeneity in community composition was marked. Although rotifers tended to be most abundant in species numbers, they were not always numerically dominant. Rotifer species numbers were higher in the four billabongs in which throughflow could be detected on the sampling date (Ryan's I, 8-Mile Creek, Cook's and Wise's). The influence of current is apparent; a higher proportion of non-planktonic taxa than in billabongs without flow were recorded in three of these. Wise's had little emergent or submerged vegetation at that time; all 15 rotifer species present (94% of the plankton) were pelagic in habit. Similarly for microcrustacea, a higher proportion of littoral species occurred near weedbeds. In the absence of hydrophytes, true limnoplankters were numerically abundant (*B. meridionalis, C. quadrangula, D. lumholtzi, M. leuckarti, B. fluvialis*).

There was a remarkable disparity in species composition between billabongs. Eighty-five taxa occurred in the spring 1978 samples, but only six of these occurred widely. These were the eurytopic *K. australis, K. procurva, K. slacki, B. meridionalis* and *C. quadrangula*, and the more restricted calanoid, *B. fluvialis*. Several other taxa occurred in 3-5 billabongs, but most were recorded from single habitats. Congeneric associations were common, e.g. 3-4 species of *Keratella*. Although the same genera were present in most billabongs, species composition differed, accounting for the generally low similarities shown in Table 6.4, which gives CC values for the September 1978 data. A similar disparity in species composition between adjacent habitats is reported from meander lakes of the Rio Suia Missu, Brazil (Green, 1972).

	# species	% planktonic	dom. group	Major taxa	Subdom. taxa	Comments
Snowdon's	16	75	R	*Gastropus* (44%)	copepodites, *Bosmina*	Volvox bloom
Ryan's I	24	43	R	*Synchaeta*, *Keratella*	copepodites	Volvox bloom, throughflow.
Ryan's II	19	58	Co	*Chydorus*, copepods	*Ceriodaphnia*	
Hawksview	13	69	Cl	*Ceriodaphnia* (95%)	*Boeckella*	dense *Volvox* bloom
8-Mile Ck	21	52	R/Co	*Conochilus*, copepods	*Daphnia*	throughflow
McFarland's	15	87	R	*Trichocerca*, copepods	*Keratella*	[illegible]
Cook's	19	53	R	*Gastropus*, copepods		throughflow
Norman's	13	62	Cl	*Bosmina*	*Ceriodaphnia*	
Blampied's	15	80	Cl	*Daphnia*, *Bosmina*	*Boeckella*	
2CO	12	92	Cl	*Daphnia*		
Corowa G/C	14	93	R	*Keratella*, copepods	*Asplanchnopus*	
Moodemere	12	92	R	*Keratella*, *Ceriodaph.*		
Wise's	20	90	R	*Conochilus*	*Keratella*	throughflow

Table 6.3 Community dominants, per cent planktonic taxa for 13 billabongs sampled 05.ix.78 (see Fig. 6.6). R=rotifers, Cl=cladocerans, Co=copepods. Genera only are given. In some cases 3-4 species in a genus

Ryan's I	Ryan's II	Hawksview	8-Mile Ck	McFarland's	Cook's	Norman's	Blampied's	2CO	Corowa GC	Moodemere	Wise's	
.25	.17	.26	.28	.24	.21	.07	.35	.27	.20	.40	.44	Snowdon's
	.23	.06	.23	.11	.19	.12	.11	.13	.12	.16	.13	Ryan's I
		.19	.21	.10	.15	.07	.06	.15	.10	.15	.15	Ryan's II
			.21	.17	.23	.18	.33	.19	.13	.25	.35	Hawksview
				.29	.29	.10	.13	.22	.21	.27	.17	8-Mile Ck
					.17	.08	.15	.17	.21	.29	.32	McFarland's
						.23	.13	.19	.18	.09	.06	Cook's
							.04	.04	.08	.09	.06	Norman's
								.17	.21	.23	.21	Blampied's
									.24	.41	.19	2CO
										.37	.33	CGC
											.33	Moodemere

Table 6.4: CC values for 13 billabongs sampled 05.ix.78

Diversity was highest in the billabongs subject to throughflow, again with the exception of Wise's, where a large population of *C. hippocrepis* resulted in a lower H' value. Lowest diversity occurred in Snowdon's and Hawksview coincident with *Volvox* blooms. This is converse to the increased diversity noted during *Melosira* blooms in the nearby river; *Volvox* colonies would not provide the same substrate potential as *Melosira* filaments.

Temporal heterogeneity: Temporal differences in open water plankton in Snowdon's, Ryan's I and Ryan's II are included in Fig. 6.7. Typically, the plankton consisted of 2-13 rotifer species, 1-6 cladocerans and 1-5 copepods. Extremes were recorded from other sites, e.g. a single cyclopoid was collected from 8-Mile Creek billabong during an *Anacystis* bloom (18.iv.79), and 33 taxa, including 22 rotifer species, were present in a summer tow from Mildren's (26.ii.79). Considerably higher species numbers and diversity were recorded from billabongs in the north of the sampling area, and from billabongs in the Northern Territory (Shiel, unpublished), where a diverse tropical plankton assemblage of 40-60 spp. was common.

In Snowdon's, Ryan's I and Ryan's II the following seasonal trends were apparent:

Snowdon's: Calanoids (*B. minuta, B. fluvialis*) were dominant from winter 1976 to autumn 1977. *A. sieboldi* and *M. tenuicornis* occurred over summer, with the calanoid pair breeding again in spring 1977. Dominants over summer 1977-78 were *B. urceolaris rubens, M. tenuicornis* and *M. decipiens*. The latter persisted as dominant through autumn. *S. litoralis* and *C. quadrangula* occurred in winter 1977. A pulse of rotifers (*G. hyptopus, G. stylifer*) occurred in spring 1978. In autumn 1979 *B. fluvialis* was dominant, with *A. sieboldi* sub-dominant. *M. tenuicornis* and *M. decipiens* were again dominant in summer 1979-80. Other common limnoplankters in Snowdon's were: *B. variabilis, K. procurva, K. slacki, F. longiseta* var. *passa, B. meridionalis, D. carinata.*

Momentary species composition in open water was 5.4 rotifers, 2.8 cladocerans and 2.0 copepods (cf. Dartmouth Dam), i.e. greater than recorded

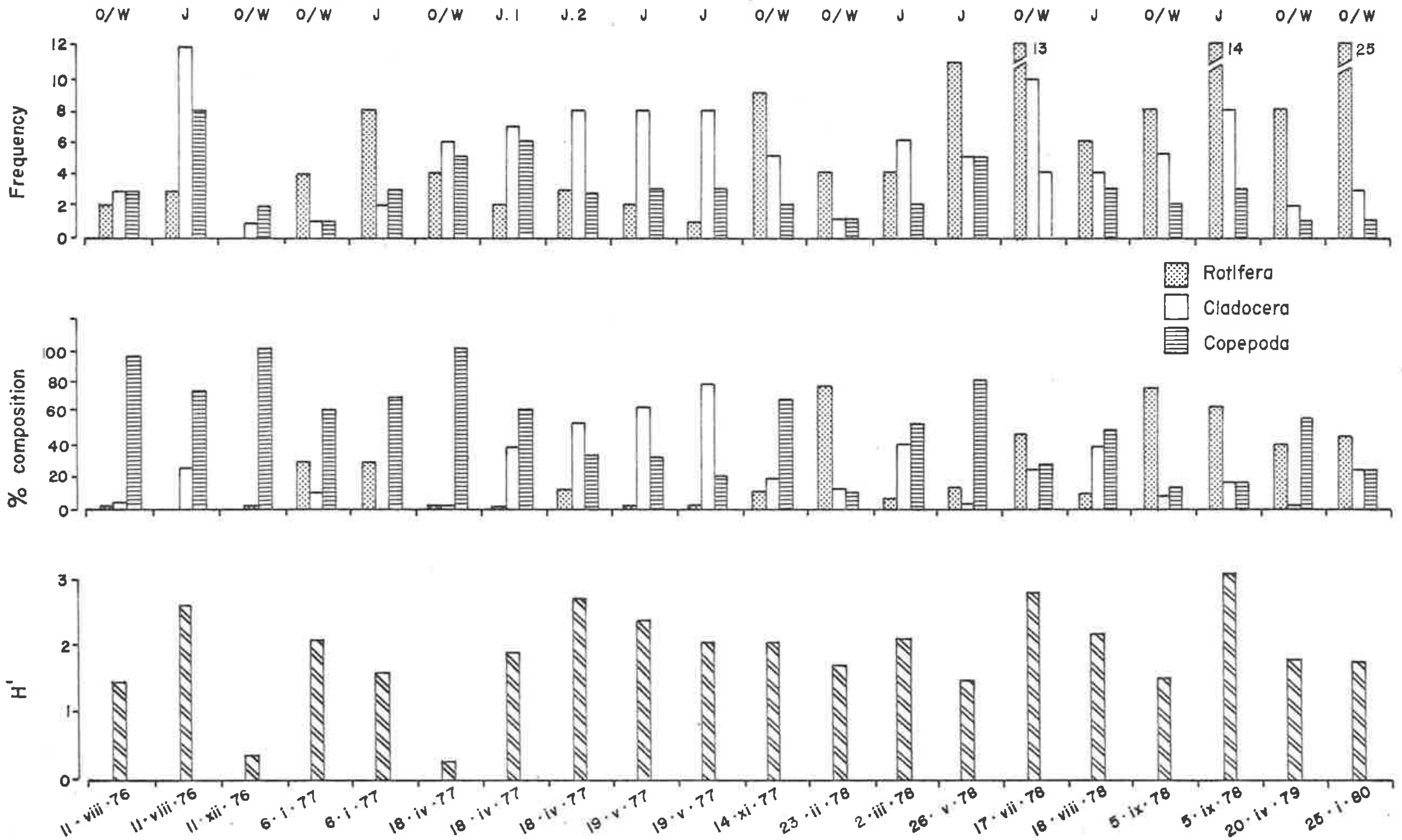


FIG. 6·7 Seasonal fluctuation in species composition and diversity in Snowdon's billabong
O/W = open water ; J = *Juncus*

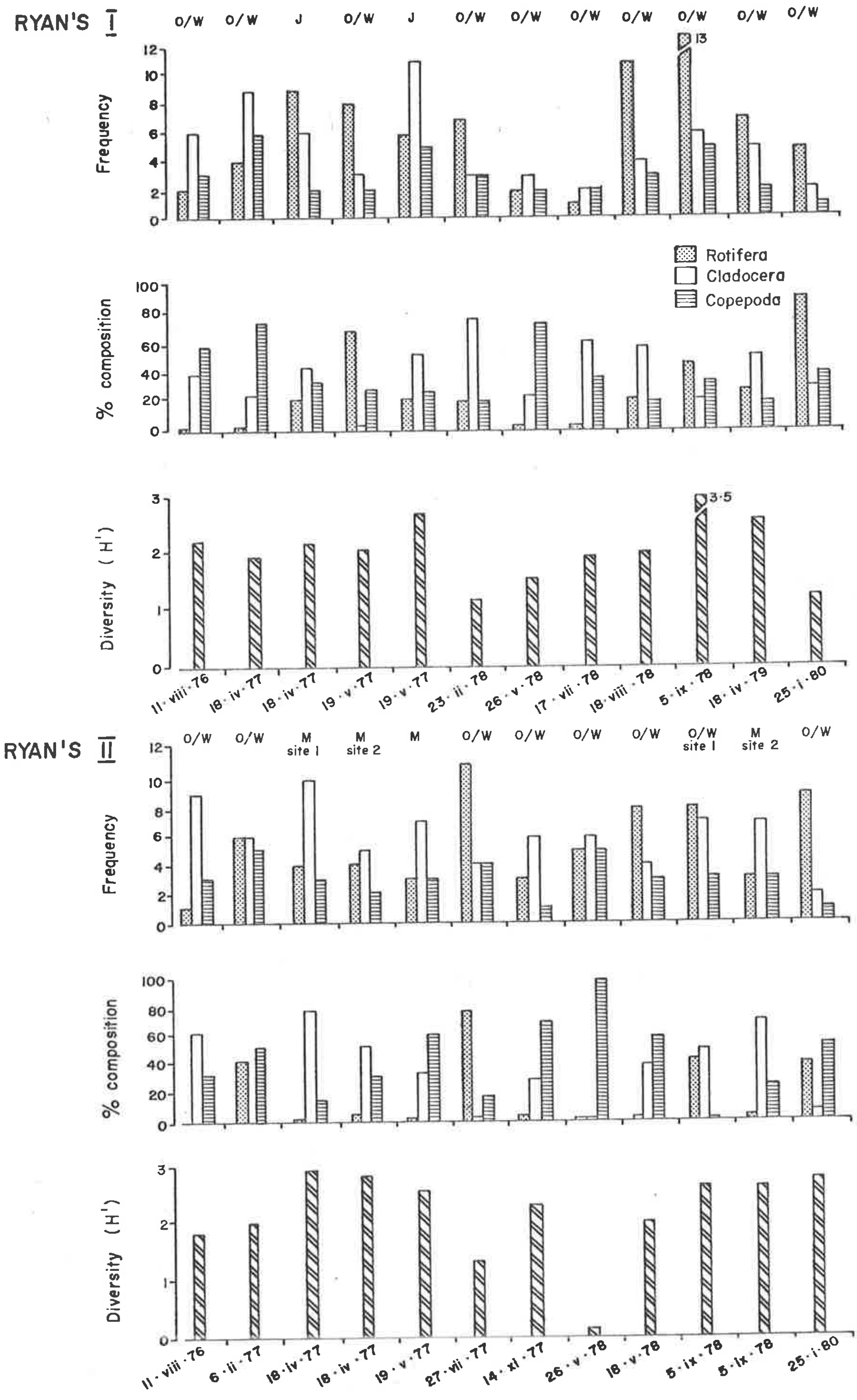


FIG. 6·7 (cont.) Seasonal fluctuations in species composition and diversity in Ryan's I and Ryan's II billabongs
O/W = open water ; J = *Juncus*; M = *Myriophyllum*

for farm dams, reservoirs or lakes in other Australian studies (e.g. Tait, 1976; Timms, 1970a,b,1980). Mean diversity was 1.45 (cf. H' 2.33 in an adjacent *Juncus* bed. See Fig. 6.7). Lowest diversity occurred during summer-autumn 1976-77, when *B. minuta* comprised >90% of the plankton. Greatest diversity in subsequent years was in autumn-winter.

Ryan's I: In autumn 1976 *C. hippocrepis* comprised > 80% of the plankton. *B. fluvialis* and *B. minuta*, as in Snowdon's, occurred over winter, and were predominant in early autumn 1977. A pulse of rotifers (*B. urceolaris, B. calyciflorus, B. quadridentatus melheni*) was recorded in late autumn. None of these occurred in Snowdon's. In summer 1978 *M. micrura* was abundant (76%). Peaks of both calanoids, also *D. lumholtzi* and *B. meridionalis* were recorded through winter 1978. A second peak of rotifers occurred in summer 1979-80 (*B. budapestinensis* 72%, *B. quadridentatus* 15%). Average momentary species composition (n=8) was 4.9 rotifers, 3.8 cladocerans and 2.6 copepods. Mean diversity was 1.68 (cf. 2.61 in a weedbed). Lowest diversity occurred during autumn 1976 and summer 1978 and 1979. Greatest diversity was recorded in autumn 1977 and spring 1978.

Ryan's II: Submerged vegetation limited open water sampling in this billabong; only at high water levels over winter were limnetic assemblages adequately sampled. In consequence, "open water" collections contained a greater proportion of littoral strays than in the preceding habitats. In autumn 1976 the dominant species was *C. sphaericus*, with *B. fluvialis* and *D. lumholtzi* subdominant. Other dominant taxa were *B. quadridentatus, E. dilatata, M. leuckarti* (summer 1976-77), *B. fluvialis* (autumn 1977, 1978, 1979), *A. brightwelli* (winter 1977), *M. leuckarti* (spring 1977 - autumn 1978). Average momentary species composition (n=8) was 6.4 rotifers, 4.6 cladocerans and 3.1 copepods. Mean H' was 1.96 (cf. 2.76 for a nearby *Myriophyllum* bed). Greater species numbers and higher diversity relative to other sites reflect the littoral influence, in particular the more complex habitat partitioning (i.e. microniches) provided by the finely divided leaf surfaces of *Myriophyllum*. Greater stability also is suggested by the distinct seasonality of several taxa; this was less apparent in other billabongs.

Temporal variations in the limnoplankton of other billabongs were comparable to those noted above, with marked differences between habitats in species composition and community dominants.

Similar temporal variations in density were apparent. Although time constraints and problems of volume samplers clogging prevented consistent quantitative sampling, several comparative 30 ℓ trap samples were taken from the Albury-Wodonga and Mitta Mitta billabongs. Densities of 200-300 ℓ^{-1} were usual, with a range of < 10 ℓ^{-1} during blue-green algal blooms (Ryan's) to > 2,000 ℓ^{-1} in spring-summer (Mildren's, 26.ii.79). Notably, this latter bloom was dominated by *A. volvocicola*, the parasite of *Volvox* (cf. Burrinjuck Dam). Densities generally were more than tenfold those of nearby Hume Reservoir.

In summary, the limnoplankton of the Albury-Wodonga billabongs was variable between habitats, but was composed largely of true limnetic species. With the exception of a few eurytopic widely distibuted taxa mentioned earlier, the dominant limnoplankters generally were not those of either the upstream reservoir or the nearby river, e.g. the calanoid dominants in Hume, *C. ampulla* and *B. triarticulata* were replaced in the billabongs by *C. lucasi* and the congeners *B. fluvialis* and *B. minuta*. The cyclopoids *M. albidus* and *M. leuckarti* were common in the billabongs, but not in the reservoir. Of the rotifers, *B. falcatus* and *B. quadridentatus*, abundant in the billabongs, did not occur at all in the reservoir. *K. cochlearis* and *F. longiseta* were Hume limnoplankters, while *K. slacki* and *F. longiseta passa* were common in the billabong plankton. Some evidence that such habitat preference occurs in other groups is provided by distribution records of freshwater mussel taxa in the AWDC study area; *Velesunio ambiguus* is the billabong form, while *Alathyria jacksoni* occurs in the river (Walker, in press).

The contribution of this billabong limnoplankton to the downstream community would depend on the flushing effects of floodwaters, as would the contribution of the upstream limnoplankton to the billabong communities.

Although major flooding was not observed during the study, higher water levels and direct connection to the river occurred in several billabongs, e.g. Wise's. On these occasions, the dominant limnoplankters were those of Hume. From all billabong samples, however, only 18% of the 170+ taxa recorded were present in the reservoir, while 40% of the billabong microfauna occurred in downstream Lake Mulwala. The nature of this inoculum is described in the following section.

6.2.5.4 Littoral microfauna

General observations on the composition of the invertebrate communities of billabong littorals were made by Shiel (1980). Predictably, an extremely diverse assemblage of rotifers and microcrustacea occurs in fringing hydrophytes, apparently the greatest microfaunal diversity recorded from any freshwater habitats (Shiel, 1976). Table 6.5 shows the species composition of each of the Albury-Wodonga billabongs (pooled samples), number of samples, species in each group, total species (S_T) and mean diversity (H'). Raw data for Snowdon's, Ryan's I and Ryan's II are given in Appendix 6.2. including sampling dates, species composition, count/10 ml aliquot, breeding seasonality and physico-chemical measurements.

Community composition: As for the open water plankton, there was pronounced spatial and temporal heterogeneity in the littoral microfauna. A small "core" of eurytopic opportunist species occurred in most billabongs, e.g. *B. quadridentatus melheni, Keratella* spp., *C. dossuarius, D. excisum, C. sphaericus, G. testudinaria, B. meridionalis, D. carinata, D. lumholtzi, S. vetulus*, with several copepod species commonly collected in weedbeds. A larger group occurred in about half the billabongs, 68 taxa in 2-4 billabongs, while 67 taxa (40%) were collected only once or from single habitats.

Spatial heterogeneity: On any sampling date, net collections from hydrophyte beds contained 2-14 rotifer taxa, 4-12 cladocerans and 2-8 copepods. Microcrustacea usually were numerically abundant. The average momentary species composition for Snowdon's, for example, was 5.2 rotifers, 7.5 cladocerans and

TABLE 6.5

Sp. code	Snowdon's	Ryan's I	Ryan's II	Johno's	Hawksview	8-Mile Ck	Norman's	Cook's	McFarland's	Mildren's	Rushy	Blampied's	2CO	Corowa G/C	Moodemere	Wise's
Rotifera																
8		*	*							*						
9			*													
10		*				*										
11	*									*						
13																*
14	*		*													
15	*	*	*													*
21		*	*													
22										*				*		
23												*	*		*	
24	*	*	*							*	*			*		
28			*							*						
30	*															
32		*								*						
36												*				
37	*	*	*													
40	*	*	*		*			*		*						
42										*		*				
43		*	*							*						
44	*															
46	*	*											*			
47	*								*	*			*	*		
48			*		*	*			*	*		*	*	*	*	*
49	*	*	*							*			*			*
52	*	*	*			*		*	*				*		*	*
56	*	*	*			*		*	*	*	*		*	*	*	*
57	*	*	*							*				*	*	
61	*															
63						*										
64		*														
65			*		*		*	*								
67	*								*							
72										*						
75	*															
76	*	*	*													
77	*				*	*										
79	*	*				*	*	*								
80			*													
85			*													
97	*	*	*					*								
103		*	*						*	*						
104	*	*	*				*									
105			*													
110			*													
114	*															
115							*	*								
126		*	*		*								*			
127		*														
130		*														
138	*															
139		*														
144	*															
147						*										
Rotifera(cont.)																
151			*													
153									*							
160		*					*									
162										*						
163			*													
164	*				*			*								
167									*			*				*
168									*							
174										*						
175	*							*		*		*				
176	*															
177	*	*	*									*				
178		*														
179												*				
181		*						*		*						
132		*														
184	*	*	*			*			*							*
188																*
191	*		*							*						*
192	*															
193			*						*					*		
194		*	*							*	*					*
195						*			*							
196		*											*	*	*	*
197	*	*									*					
204			*													
206		*														
210										*						
212			*													
214	*															
215		*				*		*	*	*			*			
216										*					*	
217			*							*						
218			*													
220			*							*						
224										*						
227		*														
230	*	*			*						*					
232			*		*	*			*					*	*	
233		*								*						*
234		*	*										*		*	
236									*							
238						*										
239														*		
240	*		*		*											*
244	*	*	*													*
247	*															
252		*														
Cladocera																
1		*			*											
3	*	*			*					*		*	*	*	*	*
5	*	*			*											

TABLE 6.5 (cont.):

Sp. code	Snowdon's	Ryan's I	Ryan's II	Johno's	Hawksview	8-Mile Ck	Norman's	Cook's	McFarland's	Mildren's	Rushy	Blampied's	2CO	Corowa G/C	Moodemere	Wise's
Cladocera (cont)																
9		*	*		*											
10		*	*													
11	*	*			*			*		*						
12										*						
13	*	*	*	*	*	*			*		*	*				
14		*														
15	*		*	*												
16	*		*							*						
20									*	*						
21	*	*	*	*												
23	*	*			*											
24	*															
26		*														
27	*	*	*						*	*						
30	*		*	*	*		*		*	*						
31	*															
33		*	*													
34				*		*				*						
35					*											
38	*			*	*			*		*						
40			*							*						
41					*					*						
42			*													
44	*															
45	*	*														
48					*											
49							*									
50	*		*		*				*	*						
52	*	*	*		*				*	*						
57			*		*							*				
59					*											
60		*	*							*				*	*	
61	*	*			*						*	*				
62	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
63	*	*	*			*				*	*					
64	*	*	*		*				*	*		*	*		*	*
65		*														
66			*													
Cladocera (cont)																
67	*	*	*	*	*		*	*	*	*	*		*			*
68	*															
69	*															
70	*	*	*		*		*		*				*			
71			*													
73	*	*	*	*	*	*	*		*	*	*	*	*		*	*
Ostracoda																
1	*											*				
28	*		*		*											
unid.	*	*	*		*			*	*	*		*		*		
Copepoda																
2	*	*	*	*	*	*	*		*	*	*		*	*	*	
4	*	*	*				*		*	*	*	*				
6			*													
7													*		*	
14			*		*		*			*	*	*	*	*	*	*
18	*		*								*					
19	*	*			*											
20	*	*	*	*	*				*	*	*	*	*			*
21	*															
23	*	*	*	*	*			*	*	*	*	*	*		*	*
24	*															
26			*													
27	*									*						
29	*				*	*			*							
30	*	*	*	*						*	*			*		
31		*														
32					*						*					
36	*															
37	*														*	
40		*														
n	20	15	13	1	8	2	2	1	4	5	3	2	2	2	3	2
ΣR	38	41	40	0	21	13	5	13	15	30	5	8	11	10	9	16
ΣCl	27	24	24	9	9	6	5	4	10	21	6	7	6	4	5	5
ΣCo	13	8	9	4	7	2	4	1	5	7	8	4	5	3	5	2
S_T	78	73	73	13	37	21	14	18	30	58	19	19	22	17	19	23
$\bar{x}$ H'	1.98	1.99	2.28	-	1.58	1.66	2.19	3.12	1.96	2.36	1.60	2.32	2.38	2.29	1.50	1.91

TABLE 6.5: Limnetic and littoral microfauna recorded from 16 Murray billabongs. n=number of samples, ΣR, ΣCl, ΣCo= number of species of Rotifera, Cladocera and Copepoda respectively, S_T=total species, $\bar{x}$H'= mean diversity.

4.3 copepods, i.e. fewer rotifers and more microcrustacea than in open water. There usually were marked differences in dominant species and community composition within and between billabongs. Three sites were sampled concurrently in Snowdon's (Fig. 6.3) during 1977. In autumn, a submerged *Myriophyllum* bed at the northern end (site 1) was dominated by chydorid cladocerans (*A. rectangula* and *A. davidi*) and cyclopoids (*E. agilis*). Site 2, a *Juncus* bed, had a community numerically dominated by *D. crassa, C. sphaericus* and cyclopoid copepodites. At site 3, in open water, 98% of the plankton was cyclopoid copepodites. At the same time, the littoral fauna of Ryan's I was predominantly chydorids (*A. davidi, B. karua, C. sphaericus*); Ryan's II copepodites and *A. rectangula*; Hawksview *C. eurynotus*; McFarland's *B. meridionalis* and *C. quadrangula*; Rushy *M. leuckarti* and *B. fluvialis*. These differences in community composition were probably related to the discrete nature of the hydrophyte communities in each habitat.

Greater species diversity was recorded from littoral collections in all billabongs than from open water (Fig. 6.7). A higher mean diversity (Table 6.5) was recorded from those billabongs with dense hydrophyte growth, e.g. Ryan's II, than from those with sparse vegetation, e.g. Moodemere. Diversity generally was highest in autumn-winter, although seasonal fluctuations were less apparent than in reservoirs, reflecting greater community stability in billabongs.

High diversity and frequent congeneric associations suggest considerable habitat partitioning, e.g. the occurrence of 5-7 species of *Biapertura* or 4-5 species of *Keratella* in a single hydrophyte bed was not uncommon. Calculation of an equitability index (Lloyd & Ghelardi, 1964) enables comparison of the number of species recorded with the number expected in a sample of the same diversity divided according to MacArthur's (1957) broken stick model. Table 6.6 gives representative data for several billabongs. The expected number of species is derived from Table 1 in Lloyd & Ghelardi (1964).

In all cases, more species were present than MacArthur's non-overlapping niche model predicted (i.e. $\varepsilon < 1.0$). Species numbers and diversity were

Table 6.6: Diversity and equitability of microfauna from some Murray billabongs. S=no. of species;H'=diversity; S'-expected no. of species;ε=Equitability component (S'/S).

Billabong	Date	S	H'	S'	ε
Snowdon's	11.viii.76	24	2.726	9	.375
Snowdon's	18.iv.77	15	2.858	10	.667
Snowdon's	05.ix.78	26	3.227	13	.500
Snowdon's	25.i.80	17	2.320	7	.412
Ryan's I	18.iv.77	17	2.271	6	.353
Ryan's I	05.ix.78	24	3.467	16	.667
Ryan's II	18.iv.77	18	2.967	11	.611
McFarland's	26.v.78	17	3.154	13	.765

greater than recorded from Brazilian floodplain habitats by Green (1972, a, b), although a similar lack of fit to the MacArthur model was noted. Green suggested some niche overlap in the cladoceran and rotifer communities of the meander lakes. This is clearly so in the billabong communities, i.e. the billabong habitat is heterogeneously diverse (Hutchinson, 1958); there is an abundance of microniches, and the co-occurrence of closely related species is possible. In such habitats the available resources are probably large in relation to the requirements of the species (cf. King, 1964). Morphological adaptations of individual species (cf. Fryer, 1968, 1971) enable habitat partitioning on a fine scale.

Temporal heterogeneity: Temporal changes in the littoral microfauna of the three main billabongs are shown in Appendix 6.2. In Snowdon's, for example, the winter 1976 assemblage was numerically dominated by copepods (*Eucyclops* sp., *B. minuta* and *Elaphoidella* sp.) with chydorids subdominant. The following autumn, chydorids predominated (*Alona* spp.) with *S. vetulus* and *M. spinosa* subdominant. In spring 1977 and summer 1978 copepods again predominated in the weedbeds (rotifers were abundant in open water), and subdominants were *D. carinata* and *M. spinosa*. Copepods, predominantly as juveniles, persisted through winter 1978, and rotifers dominated in spring (two species of *Gastropus*). Similar trends, although involving different species dominants, were apparent in other billabongs. Commonly, one or two taxa made up 60-70% of the microfaunal assemblage at any time, with 2-4 taxa subdominant (25-25%) and the remainder made up by 5-20 taxa.

Environmental factors: No significant correlations could be found between log population density of any species, overall species richness or diversity (H') and fluctuations in any measured variable (all r^2 values < 0.25) in Snowdon's, Ryan's I or Ryan's II populations. While temperature and salinity changes possibly are important environmental cues in the billabongs, community responses were not detected.

Contributions to the downstream microfauna: As noted earlier, billabong plankton and littoral taxa comprised an increasing proportion of the potamoplankton with increasing distance downstream from Hume reservoir. Hume taxa invariably predominated in collections from the Murray at Wodonga, with up to 100% of the plankton limnetic rotifers, e.g. *K. cochlearis, P. vulgaris.* There generally was a significantly lower proportion of microcrustacea than in the lake assemblage, evidence of the avoidance of the outflow by more active copepods and cladocerans. The microfauna of *Vallisneria* beds at the same point consisted of a diverse assemblage of littoral rotifers, e.g. *L. lunaris, C. uncinata, E. putorius, P. petromyzon, E. dilatata*, ostracods and cyclopoids. These and other littoral incursions comprised 15-20% of the riverine plankton in collections from Wahgunyah, near Corowa, while 30-40% of the river microfauna adjacent to Wise's billabong, near Mulwala, were littoral forms. The survival of billabong species in the river and in Mulwala was apparent, in particular when collections from Wise's, the river and the eastern end of the storage were compared. In spring 1978, for example, long spined forms of *K. slacki* occurred only at these three sites. Some 83% of the taxa recorded from Wise's occurred also in Mulwala, a higher proportion than from any other billabong, reflecting close proximity of the two habitats, and direct inflows and flushing by the river.

In view of the differences in sampling intensity, CC values were not calculated for all billabongs and the two storages. There was generally low similarity between the microfauna of Snowdon's, Ryan's I and II and that of Hume, while the species composition of the downstream billabongs closely resembled that of Mulwala. Billabong forms flushed into the river were able to survive into the impoundment, and abundant niches apparently were available in the marginal hydrophyte beds for their maintenance.

The diverse microfaunal assemblages of billabongs from which the downstream impoundment is inoculated account, in part, for the relatively rapid fluctuations in community composition noted on p.121. In a similar manner to its function as a nutrient sink, Mulwala acts as a biological sink for the upstream plankton and littoral microfauna. Gentle gradients and slow flows of the Murray, with few rapid or scouring floods, enables persistence of incursion species, hence the similarity of the Mulwala community to that of a billabong. To a lesser extent, the upstream fauna of the Goulburn River and floodplain reaches Goulburn Weir, which, in terms of microfaunal assemblages, also is more characteristic of a billabong than a lake.

6.3 Billabongs of the Goulburn River between Eildon Reservoir and Goulburn Weir

6.3.1 Introduction

Differences in floodplain morphology and flow regime of the Goulburn River have resulted in billabongs quite dissimilar to those of the River Murray. The break of slope with the Eastern Highlands is at a higher elevation near Eildon than is that of the Murray near Wodonga, the floodplain is narrower (2-3 km), and more rapid current flows, substrate and hydraulic differences have produced tighter loops in the meandering stream than on the Murray floodplain. A consequence is a greater density of billabongs than on the Murray (cf. Plate XVI, Appendix 6.1, which shows a section of the Goulburn floodplain near Alexandra, Victoria). The proximity of many of the marginal billabongs to relatively steep slopes has important consequences for runoff and water supply from high water tables, i.e. most billabongs contain permanent water. The intensity of land use is greater on the Goulburn floodplain, predominantly horticulture and dairying. The billabongs are subject to varying nutrient inputs from these activities, with marked effects on their biology.

Less is known of the biology of the Goulburn floodplain than that of the Murray. A single study of microcrustacean communities of a billabong near Alexandra (Shiel, 1976) established the extreme species richness of these habitats, but no further work has been published. To provide comparative data on the Goulburn billabongs a series was sampled early in this study, and regular sampling was continued at four of these. In the following section the disparities in community composition between Goulburn and Murray billabongs are illustrated by reference to the four principal study sites.

6.3.2 Sampling sites

Qualitative collections were made early in 1976 from nine billabongs and one flooded gravel pit on the floodplain between Eildon and Nagambie. Fig. 6.8 shows sampling sites, which are named after the property or nearest town. Continued sampling was from Seymour I & II (n=15), Acacia's (n=7), Sheepwash Lagoon (n=13) and Goulburn View (n=9). Fig. 6.9 gives comparative views of main sampling sites.

6.3.3 Billabong morphology and distribution

Goulburn billabongs are, in general, smaller than those of the Murray, less than 50 m wide, rarely more than a few hundred metres long, and usually less than 2 m deep. All of those sampled were small (<100 m long, < 2 m deep) and densely vegetated. All were at the margin of the floodplain several km from the present river course, and were presumably the longest established. None was crescentic in outline, although the original meander pattern could be determined from aerial photographs, and the filled loops they occupied were apparent. The scale of aerial photographs did not permit calculation of the respective surface area of river and billabongs as for the Wodonga series. Subjectively, a higher proportion of the water surface (i.e. >50%) was occupied by billabongs.

6.3.4 Physico-chemical features

Ranges of measured water quality characteristics recorded from several billabongs are shown in Table 6.7. Measurements for all sampling dates are given in Appendix 4.

6.3.4.1 Light penetration

As for the Murray billabongs, there was considerable variation between habitats on any sampling date. More sheltered billabongs usually were highly transparent, with light penetration to the bottom (e.g. Sheepwash). Exposed habitats were, on occasions, extremely turbid, particularly with autumn and winter runoff, e.g. several of the Seymour billabongs exceeded 300 NTU in autumn 1977 (Secchi readings < 2 cm). Biogenic influences were less apparent

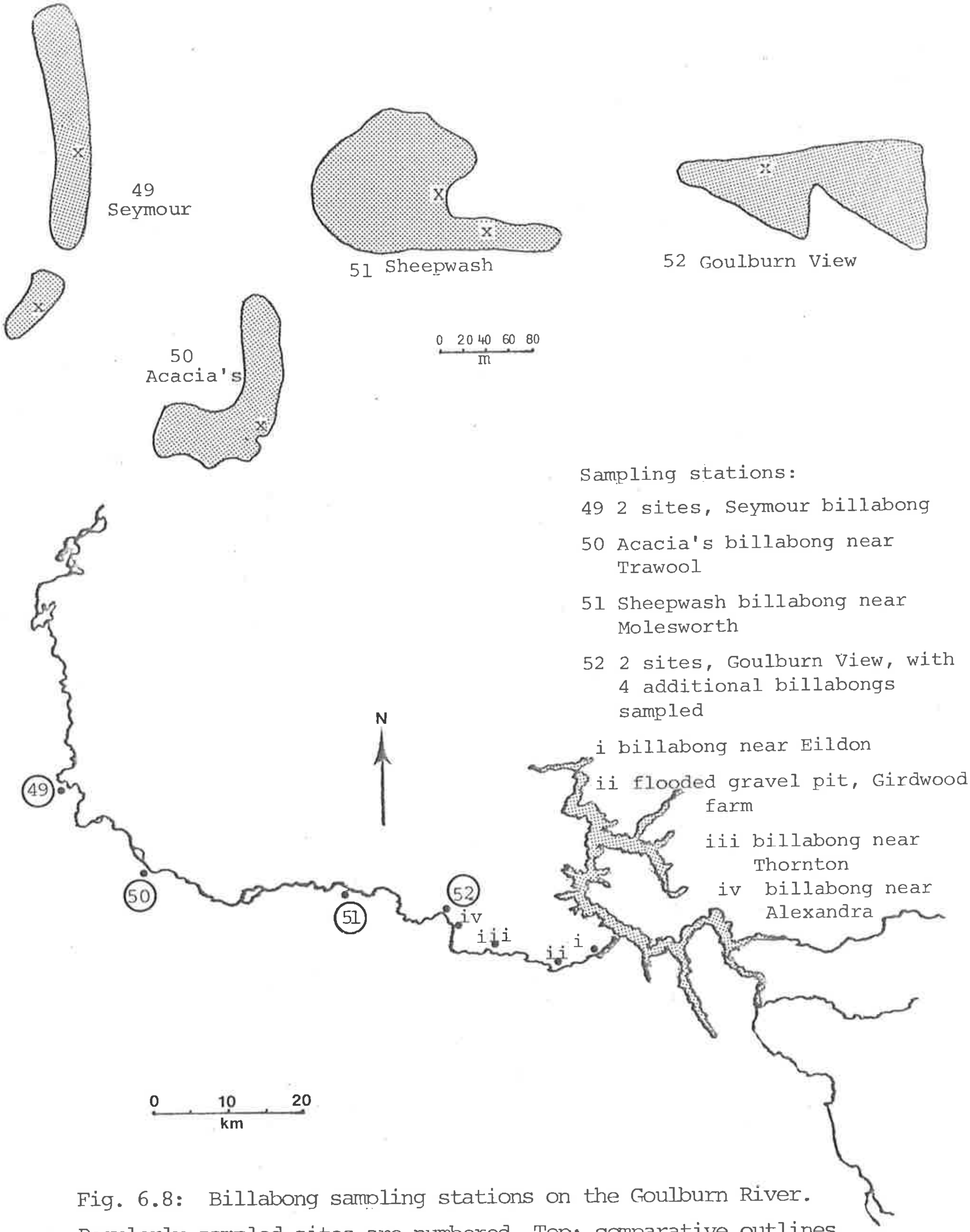


Fig. 6.8: Billabong sampling stations on the Goulburn River. Regularly sampled sites are numbered. Top: comparative outlines.

Fig. 6.9 : Comparative views of Goulburn billabongs
Top: Goulburn View, Alexandra, Bottom: Acacia's, near Trawool, Vic.

Fig. 6.9 (cont): Sheepwash Billabong near Yea, Vic.

Table 6.7: Ranges of depth and some physico-chemical measurements in four Goulburn billabongs

Billabong	Temp. (^{o}C)	pH	DO (ppm)	Cond. (μS)	TDS (ppm)	Turb. (NTU)	Depth (m)
Goulburn View	6.2- 28.0	6.8-7.2	1.4-13.8	85-250	136-266	5.5-36.0	0.30-1.8
Sheepwash	10.0- 21,5	7.0-7.7	6.1-10.4	55-200	90-100	012-17.0	2.0-2.7
Acacia's	10.0-22.0	7.0-7.4	8.6-11.4	60-175	130	0.5-10.5	0.45-1.3
Seymour	8.0-25.0	7.0-7.5	2.7-11.6	135-1080	183-500	3.-350	0.5-1.7

than in Murray billabongs; algal blooms were not recorded.

6.3.4.2 Temperature

Temperatures were similar to those recorded from Murray billabongs, i.e. within the range 6.0-30.0 °C, with occasional summer maxima of 34-36 °C in shallow *Azolla* covered billabongs. All billabongs sampled were shallow, and were isothermal to the bottom. Slight horizontal differences in temperature were attributed to effects of vegetation, or in winter, to throughflow.

6.3.4.3 Dissolved oxygen

DO levels were extremely variable, but generally were within the range 50-100% saturation. Only in autumn were low values recorded (i.e.<10%). Supersaturation was common in summer beneath floating *Azolla* and *Lemna*, e.g. in Goulburn View (27.ii.78) 13.8 mg O_2 ℓ^{-1} was recorded at the surface (177% saturation). At the bottom (0.30 m), the DO level was 1.8 mg ℓ^{-1} (23%). Elevated oxygen levels were more common in Goulburn billabongs than in the Murray series, and were a feature of the more heavily vegetated billabongs.

6.3.4.4 Conductivity

Although of similar variability between sites, the Goulburn billabongs were of lower conductivity than those of the Murray. Most were <200 µS, e.g. those with direct inflow from the water table (Acacia's and Sheepwash). Goulburn View and Seymour, with grazing and horticultural land use to the billabong margins, were more variable. Seymour was consistently more saline (cf. Snowdon's). Extreme peaks in conductivity and TDS, related to local land use practices, were common (cf. Shiel, 1976).

6.3.4.5 pH

Ranges of pH were less extreme than in the Murray billabongs, i.e. 6.8-7.7. Contributing factors possibly were greater stability of level and of algal and hydrophyte community structure, also the influence of groundwater inflows.

6.3.5.6 Major ions

Cations generally were in the order Na > Mg > Ca > K, although Sheepwash was distinctive with Mg > Na > Ca > K. Anions commonly were HCO_3 > Cl > SO_4. Orders of dominance were not typical of Australian waters, possibly a result of local geologic influences (cf. 6.2.4.6). This also may account for detectable levels of Fe, Mn and Zn in some billabongs, e.g. Goulburn View, Sheepwash.

6.3.4.7 Nutrients

Nutrient levels were not measured. Extrinsic characteristics, i.e. catchment size, intensity of land use, inflow of groundwater or river water derived from Eildon (oligotrophic), and intrinsic factors, e.g. diverse algal and hydrophyte communities, suggest that the Goulburn billabongs were less eutrophic than those on the Murray. Differences in trophic status are reflected in the biological features of the billabongs.

6.3.5 Biological features

6.3.5.1 Phytoplankton

An extremely diverse phytoplankton assemblage occurred in most collections, with up to 30 taxa of diatoms, desmids and green algae present. Blue-green algae were sparse (cf. 6.2.5.1). Each billabong had a characteristic phytoplankton community, e.g. volvocales and diatoms typically were predominant in Goulburn View, while desmids were abundant in Sheepwash. Of 68 taxa identified from Sheepwash (Appendix 5) 40% were desmids. Common genera were *Cosmarium, Closterium, Micrasterias* and *Staurastrum*. Congeneric associations were frequent, with two or three species in several genera present in most collections. Species were, in general, not those of Eildon reservoir, of the nearby river, or of the Murray billabongs. Taxa indicative of oligotrophic soft waters and eutrophic hard waters co-occurred (cf. Moss, 1972). Although assemblages could not readily be fitted to Hutchinson's (1967) classification, most abundant genera were those of Hutchinson's meso- and eutrophic groups. Overlaps between desmid, diatom and chlorococcal assemblages were evident. Clearly, considerable scope exists for study of phytoplankton associations under Australian conditions; generalizations made elsewhere are not necessarily applicable.

6.3.5.2 Hydrophytes

While superficially similar in appearance, the hydrophyte community of each billabong was, at times, composed of different species dominants. In Goulburn View, for example, some 19 taxa of aquatic plants were identified (Table 6.2). Seasonal changes in the hydrophytes of this billabong were described by Shiel (1974). During the present study, the principal emergent was *Juncus ingens; Chara australis* and *Myriophyllum propinquum* were dominant submergents, and *Riccia fluitans, Ricciocarpus natans, Azolla filiculoides* and *Lemna* spp. at times covered the entire billabong surface. In contrast, Sheepwash had a marginal bed of *Juncus* sp., dominant submergents were *Vallisneria spiralis, Myriophyllum elatinoides, Ceratophyllum demersum* and *Callitriche* sp. Floating hydrophytes (*Azolla* spp.) were sparse. Similar disparity in species composition was noted for other Goulburn billabongs, cf. Fig. 6.9. As for the Murray billabongs, these community differences account for the discrete microfaunal assemblages found in each billabong. That the communities of the Goulburn series were more complex, with a greater degree of habitat partitioning than in the Murray billabongs, is suggested by the greater species richness and community diversity of the microfauna collected from them.

6.3.5.3 Zooplankton

Limnetic assemblages in Goulburn billabongs contained a higher proportion of strays than in the Murray series,due to shallow morphology and more extensive hydrophyte cover. Goulburn View, for example, had *Myriophyllum* to the surface during most of the study. Only in Sheepwash, the deepest of the Goulburn series sampled, was there extensive open water (1-2 m deep). Open water collections from Sheepwash contained 2-16 rotifer taxa (seasonal dominants: *K. cochlearis, K. procurva, K. valga, P. vulgaris, S. pectinata, S. stylata*), 1-6 cladocerans (*C. sphaericus, B. meridionalis, D. lumholtzi, C. cornuta, C. laticaudata*) and 2-4 copepods (*M. leuckarti, Tropocyclops* spp.,*B. minuta*). Ostracods were common only in Goulburn View, and then rarely in open water.

Rotifers generally were numerically dominant. With few exceptions, e.g. *K. valga, C. laticaudata, Tropocyclops* spp., limnoplankters were the widely distributed eurytopic taxa of billabongs elsewhere. Usually, one or two dominant taxa were confined to single habitats, e.g. *H. searli* in Goulburn View. As in other billabongs, species diversity was lower in open water than in adjacent reedbeds (H' 1.88 vs 2.65 in Sheepwash, n=8). Species composition, counts/10 ml aliquot and breeding seasonality for the limnoplankton of the four main Goulburn billabongs are included in Appendix 6.

6.3.4.5 Littoral microfauna

Seasonal fluctuations in the littoral microcrustacea of Goulburn View billabong were described by Shiel (1974,1976). Discrete species assemblages were associated with different hydrophyte beds. The functional morphology of individual species (cf. Fryer, 1968, 1971) was important in maintaining niche specificity. An example of variations in community composition in a *Juncus* bed in Goulburn View is given in Appendix 3 (Fig. 50). Fifty-nine taxa of microcrustacea were recorded from the billabong over one year. Most of these, and a further 53 taxa (41 rotifers, 6 cladocerans, 5 ostracods and 1 copepod) were collected from the same site during 1976-79. Table 6.8 lists species recorded from the Goulburn billabongs, also number of collections (n), total species (S_T) and mean diversity ($\bar{x}$ H') for pooled samples. Raw data are included in Appendix 6b and summarised below.

Of 195 taxa from 52 collections, i.e. 120 rotifer taxa, 41 cladocerans, 12 ostracods and 22 copepods (cf. 175 taxa from 85 Murray collections), 35 species of rotifers (18%) and 6 of microcrustacea (3%) were recorded only from Goulburn billabongs. Nineteen of the rotifer taxa and one cladoceran were first records from Australia, and notably, several of these (e.g *M. arndti*, *D. lutkeni*, *D. robustus*, *E. phyrne*, *C. laticaudata*) are considered Palearctic, Nearctic or North American in distribution. The possibility of introduction into Australia is considered later to explain this remarkably disjunct distribution.

Fifty-two per cent (101 taxa) of the Goulburn microfauna were recorded only once or from single habitats. Only 21 species were widely distributed (see Table 6.8).

Sp. code	Goulburn View	Sheepwash	Acacia's	Seymour
Rotifera				
1				*
2			*	
5	*			
6	*			
8	*		*	*
15		*		*
24			*	
29			*	
32		*	*	
35			*	
36		*		
40	*	*	*	*
41				*
43	*			*
44		*		
46		*		
47				*
48			*	
49	*	*	*	*
52	*	*	*	*
54		*		*
56		*	*	*
57				*
58		*		
60		*		
61		*		
62			*	
64			*	
65	*	*		*
66				*
69		*	*	
75			*	
76	*			*
79	*	*	*	
80	*		*	*
Rotifera (cont)				
82		*		
84				*
85			*	*
86		*		
87				*
97				*
104	*	*	*	*
105			*	*
106				*
108	*			
109		*		
110	*	*		
111	*			
112		*	*	
114		*	*	
115		*	*	*
116			*	
125	*			
131		*		
132			*	*
133	*		*	
134			*	
135			*	
140	*		*	
141	*			
142	*			*
145		*		
147		*		
148	*			*
153	*			
154			*	
158	*		*	
160	*	*		
162		*	*	*
164	*			*
Rotifera (cont)				
165			*	*
167		*	*	*
171				*
172	*		*	*
173	*			
174			*	
176			*	
178			*	*
183				*
184		*	*	
185		*	*	*
191	*	*	*	*
193	*			
194	*	*	*	*
196		*	*	
200	*			
203				*
210			*	
211	*			
212	*	*		
214		*		*
215	*			
216		*	*	*
217		*	*	*
218	*		*	
220	*	*	*	*
221		*		
222		*	*	*
225		*	*	
226			*	
227	*			
229		*	*	
230	*			
231	*		*	
232			*	
Rotifera (cont)				
233			*	
235		*		
236		*	*	
237	*			*
238	*	*	*	
242		*		
244		*		
249		*	*	*
251			*	
254			*	
255			*	
256			*	
257				*
258			*	
259				*
Cladocera				
2				*
4				*
5	*			*
9	*	*		*
10	*			
13	*	*	*	*
15	*		*	*
16	*	*	*	*
17	*			*
19	*			
21	*	*		*
22			*	
23	*	*	*	*
26				*
27	*	*		*
30	*		*	*
33	*		*	*
40	*	*	*	
41	*	*	*	*
Cladocera (cont)				
42	*			
43	*			
44	*		*	
45	*			*
49	*			*
50	*	*	*	*
52	*	*	*	*
57	*			*
60	*			*
62	*	*	*	*
63		*		*
64		*		
66	*			*
67	*	*	*	*
68				*
69			*	*
70	*	*	*	*
71				*
72		*	*	
73	*	*	*	*
75				*
76	*			
Ostracoda				
5	*			
9	*			
11	*			
12	*			
14	*			
15	*			
17				*
25	*			
27	*			*
28	*			
30	*			
unid		*		
Copepoda				
2				*
4	*	*	*	*
7				*
8	*			
13			*	
14				*
18	*		*	*
19	*		*	*
20	*	*	*	*
21		*	*	*
23	*	*	*	*
24	*			
25			*	
26	*	*	*	
27				*
29	*		*	*
30	*	*	*	*
31	*			*
32a				*
32b				*
36	*			
37	*			
n	12	15	8	17
ΣR	41	53	62	48
ΣCl	31	17	18	32
ΣCo	13	6	11	16
ΣOs	10	2	-	4
S_T	101	78	91	100
$\bar{x}H'$	2.51	2.32	2.61	2.83

Table 6.8: Limnetic and littoral microfauna recorded from four Goulburn billabongs. Code as for Table 6.5.

Spatial heterogeneity: The same species generally were not dominant in different hydrophyte beds within a billabong. In Goulburn View, for example, on 17.iv.76, 32 taxa were collected from a *Myriophyllum* bed (northern end, H' 2.84), with cyclopoids (9 spp.) numerically abundant (78%). In a *Chara* bed (southern end) only 7 species were collected (H' 1.57) with *C. sphaericus* predominant (65%). Comparative data for 04.i.77 and 14.x.77 are included in Fig. 6.10.

On any sampling date, net collections from hydrophyte beds contained 2-21 rotifer taxa, 4-15 cladoceran taxa and 2-9 copepod species. There were seasonal extremes, e.g. 58 taxa, including 42 Rotifera were identified from a summer 1978 sample from Acacia's billabong. Microcrustacea generally were numerically abundant. Average momentary species composition for the billabongs was as follows: Goulburn View (n=12) 6.8 rotifers, 8.5 cladocerans, 4.6 copepods and 1 ostracod; Sheepwash (n=15) 8.6 rotifers, 5.1 cladocerans, 1.9 copepods; Acacia's (n=8) 18.3 rotifers, 7.2 cladocerans, 5.2 copepods; Seymour (n=17) 7.0 rotifers, 10.7 cladocerans, 4.2 copepods, i.e. greater community diversity than in the R. Murray billabongs. Further evidence of this more complex community structure is given in Table 6.9, which shows ε values for seasonal samples from the four main billabongs. In most cases there were considerably more species present than predicted by the MacArthur model. Spatial heterogeneity apparently was more pronounced than in the Murray billabongs (cf. Fig. 6.6), with habitat partitioning by a more complex assemblage leading to multiple niche overlaps.

Temporal heterogeneity: Successional changes were not synchronous between billabongs, although seasonal reoccurrence of dominant species was recorded is successive years in single habitats, e.g. Fig. 6.10 compares seasonal changes in species composition and diversity in Goulburn View and Seymour billabongs. The former tended to be numerically dominated by copepods, the latter by cladocerans. In Seymour billabong, for example, the seasonal sequence was as follows (dominant species in parentheses): autumn 1976, 70% of the microfauna were cladocerans (*S. exspinosus, S. vetulus, D. unguiculatum*);

Table 6.9: Diversity and equitability of microfauna in representative samples from four Goulburn billabongs.

Billabong	Date	No. species (s)	H'	Expected no. species (s')	Equitability ε= s'/s
Goulburn View	04. i .77	24	1.85	5	.200
	12.iv.77	16	2.93	11	.688
	14. x .77	32	1.96	5	.156
	22.viii.78	26	2.33	7	.269
Sheepwash	12.iv.77	15	3.18	13	.867
	14. x .77	17	3.06	12	.706
	22.viii.78	23	2.33	7	.304
	21. v .79	21	2.55	8	.381
Acacia's	29.iv.76	30	2.29	7	.233
	13.iv.77	19	2.02	5	.263
	14. x .77	27	2.54	8	.296
	07. i .78	53 8	3.46	16	.302
Seymour	13.iv.77	29	4.04	24	.828
	15. x .77	15	2.50	8	.533
	07. i .78	19	3.52	17	.895
	22.viii.78	24	2.04	5	.200

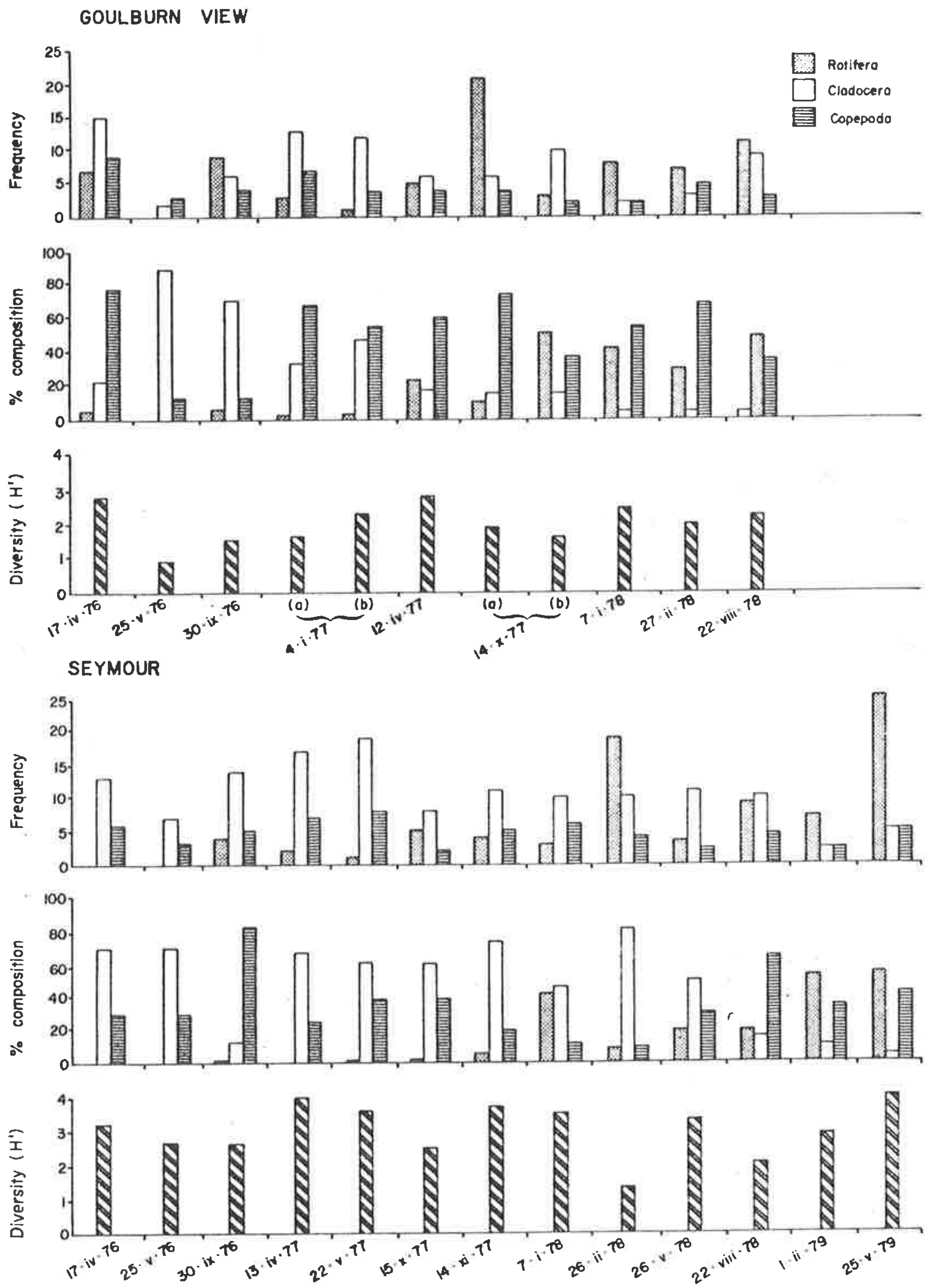


FIG. 6·10 Temporal changes in species composition and diversity of microfaunal assemblages in Goulburn View and Seymour billabongs.

In Goulburn View (4·i·77, 14·x·77) 'a' and 'b' refer respectively to northern and southern sampling sites.

winter, 51% chydorids (*B. setigera, P. globosus*), spring, 82% copepods (*B. triarticulata, B. fluvialis*); autumn 1977, 67% cladocerans (*C. cornuta, C. quadrangula*, chydorids); spring, 60% cladocerans (*B. affinis, D. carinata*); summer-autumn 1978, 97% cladocerans (*C. cornuta, C. quadrangula*); winter, 80% chydorids and copepodites; summer-autumn 1979, >50% rotifers (7-25 species).

Mean diversity was higher for the Goulburn series than for the Albury-Wodonga billabongs (Table 6.8). As in the latter, maximum species numbers occurred in autumn and spring. Diversity maxima tended also to be in autumn and spring, but this was variable. H' values for each sampling date are included in Appendix 6.3.

Environmental factors: Regressions of log density of predominant taxa and species diversity in each of the four billabongs on measured variables gave only two r^2 values > 0.20, both in Seymour billabong, which had the greatest variation in salinity. There was a positive correlation between the abundance of *C. quadrangula* and conductivity, however this was non-significant (r^2=0.56, F=1.36, P >.05. A significant negative correlation existed between species diversity and salinity (r^2=0.44, F=7.86, P <.05). Extremes were not recorded in other billabongs; as in the Murray series, detection of environmental cues probably was precluded by the patchy sampling program.

Contributions to the downstream microfauna: During prolonged flooding by the Goulburn in 1974, only 5% of the microcrustacea recorded from Eildon reservoir were collected from Goulburn View billabong (Shiel, 1976). Low survival may have been due to turbulence, or simply to dilution. In the present study, 91% (40 spp.) of the Eildon limnoplankton assemblage was recorded from floodplain habitats downstream, representing some 20% of the total microfauna identified from them. Most of these taxa were eurytopic and widely distributed.

As in the Murray, the proportion of the potamoplankton derived from floodplain and marginal habitats was directly related to increasing distance downstream. Fifty-one taxa recorded from billabongs (26%) occurred in Goulburn Weir, i.e. 82% of the Goulburn Weir assemblage. The lower proportion of billabong taxa persisting in Goulburn Weir than in Mulwala possibly reflects river flow differences, or hydrophyte community diversity/stability differences. Greater niche partitioning in Goulburn billabongs suggests individual taxa may have more stringent requirements which are not met in the rapidly fluctuating environment of the downstream impoundment, i.e. they are specialists rather than generalists. Only opportunist species with broad tolerances survive.

The billabongs sampled also were further from the river than were those on the Murray. Inflows from the Goulburn were not recorded during the study, although the floodplain between Eildon and Alexandra was inundated for most of 1974-75. Billabongs closer to the river did not have the diverse hydrophyte development of the marginal series, and fringing vegetation along the river margins was sparse. Incursions into the potamoplankton from these habitats would be expected to supply a less diverse microfauna.

6.4 Other billabongs

Comparative collections were taken from billabongs on the Mitta Mitta, Ovens, Murrumbidgee, Namoi and Moonie Rivers. A single series of collections was made from billabongs of the Magela Creek, a tributary of the Alligator River, N.T. for comparison with the plankton of the River Murray billabongs.

Species assemblages and trends of seasonality and diversity in the Ovens, Murrumbidgee and Mitta Mitta billabongs were similarly variable to those of the Murray. Only the Mitta Mitta billabongs are discussed here; they were of interest in relation to Dartmouth Dam, and quantitative samples were taken from them.

6.4.1 Mitta Mitta River billabongs (Fig. 6.11)

Four small billabongs on the western margin of the Mitta Mitta floodplain below Eskdale (Fig. 5.1) were sampled 1976-79. All were <2 m deep, with extensive open water. Physico-chemical features were similar to those of the Murray series, i.e. low conductivity, sodium bicarbonate water, pH 7.2-7.5, of high transparency. Algal communities were diverse, with desmid-diatom assemblages common. Fringing hydrophytes were less extensive than in the

Fig. 6.11: The Mitta Mitta River floodplain, view south towards the Bogong High Plains.

Murray or Goulburn billabongs. Limnetic zooplankton assemblages also were dissimilar to those of either the Murray or the Goulburn billabongs. The Mitta Mitta series was similarly heterogeneous; on any sampling date different species dominants and subdominants were present in adjacent billabongs, and seasonal succession in these communities was asynchronous. A single billabong near Eskdale ($36^{\circ}28'$ S, $147^{\circ}15'$ E) is given here as an example.

In summer 1977, 46% of the zooplankton was a species of *Tropocyclops*, with *B. falcatus* making up a further 24%. Neither species coincided in Murray billabongs. *B. meridionalis* (7%) and *B. quadridentatus* were subdominant, with 11 taxa, predominantly limnetic rotifers, making up the remaining percentage. Density was 112 ℓ^{-1}, H' 2.23.

Throughflow in autumn caused a reduction in plankton density and diversity *B. minuta* comprised 99% of the plankton, with only three other taxa recorded (*B. angularis, D. lumholtzi, Tropocyclops* spp.). Density was 42 ℓ^{-1}; H' 0.22.

In spring 1977, a diverse rotifer plankton occurred (H' 3.46), with three species of *Keratella* dominant (43%) and *D. lumholtzi* subdominant. No collection was made the following summer or autumn. In winter 1978 cladocerans predominated. *B. meridionalis, C. quadrangula* and *D. lumholtzi* comprised 53% of the plankton, *B. minuta* 32% and 10 taxa of rotifers 15% (79 ℓ^{-1}, H' 2.70).

In summer 1978, although two species of *Tropocyclops* were recorded, they were insignificant in the plankton. Twenty-nine taxa of rotifers, including three new taxa (cf. Koste & Shiel, 1980b) made up 48% of the community, with a further 48% made up of copepodites. Cosmopolitan eurytopic rotifers were most abundant (*K. cochlearis* 24%, *P. vulgaris* 12% and *K. tropica* 8%). Notably, nine taxa of *Brachionus* coexisted (*angularis, budapestinensis, calyciflorus, c. anuraeiformis, dichotomus, dichotomus reductus, falcatus, lyratus* and *quadridentatus melheni*) and six of *Trichocerca*. Approximately 24% of taxa recorded from this collection were not recorded elsewhere. Notable also was the occurrence of medusae of *Craspedacusta sowerbyi*, the first record from a billabong The species is known from Hume Reservoir (Walker & Hillman, 1977). Zooplankton density (672 ℓ^{-1}) and diversity (H' 3.56) were amongst the highest recorded from all habitats during the study. Similarly high densities occurred during autumn 1979 (482 ℓ^{-1}), with *K. cochlearis, K. quadrata* and *P. vulgaris* (59%) dominant, *B. meridionalis* (20%) subdominant.

Similar trends, with different species dominants were recorded from other billabongs on the Mitta Mitta floodplain. The distinctive nature of the microfaunal assemblage of each community was evident, comparable to that of the Murray and Goulburn billabongs. The Mitta Mitta billabongs apparently were the least "managed" of the billabong series, at least prior to construction of Dartmouth Dam; some were inaccessible to stock, not used for water supply, and generally little touched by human interference. The Goulburn billabongs were second in terms of community diversity, although some of the more "natural" billabongs had extremely complex communities, and the Murray billabongs, with the greatest human interference, had the lowest diversity. The effect of interference with billabong communities is considered later (see also Shiel, 1980).

6.5 Billabongs as refuges

As noted earlier, billabongs have long been noted for their importance as breeding refuges for an assortment of vertebrates, particularly frogs, fish and waterbirds. More than half of the available water on the floodplain may not provide appropriate conditions, i.e. the river itself, and other standing waters, e.g. impoundments, are both rare and either inaccessible or inhospitable to the species involved. Clearly, the shelter afforded by these shallow eutrophic habitats extends to the microfauna and macroinvertebrates, not only to the diverse vertebrate assemblage recorded in other studies.

In this study, of more than 400 zooplankton and littoral microinvertebrate taxa recorded from Murray-Darling waters, 45% of the Rotifera (117 taxa), 37% of the Cladocera (28 taxa), 23% of the Copepoda (9 taxa) and 75% of the Ostracoda (24 taxa) were confined to billabongs or were collected from adjacent shallow waters, apparently flushed from the billabongs. For many of these taxa, breeding populations were recorded only from billabongs, i.e. at least a third of the recorded species find suitable conditions only in these shallow, often ephemeral habitats. Some of the reasons are apparent from earlier discussion; abundant microniches, moderate physico-chemical conditions, limited effect of throughflow due to sheltering by hydrophyte beds, seasonal nutrient input from the floodplain, etc.

Given the heterogeneity of such conditions between billabongs, it is not surprising that disparate microfaunal communities have evolved to fill the available niches. While it is not yet appropriate to discuss the evolution of such communities under Australian conditions, i.e. so little is known of them, this study has provided considerable evidence that billabongs are centres of speciation. This was suggested following an earlier study of billabong microcrustacea (Shiel, 1976), but no further work has been published.

Of sixteen new taxa of Rotifera recorded during this study (see Table 4.1), 11 were from billabongs and five from the lower Murray. Three of the latter possibly are billabong or shallow water forms (*B. bidentata minor*, *B. keikoa* and *K. shieli*); they occurred in Darling floodwaters, and may have been flushed from lentic habitats on the Darling floodplain. Four new cladoceran taxa were recorded (Table 4.6). Two were billabong inhabitants, and two species of *Monospilus* recorded from Darling waters possibly also were flushed from the floodplain. At least three new harpacticoid copepods were recorded from Goulburn billabongs, and at least six new ostracod species occurred in Murray and Goulburn billabongs (P. De. Deckker, pers. comm.).

Notably, a small group of species confined to billabongs downstream of Eildon were northern hemisphere, particularly North American, in affinities. *Kurzia* was identified during the 1974 study (Shiel, 1976), *C. laticaudata* was recorded early in the present study, as were a variety of *L. ungulata* (var. *australiensis*), the typical form of which has not been recorded from the continent, *H. polyodonta*, and several widely-distributed (in the northern hemisphere) rotifer species recorded from Australia for the first time.

These remarkably discontinuous distributions suggested that introduction had occurred, and the most likely method could have been transport on heavy earthmoving equipment imported into Australia in 1954-56 by the Utah Construction COmpany to build the Eildon Dam. The transport of resting stages in dried mud is possible; stringent requirements for steam cleaning were not then enforced (Dept.Agric., Alexandra, pers. comm.). Although this is only conjecture, it is relevant that the Goulburn (and indeed the R. Murray) was in flood along its length in 1956; diapausing eggs or ephippia may have been carried from the construction site and colonised downstream billabongs. These isolated populations have in some cases evolved minor differences to the typical forms, but are the only representatives of the taxa in Australia. In any event, they are now established in restricted area of the basin, *viz.* billabongs between Eildon and Yea.

6.6 Concluding remarks

The major flooding recorded along Murray-Darling rivers during 1974-75 did not reoccur during this study, thereby precluding an assessment of the effect of flushing on the billabong communities. However, comparative information from a range of billabongs enables the following general statements to be made: The plankton of billabongs was considerably more variable between habitats than was the limnoplankton of the relatively more homogeneous impoundments. While genera were common to both lentic habitats, the species of billabongs generally were not those of lakes, although a small group of eurytopic taxa was widely distributed. Interchange between the plankton of upstream reservoirs, billabongs and downstream reservoirs was evident, with an increasing proportion of the potamoplankton downstream of dams derived from fringing or lentic habitats on the floodplain. Most marked differences between lake and billabong plankton communities were due to the high proportion of non-limnetic, i.e. littoral, epiphytic and epibenthic taxa occurring in the open water of billabongs. Community diversity was therefore considerably greater in billabongs. Plankton densities generally were two-tenfold higher than in nearby reservoirs, indicating the eutrophic nature of billabongs. High diversities, high average momentary species composition and large numbers of total taxa collected suggests that, in terms of community complexity, billabongs are the most diverse small aquatic habitats yet recorded, a unique product of climate, hydrology and biology.

7. POTAMOPLANKTON OF THE LOWER RIVER MURRAY

7.1 Introduction

Below the Murray-Darling confluence the river flows for ≃500 km to Lake Alexandrina. River water is used extensively for irrigation, particularly in the S.A. Riverland (Berri, Loxton, Waikerie)(Fig. 7.1), and for domestic supply to riverside towns and, by pipeline, Adelaide (80 km) and more distant centres on Spencer Gulf (>300 km).

In the irrigated reaches, soils are saline or sodic, and ground water generally is more saline than the river (E&WS, 1978). Irrigation returns increase river salinities, thereby creating problems of water quality for downstream use. As mentioned earlier (2.2.3), salinities may exceed acceptable WHO levels for much of the year. Additionally, high turbidities, high nutrient levels and accompanying algal blooms, and contaminants from multiple use, e.g. faecal pollutants and pesticides, may cause further deterioration of water quality. Filter clogging, taste and odour problems are common.

Most available information on hydrology and chemistry has been collected by water supply authorities, and has therefore been biased towards quality of water for abstraction, particularly into Adelaide's water supply reservoirs. Biological information is sparse (see 2.2.3); the only data on plankton prior to this study concerned nuisance algal blooms in relation to water quality (E&WS unpublished, see also Falter, 1978). A preliminary report on Murray-Darling zooplankton communities (Shiel, 1978) included information on lower Murray assemblages, and the lower Murray Rotifera were reported by Shiel (1979). The latter studies (see also Ch. 5) noted the biological consequences of disproportionate and highly variable flows from two discrete river systems. The potential for faunal dispersal between the two systems because of differences in timing of flooding was noted by Smith (1978), who regarded the systems as a transportation corridor. The distribution of northern Australian mollusc species was considerably extended by flood transport.

Investigation of the lower river plankton was directed towards determining the influence of the two discrete inputs, i.e. seasonal but highly variable flows with late summer-autumn peaks from the Darling, with abiogenic turbidity, low algal biomass and a rotifer dominated zooplankton vs. regulated flows from the Murray with spring peaks, biogenic turbidity, occasionally high algal biomass and a microcrustacean dominated zooplankton.

7.2 Sampling sites

During the first year of the project (May 1976-May 1977), 23 sites below the Murray-Darling confluence were sampled monthly-bi-monthly (Fig. 7.1). Seventeen of these were river sites (cf. Table 2.2), three were marginal lentic habitats, two impoundments (Lakes Bonney and Cullulleraine) and one a relatively saline irrigation return (Salt Creek, Berri). Fig. 7.2 shows the R. Murray at Mannum, S.A.

Initial longitudinal sampling showed considerable variation in water quality between sites, in part attributable to differences in sampling time, in flow rate, and to the effects of abstraction and multiple use. With the extent of longitudinal variability in mind, and the logistic and other difficulties of sampling flowing waters, it was considered more practical to use the most accessible site, Mannum, 80 km from Adelaide, as a base for more intensive sampling. For the remainder of the study Mannum was visited at least monthly. During passage of Darling floodwaters, sampling was weekly.

On each of 48 visits to Mannum the following were taken: physico-chemical measurement, a water sample for lab analysis, several 30 ℓ trap samples, a 30 m net tow and a cross-river tow. On three occasions a vertical series of trap samples at 2 m depth intervals 30 m apart was collected across the river. Additionally, a 24-hour series was taken from mid-stream. Vehicular ferries operated by the S.A. Highways Dept. facilitated sampling at Mannum. At this point the river is ≃300 m wide (max. depth 8.4 m, $\bar{x}$ depth 5.2 m). Riparian vegetation was predominantly eucalypts (*E. camaldulensis*) and willows (*Salix*

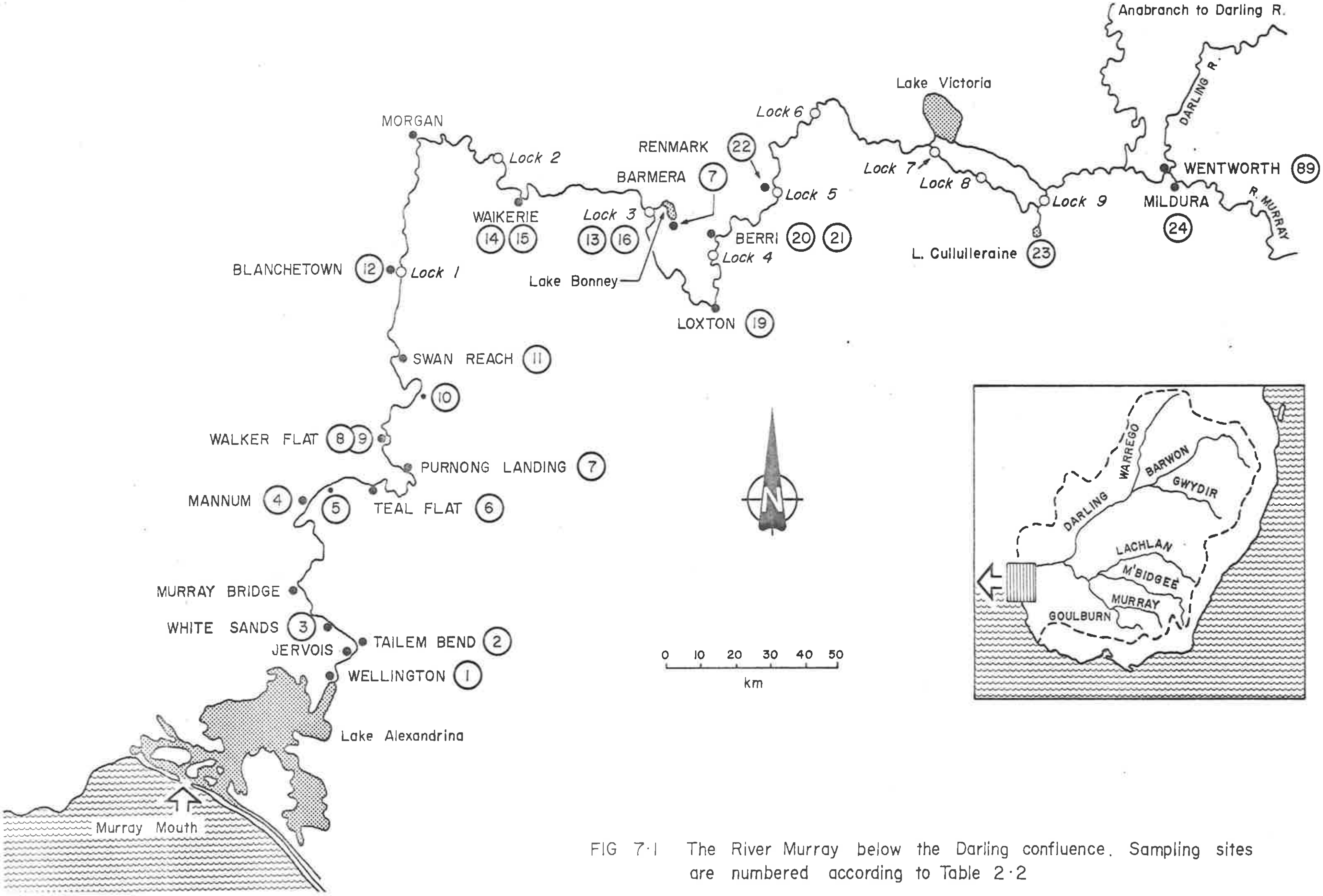


FIG 7·1 The River Murray below the Darling confluence. Sampling sites are numbered according to Table 2·2

Fig. 7.2: Main sampling site on the lower Murray at Mannum, S.A.

sp.).

7.3 Physico-chemical features

During the study the following were measured: air and water temperature, pH, dissolved oxygen, conductivity, TDS and turbidity. Major ions were measured during 1976. This was discontinued in view of the availability of more comprehensive data from the E.& W.S. Dept. Nutrient data also were available from the E.& W.S. Dept.

The Mannum data exemplify the variability of physico-chemical conditions in the lower Murray, with comparative information from other sites where relevant. Fluctuations in measured water quality are shown in Fig. 7.3 (full data are in Appendix 7.1) and discussed below. An example of diurnal variation is given in Fig. 7.4.

7.3.1 Temperature (Fig. 7.3a)

Air temperature at Mannum ranged from 4.0-31.0 °C ($\bar{x}$ 17.7 °C), water temperature from 8.5-25.5 °C ($\bar{x}$ 16.8 °C). Water temperature followed air temperature reasonably closely, a result of shallow river morphology and slow flow. Longitudinal variations of several degrees on a sampling date were due to differences in sampling time as well as variations within the water mass, i.e. 3-4 °C differences in surface temperature across the river, and 4-6 °C lower temperatures at 8 m depth in midstream were recorded at Mannum. Horizontal and vertical temperature differences were more pronounced in spring and summer than in autumn or winter. Fig. 7.5 includes an example of such horizontal and vertical variation. There were no major temperature changes with passage of Darling floodwaters.

7.3.2 pH (Fig. 7.3b)

A pH range of 7.0-8.8 ($\bar{x}$ 7.95) was recorded. A relatively rapid change accompanied alkaline Darling floodwaters in autumn 1977, with a less pronounced increase during the smaller 1978 flood. Highest pH levels were recorded during a late summer 1976-77 blue-green algal bloom (*Anabaena circinalis*

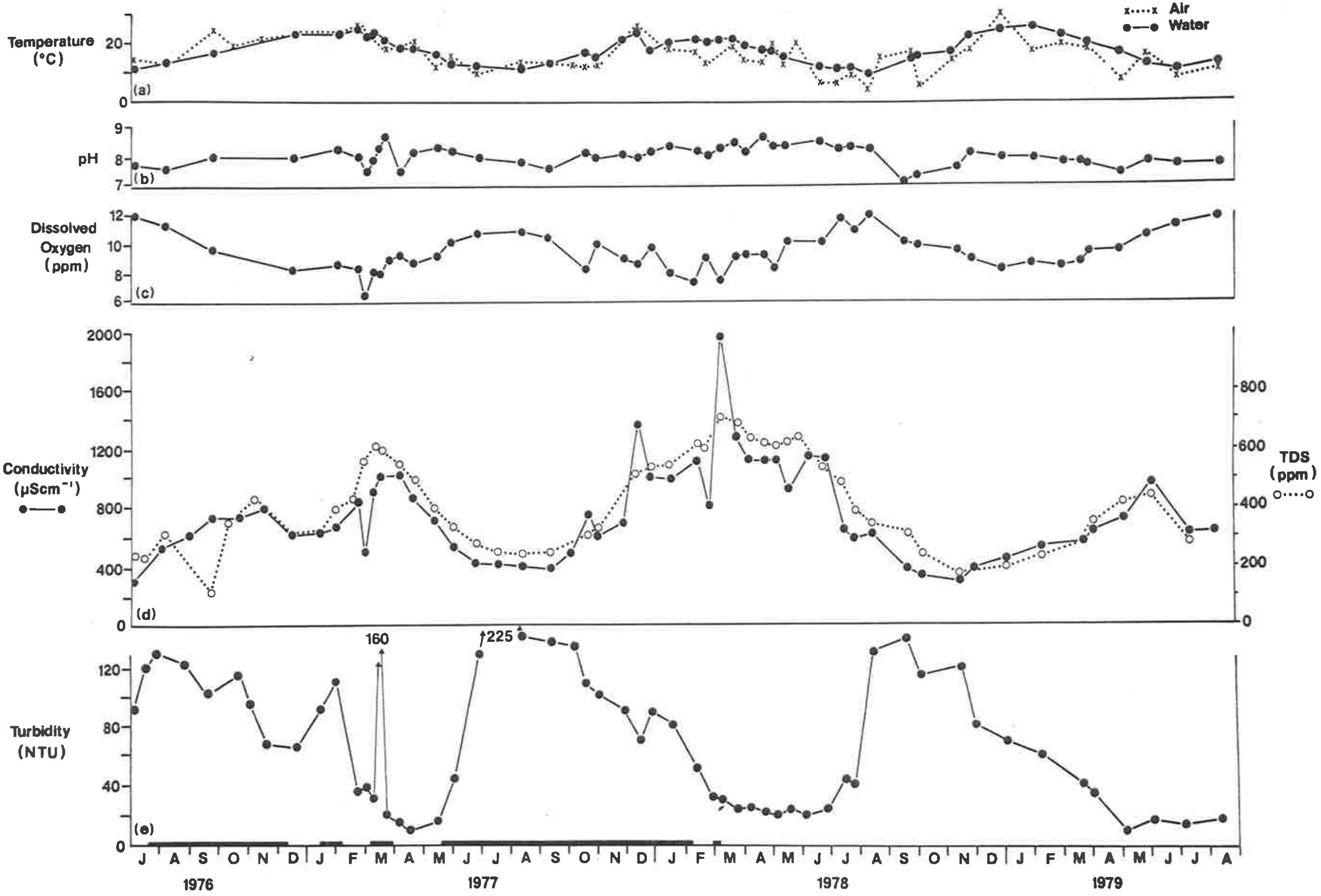


FIG. 7·3 Fluctuations in water quality (River Murray at Mannum)

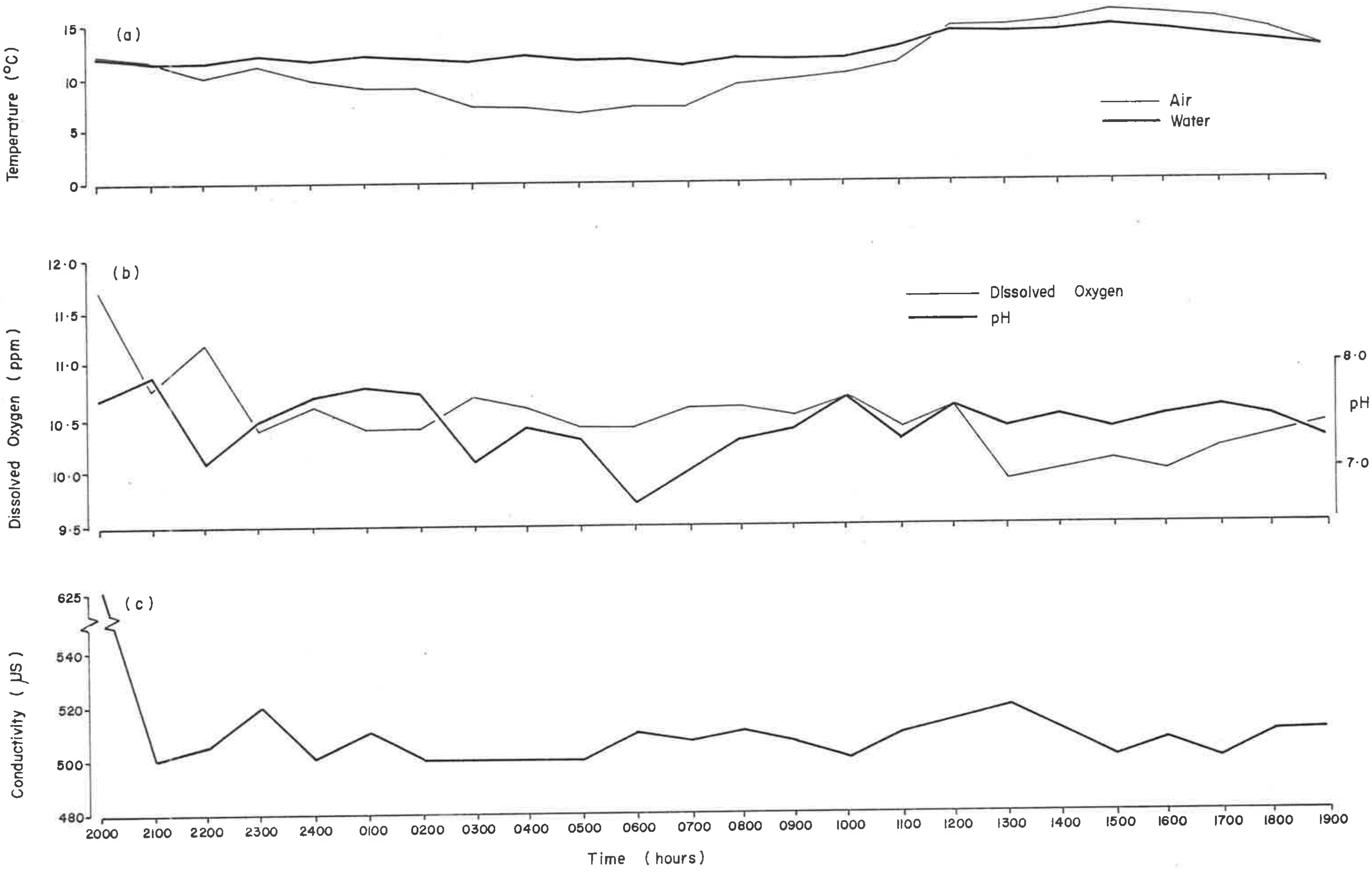


FIG. 7·4 Diurnal variations in some physico-chemical features of the River Murray, Mannum, S.A. (16·viii·7 - 17·viii·7)

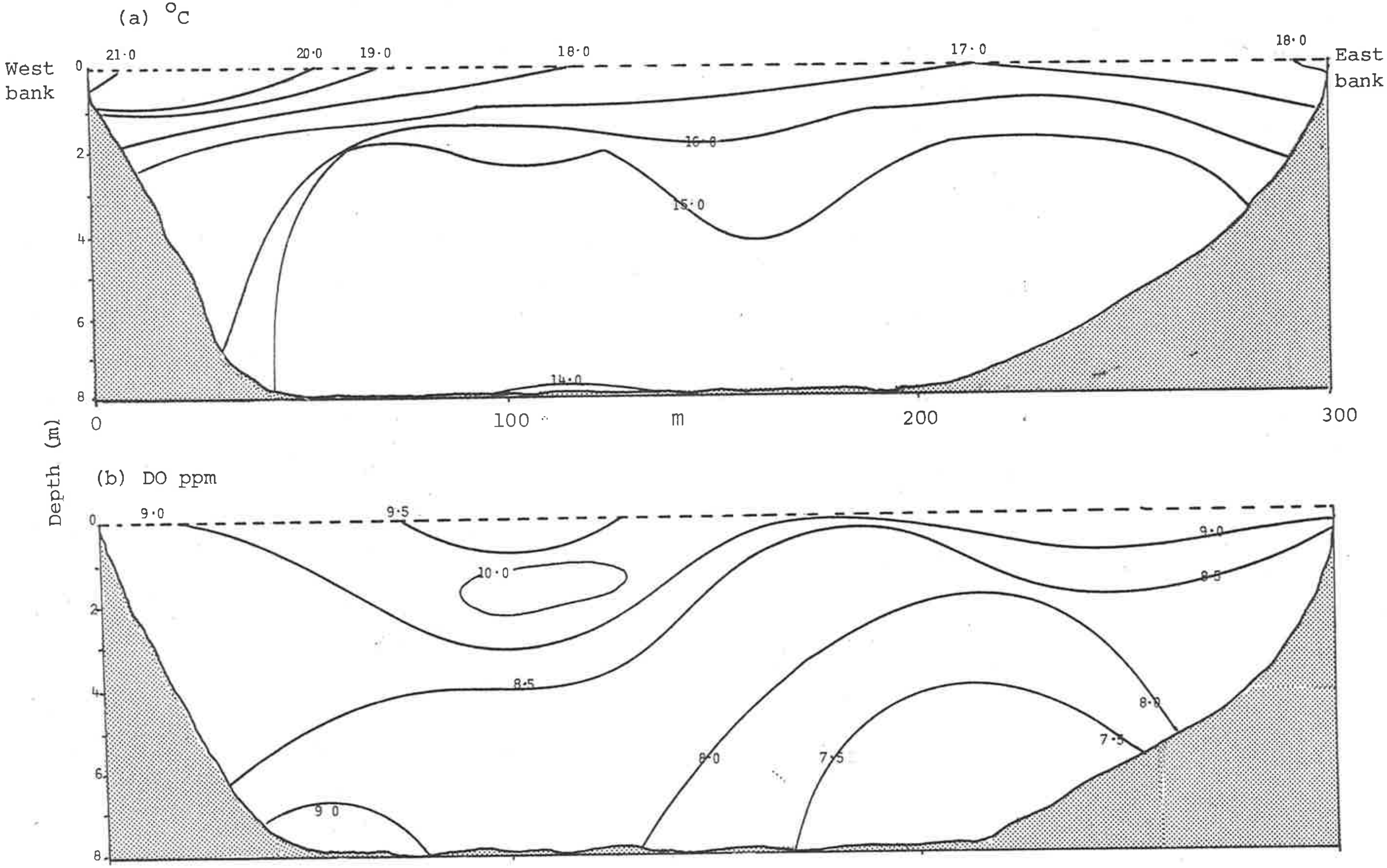


Fig. 7.5: Temperature (a) and dissolved oxygen (b) profiles, River Murray, Mannum 30.xi.77. Note that the river was warmer in the region of slower flow (west bank).

7.3.3 Dissolved oxygen (Fig. 7.3c)

DO levels rarely were below 90% saturation (range 6.4 - 12.00 ppm, $\bar{x}$ 9.4 ppm). Supersaturation occurred in winter, possibly due to turbulence. Lowest levels were recorded during the autumn 1977 Darling flood, when organic detritus accounted for the high turbidities; decomposition may have resulted in the slight oxygen depletion. DO levels were correlated with temperature ($r^2 = 0.65$, $P < .05$).

7.3.4 Conductivity & TDS (Fig. 7.3d)

Increasing salinities, largely due to modifications of the Murray flow regime and irrigation practises, are regarded as the major threat to water quality. Highest salinities occur over summer when flows are lowest and abstraction and irrigation returns are greatest. Irrigation returns show as more saline slugs travelling downstream. An average of 3000 tonnes of salt passes downstream daily (E&WS, 1977). During dry summers flushing flows may be released from upstream reservoirs, e.g. Lake Victoria, Fig. 7.1, to alleviate excessive salinities. Lake Victoria was drawn down in late summer 1976-77; diluting flows passed Mannum in late February. Flows were lower during 1977-78, and salinity correspondingly higher. A peak of 1950 $\mu S\ cm^{-1}$ was recorded at Mannum on March 9th, 1978. The following summer higher flows were maintained; salinity increases were less pronounced. Mean conductivity over the study was 930 $\mu S\ cm^{-1}$, mean TDS were 409 ppm.

7.3.5 Turbidity (Fig. 7.3e)

The lower river was characteristically highly turbid (range 18-225 NTU, $\bar{x}$ 70). Only during late summer-autumn was there relatively high transparency. High turbidity Darling flows were apparent during autumn-winter each year, i.e. typically chalk coloured due to suspended clays. A dense bloom of *Melosira* contributed to high turbidities in winter-spring 1978. The significance of high turbidities and algal blooms are considered later.

7.3.6 Major ions and nutrients

Major ion dominances during 1976-79 were as follows (ranges and means in mg ℓ^{-1}): <u>Cations</u> - Na (32-174, $\bar{x}$ 92) > Ca (15-55, $\bar{x}$ 25) $\gtrless$ Mg (8-28, $\bar{x}$ 17) $\gtrless$ K

(2.6-9.3, $\bar{x}$ 6.0); Anions - HCO_3 (67-189, $\bar{x}$ 137) $\gtrless$ Cl (46-290, $\bar{x}$ 136) > SO_4 (8-38, $\bar{x}$ 31), i.e. marked differences from world average fresh water, also from the predicted proportions for Australian fresh water (cf. Williams, 1967; Bayly & Williams, 1973; Buckney, 1980) particularly for bicarbonate levels. The influence of saline irrigation returns was apparent in the marked increase in NaCl levels over summer.

PO_4-P (0.03-0.29, $\bar{x}$ 0.13) and NO_3-N (0.1-2.7, $\bar{x}$ 0.8) levels generally were highest in winter-spring, lowest in summer. Utilization by algae in summer is suggested. Similiarly, silica, important for diatom growth, was highest in winter-spring, lowest in summer (1-19, $\bar{x}$ 8.3) coincident with *Cyclotella* and *Melosira* blooms. Nutrient levels were considerably higher for much of the year than upstream levels reported by Walker & Hillman (1977), and generally were indicative of eutrophy.

In summary, the major factors likely to influence the plankton were temperature, turbidity and salinity. The lower river, with few physico-chemical extremes, provides a habitat with features of both lotic and lentic environments: low flow rates, shallow morphology, seasonally high turbidity, salinity and nutrient levels, i.e. some features conducive to the development of a diverse plankton assemblage, others acting to reduce diversity. These influences were not readily separable, i.e. as noted earlier, there are inherent difficulties in attributing compositional changes to single factors. In the following section on plankton composition, more attention is given to the effects of environmental variables on the zooplankton; the phytoplankton is considered briefly.

7.4 Phytoplankton

During 1976, 30 ℓ trap samples taken with a 20 μm mesh were subsampled, and phytoplankters in 1 ml aliquots were enumerated in a Lund cell. Algal counts were discontinued from January 1977 when access was provided to comprehensive quantitative data from Mannum (E&WS, unpublished). Predominant genera and relative abundance only were recorded thereafter. Part of the E&WS

data was recorded in Areal Standard Units. These were converted to cells ml^{-1} by appropriate conversion factors (C. Bell, E&WS, Bolivar, S.A. pers. comm.).

In view of taxonomic difficulties, phytoplankters usually were identified only to genera; in some cases bloom species were sent for expert identification. Thirty-five genera were recorded during 1976-79, with possibly twice as many species i.e. congeners were common in several taxa, e.g. *Cyclotella, Melosira.* Table 7.1 lists genera and gives relative abundance, i.e. the percentage of samples in which the genus occurred. Data on community composition, density and seasonality are shown in Fig. 7.6 and described briefly below.

7.4.1 Community composition

Although 6-15 algal genera were present in any sample, only one or two usually were numerically abundant. With few exceptions these were diatoms (*Cyclotella, Gyrosigma, Melosira, Synedra*), with seasonal pulses of green algae (*Closterium, Hormidium, Oocystis*) and blue-green algae (*Anabaena, Anacystis, Oscillatoria*). Occurrence of all genera is shown in Fig. 7.6a.

Seasonal fluctuations were as follows: during 1976 diatoms predominated, with a small pulse of the chlorophytes *Closterium* and *Hormidium* in spring. Algal densities were low ($\bar{x}$ 361 ml^{-1}). A late summer pulse of *Hormidium* and *Oocystis* (26%) and *Anabaena/Anacystis* (67%) (cf. Fig.7.6b) reached 5000+ cells ml^{-1}. Diluting flows from Lake Victoria flushed this bloom from the lower river in February 1977, and algal densities remained low (< 200 cells ml^{-1}) until the following summer. No phytoplankters were present during spring-summer 1977. There were three major blooms during 1978; *Cyclotella* in autumn (>4,000 cells ml^{-1}), a small pulse of *Melosira* in winter (≃2,000 cells ml^{-1}) and a large *Melosira* bloom in spring-summer ($\bar{x}$ 5038 cells ml^{-1}, max. 25,636 cells ml^{-1}). *Melosira* densities declined through summer-autumn 1979, when a small pulse of the flagellate *Cryptomonas* was recorded. *Melosira* increased to a peak of 9,000 cells ml^{-1} by winter, when sampling ended.

Clearly, although the lower Murray phytoplankton assemblage is a typical riverine diatom-dominated community, there is considerable variation in response to wide fluctuations in water quality, e.g. absence of synchronous blooms each year. The typical spring diatom bloom and late summer blue-green algal peaks described by Falter (1978) did not consistently occur, i.e. only a single blue-green pulse was recorded, and there was no spring diatom bloom in 1976 or 1977.

7.4.2 Environmental factors

The role of environmental variables in regulating phytoplankton succession was reviewed by Hutchinson (1967). In the present study a combination of temperature, turbidity and nutrient availability were implicated as important in phytoplankton dynamics in the lower Murray. During 1976 there was a significant negative correlation between *Melosira* density and turbidity (r^2=0.46, $P< .05$), although Falter (1978) did not consider spring turbidity ranges to be limiting, i.e. *M. granulata* and *Synedra* are low light forms and can bloom at high turbidities. Falter noted also that at low turbidities (< 30 NTU) and temperatures over 22 °C in summer, blue-green algae would bloom at low NO_3-N levels, i.e. by fixing their own nitrogen and thereby outcompeting green algae and diatoms. This accounts for the summer-autumn 1977 blue-green pulse. The following summer, with appropriate turbidities, temperatures were below optimum for blue-greens, and the bloom species was a diatom, *Cyclotella*. The same situation applied in summer 1978-79. *Cyclotella* apparently has a higher temperature tolerance and light requirement than *Melosira*. During winter-spring 1977, *Melosira* biomass was negatively correlated with temperature (r^2= 0.47, $P< .05$), with an upper limit around 22 °C. *Cyclotella* appeared during late spring, and persisted until mid-winter 1978, disappearing at temperatures around 14 °C. *Cyclotella* biomass was significantly correlated with temperature (r^2= 0.62, $P< .05$).

There was no significant correlation between salinity and algal biomass, i.e. salinity *per se* did not influence the phytoplankton; species absent during high salinities were limited by other factors, e.g. light or temperature. There was no readily apparent reason for the sudden drop in algal biomass over spring-summer 1977, however a trophic effect is suggested, i.e. a large spring

Table 7.1: Phytoplankton genera recorded from the River Murray at Mannum. Frequency of occurrence is shown as ++++ >50% of samples, +++ 30-49%, ++ 10-29%, + <10%.

	Chlorophyceae	
1	*Chlamydomonas*	+
2	*Closterium*	+++
3	*Coelastrum*	+
4	*Eudorina*	+
5	*Hormidium*	++
6	*Oocystis*	++
7	*Pandorina*	+
8	*Pediastrum*	+
9	*Scenedesmus*	+
10	*Schroederia*	+
11	*Sphaerocystis*	+
12	*Spirogyra*	+
13	*Staurastrum*	+
14	*Volvox*	+
	Xanthophyceae	
15	*Botryococcus*	+
	Chrysophyceae	
16	*Synura*	+
	Bacillariophyceae	
17	*Actinostrum*	+
18	*Asterionella*	++
19	*Cyclotella*	++++
20	*Gyrosigma*	+
21	*Melosira*	++++
22	*Nitzschia*	+
23	*Pinnularia*	+
24	*Surirella*	+
25	*Synedra*	+++
	Dinophyceae	
26	*Ceratium*	+
27	*Glenodinium*	+
	Euglenophyta	
28	*Euglena*	++
29	*Phacus*	+
30	*Trachelomonas*	+
	Cyanophyta	
31	*Anabaena*	++
32	*Anacystis*	++
33	*Oscillatoria*	+
	Others	
34	*Geleliella*	+
35	*Cryptomonas*	++

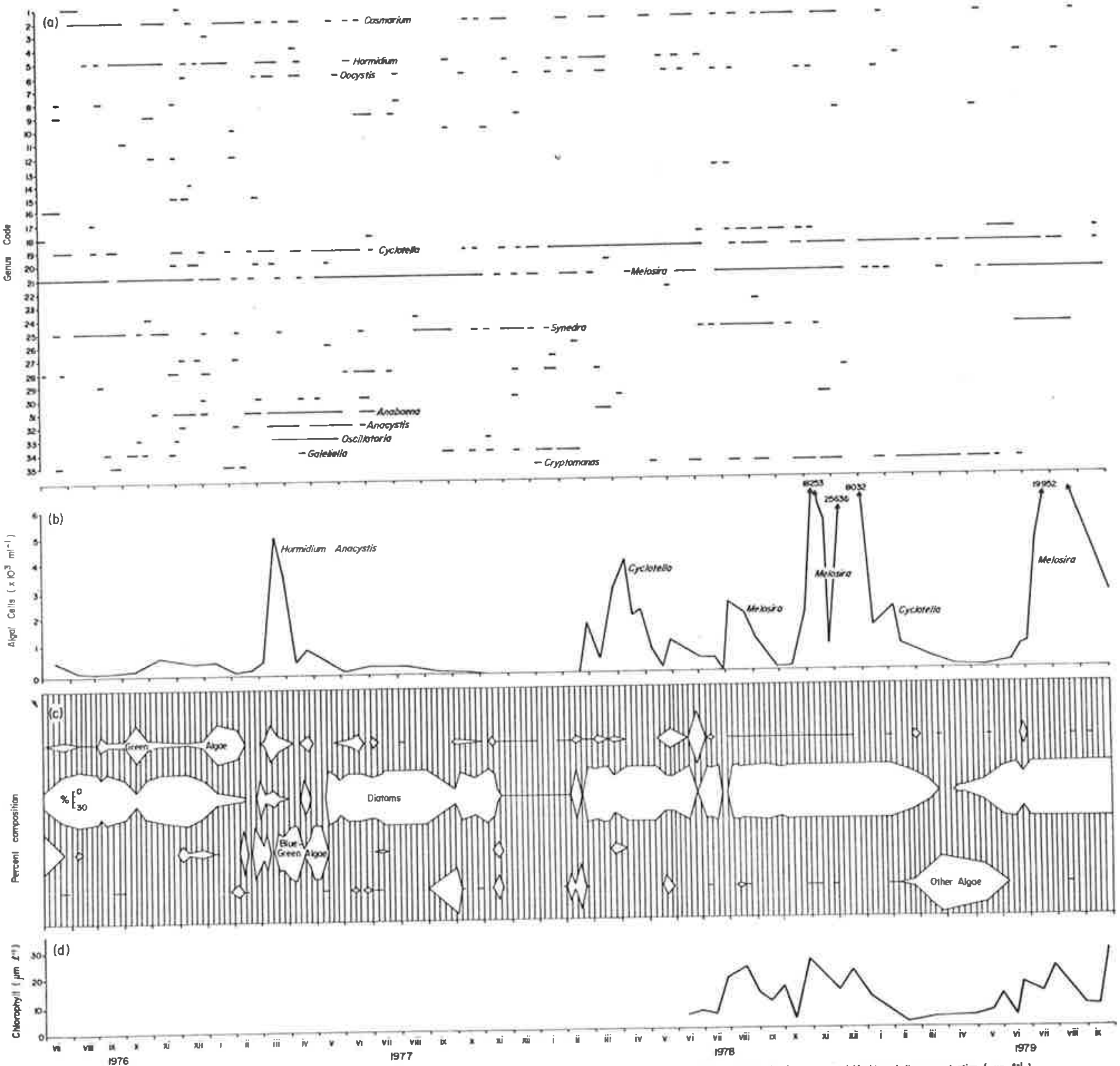


FIG. 7·6 Temporal variations in LM phytoplankton composition (Mannum) (a) seasonal occurrence ; (b) density ml⁻¹ ; (c) percent composition of dominant groups ; (d) chlorophyll concentration (μg ℓ⁻¹)

pulse ($\approx 200\ \ell^{-1}$) of herbivorous zooplankters, particularly *M. micrura*, *B. meridionalis* and *B. triarticulata*. Possible trophic relationships are considered later.

Algal densities were in general within the ranges found in other turbid rivers, e.g. the Nile had a mean algal density of 5828 cells ml^{-1} during 1951-53, with a *Melosira* bloom (27,840 cells ml^{-1}) in November (Rzoska, Brooke & Prowse, 1955). Unlike slower Murray floods, those of the Nile decimated the plankton. Considerably lower densities occurred in the highly turbid Missouri River (total plankton 67.4 ℓ^{-1}) (Berner, 1951). Contributing factors were high turbidity, high current velocity and lack of adjacent lentic habitats. Lower algal densities also are reported from, for example, the Mississippi ($\approx 5 \times 10^4$ cells ℓ^{-1}) (Reinhard, 1931), the Sacramento ($2\text{-}10 \times 10^3$ cells ℓ^{-1})(Greenberg, 1954) and the polluted River Yamuna ($34\text{-}48 \times 10^3$ cells ℓ^{-1})(Rai, 1974). Comparisons with many other earlier studies are impossible due to the use of settled volumes or areal units in algal biomass estimates.

Clearly, as in studies of river phytoplankton elsewhere, a complex of abiotic and biotic factors influence algal development in the River Murray. Although these could not adequately be assessed in the present study, the following generalizations apply: the same genera, and in some cases the same species, occur in the Murray as are found in other rivers, and diatoms predominate. Temperature, turbidity and nutrient levels are major influences in controlling algal blooms, which commonly occur in winter, spring or summer. Because of variability in water quality, the same species may not bloom at the same time in consecutive years.

7.5 Zooplankton

133 taxa of zooplankters were identified from LM collections. 86 were Rotifera, 32 Cladocera, 13 Copepoda and 2 Ostracoda. As for the phytoplankton, there was considerable longitudinal variability in community composition on any date, and, on occasions, marked community differences across the river. It is pertinent, therefore, to summarise data from the 1976 sampling series for

comparison with other studies. The remainder of this section considers temporal variation in the potamoplankton at Mannum, including diurnal fluctuations in community composition. The extent of spatial variability across the river also is considered briefly to emphasize some of the problems encountered in sampling a moving, heterogeneous water mass.

7.5.1 Longitudinal variability in community composition

Fig. 7.7 shows variations in zooplankton density (plankters ℓ^{-1}) at 8 LM stations during 1976-77. For logistic reasons sampling was not carried out for the full year at all stations. Nevertheless, the following trends are clear: high winter flows were inimical to plankton development; densities were uniformly low. Marked increases in density and diversity occurred in spring. These generally were greatest in the Riverland reaches, where locks impede flows and higher nutrient levels promote algal blooms (cf. Falter, 1978).

Although similar species assemblages occurred at each station, there were marked differences in relative proportions, diversity and density. On 27/28.ix.76, for example, the dominant plankter at Mannum was *B. meridionalis* (44%), with *K. australis* (35%) and *F. longiseta*(14%) subdominant. Density was 28.3 ℓ^{-1} (cf. algal density 186 x 10^3 ℓ^{-1}) and H' 1.90. Just upstream at Walker Flat, *B. meridionalis* comprised 58%, *K. australis* 21% and *F. longiseta* 8% (density 47.5 ℓ^{-1}, H' 1.86). At Loxton, the order of dominance was *B. meridionalis* (43%), *F. pejleri* (23%)(*F. longiseta* was present, but not more than 2%) and *K australis* (15%) (density 350 ℓ^{-1}, H' 2.14). No algae were present; detritus apparently was an important food source. Rotifers were observed feeding on and in the large amount of suspended organic debris, particularly microcrustacean remains. At Berri, *B. meridionalis* comprised 34% of the plankton assemblage, *C. dossuarius* 23%, *F. pejleri* 19% and *K. australi* 14% (density 328.6 ℓ^{-1}, H' 2.35). At Renmark the dominant plankter was a rotifer, *B. urceolaris* (52%), with *B. meridionalis* (11%), *K. australis* (9%) and *C. quadrangula* (7%) subdominant (density 23.7 ℓ^{-1}, H' 2.46).

With reduced flows over summer there was more pronounced disparity

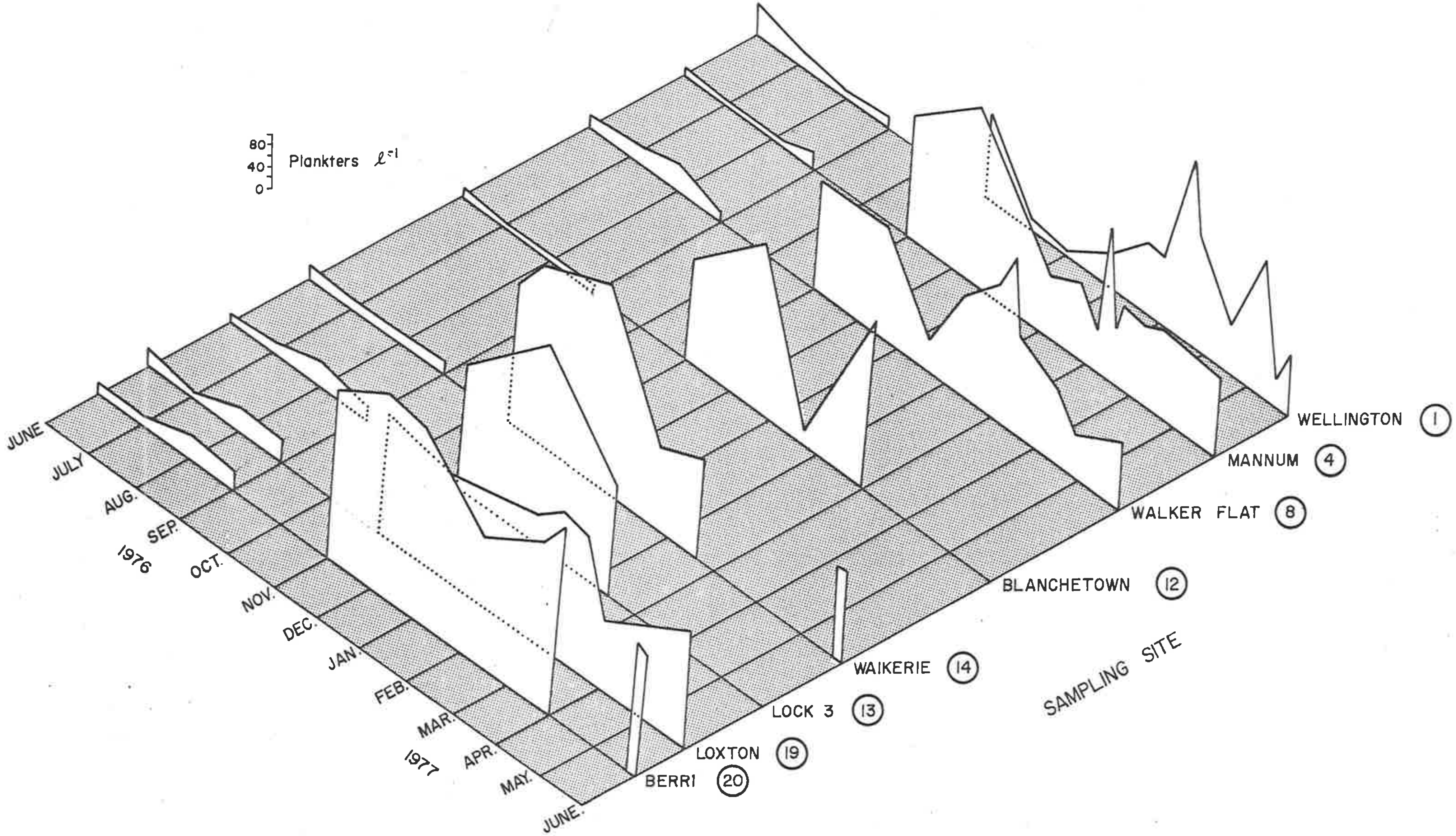


FIG. 7·7 Longitudinal variation in LM zooplankton 1976-77 expressed as plankters ℓ^{-1}

in species assemblages between stations, with blooms of some species recorded only at single sites, e.g. on 17.xii.76, 320 plankters ℓ^{-1} occurred at Mannum, (H' 1.67). Of these, 74% were *B. caudatus* f. *austrogenitus*, a pantropical acid water species (pH 5.8-6.4) typical of standing waters (Koste, 1978 and pers. comm.). pH of the river at the time was 8.0. This pulse was the only record of the taxon during the study. Downstream at Wellington on the same day the dominants were *P. complanata* (43%) and copepodite stages of *B. triarticulata* (39%) (15.8 plankters ℓ^{-1}, H' 3.06). *B. caudatus* was not present in samples from Wellington, or from collections upstream at Walker Flat.

A marked decrease in plankton density early in 1977 may have resulted from releases from Lake Victoria or an upstream Murray reservoir, i.e. increased turbulence/velocity and reduction of the plankton, or it may have been due to a slug of "plankton-dilute" floodwater preceding the main Darling flood, which reached Mannum in March. An abrupt peak in plankton density was recorded at the three southernmost stations. At Mannum, for example, on 3.iii.77, *B. triarticulata* predominated (42%), with *B. meridionalis* subdominant (33%) (density 65 ℓ^{-1}, H' 2.71). A peak of 267 ℓ^{-1} occurred on 8.iii.77 (copepodites 67%, *K. australis* 10%, *F. pejleri* 9%, H' 3.18). On 16.iii.77 there were 93 plankters ℓ^{-1}, with the same three dominants. This pulse apparently passed Tailem Bend around 22.iii.77, essentially little changed in composition.

During 1977-78 and 1978-79 sampling was primarily at Mannum, with comparative samples taken at both upstream and downstream stations. The influence of irrigation downstream of Mannum was apparent; higher densities and diversities similar to those of the Riverland were common at Tailem Bend. In general, trends were as for 1976-77, although the same taxa did not occur synchronously each year. Environmental influences are considered with the Mannum data.

In summary, the lower Murray zooplankton assemblage was more complex than that of the upper and middle reaches. Densities and diversities generally were higher, particularly in the irrigated reaches. As reported in other potamoplankton studies, there were discrete "clouds" of zooplankton which maintained their integrity as they moved downstream. Seasonal pulses occurred in regions of slow flow, possibly in response to increased nutrient levels and flow reduction. Nutrients, particularly in the form of organic detritus, may have been responsible for increases in plankton biomass accompanying floodwaters. Distinct pulses followed spring and summer phytoplankton blooms. In some years, high winter flows reduced plankton density. Darling floods produced rapid changes in zooplankton composition, introducing into the lower Murray an assemblage dominated by tropical Rotifera.

7.5.2 Cross-river variability

Considerable differences in species composition between marginal and mid-river zooplankton assemblages were apparent during the early sampling program. To assess this variability quantitatively, the cross-river ferry at Mannum was used to take trap samples from 2 m and 5 m depths at 30 m intervals across the river in summer, autumn and spring, 1977. A winter series was abandoned when high current velocities prevented lowering either the Schindler trap or a van Dorn bottle.

Least variability occurred in autumn (20.iv.77),suggesting greater homogeneity produced by the mixing effect of Darling floodwaters. Greatest variability occurred in spring (30.xi.77). Table 7.2 shows compositional differences in the spring zooplankton assemblage along a transect at Mannum. Counts represent 10 ml aliqouts from 30 ℓ trap samples made up to 40 ml with distilled water.

Of the 31 taxa collected in a series of traps, 11 were common. The remainder were rare components of the potamoplankton, occurring in only one or two samples in low numbers. All 31, and an additional 4 rotifer species, were present in a cross-river tow sample taken immediately after the trap series. To determine the extent of variation in observed proportions from that expected if each of the relatively abundant species was uniformly distributed, species numbers at each site were treated as sampling units and arranged in a contingency table (11 columns, 9 rows). H_0 was that each sampling unit was in the same

Table 7.2: Composition of multiple trap samples taken at 2m and 5m depths on a cross-river transect at Mannum, spring 1977. Distances are measured from west bank. Count/10 ml aliquot.

Sp.code	W. bank	30 m		60 m		90 m		200 m	
Rot.	1m	2m	5m	2m	5m	2m	5m	2m	5m
15		2							
24									1
33	22	34	10	15	25	19	30	107	193
36	2								
48	10	16	13	13	12	4	9	52	39
49	10	9	2	4	2				
52			1		1				
55	1		1	3	7	8	5	6	6
57		2							
148		1							
185		1							
194							1	2	2
214	2	1	1		1	1		4	15
232	2						1	1	
239	3	4	3	2	4	1	22	10	30
245		1							
Clad.									
4	1	2		3	11	10	13	4	7
13	1								
16	1								
21					1				
27	1								
60	198	141	52	67	180	288	293	449	565
62	62	11	9	7	9	5	21	37	59
63		2			7	1	1		
70		6	2						
73	36	2	9	45	175	17	103	94	113
Cop.									
7	30		15	11	20	30	51	98	83
9	2					1		2	3
14						1			
23						1	2	3	1
32			1						
cop's	98	14	56	85	71	62	84	153	334
ℓ^{-1}	64.4	49.2	23.3	34.0	70.0	59.7	84.8	136.5	192.5
S_T	17	16	13	10	14	14	13	15	15

proportion at each site. Expected values were calculated as in Elliott (1971). Observed and expected values were compared by the standard χ^2 test. H_o was rejected at the 1% level (χ^2=1001.92, with $v=(11-1)(9-1)=80$ degrees of freedom).

Although all common taxa were contagiously distributed (variance>mean), significant χ^2 values were found only for *B. meridionalis, C. quadrangula, M. micrura* and calanoid copepodites. All were considerably more abundant in midstream than at the margins. Overall plankton density was 2-3 times greater in midstream, and apparently greater at 5 m than at the surface.

Given the longitudinal and cross-river contagion in the potamoplankton, subsequent sampling at Mannum clearly was a compromise. Cross-river tows were accepted as representing proportional composition adequately, and one or two trap samples as representative of density at the sampling site, with (seasonally) two- or three-fold differences in density across the river. Order-of-magnitude differences were recorded from longitudinal samples, but not from cross-river collections.

In the following section, the species composition and dynamics of the zooplankton at Mannum is described, the influence of environmental variables is assessed, and features of the autecology of dominant species are considered. The River Murray potamoplankton is then considered in relation to that of other major rivers.

7.5.3 Temporal variation in the lower Murray zooplankton

Fluctuations in plankton composition, density and diversity are summarized in Fig. 7.8 and described below. Raw data are included in Appendix 7.2.

Community composition

In terms of species numbers (Fig. 7.8b), Rotifera > Cladocera > Copepoda was the usual sequence. Average momentary species composition at Mannum was 14.4 rotifers, 6.0 cladocerans, 2.4 copepods and 0.1 ostracods (n=42). Maximum species numbers occurred in autumn and late spring each year, with up to 35 species present in the potamoplankton. Minimum species numbers (11-15 taxa)

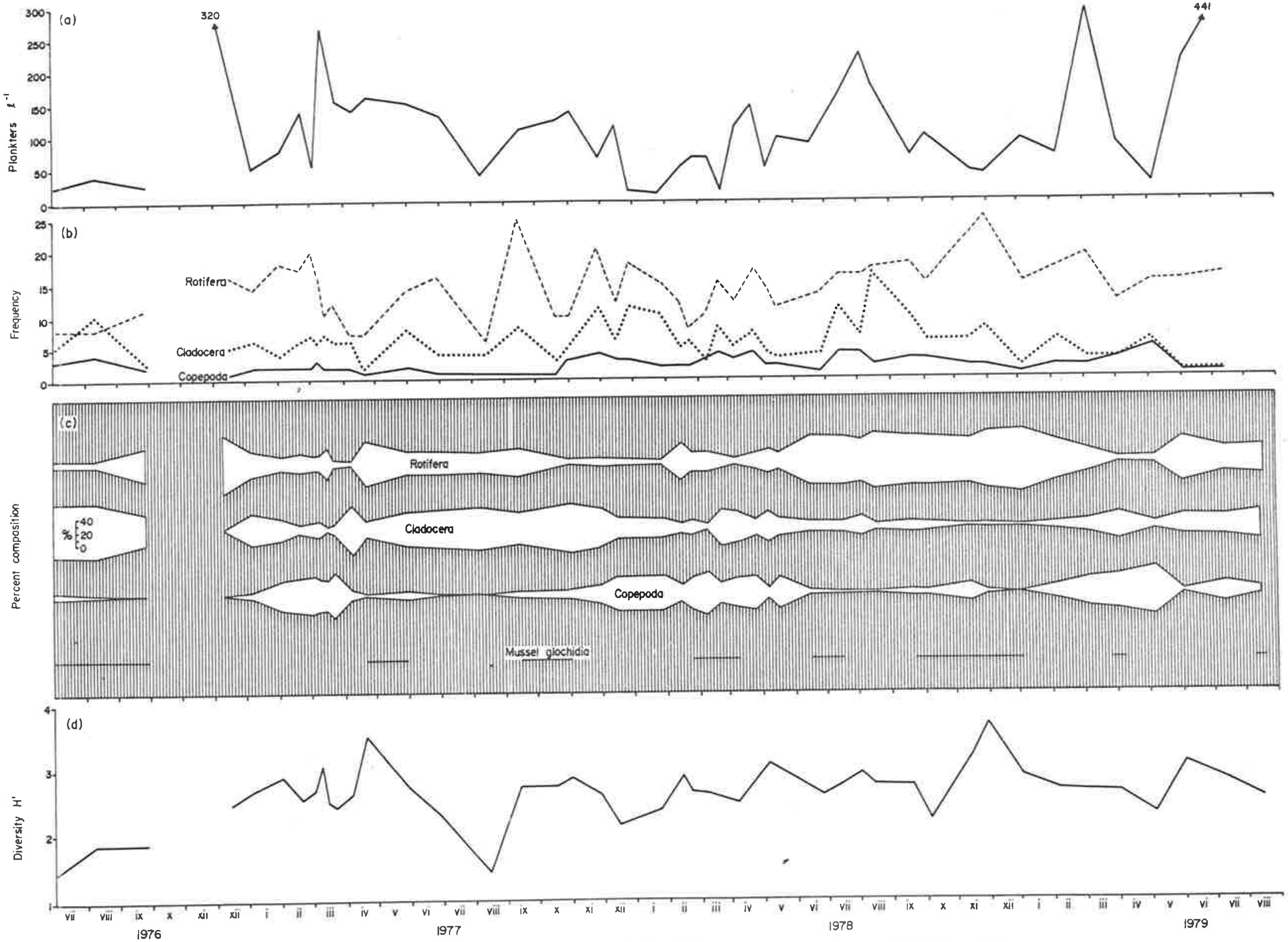


FIG. 7·8 Temporal variations in LM zooplankton composition (Mannum). (a) density; (b) no. of species of Rotifera, Cladocera and Copepoda; (c) percent composition; (d) diversity.

were in winter and early spring. Zooplankton density (Fig. 7.8a)(range 16-993 ℓ^{-1}, $\bar{x}$ 119 ℓ^{-1}) was highest in autumn and spring associated with Darling floodwaters and Murray algal blooms, lowest during winter and summer. Trends were similar to those of the phytoplankton (cf. Fig. 7.6a), suggesting a trophic relationship. This is considered later, as also is diversity.

Plankton composition fluctuated each year (Fig. 7.8c), e.g. during low flows of late 1976 and throughout 1977 cladocerans predominated, with a pulse of rotifers introduced by Darling flows each autumn. In the higher volume flows of 1978-79 (cf. Fig. 2.10), rotifers predominated, with cladocerans largely insignificant. There was a marked synchronous pulse of copepods each summer. Species composition and trends in the potamoplankton community are considered briefly below.

B. meridionalis comprised ≃75% of the plankton through winter 1976, with *A. brightwelli* (10%) and *B. triarticulata* (5%) subdominant. Some twenty other taxa were rare. Densities were low (<40 ℓ^{-1}). In spring, *B. meridionalis* (44%) still dominated, with *K. australis* (35%) and *F. longiseta* (14%) subdominant (density 28.3 ℓ^{-1}). In summer 1976-77 a bloom of *B. caudatus* f. *austrogenitus* occurred along the western margin of the river (noted earlier, density 320 ℓ^{-1}), with a distinctly different midstream community, i.e. *B. meridionalis* (36%) and four other taxa of *Brachionus*(32%) predominant (52 ℓ^{-1}). Six rotifer taxa were recorded from midstream, while a diverse assemblage with 16 taxa occurred in the western margins.

A late summer pulse of microcrustacea (*B. meridionalis, B. triarticulata*) occurred in February 1977, and comprised 78% of the plankton. Twenty-three taxa made up the remainder of the potamoplankton. These two dominants persisted through autumn, with an appearance in March of *M. micrura* accompanying a *Hormidium/Anacystis* bloom. Density (267 ℓ^{-1}) and diversity (H' 3.12) were high.

An initial flush of Darling floodwater in autumn brought a copepodite-rotifer pulse (copepodites 46%, 43 ℓ^{-1}, rotifers, particularly *K. australis* and *F. terminalis*, 36%, 93 ℓ^{-1}). This pulse of calanoid copepodites passed

Mannum in mid autumn, to be replaced by a very diverse (H' 3.55) rotifer plankton (23 of 33 taxa recorded, 69%) with tropical Darling forms predominant, e.g. *B. calyciflorus* Darling form, f. *anuraeiformis*, *B. budapestinensis*, *B. falcatus*). The most abundant cladoceran was *C. cornuta*. This assemblage was replaced in early winter, and for the remainder of 1977, by *B. meridionalis* and *C. quadrangula* dominants, with a late spring-summer reoccurrence of *M. micrura* The latter persisted over summer (32%), with *B. triarticulata*, largely as copepodites, predominant. Densities were considerably lower over the 1977-78 summer than previously (<20 ℓ^{-1}), but high diversity was maintained (H' 3.26). The late summer assemblage was dominated by rotifers and copepodites, with 12 taxa of rotifers camprising 58% of the plankton in mid February.

The autumn flush from the Darling was less pronounced in 1978, although there was a distinct pulse in density and diversity of the potamoplankton. Rotifers comprised 74% of the plankton by winter 1978, with *P. complanata* (43%), *F. terminalis* (15%) numerically abundant, *B. meridionalis* subdominant in July, and *K. australis* and *K. cochlearis* subdominant in August. An increase in density and diversity accompanied the mid winter *Melosira* bloom, e.g. on 14.viii. 78 there were 35 species, 113 plankters ℓ^{-1}, diversity 2.76. Rotifers comprised >75% of the spring assemblage (18 of 35 species present in September, 15 of 24 species collected in October, and 25 of 35 in November). On each occasion a single species, *P. complanata*, was numerically abundant. This species was not abundant the preceding year, when *K. australis* was the most common rotifer.

Rotifers comprised 95% of the summer 1978-79 plankton. An abrupt peak in diversity accompanied the dense bloom of *Melosira* in November-December, although, as in other blooms, density dropped to ≈50 ℓ^{-1}. The bloom apparently was flushed from the lower Murray by Darling flows, which contained a rotifer-copepodite assemblage, e.g. in January-February *P. complanata*, *B. angularis*, *F. pejleri* and *H. mira* comprised 75% of the river plankton, with a further 11 rotifer species present. In March, 19 species of rotifers occurred, with *H. mira*, *F. longiseta*, *F. opoliensis* and *F. pejleri* making up 33%. As in Darling flows in other years, there were considerable amounts of suspended organic debris, and low algal densities, although high zooplankton densities (≃300 ℓ^{-1})were recorded.

The summer copepod peak and occurrence of *M. micrura* was delayed until April, when microcrustacea dominated (92%). Plankton density dropped from 88 ℓ^{-1}in April to 23 ℓ^{-1} in May following the first Darling flows, then increased steadily with the onset of the winter bloom of *Melosira*. In June, rotifers comprised 66% of the potamoplankton (4 species of *Brachionus*, 4 of *Keratella* and 4 of *Filinia* were abundant). The single most abundant plankter was *B. meridionalis* (70 ℓ^{-1}). Both density (215 ℓ^{-1}) and diversity (H' 3.08) were high.

The *Melosira* bloom persisted until sampling for the study ended in August. Zooplankton density increased steadily over winter, with five rotifer species comprising >50% of the plankton (*P. complanata* > *F. terminalis* > *K. cochlearis* > *K. australis* > *S. longipes*). *B. meridionalis* (30%) once again was the only abundant microcrustacean. Diversity remained high (2.7-2.9) through the bloom.

A 24-hour sample series was collected during this bloom (August 16-17, 1979) to determine the extent of diurnal variation in the potamoplankton. Results are shown in Fig. 7.9. (Collections were taken from ≃3 m depth 10 m from the west bank; physico chemical measurements (Fig. 7.4) were taken concurrently). There was little change in water quality over the 24 hours. Passage of a slightly more saline slug of water may have accounted for the decrease in conductivity between 2000 and 2100 hrs, while respiration and cessation of photosynthesis account for changes in dissolved oxygen concentratio and pH. Turbidity (not shown on Fig. 7.4) was relatively constant around 15.0-17.5 NTU.

Of the 41 zooplankton taxa recorded, only the six mentioned above were abundant. These, and *K. tropica*, were present in all hourly samples. Several others, e.g. *K. procurva*, *F. longiseta*, *B. triarticulata*, were relatively abundant but apparently patchily distributed. There was little

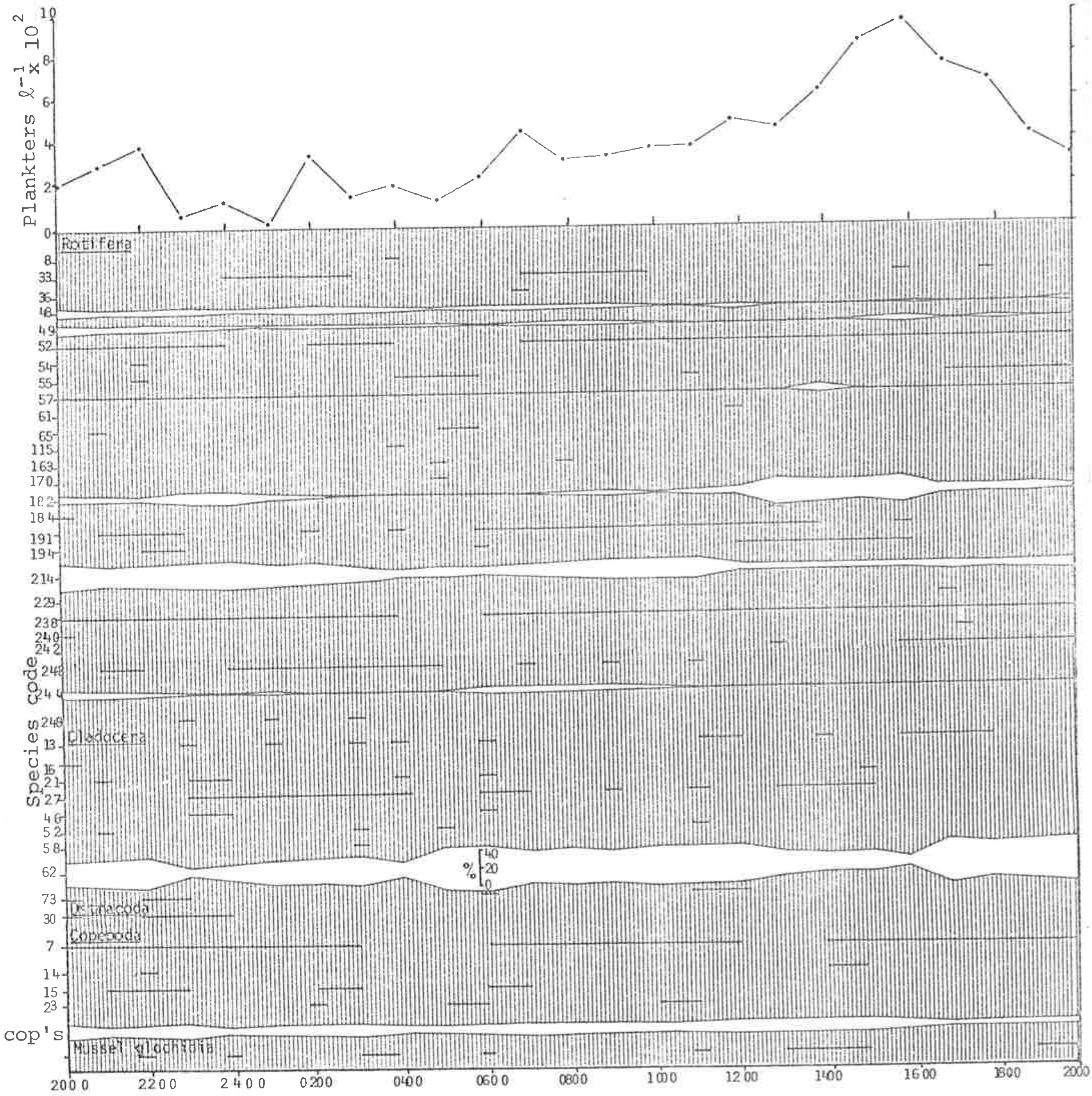


Fig. 7.9 : Diurnal variation in plankton composition, R. Murray, Mannum 16-17.viii.79.

change in species composition over the 24 hours, but there was a marked fluctuation in plankton density. At 2000 hrs, density was 217 ℓ^{-1}. After a slight rise, plankton density fell to <20 ℓ^{-1} around midnight and fluctuated between 100-300 ℓ^{-1} until dawn. Density then steadily increased to a maximum of 993 ℓ^{-1} at dusk (1800 hrs), after which it declined.

This peak was the highest recorded from the river during the study, and initially was attributed to passage of a discrete slug of plankton-rich water. However, the striking similarity of the density changes to those described from alkaline waters by Bayly (1963b), cf. also Hutchinson (1967), Bayly & Williams (1973), suggests that the river plankton may undergo reversed diurnal vertical migration. This phenomenon would account for density difference recorded on several occasions at greater depths across the river (p. 205). Although all plankters apparently were involved, more pronounced density changes occurred in the population of the rotifer, *S. longipes*.

The river plankton may be behaving in the same manner as pond and lake plankton, e.g. vertical migration was recorded from a shallow pond in Victoria (Geddes, 1968). Time constraints did not permit further study of this phenomenon. Considerable research clearly is necessary to determine if vertical migration is characteristic of the River Murray plankton; indeed, of rivers generally.

Environmental factors

The influence of measured environmental variables on overall density and diversity of the river zooplankton was investigated by linear regressions of log density ℓ^{-1} on water temperature, pH, dissolved oxygen, conductivity, turbidity, nutrients and log algal density ml^{-1}. Data are shown in Table 7.3.

A single significant negative correlation ($P < .01$) was found between log density and temperature during 1978, when mean water temperature was ≃3.0 °C lower than the preceding year. This is considered later in the context of changes in species composition. A weak correlation ($P < .05$) existed between log density and dissolved oxygen, however the latter is not independent of

Table 7.3: Regression analysis of Mannum zooplankton data 1976-1979. Dependent variable: log zooplankton density ℓ^{-1}.

Independent variable		n	Intercept	Regression coefficient	F value	R^2
Water temperature (°C)	1976	4	-0.3890	9.2619	10.03	.8338
	1977	15	19.4500	-0.3218	0.01	.0004
	1978	18	34.6929	-9.6889	16.10**	.5016
	1979	6	23.8204	-3.0762	0.38	.0875
pH	1976		7.5921	0.1492	0.43	.1685
	1977		7.5630	0.2192	0.53	.0363
	1978		7.7677	0.1855	0.24	.0147
	1979		7.6173	0.0075	<.01	.0001
Dissolved oxygen (ppm)	1976		14.7242	-2.5443	3.37	.6278
	1977		8.3321	0.3042	0.08	.0064
	1978		4.6546	2.5025	7.63*	.3228
	1979		7.3289	1.0323	0.54	.1195
Conductivity (µS)	1976		324.7265	120.6079	0.32	.1371
	1977		749.3413	-16.2605	<.01	.0002
	1978		1270.2613	-207.9017	0.32	.0193
	1979		594.3281	28.2806	<.01	.0006
Turbidity (NTU)	1976		179.4639	-43.9345	2.85	.5874
	1977		95.1893	-6.2181	0.02	.0016
	1978		39.8462	-6.6394	0.03	.0020
	1979		8.1579	13.1353	0.27	.0622
Total-P	1976		1.1189	-0.2299	2.47	.7118
	1977		1.3902	-0.3880	1.18	.1446
	1978		0.5343	-0.0467	0.02	.0022
	1979		0.1584	0.1120	0.43	.1249
NO_3-N	1976		2.8721	-1.0269	2.05	.6725
	1977		-0.3868	0.6841	0.51	.0680
	1978		-1.0415	1.0022	1.16	.1141
	1979		0.2571	0.0610	0.04	.0090
Log algal density ml^{-1}	1976		1.5618	0.4367	34.10*	.9446
	1977		-0.6777	1.3856	2.13	.1321
	1978		3.3793	-0.2281	0.29	.0175
	1979		0.3158	1.1378	4.99	.5553

* significant at 5% level

** significant at 1% level

temperature. A positive correlation between zooplankton and algal biomass was recorded only for the 1976 samples. This may be an artefact of small sample numbers (n=4), or a trophic effect, with *Bosmina*, a filter feeder, increasing in proportion to algal biomass. No other significant correlations were detected.

Similarly for diversity (Table 7.4), correlation coefficients indicated little correlation between overall species diversity and measured variables. There was a negative correlation between temperature and diversity for the 1976 samples, again possibly an artefact of the small number of samples, or biased by the bloom of *B. caudatus* f.*austrogenitus* in summer, i.e. causing a marked reduction in diversity. High abiogenic turbidities during Darling flows in autumn accounted for the negative correlation between diversity and turbidity in 1977. The apparent increased diversity during *Melosira* blooms was insignificant. Pulses of individual taxa accounted for the negative correlation between diversity and zooplankton density ℓ^{-1} in 1978.

In terms of density and diversity the lower Murray zooplankton was little affected by changes in measured water quality. Most marked changes were in species composition. The influence of environmental variables on the predominant species in the lower river potamoplankton is considered below. Only true potamoplankters are considered further, i.e. of 133 taxa recorded from the lower river, more than half were non-planktonic in habit, and occurred in small numbers in the river as a result of flushing during autumn Darling flows and winter-spring Murray flows, or during algal blooms. Raw data in Appendix 7.2 are summarised in Table 7.5, which indicates frequency of occurrence of each taxon, including predominant habit and seasonality in the lower river. For convenience, the common potamoplankters are listed separately (Table 7.6) and discussed *seriatim* below.

B. angularis: One of the most common brachionids in river studies elsewhere, this species was perennial in small numbers in the lower Murray, with an autumn pulse accompanying Darling River flows, and a more prolonged pulse in spring-summer from Lake Mulwala releases. Breeding seasonality similarly

Table 7.4: Regression analysis of Mannum zooplankton data 1976-1979. Dependent variable: species diversity (H').

Independent variable		Intercept	Regression coefficient	F value	R^2
Water temperature (°C)	1976	12.2744	-0.5203	23.91*	.9228
	1977	2.6494	0.0033	0.06	.0044
	1978	2.2829	0.0320	2.91	.1539
	1979	2.7735	-0.0029	0.01	.0030
pH	1976	7.9294	-0.0460	<.01	.0023
	1977	7.6743	0.1197	0.23	.0158
	1978	7.8505	0.0960	0.13	.0078
	1979	-5.3951	0.8219	2.70	.4030
Dissolved oxygen (ppm)	1976	12.2120	-1.1035	0.04	.0186
	1977	10.5338	-0.5862	0.47	.0348
	1978	10.6592	-0.4642	0.36	.0222
	1979	8.1665	0.4958	0.03	.0084
Conductivity (µS)	1976	-661.2764	671.4769	3.67	.5474
	1977	1013.1138	-96.1794	0.24	.0170
	1978	1273.9088	-151.7877	1.18	.0687
	1979	166.0699	174.5153	0.29	.0666
Turbidity (NTU)	1976	-73.9774	102.7366	1.71	.4615
	1977	174.7995	-36.1776	5.28*	.2737
	1978	-4.2398	20.4231	0.63	.0379
	1979	-30.7360	24.5053	0.28	.0663
Total-P	1976	0.9793	-0.1511	0.39	.0525
	1977	0.9793	-0.1511	0.39	.0525
	1978	0.8385	-0.1379	0.80	.0819
	1979	0.1138	0.0991	0.18	.0430
NO_3-N	1976	-0.1525	0.7500	0.04	.0357
	1977	-0.4925	0.5896	0.96	.1209
	1978	1.3786	-0.1857	0.11	.0120
	1979	1.8554	-0.5409	1.37	.3129
Log algal density ml^{-1}	1976	2.2357	0.0469	<.01	.0016
	1977	1.3939	0.2894	0.75	.0508
	1978	3.0011	-0.0046	0.24	.0145
	1979	2.2638	0.2086	0.44	.0985
Log zooplankton density ℓ^{-1}	1976	1.7623	-0.0201	0.01	.0028
	1977	1.3173	0.6703	2.28	.1491
	1978	4.1821	-0.7452	5.98*	.2721
	1979	2.0505	0.3174	1.96	.3292

*significant at 5% level

Table 7.5: Frequency of occurrence of rotifers, cladocerans and copepods in the River Murray at Mannum: ++++ occurred in >50% of samples (n=48), +++ 30-49%, ++ 10-29%, + <10%. Habit is shown by P=commonly planktonic in lakes/rivers; L=commonly in shallow waters, either in open water, epibenthic or epiphytic, i.e.littoral. Season is indicated by Su=summer,A=autumn,W=winter,Sp=spring,*p*=perennial. Species codes as in Ch. 4.

Sp.code	% occurrence	Habit	Season	Sp. code	% occurrence	Habit	Season	Sp. code	% occurrence	Habit	Season	Sp. code	% occurrence	Habit	Season
Rotifera															
4	+	L	W	65	+	L	*p*	215	+	P	Su/A	38	+	L	Sp
6	+	L	W	70	+	L	Sp	217	+	L	W	45	+	L	Su
8	+	L	A/W	76	+	L	Su	220	+	L	Su	46	++	?L	W/Sp
11	+	L	Sp/Su	77	+	L	A/W	229	+	L	W/Sp	47	+	?L	W/Sp
14	+	L	Su	79	+	L	A	232	++++	P	*p*	50	+	L	W/Sp
15	++++	P	*p*	97	+	L	Su	233	+	P	Sp	51	++	L	A/W
17	+	L	Sp	104	+	L	Sp/Su	234	+	P	Su	52	++	L	W/Sp
20	+	L	Su	109	+	L	Su	235	++	P	Su	58	+	L	W/Sp
21	++	P	Su/A	114	++	L	A/Sp	236	++	P	Su	60	+++	P	Sp/Su
22	++	P	A/W	115	+	L	A	237	++	P	Su	61	+	P/L	W
23	++	P	Sp/Su	117	+	L	W	238	++++	P	Sp/Su	62	++++	P	*p*
24	++	P	Sp/Su	118	+	L	Su	239	++++	P	*p*	63	++++	P	*p*
25	++	?P	*p*	123	+	L	A	240	++	L/P	Su	64	+++	P	A/W
27	+	?L	Su	124	+	L	A	241	+++	P	*p*	67	+	L	Sp
31	++	P	Su	148	+	L	A	242	+++	P	Sp/Su	70	++++	P	Su
32	+	P	Su	153	+	L	A	243	+++	P	A/W	73	++++	P	*p*
33	++++	P	*p*	163	++	L	Sp	244	++++	P	*p*	Ostracoda			
35	+	L	A	166	+	L	W/Sp	245	+	P	Sp/Su	2	+	L	A
36	++	P	*p*	170	+	L	Su	248	+	P	Sp/Su	30	++	L	A
38	+	P	Su	172	+	L	Sp	Cladocera				Copepoda			
40	+	L/P	W/Su	178	+	L	Su	3	+	L/P	A	7	++++	P	*p*
43	+	P	Sp/Su	182	+	P	W/Sp	4	++	P	Sp	9	++	P	*p*
44	++	P/L	A/Sp	184	+	P	A/W	5	++	L	*p*	14	+	P	A/Sp
45	+	P/L	Sp	185	++	P	*p*	6	++	L	Su/W	15	+	?L	W
48	++++	P	*p*	186	+	?P	Sp	7	+	L	W/A	16	++	?P	A/W
49	+++	P	W/Sp	188	+	P	Sp	9	+	L	Su	18	++	L	*p*
52	+++	L	*p*	191	++	P	A	13	+++	L/P	*p*	21	+	L	A
53	++	L	*p*	194	++++	P	*p*	16	+	L	W/Sp	23	++++	L	Sp/Su
54	+	P	W	196	+	P	A	17	+	L	W	29	+	L	W/Sp
55	+++	P	Sp/Su	197	+	P	A	20	+	L	W	31	+	L	Sp
56	++	L/P	Sp	205	+	L	Sp	21	++	L	Sp/Su	32	+	P	Sp
57	++++	P	*p*	212	+	P	Su	23	+	L	W/Su	35	+	L	W/Sp
58	+	P	Su	214	++++	P	*p*	27	+++	L/P	*p*	38	+	L	Sp
63	++	L	Su												

was bimodal. Occurrence and density of *B. angularis* was not significantly correlated with any measured environmental variable.

B. keikoa: Also perennial in low numbers, *B. keikoa* was abundant during low flows of summer 1976-77 and 1977-78. Initially collected only from Darling flows (p. 42), it was subsequently found in the Murrumbidgee below the Lachlan confluence, and was possibly transported from the north of the basin. No significant correlations with environmental variables were detected.

K. australis: This pancontinental endemic was the most widely distributed of the rotifers recorded, from the greatest physico-chemical ranges. Although present in upstream lakes it generally was sparse, reaching high population densities only in rivers, particularly the Darling below L. Menindee. Pulses at Mannum were asynchronous. Maximum breeding populations occurred in summer 1976-77, with a large pulse in winter 1978 accompanying Murray flows. The latter peak was significantly negatively correlated with temperature (r^2=0.64, $P<.01$).

K. cochlearis: This cosmopolitan limnoplankter was abundant in some Murray reservoirs, but not in those of the Darling system, and was rare in rivers. At Mannum, it occurred sporadically in autumn-winter, with a large breeding population accompanying Murray flows in winter 1978. Although it apparently had a lower temperature tolerance than other species of the genus (cf. *K. australis*), no significant correlations were detected.

K. shieli: The spring-summer occurrence of this remarkably restricted endemic (see p. 43) was strongly correlated with temperature (r^2=.80, $P<.05$) and, by association, with salinity (r^2=.68, $P<.05$). Breeding individuals were abundant only in the slower moderately saline flows of summer, at temperatures >20 °C.

K. tropica: Widely reported from rivers elsewhere, *K. tropica* was perennial in the lower Murray, with maximum breeding peaks in autumn and winter. While the species was widely distributed across the basin, it generally was not a significant component of the limnoplankton, where it may have been outcompeted by the similar sized congener, *K. procurva* (cf. p. 57). No significant correlations with environmental variables were detected.

K. procurva: A widespread pantropical species, *K. procurva* was primarily a lentic species, occurring sporadically in small numbers in the lower Murray, with a marked pulse during winter-spring 1978, i.e. passage of releases from R. Murray catchments. There were no significant correlations.

A. brightwelli: Elsewhere considered as an indicator of eutrophy in rivers (Winner, 1975), *A. brightwelli* was the only species of the genus commonly collected from the Murray at Mannum. It was perennial during 1976-77, but subsequently of only incidental occurrence. It may have been limited by high salinities, e.g. a negative relationship was indicated by regression analysis of the 1976 samples ($r^2=0.83$), but this was insignificant in view of the small sample size ($n=4$). No other correlations were found.

P. complanata: Ostensibly a heleoplankter, common in shallow lakes and ponds (Ruttner-Kolisko, 1974), this small rotifer was of patchy occurrence through 1976-77, with a spring-summer maximum, but perennial the following year under conditions of low flow. It was the most abundant zooplankter from May-November 1978. Although recorded from Darling storages, *P. complanata* was replaced in the river by *P. sulcata*, which is tolerant of higher salinities (Koste, 1978). The lower Murray population therefore possibly derived from the Lake Mulwala community. Densities were not significantly correlated with any environmental variable.

C. dossuarius: Also typical of shallow lentic habitats (Koste, 1978), and common in billabongs of the basin, this colonial rotifer apparently was perennial, although of patchy occurrence, in the lower Murray, with peaks during slow flows of summer. No significant correlations were found.

F. longiseta: Of distinctly seasonal occurrence (summer), *F. longiseta* was correlated with temperature during 1976-77 ($r^2=0.78$, $P<.05$), but under slower flow conditions and slightly lower temperatures the following year, populations were smaller, and no significant correlations were found. There was, however, a strong correlation between log density and turbidity, i.e. *F. longiseta* is a microphagous detritovore (Pourriot, 1977), and its population peaks in the lower Murray paralleled algal blooms. The rotifer may be utilizing detritus and bacteria trapped in or released by decomposition of such blooms (cf. Dumont, 1977). This could account, in part, for the greater density of *F. longiseta* during summer 1977, when the bloom species was a blue-green (*Anacystis*), i.e. more detritus was available via a decomposer shunt than in the following year, when conditions favoured a diatom (*Cyclotella*). Clearly, more subtle influences than simple temperature effects were operating.

F. australiensis: Introduced into the lower river by autumn Darling floods, this species succeeded the smaller congener, persisting through winter and spring each year. Apparently it has a lower temperature tolerance than *F. longiseta*, i.e. 10.5-20.5 °C vs. 14.0-25.0 °C in the lower river. It is possibly widespread in the basin. Although common in Darling waters, it also was recorded from Dartmouth Dam. There were no apparent correlations with environmental variables, particularly turbidity or algal biomass. It is likely that the species has similar dietary requirements to others of the genus, and obtains these from bacteria and organic detritus suspended in the characteristically turbid waters (cf. Cummins, 1972).

F. opoliensis: Also widespread in the north of the basin, occurrence of this *Filinia* was predominantly in spring-summer accompanying algal blooms. As in *F. longiseta*, it was strongly correlated with turbidity ($r^2=0.62$, $P<.01$). This species is smaller than *F. longiseta*, but may be utilizing the same food resource.

F. pejleri: Of spring-summer occurrence, this pantropical rotifer was the only species of the genus significantly correlated (positively) with algal biomass ($r^2=0.77$, $P<.01$), apparently following *Melosira* blooms. Its largest population coincided with the dense bloom of summer 1978. Of similar size to its congeners, *F. pejleri* probably is also a detritovore.

F. pejleri grandis: As *F. australiensis*, this large subspecies apparently has lower temperature tolerance than *F. pejleri*, and also is endemic to the Murray. It occurred seasonally (winter), but was not significantly

Table 7.6 : Zooplankton taxa abundant in the potamoplankton of the lower Murray, with comments on ecology and distribution. † = indicator of eutrophic conditions in rivers (cf. Winner, 1975)

Taxon	Ecology and distribution
Rotifera	
B. angularis †	Eurytopic, common in alkaline waters, cosmopolitan.
B. keikoa	Warm stenotherm, ?euryhaline. Commonly in lower Murray, may be widespread in Darling basin. Endemic.
K. australis	Eurytopic, widely distributed in basin. Endemic.
K. cochlearis †	Eurytopic, cosmopolitan
K. procurva	Eurythermal, common in alkaline waters, predominantly lentic in Murray basin. Pantropical.
K. shieli	Warm stenotherm, euryhaline, alkaline waters. Endemic.
K. tropica	Warm stenotherm, euryhaline in Murray. Cosmopolitan.
A. brightwelli †	Warm stenotherm in Murray, ?euryhaline, cosmopolitan.
P. complanata	Eurytopic, shallow water form elsewhere.
C. dossuarius	Warm stenotherm, typical of shallow lentic habitats elsewhere.
F. longiseta †	Warm stenotherm, cosmopolitan.
F. australiensis	Cool stenotherm, moderately saline alkaline waters. Endemic.
F. opoliensis	Warm stenotherm, cosmopolitan.
F. pejleri	Warm stenotherm, widely tolerant of salinity and alkalinity in Murray. Pantropical.
F. pejleri grandis	Cold stenotherm in Murray, alkaline, moderately saline waters. Endemic.
F. terminalis	Cold stenotherm, winter. See text.
Cladocera & Copepoda	
C. sphaericus	Eurytopic, cosmopolitan.
A. rectangula	Eurytopic, widely distributed.
M. micrura	? Eurytopic, cosmopolitan.
B. meridionalis	Eurytopic. ? Australasia.
D. carinata	Eurytopic. *cephalata* form from Australia/Asia.
D. lumholtzi	Warm stenotherm. Australia/Asia/Africa.
C. cornuta	Eurytopic, predominantly warm waters. Pantropical.
C. quadrangula	Eurytopic. ?cosmopolitan.
B. triarticulata	Eurytopic. Australia/Asia.
M. leuckarti	Eurytopic, cosmopolitan.

correlated with any measured environmental variable.

F. terminalis: Due to confusion with a congener, no analyses of densities of this species were made. The taxon identified as *F. terminalis* abundant during summer 1976-77 possibly was the unidentified species mentioned in Ch. 4. *F. terminalis* was abundant during winter 1978, at temperatures in accord with its known habit elsewhere as a cold stenotherm.

C. sphaericus: This chydorid occurred sporadically in small numbers throughout the study, with maximum densities during algal blooms (although no significant relationship with algal biomass was detected). It was not correlated with fluctuations in any measured variable.

M. micrura: Of common occurrence in permanent lakes and reservoirs of eastern Australia (Timms, 1970), *M. micrura* occurred seasonally (spring-summer) in the lower Murray, with autumn occurrences noted from the Darling River. Although it is possibly temperature limited, no significant correlations were found.

B.meridionalis: The most common cladoceran in the lower Murray, and one of the most widely distributed microcrustacea in the study area (cf. Jolly, 1966; Timms, 1970), *B. meridionalis* was perennial, with an autumn peak, in the lower Murray. Significantly lower densities were recorded each summer during high salinities ($r^2=0.40$, $P<.05$), and during the 1976 *Melosira* bloom ($r^2=0.98$, $P<.05$). The latter negative correlation may have resulted from small sample size from that year, i.e. *Bosmina* densities were not significantly affected by subsequent algal blooms. The widespread occurrence of bosminids in rivers elsewhere is noted by Hynes (1970), who suggests some difference in feeding mechanism favours their survival over other cladocerans.

D. carinata/D. lumholtzi: Neither species of *Daphnia* was correlated with any measured variable. The lower river *D. carinata* apparently was a cool water form, while the upper river/billabong form (i.e. f. *cephalata*) was a warm stenotherm. *D. carinata* occurred in small numbers throughout the study, with breeding individuals recorded only in autumn and spring (cf. upstream reservoirs). *D. lumholtzi* occurred in small numbers only in autumn.

C. cornuta: Common in tropical waters (cf. Holden & Green, 1960), *C. cornuta* occurred over summer 1976-77, when its density was negatively correlated with salinity ($r^2=0.58$, $P<.05$). During higher salinities the following summer the species was rare.

C. quadrangula: Perennial, but of patchy occurrence. A single pulse of this cladoceran was recorded in spring 1977. It subsequently was sparse in the river plankton, and could not be correlated with any measured variable.

B. triarticulata: Perennial, with greatest population densities of both adult and copepodite stages during slower summer flows, *B. triarticulata* was the most common and widely tolerant calanoid recorded in the study. There were no detectable correlations with measured variables.

M. leuckarti: Occurring also in the slow flows of summer (cf. Timms & Midgley, 1969; Timms, 1973) accompanying algal blooms, the cosmopolitan *M. leuckarti* was the only cyclopoid recorded in breeding populations in the lower river. There were no apparent correlations with environmental variables.

A further 40 taxa listed in Table 7.5 were planktonic or facultatively planktonic. Most were sporadic, occurring in small numbers, or were distinctly seasonal, e.g. *B. budapestinensis, B. calyciflorus, B. falcatus*, and were associated either with autumn flushes from the Darling, or winter-spring Murray flows. Most of the common rotifers in the Murray potamoplankton are considered elsewhere (Sladacek, 1973; Winner, 1975) as indicators of eutrophy.

Clearly, although statistical analysis of the data is rudimentary, and more sophisticated techniques may detect more correlations than were apparent, there was a complex of factors operating on the lower river potamoplankton. Temperature, salinity and turbidity were implicated as determinants of seasonal succession in both the phyto- and zooplankton, with different species responding to changes in water quality as the water mass moved downstream. There was evidence of interaction between the phyto- and zooplankton, e.g. density and grazing effects, although these were not studied further. Analyses were made difficult by the nature of the lower river, i.e. a heterogeneous, moving water mass; by the relative infrequency of sampling, and by the nature of the potamoplankton, i.e. predominantly eurytopic taxa, a high proportion of which are indigenous and have evolved strategies to cope with environmental extremes.

7.6 Concluding remarks

The seasonal variability of flow from two disparate sources into the lower Murray has contributed to the maintenance of a distinctive plankton assemblage peculiar to the lower river. The Murray above the Darling confluence supplies a diverse assemblage determined by seasonal releases from upstream reservoirs. In low flows a limnoplankton dominated by microcrustacea accompanies algal blooms downstream of Yarrawonga, and is inoculated from the Goulburn River by a similar (although different in species composition) microcrustacean community from Goulburn Weir. During higher flows a rotifer limnoplankton predominates in the river. The shallow and vegetated storages on the middle reaches of the Murray and tributaries provide suitable conditions for billabong species, i.e. more typical of shallow lentic habitats on the floodplain; these taxa persist in the river and, in slow flows, maintain breeding populations.

The Darling above the confluence provides a predominantly rotifer potamoplankton consisting of tropical species, i.e. warm stenotherms and eurytopic cosmopolitan species derived from the north and east of the basin. Characteristic turbidities and low flow conditions selectively eliminate some of the plankton, particularly microcrustacea. Absence of significant or deep impoundments prevents a limnoplankton from establishing, so that the plankton which arrives at the Darling-Murray junction after, in some cases, 2,000 km of river flow can clearly be considered an autochthonous Darling River plankton. Unlike more rapid flows of rivers elsewhere, slow flows of the Darling would permit considerably more generations of planktonic species, e.g. rotifer taxa with generation times of 4-5 days at 24°C could produce 18-20 generations during passage from the headwater storages.

Below the Murray-Darling confluence a diverse plankton assemblage is maintained by inoculation from the two rivers, with most marked changes in potamoplankton composition produced by asynchronous seasonal flooding. At other times of the year, the influence of Darling flows is apparent with the occurrence of characteristic tropical Darling plankters in the lower river, i.e. the river acts as a transport corridor. The composite plankton assemblage is distinctive in that the two rivers supply different species in several genera, particularly Rotifera, and congeneric associations are common, e.g. six species of *Brachionus*, five of *Keratella*, five of *Filinia* were not unusual in lower Murray samples. Other studies (e.g. Green, 1960; Rai, 1974; Rzoska, 1976) reported up to eight *Brachionus* species, but only one or two of *Keratella*. The occurrence of seven congeners of *Keratella* in the lower river, which, with a single exception (*K. shieli*) are widely distributed throughout the basin, indicates the broad physiological and ecological tolerances of local representatives of the genus. Further observations on the lower river rotifer assemblage were given by Shiel (1979).

Downstream from Mildura, the river is impeded by locked weirs, and is subject to irrigation returns and nutrient inflows from towns. The response of the plankton to this habitat heterogeneity is similar to that reported in other studies. In regions of slower flow there is an increase in density of some taxa, and usually an increase in diversity, i.e. point source nutrient inflows apparently stimulate pulses of particular species, so that order of magnitude differences are apparent in longitudinal samples. Habitat heterogeneity also influences community diversity; more diverse assemblages in regions of slow flow were often due to a higher proportion of pseudoplanktonic taxa. On occasions, lower diversity resulted from single-species pulses, although a species-rich plankton was present. In general, relative to upstream reservoirs, both density and diversity increased downstream.

Densities of plankton in the lower Murray were comparable to those reported from other river studies. Diversity generally was greater than reported from other rivers, a result of low flow conditions and the maintenance of lentic and littoral taxa. These assemblages moved downstream in discrete pulses or "clouds".

Although limiting factors could not adequately be assessed, and community dynamics were treated only superficially, factors implicated in the lower river included temperature, turbidity and salinity. The deleterious influence of high turbidities was not as pronounced as reported elsewhere (cf. Hynes, 1970), possibly because high turbidities were not accompanied by significantly greater velocities (cf. Berner, 1951). No analysis was made of trophic relationships, however it was apparent that pronounced seasonal fluctuations in algal biomass, particularly those resulting from flushes of highly turbid Darling flows, influenced significantly some components of the zooplankton. Food resource limitation may account for seasonal depletion of microcrustacea in the lower river. Clearly, considerable autecological and synecological work is necessary to clarify the effects of the two distinct waters on plankton dynamics in the Murray below the confluence.

In summary, the potamoplankton of the lower Murray consisted of a predominantly diatom phytoplankton component, the genera and in some cases species of which were those of rivers elsewhere, and a mixed rotifer-microcrustacean zooplankton, approximately half of which derived from upstream reservoirs and was essentially limnoplanktonic. Of the predominant river plankters, some 40% were restricted in distribution, either endemic to Australasia, or to the southern Hemisphere. The remainder were cosmopolitan, eurytopic taxa , or pantropical species introduced by Darling flows. Most of the Rotifera reported from river studies elsewhere occurred in the Murray (with the notable exception of the rotifer genera *Kellicottia* and *Notholca*), and a high proportion of these are considered indicators of eutrophy in rivers. The use of the zooplankton as indicators is considered briefly in the concluding chapter.

8. CONCLUSION

The Murray-Darling river system is distinctive. Evaporation exceeds precipitation over most of the basin; although the rivers drain more than a million km^2, average annual runoff from the system is only two cm. River flows are low and variable, and as a result of low gradients, exceptionally slow. Travel time from headwaters to the sea may be two to three months.

The two rivers also are distinctive from one another. The Murray flows generally westward for 2,500 km from the Eastern Highlands. There is a well-developed floodplain with numerous abandoned meanders (billabongs), many with permanent water. Peak flows follow winter rains and spring snow melt, with more than 25% of flows derived from the Murray above Hume reservoir (only 2% of the catchment). Greater reliability of water supply in the Murray basin led to intensive settlement and development. Most major tributaries have been impounded for domestic, stock and irrigation supply. Of more than 100 dams in the basin, 80% are on Murray tributaries. Impoundment has altered the flow regime of the Murray, decreasing winter flows, increasing summer flows and reducing flood frequency, to the detriment of billabong communities.

The Darling flows south-west for 2,700 km across ten degrees of latitude. Maximum flows, which are extremely variable, follow summer monsoons in the north of the basin. On average, flows are relatively small. Peak flows rarely coincide with those of the Murray. Billabong tracts are less extensive than on the Murray; as a result of flow variability permanent waters are less common. Also, the Darling channel is deeply incised into the floodplain, which is less frequently flooded. Dams are few; those on headwater rivers are for irrigation along tributary valleys on the western slopes of the Eastern Highlands. The Darling is mostly unimpounded.

The lower Murray below the confluence of the two rivers is subject to disproportionate flows from the two systems; Darling flows reach the confluence in autumn, producing a rapid change in water quality in the lower river, i.e. increased turbity, decreased salinity.

Contrasts between the two rivers have been enhanced by man's activities. The Murray is now a 'reservoir river', with effects of impoundment apparent hundreds of kilometres downstream (Walker, Hillman & Williams, 1978). In the reservoirs, abiogenic turbidity is reduced by settling, and reduction of flow and appropriate nutrient levels stimulate algal blooms, which persist downstream. Irrigation use significantly alters water quality. Salinities are increased by the return of saline groundwater. In contrast, the Darling is an ephemeral river, typically with high abiogenic turbidity, which supresses algal blooms, more alkaline (sodium bicarbonate) and of lower conductivity than middle reaches of the Murray.

This study investigated the plankton composition, particularly the zooplankton, of the Murray and Darling. The broad aim was to characterize the limnoplankton of headwater impoundments, the heleoplankton of billabongs and the potamoplankton of river reaches, particularly that of the lower Murray, and to relate differences to physical or chemical differences between the systems.

Impoundments: Impoundment reduces flow variability and modifies water quality in the riverine system. Changes in water quality result from differences in local soils, land forms, flow rate, basin morphometry and catchment use, i.e. water quality differs between storages. The plankton which develops in these waters is correspondingly heterogeneous, so that although a block of ubiquitous and eurytopic taxa was common to most Murray and Darling reservoirs, (e.g. *Melosira, Staurastrum, Ceratium, Keratella cochlearis, Bosmina meridionalis Boeckella triarticulata*), each storage had a peculiar plankton assemblage (cf. Pejler, 1965; Hammerton, 1972).

The zooplankton typically consisted of 3-8 rotifer species (commonly, *K. cochlearis, S. stylata, S. pectinata, P. vulgaris, P. dolichoptera, A. brightwelli, A. sieboldi, C. dossuarius, H. intermedia, H. mira* and *Filinia* spp.), 3-4 cladocerans (*D. unguiculatum, C. sphaericus, B. meridionalis, D. carinata, C. cornuta* and *C. quadrangula*), and 2-4 copepods (common calanoid copepods were *B. triarticulata, C. ampulla, C. lucasi*. Cyclopoid copepods were rare.

Low plankton density ($< 60\ \ell^{-1}$) and high species diversity occurred in oligotrophic storages (e.g. Eildon). The converse was true of meso-eutrophic reservoirs (e.g. Burrinjuck, $>500\ \ell^{-1}$). In shallow, turbid storages (e.g. Mulwala), phytoplankton blooms were suppressed by high turbidities (Walker & Hillman, 1977). Zooplankton also was affected ; densities were considerably lower than in less turbid storages.

Retention time was important in plankton development. Impoundments of long retention time had a stable limnoplankton dominated by microcrustacea. The limnoplankton of short retention time reservoirs usually had an unstable limnoplankton dominated by Rotifera and copepodites.

Most reservoirs supplied a small proportion of their plankton assemblage to downstream rivers. Little, if any, plankton derived from the high altitude hydro-power storage (Rocky Valley); hypolimnetic-release storages supplied a small proportion of species (<30% of taxa present) but a considerably reduced biomass. Shallow impoundments or overflow reservoirs supplied most of their limnoplankton assemblage, with a selective decrease in the microcrustacean component and proportional increase in rotifers. The phytoplankton of more rapid reaches below dams consisted predominantly of detached benthic diatoms, while slower reaches had a more diverse algal community with true limno- and potamoplankton dominants (seasonally, diatoms, green algae and blue-green algae).

The individuality of reservoir plankton communities has been reported from other rivers (e.g. Volga, Nile), and is a response to climatic differences, retention time, stability of level, marginal vegetation, nature of inflows, extent of eutrophication and agricultural/domestic pollution.

Billabongs: The floodplain is an integral part of the river system; shallow eutrophic billabongs are important as refuges and sources of inocula for downstream rivers and impoundments. In semi-arid inland Australia, with a dearth of freshwater lakes, billabongs may be the only available standing water. Complex communities have evolved in these habitats in response to an extremely variable flood-drought regime, and their maintenance undoubtedly is dependent on seasonal or at least intermittent replenishment of water and nutrients from the river and floodplain. Impoundment of the parent stream, by reducing flood height and frequency, limits replenishment. Billabongs not fed by groundwater are lost to the system. Under the modified hydrologic regime, the formation of further billabongs is unlikely. Alterations to the floodplain in this way are apparent along tributaries of the Murray, and along upper reaches of Darling rivers.

The ecological heterogeneity of reservoirs applies also to billabongs, where interaction of extrinsic and intrinsic factors has produced distinctive plant and animal communities in even adjacent billabongs. Those billabongs which have been studied have more diverse plankton and microfaunal communities than any yet recorded.

The plankton of billabongs invariably consisted of limnetic and littoral species. Any collection contained 2-15 rotifer species (commonly from *K. slacki, K. procurva, K. tropica, S. stylata, S. pectinata, A. priodonta, A. sieboldi, F. longiseta passa*), 1-6 cladocerans (*A. davidi, A. rectangula, C. sphaericus, D. carinata, C. quadrangula*) and 1-5 copepods (*B. fluvialis, B. minuta, M. leuckarti*). Congeneric associations were common. Littoral collections at the same time contained 20-50 species of rotifer and microcrustacean microfauna. Collections from Darling billabongs usually contained a greater diversity of both limnetic and littoral forms than did those of the Murray, with tropical species predominating, i.e. a response to latitudinal differences.

Plankton species composition differed between billabongs, and generally was unlike that of reservoirs, although the same genera were present. Densities in open water were considerably higher than in most reservoirs (200-600 ℓ^{-1}), and diversities were among the highest recorded in the study.

Floodplain habitats are little studied elsewhere. Clearly, as stressed by Shiel (1980), there is a need to investigate these complex floodplain habitats and their importance to the river system. Loss of billabongs due to impoundment or other interference may have profound effects on the riverine ecosystem. A significant proportion of the Murray plankton originates from them, if not directly, by way of populations established in shallow impoundments on the middle reaches, e.g. Mulwala.

River reaches: As a result of differences in gradients, soils and land use, headwater reaches of the two rivers were distinctly different. Those of the Darling usually were highly turbid. Microcrustacea were sparse; each tributary carried a characteristic plankton dominated by rotifers. This composite assemblage persisted in the downstream Darling, despite high turbidities. Low gradients and a series of weirs, with consequent low flows and lack of turbulence, contributed to the maintenance of this assemblage. High turbidities inhibited phytoplankton. Retention in the shallow and exposed Menindee Lakes did not favour development of a limnoplankton; the plankton in the lakes and downstream of them typically was dominated by rotifers. This assemblage was of low density but high diversity; predominantly detritivorous, warm stenothermal pantropical and endemic species (e.g. *K. australis, K. tropica, F. australiensis, F. opoliensis, F. pejleri*).

Tributaries of the Murray characteristically were clear. Although each had a peculiar plankton, a mixed assemblage was produced in reservoirs downstream. The last of these had a diverse assemblage of limnoplankters from upstream impoundments and adventitious forms from the floodplain. Reduction of current flow in downstream storages permitted algal blooms in response to nutrient enrichment. Bloom taxa commonly were those typical of other reservoir rivers (*Melosira, Cyclotella, Anabaena, Anacystis*). These blooms and accompanying and characteristic zooplankton assemblages persisted downstream into the lower Murray. Low gradients and lack of turbulence were contributing factors. Plankton densities were higher, and diversities commonly lower, than in the Darling.

Below the confluence of the two rivers this mixed assemblage of plankters moved downstream in distinct pulses. Weirs further impeded flows, and nutrient inflows from towns stimulated pulses of some plankters, so that there was longitudinal and cross-river heterogeneity of plankton development. Most abrupt changes in the lower river plankton were produced by variable autumn floods from the Darling. In general, plankton density and diversity increased downstream. There commonly were 10-25 rotifers, 5-8 cladocerans and 3-5 copepods, with an average density over the study of 119 ℓ^{-1}. Only rarely did zooplankton density exceed that of phytoplankton.

Although only the rotifer and microcrustacean compo~~e~~nents of the limno- and potamoplankton are documented, a diverse assemblage of macroinvertebrates was recorded from most open waters of billabongs and rivers. Common in headwater reservoirs were insect nymphal stages, particularly Ephemeroptera, and hydracarinids were characteristic of some storages (e.g. Hume). Species lists of both these groups are given in Appendix 8. The greatest diversity of macroinvertebrates was recorded from billabongs, with more than 30 taxa on occasions present in net tows. Most of these were dislodged from hydrophytes or were strays. Time did not permit analysis of the material collected; it awaits later study. Similarly, in the lower river only freshwater mussel glochidia were true plankters; other taxa recorded were adventitious forms. Mussel glochidia were recorded in all seasons in the Murray at Mannum, commonly at densities $< 1\ell^{-1}$.

The Murray-Darling system has features in common with other rivers, but clearly some features are unique. All rivers are characteristic entities, i.e. the sum of their parts. Differences in climate, soils, etc. produce different physical and chemical conditions, flow rate and travel time, all of which influence plankton development. As elsewhere, the river plankton is derived from lakes (artificial), floodplain habitats, backwaters, and from the river itself. This latter component is especially important in the Murray-Darling system in view of exceptionally long travel times. The plankton has sufficient time to develop and reproduce in the river. Travel time obviously is prolonged by impoundment, permitting development of a lacustrine plankton. In this respect the Murray-Darling as a system has similarities to the Nile, i.e. a riverine plankton has been replaced by a lacustrine microcrustacean plankton following construction of dams on the White Nile, while the less impounded Blue Nile retains a rotifer potamoplankton. Like the Nile tributaries, the Murray and Darling flow for long distances from their headwater storages, with few tributaries, through arid and semi-arid country.

In summary, the Murray has a self-sustaining plankton derived from diverse lentic and lotic habitats. Slow flows permit maintenance of this assemblage, although there is selective elimination of microcrustacea in mixing with the highly turbid waters of the Darling. Below the confluence, diatoms and rotifers usually are dominant, with seasonal pulses of blue-green algae and microcrustacea. Genera and species of phytoplankton are those of rivers elsewhere; zooplankton are more distinctive, with some cosmopolitan genera and species, some pantropical forms, and more than half the common potamoplankters apparently indigenous to the Murray-Darling basin or to Australasia.

Temperature and turbidity are important environmental influences, and were implicated as determinants of seasonal succession. Under appropriate conditions in the lower Murray, blue-green algae may bloom, but under different conditions of temperature or turbidity various diatoms dominate. The sooplankton associated with bloom species is influenced accordingly. Seasonal succession in the river zooplankton relates to temperature changes, differences in source, turbidity and algal biomass. As expected in a river plankton which has evolved in a variable environment, salinity and flow changes were less significant factors. Because of this variability, seasonal cycles of potamoplankton described in other studies were less distinct in the Murray over the period of the study.

The foregoing summarises the principal results of this investigation. Some of the original aims await later study. In particular, a considerable amount of taxonomic work is needed on the Rotifera and Cladocera, as is autecological study of species dominants, both indigenous and cosmopolitan. Under Australian conditions some of the latter clearly do not follow habitat preferences noted elsewhere. Synecological studies to determine the responses of plankton assemblages to environmental change could be carried out *in situ*, i.e. in a suitably fitted boat travelling downstream with the water mass. Perhaps of most immediate urgency is the need to characterize the relationship of the floodplain to the river system - to preserve some of these unique habitats before they are irretrievably lost.

9. LIST OF APPENDICES

Shiel, R. J. & Koste, W. (1979). Rotifera recorded from Australia. *Transactions of the Royal Society of South Australia, 103*(3), 57-68.

APPENDIX 2

Representative phytoplankters recorded from Goulburn Weir, Nagambie, Vic.,(I. J. Powling, pers.comm.).

DIATOMS:

Asterionella
Cocconeis
Diatoma
Eunotia
Gomphonema
Gyrosigma
Melosira granulata
Navicula
Nitzschia acicularis
Pinnularia
Rhopalodia
Surirella
Synedra ulna
Tabellaria

DESMIDS:

Arthrodesmus incus
Closterium gracile
C. kuetzingii
Cosmarium moniliforme
Cosmarium sp.
Desmidium
Micrasterias mahabuleshwarensis
Pleurotaenium ehrenbergii
Spondylosium
Staurastrum gracile
S. nodulosum
S. pingue
S. tohopokaligense
S. victoriense
Staurodesmus euspidatus
Staurodesmus sp.

OTHER GREEN ALGAE:

Actinastrum
Coelastrum
Cosmocladium
Gonium pectorale
Hyalotheca dissiliens
H. undulata
Kirchneriella
Mougeotia
Pediastrum
Sphaerocystis
Spirogyra
Volvox
Zygnema

FLAGELLATES:

Dinobryon divergens
Euglena
Gymnodinium aeruginosa
Mallomonas
Peridinium
Synura
Trachelomonas hispida
T. volvocina

BLUE-GREEN ALGAE

Anabaena
Coelosphaerium
Holopedium
Oscillatoria

Shiel, R. J. (1980). Billabongs of the Murray-Darling system. In W. D. Williams (Ed.), *An ecological basis for water resource management,* (pp. 376-390). Canberra, Australian National University Press.

NOTE:

Appendix 4: Physico-chemical measurements from four Goulburn billabongs.

	Date	°C	pH	DO	uS	TDS	NTU	Depth (m)	Ions
	Goulburn View								
1976	15.iv.	15.0	6.8	1.4	220	266	18.0	0.4	Na>Mg>Ca>K
	25.v.	14.0	7.0	7.4	155	205	10.6	0.65	HCO_3>Cl>SO_4
	30.ix	17.0	7.2	9.8	85	136	5.5	1.0	
	04.i.	17.0	7.0	7.4	230	138	22.5	0.35	
1977	12.iv.	19.0	6.9	8.8	110	118	35.0	1.5	
	14.x.	20.0	7.2	9.1	157	-	-	-	
1978	07.i.	28.0	7.0	8.2	243	140	17.5	0.8	
	27.ii.	28.0	7.1	13.8	250	-	15.0	0.3	
	22.viii.	6.2	7.0	11.4	73	-	36.0	2.0	
	Sheepwash								
1976	17.iv.	19.9	7.1	8.5	85	98	0.5	2.0	Mg>Na>Ca>K
	25.v.	13.0	7.0	9.8	70	90	0.2	2.7	HCO_3>Cl>SO_4
	30.ix.	16.0	7.2	9.8	62	-	0.5	2.7	
	12.iv.	17.0	7.7	8.8	130	-	3.0	1.8	
1977	22.v.	11.0	7.5	10.4	145	100	2.7	1.9	
	14.x.	20.0	7.3	9.0	55	-	2.0	1.8	
	07.i.	20.0	7.4	8.6	155	-	5.0	1.7	
1978	27.ii.	21.5	7.2	6.2	200	-	0.8	2.0	
	22.viii.	10.0	7.2	6.1	170	-	17.0	2.5	
1979	21.v.	10.5	7.2	10.1	75	-	1.0	2.0	
	Acacia's								
1976	29.ix.	17.0	7.3	9.8	80	130	0.5	1.0	Na>Mg>Ca>K
	18.iv	17.5	7.4	8.6	75	-	10.5	0.45	HCO_3>Cl>SO_4
1977	22.v.	12.0	7.3	9.8	70	-	3.0	0.65	
	14.x.	22.0	7.2	9.2	60	-	5.5	1.2	
1978	07.1.	22.0	7.0	11.4	125	-	0.5	0.7	
	22.viii.	10.0	7.3	10.8	90	-	6.0	1.3	
	Seymour								
1976	17.iv.	20.0	7.0	9.0	190	238	15cm(Secchi)		Na>Mg> Ca> K
	25.v	12.5	7.1	10.0	200	218	25.5	1.5	HCO_3>Cl>SO_4
	10.viii.	8.2	7.3	10.8	185	183	35.0	1.7	
	29.ix.	18.0	7.4	9.4	215	199	60.0	1.6	
	13.iv.	16.0	7.5	2.7	460	500	350.0	1.0	
1977	22.v.	11.0	7.0	5.8	318	-	-	1.0	
	15.x.	15.0	7.3	6.2	250	-	40.0	1.5	
	14.xi.	14.0	7.4	5.6	155	-	22.5	1.6	
	07.i.	16.0	7.4	9.0	325	-	42.5	0.8	
1978	08.ii.	17.0	7.5	6.4	585	-	23.0	0.7	
	26.ii.	22.5	7.5	7.8	1080	-	3.0	0.5	
	26.v.	14.0	7.4	9.8	860	-	4.5	0.8	
	22.viii.	10.0	7.2	11.6	330	-	85.0	1.5	
1979	01.ii.	25.0	7.5	6.2	470	-	120.0	0.9	
	25.v.	8.0	7.0	11.2	138	-	15.0	1.4	

Appendix 5 : Algal genera recorded from Sheepwash billabong, Yea, Victoria (I. J. Powling, WSCV, pers.comm.).

Desmids:

Arthrodesmus

Cosmarium (hardyi, lunula, ?lundelli, maculatus, ?pseudobroomei, ?turgidum)

Closterium (gracile, kuetzingii, lunatum)

Cosmocladium

Euastrum

Hyalotheca

Micrasterias (laticeps, lux, mahabuleshwarensis, sol, thomassiana, zeylanica)

Pleurotaenium

Spondylosium

Staurodesmus

Staurastrum (pingue, playfair, rosei, sexangulare)

Xanthidium

Diatoms:

Cymbella

Diatoma

Eunotia

Gomphonema

Gyrosigma

Melosira granulata

Nitzschia

Navicula

Pinnularia

Rhizosolenia

Surirella

Synedra (nana, ulna)

Green algae:

Asterococcus superbus

Botryococcus

Bulbochate

Coelastrum

Dictyosphaerium

Kirchneriella

Mougeotia

Green algae (cont.):

Nephrocytium

Netrium

Oedogonium

Pediastrum

Sphaerocystis

Scenedesmus arcuatus

Flagellates:

Ceratium

Dinobryon divergens

Eudorina

Euglena

Lepocinclis

Pandorina

Peridnium

Phacus

Trachelomonas (hispida, volvocina)

Volvox

Blue-green algae:

Anabaena

Oscillatoria

unidentified fine filaments

SNOWDON'S BILLABONG (Locality 31, Fig. 2.11)

Sp. code	1976		1977				1978						1979	1980
	11.viii	11.xii	06.i	18.iv	19.v	14.xi	23.ii	02.iii	26.v	17.vii	18.viii	05.ix	02.iv	25.i
ROTIFERA														
11			+											
14	+					3				6				
15							11*						+	
24														8
30													+	
37				17			1*	6*						
40														2
44			4				+	+	1				1*	
46							120*	15*						2
47														2
49									2	+				
52						5*	+		4*	3	4*	5*		
56			7*			4*			1*	3*	6*	2	2*	
57						4*				+			3*	
61									+					
67				1		1				1		1		
75				5					+	+	+	6		
76									+					
77												1		
79						1						1		
97									+					
104	+					+								
114								+						
138													+	
144												7		
164								4		1		1		
175												159		
176										+				
177												102		
184	2		+		+					+			2	
191					2						+	6		1*
192										68				
197	1*		59*	1		3					5*	1	46	
214			1			1								
230												50		
240			1*				8*							1
244			1											
247									1					
ΣSp.	4	-	8	4	2	9	6	5	9	11	5	13	8	6

Appendix 6 a: Aliquot subsample counts from collections taken from Snowdon's, Ryan's I and Ryan's II billabongs. Counts are semi-quantitative, i.e. proportional composition and comparable between sampling dates, but do not represent absolute volume samples. * indicates the presence of ovigerous ♀♀/individuals.

Sp. code	1976		1977				1978						1979	1980
	11.viii	11.xii	06.i	18.iv	19.v	14.xi	23.ii	02.iii	26.v	17.vii	18.viii	05.ix	02.iv	25.i
Cladocera														
3								3*						+
5												1		
9	+													
11	+													
13	42*			20*	101*					2	2*	12		
15				38	3				+	+				
16					1									
21	+			23*	1	+			+			8*		
23				8*								+		
24					4*									
27	8*		+	97*	81*					+				
30												+		
31	+													
38	+													
44					2									
45	+													
50	1*				1									
52	1			5	48			6*	1	+		+		
61			13*				34*	60*					2	41*
62	5*					7*		+*		1	2*	16*	1	
63		+*		+*		4*		51*	1	3	17	1*		
64					+	11*				+		1		
67	2			1	31							5*		
68									1*					
69	1			1										
70				5			5*							+
73	2					12*				36*	41*	5*		
OSTRACODA														
1					2									
28	2			4	4				1	2		4		
COPEPODA														
2						1	+*	8*	+*	+	1*	1	8	
4	69*	120*	26*	4	8	13*	+		5*	17	2*			
18		4		+										
19	5*													
20	3*			1*	1				2					
21			2*		+		+	5*						
23	+		+	+	+				2	10		2		
24												+*		
27				+										
29				8*	3*							+*		
30	58*			19*	1				3*					
36	+			+						+				
37	17*											+		
cal. cop.	206	4	6	3			2				71			
cyc. cop.	2		129	700	95	110	116	149	71	21	4	67	75	42
ΣSp.	22	3	5	19	19	7	5	7	11	13	6	17	3	3
°C	11.0	17.0	21.4	12.0	14.0	17.5	23.2	16.5	13.5	7.8	9.1	14.7	15.1	24.1
pH	7.2	7.4	7.2	7.3	7.3	7.3	7.	7.3	7.4	7.4	7.2	7.1	7.3	7.6
DO	7.2	1.0	4.5	6.6	9.6	7.8	4.7	6.0	10.2	11.6	3.1	4.1	5.2	4.0
µS	392	426	654	435	500	375	827	630	406	450	280	240	660	720
NTU	3.4	7.3	9.5	7.5	4.5	7.0	5.0	6.0	6.5	2.6	5.0	5.0	5.0	10
H'	2.83	0.41	2.07	1.69	2.72	2.23	1.91	2.21	1.72	2.62	2.28	2.93	1.73	1.82

Sp. Code	1976 31.v.	1976 11.viii	1977 18.iv.	1977 19.v.	1978 23.ii.	1978 26.v.	1978 17.vii.	1978 18.viii.	1978 05.ix.	1979 18.iv.	1980 25.i.
Rotifera											
8			+		+						
10								+			
15					+						
21										1	72*
24				71*						3*	1
32			1*		1*						
37								+			
40	2*		3*	7*							
43			10*	13*							
46				2*							
49		2									
52								3*	+		
56									+	+	
57	1		5*	4	+	1				1*	
64			1						2		
76									+		
79									2		
97									4		
103			10								
104									+		
126								+			
127								+			
130								4			
139								+			
160									+	1	2
177									7		
178									1		
181			+					1			
182					+						
184									17		
194	1		+	5				6			
196										22*	
197					+	+					
206								+			
215				+							
227									+		
230		1							6		
233	88						2	16			15*
234					+						
244			3								
252				+							
Σ sp.	4	2	10	8	7	2	1	11	13	6	4
Cladocera											
1			+								
3					+					1	1
5			9						1		
9						1					
10				6							
11			+	+							
13	+	1	56	32						46	
14			+								
21				+						3	
23			+								
26				+							
27			4	8					1	2	

RYAN'S I BILLABONG (cont):

Sp. Code	31.v.	11.viii	18.iv.	19.v.	23.ii.	26.v.	17.vii.	18.viii.	05.ix.	18.iv.	25.i.
33		1									
45			5								
52			5	+						2*	
60					94*						
61											2*
62		28		4		+	68*	81*	6		
63									10		
64	8	1	1	2*		25*	12*	3			
65			+	4					3		
67		14	+	+				+*			
70			2	2							
73		4	1	1				1	1		
Σ sp.	2	6	14	13	2	3	2	4	6	5	2
Ostracoda											
unid.				+							
Copepoda											
2	10	17	2*	22*	+	2	19	1*	5	8	
4		50		6	10*	9	22	+			
19			1	1							
20									+		
23		5	11	18	13			+		12	
30			1						+		
31				5							
40									5		
cop.	+	+	112	16	+	63	6	28	27		4
Σ sp.	1	3	4	5	3	2	2	3	4	2	1
°C	10.5	10.3	12.9	14.5	22.4	15.0	8.0	10.2	15.4	17.0	n/a
pH	7.7	7.7	7.4	7.0	9.2	6.7	7.3	7.2	7.0	7.6	
DO	8.7	5.6	6.0	9.4	5.1	10.4	10.2	9.0	10.6	9.8	
µS	95	90	150	260	170	110	71	62	50	145	
NTU	4.3	4.9	15	7.6	54	10	11	6.8	6.8	6.6	
H'	1 12	2 27	2 27	2 69	1 20	1 55	1 95	2 10	3 51	2 58	1 26

RYAN'S II BILLABONG

Sp. Code	1976	1977					1978			1979	1980
	11.viii.	6.i.	18.iv.	19.v.	27.vii.	14.xi.	26.v.	18.viii.	05.ix.	20.iv.	25.i.
Rotifera											
8			1	1							
9											+
14			1								
15											+
21										1	+
24				3	+						
28										1	
37			1		+						
40		36*	2	1							
43		2*			2*						
48					+			+			
49										+	
52					+			+	3		
56					+	2		+	3*	8	
57										10	
65		52							+		

RYAN'S II BILLABONG (cont):

Sp.	1976	1977					1978			1979	1980
Code	11.viii.	06.i.	18.iv.	19.v.	27.vii.	14.xi.	26.v.	18 .viii.	05.ix.	20.iv.	25.i.
76		5									
80									1		
85			+								
97						2					
103		2									
104							+				
105							+				
110							+		1		
126									1		
163		1									+
177								+	1		
184						2		+			
191								+			
193									2		
194	+		2		186*			1	1	8	
204			+								
212					10						
217					+						
218			+								
220					+						
232							+		+	1	
240					+			1*			
244										1	
151							1				
Σ sp	1	6	8	3	11	3	4	8	10	8	4
Cladocera											
5			5			+			+		
9			5						5*		
10							+*				
13	69*		91	15*	5*			3	45*		
15			6*								
16	+								1*		
21	+	+	45*	7*	+						
27	+	1		38*					13*		
30				1							
33	1	+							+*		
40			32*								
42			4								
50						1	+*				
52		2	8	4							
57							+				
60										12*	
62	1	+		1		14				3	
63								9*	50*		
64	36										
66			+			+	+				
67	9	+*			+*	7*			1		
70		1*									
71	1		3			1					
73					2		+*	31*	23*		
Σ sp	9	7	10	6	4	6	5	3	9	2	0
Ostracoda											
?28				1						1	
unid	+	1	7			1	+		4		

Sp. Code	1976			1977				1978		1979	1980
	11.viii.	06.i.	18.iv.	19.v.	27.vii.	14.xi.	26.v.	18.viii.	05.ix.	20.iv.	25.i.
Copepoda											
2	62*	+		11	2*		+	3*	18*	58*	+
4				10			+	3	8		
6									2		
14							+*				+
18		3	+				+*				
20		2*	1		1*						
23	1	13*	16	7*	1*	21*	8*	1	10		
26					1						
30	1	5*	+								
cop.	+	99	43	75	39	34	411	60	57	67	
Σ sp.	3	5	4	3	4	1	5	3	4	1	2
°C	11.0	21.4	8.7	14.5	7.5	20.0	15.0	10.0	15.4		
pH	7.5	7.5	7.4	7.4	7.3	7.2	4.9	7.0	7.0		
DO	6.5	8.4	2.6	9.2	-	4.5	10.4	3.3	10.6	n/a	n/a
µS	180	178	280	297	228	355	400	198	50		
NTU	15.5	13.0	36	46	9.4	15.0	11.0	5.5	6.8		
H'	1 96	2 97	2 84	2 57	1 33	2 37	0 19	2 04	2 65	2 79	

Appendix 6b. : Subsample counts from Goulburn billabong series. Physico-chemical measurements and community diversity are included. * indicates the presence of ovigerous ♀♀/ individuals.

Sp. code	1976						1977			1978		
	10.i	06.ii	08.iii	18.iv	25. v	30.ix	04. i	12.iv	14.x	07. i	27.ii	22.viii
ROTIFERA												
5				+				1				
6										2		
15											1*	
40								4		17	1*	
43										3		
49												+
52									55*			
63								8			1	1
76									1	16		
79									+			
80									2			
104									+			
108									+			
111				2					+			+
125						+					13	+
133									+			
140				4								
141									+			
142							+					
148									+			
153												4
158									2			
160									+			
164									+			+
172									+			
173									+			+
191				3					+			
193											1	+
194				+		+	+	9				
200									2			
211									+			
212				2					+			+
215				1				+				
218				1					+			
220									+			
227									+			
230												+
231										2	1	+
237										2		
240										1		
ΣSp.				8	-	2	2	5	22	7	6	11
MICROCRUSTACEA												
CLADOCERA												
5				+								
9	+	+							1			
10												+
13	6	142*	23*	1	86*	269*	2*	+	22*			81
15				+			+		1			
16	+						4					+
17				+								
19									+			
21	6	2	+	4*		+*	1	2	1			
23	+	4	13				7*		+			
27	+	10*	15*	9*		1*					+	+
30		2		+		1	10*		+			

"GOULBURN VIEW" (Cont.):

Sp. code	1976						1977			1978		
	10.i	06.ii	08.iii	18.iv	25.v	30.ix	04.i	12.iv	14.x	07.i	27.ii	22.viii
CLADOCERA												
33							3*		+			+
38		+*		2*		4*	6*	7	+*			
40	2	+	3*	3*			3					
41			+	+		1	2*		+			
42									+			
43												+
44	+*	+		1*			1					
45				2		3*	3*					
49							+	4				
50			1	+		11						
52											1	
53											+	
57						1						
60	+	2*									1*	
62	3	7					3*					
66	+	4*	2			1	+	2				+
67	2*	1	+	1	3		22*		+	2		+
70				1				2		1		
71	3*	1	+	+			4*					
73	+	3	2			6	88*		4*			18
OSTRACODA												
5	23		17				+					
9						1						5
11						48						3
12												7
15						1						
23			+									
25				2								
27								1				
28	4	3	7			14						4
29	1	+	+				+		5			2
32	2	11	16									
COPEPODA												
4	11	14	3*			1	+*	1	1		1	+
8	+	2				4			1		1	+
18	3	+	2	2			4					
19	8			+								
20		+	2	+			5					
23	83*	37*	23*	3*	7	+	60	47*	+*	12*	4*	4*
24		3	+*			+	6		1			
25	42*	27*	11	12*	3						1	4
26	18*	13*	+	2			7*					
29		+*	2*	35*	1	+						
30	+			+			22*	13*		4*	4	
31	+	+		+								
36				+		5*	+	1	1			2*
37				+				+				
cop.	31	44	67	45		50	145		133	41	43	69
ΣSp.	27	28	24	28	5	21	28	12	19	4	9	19
°C	29.4	26.6	20.5	15.0	12.5	17.0	17.0	19.0	16.5	28.0	28.0	10.0
pH	7.2	7.1	7.1	7.2	6.9	7.2	7.1	6.9	7.2	7.2	7.1	7.3
DO	1.6	1.2	1.5	1.4	1.0	9.8	8.2	8.8	9.1	6.1	13.8	13.0
µS	164	230	245	220	280	227	230	110	95	175	250	52
NTU	2.5	4.5	10	27	44	–	–	35	–	–	–	23.5
H'	2.99	2.93	3.45	3.18	0.83	1.94	2.98	2.72	1.91	2.54	2.19	2.37

SHEEPWASH BILLABONG, YEA, VIC.

Sp. code	1976			1977			1978					1979	
	17.iv.	25.v.	30.ix.	12.iv.	22.v.	14.x.	07.i.	27.ii.	04.v.	07.vi.	22.viii	20.iii	21.v.
ROTIFERA													
2						+							
15				2*						1*			
32				10*			11*	3					
36			+										
39				1*	1*		+						
44										+			
46								+					
49	+		+		+	5*	2	24*	115*	56*	3	6*	17*
52													11*
54						4*			2		1		
56										+			
57					+*		+	1		41*			
58												10	
61					1								3
65	2		+					19		+			
69							1				1		+
79	3					1					+		
82												4	
86	+												
103													+
104							2	+		1	+		+
109	+										+		
110													+
112	+												
114						2		5					
115											3		
131											9		
145							3						
147	+												
160						3							
162											3		
167	2									6	+		2
184			+	13	3	4				4	+		
185						3							
191			+			1		6		12*	1		16
194	1	1*		2*						+		5	
196													+
214										+			
216	+												+
217	1												
220	2												
221	+												
222	1												
225	+	1											
229						7	6						
235			+		+					1			
236							+	7					
240										+			
244													2*
247	+	2											
ΣSp.	16	3	6	5	7	10	9	9	2	14	13	4	13
CLADOCERA													
9	+*												
13			629*		+*					+	62*		
16	1		2		+					+			
21	4*		5								9		

SHEEPWASH BILLABONG (Cont.):

Sp. code	1976			1977			1978					1979	
	17.iv.	25.v.	30.ix	12.iv.	22.v.	14.x.	07.i.	27.ii.	04.v.	07.vi.	22.viii	20.iii.	21.v.
CLADOCERA													
23						1*							
27	1						1						
40				+							1		
41						1*	1				1		
45	+												
50	38*	11		3*	+*			+					+
52	+												
62	3*	17*		27*	13*	1		+	2	+	3		+*
63										+			
64											+		+
67	36*	72*	202*	3	+*	1		+	+	+	1*		+
70		2*		2*									
72	7*	7*	105*	1*	8*					1		3*	
73			+*										
OSTRACODA													
29					+	1					2		
30						1					1		
COPEPODA													
4	1	2		1*	13*	+							
20	3	1*	7				1						
21								+					
23	8	4	47	8				+	+			2	
25			12	12	84*				4	19			+*
30		1	41			9*	3				2		
cop.	2	2	7	18	14	36	11	17	32	12	3	49	30
ΣSp.	13	9	10	9	9	8	4	5	4	7	10	2	5
°C	19.9	18.0	16.0	17.0	8.0	20.0	20.0	21.5	14.0		10.0		10.5
pH	7.1	7.2	7.1	7.7	7.5	7.3	7.2	7.2	7.1		7.2		7.2
DO	8.5	9.6	9.8	8.8	10.4	9.0	9.4	6.2	9.8		6.1		10.1
µS	85	104	60	130	145	130	165	200	35		170		150
NTU	2	2.5	1	3	2.7	3	2.5	0.8	0.5		17		5
H'	2.90	2.17	1.84	3.07	1.88	2.97	2.89	2.56	1.09	2.33	2.45	1.82	2.30

"ACACIA'S" BILLABONG, TRAWOOL, VIC.

Sp. code	1976		1977			1978	
	25 v	29 ix	18 iv	22 v	14 x	7 i	22 viii
ROTIFERA							
2	+						
24					+		
29						2	
32			9				
34		+					
40		+	2			3*	
48			+				+
49							19*
52		+			20*	6*	4*
57						2	
62			2			1	
64		+		1		2	1
79		2			+		
80					+	3	
104		+			+	1	
112		+			+		
114						7	
115					1		
132					1		
134					+	9	
154		1			+		
158		1			+	1	
162					1		
165	+	+				2	18
167					+		
172					+		
176					+		
184			+				26
185					11		
191		+			+		
192	1*	1	109	1			
194							+
196		+					
210				+			
214	+						
217	+			+			
220	+			+			
226	1				+	2	
229		+	+	+			1
231					+		
237						+	
ΣSp.	7	14	8	6	19	14	8

Sp. code	1976		1977			1978	
	25 v	29 ix	18 iv	22 v	14 x	7 i	22 viii
MICROCRUSTACEA							
CLADOCERA							
13	26*	7*	+	33*	1	1	2
15	1	+	+	2			
16	2	1	+	5*			
20		3					
22						+	
23		+*					
30		+	+	3*		2	
33		1*					
38		2					
40						1	+
41		1*	1	1*	+*	1	2
44	1						
50	2						
52	1					1	
62	3	234*	30	13*	18*	41	95*
67	30*	5*	2*	9*	1*	2*	
69		+*					
70				7*			+
72	27*	16				2*	
73		83*	8*	26*	3*		1
COPEPODA							
4	157*	1	1	4*			22*
13		4	4		2*		
18				1			
19	1						
20	52*	11		1	+		+
21	+						
23	9	19*	19*	1*	1*	2*	+
25			1		+*		
26							2
29		2					
30				1*	1*	1*	
cop.	15	31	17	4	47	58	33
°C	18.0	17.0	17.5	12.0	22.0	22.0	10.0
pH	7.1	7.2	7.0	7.3	7.2	7.3	7.1
DO	8.4	9.8	8.6	9.8	9.2	8.0	10.8
μS	125	142	230	140	60	155	95
NTU	2.5	5	27	2.2	6	10	12.5
H'	2.50	2.26	2.31	3.16	2.43	3.01	2.60
ΣSp.	14	19	12	14	10	11	10

GOULBURN BILLABONG, SEYMOUR, VIC.

Sp. code	1976				1977				1978					1979	
	17.iv.	25.v.	11.viii	29.ix.	13.iv	22.v.	15.x.	14.xi.	07.i.	08.ii.	26.ii.	26.v.	22.viii	01.ii	25.v.
ROTIFERA															
1							+								
15											+				
40				+						+	+			2*	3
43			11	+											+
47															1
49															6
50					+										
52						+			2	2	+	2*		3	3
54															1*
56									1*		2				2
57														1	
65					+						+				
66													1		
76								+		+					
79													+	1	
80															2
84															3
85				+							+				3
87															3
97											+		+		
104								2			3		1	8	
105											+		+		
106											2				
115							1	1			+				
132														16	
142													+		
148													+		
162															5
164													11		3
165							+				+	4			7
167											+				
171															1
172															2
178															7
183							+					16			
185															4
191											7			1	4
194											1				
203											+				
214								+			+		5		
216															5
217	+														13
220															5
222															8
227															5
237											+*				
249															6
ΣSp.	1	-	1	3	2	1	4	4	2	3	18	3	9	7	24
CLADOCERA															
2				+		+	+								
4	72*					9	1								
5	1	12					+	+							
9			9*												
13	15*	6	9		8	15*	5	1	+		2	2		3	8*

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GOULBURN BILLABONG (Cont.)

Sp. code	1976				1977				1978					1978	
	17.iv.	25.v.	11.viii	29.ix.	13.iv.	22.v.	15.x.	14.xi	07.i.	08.ii.	26.ii.	26.v.	22.viii	01.ii.	25.v.
CLADOCERA															
15	2	2		10*	5*	1*			5	3	1	1	+		+
16	2		13*	+	+	+*	1	+		1	+		+		+
17	6	6*					2								
21	3			+*	1	15*		1	5				5	3*	
23	+*							5*	3*		+	1	4		
26					+*	+			1						
27			17	+	15*	+*				3	+	4	3		
30	2*			1	10*	12*	11	4*	1	3	+		+		
33	1				1			1		1					
38	5			+	2				25*	+					
41	+*								4*	1	+		+		
45	+	1*	32*	2*		+						9	1		+
49			3	2	1										
52			6	4	6*	+*									
57												+			
60	+*				1	+					+				
62	+		3	3*	4	2*			3			4*			
63				1		+	58*	6							
66	27	31*			4	+*	1	4*	2*						
67	5*	8*				1*		1		4*	+	1			+
68													+		
69	1														
70					7*	6*			1	79*	112*				
73	8			2	18*	14*	8	2*				21*	1		
OSTRACODA															
17					+				+	+					
27					2										
30	2				2	1		+		+		2	2	1	
COPEPODA															
2	19*		4	21*	6*		8*						+		12*
4		23*			2*	16	4	+	+					1	8
7	+			39*			2*								
14	+				+*				+		2	2*			
18		3				4*	1		1*						
19			3	+		+			+						
20	15*	1	8*		6*		1		+*	+*	+				+
21					14*					2			1	2	
23	+			7*		9*					+	6*			2
24	3				2*		3*	+							
25	23										1				
29			7										1		
30	3			7*		14	3*		1*		+		+		6*
31	2						2	1					+		
32									+						
cop.	23	2	16	91	10	2	44	43	5	8	13	24	64	19	59
ΣSp.	29	10	12	18	25	24	18	15	18	13	15	12	16	5	10
°C	20.0	15.0	14.0	18.0	16.0	12.0	15.0	14.0	16.0	14.0	22.5	14.0	10.0	25.0	8.0
pH	7.1	7.3	7.2	7.3	7.5	7.3	7.2	7.4	7.3	7.2	7.5	7.4	7.2	7.5	7.0
DO	9.0	9.8	6.2	9.4	2.7	7.0	6.2	5.6	4.5	6.4	7.8	9.8	11.6	8.2	11.2
µS	190	145	300	-	460	220	-	-	450	660	1080	415	330	425	135
NTU	60	130	75	-	350	120	-	-	25	15	3	10	62	35	15
H'	3.52	2.73	3.47	2.40	3.99	3.49	2.79	2.37	3.03	1.62	1.47	3.17	1.98	2.34	4.06

APPENDIX 70 : Physico-chemical data and algal biomass, Mannum:

Date	Sample #	Temp. °C air	wat.	pH	DO ppm	%	µS	NTU	TDS	algae ml^{-1}
29.vi.76	40	15.0	11.0	7.8	12.0	108	300	94	239	debris
13.vii.76	E&WS	12.0	10.0	7.7	11.1	98	401	100	237	532
09.viii.76	44	14.0	12.5	7.6	11.4	107	522	125	315	162
27.ix.76	70	25.5	16.0	8.0	9.6	97	700	130	115	186
12.x.76	E&WS	20.0	18.0	7.9	9.2	97	717	100	369	202
08.xi.76	E&WS	22.0	20.0	8.0	8.6	94	816	115	434	630
17.xii.76	111	23.5	23.0	8.0	8.3	96	611	65	308	458
10.i.77	E&WS	-	-	7.7	-	-	610	65	319	528
03.ii.77	149	24.0	23.0	8.3	8.6	99	650	110	400	140
22.ii.77	151	27.5	25.0	8.0	8.4	100	770	65	425	200
03.iii.77	152	24.5	22.5	7.5	6.4	73	500	37	560	484
16.iii.77	160	21.5	24.0	8.3	8.0	94	1000	27	610	5152
23.iii.77	161	19.0	20.5	8.8	8.7	96	1000	20	600	3756
08.iv.77	163	19.5	18.0	7.5	9.2	97	972	160	557	490
20.iv.77	193	21.0	18.0	8.2	8.6	91	850	10	500	960
16.v.77	E&WS	13.5	14.5	7.8	9.8	95	600	72	410	449
01.vi.77	247	16.0	13.0	7.7	10.1	95	430	125	329	151
29.vi.77	249	12.0	12.0	8.0	10.6	98	420	130	285	336
11.vii.77	E&WS	-	-	7.6	-	-	436	150	248	300
08.viii.77	E&WS	-	-	7.7	-	-	430	205	245	300
13.ix.77	E&WS	14.0	13.0	7.6	10.2	96	380	120	253	95
19. x .77	271	13.0	16.5	8.2	8.3	85	750	110	308	20
02.xi.77	272	14.0	15.0	8.0	10.0	98	600	100	335	32
30.xi.77	293	23.0	21.0	7.9	9.0	100	820	82	415	0
14.xii.77	294	26.0	23.5	8.0	8.4	98	1350	75	516	0
28.xii.77	295	19.5	17.0	8.2	9.7	100	1000	88	536	16
04. i .78	E&WS	18.0	19.0	7.7	9.4	101	960	60	540	0
14.ii.78	305	18.0	20.5	8.2	7.2	79	1100	50	640	50
26.ii.78	306	15.0	20.0	8.0	9.0	98	800	33	600	1800
09.iii.78	334	21.5	21.2	8.3	7.4	82	1950	28	718	480
24.iii.78	336	20.0	21.0	8.5	9.0	100	1250	23	690	3010
06.iv.78	352	14.5	18.5	8.2	9.1	97	1100	25	638	4147
14.iv.78	355	14.0	17.5	8.4	9.2	94	1120	22	627	2050
24.iv.78	356	21.5	17.5	8.7	9.1	93	1100	20	616	2290
05.v.78	369	14.0	16.5	8.4	8.1	83	1100	19	604	810
16.v.78	370	15.0	14.5	8.4	10.0	97	900	23	620	190
27.v.78	425	21.0	16.5	7.8	9.4	96	1135	18	640	1160
27.vi.78	465	7.0	14.0	8.2	9.2	89	1100	24	540	570
13.vii.78	479	6.3	10.5	8.3	11.8	105	630	43	489	470
27.vii.78	482	10.0	11.0	8.4	10.8	97	575	40	390	2520
14.viii.78	485	4.0	8.5	8.3	12.0	102	600	130	345	2050
25.viii.78	512	16.0	12.5	8.2	9.4	88	750	100	330	1190
20.ix.78	537	17.5	14.0	7.0	9.2	88	365	130	230	123
05. x .78	538	6.0	15.0	7.3	9.8	96	325	115	244	163
16.xi.78	543	14.5	17.0	7.6	9.6	99	290	120	172	880
30.xi.78	552	19.0	22.0	8.1	8.8	100	370	80	194	25636
04. i .79	560	31.0	24.0	8.0	8.2	96	440	68	200	1592
05.ii.79	595	18.0	20.3	7.1	8.0	88	590	62	247	960
03.iv.79	603	18.5	19.5	7.7	9.4	103	620	37	350	123
06. v .79	607	8.0	16.0	7.4	9.4	95	700	9	415	80
04.vi.79	640	17.0	12.0	7.9	10.4	96	950	15	440	272
17.vii.79	E&WS	-	-	7.8	-	-	548	32	279	19952
16.viii.79	671	12.0	12.0	7.7	11.7	108	625	25	315	5664
Range		4.0-31.0	8.5-25.5	7.0-8.8	6.4-12.0	73-108	290-1950	9-225	115-718	0-25636
$\bar{X}$		17.7	16.8	7.95	9.4		930	62	409	2275

Rotifera

	1976				1977																
Species code	29 vi	09 viii	27 ix	17 xii	04 ii	22 ii	03 iii	08 iii	16 iii	23 iii	08 iv	20 iv	01 vi	29 vi	14 viii	13 ix	19 x	02 xi	30 xi	14 xii	28 xii
4																					
6												+									+
8												+									
11									1							1					+
14																					+
15	1		+	22	20	7	4	5		6		19*	62			20	1		2	3*	
17																					
20																					+
21				1*								1									
22	2*	3*										12*									
23				47	12	4	20*	3	1												+
24				31*	4				14*	2	6	25*	+						1		
25	+*	5*												2		+					
27				216*																	
31				26*	2	15	12	5*	7	25	3	1		1							
32									3	7*	+	1*									
33			+	1	38*	28*	6*	+	6*					2*	+	1*	5	6*	283	9*	6*
35																					
36																			2	2	
38																					
40	+				+					1											
43																+					
44									4		+						2				
45																+					
48	2*	5	277*	3	58	537*	100*	60	166		1	5*	33	73	20*	58*	7	4	144	57*	5*
49			+			1							4	8		15	2		30		
52				+	3	1	1*					1				1*			2		
53							2	10	39	53						4*		1*			
54				+										20*							
55																1	2	1*	24	17*	9*
56			+		+								2			+					
57	2*			1	10	9	14	3	18	18		56*	31	4	+	4*			3		
58																					
63						1	1	+													
65																					
70																					
76																					
77																					
79																					
97					1																
104					+														+		1
109																					
114												9							1		
115																					
117																					
118							1														
123																					
124																					
148												1							+		
153																					
163	1						+									1					
166													2								
170																					
172																					
178																					
182								+						2		+					
184																					
185				1	+	3			2			+							1		
186				+																	
188																			+		
191					2			+				3*									
194	48*	11	2	11	3	1	6	11	4	1	1	9	+	4	+			2	3		+
196												1									
197												3									
205																					
212																					
214			+	30	59*		1*						20	1		62*	19	1*	12	3*	
215																					8*
217																					
220								+													
229																			+		
232		8	3		59			3				2	8	5	1	3	3	27	8		+
233												+									+
234																				+	3
235		3			27	16	4	2									2			+	
236				1	4	20	4											+			
237																				+	1
238			108*	+	41*	61*	39*	4	12	2	1										
239		+										+	6	22*	+*	6*	3	2	51	13*	5*
240													+			+					+
241			5		17*	15*	+*	+						2	+	12					
242	1*		13*		1	+	1*									9*					+
243		21					1					+	+	1		2					
244		3	2	15	54	22	69	37	147	41	1	1	2	+*	+	5			+	1	
245					+											+			+		+
248					+																
Σ Sp.	9	8	12	18	24	17	20	17	13	10	8	23	13	15	8	24	10	9	21	12	18

Appendix 7b : Zooplankton counts/15 ml aliquot subsample, Mannum trap samples.
* presence of ovigerous individuals

Appendix 7b (cont).

Rotifera

Sp. code	1978																1979					
	14 ii	26 ii	09 iii	23 iii	06 iv	26 iv	05 v	16 v	27 vi	13 vii	27 vii	14 viii	20 ix	05 x	16 xi	30 xi	04 i	05 iii	03 iv	06 v	04 vi	[illegible] vii
2																					+	
6																					+	
8																					+	
11																						
14	+																					
15		5		11*			16		9*		1		2	2	39*	16*	47*	+*	3*	+	3	
17																+						
20																						
21							21										10*				1*	
22														+							3*	
23				24*	2											16*		+				
24						+*	1															
25				9*													1			+	3	
27																						
31																		3	+			
32																						
33	3	1	3		1	1				+		3*	+	2*	4	1		+	2*		2*	7
35																			+			
36						1			+		1	1										
38			+																			
40																						
43				+									3									
44								9							2	+						
45																						
48	12*	3*	5	2	3	31	6	50*	25	23*	19	111*	41*	41*	11*	3		+	+	5*	24*	88*
49									3	26*	70*	69*	9	11	6	9*		+			+	156*
52				1				1	6	2		3	12*	29*	+	1				2	9*	2
53								2			4				4				+	+*	+	
54												+*										
55	+		2		3	1							2*	2	8	2				+*		+*
56											+	8	7	1		2						
57	+		5	1	+	6	50	10*	10*	63*	7	6*			7*	19	1		1	+	31*	35*
58								4										+				
63				+			1															
65	+									+					+							1
70													+									
76																			+			
77											+											
79																				2		
97																						
104				1											+							
109																		+				
114											+		+						+			
115					+	+																
117											+											
118																						
123							2															
124											2											
148							6															
153										1	2	4										
163															+	43						
166													1	2								
170																	+				1	
172														+	+	5						
178																		+				
182												+										
184																				+		112
185					+	+			3	61			1			+	7					
186																						
188															13*	28	2					
191					+	5		28	1		2	4							2	5*		5
194	+	+				+	1			+					8	5	1	+				4
196																2		+				
197													+					+				
205																+						
212																		+				
214	+		22	13	+	98	8	69	212*	217*	78*	307*	142	246*	99*	103	50*	2*				384*
215																				+	19*	
217																					+	
220																						
229						2																
232						6			2	1		2	+			10	3			1		
233	+														+							
234																			+			
235				1			1	1		2				+								
236			5	1	+		1															
237	13	7*	1														11*	24*	3	1		
238	4*	5*	4	2	+	1	2	7*	13*	+				1	9							
239	19*	14*									2	3	4		3*	3*	3	11*	+	2*		14*
240																		2		1		+
241	14	2	6	1	+	1*									+	30*	3	12*	4			
242								+				+		1	5	13	15*	8	+	+	2*	
243									5*	2*	57*	7*	4		1	+*						+
244	3	+	4	4	+	3	3		73*	146*	66*	41*	+	1		20*		+			14*	76*
245																						
248																+	+					+*
Σ Sp.	13	9	11	15	12	16	14	11	13	15	17	17	18	15	22	26	15	20	15	15	18	16

Sp. code	1976				1977																
	29 vi	09 viii	27 ix	17 xii	04 ii	22 ii	03 iii	08 iii	16 iii	23 iii	08 iv	20 iv	01 vi	29 vi	14 viii	13 ix	19 x	02 xi	30 xi	14 xii	21 xii
CLADOCERA																					
3																					
4						2												37	48	4*	2
5									3	1											
6														2		1					+
7																					+
13		1		1	+	+	1		3		+	+			1				1		
16																			1		
17																					
20																					
21					+											1			1		2
23									1												
27	1	3*		1	7		2	4	4	2	2		3	2	5*	1*		+	+		3
38																			1		
45																					+
46		1														+					
47																					
50		1		+																	
51												+		5							
52							2						1		1				+		
58													2								
60		1		42	642*	102	77*	51	81	135*	57	6							1739	223*	107*
61		1																			
62	338*	303*	351*	113*	245	250*	157*	61*	68*	89*	31	7*	211*	214*	164*	231	66	47*	195	13*	18
63	1	2	1		1	2		1					1			+		2	11	4*	+
64	5	1								2	+	1	1*	1		2					
67																					
70					40	26	27*	18*	48	74*	67	40*				1	3		8	3	
73	13	23	11				5*	3	8		4	1*	2				5	260*	495	21	9
9																					+
OSTRACODA																					
2																					
30	+				+							+						1			+
COPEPODA																					
7	22*	8	15	40	1062	182*	113*	58	91*	98*	29	5	32*	3	2	19	54	36*	257	12*	42*
9																		1	6	3*	+
14																			3		
15																					
16															+						
18	3	1			2			+											+		
21																					
23		1	1	1	1	6	3	10	10	41*	15	3							4		
29	1	1							1												
31																					
32																			1		
35																		1			
38																				+	
cal. cop.	5	4		14	823	1001	656	196	384	1085		6	9	13	2	25		24	690	392	215
cyc. cop.						+	2	+		96			1							2	2
ΣSp.	9	14	5	7	11	8	9	9	11	8	10	10	8	6	6	9	4	9	18	9	14
n ℓ^{-1}	23	40	28	320	36	137	43	267	93	151	140	162	150	117	92	109	126	137	64	117	18

APPENDIX 7b (cont)

Sp. code	1978																1979					
	14 ii	26 ii	09 iii	24 iii	06 iv	24 iv	05 v	16 v	27 vi	13 vii	27 vii	14 viii	20 ix	05 x	16 xi	30 xi	04 i	05 iii	03 iv	06 v	04 vi	16 viii
CLADOCERA																						
3																				+*		
4															+							+
5												+	1			3						
6		2		1*						+												
7										+												
9																						
13										+		1	2	+		1						+
16												+	+									1
17												+										
20												+										
21				1	+						+			+								
23											+	2										
27				2						+		21*	6*	+	2*	2						2
38																						
45				+																		
46										+		2	2*			1						+
47										+		2										
50												+										
51										+	4	3*	3			6						+
52										+	4	3*	3			6						+
58												+				+						
60	17	7	8	82*	2	30	23	17							1	4	1	8		5		
61																						
62	1	14	15	96*	42	141	116	184*	89	124*	152*	57*	32*	47	13*	11	+*	20*	31*	8	54*	199*
63	+	+		2	1	+*	+		+	+*	2	2	+	1						2		
64		+				6	3		+	+	1	+										
67													+									
70	+	2		26*	3	2	3	5										2*	14*	3		
73	+		1				1		+	+	2	3*	2*	7*	+					4		+
OSTRACODA																						
2						+			+													
30	+			+						+			7	+								+
COPEPODA																						
7	5	4	1*	6	29*	61*	31	1	3	3*	4	2*	1*	+*	2	2		+	17*	4*	3	9*
9			6	+						+*	+			+	+					+		+*
14					6	+														1		
15																						+
16						+*					+			+	1					+		
18	+									+												
21																			+			
23		2	8	44*	9	6*	3	5										3*	9*			1*
29													+									
31				+								+										
32																						
35										+												
38													+									
cal. cop.	29	61	109		+	270	23	371	35	37	3	17	23	45	83	24	6	3	74	100	2	93
cyc. cop.							+				1		+					69	3	4		
ΣSp.	8	8	6	13	8	11	7	5	6	16	10	18	14	10	8	10	2	5	5	10	2	13
$n\ell^{-1}$	52	63	65	16	112	150	50	90	86	162	228	80	68	100	124	42	91	299	88	23	215	441

APPENDIX 8a: Hydracarinid mites identified from Murray-Darling waters (K. O. Viets, pers. comm.).

	Reservoirs	Billabongs	Rivers
Australiobates mutatus			√
A. linderi			√
Corticacarus angulocoxalis			√
Frontipoda pectinata			√
?Geacaridae		√	
Hydrodroma monticola		√	
Kallimobates australicus			√
Limnesia longigenitalis		√	
Piona uncatiformis		√	
Piona sp.	√		
Piona n. sp.	√		
Sigthoria nilotica		√	
Unionicola longiseta	√		
Unionicola n. sp.	√		

APPENDIX 8 b: Ephemeroptera recorded from plankton collections from Murray-Darling waters (P . J. Suter, pers.comm.).

	Reservoirs	Billabongs	Rivers
Atalonella sp.			✓
Atalophlebia australis	✓		
Atalophleboides sp.			✓
Baetis spp.			✓
Coloburiscoides giganteus			✓
Cloeon sp.		✓	
Tasmanoceonis tillyardi			✓

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11. PAPERS BY THE AUTHOR OFFERED IN SUPPORT OF THE THESIS

In addition to the two papers included as appendices, five papers by the author are offered in support of the author's scholarship. They are:

1. (1978) Zooplankton communities of the Murray-Darling system, a preliminary report. *Proc.R.Soc.Vict.*,*90*(1):193-202.
2. (1979) Synecology of the Rotifera of the River Murray, South Australia. *Aust.J.Mar.Freshwater Res.*,*30*(2):255-63.
3. (1980a) (with W. Koste) On *Brachionus dichotomus* Shephard, 1911 (Rotatoria:Brachionidae) from the Australian region, with a description of a new subspecies, *Brachionus dichotomus reductus*. *Proc.R.Soc.Vict.*, *91*(2):127-134.
4. (1980b) (with W. Koste) Preliminary remarks on the characteristics of the rotifer fauna of Australia (Notogaea).*Hydrobiologia 73*:221-227.
5. (1980c) (with W. Koste) New Rotifera from Australia. *Trans.R.Soc.S.A.*, *104*(5):133-144.

Other papers by the author are listed by title:

6. (1976) Associations of Entomostraca with weedbed habitats in a billabong of the Goulburn River, Victoria. *Aust.J.Mar.Freshwater Res.*,*27*(4):533-549.
7. (1977) (with K. F. Walker, J. E. Bishop & W. D. Williams) Freshwater invertebrates. In: *Natural history of the Adelaide region* pp.131-141 (ed. C. R. Twidale, M. J. Tyler & B. P. Webb). R.Soc.S.A., Adelaide, 189 pp.
8. (1979) (with W. Koste) Rotifera recorded from Australia. *Trans.R.Soc.S.A.*, *103*(3):57-68 (Bound as Appendix 1).
9. (1980d) Billabongs of the Murray-Darling system. In: *An ecological basis for water resource management* pp. 376-390. (ed. W. D. Williams). A.N.U. Press, Canberra, 417 pp. (Bound as Appendix 6.1)
10. (in press) Planktonic Rotifera of the Murray-Darling river system, Australia: endemism and polymorphism. *Verh.Internat.Verein.Limnol.*,*21*.

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NOTE:

This publication is included in the print copy
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Koste, W. & Shiel, R. J. (1980). On *Brachionus dichotomus*, Shephard, 1911 (Rotatoria: Brachionidae) from the Australian region, with a description of a new subspecies, *Brachionus dichotomus reductus. Proceedings of the Royal Society of Victoria*, *91*(2), 127-134.

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