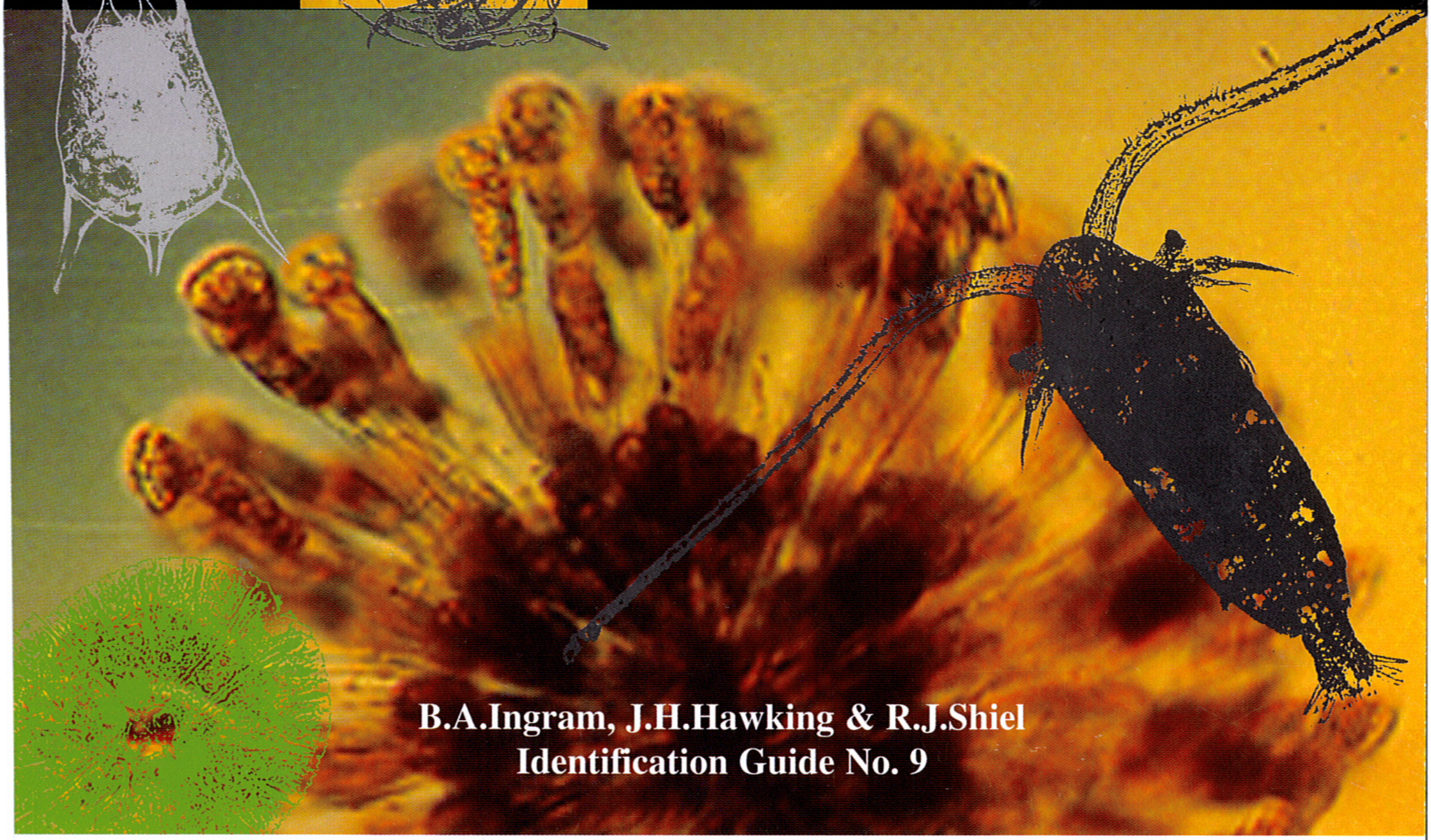
AQUATIC LIFE IN FRESHWATER PONDS

A guide to the identification and ecology of life in aquaculture ponds and farm dams in South Eastern Australia.



B.A.Ingram, J.H.Hawking & R.J.Shiel

Identification Guide No. 9

Cooperative Research Centre for Freshwater Ecology

Natural Resources and Environment

Marine & Freshwater Resources Institute

The Murray-Darling Freshwater Research Centre

AQUATIC LIFE IN FRESHWATER PONDS:

A GUIDE TO THE IDENTIFICATION AND ECOLOGY OF LIFE IN AQUACULTURE PONDS AND FARM DAMS IN SOUTH EASTERN AUSTRALIA

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Preface

The complex and diverse nature of Australia's freshwater invertebrate fauna is becoming increasingly relevant to the sustainable management of our aquatic natural resources. The productivity and integrity of aquatic ecosystems is largely reflected in the diversity and abundance of resident invertebrate communities.

As efforts to develop sustainable aquaculture production in Australian freshwaters increase, so to does the need to optimise natural resource inputs. For aquaculture in stillwaters this occurs through enhanced pond management and intensification, all of which demands an understanding of the trophic dynamics of resident aquatic invertebrate communities, including mechanisms of successional change and associated taxonomic complexities. However, there remains much uncertainty as to the sorts of organisms that might flourish in manipulated aquatic ecosystems which are designed to enhance biological production for aquaculture purposes.

Managers must be able to identify the organisms that might be desirable in their production systems as food, and those that might be undesirable for various reasons. Additionally, with the shift towards management of aquatic natural resources within an ecosystem framework comes the need for reliable invertebrate databases for general application. Such information is necessary for the purposes of monitoring and assessment of aquatic biodiversity and ecosystem integrity within natural waterways.

The Marine and Freshwater Resources Institute (MAFRI), with support from the Department of Natural Resources and Environment, is playing a significant role in providing technical support for the Victorian aquaculture industry, as well as providing reliable and timely information to support the management of Victoria's freshwater fish and aquatic resources.

The Cooperative Research Centre for Freshwater Ecology (CRCFE) aims to provide knowledge to support the Australian water industry, and the upsurge in freshwater aquaculture over the last decade now makes this a significant and important element in this industry.

Unlike much of the water industry which harvests and treats water, aquaculture manages aquatic ecosystems for desirable biological production. The aquaculture industry thus requires an understanding of the organisms that might flourish in these manipulated systems.

The Murray Darling Freshwater Research Centre, the CRCFE and MAFRI, have long recognised the need to support taxonomic work so that aquatic organisms can be accurately identified. With this manual, the authors have successfully produced an authoritative, but user friendly text in the form of an annotated invertebrate species checklist for fresh, temperate stillwaters. The manual is further complemented by a comprehensive collection of taxonomic keys, figures and photographs. Although the original intention was to provide a resource handbook specifically for practising aquaculturists, the quality and extent of the information provided is such that the manual should also serve as a valuable reference for researchers and students of aquatic science, natural resource managers and community groups alike.

The manual is also recognition of the benefits and synergies which can be achieved through active collaboration between researchers and institutions with common goals and complementary skills.

Dr Garth Newman
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INTRODUCTION

Aquaculture is the farming of aquatic organisms for commercial purposes and usually implies that some form of intervention in the rearing process occurs to enhance production under controlled or semi-controlled conditions. Aquaculture is an old industry which was first practised more than 2,500 years ago in Egypt and China when carp and tilapia were reared in earthen ponds (Landau 1992). However, in recent years there has been a considerable increase in the world production of aquatic animals and plants under aquaculture conditions (FAO 1994), and this trend is also occurring in Australia (O'Sullivan 1992).

Many different culture systems are used to raise aquatic organisms, including sea ranching, cage culture in lakes and open waters, and intensive culture in raceways and tanks (Landau 1992). However, the most commonly used culture systems for rearing fish, especially freshwater species and invertebrates, involve the use of earthen ponds (Plates 1a & 1b). In fact, most of the production of the world's major aquaculture fish species, in particular the cyprinids (carps etc.), cichlids (tilapias etc.) and channel catfish, is undertaken in ponds (Landau 1992).

Aquaculture in south eastern Australia primarily involves the farming of native fish, such as silver perch (*Bidyanus bidyanus*), Murray cod (*Maccullochella peelii peelii*) and golden perch (*Macquaria ambigua*), salmonids (*Oncorhynchus* spp. and *Salmo* spp.), goldfish (*Carassius auratus*) and yabbies (*Cherax* spp.). With the exception of salmonids, which are grown in ponds and raceways that have a continual flow of water through them, most species are grown in stillwater earthen ponds of various shapes and sizes.

Aim of this manual

The aim of this resource manual is to introduce aquaculturists and students to the aquatic life, both plant and animal, in freshwater aquaculture ponds and farm dams of south eastern Australia including southern Queensland, New South Wales (NSW), Victoria, and eastern South Australia. This is achieved by providing simplified identification keys and descriptions, accompanied by illustrations for the more common organisms, as well as brief notes on their biology and ecology. The species described here are those of typically still water (lentic habitats) such as aquaculture ponds and other standing water bodies, including farm dams, swamps, lagoons and billabongs. Species not covered here include those found in flowing (lotic) waters, species of limited distribution and or abundance, species which are restricted to brackish or marine waters, species which are more terrestrial than aquatic (littoral or marginal in habit), or predominantly occur outside south eastern Australia.

Occasionally, species which do not fit into the keys or descriptions of this manual will be encountered in aquaculture ponds and farm dams. However, their identity may be determined by using other taxonomic guides such as those produced by the Murray-Darling Freshwater Research centre (MDFRC) (see below), Williams (1980), CSIRO (1991), and other taxonomic literature pertaining to specific groups of Australian aquatic life. An extensive list of these references is provided in this manual.

Aquatic life in freshwater aquaculture ponds and farm dams

There is a wide diversity of aquatic life in freshwater aquaculture ponds and farm dams, with more than 65 genera of algae and over 275 invertebrate species known to occur in such waters in south eastern Australia (Table 1, Appendix I).

However, there are no specific identification guides to the aquatic organisms of Australian aquaculture ponds or farm dams, although a range of general texts exist which identify and describe aquatic life in Australian freshwaters. Williams (1980) gives an overview and provides useful keys to the aquatic invertebrates, and CSIRO (1991) provides detailed keys to aquatic insects. However, the MDFRC has commenced producing a series of identification guides to the Australian aquatic fauna (eg. Pinder and Brinkhurst 1994; Hawking 1994; Shiel 1995; Horwitz 1995; Horwitz *et al.* 1995; Smith 1996; Dean and Suter 1996; Hawking and Smith 1997). Currently there is no guide to the Australian freshwater algae, although Day *et al.* (1995) have produced a bibliographic checklist. Some helpful international texts such as Prescott (1978) and Canter-Lund and Lund (1995) for algae, Pennak (1989) and Thorp and Covich (1991) for invertebrates, and Merritt and Cummins (1984) for aquatic insects are available. However, as these texts refer more to northern hemisphere organisms, they inevitably include many species which will not be encountered in Australia. In addition, many species described in these general texts may not live in aquaculture ponds and farm dams. For example, species which have specific habitat requirements which do not occur in aquaculture ponds (eg. running water, low nutrient loads, low turbidity etc.), have limited geographical distributions, or are otherwise rare in terms of distribution and abundance. The ideal text for an aquaculturist would therefore not necessarily include these species.

Given the lack of published literature, it is not surprising that little is known about the aquatic life in freshwater aquaculture ponds of Australia. When compared with studies overseas, few detailed species surveys and ecological studies have been undertaken (eg. Arumugam and Geddes 1987; Culver 1988; Culver and Geddes 1993). Similarly, investigations of

Table 1 Number of invertebrate taxa known to occur in aquaculture ponds and farm dams of south eastern Australia, and examples of common groups, genera and species

Group	No. of species*	Examples of common taxa
PROTOZOA	unknown	*Actinosphaerium, Chilomonas, Difflugia, Euplotes, Stentor*
NEMATODA	unknown	Dorylaimids
ROTIFERA	75+	*Asplanchna, Brachionus, Filinia, Keratella, Polyarthra*
MOLLUSCA	5+	*Physa acuta*
ANNELIDA	8+	*Lumbriculus variegatus*
ARACHNIDA	3+	*Eylais & Piona*
CRUSTACEA		
Anostraca	1	*Brachinella*
Notostraca	2	*Lepidurus*
Cladocera	30+	*Daphnia carinata, Moina micrura, Bosmina meridionalis*
Ostracoda	3+	*Newnhamia*
Conchostraca	1+	*Cyzicus*
Copepoda	14+	*Boeckella, Mesocyclops, Microcyclops*
Amphipoda	1	
Decapoda	4	*Paratya australiensis, Macrobrachium australiense, Cherax destructor*
INSECTA		
Collembola	3	
Ephemeroptera	4	*Cloeon, Tasmanocoenis*
Odonata	17	*Hemicordulia, Hemianax, Orthetrum, Ischnura*
Plecoptera	2	
Hemiptera	22	*Agraptocorixa, Anisops, Micronecta, Ranatra, Sigara*
Coleoptera	43	*Allodessus, Antiporus, Berosus, Eretes, Hyphydrus, Megaporus*
Diptera	29	*Chironomus, Polypedilum, Procladius*
Trichoptera	5	*Oecetis, Triplectides*
Lepidoptera	1	
OTHER PHYLA	5+	Porifera, Cnidaria, Turbellaria, Nematomorpha, etc.
TOTAL	278+	

* Determined from Appendix I.
\+ indicates that more species are expected to occur for this group.

the aquatic life of farm dams are also limited (eg. Timms 1970, 1988; Morton and Bayly 1977; Barlow and Bock 1981; Geddes 1986).

There is a wide degree of manipulation and intervention to enhance production in aquaculture ponds. Ponds stocked with target species (eg. fish and yabbies) at low densities require little management and animals are allowed to grow unassisted while foraging on naturally occurring food items such as zooplankton and other aquatic invertebrates. However, as the stocking density increases, naturally occurring food becomes limited or depleted and needs to be supplemented by the addition of food to the ponds. Intensification of aquaculture production, through increased stocking densities and an associated increase in management, nutrient and technological input, requires an increase in the level of understanding of the environmental processes occurring within the ponds in order to manage them effectively and to ensure successful production.

All the flora and fauna in aquaculture ponds play a role in the pond community. There are complex relationships between the primary producers (eg. phytoplankton), herbivores, carnivores, scavengers, decomposers and the surrounding environment, all of which are important components of the trophic web (Fig. 1).

Knowledge of the organisms that are present, how many there are, how they relate to each other, and what their role is in the community, will assist aquaculturists in managing and enhancing productivity in their ponds. For example, the survival of golden perch larvae and fry stocked into fertilised rearing ponds is dependent on the availability of suitable quantities, appropriate sizes and species of zooplankton at the time of stocking (Arumugam and Geddes 1987). Furthermore, an understanding of the flora and fauna of ecosystems in natural stillwaters, such as billabongs and swamps, is a fundamental requirement for sustainable management of aquatic biodiversity and habitat.

Marine and Freshwater Resources Institute, Snobs Creek

The Marine and Freshwater Resources Institute, Snobs Creek (MAFRISC) is situated on 57 ha of land approximately 130 km north east of Melbourne, adjacent to the Goulburn River near Eildon. This facility includes a fully functioning fish hatchery, which was established in 1946, initially to produce the salmonid species brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*), and more recently chinook salmon (*Oncorhynchus tshawytscha*). However, following redevelopment during the early 1980's, research and development into the aquaculture of native fish, particularly Murray cod, trout cod (*Macculochella macquariensis*), golden perch, Macquarie perch (*Macquaria australasica*), silver and

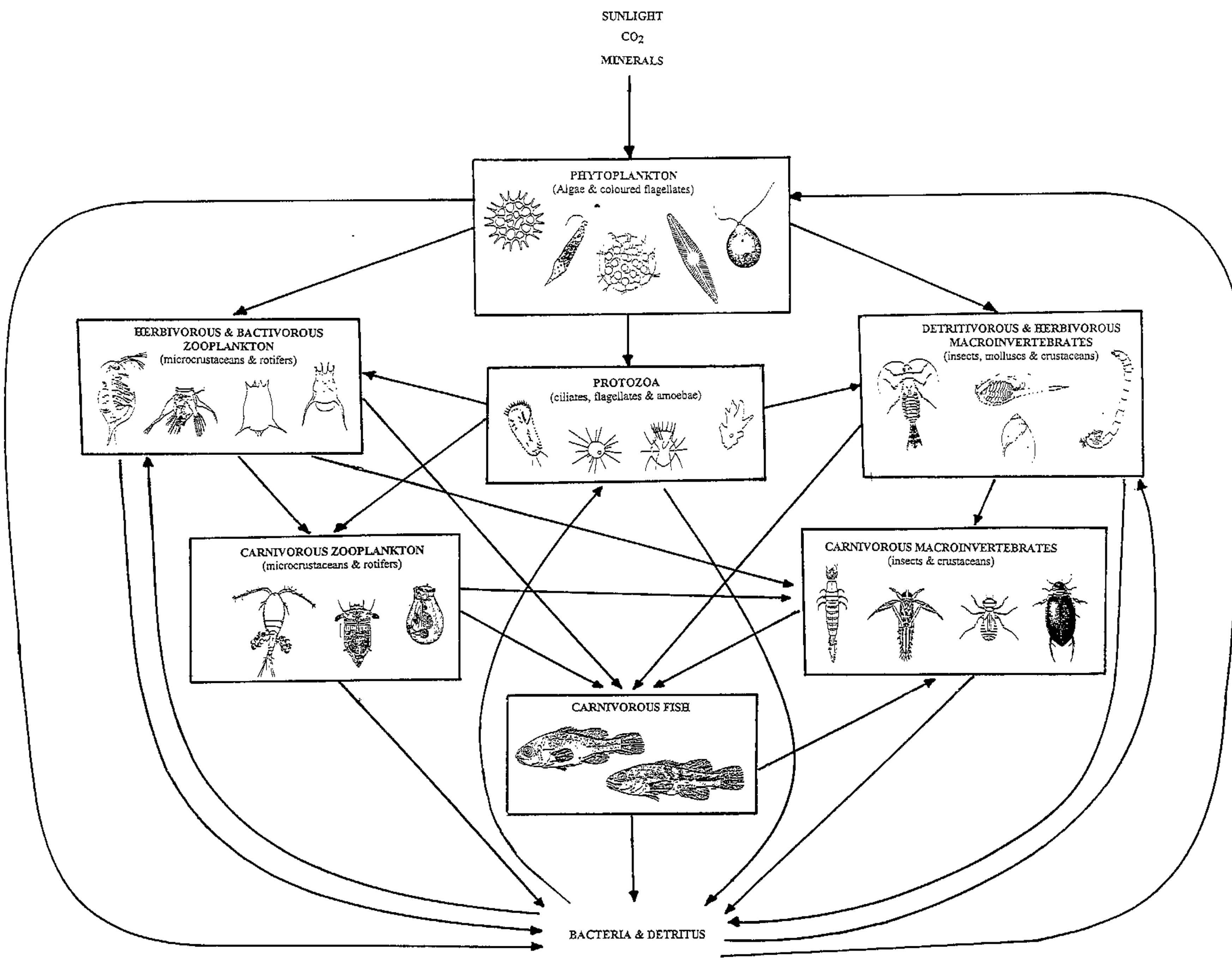


Fig. 1 The trophic web of an aquaculture pond (arrows indicate flow of energy in the form of food and nutrients)

short-finned eels (*Anguilla australis*), has been undertaken.

At the present time, one of the primary roles of the MAFRISC has been the production of juvenile native fish and salmonids for stocking into Victoria's waterways for recreation and conservation purposes. Salmonids are reared in flow-through tanks and concrete raceways, while most of the production of native fish at the MAFRISC is undertaken in specially designed stillwater, earthen ponds.

In 1990, a major study of native fish fry rearing ponds commenced at the MAFRISC. This study aimed to obtain a better understanding of the interactions between the growth and survival of juvenile fish and physical (water chemistry) and biological (phytoplankton, zooplankton and benthic invertebrates) processes occurring within the ponds. Results from this study form the basis for much of the information presented in this manual.

In addition to producing fish for stocking purposes, the MAFRISC has an important role in commercial aquaculture in Victoria, through ongoing aquaculture research and development and provision of advice to the aquaculture industry. Furthermore, MAFRISC is also responsible for undertaking inland fisheries and associated ecological research, monitoring and assessment. Such information is provided for the purposes of managing Victoria's fish and aquatic resources in an ecosystem framework.

Murray-Darling Freshwater Research Centre

The Murray-Darling Freshwater Research Centre (MDFRC), located at Albury, NSW, is the headquarters of the Co-operative Research Centre for Freshwater Ecology (CRCFE). The MDFRC commenced limnological and ecological research in the Murray-Darling basin in the early 1970's, when it was first known as the Peter Till Environmental Laboratory.

Research at the MDFRC has focused on biological, chemical and physical interactions in turbid waters; the limnology and ecology of floodplain and wetland environments, especially billabongs; and the use of wetlands for wastewater treatment. Identification of the diverse array of plants and animals encountered in aquatic ecosystems is essential to much of this research if, for example, any reasonable estimate of environmental impact of catchment activities is to be made, or trophic web interactions are to be understood and/or manipulated.

The MDFRC has established a reputation for expertise in the identification of aquatic plants and animals, and maintains one of Australia's most comprehensive reference collections of aquatic invertebrates. This collection, together with Guides to Identification already produced or planned, will enable identification of many of the invertebrate fauna known to date from Australia's inland waters.

THE AQUACULTURE POND

Design, construction and use

The location of aquaculture ponds is usually subject to a number of important criteria, including water supply (quality and quantity) and soil type (availability of impervious clay or clay loams). The design of aquaculture ponds often depends on the topography of the surrounding land. Gully ponds are constructed in hilly land by building an embankment across a gully or ravine, and their size, shape and depth is generally dictated by the structure of the gully. Excavated ponds and levee ponds are partially or completely dug into the ground; the soil removed is used to form the pond banks. These ponds, which are generally square or rectangular in shape, are constructed on flat or slightly undulating land to take advantage of natural contours. Water is supplied by gravity from a reservoir or by pumping. The majority of aquaculture ponds, such as those at the MAFRISC (Plates 1a & 1b), are of this design. Size, shape and depth can be controlled during construction and their subsequent operation and management is improved by the ability to regulate water supply and drainage.

Most freshwater aquaculture ponds are between 0.1 and 0.5 ha in surface area (0.5-2.5 m in depth), but smaller and larger ponds are used in some circumstances. For example, ponds used to rear channel catfish (*Ictalurus punctatus*) in the USA may exceed 10 ha in surface area. Pond banks generally have a 1 in 3 slope and are lined with topsoil, though some may have concrete walls. Aquaculture ponds ideally have separate reticulated water supply and drainage, including an overflow structure, such as a penstock or standpipe, to control water level within the pond (Plate 1c). Many aquaculture ponds are generally classed as stillwater ponds in that, once they are filled, little additional water is passed through them. However, it is necessary to have a water supply available at all times, not only to fill ponds, but also to replace water lost through evaporation and seepage, and for flushing purposes when water quality deteriorates.

Some aquaculture ponds may remain permanently filled with water, such as broodfish ponds, while other ponds are filled seasonally or for short periods of time, such as fry rearing ponds. Correctly designed aquaculture ponds can be fully drainable for harvesting purposes. In most cases this is facilitated by the pond having a gently sloping floor and a concrete sump or raceway situated in the deepest section for concentration and collection of stock (Plate 1c).

The design and size of earthen ponds used in aquaculture also depends on the species to be cultured. Reservoirs, which are typically situated at the highest elevation, are large, deep, permanently filled ponds which serve as a water source from which water is pumped or gravitated to other ponds and facilities. The water level in the reservoir is most often maintained by pumping from a river, bore or other permanent water source.

The fry of most cultured native fish are on-grown in fertilised fry rearing ponds (also called nursery, plankton or greenwater ponds) (Plate 1b). Fry are stocked into these ponds shortly after they commence feeding, and subsequently are harvested as fingerlings (35-55 mm in length) up to 10 weeks later. The MAFRISC has two types of fry rearing ponds. Four ponds are rectangular in shape and 0.09-0.24 ha in surface area, with a large shallow section (0.5-1.0 m deep) which covers about three quarters of the pond surface area, and a smaller deep section (1.5-2.0 m deep) (Plate 1b). A fifth pond is 0.3 ha in surface area, saucer-shaped and 1.0 m deep in the centre.

Fry rearing ponds are constructed in such a way as to promote the production of high densities of plankton. Prior to filling and stocking, these ponds are scarified, graded and sometimes limed to increase alkalinity. Once filled with water they are fertilised with inorganic and organic fertilisers (nitrogen and phosphorus) to encourage the growth of bacteria, protozoans, phytoplankton and, in turn, zooplankton which will become the food of the fry stocked into the pond. These ponds are normally operated during the warmer months of the year and are filled only for short periods (up to 10 weeks) at a time. When not in use, such as during winter, they are left empty and fallow.

Earthen ponds are also used to grow juvenile fish to a marketable size (over 350 g), which may take up to two years. These on-growing ponds are of various shapes and sizes. Fish are stocked at either low densities, and allowed to feed on food naturally occurring in the ponds, or at higher densities, and their diet is partially or completely supplemented by the addition of commercially available fish foods.

Ponds in which broodfish are held tend to be smaller and deeper than fry rearing ponds. At the MAFRISC these ponds are 0.1-0.2 ha (1.0-2.5 m deep) in size (Plate 1a). Normally broodfish ponds are kept permanently filled with water, except when they are harvested each year to remove stock for breeding purposes. Because of the relatively permanent nature of broodfish ponds, and reservoirs, aquatic macrophytes often become established around their margins.

Ponds used to grow yabbies are more or less similar in design and construction to those used for rearing fish, albeit often shallower in depth, but management practices may differ. For example, in some cases a legume crop may be planted in the pond prior to filling. Cover, in the form of pipes or car tyres, may also be added to provide shelter from predation by cormorants and to reduce cannibalism (Merrick and Lambert 1991).

Earthen raceway ponds are long, narrow ponds (up to 30 m long, 4-10 m wide, 1-1.5 m deep) used to grow salmonids (trout and salmon). One of the main features of these ponds, in contrast to the ponds used for growing native fish, is that they have high volumes of water (2-6 Ml/day per pond) continuously passing through them to maintain high water quality and dissolved oxygen concentrations, which are required for trout production. The volume of water used depends on the species, size and number stocked into the ponds, dissolved oxygen concentration and water temperature.

[***Further reading:*** Brown and Gratzek (1980); Rowland (1986a, 1986b, 1986c, 1996); Rowland and Bryant (1995); Wheaton (1985); Stevenson (1987); Landau (1992)]

Species reared in aquaculture ponds in south eastern Australia

A variety of Australian freshwater fish species are held and reared in freshwater aquaculture ponds. These have included Murray cod, Mary River cod (*Maccullochella peelii mariensis*), trout cod, eastern freshwater cod (*M. ikei*), golden perch, Macquarie perch, Australian bass (*Macquaria novemaculeata*), silver perch, short-finned eels and freshwater catfish (*Tandanus tandanus*).

Introduced species, in particular several species of salmon and trout (*Salmo* spp. and *Oncorhynchus* spp.) and goldfish also are grown in ponds in south eastern Australia.

The main species of freshwater crayfish reared in aquaculture ponds include the common yabby (*Cherax destructor*), redclaw (*C. quadricarinatus*) and marron (*C. tenuimanus*).

ECOLOGY OF AQUACULTURE PONDS

Communities and ecological zones

Aquaculture ponds and farm dams can be divided into several ecologically unique zones, each with its own distinctive community (Fig. 2). The open water (limnetic zone) is occupied by plankton and pelagic organisms. Plankton is the term given to the small plants (phytoplankton) and animals (zooplankton) which float or drift in the water column. The open water of ponds (limnetic zone) is divided into the upper trophogenic and the lower tropholytic zones. The trophogenic zone is the upper layer of the pond in which illumination is sufficient for aquatic plants to photosynthesize. Below this layer, in the tropholytic zone, there is insufficient sunlight for photosynthesis to occur. Around the perimeter or shoreline of the pond is the littoral zone where emergent and submerged aquatic and semi-aquatic plants grow. The pond floor incorporates the benthic zone, and the organisms which live on and in the pond floor are collectively termed benthos.

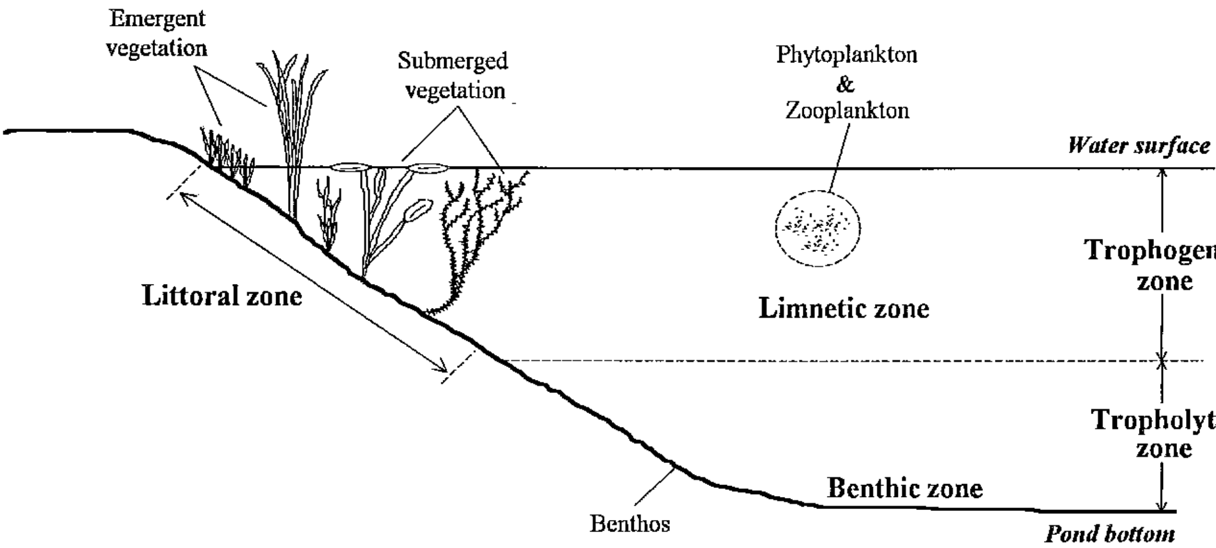


Fig. 2 Major communities and ecological zones of an aquaculture pond

Macroinvertebrate fauna refers to the aquatic insects and large crustaceans that are visible to the naked eye, while the microinvertebrates are the small crustaceans, rotifers and protozoans that typically make up a large proportion of the zooplankton. Other terms used throughout this manual are defined in the glossary.

The trophic web

The organisms within a community continually interact with each other and the environment to form a complex trophic web (Fig. 1). Understanding the pathways within a trophic web is essential to the effective management of aquaculture ponds. Energy, in the form of food or nutrients, flows from one level of the trophic web to another. Each level within the trophic web has a characteristic suite of organisms. A simplified trophic web of a typical aquaculture pond can be broken into several trophic levels including primary producers (plants), primary consumers (herbivores), secondary and tertiary consumers (carnivores) and decomposers (Fig. 1). The flow of energy (food) in this trophic web is indicated by the arrows which link the various levels together. Within the trophic web there may be few linkages between each level, for example, algal cell → rotifer → larval fish, or there may be many linkages, for example, algal cell → ciliate → rotifer → copepod → aquatic beetle larva → dragonfly larva → juvenile fish.

The primary producers in aquaculture ponds are represented by algae (especially phytoplankton), other aquatic plants and certain bacteria. These organisms utilise sunlight energy to convert inorganic nutrients into organic plant matter, through a process called photosynthesis. This ability is unique to the primary producers and for this reason they are the source of food and energy for all other aquatic animal life.

Primary consumers, the herbivores, graze on the primary producers, converting the plant matter and the energy it contains into animal matter. Many species of protozoa, rotifers, molluscs, crustaceans and aquatic insects are herbivores. These herbivores are preyed on by secondary consumers, such as carnivorous rotifers, copepods, aquatic insects and juvenile fish. In turn, the secondary consumers are consumed by larger carnivores, such as some aquatic insects and larger fish.

Not all organisms can be placed into a clearly defined trophic level as some may occupy more than one level, or move between levels. Certain flagellated protozoans can switch between being a primary producer and a primary consumer. Omnivores ingest both plants and animals. Suspension or filter feeding animals, such as sponges, many rotifers, bivalve molluscs and cladocerans, sieve food, including detritus, phytoplankton and zooplankton, from the water. Hydrophilid beetles have carnivorous larvae, yet the adults are herbivores and scavengers.

Another important component in the trophic web involves the breakdown and regeneration of the excreted wastes of living organisms and dead plant and animal tissues. Some species of rotifers, larval chironomids and oligochaete worms are effective at converting this matter into living tissue. Aquatic fungi also play an important role in the breakdown of dead organic matter.

The process of decomposition of organic matter into nutrients, which can be utilised by the primary producers, closes the loop in the trophic web. Decomposition and the subsequent recycling of organic matter back into inorganic nutrients is primarily undertaken by aerobic and anaerobic bacteria. In aquatic environments oxidation of organic matter by bacteria is slow and incomplete, though drying and scarifying the pond floor to aerate the sediments apparently aids this process (Wurtz 1960). Bacteria may also be consumed by other animals in the trophic web.

[*Further reading:* Marcel (1990); Chang (1986); Lannan *et al.* (1986); Delincé (1992)].

Community succession patterns in fry rearing ponds

The most common and effective means of rearing and feeding the larvae and fry of freshwater fish is to stock them into an earthen fry pond containing high densities of food organisms (ie. zooplankton and other invertebrates). Thus fish production in these ponds relies on the maintenance of an appropriate size and abundance of these food organisms, while simultaneously maintaining water quality suitable for survival and growth of larval and juvenile fish.

One of the most important biological processes occurring in fry rearing ponds is the development and succession over time of large blooms of organisms that occur in the community. Between the time when a fry rearing pond is filled with water and subsequently drained to harvest stock weeks or months later, different species of plants and animals will appear and disappear, and their abundance will change. These fluctuations can be quite considerable and vary from day to day and week to week, and the patterns may differ from pond to pond, season to season, and region to region. These variations are seen in fry rearing ponds at the MAFRISC where, for example, three different ponds filled during the same season (Figs 3a, 3b & 3c), and the same pond filled over four different seasons (Figs 3c, 3d, 3e & 3f), developed different

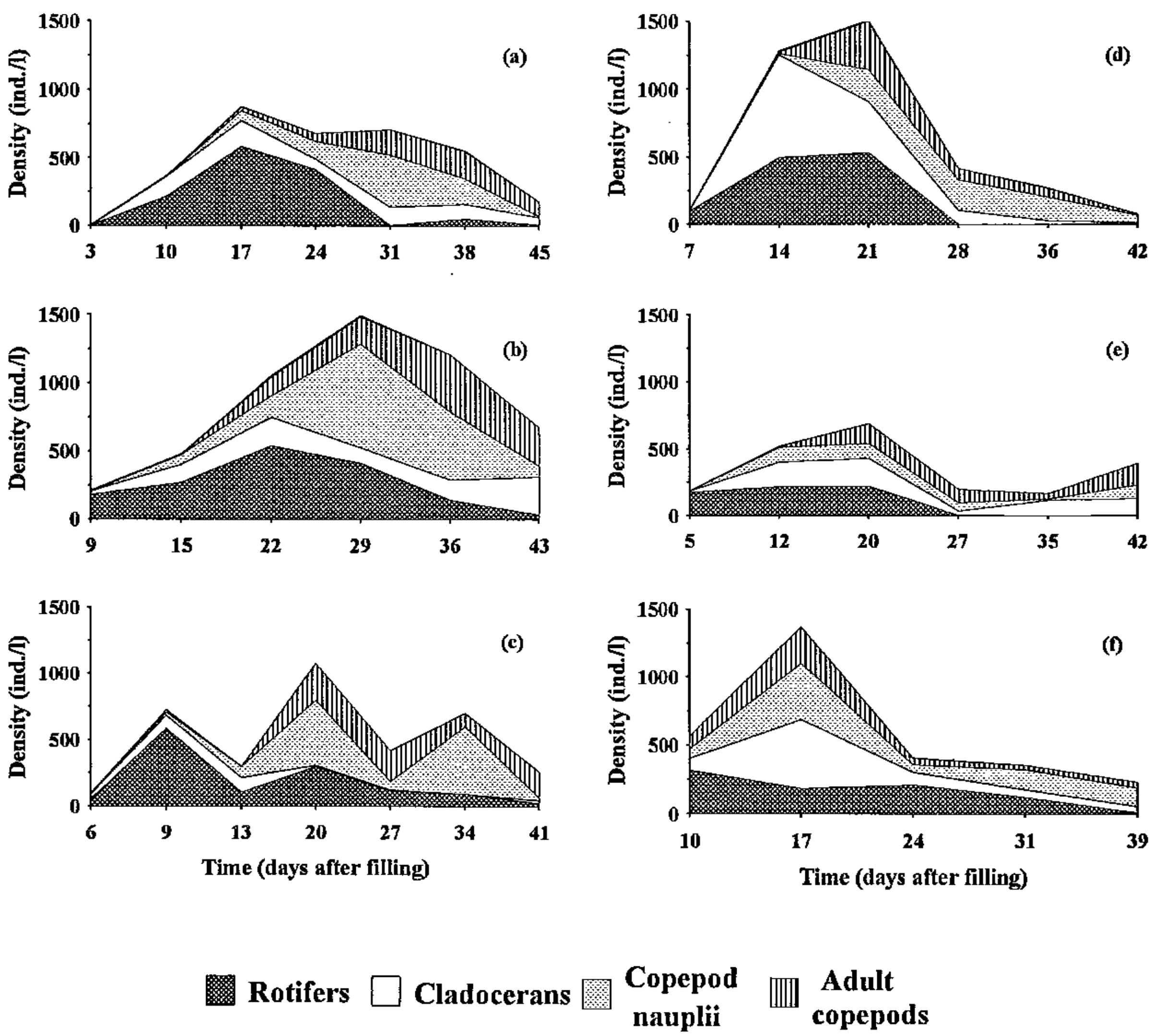


Fig. 3 Zooplankton species composition and abundance in fry rearing ponds at the MAFRISC. (a) Pond 12 (filled 15 November 1991); (b) Pond 15 (filled 27 October 1991); (c) Pond 14 (filled 26 November 1991); (d) Pond 14 (filled 17 November 1992); (e) Pond 14 (filled 25 November 1993); (f) Pond 14 (filled 18 November 1994).

plankton succession patterns. Understanding the dynamics of these patterns can assist pond managers to optimise production in fry rearing ponds through increased growth and survival of stock.

Studies have shown that phytoplankton and zooplankton communities undergo a succession of blooms and crashes (Geiger *et al.* 1985; Culver 1988; Culver *et al.* 1993). A generalised succession pattern of different organisms during the development of a community in a fertilised fry rearing pond is presented in Fig. 4. In general, once the pond is filled and fertilised, blooms of bacteria and phytoplankton occur first. These organisms can develop massive blooms in just a few days, and as they continue to grow there is a corresponding increase in the biomass of predatory zooplanktonic species. Blooms of zooplankton, and other herbivores, eventually reach a level where their increased grazing pressure causes a decline in phytoplankton biomass. As phytoplankton biomass declines, less food is available to herbivores in the zooplankton, which also then undergo a similar decline. The crash in zooplankton biomass may also be due to increasing biomass and associated predation from fish. Under ideal conditions, such as high water temperature, dissolved oxygen and food supply in the form of zooplankton, fish growth and total biomass rapidly increase. However when food becomes limiting, growth rate declines or ceases accordingly.

This pattern is more or less observed in fry rearing ponds at the MAFRISC (Fig. 5). An initial peak in chlorophyll *a* concentration (a measure of phytoplankton biomass) occurs within two weeks of filling and fertilisation of the ponds, while the abundance of zooplankton blooms peaks between two and four weeks after filling. Typically, amongst the zooplankton, the rotifers are first to develop high densities (2nd week), followed by blooms of the cladoceran *Moina* (cladoceran) (2nd-3rd weeks), copepods (2nd-5th weeks), and then the cladoceran *Daphnia* (cladoceran) (3rd-5th weeks). Similar succession patterns have also been observed in ponds at the NSW Fisheries, Narrandera Fisheries Centre (NFC) (Arumugam and Geddes 1987). Smaller, secondary peaks in chlorophyll *a* concentration and zooplankton abundance occur 5-7 weeks after filling (Fig. 5). The marked declines in abundance of phytoplankton and zooplankton communities observed 4 to 5 weeks after fillings have also been observed by Culver *et al.* (1993), with or without fish present.

Changes in abundance of species during these blooms are accompanied by changes in species composition. For example, algal diversity in fry rearing ponds at the NFC initially was high in the first few weeks after filling, with species of Chrysophyta and Chlorophyta abundant, but later algal blooms were dominated by the Cyanophyta *Anabaena* (Culver and Geddes 1993). The types and numbers of algal species present can also affect the composition of the zooplankton community (Gliwicz 1977).

Sources of aquatic plants and animals

Plants and animals which live in ponds are derived from a number of sources. Many organisms that colonise newly filled aquaculture ponds enter with the incoming water. However, fry rearing ponds at the MAFRISC are filled from a flowing upland stream, which has a community markedly different from that which occurs in stillwater ponds. It is likely that much of the community in these ponds develops from dormant, desiccation-resistant eggs, cysts and spores which are already present in the pond substrate. When conditions are appropriate, such as when the ponds are filled with water, these hatch. Many species of plants and animals typical of temporary water bodies, including algae, protozoans, rotifers, cladocerans, copepods, anostracans and conchostracans, have a stage in their lifecycle in which their eggs, spores, cysts etc. that is resistant to drying out and even ingestion by predators. These resistant stages are an important

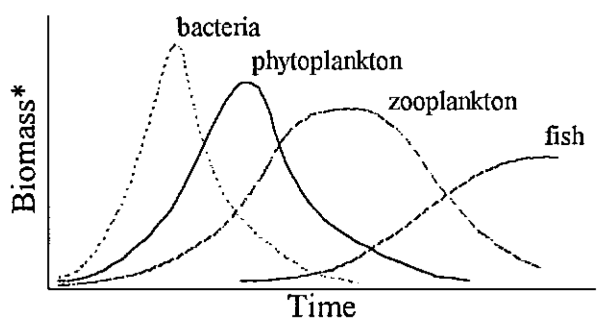


Fig. 4 Phases in the succession of different organisms during the development of an aquaculture pond community (*scales cannot be compared).

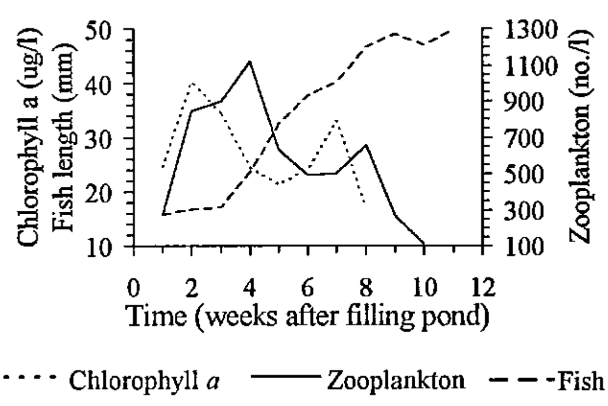


Fig. 5 Succession patterns in the concentration of chlorophyll *a*, abundance of zooplankton and growth of Murray cod in fry rearing ponds at the MAFRISC (summary of 5 seasons of data 1991-1995).

survival strategy and enable the species to withstand often harsh and otherwise variable environmental conditions, as they can remain dormant for many years (Wallace and Snell 1991). Some spores and cysts are small and light enough to be blown by winds, or carried on (or in) the bodies of animals such as water birds. Ponds are also colonised by aquatic insect larvae, deposited as eggs into the water by non-aquatic flying adults, such as mayflies, caddisflies and dragonflies, or directly by aquatic adults, such as hemipterans and some beetles.

[*Further reading:* Williams (1980); Pennak (1989); Thorp and Covich (1991)]

Biomanipulation of plankton communities

Management procedures can have a profound effect on plankton communities in aquaculture ponds. In the broad sense, biomanipulation is the deliberate modification of the trophic web and succession patterns within a pond to provide more favourable conditions for the growth of fish. In aquaculture ponds the succession patterns can be manipulated in several ways. In some cases development of plankton blooms may be enhanced by seeding or inoculating with preferred species of zooplankton from another pond or culture system. For example, inoculation of a pond with cladocerans from elsewhere can shift the community structure away from less favoured blooms of rotifers, if this is desired (Geiger 1983a, 1983b). Mims *et al.* (1991) found that inoculation with *Daphnia* sustained the cladoceran population over a 40 day period.

Insecticides have been added to ponds to remove predacious aquatic insects and planktonic crustaceans prior to stocking. This practice alters the structure of the zooplankton community to favour rotifers, and has been widely used in carp culture (Opuszynski *et al.* 1984). Verreth and Kleyn (1987) found that treating ponds with Dipterax™ resulted in a domination of zooplankton populations by rotifers and copepods, which in turn improved the survival of pikeperch (*Stizostedion lucioperca*), whereas in untreated ponds cladocerans dominated the zooplankton. Oils (diesel oil, cotton seed oil etc.) have also been sprayed onto the surface of fry rearing ponds to eliminate predacious air breathing aquatic insects, especially notonectids (Hemiptera) (Brown and Gratzek 1980).

Fertilisers applied to aquaculture ponds increase the concentrations of nutrients, which stimulate the growth of phytoplankton and other autotrophic organisms. In turn, zooplankton concentrations increase, which ultimately enhances fish production (Geiger 1983a, 1983b; Boyd 1990). Phosphorus and to a lesser extent nitrogen are the most important nutrients which stimulate phytoplankton growth (Boyd 1990). Phosphorus is a key element in virtually all aspects of cellular metabolism, and is an essential nutrient for primary productivity. Nitrogen, along with carbon, oxygen and hydrogen, is one of four major elements of which organic molecules are composed. Fertilisers used in aquaculture ponds are derived from organic sources such as animal manures and agricultural byproducts, and commercial inorganic sources of phosphorus and nitrogen including superphosphate, monoammonium phosphate, diammonium phosphate, triammonium phosphate, phosphoric acid, ammonium nitrate, ammonium sulphate and urea.

[*Further reading:* Geiger (1983a, 1983b); Parmley and Geiger (1985); Lannan *et al.* (1986); Boyd (1990); Delincé (1992); Anderson and Tave (1993)]

Fish and pond community interactions

As previously stated, the phytoplankton, zooplankton, zoobenthos and fish communities in an aquaculture pond are continually interacting with each other and their environment in which they live. The successful production of fry depends on having an understanding of the complex inter-relationships which exist between these communities and their immediate environment.

Before fry can be stocked into a pond there needs to be a sufficient amount of appropriate (species and size) food present (eg. zooplankton etc.) for them to survive and grow. Ponds at the MAFRISC are not stocked with fry until zooplankton densities, dominated by *Moina micrura* (cladoceran), exceed 500 individuals per litre (ind./l). *Moina micrura* is the preferred diet of fry at the time of stocking for most of the target species cultured at the MAFRISC (Ingram *unpub data*). This dominance usually occurs late in the second week after filling of the ponds at MAFRISC. Rowland (1996) found a positive correlation between the survival of golden perch and the volume of small zooplankton (<500μm) in ponds at the time of stocking. The small mouth gape of these larvae at stocking restricts the size of initial prey items (Arumugam and Geddes 1987). Fry rearing ponds at MAFRISC are generally stocked at low fish densities (less than 30 fry/m^2) to maximise fry growth and survival, but in ponds stocked at higher densities (up to 100 fry/m^2) a corresponding higher initial concentration of zooplankton is required.

Australian and overseas studies have generally shown that the main prey species preferred by many species of fry reared in ponds include cladocerans, especially *Daphnia* and *Moina*, cyclopoid and calanoid copepods, and chironomid larvae (eg. Arumugam and Geddes 1987; Fox 1989; Rowland 1992; Qin *et al.* 1994; Mims *et al.* 1995; Rowland 1996). Growth and survival of stocked fish depend on there being a high abundance, and appropriate size, of these favoured species.

Stocking density experiments conducted on Murray cod, trout cod and Macquarie perch at the MAFRISC, and on other species of fish fry (eg. Fox and Flowers 1990 (walleye, *Stizostedium vitreum*); Qin *et al.* 1994 (saugeye, *Stizostedium canadense* and walleye)) have shown that the growth of fry is reduced as stocking density is increased, whereas the rate of survival is generally less affected. This inverse relationship between fish growth and stocking density is presumably due to there being more competition for prey at the higher densities.

At high stocking densities, fish predation causes a shift in the size and the species composition of zooplankton communities. As large species of zooplankton, such as some cladocerans (eg. *Daphnia*) and some calanoid copepods (eg. *Boeckella*), are selectively preyed upon by the fry, the zooplankton community becomes dominated by smaller individuals or species, such as rotifers and small crustaceans (Brooks and Dodson 1965; Culver *et al.* 1984). However, some studies have shown that increasing stocking densities, within reason, can improve fish production in ponds (Culver *et al.* 1984; Culver *et al.* 1993). At low initial stocking densities the abundance and production of zooplankton and, in turn, fish yield are affected by overgrazing of algae by the zooplankton. However, at higher fish stocking densities the increased predation by fish limits zooplankton abundance, which in turn prevents overgrazing of algae by the zooplankton. As a result, both algae and zooplankton are produced for a longer period (Culver *et al.* 1984; Culver *et at.* 1993).

Other factors, besides fish and bird predation, influence the species composition and abundance of aquatic communities in aquaculture ponds. These include availability of nutrients or food, competition for food, predation, parasitism and extreme water quality conditions (eg. high pH, high ammonia, low dissolved oxygen etc.), water temperature, water turbulence and algal blooms (eg. filamentous algae, blue-green algae, etc).

[***Further reading:*** Geiger (1983a, 1983b); Evans (1986); Lannan *et al.* (1986); Torrans (1986) Culver *et al.* 1993]

METHODS OF SAMPLING AND IDENTIFYING SPECIMENS

SAMPLING AND EXAMINATION METHODS

Plankton

The most commonly used sampling device for collecting planktonic organisms from the waters of aquaculture ponds is the plankton net (Fig. 6). Plankton nets are constructed of a metal hoop to which is stitched a fine conical mesh bag made from nylon material. The mesh size used is commonly 75-250 µm which will capture much of the zooplankton including the microcrustaceans, but few of the protozoans and phytoplankton, as they are as small as 2 µm and will pass through. A sample is collected by pulling the net through the water with a rope or pole attached to the hoop. The contents of the net are transferred to a bucket of water for later examination or preservation. The amount of water sampled by a plankton net is crudely estimated by multiplying the area of the net opening by the tow length. However, plankton nets do not collect quantitative samples because the amount of water passing through the net can be reduced by variables such as bow waves, net clogging and tow speed.

Alternatively, plankton can be sampled with a 50 mm diameter PVC water sampling pipe fitted with a non-return valve (Fig. 7). A long handle is attached to the top of the pipe (at a pivot joint) which allows the pipe to be swung out over the water away from the bank. Attached to the non-return valve is a guard to prevent the open end of the pipe from coming into contact with sediments on the pond bottom. A sample of plankton is collected with this device by plunging the pipe (valve first) into the water then withdrawing. The water trapped in the pipe is then decanted into a bucket which is subsequently filtered through an Endecott sieve (75-150 µm) to concentrate the plankton. Protozoans and algae, which cannot be collected adequately by netting, can be sampled with this pipe then concentrated by gentle centrifugation.

Plankton is not evenly distributed throughout the water of a pond as both abundance and composition will vary from one site to another. Therefore, a more representative estimate of plankton abundance and composition is obtained when several samples are collected from different sites and depths within the pond.

[***Further reading:*** Bottrell *et al.* (1976); Lincoln and Sheals (1979); APHA (1992); Shiel (1995)]

Macroinvertebrates and fish

Many of the larger pond animals (macroinvertebrates) cannot be sampled adequately by plankton nets as they are either good swimmers and quick enough to evade a plankton net, or live in habitats which cannot be sampled with a plankton net, such as near or at the pond bottom, or amongst submerged and emergent vegetation. Sweep nets which are similar in design to plankton nets but have a coarser mesh bag (0.25-2.0 mm diameter mesh size) attached to a pole, can be used to sample around the margins of ponds and amongst submerged and aquatic plants. Benthic invertebrates and small fish may be sampled with a dredge or sled which is dragged across the bottom of the pond by a rope (Fig. 8). A dredge is basically a mesh bag attached to a metal frame mounted on runners. Often samples collected with these methods may need to be sieved to facilitate locating animals amongst the sediment and debris. This is done by washing the collected samples through progressively finer Endecott sieves (eg. 5 mm, 2 mm, 1 mm, 0.5 mm and 0.25 mm). The animals are removed from the collected samples using fine forceps or a pasteur pipette while taking care not to damage specimens.

Some macroinvertebrates may also be caught in bait traps made of plastic mesh (3-5 mm) sewn into a cylinder. Into one or both ends of the cylinder are stitched truncated cones through which animals can enter but not escape (Fig. 9). Sweep nets, dredges, vertical lift nets and bait traps are also suitable for capturing small fish, but gill nets or seine nets are needed for larger fish. Further descriptions of methods used to collect fish are described in Nielson and Johnson (1983).

[*Further reading:* Lincoln and Sheals (1979); APHA (1992)].

Sample examination

Many of the organisms found in aquaculture ponds and farm dams are too small to be seen clearly by the naked eye and so special instruments and equipment are usually needed to examine them in detail for identification purposes. A hand lens or magnifying glass may be suitable for larger specimens, but higher magnifications provided by microscopes, will be needed for examination of smaller specimens.

Light microscopes are broadly separated into two types, dissecting microscopes and compound microscopes, based on their magnifying ability. The dissecting microscope (Fig. 10) is used for viewing specimens at low magnifications of between 5x and 60x. Combinations of lighting from beneath and above the specimen greatly improve viewing with a dissecting microscope. The compound microscope (Fig. 11) is used for examination of material at magnifications of between 40x and 1,000x, typically microscopic organisms such as algae, protozoans, rotifers and small crustaceans, or the dissected body parts of larger specimens. Microscopes with built-in illuminators and binocular eyepieces are more convenient than those with a separate lightsource or fitted with a single eyepiece.

Various sized petri dishes or shallow plastic trays are used for holding larger specimens for observations while small (10 ml volume) and large (50 ml volume) sorting trays, cut from a single block of clear perspex (Fig. 12), are used to sort and count of zooplankton and macroinvertebrates. In some cases, it may be necessary to dissect some animals to obtain a better view of a particular body part or appendage for identification purposes. Fine-pointed forceps and pointed probes are needed to manipulate and dissect macroinvertebrates.

Microscopic organisms are best viewed with a compound microscope. This is done by first locating the specimen with a dissecting microscope, then transferring it into a drop of water on a microscope slide with either a pasteur pipette or tungsten wire loop. A coverslip may then be gently lowered onto the drop of water. Placing fragments of coverslip glass in the drop of water prior to adding the coverslip will prevent the coverslip distorting or squashing fragile specimens. Alternatively, cavity slides, microscope slides which have concave cavities ground into them, serve the same purpose. Specimens may be kept on slides for up to several weeks by mounting in a drop of 10% glycerol instead of water. Counting of algal cells and microscopic plankton with a compound microscope is done by placing a 1 ml sample in a specially designed microscope slide called a Sedgewick-Rafter chamber.

Often it is better to make observations on living animals because preservation can distort soft bodied organisms. Observations of motion and morphology of live animals assists identification.

[*Further reading:* APHA (1992); Shiel (1995)].

Sample preservation

There are several preservatives in which organisms can be stored, but formalin (2-5%) or alcohol (70-80% ethanol, methanol or isopropanol) are most commonly used. There are, however, certain risks associated with using some of these chemicals. Gloves need to be worn while handling preservatives and for some, especially formalin which has toxic fumes, work should be conducted in a well ventilated place or while wearing a respirator.

Preserved samples are best kept in leak-proof glass containers stored in a dark place. If the samples are to be kept for an extended period, whatever the preservative used, addition of glycerol (to make up a 1-2% solution in the final volume) protects against loss of specimens in the event of the sample drying out.

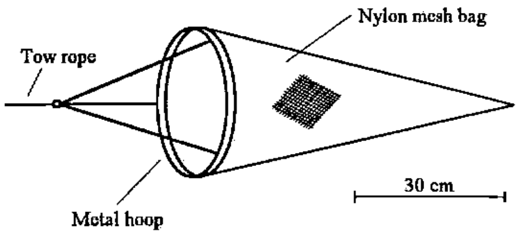


Fig. 6 Plankton sampling net

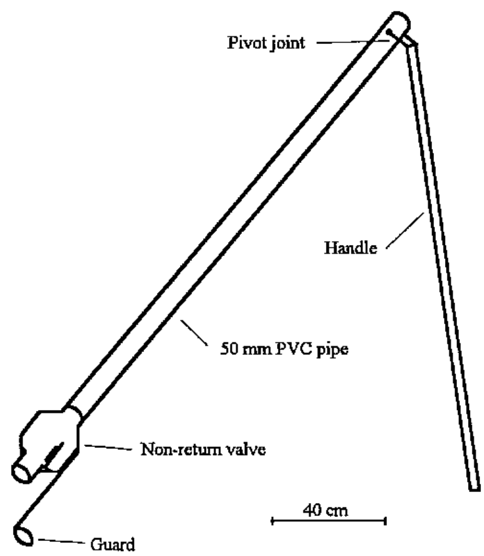


Fig. 7 Water sampling pipe

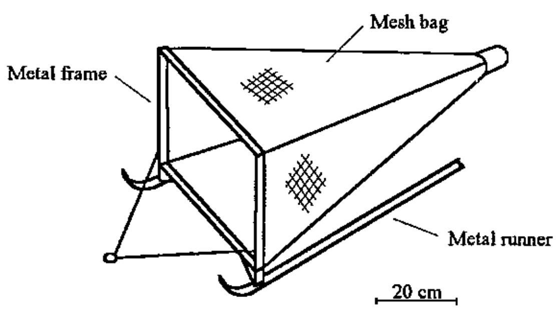


Fig. 8 Dredge for sampling pond macroinvertebrates

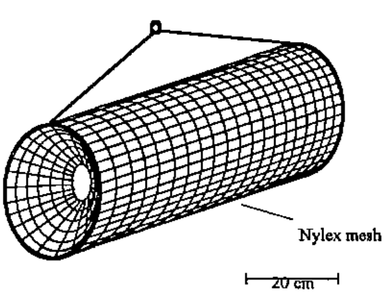


Fig. 9 Bait trap

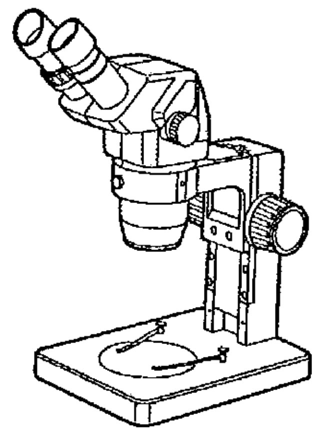


Fig. 10 Dissecting microscope

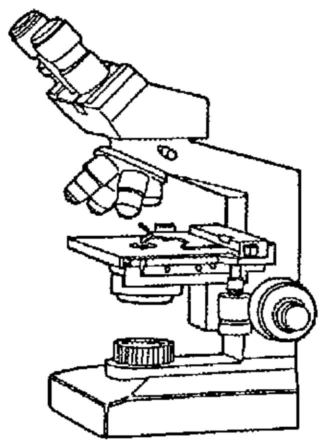


Fig. 11 Compound microscope

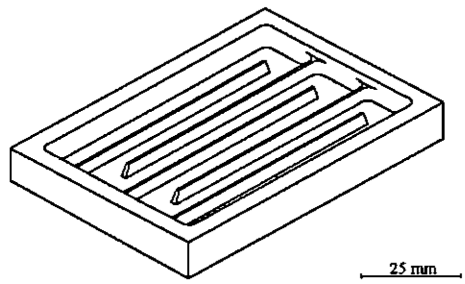


Fig. 12 10 ml perspex sorting tray

Small specimens, or body parts of larger animals, can be semi-permanently stored mounted on a microscope slide. Common mounting media used include polyvinyl lactophenol (PVA) and 100% glycerol (both available from scientific suppliers). Prior to mounting, specimens should be gradually equilibrated to the mounting medium. For example, to mount in 100% glycerol the specimens are passed through increasing concentrations of glycerol (10-20-40-60-80-100%) over a period of a week. Specimens to be mounted in PVA are passed through increasing concentrations of alcohol. Once the specimen has equilibrated, it is transferred to a drop of the mounting medium on a microscope slide. A coverslip is then gently placed over the specimen. When the mounting medium has dried and hardened the edge of the coverslip is sealed with nail polish to prevent further shrinkage, drying out of specimens or air bubbles appearing under the coverslip.

[*Further reading:* Lincoln and Sheals (1979); Shiel (1995)].

Determination of zooplankton density

The water sampling pipe is employed at the MAFRISC to collect integrated water and plankton samples from which zooplankton composition and densities can be determined. To ensure that a representative sample of plankton is obtained, samples of water should be collected from several locations around the pond. These samples, which together should amount to 15-20 l of water, are combined in a bucket. The total amount of water in this pooled sample is accurately measured then poured through an 80 μm Endecott sieve to concentrate the zooplankton. The contents of the sieve are rinsed into a clean 1,000 ml measuring cylinder which is then filled with water to the 1,000 ml mark. The contents of the measuring cylinder are then transferred to a 1,000 ml beaker. The water in the beaker is stirred to ensure the plankton is evenly distributed, and then a 10 ml subsample of water is taken from the beaker and placed in a 10 ml sorting tray (Fig. 12) which is placed under a dissecting microscope. All the zooplankton individuals within the 10 ml subsample are identified and counted. At least two 10 ml sub-samples and a minimum of 100 individuals should be counted to improve the accuracy of estimating plankton composition and density.

Zooplankton density, recorded as individuals per litre (ind./l), in the sampled pond can then be estimated using the following formula.

$$\text{Zooplankton density (ind./l)} = \frac{\text{No.} \times \dfrac{\text{Conc. Vol.}}{\text{Sub. Vol.}}}{\text{Tot. Vol.}}$$

Where:

Tot. Vol.	=	Total volume of water (l) collected from pond.
Conc. Vol.	=	Volume of water (ml) containing concentrated zooplankton after sieving (ie. 1,000 ml).
Sub. Vol.	=	Sub-sample of water (ml) from concentrated volume in which all zooplankton is counted (ie. 10 ml)
No.	=	Mean number of individuals counted per 10 ml subsample

Example calculation

$$\text{Zooplankton density (ind./l)} = \frac{135 \times \dfrac{1{,}000 \text{ ml}}{10 \text{ ml}}}{19.8 \text{ l}}$$

$$\text{Zooplankton density (ind./l)} = 682 \text{ ind./l}$$

Secchi disk visibility

An alternative method to estimating the amount of plankton is to determine secchi disk visibility. This measurement provides an estimate of water turbidity which can be highly related to plankton abundance, and in aquaculture ponds plankton is usually the main source of turbidity (Boyd 1990). Secchi disk visibilities have been highly correlated with concentrations of chlorophyll *a* and particulate organic matter (including zooplankton, phytoplankton and dead organic particles) (Almazan and Boyd 1978). A secchi disk is constructed from a weighted metal disk, 20 cm in diameter, painted with alternate black and white quadrants (Fig. 13). Secchi disk visibilities are determined by lowering the disk into the water until it just disappears and recording the depth, then raising it to the point where it reappears and recording the depth again. The average of these two recordings is the secchi disk visibility.

When secchi disk visibilities are less than 20 cm, the pond is too turbid due to either excessive phytoplankton or suspended soil particles, which are both detrimental to productivity. When secchi disk visibilities are between 30 and 60 cm, the pond is in good condition, providing that turbidity is caused by plankton. But when visibilities exceed 60 cm, phytoplankton is becoming scarce and inadequate productivity is occurring (Boyd 1990).

However, secchi disk visibility readings should be used with caution and only when plankton is the primary source of turbidity. Disk readings can vary appreciably if read at different times of the day, under different levels of illumination (ie. clouds and shadows) and when taken by different observers (Almazan and Boyd 1978).

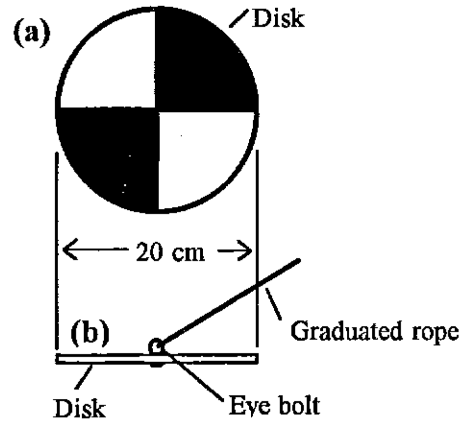


Fig. 13 Secchi disk. (a) top view, (b) side view

CLASSIFICATION OF LIVING ORGANISMS

An arbitrary system of classification has been adopted by biologists to name the different types of plants and animals according to their degree of similarity or likeness to each other. This system comprises several hierarchical levels of classification from kingdom at the broadest level through to the species which is the fundamental unit of this system (Table. 2). Each kingdom is divided into several phyla, each phylum is divided into several classes, and so on. The species is defined as a group of actually or potentially interbreeding individuals living under natural conditions that are reproductively isolated from other such groups. Each species receives two names; first is the generic name (eg. *Cherax*) which is common to all species of that genus, and second is the specific name (eg. *destructor*) which is peculiar to the species in question. Both generic and specific names are commonly Greek or Latin in origin, although frequently modern names of persons or places, with latinised terminations, are employed. Traditionally the genus and species names are written in italics, and the genus starts with a capital letter while the species is written all in lower case (eg. *Cherax destructor*). After the first use of a species name in a block of text, the genus is abbreviated to the first letter in subsequent uses of that species name (eg. *C. destructor*). In some cases identification is taken below the level of species, ie. subspecies (eg. *Cherax destructor destructor*) or race.

[*Further reading:* Williams (1980)].

Table 2. The classification categories for the yabby (*Cherax destructor destructor*)

Classification category	Taxonomic name
Kingdom	Animalia
Phylum	Arthropoda
Subphylum	Crustacea
Class	Malacostraca
Subclass	Eumalocostraca
Superorder	Eucarida
Order	Decapoda
Family	Parastacidae
Genus	*Cherax*
Species	*destructor*
Subspecies	*destructor*

Using identification keys

Rather than working through a series of detailed descriptions to identify an individual specimen, an identification key is used. Identification keys employed in this manual are designed primarily to assist in the rapid identification of animals typically encountered in aquaculture ponds and farm dams. The level (ie. family, genus, species) to which each key will identify an animal depends on the amount of specialised knowledge needed for that particular group, and the amount of taxonomic information available. The keys concentrate on common organisms in preference to rarer organisms, or those less likely to be collected from aquaculture ponds and farm dams. There are some groups, however, where there is little taxonomic information and detailed keys for these could not be provided.

Each dichotomous identification key consists of a pair of alternative statements, only one of which is applicable to the specimen in question. By progressing through each pair of statements one will eventually reach an identification. To assist users in understanding terminology employed, each key is accompanied by illustrations of animals showing the key features, and an explanation of specific biological terms is provided is provided in the glossary. The following example is of a dichotomous key used to identify the object below.

The following key can be used to identify the above shape.

1. Shape round, without pointed corners.......**Circle**
- Shape not round, with pointed corners..............2

2. Shape with three pointed corners..........**Triangle**
- Shape with more than three pointed corners.....3

3. Shape with four pointed corners, all angles equal to 90°, all sides equal in length.............. **Square**
- Shape with five pointed corners, all angles greater than 90°.................................**Pentagon**

KEY TO MAJOR GROUPS OF FREE-LIVING INVERTEBRATE ORGANISMS OCCURRING IN FRESHWATER AQUACULTURE PONDS AND FARM DAMS

1. Organism without appendages, but may bear cilia flagella, or setae (Plates 1d-k, 2d-l, 3a-l, 8c, 8f & 8g) 2

- Organism with distinct appendages (prolegs, legs, tentacles) (Plates 4a-k, 5a-k, 6a-k, 7a-l, 8a, 8b, 8d, 8e, 8h & 8i-m) 10

2. Body segmented (Plates 3k, 3l, 8c, 8f & 8g) 3

- Body unsegmented (Plates 2g-l, 3a-g, & 3h-j) 4

3. Most body segments each bearing 2-4 bundles of setae (Plate 3l); or body with a sucker at each end of the body (Plate 3k) .... **ANNELIDA (aquatic worms and leeches)** (Page 40)

- Body segments without bundles of setae, but may bear fine hairs on some segments (Plates 8c, 8f & 8g) .... **INSECTA (insects)** (Page 58)

4. Body enclosed in hard single or bivalved shell (Plates 3h, 3i & 3j) .... **MOLLUSCA (snails & mussels)** (Page 37)

- Body not enclosed in a hard shell 5

5. Body elongate, worm-like (Figs 59, 60 & 61) 6

- Body neither elongate nor worm-like 8

6. Body round in cross-section 7

- Body otherwise (Figs 59 & 60) .... **NEMERTEA & PLATYHELMITHES** (Page 28)

7. Body small (< 10 mm) (Fig. 61) .... **NEMATODA** (Page 29)

- Body hair-like, large (> 100 mm) .... **NEMATOMORPHA** (Page 29)

8. Body sponge-like, usually an encrusting growth... .... **PORIFERA (sponges)** (Page 27)

- Body not sponge-like 9

9. Microscopic multi-celled animals; head bears a circular arrangement of cilia; solitary or colonial (Plates 2g-l & 3a-g) .... **ROTIFERA** (Page 29)

- Microscopic single-celled organisms (animals and plants), often with cilia or flagella (may form colonies) (Plates 1d-k & 2d-f) .... **ALGAE** (Page 16) **& PROTOZOA** (Page 24)

10. Appendages jointed (Plates 4a-k, 5a-k, 6a-k, 7a-l & 8i-m) 11

- Appendages not jointed (Fig. 58; Plates 8a-h) .. 13

11. Body with 3 pairs of legs, with or without wings (Plates 5h-k, 6a-k, 7a-l & 8i-m) .... **INSECTA (insects)** (Page 58)

- Body with more than 3 pairs of legs, without wings (Plates 4a-k & 5a-g) 12

12. Body mite-like or spider-like, with 4 pairs of legs (Plate 4a) .... **ARACHNIDA (mites and spiders)** (Page 41)

- Body segmented, with at least 3 pairs of legs; some partially or completely enclosed in a bivalved shell (microscopic and macroscopic in size) (Plates 4b-k & 5a-g) .... **CRUSTACEA (water fleas, yabbies, shrimps, prawns, etc.)** (Page 42)

13. Body soft and sack-like, bearing tentacles (usually 6) (Fig. 58) .... **CNIDARIA** (Page 28)

- Body variable, with at least 1 pair of prolegs or unjointed legs (Plates 8a-h) .... **INSECTA (insects)** (Page 58)

AQUATIC PLANTS

In aquaculture ponds, there is often a tremendous amount of plantlife, from microscopic algae growing in the water column (phytoplankton), to the macrophytes which may floating on the water surface (eg. *Azolla*), growing submerged on the pond bottom (eg. *Pomatogeton*) or around the pond margins (eg. *Typha*). Plants are primary producers which are capable of utilising sunlight for energy to convert simple inorganic substances into complex organic substances by a process called photosynthesis. This ability makes plants extremely important in trophic webs as all other organisms, either directly or indirectly, rely on them for energy. Apart from being a source of food for many aquatic organisms, other animals may rely on plants for shelter or a surface on which to live (epiphytes). Because plants are dependent on sunlight for energy, their growth in aquatic habitats is generally limited to the zone in which there is sufficient light penetration for net photosynthesis to occur (trophogenic zone).

ALGAE

BIOLOGY, ECOLOGY AND IDENTIFICATION

The Algae encompass several major divisions (phyla) of simple non-vascular plants which include microscopic single-celled species to large thallus forming species such as the marine seaweeds and kelps which are many metres long. Although most algae are aquatic, some can exist in damp or moist areas, such as bogs and splash zones. Some species of algae such as found amongst the Euglenophyta, Chrysophyta and Pyrrhophyta, are capable of changing from being a plant or alga (autotroph) to being an animal (heterotroph), which makes classification of these species difficult. These species which are known as mixotrophs are sometimes grouped with the protozoans.

Algae are extremely diverse in form, colour and habit. The cells of algae are generally microscopic in size (< 10 µm to 250 µm) and require high magnifications (40-1,000x) to be seen. Many algae occur as individual cells while other species form colonies which may contain just a few cells to many 1000's of cells and be visible to the naked eye. Colonies may be spherical, occur in gelatinous or mucilaginous masses, form unbranched and branched filaments, or form large complex growths that can be confused with higher plants. Many species of algae bear flagella (mostly 2-8) which provide locomotion and a means to maintain their position in the trophogenic zone of the water column. Species that are non-motile may use oil droplets, gelatinous envelopes and gas or fluid filled bodies to assist flotation.

In aquaculture ponds algae are most conspicuous in the water column as free-floating and motile forms collectively called phytoplankton. The presence of dense blooms of phytoplankton is usually indicated by green- blue-green- red- or yellow-brown-coloured water, and similar coloured wind-rows or slicks may form on the water surface (Plate 11). Benthic and epiphytic algae grow on, or glide over, most surfaces in the trophogenic zone of ponds.

One of the more obvious features of algae is their varied colouration, which is caused by the presence of pigments such as the chlorophylls (predominantly chlorophyll *a*), carotenes and xanthophylls. Each phylum has its own particular combination of pigments which usually gives them a characteristic colour. These pigments are contained within chloroplasts within the cells in all but the Cyanophyta (Prescott 1969).

Algae mostly reproduce asexually by cell division or colony fragmentation. Sexual reproduction occurs in most groups but is less common, and is usually triggered by unfavourable or critical changes in the environment. Many algae produce spores or cysts which provide a means to survive harsh conditions. Motile zoospores and desiccation resistant cysts or spores play an important role in surviving harsh conditions, dispersal and colonisation of newly inundated habitats.

[*Further reading:* Prescott (1969); Reynolds (1984); Patterson and Hedley (1992); Canter-Lund and Lund (1995)].

Primary production and photosynthesis

All production within an ecosystem stems from the energy and substances that plants (and some bacteria) create from inorganic raw materials and sunlight through a process called photosynthesis. This process is undertaken by the pigments, especially the chlorophylls. Light energy is captured by the chlorophylls within the plant's cells and used in the photosynthesis reaction in which inorganic carbon, in the form of carbon dioxide (CO_2), and water (H_2O) are reduced to organic carbon, in the form of a simple sugar ($C_6H_{12}O_6$), and oxygen (O_2) (Boyd 1990). A simplified equation for the photosynthesis reaction is shown below:

$$6CO_2 + 6H_2O + \begin{matrix}\text{light}\\\text{energy}\\\&\\\text{inorganic}\\\text{nutrients}\end{matrix} \xrightarrow{\text{Chlorophyll}} C_6H_{12}O_6 + 6O_2$$

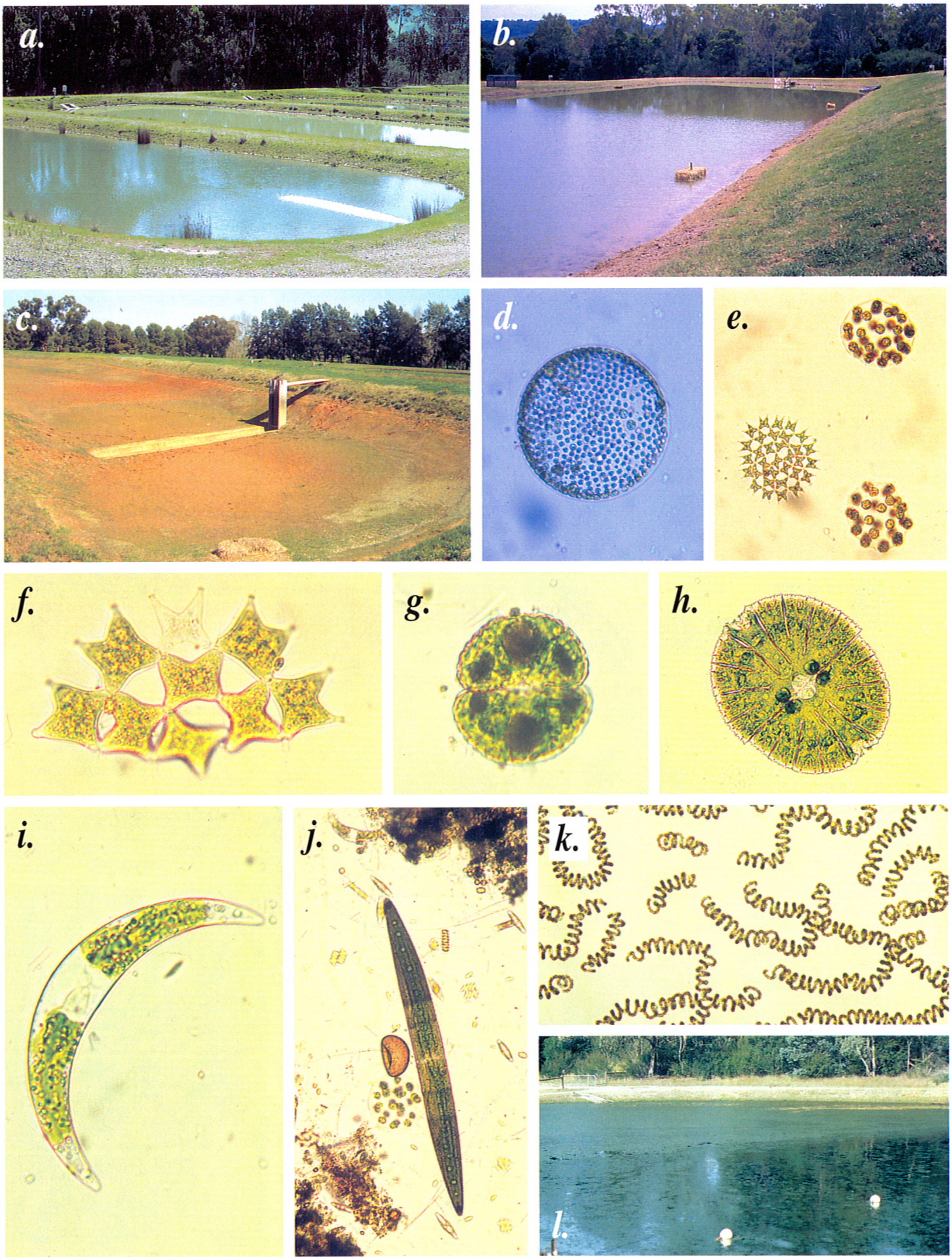


Plate 1:

(a) Broodfish ponds at the MAFRISC. **(b)** Fry rearing pond at the MAFRISC. **(c)** Empty fry rearing pond (at NFC) showing penstock structure for controlling water level and concrete sump. **(d)** *Volvox* sp. colony (Chlorophyta). **(e)** *Pediastrum* sp. colony (left) and colonies of *Eudorina* sp. (upper right and lower right) (Chlorophyta). **(f)** Colony of *Pediastrum* sp. (Chlorophyta). **(g)** *Cosmarium* sp. (Chlorophyta). **(h)** *Micrasterias* sp. (Chlorophyta). **(i)** *Closterium* sp. (Chlorophyta). **(j)** *Closterium* sp. (Chlorophyta) (right) and *Arcella* sp. (Protozoa) (brown object on left). **(k)** Colonies of *Anabaena spiroides* (Cyanophyta). **(l)** Floating algal scum covering the water surface of a fry rearing pond.

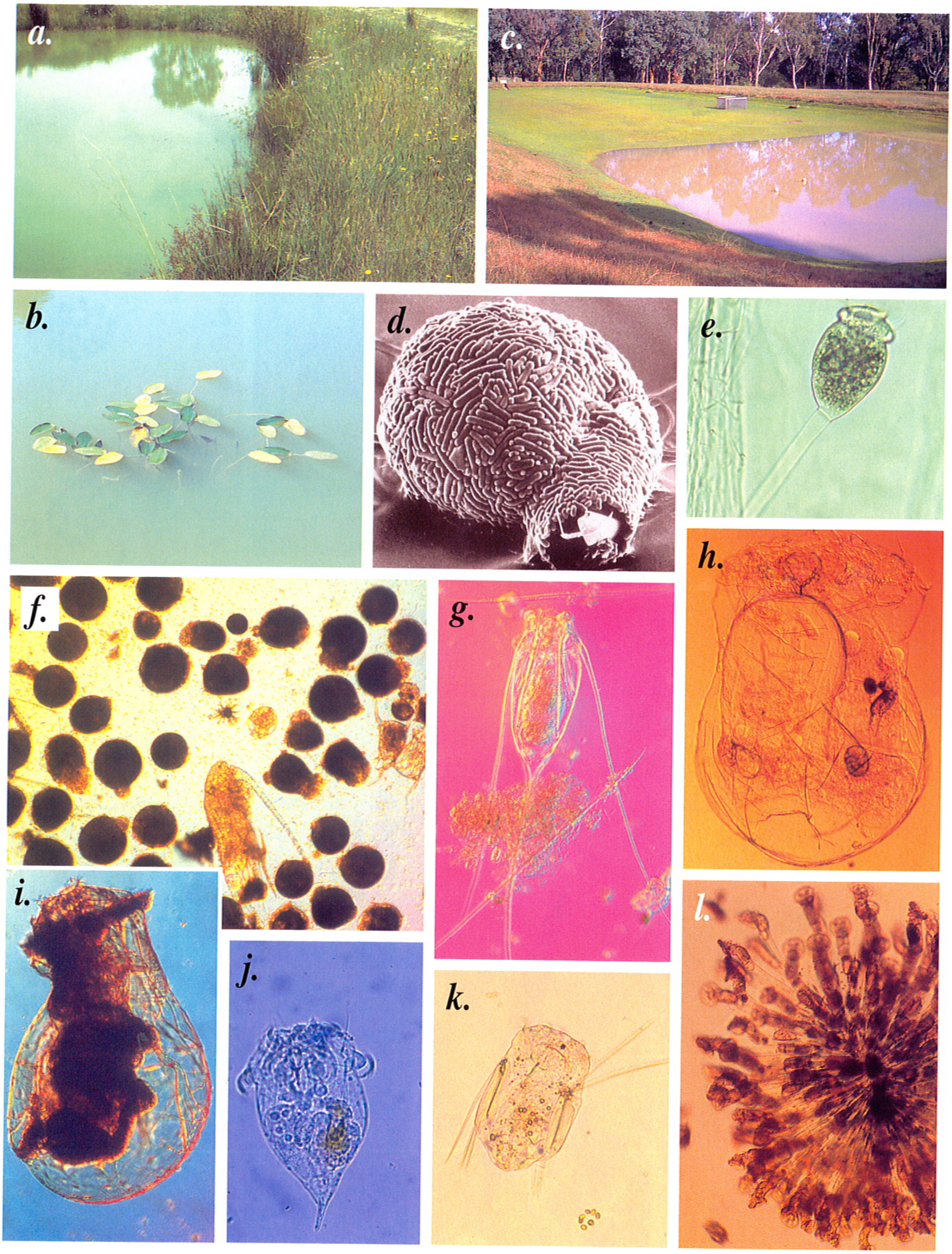


Plate 2:

(a) Aquatic macrophytes growing along the margin of an aquaculture pond. **(b)** The swamp lily, *Ottelia ovalifolia.* **(c)** The aquatic plant G*lossostigma* sp. growing across the floor of a partially drained fry rearing pond. **(d)** Electron micrograph of *Lecquereusia spiralis* (Sarcodina). **(e)** *Epistylis* sp. (Ciliophora). **(f)** Bloom of planktonic *Stentor* (Ciliophora). **(g)** *Filinia pejleri* (Rotifera). **(h)** *Asplanchna sieboldi* (Rotifera), with young (on left of abdomen) and prey (*Keratella*) on right. **(i)** *Asplanchnopus multiceps* (Rotifera). **(j)** *Synchaeta* sp. (Rotifera). **(k)** *Polyarthra* sp. (Rotifera). **(l)** Colony of *Lacinularia* sp. (Rotifera).

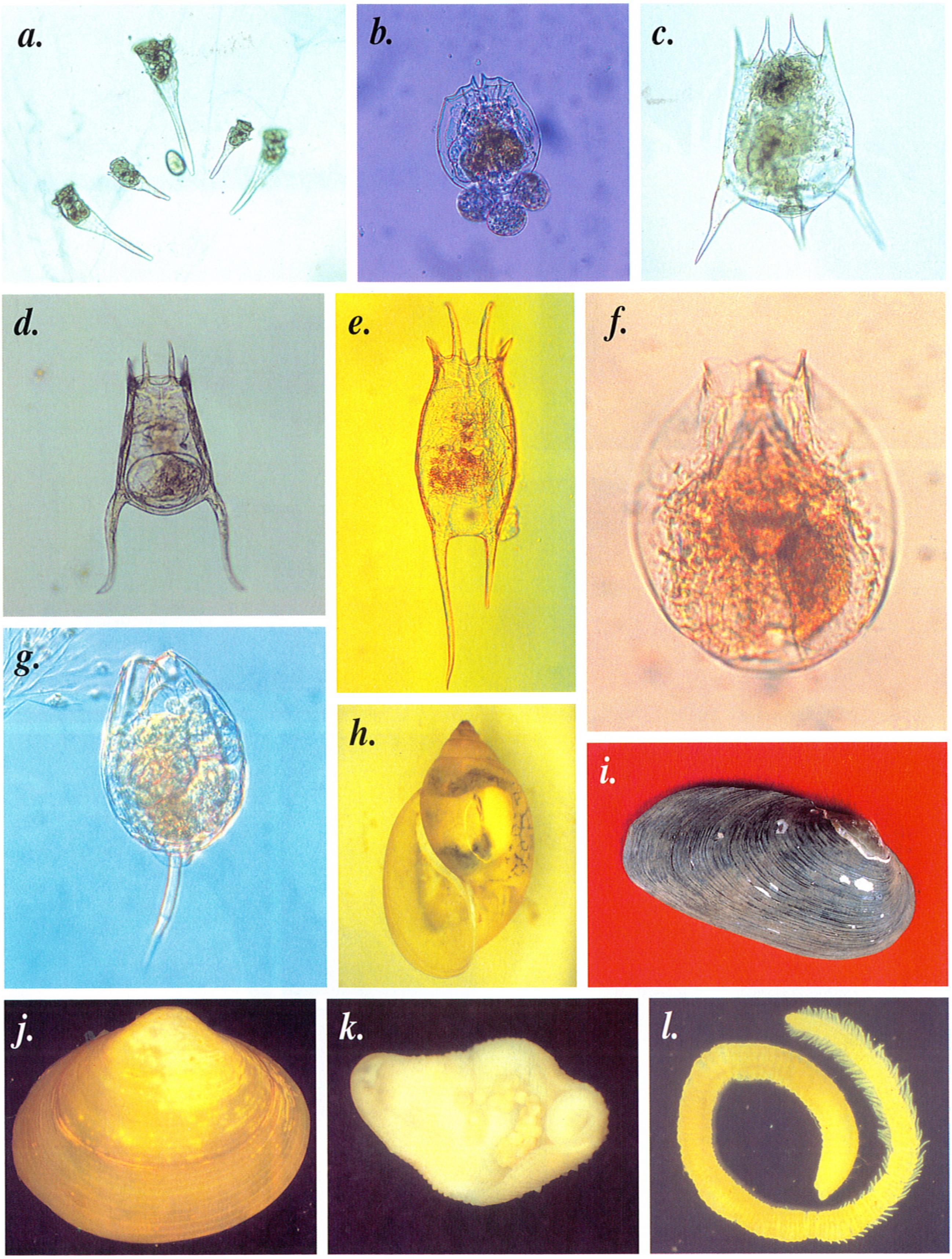


Plate 3:

(a) *Conochilus* sp. (Rotifera). **(b)** *Brachionus angularis* (Rotifera) carrying eggs. **(c)** *Brachionus calyciflorus* (Rotifera). **(d)** *Keratella australis* (Rotifera). **(e)** *Keratella slacki* (Rotifera). **(f)** *Testudinella emarginula* (Rotifera). **(g)** *Lecane bulla* (Rotifera). **(h)** *Physa acuta*. (Mollusca). **(i)** *Velesunio ambiguus* (Mollusca). **(j)** *Corbiculina* sp. (Mollusca). **(k)** Glossiphoniid leech (Annelida). **(l)** *Branchiura sowerbyi* (Annelida).

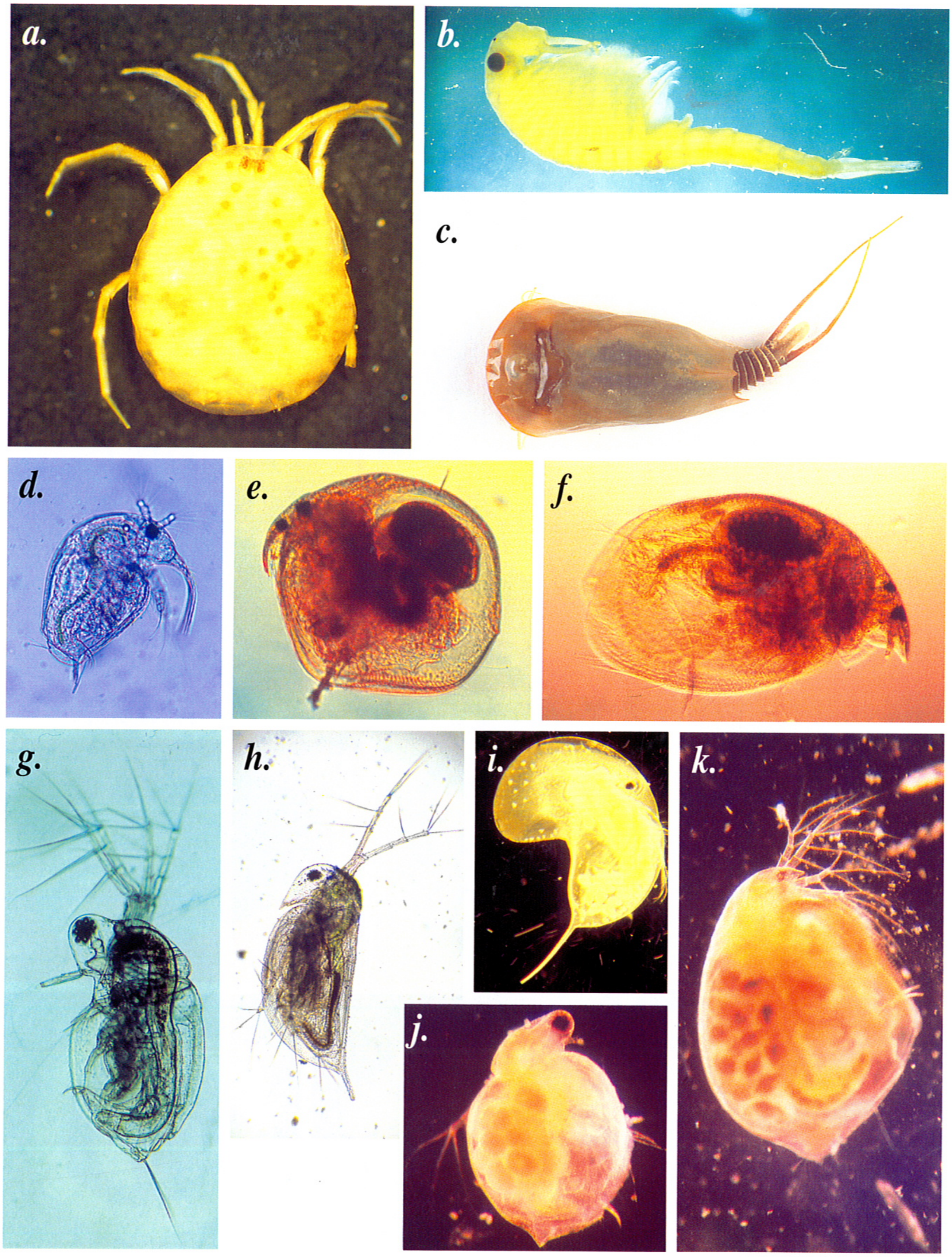


Plate 4:

(a) *Eylais* sp. (Arachnida). **(b)** *Branchinella* sp. (Anostraca). **(c)** *Lepidurus apus viridis* (Notostraca). **(d)** *Bosmina meridionalis* (Cladocera). **(e)** *Chydorus* sp. (Cladocera). **(f)** *Leydigia* sp. (Cladocera). **(g)** *Moina micrura* sp. (Cladocera). **(h)** *Daphnia carinata* (Cladocera). **(i)** *Daphnia cephalata* (Cladocera) carry eggs. **(j)** *Ceriodaphnia* sp. (Cladocera) carrying eggs. **(k)** *Simocephalus victoriensis* (Cladocera) carring eggs.

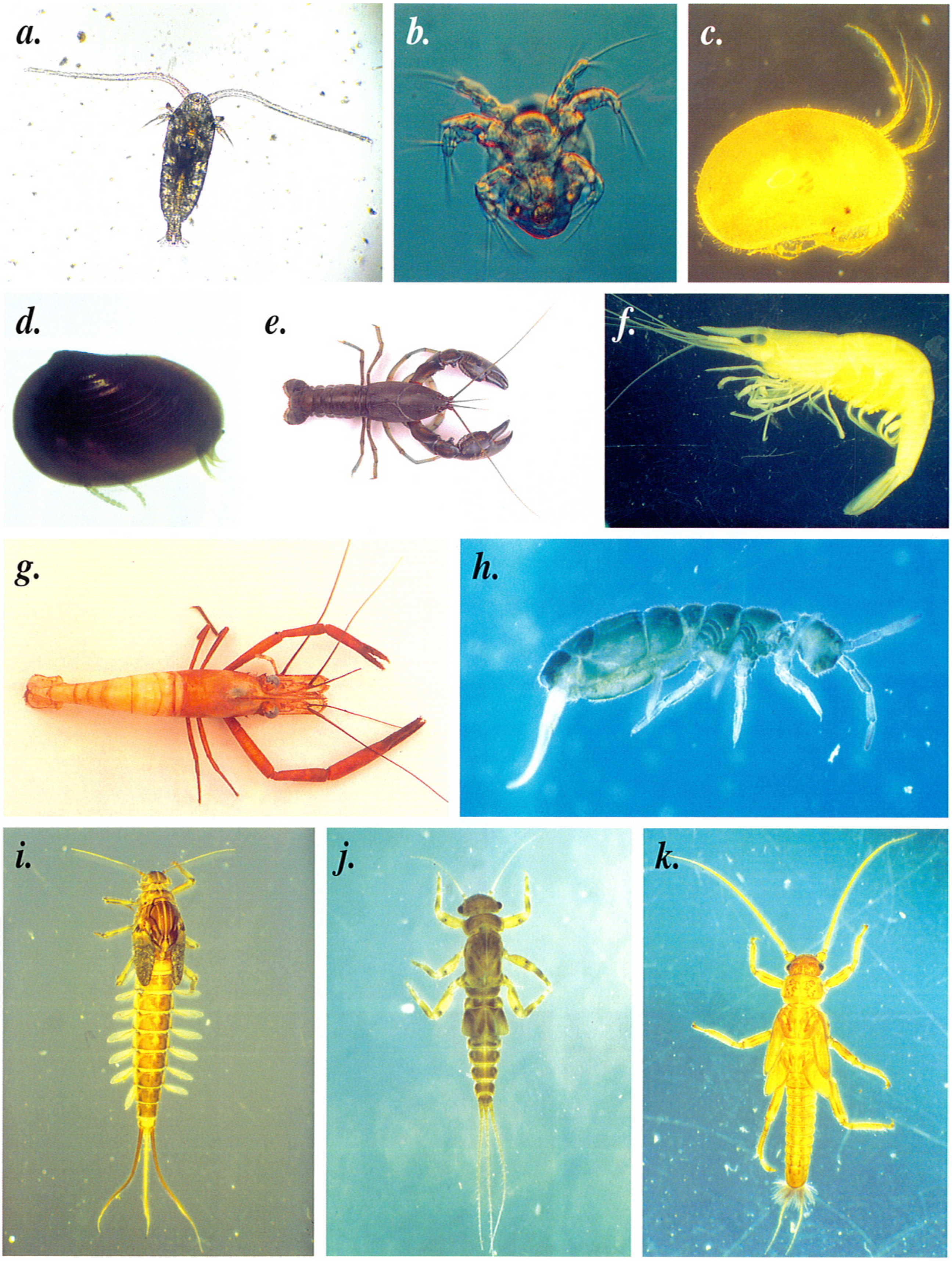


Plate 5:
(a) *Boeckella* sp. (Copepoda). **(b)** Copepod nauplius (Copepoda). **(c)** *Australocypris* sp. (Ostracoda) **(d)** *Cyzicus* sp. (Conchostraca). **(e)** *Cherax destructor* (Decapoda). **(f)** *Paratya australiensis* (Decapoda). **(g)** *Macrobrachium australiense* (Decapoda). **(h)** Isotomidae (Collembola). **(i)** *Cloeon* sp. nymph (Ephemeroptera). **(j)** *Tasmanocoenis* sp. nymph (Ephemeroptera). **(k)** *Dinotoperla serricauda* nymph (Plecoptera).

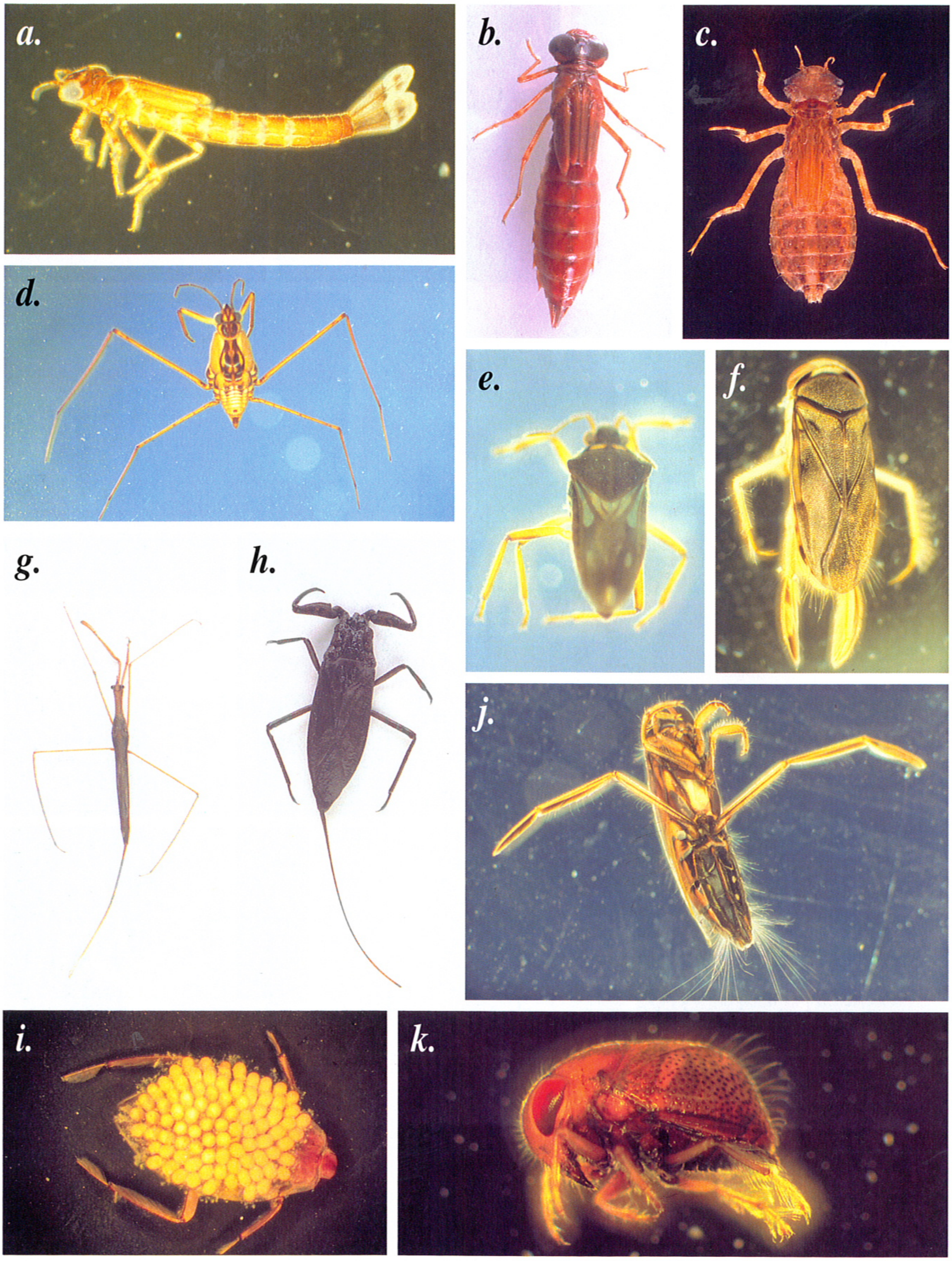


Plate 6:

(a) *Ischnura* sp. larva (Odonata). **(b)** *Hemianax papuensis* larva (Odonata). **(c)** *Hemicordulia tau* larva (Odonata). **(d)** *Tenagogerris euphrosyne* (Hemiptera). **(e)** *Microvelia peramoena* (Hemiptera). **(f)** *Agraptocorixa* sp. (Hemiptera). **(g)** *Ranatra dispar* (Hemiptera). **(h)** *Laccotrephes tristis* (Hemiptera). **(i)** Male *Diplonychus eques* (Hemiptera) carrying eggs. **(j)** *Anisops* sp. (Hemiptera). **(k)** *Paraplea* sp. (Hemiptera).

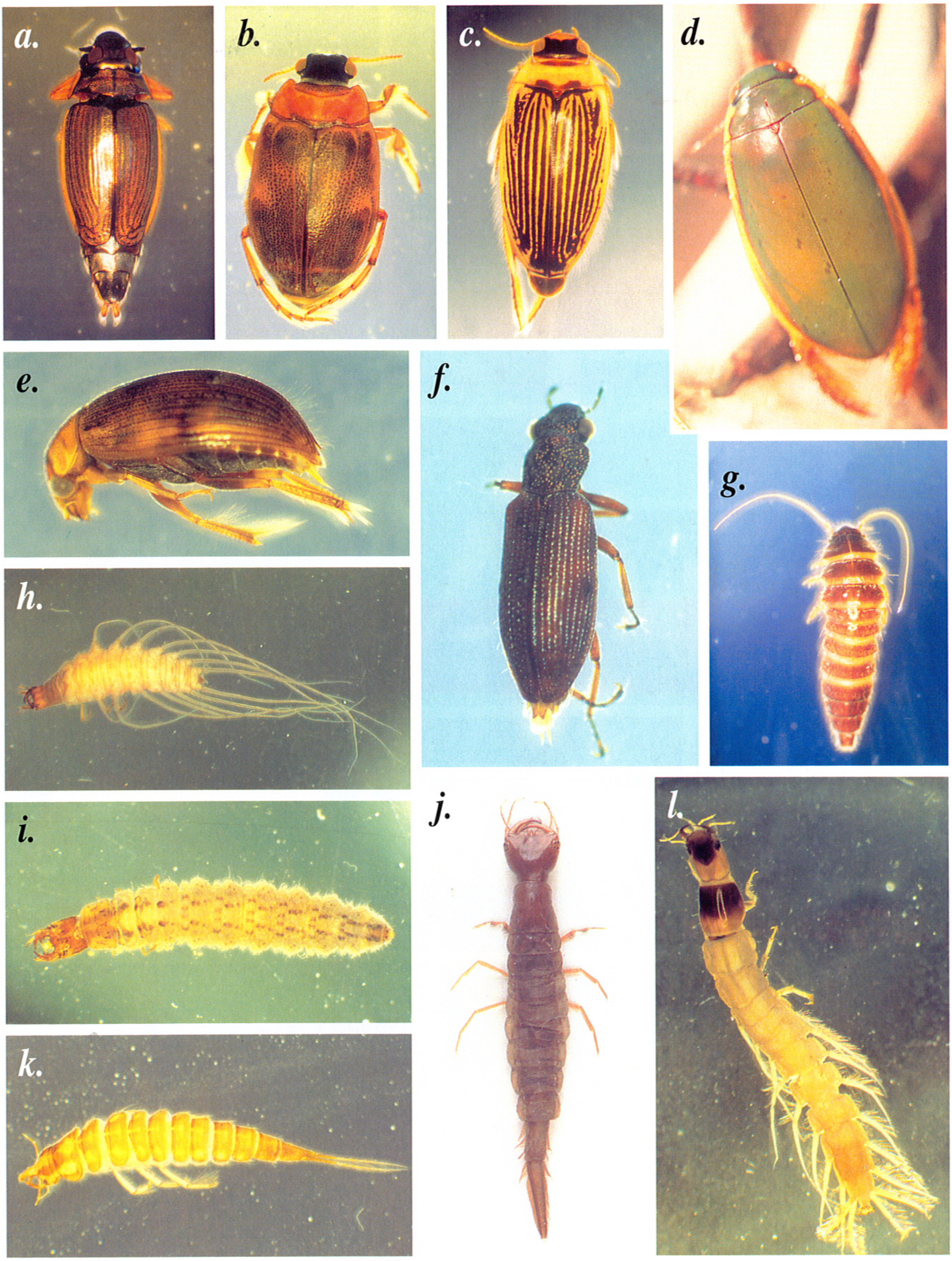


Plate 7:

(a) *Aulonogyrus strigosus* (Coleoptera). **(b)** *Hygrobia* sp. (Coleoptera). **(c)** *Lancetes lanceolatus* (Coleoptera). **(d)** *Homeodytes scutellaris* (Coleoptera). **(e)** *Berosus majusculus* (Coleoptera). **(f)** *Hydrochus* sp. (Coleoptera). **(g)** Scirtid larva (Coleoptera). **(h)** *Berosus* sp. larva (Coloptera). **(i)** Hydrophilid larva (Coleoptera). **(j)** *Homeodytes* sp. larva (Coleoptera). **(k)** *Chostonectes* sp. larva (Coleoptera). **(l)** Gyrinid larva (Coleoptera).

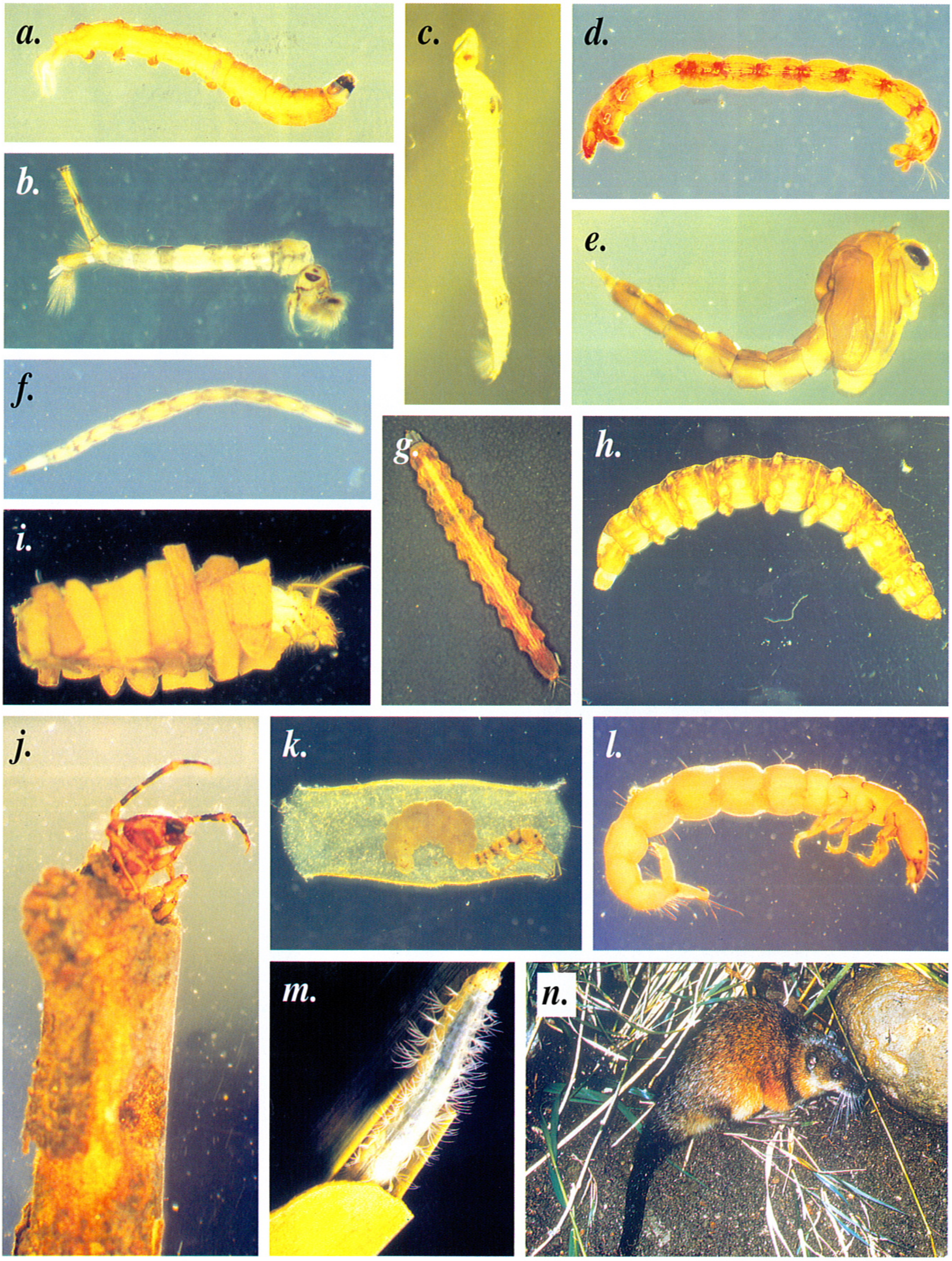


Plate 8:

(a) Tipulid larva (Diptera). **(b)** *Culex* sp. larva (Diptera). **(c)** *Chaoborus* sp. larva (Diptera). **(d)** *Chironomus* sp. larva (Diptera). **(e)** Chironomid pupa (Diptera). **(f)** Ceratopogonid larva (Diptera). **(g)** *Odontomyia* sp. larva (Diptera). **(h)** Tabanid larva (Diptera). **(i)** *Oecetis lacustris* larva (Trichoptera) in case. **(j)** *Triplectides* sp. larva (Trichoptera) in case. **(k)** *Hellyethira* sp. larva (Trichoptera) in case. **(l)** *Ecnomus pansus* larva (Trichoptera). **(m)** Pyralid larva (Lepidoptera). **(n)** water-rat, *Hydromys chrysogaster* (Mammalia).

A myriad of factors control the rate of photosynthesis. Among the more important are temperature, the amount of light, and the concentration and composition of the raw materials (gases and nutrients). Essential inorganic nutrients required for many plants to complete this reaction include nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, zinc, copper and molybdenum (Boyd 1990). Because the process of photosynthesis produces large amounts of dissolved oxygen (O_2), phytoplankton is a major source of dissolved oxygen in ponds. Therefore, phytoplankton growth and the levels of dissolved oxygen present in water are interrelated, and it has even been suggested that levels of dissolved oxygen in aquaculture ponds can be raised by controlled promotion of phytoplankton (Smith and Piedrahita 1988).

However, fluctuations in illumination, season and cloud cover, affect the rate of photosynthesis. When sunlight is reduced, a corresponding reduction in photosynthesis occurs. At very low levels of light intensity, such as at night, the process of photosynthesis is reversed and phytoplankton consume O_2 and release carbon dioxide (CO_2). This process is called respiration and the simplified equation is represented below:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{heat energy}$$

At night, in ponds with an excessive abundance of phytoplankton and other primary producers, depletion of O_2 may occur and CO_2 concentrations increase (Boyd 1990). If this happens in fish rearing ponds, and there is no supplementary aeration, such as with paddlewheels, stock will be lost due to lack of dissolved oxygen in the water.

Ecology

Algae play an essential ecological role in aquaculture ponds and farm dams. However, there have been very few studies of the algal communities in aquaculture ponds in Australia. Culver (1988) and Culver and Geddes (1993) listed 38 genera (plus other unidentified species) (Appendix I) and described trends in phytoplankton abundance in fertilised fry rearing ponds at the NFC. Algal diversity was high in these ponds during the first few weeks after filling, but eventually *Anabaena* (Plate 1k) became the dominant and most common species in the phytoplankton.

One method of measuring the amount of algae in water is to count the number of cells in a small sample of water with a microscope (APHA 1992). Using this method Culver and Geddes (1993) recorded densities of 506,000 cells/ml in phytoplankton blooms dominated by *Anabaena*, in fry rearing ponds at the NFC. Alternatively, chlorophyll *a* can be extracted from algal cells and measured with a spectrophotometer (APHA 1992). Chlorophyll *a* readings can then be used as an indicator of algal biomass. Concentrations of chlorophyll *a* in fry rearing ponds at the MAFRISC are commonly 10-50 µg/l, but have reached 185 µg/l. In comparison, average chlorophyll *a* levels recorded by Tucker and van der Ploeg (1993) in commercial channel catfish ponds during summer ranged from 450 to 605 µg/l. Examples of chlorophyll *a* concentrations recorded in five fry rearing ponds at the MAFRISC are presented in Fig. 14, which indicate peak concentrations occurring 1-2 weeks after filling the ponds.

Algae are consumed by a range of planktonic organisms such as rotifers, cladocerans and copepods, as well as by macroinvertebrate grazers including snails and many aquatic insect larvae. Tadpoles and some fish species also feed on algae. A proportion of the diet of silver perch is composed of plant matter. Arumugam (1986) found golden perch fry (10-20 mm in length) ingested *Eudorina* (apparently when other prey items were rare) and Ingram (*unpub. data*) has observed *Pediastrum* in the stomachs of Murray cod fry.

[*Further reading:* Boyd (1973); Reynolds (1984); Tucker and Lloyd (1984); Smith (1988)].

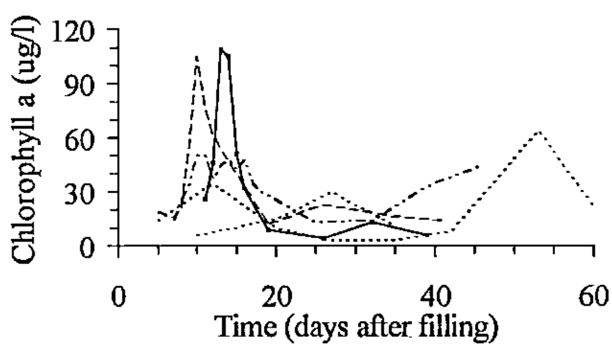


Fig. 14 Chlorophyll *a* concentrations (µg/l) in five rearing ponds at the MAFRISC during the 1993-94 production season

Nuisance algal blooms

In aquaculture ponds where nutrients, in the form of added fertilisers, fish food and fish wastes, are often in abundance, massive problematic blooms of algae can develop (Plate 1l). Nuisance algae which form such blooms, especially species of Cyanophyta (blue-green algae), have been the focus of several reviews (Paerl 1988; Smith 1988; Sevrin-Reyssac and Pletikosic 1990; Paerl and Tucker 1995).

Dense algal blooms can cause serious water quality problems, particularly oxygen depletion during the night, and high levels of pH (greater than 9.50) during daylight hours. At night algae use oxygen through respiration, but during the day, photosynthesis removes carbon dioxide and causes the pH of the water to rise (Boyd 1990) (Fig. 15). The collapse or die-off of dense blooms (naturally or after treatment with an algicide) can also lead to oxygen depletion and increases in levels of ammonia due to the decomposition of the algae.

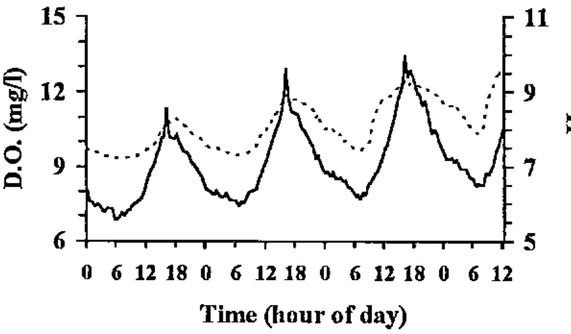


Fig. 15 Diurnal fluctuations in dissolved oxygen and pH recorded from a fry rearing pond at the MAFRISC

Filamentous green algae, such as *Cladophora* (Fig. 23), *Hydrodictyon* (Fig. 24) and *Spirogyra* (Fig. 25), can form dense, entangled mats in aquaculture ponds. During harvest these mats can entrap and smother animals, clog nets and other harvesting equipment and block outlet screens.

Under certain conditions, some species of blue-green algae, including *Anabaena* (Plate 1k) and *Microcystis* (Fig 39), which are common in aquaculture ponds, can produce toxic metabolites and excessive blooms of these algae have been implicated in fish kills and the deaths of livestock (Prescott 1969; Sevrin-Reyssac and Pletikosic 1990). Some species of blue-green algae, and some actinomycete fungi which are associated with the algae, are a primary source of the "muddy" off-flavours or taints in the flesh of fish grown in earthen aquaculture ponds. The most prevalent off-flavours are caused by the compounds geosmin and 2-methylisoborneol (MIB) (Lovell *et al.* 1986). Off-flavour in fish flesh is considered to be a serious economic problem for commercial fish farmers, however, it can be removed by holding the fish in clean flowing water for several days.

Because of the potentially harmful effects of heavy blooms of algae, particularly blue-green algae, fish farmers are encouraged to limit their growth in aquaculture ponds. Algicides such as copper sulphate and simazine have been used, but their drawbacks may outweigh their benefits. These compounds can be detrimental to the environment and may even kill other beneficial organisms (eg. zooplankton) within the pond and cause water quality problems associated with decomposition of the killed algae (Tucker and Boyd, 1978). There may also be restrictions on the use of these chemicals for food fish and discharge into river systems. Increasing the Nitrogen:Phosphorus (N:P) ratio (by weight) in the water of the pond to greater than five may control blue-green algae by allowing other algae such as the Chlorophyta to dominate. When inorganic Nitrogen is deficient, algae that are capable of assimilating atmospheric nitrogen, such as the blue-green algae, are favoured (Rhee and Gotham 1980; Reynolds 1984). Aerating ponds to destratify and oxygenate the water may also assist in controlling blooms of blue-green algae (Stewart and Pearson 1970).

[***Further reading:*** Smith (1985, 1988); Paerl (1988); Sevrin-Reyssac and Pletikosic (1990); Paerl and Tucker (1995)].

Identification

Generally, species of algae which occur in aquaculture ponds and farm dams belong to six phyla, the Chlorophyta (green algae), Euglenophyta, Chrysophyta (yellow- or brown-green algae), Pyrrhophyta (dinoflagellates), Cryptophyta (cryptomonads) and Cyanophyta (blue-green algae) (see Appendix I). Features that help to distinguish these phyla include pigments (colour, composition and amount), flagella (number, type, location) and features of the cell wall. The Cyanophyta and Chlorophyta are usually the most abundant and common, but other groups may become abundant under certain conditions (Boyd 1990).

With the exception of a guide to macroscopic freshwater algae (Entwisle 1994a), there are no comprehensive identification guides to the Australian algae. However, the bibliographic checklist of non-marine algae of Australia (Day *et al.* 1995) contains representative line drawings of species for many families. Since algae, particularly temperate water species, are comparatively cosmopolitan, common genera in aquaculture ponds of south eastern Australia can be identified using international guides such as Belcher and Swale (1978), Prescott (1978), Patterson and Hedley (1992) and Canter-Lund and Lund (1995).

CHLOROPHYTA
(green algae including desmids)

The Chlorophyta is a large and diverse phylum of green-coloured algae which has many representatives occurring in aquaculture ponds. Some species are solitary (eg. *Chlamydomonas* (Fig. 16), *Arthrodesmus* (Fig. 17), *Staurastrum* (Fig. 18)) while others may form colonies containing just a few cells (eg. *Scenedesmus* (Fig. 19)) to thousands of cells (eg. *Volvox* (Plate 1d; Fig 20a)). The cells of *Eudorina* (Plate 1e; Fig. 21), *Pandorina* (Fig. 22) and *Volvox* develop large, rolling, free-swimming, spherical

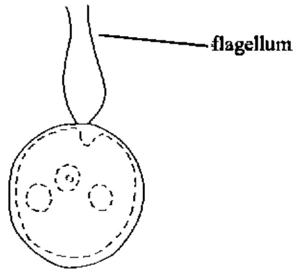


Fig. 16 *Chlamydomonas*

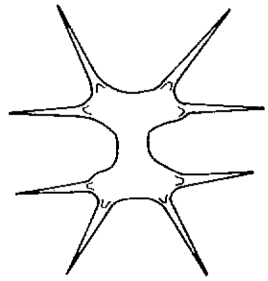


Fig. 17 *Arthrodesmus*

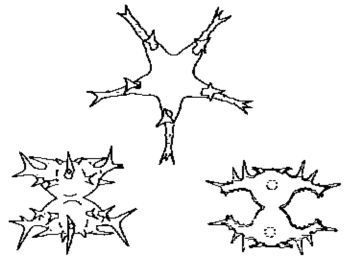


Fig. 18 *Staurastrum* spp.

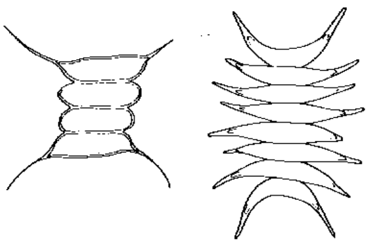


Fig. 19 *Scenedesmus* spp.

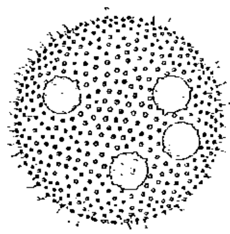


Fig. 20a *Volvox* colony

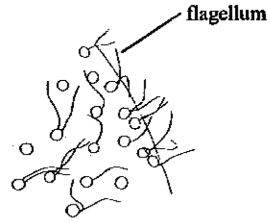


Fig. 20b *Volvox* cells

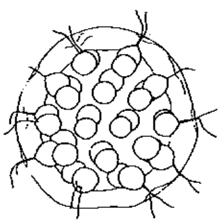


Fig. 21 *Eudorina* colony

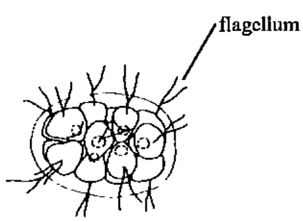


Fig. 22 *Pandorina* colony

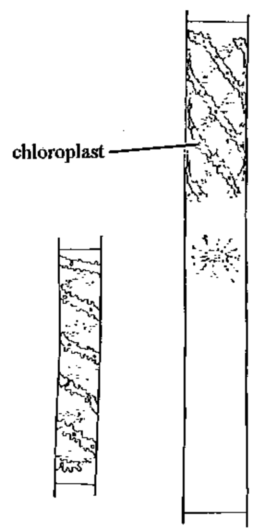


Fig. 25 *Spirogyra*

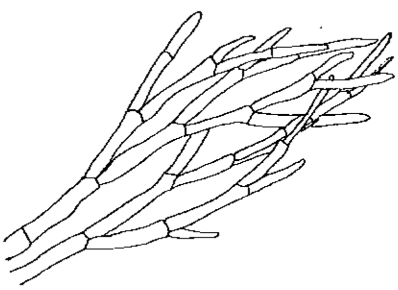


Fig. 23 *Cladophora*

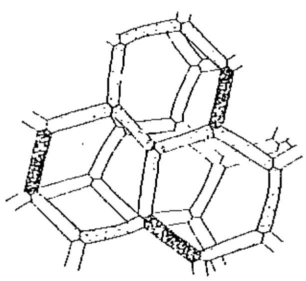


Fig. 24 *Hydrodictyon*

Fig. 26 *Nitella*

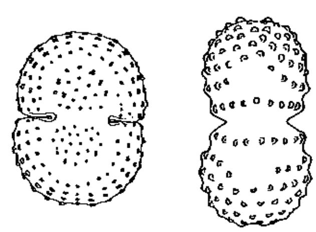


Fig. 28 *Cosmarium* spp.

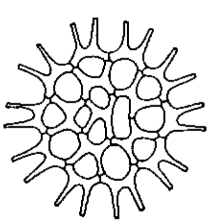


Fig. 27 *Pediastrum*

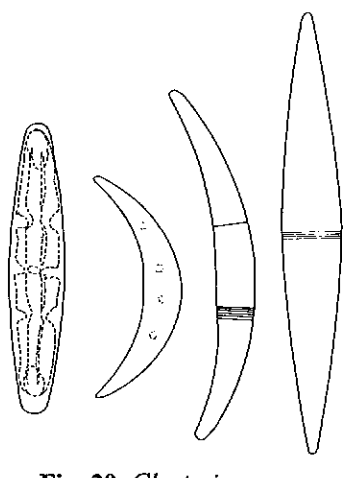


Fig. 29 *Closterium* spp.

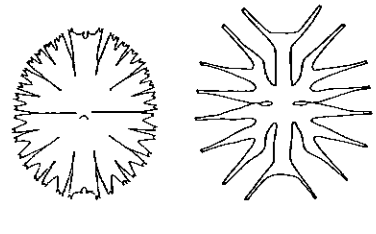


Fig. 30 *Micrasterias* spp.

colonies. *Volvox* colonies can contain up to 3,000 cells which are distributed around the periphery of the gelatinous colony (Fig. 20b) while daughter colonies may be seen within the parent colony. The flagella, which face outwards, provide locomotion. *Pandorina* and *Volvox* have caused problematic blooms in small eutrophic ponds (Paerl 1988).

Common filamentous green algae include *Cladophora* (Fig. 23), *Hydrodictyon* (Fig. 24) and *Spirogyra* (Fig. 25). *Hydrodictyon reticulatum* (water net) is a greenish-yellow alga which forms free-floating, branched, lattice or net-like colonies. The cells of *Spirogyra* have characteristically spiralled chloroplasts and grow in unbranched filaments which usually become yellowish-brown in colour when floating mats are formed.

Nitella (Fig. 26) and *Chara* (stoneworts) are widespread and common in south eastern Australia where a number of species of both genera occur (Aston 1973). These branched, macroscopic green algae grow attached to the substrate in up to 6 m of water and individual plants may be up to 1 m long. *Chara* grows particularly well in hard or alkaline waters whereas *Nitella* prefers more acidic or softer waters (Prescott 1978; Sainty and Jacobs 1981).

Pediastrum (Plates 1e & 1f; Fig. 27), a common alga in the phytoplankton of aquaculture ponds, has bright green-coloured cells joined together to form a distinctive circular, plate-like arrangement.

Desmid algae (family Desmidaceae) are characteristically constricted into two semi-cells which are joined by an interconnecting neck. The two semi-cells are mirror images of each other. Most desmids are solitary and planktonic. The genera *Cosmarium* (Plate 1g; Fig. 28) and *Staurastrum* (Fig. 18), which contain many thousands of species, more than any other genus in the Chlorophyta (Prescott 1978), exhibit tremendous variation in shape, size and cell ornamentation. Unlike most desmids, *Closterium* (Plates 1i & 1j; Fig. 29) lacks the constriction in the midregion of the cell. Other desmids regularly seen in aquaculture ponds include *Arthrodesmus* (Fig. 17) and *Micrasterias* (Plate 1h; Fig. 30).

[*Further reading:* Prescott (1978): Ling and Tyler (1986); Entwisle (1994a); Canter-Lund and Lund (1995)].

CHRYSOPHYTA
(yellow-green or yellow-brown algae, including diatoms)

Species of algae belonging to the Chrysophyta are yellow-green, yellow- or golden-brown in colour, although some are colourless and heterotrophic. *Dinobryon* (Fig. 31) is either solitary or forms branched colonies. Each cell of this species lives in a clear vase-like lorica. The cells of *Synura* (Fig. 32) bear minute siliceous scales and form free-swimming brown-coloured, globose colonies which are up to 0.5 mm in diameter. Both *Dinobryon* and *Synura* prefer hard waters and when abundant, can impart a distinctive odour and taste to water.

The most common species in this phyla are the diatoms (Bacillariophyceae) which have characteristic, and often strikingly beautiful, cell walls composed of two overlapping siliceous shells. *Aulacoseira* (formerly *Melosira*) (Fig. 33), a common and widespread diatom, forms brown-coloured free-floating, unbranched filaments whereas *Acnanthes* (Fig. 34) and *Navicula* (Fig. 35) are solitary. Benthic and epiphytic diatom species may also occur in aquaculture ponds. A comprehensive identification guide to the common freshwater diatoms is provided by Cox (1996). Some Australian freshwater diatoms are described by Thomas (1983) and Holland and Clark (1989).

[*Further reading:* Prescott (1978); Patterson and Hedley (1992); Canter-Lund and Lund (1995); Day *et al.* (1995)].

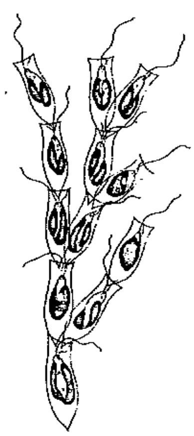


Fig. 31 *Dinobryon* colony

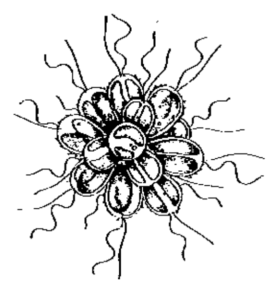


Fig. 32 *Synura* colony

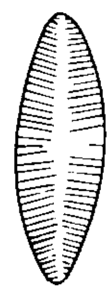


Fig. 34 *Acnanthes*

Fig. 33 *Aulacoseira*

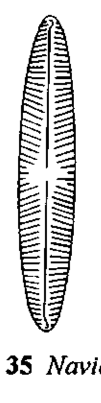


Fig. 35 *Navicula*

CYANOPHYTA (blue-green algae)

The Cyanophyta are more like bacteria than algae because they lack certain cellular organelles particularly nuclear membranes, endoplasmic reticulum, chloroplasts, and mitochondria. Indeed many authors call them cyanobacteria. However, unlike bacteria, blue-green algae possess chlorophyll *a*. Blue-green algae are small, simple cells which occur as solitary cells, filaments (mostly unbranched) or in gelatinous or mucilaginous masses. Filamentous species may be coiled such as some species of *Anabaena* (Plate 1k; Fig. 36), *Anabaenopsis* and *Spirulina* (Fig. 37), or straight such as *Oscillatoria* (Fig. 38) and *Aphanizomenon*.

Anabaena (Fig. 36), with over 25 species known from Australia, is one of the most common and abundant algae in aquaculture ponds. The filaments of *Nostoc* are embedded in a firm, gelatinous ball-shaped colony, which may reach a diameter of 10 cm. These colonies are often encountered in aquaculture ponds. *Microcystis* (Fig. 39), which frequently develops blooms in aquaculture ponds, forms free-floating irregular-shaped mucilaginous colonies composed of a few to many small cells.

The Cyanophyta constitutes a major part of the planktonic biomass of aquaculture ponds during summer (Tucker and Lloyd 1984; Sevrin-Reyssac and Pletikosic 1990) and are often conspicuous as a characteristic blue-green coloured scum on the water surface.

[***Further reading:*** Prescott (1978); Baker (1991, 1992); Jones (1994); Canter-Lund and Lund (1995); Day *et al.* (1995)].

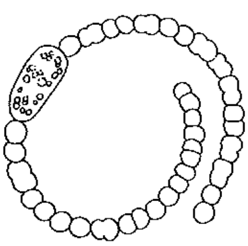


Fig. 36 *Anabaena*

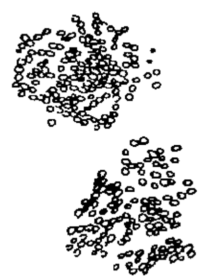


Fig. 39 *Microcystis*

Fig. 37 *Spirulina*

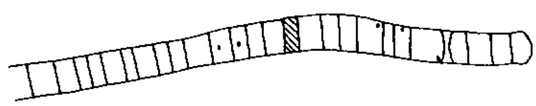


Fig. 38 *Oscillatoria*

PYRRHOPHYTA (dinoflagellates)

Most dinoflagellates are marine, but a few, notably species of *Peridinium* (Fig. 40) and the distinctively-shaped *Ceratium* (Fig. 41), occur in freshwater. The cell walls of these species are covered with sculptured plates, and one of the two flagella lies in a groove around the "equator" of the cell. *Peridinium* can occasionally cause nuisance blooms called red-tides (Paerl 1988). Many dinoflagellates are colourless, and some are symbiotic on or in other organisms.

[***Further reading:*** Ling *et al.* (1989); Canter-Lund and Lund (1995); Day *et al.* (1995)].

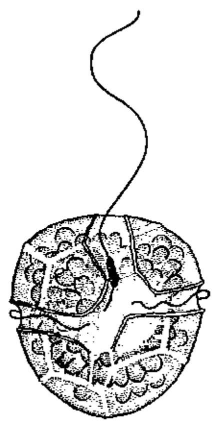


Fig. 40 *Peridinium*

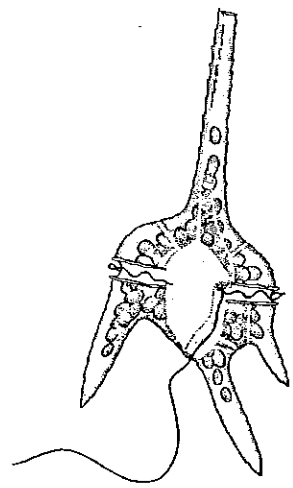


Fig. 41 *Ceratium*

CRYPTOPHYTA (cryptomonads)

The Cryptophyta is a small phylum of flagellated algae which are small (< 50 μm long), motile, and often slightly flattened in appearance. Species recorded from aquaculture ponds include *Chroomonas* (Fig. 42) and *Cryptomonas* (Fig. 43) (Culver and Geddes 1993).

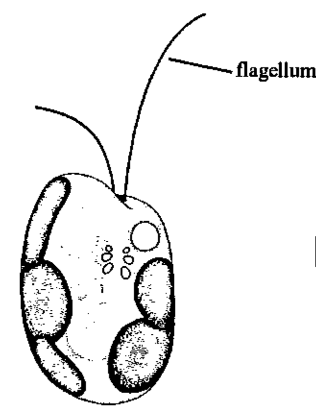


Fig. 42 *Chroomonas*

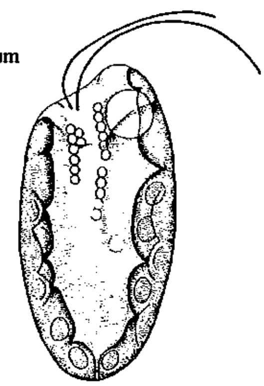


Fig. 43 *Cryptomonas*

EUGLENOPHYTA (euglenoid algae)

Most euglenoids are solitary (10-200 μm long), flagellated (1-8 flagella), motile, planktonic cells, which are either green or red in colour, while others are colourless and heterotrophic. Some species can change between being red and green in colour (Sainty and Jacobs 1981). *Euglena* (Fig. 44) is typically spindle-shaped with green chloroplasts and a prominent red eye spot. The green chloroplasts of *Trachelomonas* (Fig. 45) are often masked by a brown-coloured covering (lorica) over the cell. At times euglenoids can develop dense red- or green-coloured blooms which form visible powdery films on the surface of aquaculture ponds.

[*Further reading:* Prescott (1978); Ling and Tyler (1986); Entwisle (1994a); Canter-Lund and Lund (1995); Day *et al.* (1995)].

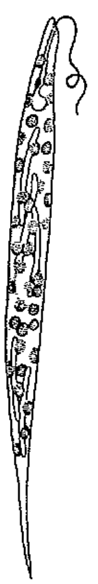


Fig. 44 *Euglena*

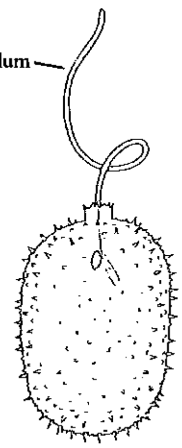


Fig. 45 *Trachelomonas*

OTHER (HIGHER) AQUATIC PLANTS

Higher aquatic plants are generally more complex in design than algae and include the mosses, ferns, lichens, liverworts and flowering plants. These plants are also called aquatic macrophytes or waterplants.

Many waterplants play an important role in aquatic habitats by providing food and cover for animals, stabilising substrates against erosion and cycling nutrients (Sainty and Jacobs 1981, 1994). Some species, such as the common reed (*Phragmites australis*), have even been planted in constructed wetlands to cleanse effluent water. However, under certain conditions development of dense growths of waterplants can become a major nuisance. For example, pondweeds (*Potamogeton* spp.), water hyacinth (*Eichhornia crassipes*), water milfoil (*Myriophyllum* spp.), elodea (*Elodea canadensis*) and cumbungi (*Typha* spp.) can impede the flow of water in open channels and drains. Dense growths of free floating plants (especially *Salvinia molesta* and water hyacinth) block screens and pumps, and decrease production by reducing light penetration. Plants growing around pond margins (Plate 2a), such as cumbungi, reeds, sedges (*Cyperus* spp.), spikerushes (*Eleocharis* spp.) and rushes (*Juncus* spp.), can restrict access and hinder netting or harvesting operations. Some waterplants, in particular *Salvinia molesta* and *Myriophyllum verrucosum*, can cause water quality problems such as tainting (Sainty and Jacobs 1981, 1994).

Waterplants can be divided into four groups based on their particular growth forms or adaptations to aquatic life. These are: (a) unattached plants floating free on, or just beneath, the water surface; (b) attached (rooted to substrate) plants which are mostly or wholly submerged below the water surface (flowers and some leaves may emerge above the water surface); (c) attached plants which have leaves floating on the water surface (Plate 2b); and (d) attached plants with leaves that emerge above the surface of the water (Plate 2a) (Table 3).

Keys to and descriptions of Australian freshwater aquatic and semi-aquatic plants, including species that occur in and around aquaculture ponds, can be found in Aston (1973), Sainty and Jacobs (1981, 1994) and Entwisle (1994b) (lichens, liverworts and mosses). A list of common aquatic plants from south eastern Australia and their typical growth forms is presented in Table 3.

Liverworts and ferns

Most liverworts (Bryophyta) are non-aquatic but a number of the Ricciaceae, namely *Riccia* and *Ricciocarpus* are often observed floating on or just below the water surface in slow flowing or still water.

Aquatic ferns (Pteridophyta) include the free-floating *Azolla* spp. and *Salvinia molesta*, and attached ferns such as *Marsilea* spp. (nardoo). Under ideal conditions, free-floating ferns are capable of rapid growth and can quickly cover the entire surface of a farm dam, preventing light from penetrating into the water, which impedes the growth of other macrophytes and phytoplankton. *Salvinia molesta*, introduced from South America, is a declared noxious plant.

[*Further reading:* Entwisle (1994b)].

Flowering plants

Members of the Cyperaceae including sedges (*Cyperus* spp.), spikerushes (*Eleocharis* spp.) and clubrushes (*Scirpus* spp.), and Junaceae (*Juncus* spp.), commonly grow around the perimeter of ponds

(Plate 2a) as well as in damp habitats. Most aquatic species are restricted to shallow waters (less than 0.5 m) but tall spikerush (*E. sphacelata*) will grow in water up to 2.0 m deep (Sainty and Jacobs 1994). Some species, particularly dirty dora (*C. difformis*), are serious weeds in rice fields.

The common reed (*Phragmites australis*) and cumbungi (*Typha* spp.) are large aquatic grasses which may grow to a height of over 1.0 m. Because they can form dense growths in up to 2.0 m of water they can become a major pest in waterways and ponds.

Pondweeds, such as *Elodea canadensis* and *Potamogeton* spp., often grow in permanently filled aquaculture ponds and farm dams. *Elodea canadensis* is an introduced species which is a declared noxious weed and, once established, is extremely difficult to eradicate. *Potamogeton tricarinatus* grows in up to 3 m of water and its upper oval-shaped leaves float on the water surface like those of waterlilies. In contrast, *P. crispus*, another common pondweed, has long narrow curly leaves which are mostly submerged.

A number of water milfoils, *Myriophyllum* (Haloragaceae), including *M. aquaticum*, *M. papillosum* and *M. verrucosum*, grow in aquaculture ponds and farm dams. Many of these waterplants are potential major weeds of waterways and farm dams. The flowers of water milfoils grow up to 20 cm above the surface of the water.

The swamp lily (*Ottelia ovalifolia*) (Plate 2b) has oval-shaped leaves which float on the water surface and produces small white flowers which open several cm above the water. Swamp lilies usually grow in up to about 1.0 m of water in permanently filled ponds.

Table 3. Common pond-inhabiting waterplants of south eastern Australia

Plant growth form	Common name	Species (family)
(a) Unattached, free floating	azolla*	*Azolla* spp. (Azollaceae)
	duckweeds	*Lemna* spp., *Spirodela* spp. & *Wolffia* spp. (Lemnaceae)
	liverwort	*Ricciocarpus natans* (Ricciaceae)
	salvinia**	*Salvinia molesta* (Salviniaceae)
	water hyacinth**	*Eichhornia crassipes* (Pontederiaceae)
(b) Attached, mostly or wholly submerged below the water surface	dense waterweed	*Egeria densa* (Hydrocharitaceae)
	elodea**	*Elodea canadensis* (Hydrocharitaceae)
	hornwort	*Ceratophyllum demersum* (Ceratophyllaceae)
	hydrilla*	*Hydrilla verticillata* (Hydrocharitaceae)
	pondweeds*	*Potamogeton* spp. (Potamogetonaceae)
	ribbonweed*	*Vallisneria gigantea* (Hydrocharitaceae)
	waternymph	*Najas tenuifolia* (Najadaceae)
	waterwort	*Elatine gratioloides* (Elatinaceae)
	water milfoil*	*Myriophyllum* spp. (Haloragaceae)
		Glossostigma spp. (Scrophulariaceae)
(c) Attached with leaves floating on the water surface	nardoo	*Marsilea* spp. (Marsileaceae)
	floating pondweed*	*Potamogeton tricarinatus* (Potamogetoneae)
	starworts	*Callitriche* spp. (Callitrichaceae)
	swamp lily	*Ottelia ovalifolia* (Hydrocharitaceae)
	waterlilies	*Nymphaea* spp. (Nymphaeaceae)
	water primrose	*Ludwigia peploides*(Onagraceae)
(d) Attached with leaves that emerge above the water surface	common reed*	*Phragmites australis* (Gramineae)
	cumbungi*	*Typha* spp. (Typhaceae)
	dirty dora & sedges	*Cyperus* spp. (Cyperaceae)
	rushes	*Juncus* spp. (Juncaceae)
	sagittaria*	*Sagittaria* spp. (Alismataceae)
	spikerushes*	*Eleocharis* spp. (Cyperaceae)
	water couch*	*Paspalum distichum* (Gramineae)
	water ribbons	*Triglochin procerum* (Juncaginaceae)
	watercress	*Rorippa nasturtium-aquaticum* (Brassicaceae)
		Glossostigma spp. (Scrophulariaceae)

* Species which may become a nuisance in waterways or ponds

** Declared noxious weed in some or all States of south eastern Australia

Heavy growths of swamp lily may restrict access to ponds, but can also be beneficial by providing shelter and being a source of food for some animals, such as yabbies.

Glossostigma spp. (Scrophulariaceae) are often found growing in the mud of fry rearing ponds (Plate 2c). At times these small, prostrate (less than 2 cm high) flowering plants will carpet the entire substrate down to a water depth of 2.0 m.

Water hyacinth is an introduced free-floating plant with long (up to 1 m), purple to black submerged roots, leaves with spongy inflated stalks and large blue flowers. Because this plant has the ability to spread rapidly and form massive dense floating mats, particularly in nutrient rich water, it is a declared noxious plant throughout Australia.

[***Further reading:*** Aston (1973), Sainty and Jacobs (1981, 1994)].

AQUATIC ANIMALS

PROTOZOA

BIOLOGY ECOLOGY AND IDENTIFICATION

The Kingdom Protozoa refers to a number of diverse phyla containing microscopic, single-celled organisms (plants and animals). There is considerable difficulty in classifying protozoans. The three main types of free-living protozoans that occur in aquaculture ponds are the flagellates, amoebae and ciliates. The amoebae and ciliates are animal-like (heterotrophs), but many of the flagellates contain chloroplasts and so are capable of photosynthesis (autotrophs). These species possessing chloroplasts may be called algae as well as being referred to as protozoans. However, there are some flagellates that lack chloroplasts (non-pigmented) and are classified as heterotrophs, and some can switch between being an autotroph and a heterotroph (mixotrophs). Generally the non-pigmented, or heterotrophic, protozoans are dealt with in this section while autotrophic protozoans are covered in more detail in the section on Algae. Table 4 provides a guide to the classification of the freshwater heterotrophic protozoans which may occur in freshwater aquaculture ponds and farm dams.

Protozoans vary greatly in size and structure. Generally protozoa are microscopic (< 0.5 mm), some species may be just a few micrometers (microns) in size while others can exceed 2.0 mm in size and be visible to the naked eye. Some species form colonies which may contain just a few cells to many 1,000's of cells. Protozoa may bear flagella (long thread-like hairs), cilia (short thread-like hairs) or pseudopodia (irregular flowing extensions of the cell), which aid in locomotion and collection of food. Most protozoa reproduce asexually by binary fission, which involves the division of the parent cell into two new cells. Sexual reproduction, usually by conjugation, also occurs but is less common. Many species of Protozoa are capable of encystment, which may be induced by changes in the environment, such as the drying out of their habitat, changes in food availability and changes in water quality (Corliss and Esser 1974). Cysts help protozoans survive harsh or unfavourable conditions, and play an important role in their dispersal and colonisation of new habitats.

Protozoa are ubiquitous throughout Australian freshwaters and are found in just about every conceivable habitat. In the aquatic environment, free-living species swim or float in the water column, whereas benthic species either attach to various surfaces, or crawl and glide on and in the substrate. Many Protozoa are epizoic, epiphytic, commensal or parasitic on and in other plants and animals. Protozoa associated with decapod crustaceans are described in Sprague and Couch (1971) and O'Donoghue *et al.* (1990), and Beumer *et al.* (1983) provide a checklist of parasitic Protozoa recorded from Australian fish species.

Protozoa are an important group of organisms in the aquatic trophic web as they play a major role in primary production (autotrophs) as well as in the transfer and regeneration of organic compounds. Heterotrophic protozoa feed on fine organic matter, bacteria, algae and other protozoa. The presence of large numbers of protozoa in the water of an aquaculture pond may be due to high levels of organic matter and bacteria, which are indicative of poor water quality associated with eutrophic conditions (Patterson *pers comm.*). Larger protozoa may even take larger animals. For example, small crustaceans and rotifers can become entangled in the sticky axopodia (pseudopodia) of heliozoans and eventually be engulfed, while the planktonic ciliate *Bursaria* can swallow rotifers whole. Feeding is usually by phagocytosis, in which food items are taken into a vesicle or vacuole within the cell via engulfment. In turn, protozoa may form an important part of the diet of other aquatic invertebrates, such as rotifers, copepods and cladocerans.

Epizoic protozoa, particularly peritrichous ciliates (eg. *Epistylis*) are often found on the body surfaces of planktonic and benthic crustaceans. Heavy infestations of these protozoa may impair activity of the host, and their presence in large numbers may indicate high pollution conditions in the environment (Henebry and Ridgeway 1980).

Unfortunately, protozoa of Australian freshwaters are poorly known and there are no significant taxonomic or ecological works. However, published keys to the Northern Hemisphere protozoa (eg. Lee *et al.* 1985; Finlay *et al.* 1988; Pennak 1989; Patterson and Hedley 1992; Foissner and Berger 1996)

Table 4 Classification of major groups of free living and parasitic freshwater Protozoa

Phylum Subphylum Class	Common names	Description
Sacromastigophora		
Mastigophora	flagellates	Cells with usually 1-4 flagella
Phytomastigophora	flagellated algae	Plant-like flagellates, typically possess chloroplasts (mostly free-living) (eg. *Euglena, Volvox*)
Zoomastigophora	flagellates	Animal-like flagellates, non-pigmented (free-living, and parasitic) (eg. *Bodo, Chilomonas, Ichthyobodo*)
Sarcodina	naked amoebae, testate amoebae & heliozoa	Cells with pseudopodia or long fine radial pseudopodia, or complex external shell (test); without cilia or flagella (mostly free-living) (eg. *Arcella, Actinophrys, Difflugia*)
Apicomplexa	sporozoa & coccidia	With or without spores (all parasitic) (eg. *Eimeria, Goussia*)
Microspora	microsporidia	Spores unicellular, minute, with a single polar capsule (all parasitic) (eg. *Thelohania, Pleistophora*)
Acetospora	haplosporidia	Spores multicellular, without polar capsules (all parasitic) (eg. *Haplosporidium*)
Myxozoa	myxosporidia	Spores multicellular, with one or more polar capsules (all parasitic) (eg. *Myxobolus, Myxosoma*)
Ciliophora	ciliates	Cells with bundles (cirri) and/or rows of cilia (free-living, commensal, epizoic, parasitic) (eg. *Chilodonella, Epistylis, Paramecium, Stentor*)

will assist in identification at least to the level of family. The main protozoan types that occur in fresh waters can be distinguished by their locomotor organelles: flagella, pseudopodia or cilia. The following key provides a guide to the free-living, planktonic, heterotrophic, types of protozoa.

Key to common free-living planktonic protozoa of aquaculture ponds

1. Cells with cilia or flagella (Figs 50-57) 2

- Cells with pseudopodia, or long fine radial pseudopodia, or complex external shell; without cilia or flagella (Figs 46, 47, 48 & 49) ....**Sarcodina (amoebae and heliozoa)**

2. Cells usually with 1-4 flagella (Figs 50 & 51) ....**Mastigophora (flagellates)**

- Cells with few to many cilia arranged in bundles (cirri) and/or in rows (Figs 52-57) .... **Ciliophora (ciliates**

[*Further reading:* Williams (1980); Fenchel (1987); Pennak (1989); Taylor and Sanders (1991); Patterson and Hedley (1992); Foissner and Berger (1996)].

SARCODINA (amoebae and heliozoa)

The amoebae (Sarcodina) are traditionally viewed as naked cells which move by extrusions of the cell body called pseudopodia (Fig. 46). The amoebae also includes the planktonic heliozoa, which have spherical bodies with stiffened pseudopodia radiating from all sides giving them a star-like appearance (Fig. 47), and testate amoebae, which make characteristic skeletons (or *tests*) from organic material and/or silica (Figs 48 & 49). Heliozoa are pelagic and benthic with *Actinosphaerium* and *Actinophrys* (Fig. 47) being common in the plankton. These two species may be significant predators of other protozoa and rotifers. Naked amoebae, such as *Mayorella* (Fig. 46), and testate amoebae, such as *Arcella* (Plate 1j; Fig. 48), *Difflugia* (Fig. 49) and *Lecquereusia* (Plate 2d) are more likely to be littoral, epibenthic or epiphytic, but some species are occasionally collected in open water.

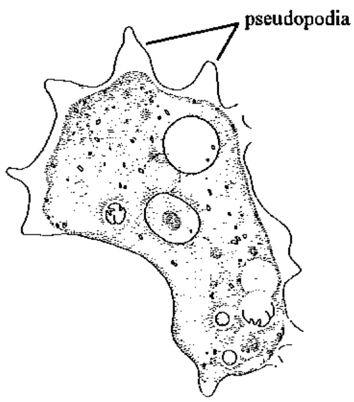


Fig. 46 *Mayorella*

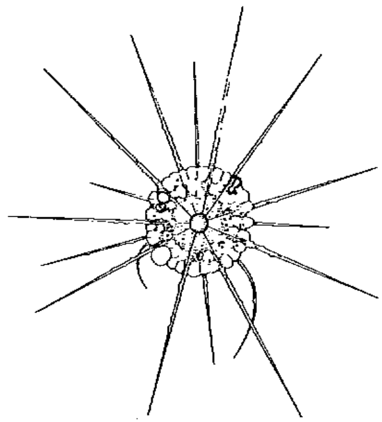


Fig. 47 *Actinophrys*

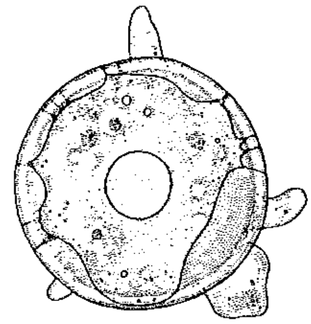


Fig. 48 *Arcella*

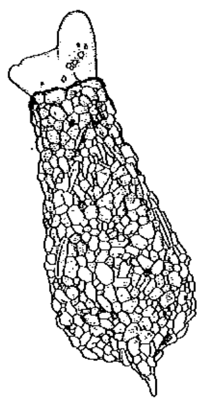


Fig. 49 *Difflugia*

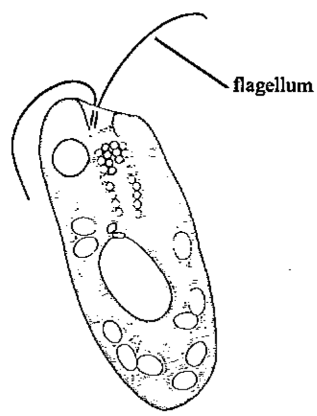


Fig. 50 *Chilomonas*

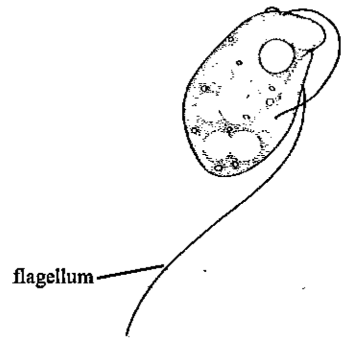


Fig. 51 *Bodo saltans*

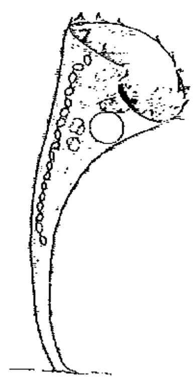


Fig. 52 *Stentor*

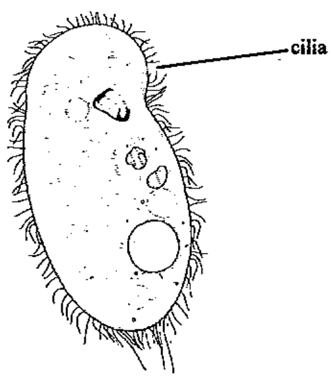


Fig. 53 *Colpidium*

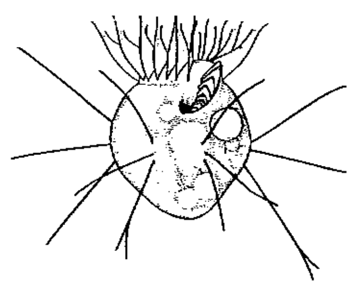


Fig. 54 *Halteria*

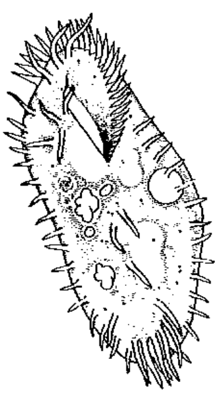


Fig. 55 *Oxytricha*

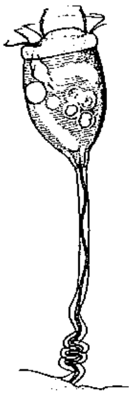


Fig. 56 *Vorticella*

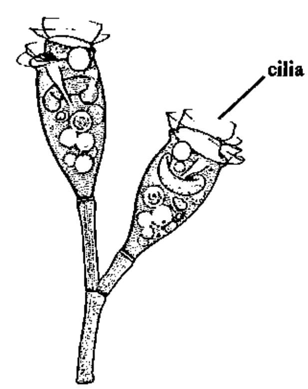


Fig. 57 *Epistylis*

The test of *Difflugia* is constructed from particles of quartz whereas *Arcella* constructs an organic test which has a single central aperture on the ventral side.

[*Further reading:* Croome (1986, 1987); Bell (1993); Ogden & Hedley (1980); Patterson and Hedley (1992)].

MASTIGOPHORA (flagellates)

Flagellates (Mastigophora) are distinguished from other protozoa by possessing 1-4 (usually 2) flagella, but some species have 8 or more flagella. The most common flagellates that occur in aquaculture ponds are autotrophs (Phytomastigophora) which are traditionally regarded as algae (see section on algae). Free-living heterotrophic flagellates (Zoomastigophora) feed on small organic particles, bacteria and other small protozoa. Common heterotrophic flagellates include *Chilomonas* (Fig. 50), *Bodo saltans* (Fig. 51), *Bicosoeca*, *Anthophysa* and *Entosiphon*. Probably the most common parasitic flagellate recorded from freshwater aquaculture ponds is *Ichthyobodo necator* which infests the skin and gills of fish (Rowland and Ingram 1991). Due to the very small size of flagellates, identification is very difficult and usually requires an electron microscope.

[*Further reading:* Ling *et al.* (1989); Patterson and Hedley (1992)].

CILIOPHORA (ciliates)

The Ciliophora (ciliates) comprises the largest and most conspicuous group of Protozoa. Their cilia are generally short and densely packed and are often organised into rows or bundles over the cell surface. Apart from providing locomotion, cilia can be specialised for collection of food. Ciliates are particularly abundant in aquaculture ponds, where they may feed on organic particles, phytoplankton, other protozoa and rotifers. The common, trumpet-shaped *Stentor* (Fig. 52) attaches to the substrate by means of a holdfast, but occasionally will release its hold to contract into a cone or teardrop shape and swim in open water (Plate 2f) (Foissner and Wölfl 1994). Species of *Stentor* may contain pigmented granules or symbiotic autotrophic algae which give them a dark green to almost black coloration (Foissner and Wölfl 1994). In spring and summer motile *Stentor*, which can be visible to the naked eye, may occur in sufficient densities to colour the water black (Plate 2f). *Colpidium* (Fig. 53), *Euplotes*, *Halteria* (Fig. 54) and *Oxytricha* (Fig. 55) are common and widespread genera. *Colpidium* is often found in large numbers in organically enriched waters.

Vorticella (Fig. 56) and the colonial *Epistylis* (Plate 2e; Fig. 57) attach themselves to surfaces by means of a stolon. These species are generally epiphytic, epizoic or commensal and have been found attached to the body surface and gills of crustaceans (Sprague and Couch 1971; O'Donoghue *et al.* 1990) and fish in aquaculture ponds (Rowland and Ingram 1991).

[*Further reading:* Corliss (1979); Lee *et al.* (1985); Foissner and O'Donoghue (1990); Patterson and Hedley (1992); Foissner and Berger (1996)].

PORIFERA (sponges)

The phylum Porifera contains a group of simple, multicellular, colony-forming animals. Although better known as marine animals, sponges are also common in freshwater environments. Sponges usually require a hard surface on which to grow and appear to prefer still shallow waters. The supporting structure of sponges is composed of tiny siliceous spicules which are bound together by collagen to give a rigid skeleton (Frost 1991). The morphology of these spicules can be used to identify different species. Freshwater sponges are mostly encrusting in habit and some may grow up to several metres across (Williams 1980).

Neither true tissues nor organs are present in sponges. Instead, specialised cells within the colony undertake basic biological functions such as feeding, digestion, and reproduction (Frost 1991). Sponges feed by filtering water, which is drawn into the sponge by currents created by specialised cells possessing beating flagella. Sponges are usually dull coloured, but many contain symbiotic algae which gives them a green colouration. This has led to some people mistakenly identifying sponges as plants. The symbiotic algae are retained within the cells of the sponge and, to a certain extent, provide nutrients to the sponge (Frost 1991).

Sponges will grow on hard substrates in aquaculture ponds and farm dams, and can become a nuisance if allowed to grow on screens over inlets and outlets, thereby blocking water flow. Sponges provide habitat for other aquatic animals which reside within the colony. Freshwater fish are not known to eat sponges.

Most freshwater sponges belong to the family Spongillidae in which 10 genera are known from Australia.

[*Further reading:* Racek (1969); Williams (1980); Frost (1991)].

CNIDARIA (hydras and jellyfish)

The phylum Cnidaria (Coelenterata) includes the Hydrozoa (hydras), Scyphozoa (jellyfish) and Anthozoa (sea anemones and corals). These animals are best known from the marine environment, but a few species of the Hydrozoa occur in freshwater. Hydrozoans are small, soft-bodied animals which are usually found attached to surfaces. The mouth is surrounded by tentacles (usually 6) which aid in capturing food. The tentacles bear stinging cells (containing nematocysts) which immobilise prey by injecting paralysing toxins. Hydrozoans feed on small planktonic animals. Because of their ability to sting, some hydrozoans are sometimes a pest in fish hatcheries (Slobodkin and Bossert 1991).

Freshwater hydrozoans occur in three morphologically different groups. Hydras (eg. *Hydra*) (Fig 58) occur as solitary polyps which are up to 15 mm long, and can be common on hard surfaces in aquaculture ponds. *Cordylophora* spp. form branching colonies in which individual polyps are joined together by a stolon. The third group occur as free-floating transparent jellyfish (medusae) and one species, the introduced *Craspedacusta sowerbyi*, sporadically forms blooms in lakes.

[*Further reading:* Williams (1980); Slobodkin and Bossert (1991)].

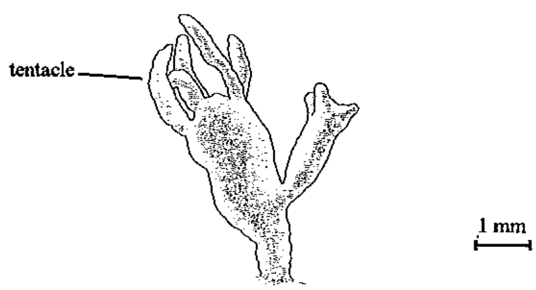


Fig. 58 *Hydra* (Cnidaria)

PLATYHELMINTHES (flatworms)

The phylum Platyhelminthes includes the Cestoidea (tapeworms), Trematoda (flukes), Turbellaria (flatworms) and Temnocephalidea. The Cestoidea and Trematoda are entirely parasitic. Information on species that parasitise Australian fish species and freshwater crayfish is provided in Beumer *et al.* (1983) and O'Donoghue *et al.* (1990), respectively.

The **Turbellaria** (flatworms or planarians) are primitive, flattened, elongate (5-100 mm, usually < 30 mm), soft-bodied animals (Fig. 59). Their body surface is smooth, covered with cilia and often with distinctive colour patterns. The head is usually distinct from the body and may have one or more pairs of eyes. Flatworms are mostly free-living in a wide variety of aquatic habitats, including aquaculture ponds, where they can be found creeping over and beneath the surfaces of submerged objects such as stones and debris. Flatworms feed mostly on live and decaying animal matter. All of the known Australian species belong to the Order Tricladida.

The **Temnocephalidea**, which live on the body surface of freshwater crayfish, are small (1-12 mm), oval animals bearing 2-6 finger-like tentacles on the anterior end (Fig. 60). A pair of small eyes are sometimes present. Although temnocephalids are commensals on crayfish (they do not feed on their host), heavy infestations in the branchial chamber of the crayfish may impair respiration. Temnocephalids feed on small aquatic invertebrates, and apparently only use their host as a surface on which to live and as a transport vehicle. A key to the Australian species of Temnocephalidea is presented in Williams (1980).

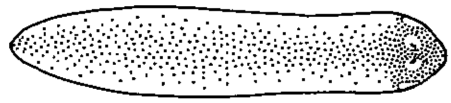


Fig. 59 planarian (Turbellaria)

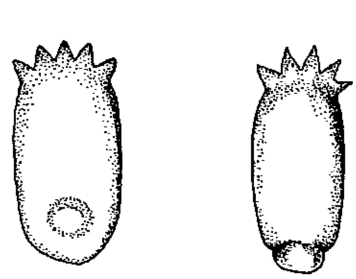


Fig. 60 *Temnocephala chaeropsis* (Temnocephalidea)

NEMERTEA

The phylum Nemertea encompasses a group of worms that are mostly marine. Freshwater nemerteans are free-living, benthic, small (< 25 mm) flattened, worm-like animals which lack external segmentation. Their body surface is smooth and covered with cilia, and the anterior end usually bears three pairs of eyespots and a muscular proboscis which aids in the capture of food. Nemerteans are uncommon and confined to sluggish or standing, permanent waters, particularly where aquatic plants are growing. Nemerteans are rarely seen in aquaculture ponds.

[*Further reading:* Williams (1980)].

NEMATODA (roundworms)

Nematodes are elongate, thin, worm-like invertebrates that lack segments and appendages. Most species are less than 10 mm long and their body surface is usually smooth or striated, occasionally bearing small protuberances or setae. In the aquatic environment, many species are free-living in the water and substrate while others are parasites of animals and plants. Some species may be both free-living and parasitic at different stages of their lifecycle.

Free-living nematodes feed on fine organic matter and microscopic organisms particularly those that live amongst the benthic organic debris, such as bacteria, algae, fungi and protozoans. Some are predacious on small invertebrates including nematodes. Due to their relatively high diversity and abundance, aquatic nematodes constitute an important and significant portion of the zoobenthic community (Poinar 1991), yet very little attention has been paid to them. Densities of large species of nematodes (retained on a 250µm sieve), particularly dorylaimids and mononchids, in aquaculture ponds at the MAFRISC have exceeded 112,600 ind./m². But many more smaller species, including monhysterids and tripylids, are expected to be present. One of the more conspicuous groups of nematodes in these ponds are the dorylaimids which are large (up to 3.0 mm long) nematodes possessing a stylet, smooth cuticle and thin pointed tail (Fig. 61).

Beumer *et al.* (1983) provide a checklist of the nematodes that parasitise Australian fish species, and the species that parasitise native fish in aquaculture ponds are briefly described in Rowland and Ingram (1991). Nematode parasites of freshwater crayfish are described in O'Donoghue *et al.* (1990).

There are no descriptions or keys available to identify Australian aquatic nematodes, but keys in Poinar (1991) and APHA (1992) may be of some assistance.

[*Further reading:* Goodey (1963); Williams (1980); Poinar (1991)].

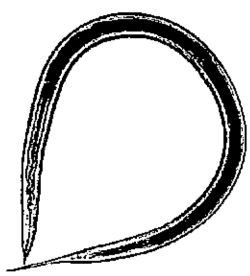


Fig. 61 Dorylaimid nematode

NEMATOMORPHA (gordian worms)

The phylum Nematomorpha contains a small group of unsegmented, worm-like animals commonly known as gordian or horse-hair worms. Larval gordian worms are parasites of arthropods, particularly insects, while the adults are free-living in freshwater and are frequently found in groups forming writhing tangled masses. Adult gordian worms are yellow to dark brown in colour, and the body is cylindrical, extremely long (0.1-1.0 m) and thin. The adults, which do not feed, occur in a wide range of aquatic habitats, but are rarely found in aquaculture ponds. Williams (1980) provides a key to the six known genera which occur in Australia.

[*Further reading:* Williams (1980); Poinar (1991)].

ROTIFERA

BIOLOGY, ECOLOGY AND IDENTIFICATION

Rotifers possess two distinct features. The head has a ciliated region called a corona encircling the mouth region (Fig. 62), and a distinctive muscular pharynx which has a complex set of hard jaws called a trophus (Fig. 63). Movement of the cilia on the corona of some species creates an appearance of rotating wheels. These cilia are used for locomotion and to create water currents for gathering food. Due to the presence of this ciliated corona, some rotifers are mistaken for ciliated protozoans.

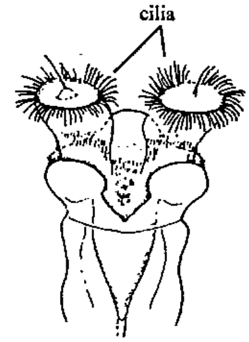


Fig. 62 Corona of a rotifer

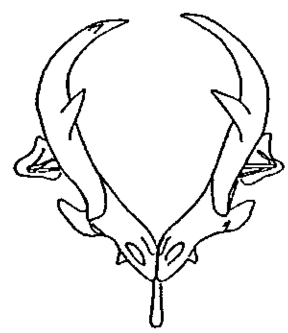


Fig. 63 Trophus of a rotifer

Rotifers are small animals usually 0.1-1.0 mm long, but more commonly are less than 0.2 mm. Occasionally the predatory genus *Asplanchna* (Plate 2h; Fig. 69) may exceed 1.0 mm in length and be visible to the naked eye. Some species of rotifer, such as *Lacinularia* (Plate 2l; Fig. 73) and

Conochilus (Fig. 74), form colonies, which may be composed of up to 1,000 individuals and be up to 5.0 mm in diameter. Most rotifer species are free-living herbivores or carnivores, but some are parasitic. Although rotifers are conspicuous in the plankton due to their abundance, there are also many species that are associated with littoral and vegetated habitats, or attach themselves to surfaces such as aquatic plants and other animals.

Nearly 700 rotifer species are known to date from Australia's inland waters. The majority of these are littoral or benthic, and are found in the floating or submerged vegetation of billabongs, lakes and river margins, weedy puddles, in damp moss, in fact any place that holds water for more than a few days.

Lifecycle

Rotifers have a very complex lifecycle. In the asexual (or amictic) phase of the lifecycle of monogonont rotifers, females reproduce without the aid of males by producing diploid eggs that always develop into females (Fig. 64). Reproduction in the absence of males is called parthenogenesis. Indeed, for many species of rotifers males are extremely rare, and in some groups, such as the digonont rotifers, males are not known. Most of the rotifer lifecycle is spent in this asexual phase. However, following specific environmental stimuli, the sexual (or mictic) phase of the lifecycle is initiated and the females begin producing haploid eggs which develop into mictic females. These mictic females then produce more haploid eggs. If these eggs are unfertilised they develop into short-lived male rotifers. When these males mate with mictic females, a resting diploid egg or cyst is formed.

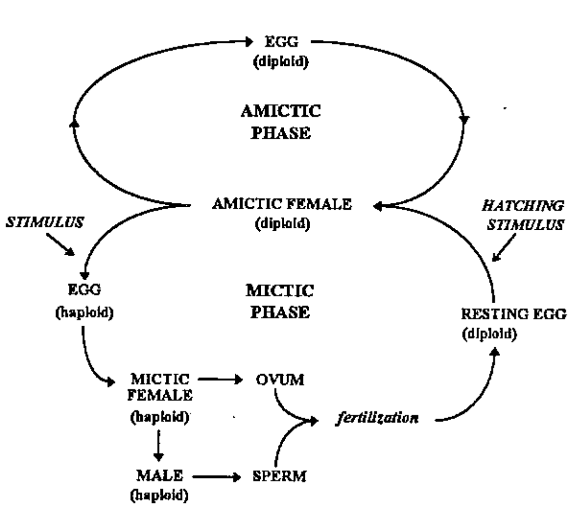


Fig. 64 The lifecycle of a monogonont rotifer

The environmental stimuli that initiate the sexual phase of the rotifer lifecycle, and the production of resting eggs, are poorly understood, but factors such as population density, rotifer age, diet and photoperiod, or the onset of unfavourable environmental conditions are suggested. The resting (dormant) eggs (70-150 µm in diameter) possess thickened shells and are very resistant to harsh environmental conditions, such as the drying out of ponds. These eggs can remain dormant for many years during which they may be dispersed by the wind, water or migrating animals (Wallace and Snell 1991). Eventually species specific cues cause these eggs to hatch into amictic females which enter the asexual phase of the rotifer lifecycle. Cues which stimulate hatching include light, temperature and salinity (Pourriot and Snell 1983).

Ecology

Along with protozoans and microcrustaceans, rotifers dominate freshwater zooplankton. When conditions are ideal rotifers can become very abundant and make significant contributions to zooplankton biomass and productivity in aquaculture ponds. At the MAFRISC rotifer densities are commonly between 100 and 1,000 ind./l and have occasionally reached 6,000 ind./l. Higher densities have been recorded in other aquaculture ponds. In ponds at the NFC maximum densities of 26,000 ind./l have been reported for rotifers (Arumugam 1986) and the density of *Brachionus* spp. has reached 12,100 ind./l (Culver 1988; Culver and Geddes 1993). In intensive tank culture systems, densities greatly exceed those recorded in aquaculture ponds. For example, maximum densities of 55,000-1,100,000 ind./l have been reported in mass culture systems for *Brachionus plicatilis* (Lubzens 1987).

Rotifers eat bacteria, algae, protozoa and other small microfauna including other species of rotifers, and compete with cladocerans and copepods for food resources. In turn, rotifers are important as food for other aquatic animals. Rotifers can often be a major component in the diet of small fish, as is the case for silver perch fry which, in the first week of being stocked in fertilised rearing ponds at the NSW Fisheries, Grafton Research Centre (GRC), feed extensively on species of *Brachionus* (C. Mifsud *pers comm.*). In comparison, rotifers are rarely ingested by the fry of golden perch (Culver 1988), Macquarie perch, Murray cod and trout cod (Ingram *unpub. data*) stocked into fertilised fry rearing ponds. However, it should be noted that many species of rotifer are delicate and when ingested break down very quickly. Often the only way to determine if fish have been feeding on rotifers is to search for rotifer trophi amongst the stomach contents, which requires high magnifications (> 400x).

Individuals within some species of rotifer can have different body forms, termed polymorphism, which can cause problems in identifying species.

Polymorphism is apparently induced by both biotic and abiotic factors including changes in the season, diet and predation (Wallace and Snell 1991; Nogrady *et al.* 1993). For example, the anterior and posterior body spines of *Brachionus calyciflorus* (Fig. 83) grow longer in the presence of predators such as *Asplanchna* (Gilbert 1967).

Rotifer populations are affected by a number of environmental and biological factors including water temperature, oxygen concentration, pH, light intensity, the amount of food present and its quality, competition from other organisms, predation and parasitism (Hofmann 1977; Wallace and Snell 1991). Rotifers have such a short lifespan that their peak reproductive period only lasts about 3-4 days (Allan 1976). Therefore the rate at which blooms develop is extremely fast, and maximum densities may be reached in a matter of days (Tan and Shiel 1993).

Many rotifers are limited in distribution, and there are marked differences in species composition with latitude. Within the Brachionidae, for example, species of *Brachionus* are more common in south eastern Australia while species of *Keratella* predominate in the north. Similar geographical differences apply across all rotifer families (Shiel and Koste 1986).

Identification

The current systematic status of the rotifers is given by Nogrady *et al.* (1993). Two classes are recognised: Digononta, rotifers with paired ovaries, and Monogononta, rotifers with a single ovary. Of the Digononta, only the Order Bdelloidea is found in freshwater. Most rotifers that occur in the plankton of aquaculture ponds and farm dams are monogononts, and the more common species encountered belong to the genera *Asplanchna, Brachionus, Filinia, Keratella, Polyarthra* and *Synchaeta* (Appendix I).

Common planktonic monogonont families and genera from freshwater aquaculture ponds and farm dams of south eastern Australia can be identified using the following key. Identification beyond the level of this key often requires a detailed examination of the trophi, which are an important taxonomic feature. A description of the method used to prepare trophi for examination is given in Koste and Shiel (1991) and Shiel (1995). Bdelloid rotifers are excluded from the key as they are rare in the plankton and extremely difficult to identify either alive or preserved. Species belonging to other families not included in the key are predominantly littoral and mostly associated with marginal or vegetated habitats, but these may occasionally be collected, or occur in localised 'blooms'. Keys provided by Shiel (1995) should be used to identify species beyond the level of this key, and species not included in the key. Shiel (1995) also includes biological and ecological notes, sampling and identification methods.

Key to families and genera of common pond-inhabiting monogonont rotifers of south eastern Australia

1. Small globular body with 2-3 long setae that are much longer than the body (Plate 2g; Figs 65 & 66) .... **Filiniidae** (*Filinia*)

\- Long setae absent (Figs 67-96) 2

2. Body large (usually > 400 μm long), transparent, sack-like or globular, without a firm rigid lorica (Figs 67, 68 & 69) 3

\- Body usually < 400 μm long, with or without a rigid lorica (Figs 70-96) 5

3. Corona with groups of large cilia; well developed foot present (Fig. 67)... **Epiphanidae** (*Epiphanes*)

\- Corona without large groups of cilia; foot rudimentary or absent (Figs 68 & 69) .... **Asplanchnidae**....4

4. With rudimentary foot and toes (Plate 2i, Fig. 68) .... *Asplanchnopus*

\- Without foot and toes (Plate 2h; Fig. 69) .... *Asplanchna*

5. Body with lateral, ciliated auricles or leaf-like paddles or foliate appendages (Figs 70, 71 & 72). 6

\- Body without lateral appendages (Figs 73-96)..... 8

6. Body with ciliated auricles or paddle-like swimming appendages (Figs 71 & 72) .... **Synchaetidae**....7

\- Body with branching, foliate, arm-like appendages (Fig. 70).. **Hexarthridae** (*Hexarthra*)

7 Body cone-shaped (pyriform) with lateral ciliated auricles (Plate 2j; Fig. 71) .... *Synchaeta*

\- Body cube-shaped with lateral serrated leaf-like paddles (Plate 2k; Fig. 72) .... *Polyarthra*

8. Body amorphous, without a firm rigid lorica, or with elongate body in a gelatinous sheath; solitary or colonial (Figs 73 & 74) 9

\- Body usually with firm to rigid lorica; solitary only (Figs 75-96) 10

9 Solitary or colonial; body elongate, greater than 1 mm long; colonies up to 5 mm in diameter (Plate 2l; Fig. 73).... **Flosculariidae** (*Lacinularia*)

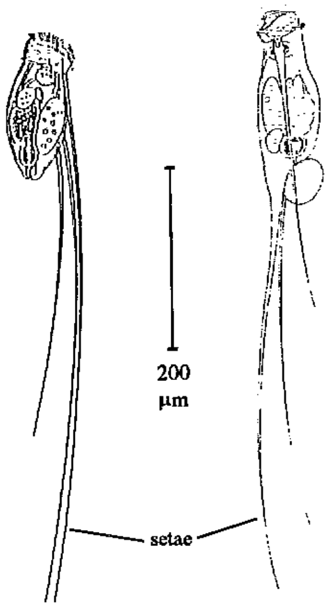


Fig. 65 *Filinia longiseta* Fig. 66 *Filinia pejleri*

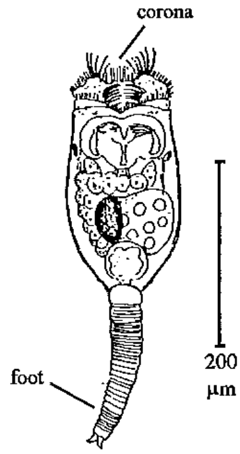


Fig. 67 *Epiphanes macrourus*

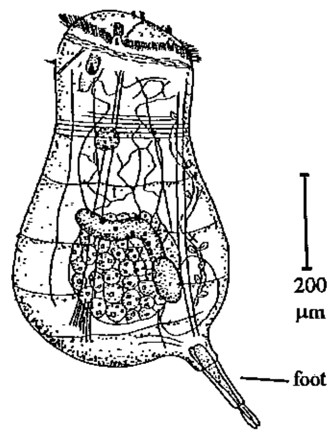


Fig. 68 *Asplanchnopus hyalinus*

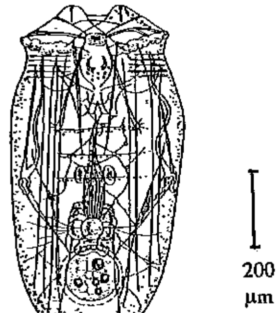


Fig. 69 *Asplanchna priodonta*

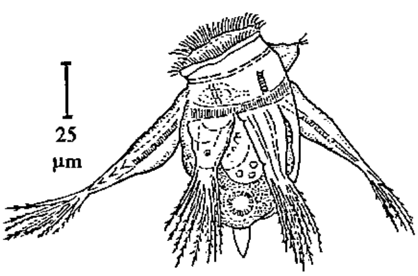


Fig. 70 *Hexarthra*

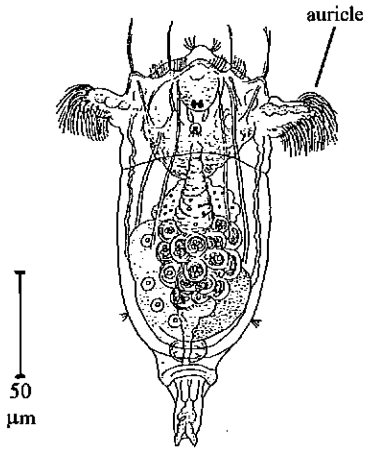


Fig. 71 *Synchaeta oblonga*

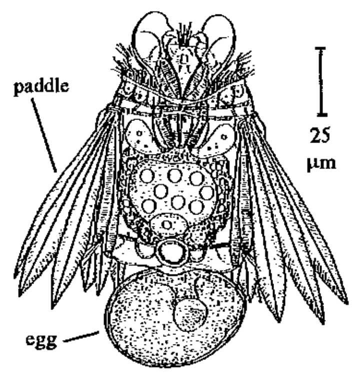


Fig. 72 *Polyarthra vulgaris*

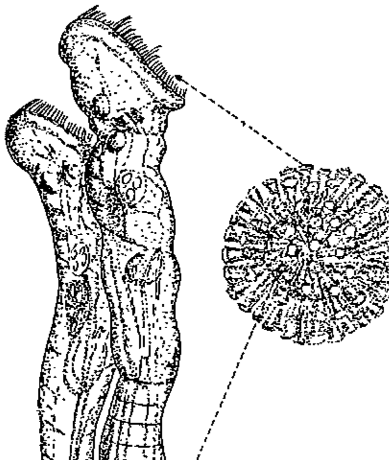


Fig. 73 *Lacinularia* colony

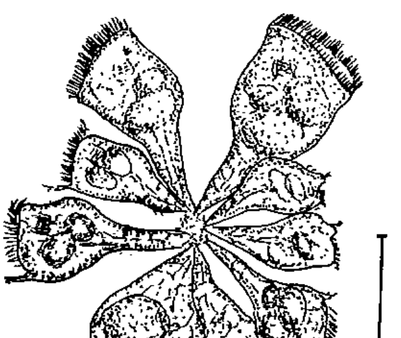


Fig. 74 *Conochilus* colony

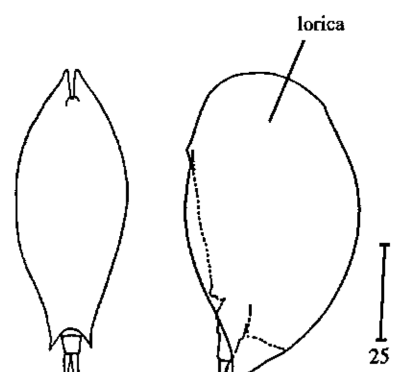


Fig. 75 *Colurella uncinata*

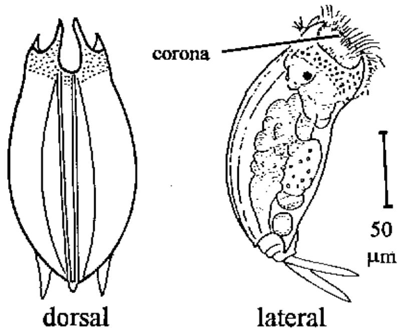


Fig. 76 *Mytilina*

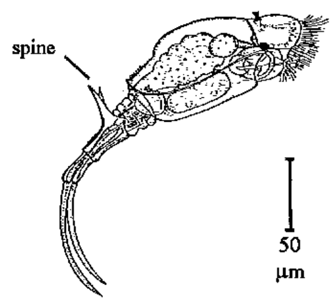


Fig. 77 *Trichotria*

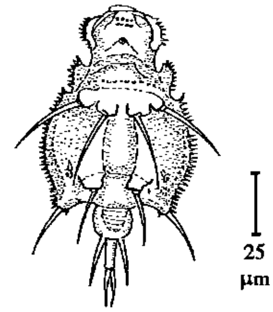


Fig. 78 *Macrochaetus*

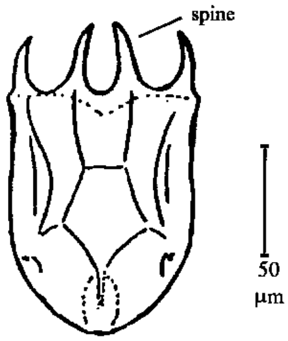


Fig. 79 *Brachionus budapestinensis*

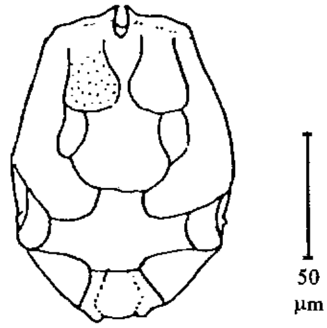


Fig. 80 *Brachionus angularis*

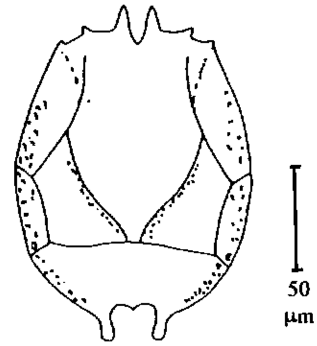


Fig. 81 *Brachionus lyratus*

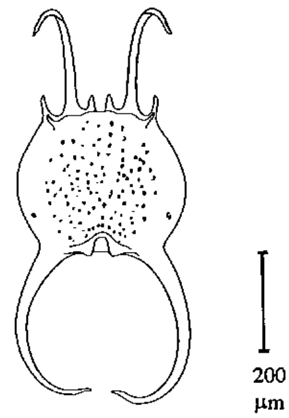


Fig. 82 *Brachionus falcatus*

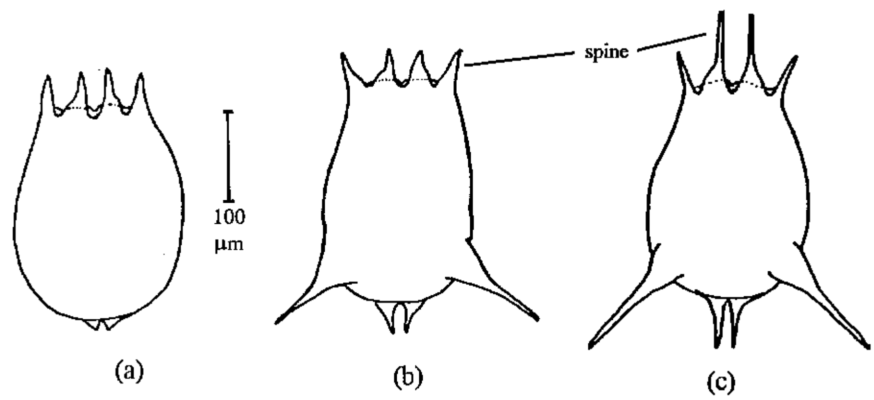


Fig. 83 Polymorphic forms of *Brachionus calyciflorus*

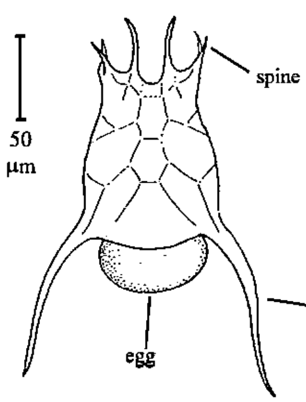


Fig. 84 *Keratella australis*

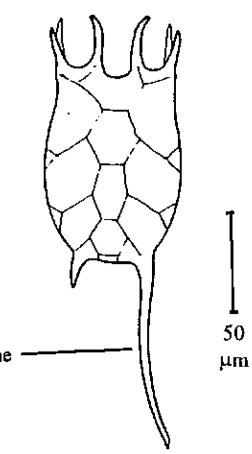


Fig. 85 *Keratella tropica*

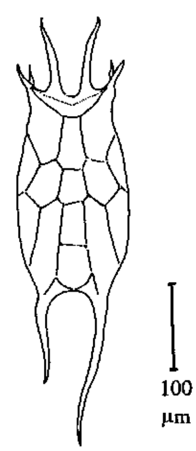


Fig. 86 *Keratella slacki*

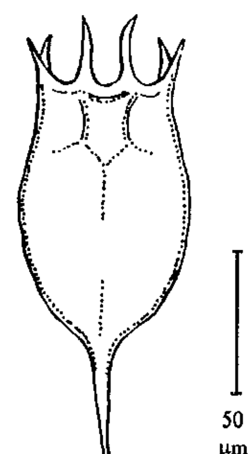


Fig. 87 *Keratella cochlearis*

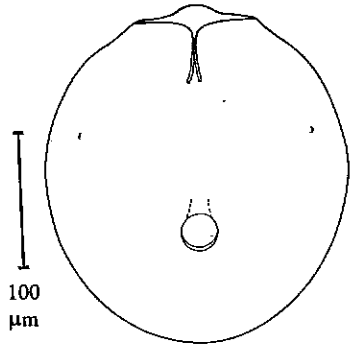


Fig. 88 *Testudinella patina*

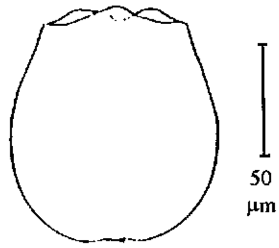


Fig. 89 *Pompholyx complanata*

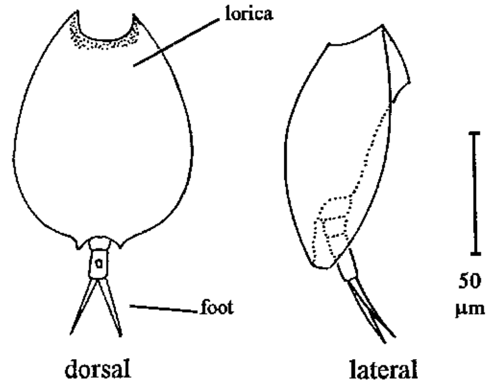


Fig. 90 *Lepadella patella*

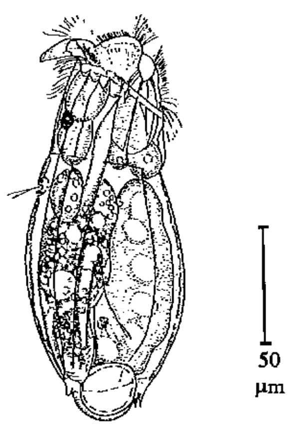


Fig. 91 *Ascomorphella volvocicola*

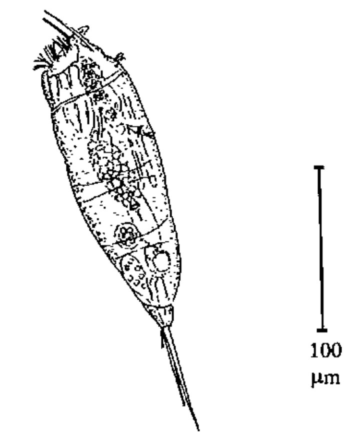


Fig. 92 *Trichocerca similis*

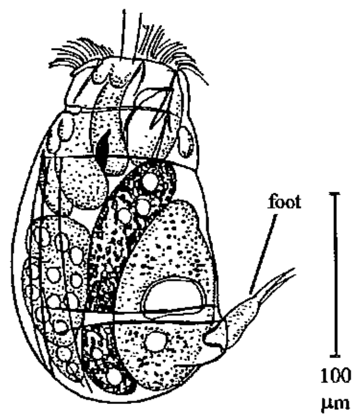


Fig. 93 *Gastropus hyptopus*

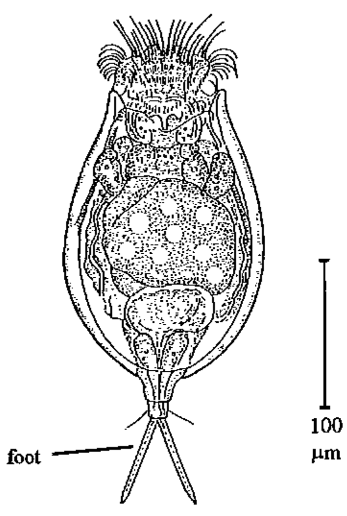


Fig. 94 *Euchlanis dilatata*

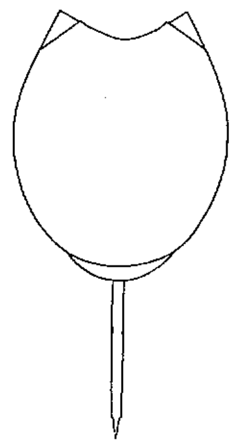


Fig. 95 *Lecane lunaris*

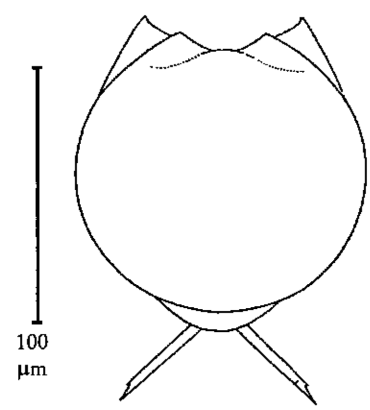


Fig. 96 *Lecane luna*

- Solitary or colonial; body short usually less than 1 mm long; colonies less than 3 mm in diameter (Plate 3a; Figs 74) .... **Conochilidae** (*Conochilus*)

10. Body laterally compressed (Figs. 75 & 76) 11

- Body cylindrical, discoid, shield-like or dorso-ventrally flattened (Figs 77-96) 12

11. Lorica bivalved, usually covering corona, with head and foot openings (Fig. 75) .... **Colurellidae** (*Colurella*)

- Lorica not bivalved, corona exposed (Fig. 76); rare in plankton .... **Mytilinidae** (*Mytilina*)

12. Body with a firm rigid lorica, usually with prominent spines; foot present or absent (Figs 77-87) 13

- Body lacking prominent spines, with or without a firm lorica; foot present (Figs 88-96) 15

13. Foot with a pair of heavy spines on dorsal side (Fig. 77); or lorica with numerous spines along lateral margins (Fig. 78) .... **Trichotriidae**

- Body usually with anterior and/or posterior spines, foot present or absent; common in plankton (Figs 79-87) .... **Brachionidae** 14

14. Foot present; dorsal lorica without facets; 2, 4 or 6 anterior spines, posterior spines absent, or 2, 4 or 6 when present (Plates 3b & 3c; Figs 79-83)... .... *Brachionus*

- Foot absent; dorsal lorica with facets, 6 anterior spines and 1, 2 or no posterior spines (Plates 3d & 3e; Figs 84-87) .... *Keratella*

15. Body a dorsoventrally-flattened disc (Plate 3f; Fig. 88) or a small sphere (Fig. 89); foot and toes reduced .... **Testudinellidae**

- Body otherwise, foot and toes obvious, usually extend past margin of lorica (Figs 90-96) 16

16. Corona, head and foot openings usually covered by lorica (Fig. 90); rare in plankton .... **Colurellidae** (*Lepadella*)

- Corona, head and foot openings not covered by lorica (Figs 91-96) 17

17. Body barrel-shaped to cylindrical, with a firm rigid lorica, often curved or twisted, tapers to a single toe or pair of short toes (Figs 91 & 92) .... **Trichocercidae**

- Body not cylindrical or barrel-shaped, not curved or twisted (Figs 93, 94, 95 & 96) 18

18. Body more or less laterally compressed, highly coloured; foot projects from ventral surface (Fig. 93) .... **Gastropodidae** (*Gastropus*)

- Body dorso-ventrally flattened, not highly coloured; foot projects from posterior end (Figs 94, 95 & 96) 19

19. Toes fully retractable (Fig. 94) .... **Euchlanidae** (*Euchlanis*)

- Toes non-retractable (Plate 3g; Figs 95 & 96) .... **Lecanidae** (*Lecane*)

DIGONONTA

Bdelloidea

Bdelloid rotifers are morphologically similar (Figs 97 and 98), with telescoping tubular or worm-like bodies and characteristic corona and teeth. However, bdelloid rotifers are poorly known, rarely studied and very difficult to identify. Shiel (1995) provides keys to the genera and species known from Australia. Bdelloid rotifers are predominantly epiphytic or epibenthic and are rarely seen in plankton samples, but some genera, such as *Rotaria* (Fig. 97) and *Habrotrocha* (Fig. 98) often occur in open waters (Koste and Shiel 1986).

Fig. 97 *Rotaria neptunia*

Fig. 98 *Habrotrocha* sp.

MONOGONONTA

Asplanchnidae

Asplanchnids are planktonic, transparent, sack-like rotifers which may reach a length of 2.5 mm, making them the largest rotifer in Australia and, because of this size, are easily distinguished from other rotifers. Being omnivorous or carnivorous, asplanchnids eat algae, protozoa, other rotifers and small microcrustaceans. The two known genera, *Asplanchnopus* (Plate 2i; Fig. 68) and *Asplanchna* (Plate 2h; Fig 69), are common in most standing waters such as aquaculture ponds.

[***Further reading:*** Shiel and Koste (1993); Shiel (1995)].

Brachionidae

Members of the family Brachionidae are probably the most often encountered planktonic rotifer species in aquaculture ponds. Most brachionids are pelagic and semi-planktonic, being bacteriovores and herbivores. Species of *Brachionus* are often cultured intensively for use as a live diet for newly hatched fish larvae (Lubzens 1987). *B. plicatilis*, a brackish water rotifer, is widely used as a food for marine fish larvae and techniques to culture this species are well known (Gatesoupe and Luquet 1981; Hoff and Snell 1987; Lubzens 1987; Talbot *et al.* 1990). The intensive culture of freshwater rotifers is less developed but techniques to mass culture several species, including *B. calyciflorus*, are being developed (Mitchell 1986; Rico-Martínez and Dodson 1992). Six genera containing 47 species are known to occur in Australia, but only two genera, *Brachionus* (Plates 3b & 3c; Figs 79-83) and *Keratella* (Plates 3d & 3e; Figs 84-87), are common and abundant in the plankton of aquaculture ponds. Other brachionid genera are rare and/or non planktonic.

[***Further reading:*** Koste and Shiel (1987); Shiel (1995)].

Conochilidae

The family Conochilidae contains a single genus, *Conochilus* (Plate 3a; Fig. 74), which is found in most inland waters. Some species form colonies which may contain up to several hundred individuals and be visible to the naked eye. The process of collecting plankton samples from aquaculture ponds may cause these colonies to break up. However, some species of *Conochilus*, notably *C. dossuarius*, do not form colonies. *C. unicornis*, which forms colonies containing fewer than 30 individuals, are common in ponds at the MAFRISC. Conochilids are detritivores, bacteriovores or herbivores

[***Further reading***: Shiel (1995)].

Filiniidae

This family is represented by one genus *Filinia* (Plate 2g; Figs 65 & 66), which is distinguished from other rotifers by possessing setae which are usually at least twice as long as the body. Filiniids are either bacteriovores or herbivores. Species of *Filinia* are common, and often very abundant in the plankton of standing waters, for example densities of *Filinia* have reached 1,500 ind./l in ponds at the MAFRISC.

[***Further reading:*** Shiel (1995)].

Synchaetidae

The family Synchaetidae contains three genera, with species of *Synchaeta* (Plate 2j; Fig. 71) and *Polyarthra* (Plate 2k; Fig. 72) being common in the plankton of aquaculture ponds. Synchaetids are more or less exclusively pelagic and at times they can occur in very high densities (> 25,000 ind./l) (Shiel *et al.* 1987). When disturbed, *Polyarthra* has a characteristic "flicking" or "jumping" motion which is achieved by flexing of the lateral serrated paddles. This behaviour assists in avoiding predation. Synchaetids are herbivores.

[***Further reading:*** Shiel and Koste (1993); Shiel (1995)].

Other common families

Of the five genera of **Epiphanidae**, only *Epiphanes* (Fig. 67) may be important seasonally in the plankton of aquaculture ponds. The larger *Epiphanes clavulata* (up to 520 μm) is sometimes confused with the superficially similar *Asplanchna* species. Other species of epiphanids are littoral in habit.

Of five recorded genera of **Euchlanidae**, only species of *Euchlanis*, particularly *E. dilatata* (Fig. 94), are found in plankton.

The **Flosculariidae** mostly contains species that are epiphytic or sessile. Only a few representatives of some genera are planktonic. For example the large and conspicuous colonies of *Lacinularia* (Plate 2l; Fig. 73), which have a diameter of up to 5.0 mm and may contain 300-1,000 individuals, are often encountered in aquaculture ponds.

Species belonging to the **Gastropodidae**, such as *Gastropus hyptopus* (Fig. 93), are small, fast, spherical rotifers which are perennial in the plankton of ponds. These rotifers are usually highly coloured due to incorporation of ingested algal cells into the stomach wall.

Species of *Hexarthra* (**Hexarthridae**) (Fig. 70) are often collected from the plankton of aquaculture ponds, sometimes in abundance. *H. intermedia* and *H. mira* are the two most common species in this family.

The **Lecanidae** contains species that are mostly epiphytic or epibenthic, and are common in shallow vegetated habitats. *Lecane lunaris* (Fig. 95) and *L. luna* (Fig. 96) are occasionally found in the plankton of aquaculture ponds (Plate 3g).

The family **Trichocercidae** contains 45 species in three genera, *Ascomorphella* (Fig. 91), *Elosa* and *Trichocerca* (Fig. 92). Some species occur in the plankton, but most are found in littoral and marginal habitats. *Ascomorphella volvocicola* (Fig. 91) is an obligate parasite of the green colonial planktonic algae *Volvox* and can become abundant during seasonal blooms of this alga.

[***Further reading:*** Order Bdelloidea, Koste and Shiel (1986), Shiel (1995); Order Ploimida, Koste and Shiel (1987), Shiel (1995); Families: Colurellidae, Koste and Shiel (1989b); Epiphanidae, Koste and Shiel (1987); Euchlanidae, Mytilinidae and Trichotriidae Koste and Shiel (1989a); Gastropodidae, Synchaetidae and Asplanchnidae Shiel and Koste (1993); Lecanidae, Koste and Shiel (1990a), Segers (1995); Proalidae and Lindiidae, Koste and Shiel (1990b); Notommatidae, Koste and Shiel (1991), Nogrady *et al.* (1995); Trichocercidae, Shiel and Koste (1992)].

MOLLUSCA (snails and mussels)

BIOLOGY, ECOLOGY AND IDENTIFICATION

The Mollusca is one of the largest phyla in the animal kingdom. There are six classes of molluscs occurring in the marine environment, but of these only the Gastropoda (snails and limpets) and the Bivalvia (mussels) inhabit freshwater environments. The main features that distinguish molluscs from other animals are the presence of a single or bivalved calcareous shell secreted by the animal, and a large muscular foot.

Herbivorous molluscs are important algal grazers and detritivorous species play a role in the break down of dead animal and vegetable matter. Molluscs are not a major part of the diet of native fish, nevertheless some species are eaten occasionally. The fry of Macquarie perch stocked into fry rearing ponds at the MAFRISC have, at times, eaten snails (*Physa acuta*) (Ingram *unpub. data*), and large numbers of mussel larvae (probably an estuarine species) have been found in the stomachs of silver perch larvae and fry being reared in ponds at the GRC (C. Mifsud *pers comm.*).

Smith and Kershaw (1979) have reviewed the identification, distribution and biology of non-marine molluscs of south eastern Australia, and Smith (1996) provides an identification guide to the genera of Australian freshwater bivalves and gastropods. These authors describe some 235 species, including eight introduced species, from 12 families of gastropods and three families of bivalves. The following key provides a guide to families with species known to occur in aquaculture ponds.

Key to common pond-inhabiting molluscs of south eastern Australia (modified from Smith and Kershaw 1979 and Smith 1996)

1. Shell of one valve (snails & limpets) (Figs 99, 101 & 102) .... **GASTROPODA**...2

- Shell of two valves joined by a hinge and ligament (mussels) (Figs 104, 105 & 106)........... .... **BIVALVIA**...6

2. Shell not coiled, limpet-like (Fig. 99) .... **Ancylidae** (*Ferrissia*)

- Shell with a coiled spire (Figs 101 & 102)..........3

3. Animal with a hard plate (operculum) (Fig. 100) attached to the foot which closes the aperture of the shell when the animal is withdrawn .... **Hydrobiidae**

- Animal without an operculum 4

4. Aperture on right hand side when viewed from below (Fig. 101).......**Lymnaeidae** (*Austropeplea*)

- Aperture on left hand side when viewed from below (Fig. 102)..5

5. Shell almost transparent, mottling of animal visible through shell (Plate 3h; Fig. 102); radula* split at the posterior end (Fig. 103a)....... .... **Physidae** (*Physa acuta*)

- Shell not transparent, animal not mottled and not visible through shell; radula* rectangular, not split posteriorly (Fig. 103b)............. **Planorbidae**

6. Valves large (> 40 mm), black to dark horny brown, umbos not central (Plate 3i; Fig. 104)...... .... **Hyriidae** (*Velesunio ambiguus*)

- Valves medium to small (< 30 mm), umbos central (Figs 105 & 106)...................................7

7 Valves medium (10-25 mm), thick, solid, with obvious concentric sculpture; valves usually brightly coloured inside and out (Plate 3j; Fig. 105).... **Corbiculidae** (*Corbiculina australis*)

- Valves small (< 10 mm), thin, fragile semi-transparent with weak sculpture; valves not brightly coloured (Fig. 106) .... **Sphaeriidae**

* The technique used to extract the radula from the animal is given below in the gastropod section

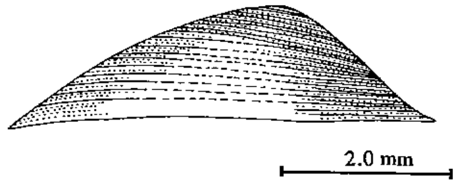


Fig. 99 *Ferrissia* sp.
(Ancylidae)

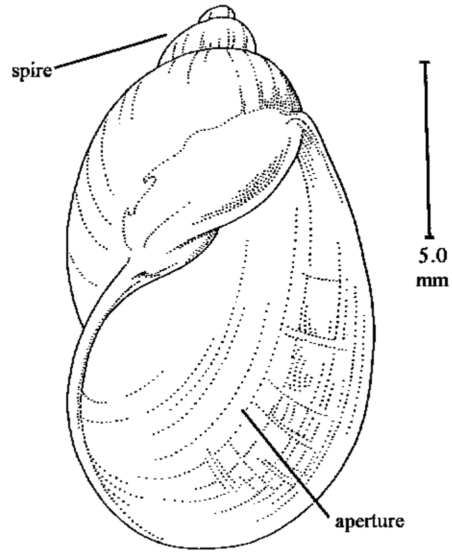


Fig. 101 *Austropeplea lessoni*
(Lymnaeidae)

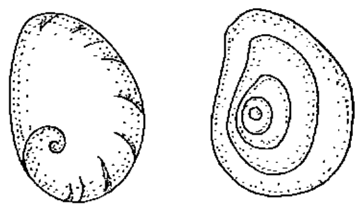
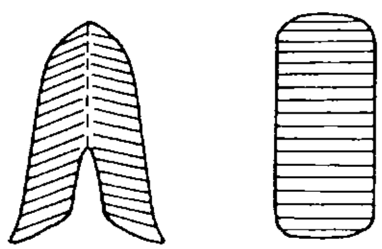


Fig. 100 Gastropod opercula



(a) Physidae
(*Physa acuta*)

(b) Planorbidae

Fig. 103 Mollusc radulas

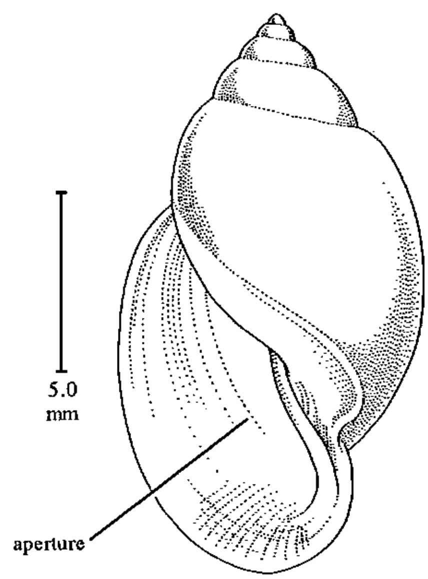


Fig. 102 *Physa acuta* (Physidae)

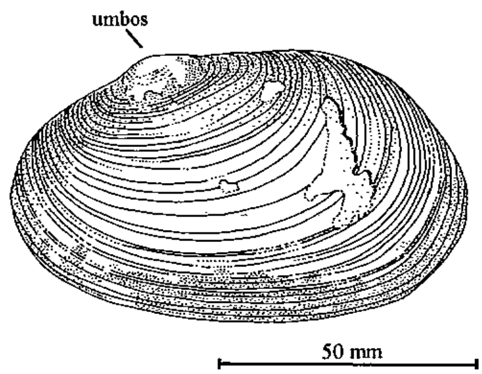


Fig. 104 *Velesunio ambiguus*
(Hyriidae)

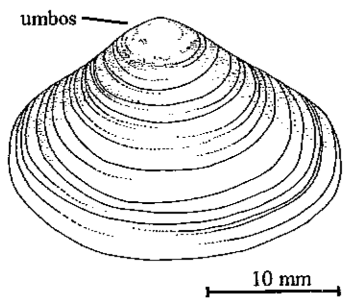


Fig. 105 *Corbiculina australis*
(Corbiculidae)

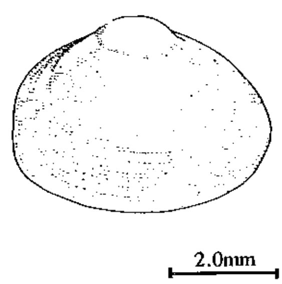


Fig. 106 *Sphaerium* sp.
(Sphaeriidae)

GASTROPODA (snails and limpets)

Gastropods possess a single shell that is either coiled or limpet-like. Many freshwater snails are dioecious, but some are hermaphrodites, having both male and female reproductive organs. Copulation takes place with the reciprocal exchange of sperm packets, and eggs are typically laid in characteristic gelatinous masses attached to the substrate (Smith and Kershaw 1979). Most gastropods are herbivores which feed on aquatic plants and algae, or detritivores which feed on dead plant and animal matter. Gastropods possess a unique feeding structure called a radula (Fig. 103), a belt of chitinous recurved teeth stretched over a cartilage base, which is used for grinding and rasping at food.

Gastropods are found in a wide range of aquatic habitats from fast flowing streams to billabongs, ponds and bogs. Many species only occur in habitats with particular aquatic plants or algal growths on which they feed.

The freshwater limpets (Ancylidae) are easily recognised by their shape (Fig. 99), however, because of their small size (up to 5 mm) and drab coloration, they are often overlooked. Two species of *Ferrissia* are recognised from south eastern Australia (Smith and Kershaw 1979).

Distinguishing the Planorbidae from the Physidae is difficult without examination of the radula. Smith and Kershaw (1979) and Smith (1996) describe a technique for preparing the radula for examination:

Radula preparation and examination

1. Cut off and boil the head and foot region in a 10% solution of caustic soda (dissolve 10 g sodium hydroxide in 100 ml of water) until the tissues disintegrate on shaking.
2. Allow to cool then transfer to a petri dish.
3. With the aid of a dissecting microscope locate the radula, a small, somewhat shiny, transparent structure.
4. Transfer the radula to a drop of water on a microscope slide then place a coverslip on the radula.
5. Examine with a compound microscope at a magnification of at least 30x.

The Planorbidae is one of the largest and most diverse families of freshwater snails in the world and dominates the gastropod fauna in many areas of Australia. *Physa acuta* (Physidae) (Plate 3h; Fig. 102), an introduced species, is by far the most abundant snail species in fry rearing ponds at the MAFRISC. Species of Lymnaeidae (Fig. 101) are usually found in association with aquatic plants and some species, especially *Austropeplea tomentosa*, are economically important as intermediate hosts for the sheep liver fluke, *Fasciola hepatica*. *A. lessoni* is common in vegetated aquaculture ponds and farm dams.

There are eight families of Australian freshwater gastropods with species that possess an operculum (Fig. 100) attached to the foot which closes the aperture of the shell when the animal is withdrawn. However, only species from the Hydrobiidae are likely to be found in stillwaters in south eastern Australia. The Hydrobiidae is a large complex family of freshwater snails which occur in a wide spectrum of habitats. The shells of most hydrobiids are small (3-12 mm in length), coiled and light to dark in colour. The family contains at least 115 species in Australia, but identification, even to genus, is difficult (Smith 1996).

[*Further reading:* Smith and Kershaw (1979); Williams (1980); Smith (1996)].

BIVALVIA (mussels)

Bivalves possess two valves or shells that are hinged together along their dorsal edge. Bivalves will inhabit most permanent or semi-permanent freshwater environments including aquaculture ponds and farm dams. Some are capable of surviving extended periods of drying out. Because many species of bivalve are sedentary and burrow into sand, silt and mud, a complex arrangement of gills generate a water current through the shells from which oxygen and food are obtained (Smith and Kershaw 1979). Bivalves are typically filter feeders and use their gills to entrap phytoplankton, zooplankton and organic detritus. With the exception of the Sphaeriidae, the sexes are separate (Williams 1980). The Hyriidae have a special larval stage called a glochidium which is temporarily parasitic on the gills of freshwater fish including golden perch and Macquarie perch (Hiscock 1951; Atkins 1979).

The most commonly encountered species in aquaculture ponds are the freshwater mussel *Velesunio ambiguus* (Hyriidae) (Plate 3i; Fig. 104) and two species belonging to the family Sphaeriidae (pea shells), such as *Sphaerium* (Fig. 106). Because *Corbiculina australis* (Corbiculidae) (Plate 3j; Fig. 105) requires swiftly flowing water, they are rarely recorded from ponds. However, they can become a pest in water reticulation systems where a build-up of numbers can lead to blockages in pipes and around valves.

[*Further reading:* Smith and Kershaw (1979); Williams (1980); Smith (1996)].

ANNELIDA
(segmented worms and leeches)

BIOLOGY, ECOLOGY AND IDENTIFICATION

The phylum Annelida encompasses the soft-bodied, "true" segmented worms, and is divided into three main classes, the Polychaeta (bristle worms), Oligochaeta (earthworms and aquatic worms), and Hirudinea (leeches). Polychaete worms are almost all marine, but species of *Stratiodrilus* have been found living in the gill chamber of certain freshwater crayfish. The Oligochaeta and Hirudinea found in both terrestrial or aquatic habitats.

Annelids are hermaphrodites, having both female and male sex organs, and usually reproduce by exchanging gametes. But asexual reproduction is known to occur in some species, such as *Lumbriculus variegatus* (Lumbriculidae) which can reproduce by fragmentation of the body (Pinder and Brinkhurst 1994).

Key to common pond-inhabiting annelids of south eastern Australia

1. Body with an anterior and posterior sucker; segments without bundles of setae (Plate 3k; Fig. 107)..**HIRUDINEA**

- Body without suckers; most segments each with 2-4 bundles of setae (Plate 3l; Fig. 108).............
....**OLIGOCHAETA**...2

2. Adults small (< 1 cm), body colourless (transparent or opaque)........................**Naididae**

- Adults elongate (≥ 1 cm), body usually coloured (red or brown)..3

3. Setae usually sigmoid and bifid, two per bundle (Fig. 109)..
...........**Lumbriculidae** (*Lumbriculus variegatus*)

- Setae of various forms, more than 2 per bundle (Figs 108 & 110).............................**Tubificidae**

HIRUDINEA (leeches)

The Hirudinea (leeches) are easily distinguished from other annelids by the presence of anterior and posterior suckers, the lack of setae, and a distinctive peristaltic crawling action. Both aquatic (freshwater and marine) and terrestrial species of leeches occur. Unlike oligochaetes, aquatic leeches have a muscular body, and some species can swim through the water with a serpentine swimming action. Not all species feed on warm-blooded vertebrates (birds and mammals). Some aquatic leeches may also suck the blood of fish, frogs and turtles (Richardson 1968) and some are carnivorous, such as species of Glossiphoniidae (Plate 3k; Fig. 107) which commonly prey on small gastropods. Glossiphoniid leeches are collected regularly from aquaculture ponds and can be readily recognised by their habit of carrying their eggs attached to the ventral side of the body.

[*Further reading:* Richardson (1968); Williams (1980)].

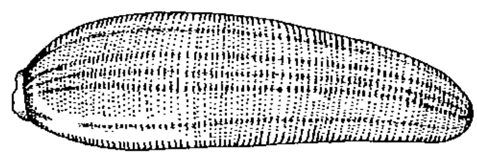


Fig. 107 *Glossiphonia* sp. (Hirudinea)

OLIGOCHAETA (segmented worms)

Aquatic oligochaetes are typically segmented animals with soft, often thin-walled and fragile bodies. The number of body segments varies from fewer than 10 to several hundred segments. Each segment, with the exception of a few of the most anterior ones, bear four bundles (2 dorso-laterally and 2 ventro-laterally) of chitinous bristles or setae (Fig. 109, 110). Each bundle may contain from two to 20 setae which are thought to assist in locomotion by increasing traction on the surrounding substrate. The shape, number and distribution of these setae are used to identify many of the species. Aquatic oligochaetes range in size from less than 0.5 mm to over 100 mm long. Most oligochaetes are detritivores which feed on fine organic matter and bacteria, but some species of the Naididae are carnivorous.

Over 90 species have been recorded from Australia (Pinder and Brinkhurst 1994). Some species are noted for their tolerance to waters with a high organic load, and it is these species that are most often found living in the substrate of aquaculture ponds. At times oligochaetes can become the most abundant benthic macroinvertebrate in aquaculture ponds (Stirling and Wahab 1990). Densities of oligochaetes in rearing ponds at the MAFRISC are usually 200-5,000 ind./m^2, but have reached 22,000 ind./m^2. Despite these large numbers, oligochaetes are rarely eaten by fish reared in these ponds. Stirling and Wahab (1990) suggested that the burrowing habit of oligochaetes in sediments may limit their dietary importance to fish. Yet some species, such as *Lumbriculus variegatus* and *Tubifex tubifex* are widely cultured as a food for aquaculture and aquarium fish (eg. Bouguenec 1992; Mason 1994).

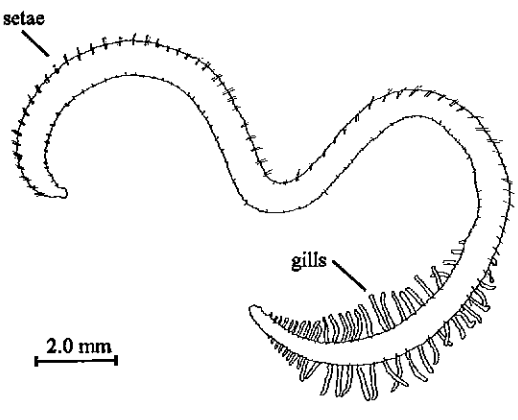


Fig. 108 *Branchiura sowerbyi* (Tubificidae)

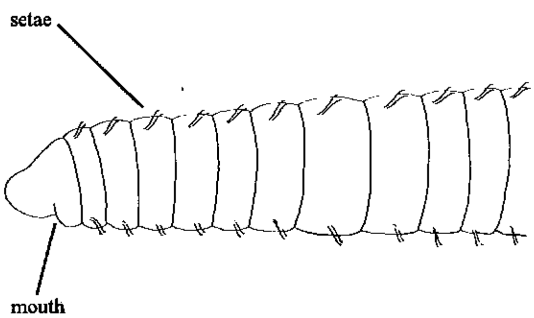


Fig. 109 Anterior end of *Lumbriculus variegatus* (Lumbriculidae)

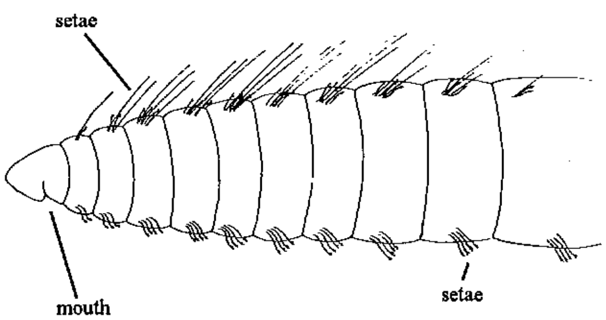


Fig. 110 Anterior segments of Tubificidae

Lumbriculus variegatus (black worm) (Fig. 109) is probably the most common species in aquaculture ponds. These long (up to 100 mm), slender worms, are dark red to black in colour. Several species of tubifid, naidid and enchytraeid worms also are collected from aquaculture ponds (see Appendix I). *Branchiura sowerbyi* is readily identified by the gills on each of the segments of the posterior third of the body (Plate 31; Fig. 108). Pinder and Brinkhurst (1994) provide keys to the species of Australian aquatic oligochaetes.

[*Further reading:* Williams (1980); Brinkhurst and Jamieson (1971); Pinder and Brinkhurst (1994)].

ARACHNIDA
(water spiders and water mites)

The Arachnida contains the spiders, scorpions, mites and ticks. Most are terrestrial, but some spiders and mites have adapted to an aquatic existence. Arachnids are characterised by having four pairs of legs, no antennae, and two pairs of appendages on the head called the chelicera and pedipalps. Spiders (Araneae) have a body which is separated into a head, thorax and abdomen whereas the mites (Acarina) have a single, often globular, body mass.

ARANEAE (water spiders)

The only spiders that can be classed as being at least semi-aquatic are the fisher spiders which includes several species of *Dolomedes* and *Megadolomedes australianus* (Pisauridae). These spiders can completely submerse themselves in water, particularly when disturbed, for long periods of time by relying on oxygen in the air trapped between the many fine hairs that cover the body. Fisher spiders, also called nursery web spiders, are widespread and mainly feed on aquatic insects, but will occasionally attack crayfish, tadpoles and, as the name implies, small fish. McKeown (1963) gives several descriptive accounts of these spiders capturing fish, including one that captured a goldfish 65-75 mm long. However, since these spiders are generally found in low densities around ponds, they are not considered to be a significant predator of small fish.

Some species of wolf spider (Lycosidae) and some web-weaving spiders (eg. *Tetragnatha* and *Argiope*) can be found near water bodies or amongst marginal vegetation.

[*Further reading:* Barr and Huner (1977); Davies (1986)].

ACARINA (water mites)

Aquatic mites generally belong to the Hydracarina (water mites). These mites have a globular body which is 0.5-10 mm long and coloured in shades of red, green and blue (Fig. 111). The legs are often fringed with long setae or hairs which aid in swimming. Non-swimming species which crawl over the substrate lack these setal fringes. Water mites are most abundant in shallow vegetated areas of standing waters, but will also occur in flowing waters.

Water mites have a complex and variable lifecycle, which typically includes parasitic larvae and free-swimming nymphs and adults. After hatching, the larvae attach to a host, usually an aquatic insect. Attachment to flying insects aids in their dispersal to other water bodies. After feeding on the body juices of their host, the larvae drop off and undergo metamorphosis to a free-living nymph which, in turn, metamorphoses into the adult stage. Both the nymphs and adults are predators which feed primarily on small aquatic insects and crustaceans, and it is these two life stages that are most often collected in the water of aquaculture ponds.

Water mites may occasionally be eaten by fish, but red-coloured species are known to be distasteful to fish (Kerfoot 1982). Species of *Eylais* (Eylaidae) (Plate 4a) and *Piona* (Pionidae) have been collected from ponds at the MAFRISC, but other widespread species expected to occur in aquaculture ponds include species of *Hydrachna* (Hydrachnidae) (Fig. 111), *Limnochares* (Limnocharidae), *Hydrodroma* (Hydrodromidae) and *Australiobates* (Hygrobatidae). Identification of water mites can be difficult but Cook (1974, 1986) and Harvey (1989) provide keys and descriptions of the Australian species.

[*Further reading:* Williams (1980); Smith and Cook (1991)].

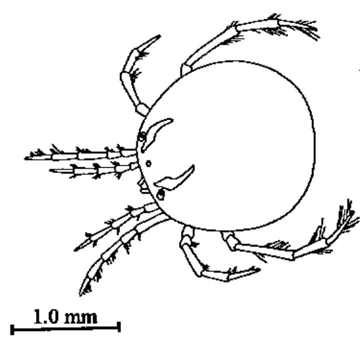


Fig. 111 *Hydrachna* (Hydracarina)

CRUSTACEA

BIOLOGY, ECOLOGY AND IDENTIFICATION

Representatives of the subphylum Crustacea have highly variable morphology. Crustaceans typically have a hard, rigid exoskeleton composed of chitin, and which is calcified in large species (decapods), two pairs of antennae (antennae and antennules) and 16-60 body segments (divided into the head, thorax and abdomen). Attached to these body segments are various segmented appendages used for feeding (mandibles and maxillae), walking (legs or pereiopods), grasping (claws or chelipeds) and swimming (pleopods). The thoracic segments usually are covered by a carapace, a shield-like extension of the exoskeleton, but in some groups, such as the Branchiopoda (Cladocera), Ostracoda and Conchostraca, most or all of the body may be covered by the carapace. Gills may be present or absent. With the exception of the antennae, most appendages are divided into two branches (biramous). Generally crustaceans are aquatic or associated with damp environments.

The most common crustaceans found in aquaculture ponds and farm dams are the *micro*crustaceans (< 6 mm long), particularly the Copepoda (Calanoida and Cyclopoida) (Figs 117, 144 & 145), Cladocera (Figs 114 & 121-141) and Ostracoda (Figs 115 & 155). Larger crustaceans which occur in aquaculture ponds and farm dams include the Anostraca (Fig. 112), Conchostraca (Fig. 116), Notostraca (Fig. 113) and Decapoda (Figs 118, 157, 161, & 163).

Lifecycle

Most crustaceans have separate sexes and reproduce sexually, but some groups contain hermaphrodites, and reproduction without the aid of males (parthenogenesis) occurs in some groups. Eggs are either held within a brood chamber (eg. cladocerans), attached to certain body appendages (eg. the swimming legs of yabbies, prawns and shrimp), or retained in an external sac (ovisac) formed when the eggs are expelled (eg. copepods). The first larval stage is called a nauplius (Plate 5b) which is planktonic. In the cladocerans and decapods the nauplius stages occur in the egg before hatching. Various other larval stages, such as neonates, copepodites or post-larvae, may also occur before the final adult form is reached. Usually each developmental stage involves the addition of body segments and appendages.

Growth in crustaceans is achieved by periodic shedding of the rigid exoskeleton through a process called moulting or ecdysis. As the old exoskeleton is out-grown a new soft skeleton forms underneath. Immediately after the old exoskeleton is shed, the body is rapidly expanded (by taking in water to allow for future growth) before the new exoskeleton hardens. This process may take just a few minutes to several hours. Some species may then consume the old exoskeleton for the calcium it contains. The rate of moulting and growth is dependent on factors such as temperature, food availability, population density and other environmental conditions.

Ecology

Crustaceans occupy a wide range of habitats. Some are only found in permanent waters (eg. some decapods) while others thrive in temporary ponds (eg. notostracans and cladocerans). Some species are benthic and may even burrow into the substrate while others are planktonic. Most crustaceans are free-living, but the Branchiurans (fish lice) and some copepods are parasites on the bodies of other animals.

Crustaceans occupy many levels of the trophic web. Suspension feeding is common amongst smaller crustaceans and involves the filtering of food (bacteria, protozoans, algae or small animals) from the water column using the fine setae or hairs on certain appendages. Other species may either be detritivores, omnivores, predators or scavengers.

Crustaceans are an important part of the diet of many species of fish. Planktonic crustaceans, primarily cladocerans and copepods, are an important component in the food of fish larvae and fry reared in fertilised aquaculture ponds (Arumugam and Geddes 1987; Rowland 1992; Barlow *et al.* 1993). Larger crustaceans such as yabbies, shrimps and crayfish are eaten by larger fish.

[*Further reading:* Williams (1980); Thorp and Covich (1991)]

Identification

The following key to crustaceans of freshwater aquaculture ponds is based on keys and descriptions given by Bayly *et al.* (1967), Williams (1980), Pennak (1989), and Thorp and Covich (1991).

Key to the freshwater pond-inhabiting crustaceans of south eastern Australia

1. Animals with no carapace, and stalked eyes; extremely delicate forms of moderate size; swim upside down (fairy shrimp) (Plate 4b; Fig. 112)... .... **Anostraca**

- Not with the above combination of characters.....2

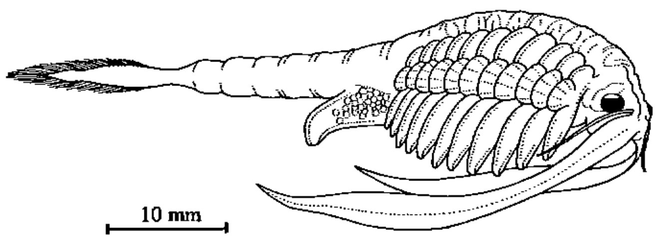


Fig. 112 *Branchinella* sp. (Anostraca)

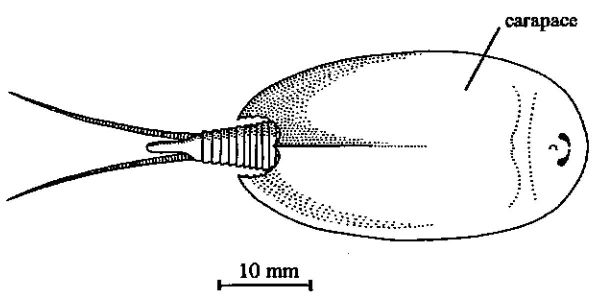


Fig. 113 *Lepidurus apus viridis* (Notostraca)

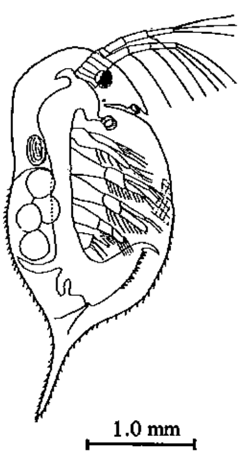


Fig 114 *Daphnia carinata* Branchiopoda (Cladocera)

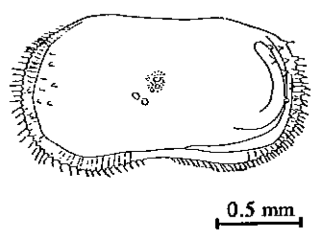


Fig. 115 Ostracoda

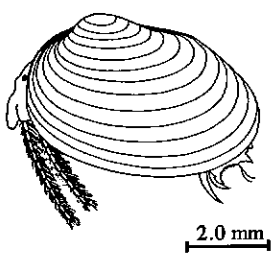


Fig. 116 *Cyzicus* sp. (Conchostraca)

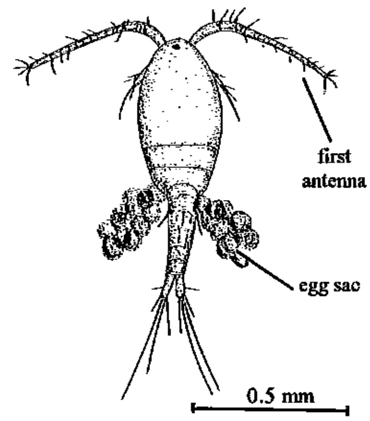


Fig. 117 *Eucyclops* sp. (Copepoda)

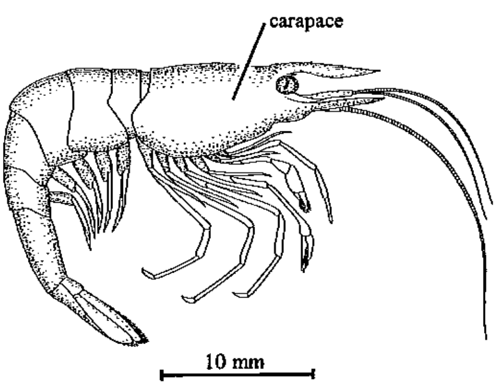


Fig. 118 *Paratya australiensis* (Decapoda)

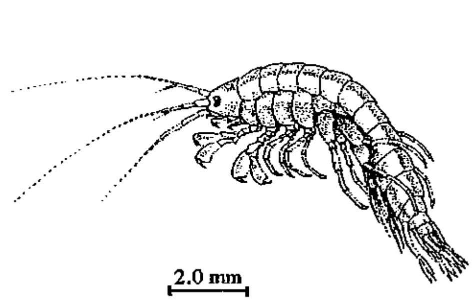


Fig. 119 Amphipoda

2. Animal with enlarged dorsal, shield-shaped carapace (tadpole shrimp) (Plate 4c; Fig. 113) .... **Notostraca**

- Animals without enlarged dorsal, shield-shaped carapace (Figs 114-116) 3

3. Animals wholly or nearly always enclosed in a bivalved carapace (Figs 114, 115 & 116) 4

- Animals not enclosed in a bivalved carapace (Figs 117, 118 & 119) 6

4. Bivalved carapace enclosing thorax (trunk) and its appendages, but not head (water-fleas) (Plates 4d-k; Fig. 114) ....**Branchiopoda (Cladocera)**

- Animal nearly always completely enclosed in bivalved carapace (Figs 115 & 116) 5

5. Animals with never more than three pairs of thoracic (trunk) appendages, carapace surface smooth, setose, pitted or sculptured, but never with growth lines; small in size (mostly < 2.0 mm) (seed shrimp) (Plate 5c; Fig. 115) .... **Ostracoda**

- Animals with several to numerous (10-30) thoracic appendages; carapace surface with or without growth lines; small to moderately large in size (mostly > 2.0 mm) (clam shrimp) (Plate 5d; Fig. 116) .... **Conchostraca**

6. Microscopic to small pear-shaped to cylindrical animals, without a carapace; well-developed first antennae (Plate 5a; Fig. 117) .... **Copepoda**

- Not with the above combination of characters..... 7

7. Body with a carapace covering dorsal and lateral sides of the thorax (yabbies, shrimp and prawns) (Plates 5e-g; Fig. 118) .... **Decapoda**

- Body without a carapace covering the dorsal and lateral sides of the thorax (scuds) (Fig. 119) .... **Amphipoda**

ANOSTRACA (fairy shrimp)

The fairy shrimps are soft, delicate, primitive crustaceans (10-50 mm long) (Plate 4b; Fig. 112). They are recognised by the lack of a carapace, presence of leaf-like appendages (usually 11) and the unusual action of swimming upside-down. The second antennae of the males are enlarged and used to grasp the female during copulation. Species of *Branchinella* (Fig. 112) are the only fairy shrimp to occur in freshwater aquaculture ponds. The remaining two genera known in Australia, *Artemia* and *Parartemia*, are found only in saline waters such as salt lakes.

Anostracans are generally planktonic and are non-selective filter-feeders which use their thoracic legs to filter microscopic organisms from the water. Under ideal conditions, such as may occur in freshly flooded areas, *Branchinella* can quickly develop dense populations from resting eggs. Large nuisance blooms of *Branchinella* (along with blooms of the conchostracan *Cyzicus*) have developed in fry rearing ponds at the NFC. These blooms dominate the plankton and appear to limit production of other, more desired, species of zooplankton. Their large size also prevents them from being eaten by the smaller fry which are stocked into these ponds (Thurstan 1995).

The Anostraca also includes the cosmopolitan brine shrimps (mostly *Artemia franciscana*) which occur in habitats where salinities are very high (> 50 ppt), such as salt lakes. The newly hatched nauplii of brine shrimp are widely cultured as food for fish larvae and fry in hatcheries around the world, and culture techniques are well established (Persoone *et al.* 1980; Sorgeloos *et al.* 1986). Briefly, the resting eggs (cysts) of brine shrimp, which are resistant to desiccation, are harvested from salt lakes, cleaned and canned for distribution to fish farms. Hatching of the cysts usually involves several steps. The shell of the cysts is first removed by soaking in a hypochlorite solution, a process called decapsulation. The decapsulated cysts are then incubated under continuous illumination in aerated water which has a salinity of 10 ppt and a temperature of 27-30°C. Under these conditions hatching occurs in about 24 hours.

Geddes (1981) provides a key to the Australian genera of Anostraca as well as the species of *Branchinella*.

[*Further reading:* Bayly *et al.* (1967); Williams (1980); Geddes (1981); Dodson and Frey (1991)].

NOTOSTRACA
(tadpole shrimp or shield shrimp)

Tadpole shrimps are primitive animals with a large dorsal shield and sessile eyes (Plate 4c; Fig. 113). The body consists of a variable and large number of segments and legs (35-71). Tadpole shrimps creep or burrow superficially in soft substrates, feeding on algae, bacteria, protozoans, rotifers and plant matter. They are generally associated with standing water bodies which periodically dry up, which suggests that the eggs require a period of desiccation before development.

[*Further reading:* Bayly *et al.* (1967); Williams (1980); Dodson and Frey (1991)]

BRANCHIOPODA (CLADOCERA)

Biology, ecology and identification

The Class Branchiopoda contains a group of small crustaceans which are commonly known as cladocerans (water fleas), a name with no taxonomic significance. Cladocerans are characterised by having a carapace that encloses the body while leaving the head exposed, unlike ostracods and conchostracans in which the head is enclosed by the carapace. Beneath the carapace are 4 to 6 pairs of legs. The head has a single large black compound eye and bears two pairs of antennae. The first pair of antennae, called antennules, are small and sensory in nature (Dodson and Frey 1991). The second pair of antennae are large, segmented and branched, and are primarily used for locomotion. The term "water fleas" is derived from the characteristic "jerky" swimming action produced by the antennae. Cladocerans range in size from < 250 µm, such as in the chydorid genus *Alonella*, to 4-6 mm as in the daphniid genera *Daphnia* and *Simocephalus*.

To date, some 165 species of Cladocera representing 53 genera have been recorded from Australia (Shiel and Dickson 1995). Most species are littoral or epiphytic/epibenthic and rarely collected in open water. Generally, the planktonic cladocerans are dominated by four families: Bosminidae, Daphniidae, Moinidae and Sididae, although some taxa from other families may also venture into open water.

The lifecycle of cladocerans is complex (Fig. 120). Usually female cladocerans reproduce asexually without the aid of males, which is termed parthenogenesis (Dodson and Frey 1991). For this reason, most cladocerans in the community are females. The eggs are incubated in the brood chamber, the space between the body and the carapace (Plates 4j & 4k; Fig. 122). After the eggs have developed into neonates, which resemble miniature versions of the adult, they are released from the brood chamber into the water. A new clutch of eggs is produced after each moult, and some species of *Daphnia* may brood up to 300 eggs at a time (Hebert 1978).

However, following specific environmental stimuli, the sexual phase of the lifecycle is initiated and the females begin producing mixed clutches of males and females. Eggs that are subsequently fertilised by these males develop into resting eggs which are protected from the elements by being enclosed in a specially thickened and often pigmented section of the carapace, called the ephippium. These ephippial eggs are resistant to drying, freezing, and even the digestive enzymes of animals that may consume them (Hebert 1978). When the female moults, the ephippium is released. Ephippial eggs may lie dormant for years, during which they can be dispersed far and wide by the wind or carried on the fur and feathers of animals (Dodson and Frey 1991). Therefore, the ephippial eggs play an important role in colonising new habitats.

Conditions that induce the production of males, and eventually ephippial eggs, are usually associated with a deterioration of environmental conditions, such as declining food concentration, over-crowding, and change in the day length and temperature (Dodson and Frey 1991).

An external stimulus is required for the resting eggs to recommence development and eventually to hatch. This stimulus may be the presence of water, changes in day length, temperature or oxygen pressure (Schwartz and Hebert 1987).

Cladocerans occupy an important place in aquatic communities. They are important grazers of algae and bacteria, and also major prey items for many species of invertebrates and vertebrates.

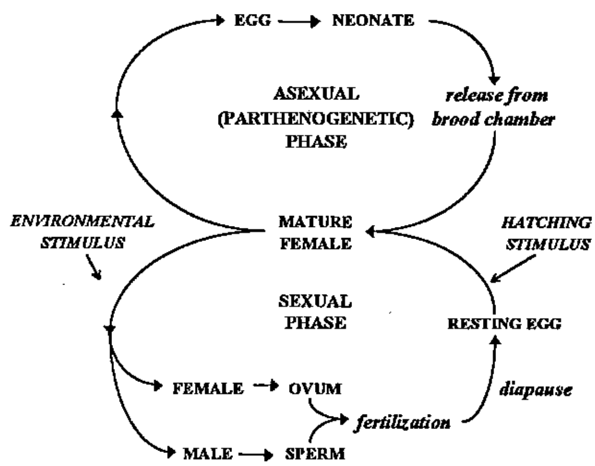


Fig. 120 The lifecycle of a cladoceran

Cladocerans in Australia are bacterivorous, herbivorous or detritivorous, and are suspension feeders. The beating of the body legs creates currents which draw food particles into the body cavity where they are caught by fine combs of setae on the thoracic legs and passed to the mouth. Probably the most important component in their diet is small algae, but bacteria, protozoans and other small zooplanktonic animals such as rotifers may also be eaten. Some species, particularly chydorids, may feed directly on detritus in bottom sediments.

Studies conducted at the MAFRISC have shown that the cladocerans *Moina* and *Daphnia* are consumed in large numbers by the fry of trout cod, Murray cod, Macquarie perch and golden perch reared in fertilised fry rearing ponds. In some cases the stomach may contain only these species. These two genera are major food items for Murray cod and golden perch fry at other locations (Arumugam and Geddes 1987; Rowland 1992) and for barramundi fry (Barlow *et al.* 1993).

Some planktonic cladocerans exhibit variations in the form of the body (cyclomorphosis), particularly enlarged head shields (helmets) and/or elongated tail spines. Cyclomorphosis has been observed in species of *Daphnia* and *Bosmina*. These changes may be associated with seasonal changes (temperature), food supply and water turbulence, and are a mechanism for avoiding predation by large invertebrates and fish (Mitchell 1978; Grant and Bayly 1981; Tollrian 1994). Cladocerans with enlarged heads and long tail spines are presumably more difficult to ingest than smaller animals.

Occasionally the body of cladocerans can become encrusted with epizoic ciliated protozoans belonging to the Peritrichida, which can reduce swimming and feeding efficiency. This occurs particularly when moulting has not occurred for some time and when environmental conditions favour the growth of peritrichs.

Cladocerans, particularly species of *Bosmina, Ceriodaphnia, Daphnia* and *Moina*, are often quite abundant in aquaculture ponds. In fry rearing ponds at the MAFRISC, densities are commonly between 100 and 500 ind./l, but have reached 1,300 ind./l. These blooms are dominated by *Moina micrura* and *Daphnia carinata*, the two most common cladoceran species recorded from these ponds. *Bosmina* has reached densities of 1,396 ind./l in hatchery ponds in the USA (Culver *et al.* 1984).

Planktonic cladocerans are capable of hundred-fold variations in population size, with peaks generally occurring during algal blooms (Dodson and Frey 1991). The ability of cladocerans to develop populations rapidly is a result of asexual reproduction because all offspring are usually females capable of reproducing. Cladocerans reach maturity and are capable of reproducing in about 7 days (at 20°C), but usually require about 14-15 days to reach their optimum reproductive capacity (Allan 1976). The life-span of copepods is about 50 days.

Some species of cladoceran are cultured intensively for use as a live food fish. In particular, techniques have been developed to mass culture *Moina* (Ventura and Enderez 1980) and *Daphnia* (De Pauw *et al.* 1981; Hoff and Snell 1987; Pierce 1988).

The taxonomy of Australian cladocerans is still poorly known for several groups, while in others it is often confusing. Shiel (1995) provides keys to some genera and species. The revision of the Australian cladocerans, which includes keys to species of most genera, by Smirnov and Timms (1983) should be used with caution because in some places it is inaccurate, and many new species have been described since its publication. To identify species other than the common taxa given in the key below, refer to the references cited with each family. A checklist of cladoceran species known to occur in aquaculture ponds and farm dams is provided in Appendix I.

[***Further reading:*** Dodson and Frey (1991); Smirnov (1992); Shiel (1995); Shiel and Dickson (1995)].

Key to the families of pond-inhabiting cladocerans of south eastern Australia

1. Acute angle or prominent tail spine at the postereoventral corner of carapace (Figs 121, 122 & 123)............ 2

\- Postereoventral corner of carapace rounded, without a tail spine (Figs 124-129)............ 3

2. Small hemispherical animals (usually < 0.5 mm); 1st antennae (antennules) long, fused to head to form long elephant like tusk (Plate 4d; Fig. 121)............ **Bosminidae**

\- Large animals (usually > 0.5 mm); 1st antennae short, not fused to head; head with or without a distinct rostrum (Plate 4h-j; Figs 122 & 123)............ **Daphniidae** (in part)

3. Small hemispherical animals (usually < 0.5 mm); 1st antennae short, partly or completely hidden by rostrum; gut looped; ephippium contains on eggs (Plates 4e & 4f; Fig. 124)............ **Chydoridae**

\- Large animals (usually > 0.5 mm); gut not looped, 1st antennae short or long; ephippium contains one or two eggs (Figs 125-129)............ 4

4. Head with a distinct rostrum present; 1st antennae short (Plate 4k; Fig. 125)............ **Daphniidae** (in part)

\- Head without an obvious rostrum; 1st antennae long (Figs 126, 127, 128 & 129)............ 5

5. Base of 2nd antennae enlarged; 1st antennae feathery; long setae present on posterior margin of carapace (Fig. 126)............ **Sididae**

\- Base of 2nd antennae not enlarged; 1st antennae not feathery; posterior margin of carapace without long setae (Fig. 127, 128 & 129)............ 6

6. 1st antennae 2-segmented; postabdomen characteristically wide (Fig. 127); rare in plankton............ **Ilyocryptidae**

\- 1st antennae 1-segmented (Figs 128 & 129); postabdomen usually straight or convex............ 7

7. 1st antennae situated on anterior side of head usually forward of the eye; 1st antennae broad distally; postabdomen without basal spine(s) just behind claw (Fig. 128); rare in plankton............ **Macrothricidae**

\- 1st antennae situated on posterior side of head, behind eye; 1st antennae not broad distally; postabdomen with bifurcate tooth or pronounced spines (Plate 4g; Fig. 129)............ **Moinidae**

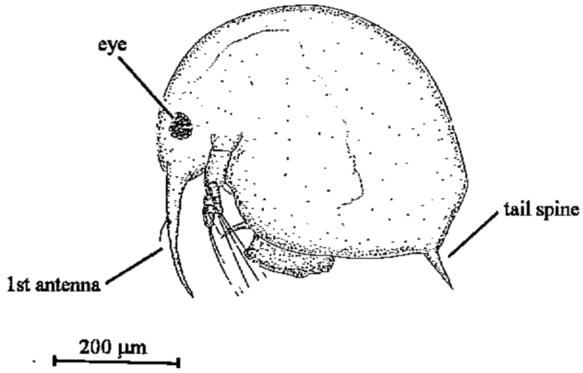


Fig. 121 *Bosmina meridionalis* (Bosminidae)

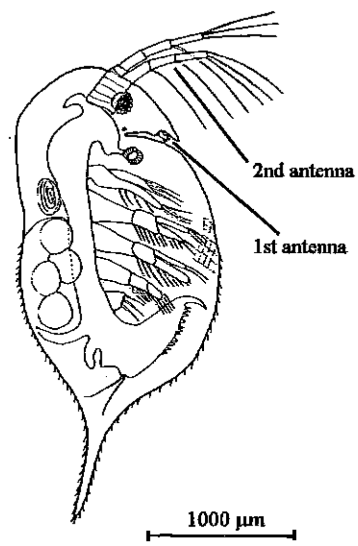


Fig. 122 *Daphnia carinata* (Daphniidae)

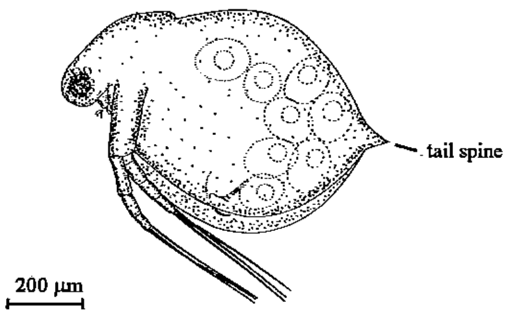


Fig. 123 *Ceriodaphnia* sp. (Daphniidae)

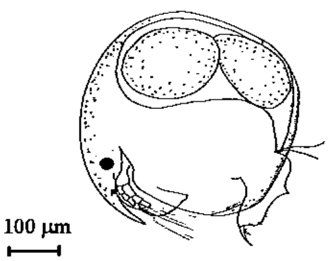


Fig. 124 *Chydorus sphaericus* (Chydoridae)

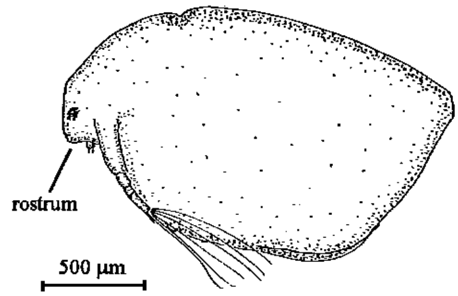


Fig. 125 *Simocephalus* sp. (Daphniidae)

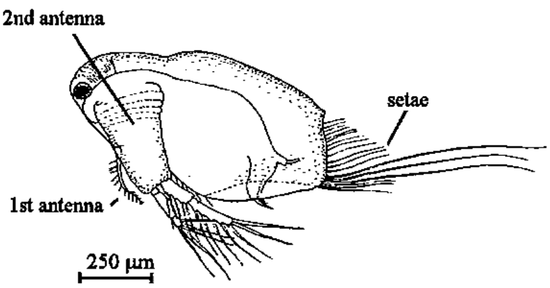


Fig. 126 *Latonopsis australis* (Sididae)

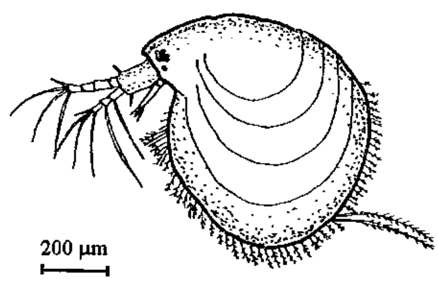


Fig. 127 *Ilyocryptus "sordidus"* (Ilyocryptidae)

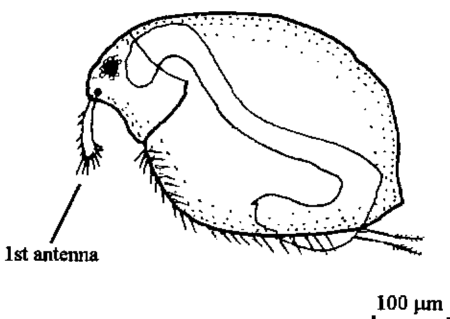


Fig. 128 *Macrothrix* sp. (Macrothricidae)

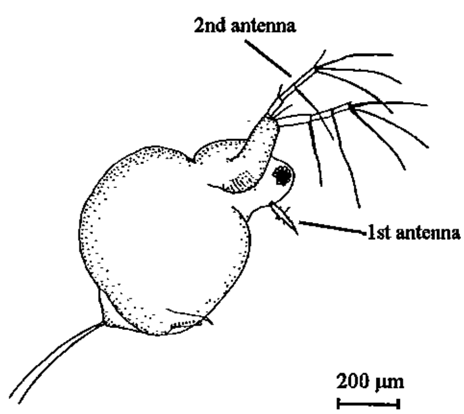


Fig. 129 *Moina micrura* (Moinidae)

Chydoridae

The Chydoridae is a large family of small cladocerans (mostly < 0.5 mm in length) which occurs predominantly in benthic or vegetated habitats. However, adaptive radiation appears to have occurred in Australia, and there are some species which occur frequently in the plankton of ponds. This family contains at least 100 species in 29 genera, but their taxonomy is poorly known, and Smirnov and Timms (1983) lacks a comprehensive treatment. The following key is a guide to the more common genera that occur in aquaculture ponds only. However, for species that cannot be keyed out here, a preliminary key to the known genera, and known species of *Chydorus*, are provided by Shiel (1995).

Key to common pond-inhabiting chydorid genera of south eastern Australia

1. Postabdominal claw with two basal spines; body spherical (Plate 4e; Fig. 130) .... **Chydorinae** (*Chydorus*)

\- Postabdominal claw with one basal spine; body more elongate than spherical (Figs 131-135)........ ....**Aloninae**...2

2. Body strongly compressed laterally, carapace with a dorsal keel; postabdomen very long and narrow (Fig. 131) .... *Camptocercus*

\- Body not strongly compressed, carapace without dorsal keel (Figs 132-135)................................ 3

3. In dorsal view, rostrum very broad, shovel-like, wider than body; ventral margin of carapace straight (Fig. 132) .... *Graptoleberis*

\- Rostrum not broad (Figs 133, 134 & 135).......... 4

4. Postabdomen enlarged and broadly curved, with long lateral spine-like setae; ocellus larger than compound eye (Plate 4f; Fig. 133) ....*Leydigia*

\- Postabdomen and ocellus otherwise (Figs 134 & 135) ....*Biapertura* and *Alona*

[***Further reading:*** Williams (1980); Smirnov and Timms (1983); Dodson and Frey (1991); Shiel (1995)].

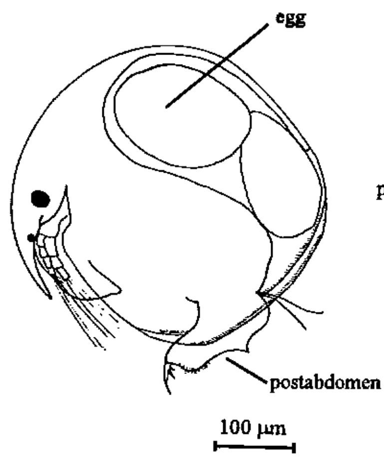


Fig. 130 *Chydorus sphaericus*

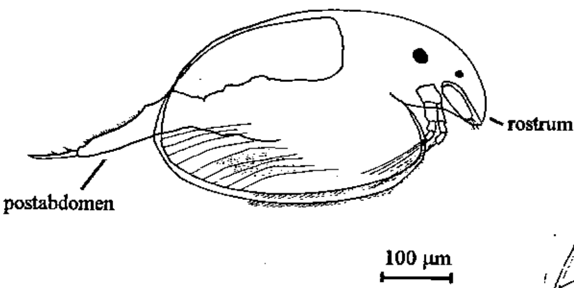


Fig. 131 *Camptocercus australis*

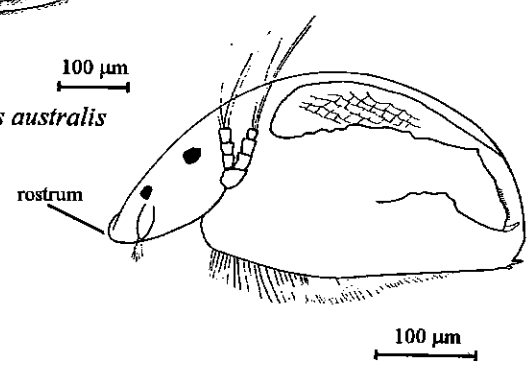


Fig. 132 *Graptoleberis testudinaria*

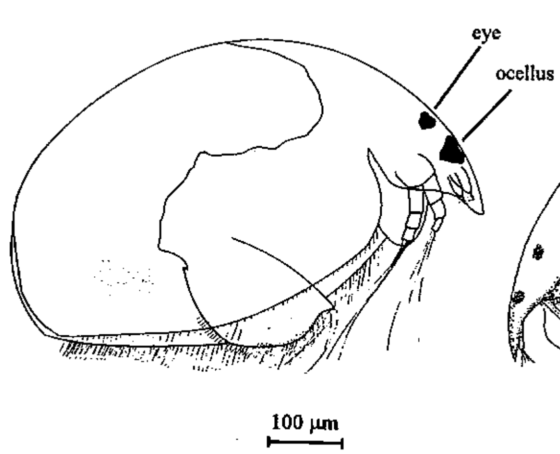


Fig. 133 *Leydigia leydigi*

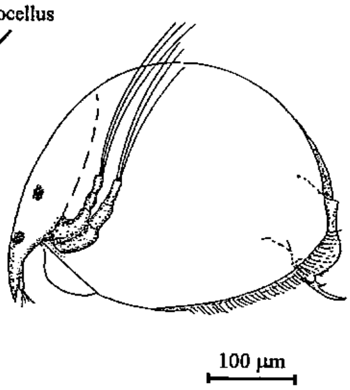


Fig. 134 *Biapertura rigidicaudis*

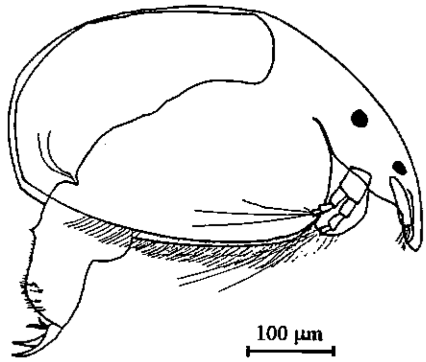


Fig. 135 *Alona macracantha*

Daphniidae

Species of Daphniidae are often common and widespread in the plankton and littoral region of ponds, lakes and reservoirs. Daphniids include the most familiar of the "water fleas" - species of the genus *Daphnia*, which are usually the largest microcrustaceans in the plankton. Daphniids are significant grazers of bacteria and phytoplankton, and are, in turn, important food items for both juvenile and adult fish.

The family contains six genera, four of which regularly occur in aquaculture ponds.

Key to pond-inhabiting daphniid genera of south eastern Australia

1. Ventral margin of carapace straight and heavily pigmented (Fig. 136) .... ***Scapholeberis kingi***

- Ventral margin of carapace rounded, not heavily pigmented (Figs 137-141) 2

2. Head large, rostrum large; tail spine short to long (Plates 4h & 4i; Figs 137, 138 & 139)... ***Daphnia***

- Head small, rostrum small or absent; tail spine reduced or absent (Figs 140 & 141) 3

3. Front of head rounded, lacks obvious rostrum (Plate 4j; Fig. 140) .... ***Ceriodaphnia***

- Head small in proportion to body, front of head pointed, rostrum small (Plate 4k; Fig. 141) .... ***Simocephalus***

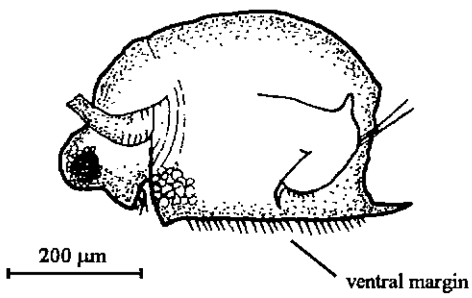


Fig. 136 *Scapholebris kingi*

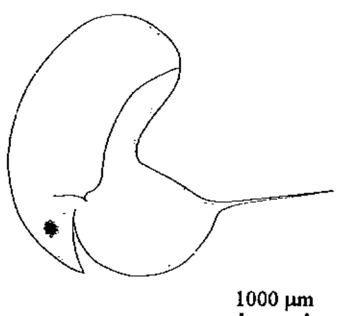


Fig. 137 *Daphnia cephalata*

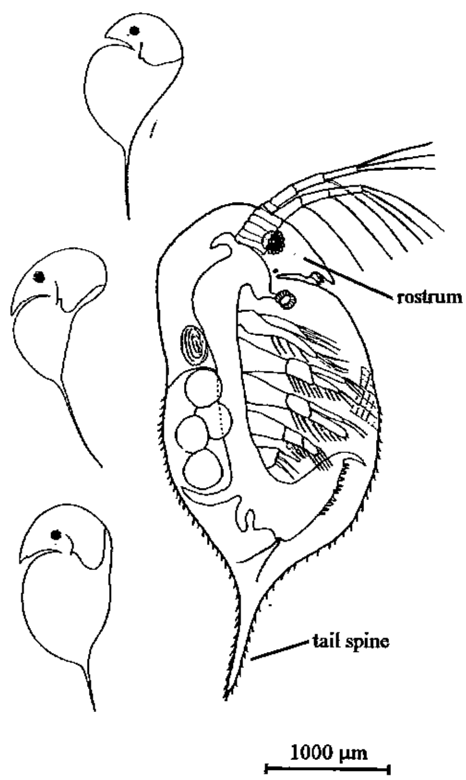


Fig. 138 *Daphnia carinata*

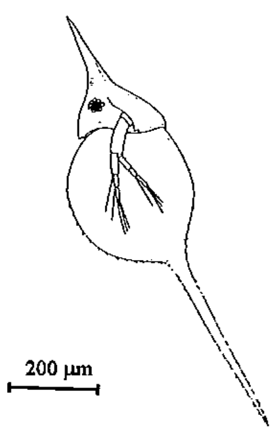


Fig. 139 *Daphnia lumholtzi*

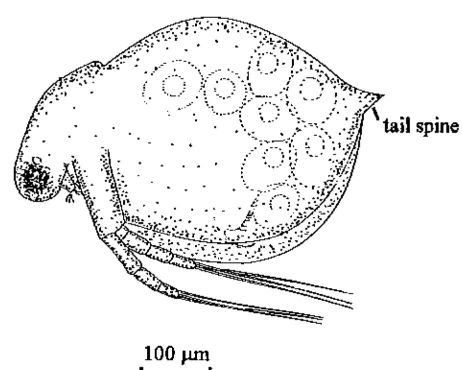


Fig. 140 *Ceriodaphnia* sp.

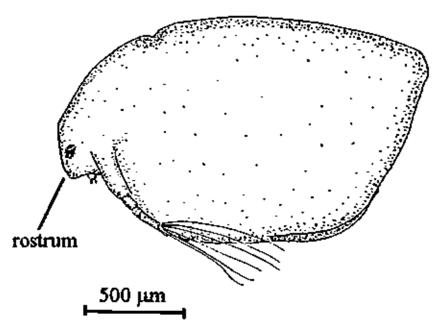


Fig. 141 *Simocephalus* sp.

Six species of *Daphnia* are recognised by Benzie (1988) as occurring in Australia, three of these, *D. cephalata* (Plate 4i; Fig. 137), *D. carinata* (Plate 4h; Fig. 138) and *D. lumholtzi* (Fig. 139), regularly occur in aquaculture ponds. The spine on the head of *D. lumholtzi* easily distinguishes it from other species of *Daphnia*. In the ephippium of *D. cephalata* the two egg chambers are fused together while in *D. carinata* the egg chambers are separate. *D. cephalata* are large (3-7 mm long excluding the spine).

Daphnia carinata is the most common daphniid in aquaculture ponds. This species first appears in the plankton 1-2 weeks after the dry ponds are filled with water, and has reached densities of up to 520 ind./l in fry rearing ponds at the MAFRISC. Recent genetic evidence indicates that there is more than one species in the *D. carinata* group of taxa.

Also common seasonally are several species of *Ceriodaphnia* (Plate 4j), which cannot be identified with certainty as the taxonomy requires revision. *Scapholeberis kingi*, the only known species in the genus, occurs in aquaculture ponds, but fish may not eat this species because it is known to be distasteful (Dodson and Frey, 1991). Six species of *Simocephalus* (Plate 4k) are known from Australia (Smirnov and Timms 1983), but they are generally littoral or benthic. *Daphniopsis*, which is not included in the key above, occurs in saline water only and is unlikely to be found in freshwater ponds, although they are a food item for fish in saline aquaculture ponds.

[*Further reading:* Daphnia: Benzie (1988); Other genera: Smirnov and Timms (1983); Shiel and Dickson (1995)].

Moinidae

Moinids are common and often abundant in the plankton of aquaculture ponds. The family contains two genera, *Moinodaphnia* and *Moina* (Plate 4g; Fig. 129). *Moinodaphnia macleayi* is more northern in distribution and only occurs in acidic coastal lagoons and swamps (Smirnov and Timms 1983). Species of *Moina* are medium-sized cladocerans (mostly 0.4-1.0 mm long) with a large round body which lacks a tail spine. Their head, which is separated from the body, lacks an obvious rostrum and does not develop a head shield. Two species of *Moina*, *M. micrura* and *M. tenuicornis*, are regular inhabitants of aquaculture ponds and farm dams ponds in south eastern Australia. The first antennae of *M. micrura* (Fig. 129) is short and broad (< 10X long as wide) and the ephippium contains one egg, whereas in *M. tenuicornis*, the first antennae is long and thin (> 10X long as wide) and the ephippium contains two eggs.

Moina micrura (Plate 4g; Fig. 129) is the most common and abundant cladoceran species in rearing ponds at the MAFRISC, and is an important food item for native fish larvae and fry reared in ponds. In rearing ponds at the MAFRISC, *M. micrura* appears in the plankton 3-7 days after the ponds are filled, and is usually the first crustacean to develop blooms. *M. micrura* blooms have reached densities of 1,300 ind./l in these ponds, but more often densities are between 100 and 500 ind./l.

[*Further reading:* Smirnov and Timms (1983)].

Bosminidae

Of the two genera that are recognised in this family of small (usually < 0.5 mm) cladocerans, only one species from each is known from Australia, although it is likely that more occur here. These two species are separated by their antennae. The first antennae of *Bosminopsis dietersi* are fused together at their bases to form a y-shaped arrangement, while in *Bosmina meridionalis* (Plate 4d; Fig. 121) the first antennae are separate and parallel. *Bosminopsis dietersi* has a tropical distribution, although it has been recorded as far south as Sydney. *Bosmina meridionalis* is the common species in aquaculture ponds of south eastern Australia.

[*Further reading:* Smirnov and Timms (1983); Shiel and Dickson (1995)].

Other families

The family **Ilyocryptidae** contains only the one genus, *Ilyocryptus* (Fig. 127), and three described species. Species of *Ilyocryptus* have a distinctive small triangular head and rounded body. The carapace is mottled with numerous long spines or feathery setae along the margins. *Ilyocryptus* spp. are slow moving benthic dwellers which are rarely collected from the plankton.

Cladocerans in the family **Macrothricidae** are predominantly littoral and/or benthic, and so are rarely recorded in plankton collections. Of the five genera in the family (*Grimaldina*, *Macrothrix*, *Neothrix*, *Pseudomoina* and *Streblocerus* recorded from Australia), only one or two species, such as *M. spinosa* (Fig. 128) and *P. lemnae*, may occasionally be collected in the plankton.

Cladocerans in the family **Sididae** are generally recognised by their large head, feathery first antennae, and long setae along all or part of the carapace margin (Fig. 126). The family contains seven genera in Australia but only the species *Diaphanosoma unguiculatum* can become common in the plankton of ponds in south eastern Australia. More often sidids are associated with aquatic vegetation.

[*Further reading:* Ilyocryptidae and Macrothricidae: Smirnov and Timms (1983); Smirnov (1992); Sididae: Korovchinsky (1992)].

COPEPODA

Biology, ecology and identification

The Class Copepoda is the largest class of the Crustacea, being predominantly marine in affinity, with a large group of species parasitic on fishes. In freshwaters there are three free-living orders, Harpacticoida (Fig. 143), Cyclopoida (Fig. 144) and Calanoida (Fig. 145). In large lakes and reservoirs of south eastern Australia, the Calanoida are numerically important; with the Cyclopoida infrequent or seasonal, though both are common in aquaculture ponds and farm dams. Most copepod species are 1-2 mm long but some, such as *Boeckella major* and *B. robusta*, are larger (4.5 mm long) (Bayly 1964). Calanoids are primarily planktonic, whereas harpacticoids are benthic, and rarely collected in the plankton. Cyclopoids are predominantly benthic, occurring in shallow and/or vegetated habitats, but some species can become abundant in the plankton. In aquaculture ponds of south eastern Australia the more common species encountered belong to the genera of *Boeckella* and *Calamoecia* (Calanoida), and *Mesocyclops* and *Microcyclops* (Cyclopoida).

Copepods generally have an elongate cylindrical body which bears a single eye anteriorly. Copepods are generally active and capable swimmers, propelling themselves through the water by beating their first antennae in a rowing action. Antennae also help to sense both predators and prey, and males use their first antennae to hold the female during copulation. The body possesses five pairs of swimming appendages and the cephalothorax includes mouth parts and manipulative appendages.

In most cases copepods reproduce sexually. The generalised lifecycles of calanoid and cyclopoid copepods are illustrated in Fig. 142. The male attaches a spermatophore (a sack containing sperm) to the genital segment of the female. The eggs are subsequently fertilised when expelled by the female. Fertilised eggs are carried by the female attached to the genital segment until hatching occurs. Two types of eggs are produced by calanoids and harpacticoids. One type develops directly while the other type develops indirectly and becomes a resting egg which can lie dormant for extended periods of time. In contrast, cyclopoids do not produce resting eggs, instead the late instar copepodites are capable of entering a diapause phase in which development is suspended. The first larval stage that hatches from the egg is termed a nauplius (Plate 5b; Fig. 146) which has a rounded unsegmented body and three pairs of appendages. Six nauplius and 5 copepodite stages occur before the adult form is reached.

Copepods reach maturity and are capable of reproducing in about 14 days (at 20^{o}C), but usually require about 24 days to reach their optimum reproductive capacity (Allan 1976). The life-span of copepods is about 50 days. Environmental factors that influence the lifecycles of copepods include water temperature, food availability, predation and overcrowding (Williamson 1991).

Most species of copepod are herbivorous or omnivorous. Their diet may include detritus, phytoplankton or small invertebrates such as nauplii, rotifers and small cladocerans. However, some of the larger species of cyclopoid copepod are predatory and may even prey on small fish larvae (Hartig *et al.* 1982; Labay and Brandt 1994). The genus *Mesocyclops* contains large predatory cyclopoids and is very common in aquaculture ponds of Australia, but there have been no reports of species from this genus attacking fish. Because copepods occupy several levels in the trophic web they are important in the aquatic community and can influence the structure of zooplankton communities (Kerfoot 1977). For example, Gliwicz (1994) found that the presence of the predatory cyclopoid *Acanthocyclops robustus* retarded the growth of cladocerans.

In addition, copepods are an important part of the diet of fish fry reared in aquaculture ponds. Juvenile stages (nauplii or copepodites) may be a major food supply for fish larvae, while adult copepods may be eaten by larger fry. Rowland (1992) showed that Murray cod fry consumed *Boeckella fluvialis* and *Calamoecia lucasi* in ponds at the NFC. Calanoids and cyclopoids are ingested in large numbers by all the fry of native fish which are reared in earthen ponds at the MAFRISC.

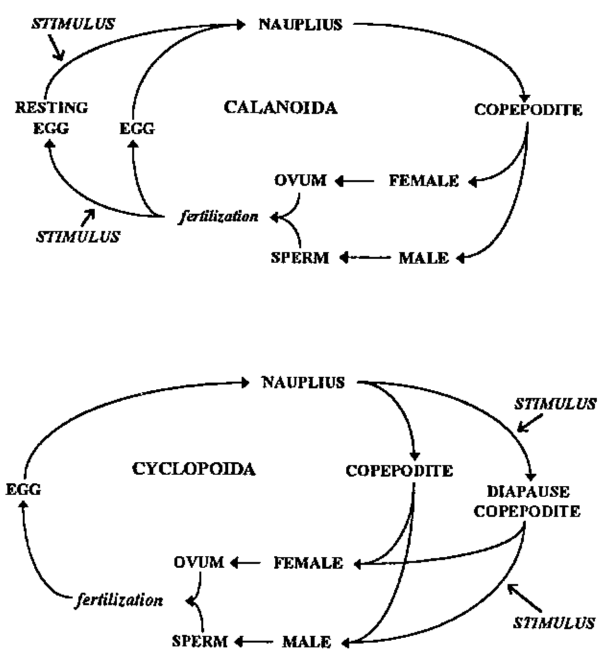


Fig. 142 Lifecycles of calanoid and cyclopoid copepods

Copepods can become abundant in fry rearing ponds with densities of copepodites and adults reaching 500 ind./l at the MAFRISC and 920 ind./l in fry rearing ponds near Benalla. Densities of copepod nauplii have reached 1,200 ind./l in these same ponds.

Some copepods are parasites on fish. Species belonging to two parasitic cyclopoid genera have been recorded from aquaculture ponds in south eastern Australia. *Ergasilus*, which closely resembles its free-living cyclopoid relatives in appearance, uses the second antennae to attach itself to the gill filaments of its fish host. In contrast, *Lernaea* (anchor worm), a common cyclopoid parasite, is highly modified and does not look at all like a copepod. The female *Lernaea* parasitises many freshwater species of fish by burrowing her anchor-shaped head into the flesh of the host. Only the posterior part of her body and two greenish coloured egg sacs can be seen protruding from the fish.

Identification of copepods requires microscopic examination of the appendages, often from only one of the sexes. This can only be achieved by dissecting the specimens and mounting these appendages on a microscope slide for examination under high magnification (400X). The first antennae of male copepods are geniculate (with an abrupt bend part way along its length). Cyclopoid males have both antennae geniculate while calanoids have one geniculate. Female cyclopoids and calanoids have straight first antennae and bear egg sacs when mature.

The key below is a guide to the more commonly encountered genera of mature copepods found in aquaculture ponds of south eastern Australia.

Key to orders and common genera of mature pond-inhabiting copepods of south eastern Australia

1. First antennae very short, fewer than 10 segments, do not reach past end of cephalothorax; body cylindrical (Fig. 143); female usually carries a single egg sac .... **Harpacticoida** (*Canthocamptus*)

- First antennae with more than 10 segments, may reach past posterior end of the cephalothorax (Figs 144 & 145) 2

2. First antennae with up to 18 segments, may reach past the posterior end of the cephalothorax; body widest behind the head, tapers toward urosome (Fig. 144); female usually carries two egg sacs.... ....**Cyclopoida**....3

- First antennae long, more than 20 segments, extend to urosome or past end; body torpedo-like; female usually carries a single egg sac (Plate 5a; Fig. 145) .... **Calanoida**....5

3. Rami of 1st swimming leg 2-segmented, rami of 2nd to 4th swimming legs 3-segmented (Fig. 147) ....*Australocyclops*

- Rami of 1st to 4th swimming legs all 2-segmented (Fig. 148); 5th swimming leg of female as Fig. 149... *Microcyclops*

- Rami of 1st to 4th swimming legs all 3-segmented (Fig. 150) 4

4. 5th swimming leg of female a single broad segment with one inner spine and two outer setae (Fig. 151) ....*Eucyclops*

- 5th swimming leg of female 2-segmented (Fig. 152) ....*Mesocyclops*

5. Endopodite of 1st swimming leg 3-segmented; each exopodite of male 5th swimming leg with long curved claw (Fig. 153)..................*Boeckella*

- Endopodite of 1st swimming leg 1-segmented; only one exopodite of male 5th swimming leg with curved claw (Fig. 154)..............*Calamoecia*

[***Further reading:*** Kabata (1970); Kerfoot (1977); Williams (1980); Rowland and Ingram (1991); Williamson (1991); Dussart and Defaye (1995)].

Harpacticoida

Harpacticoid copepods (Fig. 143) are benthic and rarely collected in plankton samples. However, specimens of *Canthocamptus australis* have been collected in plankton samples on two occasions from the one pond at the MAFRISC. Hamond (1987) describes the Australian species of *Canthocamptus.*

Cyclopoida

Free-living cyclopoids recorded from aquaculture ponds of south eastern Australia belong to the family Cyclopidae, and are mostly from the genera *Australocyclops, Eucyclops* (Fig. 144), *Mesocyclops* and *Microcyclops.* Occasionally other genera, which are not included in the above key, may also occur in aquaculture ponds. These genera can be identified from the key provided by Williams (1980). Most species are less than 1.0 mm long, however, *Australocyclops australis*, a common and widespread species, can reach a length of 2.0 mm. Cyclopoid densities, predominantly *Mesocyclops*, of up to 407 ind./l have been observed in ponds at the MAFRISC.

[***Further reading:*** Morton (1985, 1990); Dussart and Defaye (1995)].

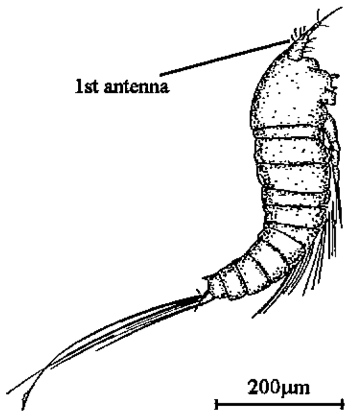


Fig. 143 *Canthocamptus* sp. (Harpacticoida)

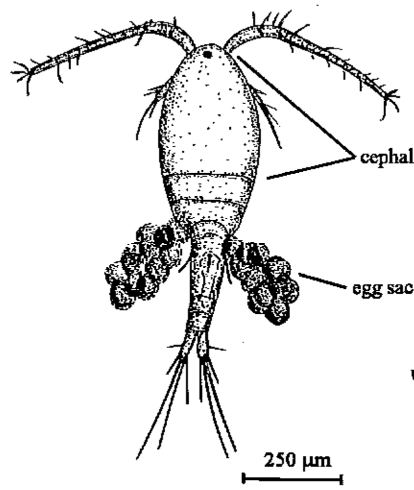


Fig. 144 *Eucyclops* sp. (Cyclopoida)

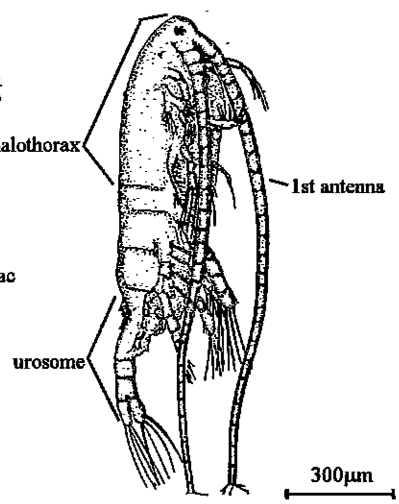


Fig. 145 *Boeckella* sp. (Calanoida)

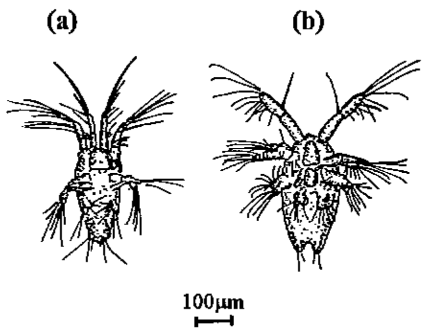


Fig. 146 Copepod nauplius larvae (a) cyclopoid, (b) calanoid

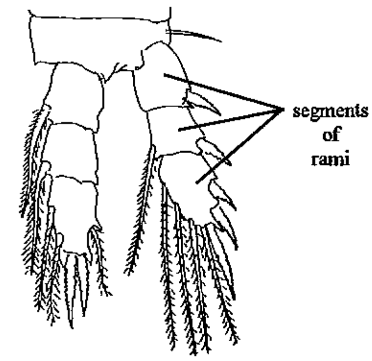


Fig. 147 Rami of 4th swimming leg of *Australocyclops*

Fig. 148 Rami of 4th swimming leg of *Microcyclops*

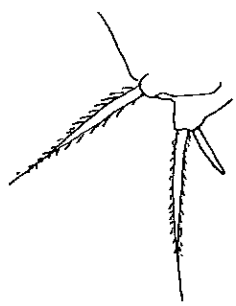


Fig. 149 5th swimming leg of female *Microcyclops*

Fig. 150 Rami of 4th swimming leg of *Eucyclops*

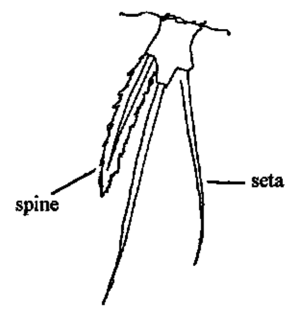


Fig. 151 5th swimming leg of female *Eucyclops*

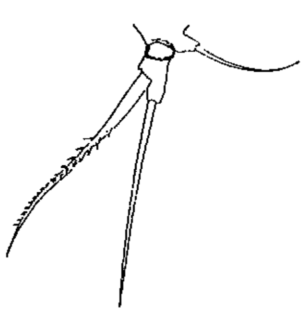


Fig. 152 5th swimming leg of female *Mesocyclops*

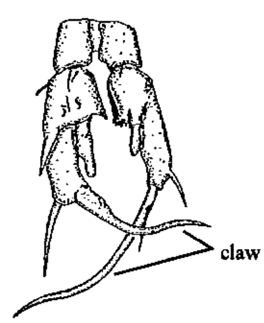


Fig. 153 5th swimming leg of male *Boeckella*

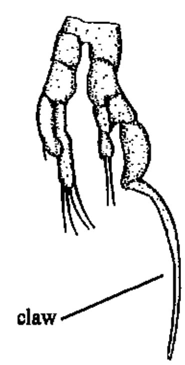


Fig. 154 5th swimming leg of female *Calamoecia*

Calanoida

Generally only calanoid species of two genera, *Boeckella* (Plate 5a; Fig. 145) and *Calamoecia* (Centropagidae), are found in aquaculture ponds and farm dams of south eastern Australia. Other genera of calanoids known from inland Australia have restricted distributions (*Diaptomus* and *Hemiboeckella*) or are usually confined to saline or estuarine habitats (*Gladioferens* and *Sulcanus*).

The most common species recorded in ponds at the MAFRISC are *B. triarticulata* and *B. fluvialis*, which are relatively large species (1-2 mm long). *B. triarticulata* is the most common (especially in farm dams) and widely distributed of the *Boeckella* species in Australia (Bayly 1964). *B. fluvialis* occurs in southern Queensland, NSW and parts of Victoria (Bayly 1964). Densities of *Boeckella* spp. have reached 450 ind./l at both the NFC (Culver and Geddes 1993) and MAFRISC. The smaller *Calamoecia* species (*C. ampulla* and *C. lucasi*) may co-occur with the *Boeckella* species.

[*Further reading:* Bayly (1961, 1964, 1992); Dussart and Defaye (1995)].

OSTRACODA (seed shrimps)

Ostracods are distinguished from other crustaceans by being completely enclosed in a calcareous bivalved shell formed by the carapace (Plate 5c; Fig. 155). Indeed, they are often confused with bivalved mussels. The shell may bear setae or have either a smooth, pitted, wrinkled or sculptured surface, which can be used to assist identification of many species. Unlike conchostracans, which are also enclosed in a bivalved carapace, ostracods do not develop growth lines on the shells and are usually much smaller in size (mostly < 2.0 mm). Because of their resistant shell, ostracods can withstand habitat fluctuations and, like several other species of crustaceans which live in temporary waters, the eggs can also withstand physical and chemical extremes. De Deckker (1995) provides a guide to the identification of Australian freshwater ostracods including a key to most genera. De Deckker (eg. De Deckker 1981, 1983, 1995) has also published a series of papers describing Australian species of Ostracoda (see Hawking 1994). Freshwater ostracods are generally associated with vegetated or benthic habitats, except for species of *Newnhamia* (Fig. 155) a small (0.7-0.8 mm), roundish, green- or brown-coloured genus, which is often found swimming upside-down at the water surface on the windward side of ponds. *Newnhamia* can be distinguished from other ostracods by the presence of "eye lens" (one on each valve near the hinge).

Some species of ostracod are commensal on crayfish but are apparently not harmful to the host. Ostracods feed mostly on organic detritus and algae. In turn, they are preyed on by other aquatic carnivorous animals including native fish fry. Approximately 200 ostracod species are known from Australian inland waters. *Australocypris* (Plate 5c), *Candonocypris*, *Cypretta*, *Eucypris*, *Heterocypris*, *Ilyocypris* and *Newnhamia* (Fig. 155) are some of the more common genera expected to be encountered in aquaculture ponds and farm dams of south eastern Australia.

[*Further reading:* Bayly *et. al* (1967); Williams (1980); Delorme (1991)].

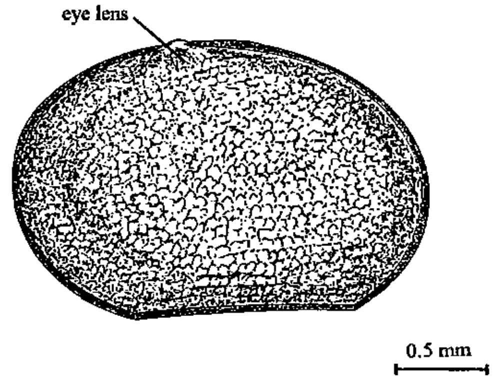


Fig. 155 *Newnhamia* sp. (Ostracoda)

CONCHOSTRACA (clam shrimp)

Conchostracans have a bivalved carapace which encloses the whole animal, thus resembling the Ostracoda, but can be distinguished by being larger in size (up to 25 mm), having between 10 to 30 thoracic appendages and, in some cases, growth rings on the carapace. Conchostracans occur as free-swimming animals in ponds, dams and temporary freshwater pools (Williams 1980). They swim slowly, spending most of their time skimming near the bottom. One of the most common genera found in aquaculture ponds of south eastern Australia is *Cyzicus* (Plate 5d; Fig. 156).

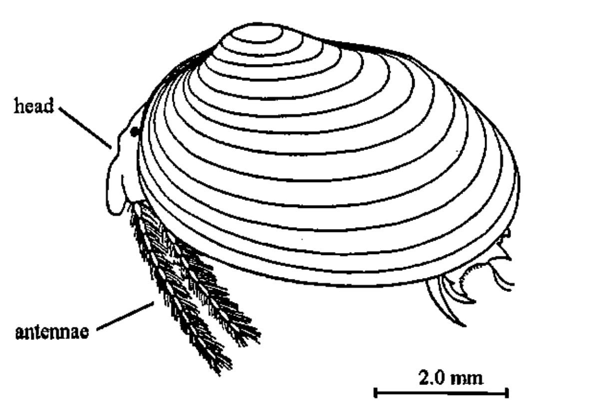


Fig. 156 *Cyzicus* sp. (Conchostracana)

Cyzicus can become a nuisance in fry rearing ponds. Large blooms of *Cyzicus* (along with the anostracan *Branchinella*) can dominate and interfere with or reduce the production of phytoplankton and zooplankton and, in turn, reduce fish production in these ponds by as much as 50% (Czarnezki *et al.* 1993; Thurstan 1995). They are too big to be eaten by the smaller fry, and will block screens and impede harvest. Chemicals such as Dipterex may be applied to the ponds to control *Cyzicus*, however, these chemicals will also be detrimental to other desirable planktonic species. Interrupting the breeding cycle of *Cyzicus* may help to control numbers. Conchostracans that inhabit temporary waters usually only have one generation per wet event (Dodson and Frey 1991). Each generation produces resting eggs which may require a drying period before hatching will occur. Czarnezki *et al.* (1993) found that numbers of *Cyzicus* were reduced by not allowing fry rearing ponds to dry out during winter when the ponds are not in use. Thurstan (1995) successfully reduced nuisance blooms of both *Cyzicus* and *Branchinella* in rearing ponds by removing a few centimetres of sediment, and presumably a majority of the cysts therein, from the bottom of ponds which were then filled and drained several times.

Bayly *et al.* (1967) and Williams (1980) provide keys to genera of Australian Conchostraca.

[*Further reading:* Dodson and Frey (1991)].

DECAPODA (crayfish, yabbies, shrimps, prawns and crabs)

Biology, ecology and identification

Species from three families of Decapoda (Parastacidae, Palaemonidae and Atyidae) are commonly found in aquaculture ponds and farm dams. Decapods live in a wide range of aquatic habitats, including ponds, lakes, streams, rivers, bogs; some crayfish are semi-terrestrial burrowers. The first three pairs of appendages of decapods are modified into claws and pincers to aid in feeding. The decapods are the largest in size of the freshwater crustaceans, particularly species of *Astacopsis* and *Euastacus*, which can exceed 2.5 kg in weight and 40 cm in length. Most decapods, particularly the crayfish and yabbies, are benthic or littoral, some even burrow into the substrate. Some species, such as *Paratya australiensis* and *Macrobrachium australiense*, can be active swimmers. Swimming is achieved by two methods - using the swimming legs to swim forwards, or flicking of the tail which causes quick backward darts, a method used as a response to fright or predator attack.

Most decapods are opportunistic feeders and may feed on detritus, dead plant and animal matter and, at times, may even prey on live aquatic animals such as aquatic insects, small fish and crustaceans including other decapods. Thus, they are important in the community particularly as converters of organic matter. Shrimps, prawns and yabbies are, in turn, the food of larger predator species such as Murray cod, golden perch, Macquarie perch, silver perch, barramundi and freshwater catfish (Cadwallader and Eden 1979; Barlow and Bock 1981; Barlow *et al.* 1993).

Keys to the various families and genera of Australian freshwater Decapoda are found in Williams (1980), Horwitz (1995) and Horwitz *et al.* (1995). The following key, which has been modified from these works, provides a guide to the most commonly encountered genera that occur in aquaculture ponds. "Freshwater" crabs are not included in the key, but two species, *Amarinus lacustris* (Hymenosomatidae) and *Holthuisana transversa* (Sundathelphusidae), are recorded from Australia (Williams 1980), which have not been reported from aquaculture ponds. However, *Amarinus laevis*, an estuarine species of spider crab, has been collected from a pond at the GRC during a drought when the salinity in the pond had reached 7.9 ppt (C. Mifsud *pers. comm*).

Key to the common freshwater pond-inhabiting Decapoda of south eastern Australia.

1. First abdominal segment overlapping second abdominal segment; legs well developed; first pair of legs robust and developed into pincer-like claws (crayfish and yabbies) (Plate 5e; Fig. 157). ....**Parastacidae...2**

\- First abdominal segment overlapped by second abdominal segment; legs long and thin; first pair of legs not robust and not well developed (prawns and shrimps) (Figs 161 & 163) 4

2. Spines (usually 2) present on the dorsal surface of the telson (Fig. 158); lateral sides of carapace with scattered raised knobs; body brown or black, sometimes blue, in colour.......*Cherax tenuimanus*

\- Dorsal surface of telson without spines; lateral sides of carapace without raised bumps 3

3. Rostrum with 4-6 well-developed spines (Fig. 159); body green-brown in colour, claws of male with red patch on the outer surface of the rigid finger......................*Cherax quadricarinatus*

\- Rostrum with 0-3 (usually 2) blunt to sharp spines (Fig. 160); body brown, green-brown, or green, sometimes pale blue, in colour (Plate 5e)............. ....*Cherax destructor*

4. First two pairs of legs similar, of moderate size and tipped with tufts of long setae (freshwater shrimps) (Fig. 161) .... **Atyidae...5**

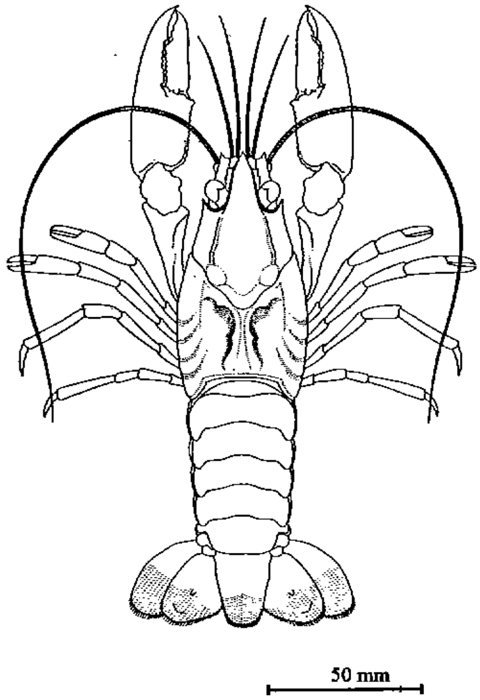


Fig. 157 *Cherax destructor* (Parastacidae)

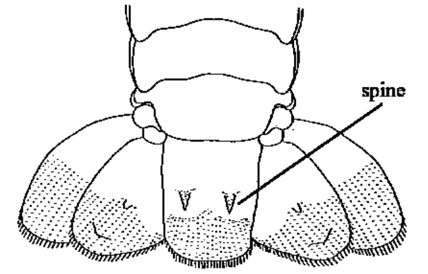


Fig. 158 Tail of *Cherax tenuimanus*

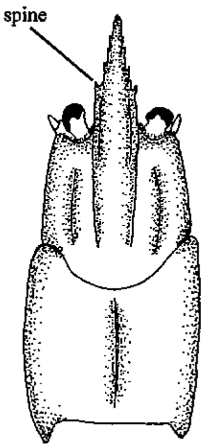


Fig. 159 Rostrum of *Cherax quadricarinatus*

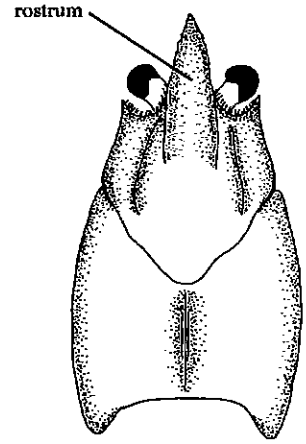


Fig. 160 Rostrum of *Cherax destructor*

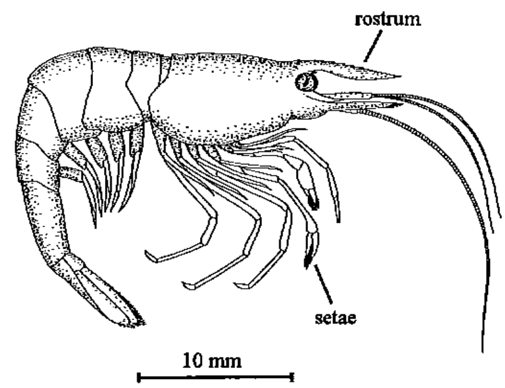


Fig. 161 *Paratya australiensis* (Atyidae)

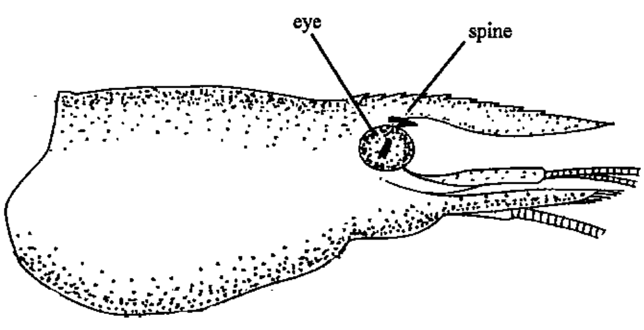


Fig 162 Supra-orbital spine of *P. australiense*

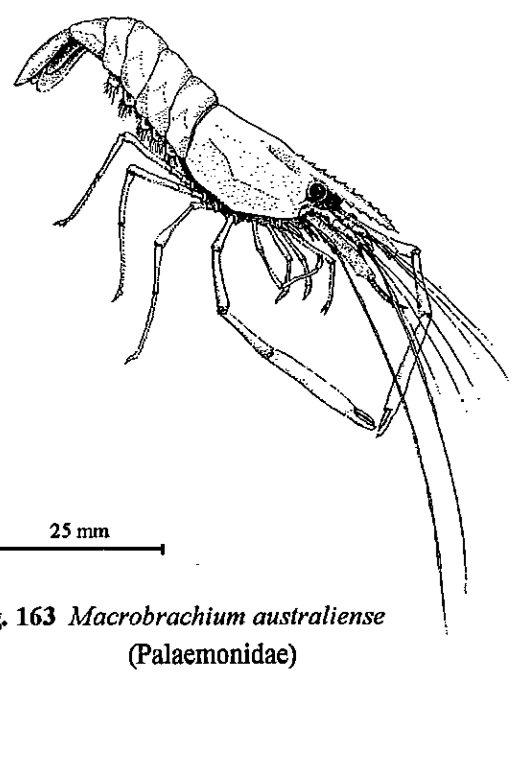


Fig. 163 *Macrobrachium australiense* (Palaemonidae)

- First two pairs of limbs dissimilar, the second pair much longer than the first (freshwater prawns) (Plate 5g; Fig. 163).. .....**Palaemonidae** (*Macrobrachium australiense*)

5. Animal with a supra-orbital spine on each side of the carapace, between eye and rostrum (Plate 5f; Fig. 162) ....*Paratya australiensis*

- Animal without a supra-orbital spine ....*Caridina mccullochi*

Parastacidae (crayfish and yabbies)

Parastacids are recognised by their large size and the first pair of limbs which are modified to form large, robust, pincer-like claws. Probably the best known species of parastacid in south eastern Australia is the common yabby, *Cherax destructor* (Plate 5e; Fig. 160). Yabbies are usually found in semi-permanent and permanent water bodies where they may excavate burrows up to 5 m deep. Their burrowing activities can be a problem because dam walls may be weakened, which can lead to leakage or even collapse of the wall. Yabbies are an important prey species for many of the larger species of freshwater fish, and fish farmers often add yabbies to ponds containing broodfish as a food source.

Yabbies are collected for consumption as well as for fish bait by both amateur and commercial fishermen. Their popularity has lead to an increase in their culture in south eastern Australia (Mills 1989; Merrick and Lambert 1991). Two other species are also being farmed, Marron (*C. tenuimanus*) in western Australia, and red claw (*C. quadricarinatus*) in northern Australia. Descriptions on the general biology and culture of *Cherax* spp. are given in Mills (1989) and Merrick and Lambert (1991).

Species belonging to other genera in the family, such as *Euastacus* and *Engaeus*, are generally not encountered in aquaculture ponds and other standing waters because they are either restricted to permanent waters such as lakes and rivers, have restricted distributions, or are semi-terrestrial. Preliminary keys to these and other species of Parastacidae are provided by Horwitz and Austin (in Horwitz 1995).

[*Further reading:* Williams (1980); Horwitz (1995)].

Atyidae (freshwater shrimp)

The freshwater shrimp *Paratya australiensis* (Plate 5f; Fig. 161) is very common in aquaculture ponds and farm dams of south eastern Australia, particularly where aquatic plants occur. A second less common species, *Caridina mccullochi*, may also be found in aquaculture ponds. Unlike freshwater prawns, the first two limbs of shrimp are similar in size and tipped with tufts of long setae. Atyid shrimps are detritus feeders which are benthic and littoral. Many species of fish will eat these shrimp. *Paratya* breed in spring and summer. Females produce 50-250 eggs and the larvae are planktonic. A preliminary key to the species of Atyid shrimp of inland Australia is provided by Choy and Horwitz (in Horwitz 1995).

[*Further reading:* Riek (1953); Williams (1977, 1980); Williams and Smith (1979)].

Palaemonidae (freshwater prawns)

Of the freshwater prawns that occur in Australia, generally only *Macrobrachium australiense* is found in fresh waters throughout south eastern Australia. Freshwater prawns are recognised by their second pair of limbs which are very long and tipped with pincer-like claws (Plate 5g; Fig. 163). *M. australiense* live on the bottoms of ponds and amongst aquatic plants. Since freshwater prawns are eaten by fish they are a good source of food in aquaculture ponds, particularly for broodfish. There has been some interest in the aquaculture of *M. australiense* (Fielder 1983) for consumption and fish bait. The most recent revision of the genus is given by Fincham (1987), and a preliminary key to the species is provided in Horwitz (1995).

[*Further reading:* Williams (1980)].

OTHER CRUSTACEAN GROUPS

Branchiura (fish lice), are dorso-ventrally flattened crustaceans which are parasites on the body surface of fish (Kabata 1970). Their appendages have been modified for holding onto their host. A species of *Argulus* has been collected from the body surface of eels in a dam at the GRC (Rowland and Ingram 1991).

Amphipods (scuds) (Fig. 119) are laterally flattened crustaceans which lack a carapace. Amphipods are generally stream dwellers and have rarely been collected from aquaculture ponds. Williams (1980) and Horwitz *et al.* (1995) provide further information on amphipods, including a key to the families.

Isopods (slaters), with few exceptions, are dorso-ventrally flattened crustaceans, which, like amphipods, also lack a carapace. Most are stream-dwelling species and are rarely collected from standing waters. Some species are parasitic on *Paratya* and *Macrobrachium*. A key to the families is provided by Horwitz *et al.* (1995).

INSECTA (insects)

BIOLOGY, ECOLOGY AND IDENTIFICATION

The insects are a highly diverse, and often a very abundant group of animals that occupy a wide range of habitats. Generally, adult insects can be distinguished from other animals by having a clearly defined head, a three segmented thorax each segment with a pair of jointed legs, and an abdomen with up to 11 segments. Many adults have one or two pairs of wings attached to the last thoracic segment. The aquatic larvae and nymphs of insects have a range of body forms from having the generalised insect features (eg. Odonata) (Plate 6a-k) to a maggot-like appearance (eg. some Diptera) (Plate 8a-h).

Thirteen orders of insects have representatives that spend some part of their lifecycle in an aquatic environment in Australia (CSIRO 1991), nine of these have been recorded from aquaculture ponds and farm dams (Table 5). At times, some groups, such as the Notonectidae and Corixidae (Hemiptera), the Chironomidae (Diptera) and the Dytiscidae and Hydrophilidae (Coleoptera), can become abundant in aquaculture ponds and so are important either as predators of other aquatic animals, including fish, or as prey for animals stocked into the ponds.

Adaptations to aquatic life

Insects have developed a variety of methods of survival in the aquatic environment. Some insects are bottom dwelling, crawling on vegetation, burrowing into or attached to the substrate, while others swim through the water using various means. Aquatic insects exhibit varying degrees of morphological adaptation to swimming in water. Some larval dipterans and zygopterans (Odonata) swim by a serpentine action. Anisopterans (Odonata) are capable of jet propulsion, which is achieved by expelling water from the rectum (Corbet 1983). Legs are often flattened and widened into paddles (eg. Gyrinidae), and fringed with hairs (eg. *Berosus*, corixids and notonectids), to aid swimming. The body may also be flattened and streamlined such as in many adult aquatic beetles.

The surface dwelling insects, such as the Gerridae (Hemiptera) and the Collembola, have a covering of minute hydrofuge (non-wettable) hairs on the legs and body that allows them to rest on and move over the surface film.

Aquatic insects have developed several remarkable adaptations for aquatic respiration. Some aquatic insects need to return to the surface to replenish their air supply. Diving beetles and bugs entrap air beneath the hard shell-like forewings (elytra) and between microscopic hydrofuge hairs on the body. The entrapped bubble of air may last several hours to days at low temperatures. In some adult beetles (eg. Elmidae and Hydraenidae) and adult bugs (eg. Naucoridae) hydrofuge hairs covering large areas of the body entrap a thin layer of air around the body. Because the oxygen in this layer of air, known as a plastron, is renewed by diffusion from the surrounding water, these insects can remain permanently underwater.

Gills are a feature of many aquatic insect larvae and nymphs. Usually they are situated on the abdominal segments, though gills may also occur on the rectum (Zygoptera), the coxal bases (*Hygrobia*) or the mouth parts (some mayfly nymphs).

[*Further reading:* Merritt and Cummins (1984); Norris (1991)].

Lifecycles

Aquatic insects lay eggs onto or into the water with some being laid into masses. At hatching the juvenile is usually called a larva, but in some insect orders (Ephemeroptera, Plecoptera and Hemiptera) this stage may also be called either a nymph or naiad. As the larva (or nymph) grows it undergoes a series of moults through consecutive instars (stages between each moult). Most insects have 4-6 instars but some species may have more than 30 instars. (Merritt and Cummins 1984)

Insects have two major types of development, gradual metamorphosis and complete metamorphosis. Insects that undergo gradual metamorphosis have larvae (nymphs) which more or less resemble the adults. These larvae usually have well-developed legs, antennae and compound eyes, but their wings, which are visible as wing pads or buds on the thoracic segment, are not fully developed (Figs 170a, 171a & 172a). This form of development occurs in only four orders that have aquatic species, the Ephemeroptera, Odonata, Plecoptera and Hemiptera (Table 5).

Larvae which undergo complete metamorphosis are usually totally unlike the adult form (Table 5). The wings develop internally and cannot be seen, the legs and antenna may be reduced, and the eyes are simple, not compound (Figs 174-180). Once the larvae are fully grown, they enter a non-feeding pupal stage in which the legs, wings and compound eyes are developed (Fig. 173). The adult form emerges from this pupal stage.

In many groups of aquatic insects, only the larvae or nymphs live in water while the adults are terrestrial (Table 5). However, in some insect groups both the larvae and adults are aquatic.

Table 5 Number of families and lifecycle metamorphosis type of aquatic and semi-aquatic insects recorded from aquaculture ponds and farm dams

Insect order	No. of families *	Lifecycle metamorphosis type		Semi-aquatic/aquatic life stage
		gradual	complete	
Collembola	3			juveniles & adults
Ephemeroptera	4	+		nymphs
Odonata	7	+		larvae (or nymphs)
Plecoptera	2	+		nymphs
Hemiptera	12	+		nymphs & adults
Coleoptera	11		+	larvae & adults
Diptera	10		+	larvae
Trichoptera	3		+	larvae
Lepidoptera	1		+	larvae

* Determined from Appendix I.

Table 6 Habitats occupied, habits and feeding types of semi-aquatic and aquatic insects recorded from aquaculture ponds and farm dams

Insect order	Habitat	Habit	Feeding type
Collembola	littoral/ surface dwelling	floaters/crawlers	detritivores/herbivores
Ephemeroptera	benthic	crawlers/climbers	detritivores/herbivores
Odonata	benthic	crawlers/burrowers/ climbers	carnivores
Plecoptera	benthic	sprawlers	detritivores/herbivores/carnivores
Hemiptera	littoral/pelagic/ surface dwelling	swimmers/striders	detritivores/carnivores
Coleoptera	littoral/pelagic/ benthic	swimmers/climbers/ crawlers	detritivores/herbivores/carnivores
Diptera	pelagic/benthic	burrowers/ swimmers/crawlers	detritivores/herbivores/carnivores
Trichoptera	benthic	crawlers	detritivores/herbivores/carnivores
Lepidoptera	benthic	crawlers	herbivores

Ecology

Aquatic insects are important in the pond ecosystem and occupy many levels of the trophic web. Detritivorous insects, which occur in a number of orders (Table 6), eat fine organic matter, and dead and decomposing plants and animals. These insects play an important role in the recycling and regeneration of nutrients in the aquatic environment. Herbivorous insects feed on microscopic algae through to aquatic macrophytes, whereas carnivores prey on other living animals. The diet of aquatic insects may change as they develop, for example, hydrophilids (Coleoptera) are carnivores as larvae, but herbivores as adults.

Many species of aquatic insects are predatory, such as the Aeshnidae (Odonata), Dytiscidae (Coleoptera) and Notonectidae (Hemiptera). Predatory aquatic insects may feed on a wide range of animals from protozoans, rotifers and small crustaceans to other aquatic insects and tadpoles (Merritt and Cummins 1984). In fry rearing ponds, these aquatic insects, particularly when abundant, can compete with fish for food such as zooplankton, or even prey directly on fish larvae and small fry.

Aquatic insects are important in the diet of fish, so much so that some fish farmers have used night-lamps to attract flying insects (both aquatic and terrestrial) as a supplementary food source. Fish dietary studies have shown that the more commonly eaten groups include the Coleoptera, Diptera, Ephemeroptera, Hemiptera, Odonata and Trichoptera (Cadwallader and Eden 1979; Harris 1985; Barlow *et al.* 1986; Rowland 1992). Even terrestrial insects which fall onto the water surface can make up a substantial part of the diet of some species of fish (Cadwallader and Eden 1979; Harris 1985; Davies and McDowall 1996).

Identification

Texts which provide further information on the general ecology and biology of Australian aquatic insects include CSIRO (1991), Williams (1980) and Goode (1987). The key provided covers all known orders of aquatic and semi-aquatic insects including those that are non-pond dwellers or rare, but which may occasionally be encountered, such as the Neuroptera, Megaloptera, and Mecoptera

Key to orders of aquatic and semi-aquatic insects of south eastern Australia

1. Forewings hard, shell-like, hindwings folded lengthwise and crosswise beneath forewings; biting mouthparts only (adult beetles) (Fig. 164) .... **Coleoptera** (in part)

- Forewings not hard and shell-like, or wings reduced to buds or absent; biting or piercing mouthparts (Figs 165-180) 2

2. Small insects (< 4 mm) with a springing apparatus (or furca) at posterior end of abdomen; dwelling on surface film (springtails) (Fig. 165).. .... **Collembola**

- Abdomen without a springing apparatus 3

3. Mouthparts beak-like for piercing and sucking (Fig. 166); animals dwell on the water surface or in the water 4

- Biting and chewing mouthparts (Fig. 167); animals fully aquatic living, beneath the water surface.. 5

4. Mouthparts form a short segmented suctorial beak (Fig. 166); wings present or reduced to wing buds or absent (bugs) (Fig. 168) ....**Hemiptera**

- Mouthparts form a long straight or slightly recurved suctorial tube; body less than 10 mm long; with prominent sparsely distributed projecting hairs; without wings (Fig. 169) ....**Neuroptera**

5. Larvae/nymphs with wing buds usually present as external flap-like appendages (Figs 170a, 171a & 172a).. 6

- Larvae with wing buds usually invisible but never present as external flap-like appendages (Figs 174-180).. 8

6. Mouthparts include a hinged jaw (labium) which is folded beneath the head and when extended, is longer than the head (dragonfly and damselfly larvae) (Figs 170a & 170b)................... **Odonata**

- Jaw not hinged and not longer than head 7

7. One claw at tip of each leg; abdomen terminating in three long to very long cerci (mayfly larvae) (Figs 171a & 171b) ....**Ephemeroptera**

- Two claws at tip of each leg; abdomen typically terminating in two usually long to very long cerci (stonefly larvae) (Figs 172a &172b)....**Plecoptera**

8. Body completely enclosed in a hard, capsule like case or puparium, or mummy-like with appendages free or fused to the body covering (Fig. 173)........................... Aquatic insect pupae

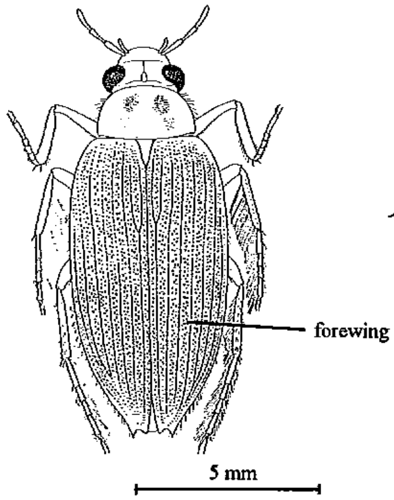


Fig. 164 *Berosus* sp.
(Coleoptera)

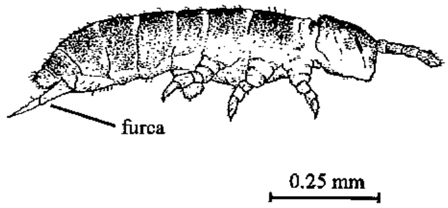


Fig. 165 *Proisotoma* sp.
(Collembola)

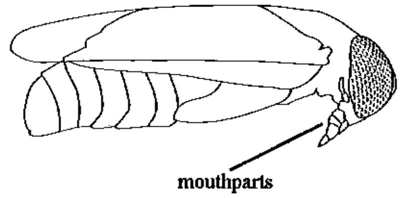


Fig. 166 Hemiptera
(lateral view)

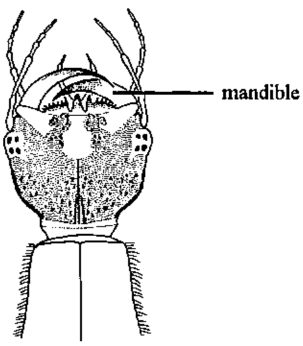


Fig. 167 Head of
Coleoptera larva

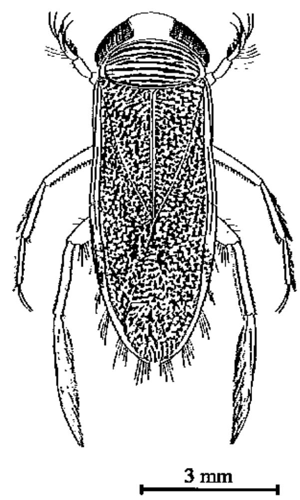


Fig. 168 *Sigara* sp.
(Hemiptera)

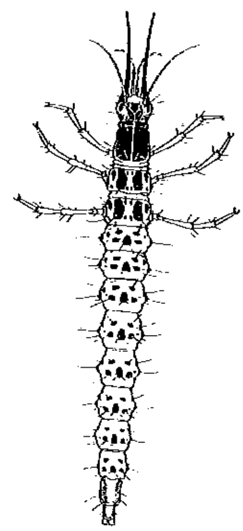


Fig. 169 *Kempynus* sp. larva
(Neuroptera)

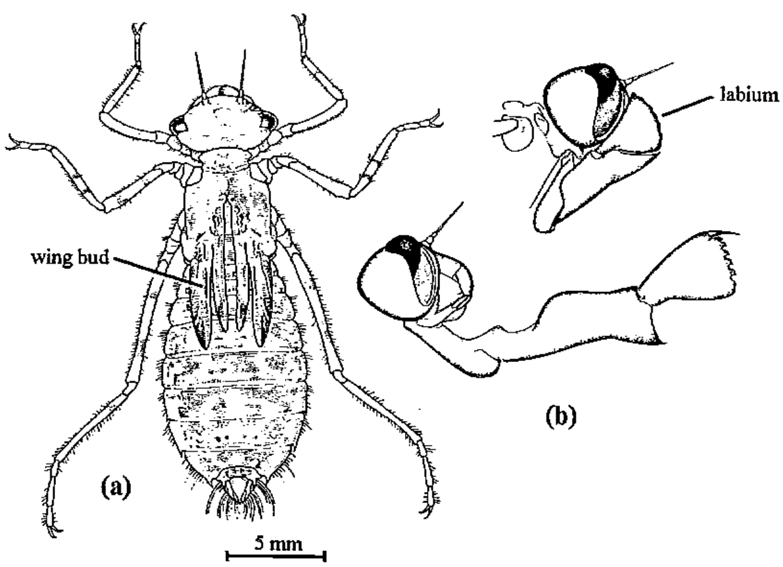


Fig. 170 *Hemicordulia tau* larva (Odonata). (a) larva,
(b) head and mouthparts (withdrawn and extended)

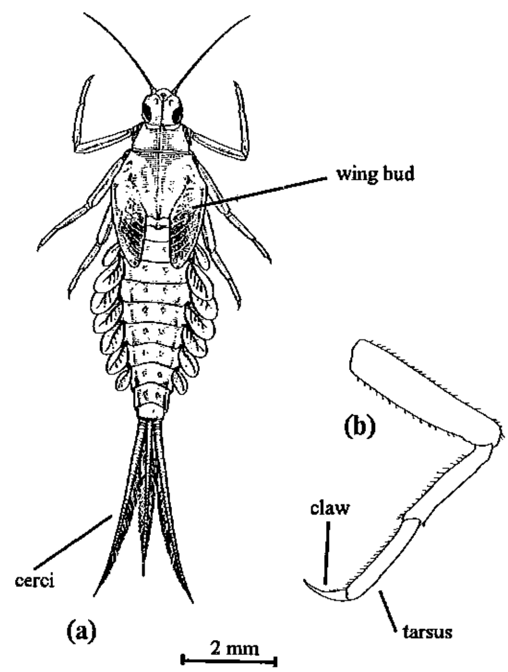


Fig. 171 *Centroptilum* sp. nymph
(Ephemeroptera). (a) nymph, (b) leg

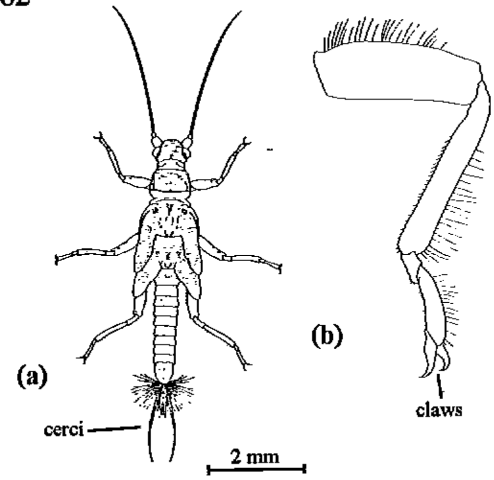


Fig. 172 *Dinotoperla serricauda* (Plecoptera). (a) nymph, (b) leg

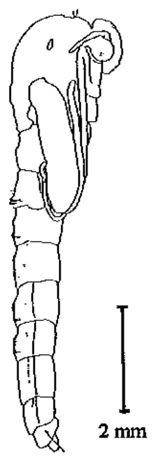


Fig. 173 chironomid pupa (Diptera)

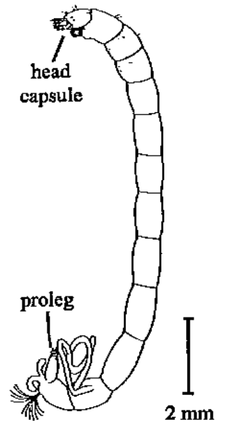


Fig. 174 *Chironomus* sp. larva (Diptera)

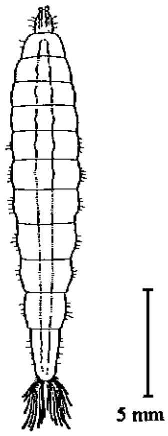


Fig. 175 *Odontomyia* sp. larva (Diptera)

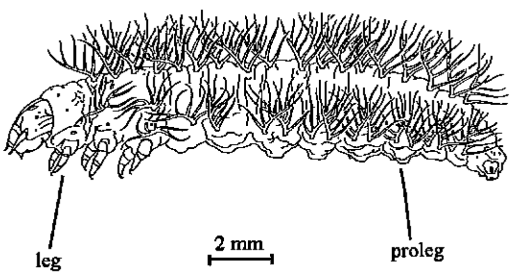


Fig. 176 Lepidoptera larva

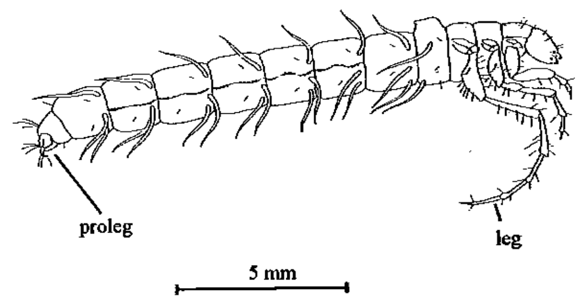


Fig. 178a *Triplectides australis* larva (Trichoptera)

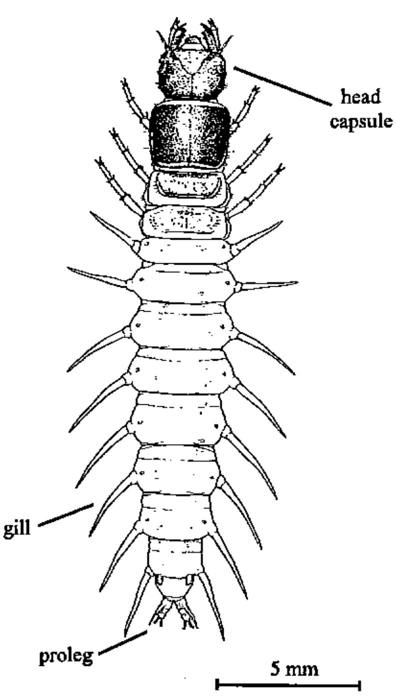


Fig. 177 *Archichauliodes* sp. larva (Megaloptera)

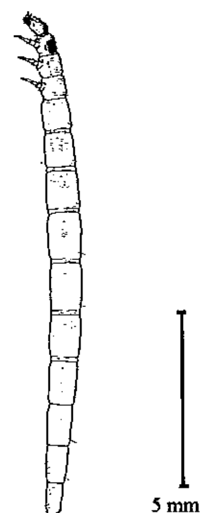


Fig. 179a *Nannochorista* sp. larva (Mecoptera)

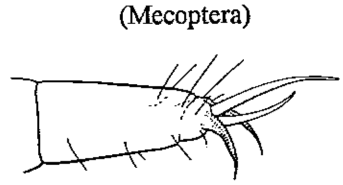


Fig. 179b Last abdominal segment of *Nannochorista* sp.

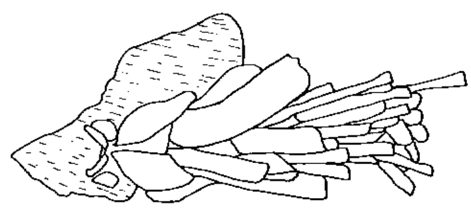


Fig. 178b Trichoptera larval case

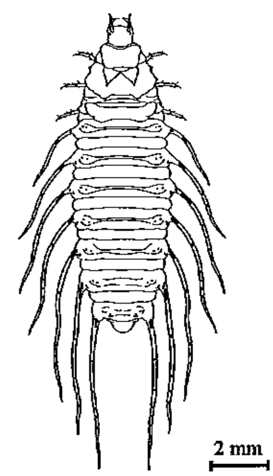


Fig. 180 Coleoptera larva (Hydroptilidae)

- Without the above combination of characters.... 9

9. Thorax without legs, but unjointed legs (prolegs) may be present on the abdomen or thorax; head capsule distinct, or incomplete or absent (mosquito and fly larvae) (Figs 174 & 175) .... **Diptera**

- Thorax with three pairs of jointed legs; head capsule distinct (Figs 176-180) 10

10. Abdominal segments 3-6 and last abdominal segment each bearing a pair of stumpy prolegs; often living in a portable case of vegetable matter (moth caterpillars) (Fig. 176) .... **Lepidoptera**

- Abdominal segments 3-6 without prolegs (Figs 177-180) 11

11. Abdomen with 7 or 8 lateral, often setose, filaments or gills; 9th abdominal segment with either a pair of prolegs each bearing 2 prominent claws or a single long filament (Fig. 177) .... **Megaloptera**

- Either, without paired lateral abdominal gills, or, if such gills are present, without prolegs each bearing 2 claws on the 9th abdominal segment (Figs 178a, 179a & 180) 12

12 Terminal abdominal segment with a pair of hook-bearing appendages (Fig 178a); usually living in a case made from vegetable or inorganic material (caddisfly larvae) (Fig. 178b)............ **Trichoptera**

- Without the above combination of characters 13

13 Body very narrow and worm-like; last abdominal segment more or less conical bearing a pair of terminal hooks and 2 reversible, anal gills; rare (Figs 179a & 179b) .... **Mecoptera**

- Body not worm-like; larvae of a wide variety of form but not fitting into any of the above categories (beetle larvae) (Fig. 180) .... **Coleoptera** (in part)

COLLEMBOLA (springtails)

The Collembola is a group of small (less than 13 mm), wingless, soft bodied arthropods found in damp soils, wet sand and on and under rocks. Occasionally collembolans are found on the water surface and around the margins of aquaculture ponds. In particular, species of *Sminthurides* (Sminthuridae) are aquatic and have been recorded from ponds (Williams 1980). Collembolans feed mainly on algae and detritus. The name springtail is derived from the ability to leap like fleas, using a hinged springing apparatus, called a furca, at the posterior end of the abdomen. The body of collembolans may be either globular such as in the Sminthuridae (Fig. 181), or elongate, such as in the Hypogastruridae (Fig. 165) and Isotomidae (Plate 5h).

[*Further reading:* Greenslade (1991)].

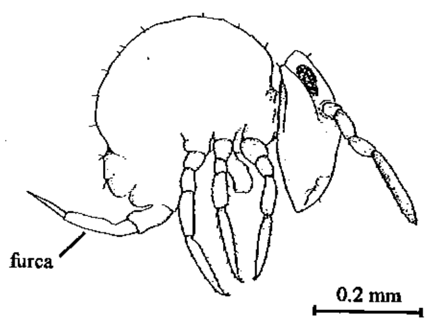


Fig. 181 Sminthuridae (Collembola)

EPHEMEROPTERA (mayflies)

The nymphs (larvae) of all species of the Ephemeroptera (mayflies) are aquatic. Mayfly nymphs are readily distinguished from other aquatic insects by the presence of gills on most of the abdominal segments and three, usually long, cerci protruding from the last abdominal segment (Figs 182, 183 & 184). Most species of mayfly are confined to more permanent water bodies particularly streams and lakes, while only a few occur in seasonal or ephemeral water bodies. Many species of mayfly nymph are either herbivores or detritivores. The nymphs of *Centroptilum* sp. (Baetidae) (Fig. 182), have been found to be an important part of the diet of barramundi fry in rearing ponds (Barlow *et al.* 1993).

There are nine families of Ephemeroptera in Australia, of which three families, Baetidae, Caenidae and Leptophlebiidae have representative species that occur in aquaculture ponds. Species of *Cloeon* (Plate 5i) and *Tasmanocoenis* (Plate 5j) are the most common ephemeropterans encountered in ponds at the MAFRISC.

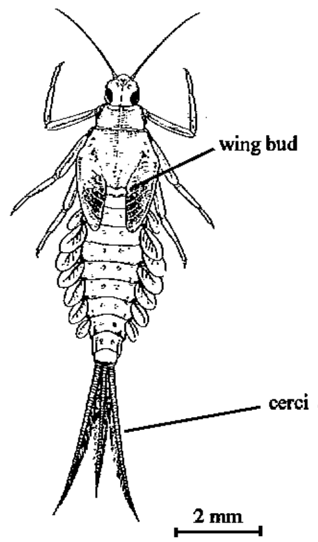


Fig. 182 *Centroptilum* sp. nymph (Baetidae)

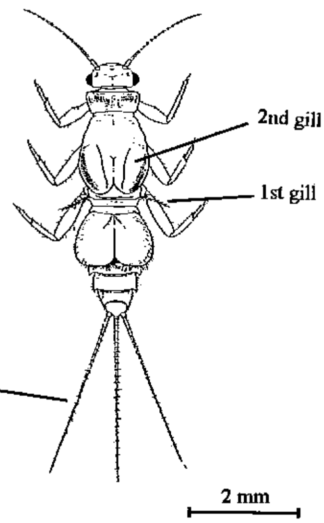


Fig. 183 *Tasmanocoenis* sp. nymph (Caenidae)

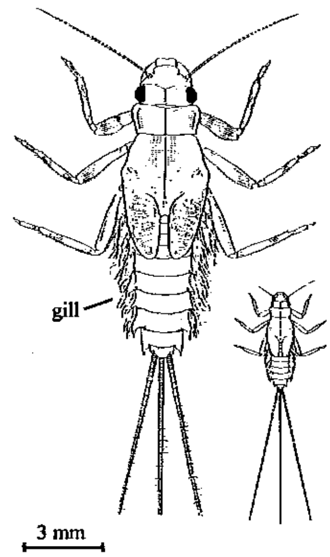


Fig. 184 *Atalophlebia* sp. nymph (Leptophlebiidae)

Key to common pond-inhabiting ephemeropteran nymphs of south eastern Australia

1. Inner margins of outer cerci and lateral margins of central cerci fringed with long setae (Fig. 182); head projected downwards ....
....................**Baetidae** (*Cloeon* & *Centroptilum*)

- Cerci with whorls of setae at apex of each segment (Figs 183 & 184); head projected forwards 2

2. First gill a short single filament, second gill enlarged to form a cover over the remaining gills; cerci shorter than body (Fig. 183) ....
.... **Caenidae** (*Tasmanocoenis*)

- All abdominal gills exposed, second gill not enlarged to form a cover; cerci longer than body (Fig. 184) .... **Leptophlebiidae** (*Atalophlebia*)

[*Further reading:* Peters and Campbell (1991); Suter (1979); Dean and Suter (1996)].

PLECOPTERA (stoneflies)

Four families of Plecoptera (stoneflies) are recorded from Australia, and the nymphs (larvae) (Fig. 185) of all species are aquatic. Stonefly nymphs are often confused with mayfly nymphs, but are easily distinguished by having two cerci on the abdomen. Stonefly nymphs usually require cool, well-aerated waters and so, typically dwell in flowing waters such as mountain streams. For this reason they are rarely found in standing waters such as aquaculture ponds.

Dinotoperla serricauda (Gripopterygidae) (Plate 5k; Fig. 185) has been recorded from the settlement pond at the MAFRISC, and *D. evansi* has been collected from farm dams in South Australia (Suter and Bishop 1990). Other species of stonefly have been collected from the flowing waters of trout farms and include *Acruroperla atra*, *Stenoperla australis* and *Trinotoperla nivata*.

[*Further reading:* Hynes (1978); Theischinger (1991a)].

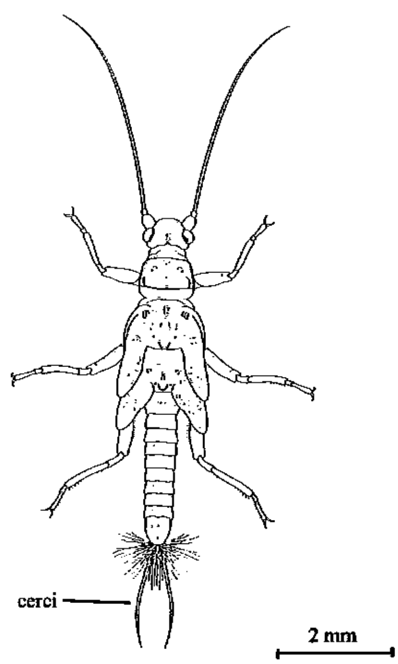


Fig. 185 *Dinotoperla serricauda* larva (Plecoptera)

ODONATA (dragonflies and damselflies)

The order Odonata is subdivided into the Zygoptera (damselflies) and Anisoptera (dragonflies), the larvae (or nymphs) of which are mainly aquatic. The larvae of damselflies possess three leaf-like gills on the tip of the abdomen, while the larvae of dragonflies lack gills. A distinguishing feature of the larvae is the labium (Fig. 186), which is a hinged feeding appendage capable of rapidly extending to grasp prey. Features of the labium are used to identify the larvae of many species. Damselfly and dragonfly larvae occur in a range of habitats from temporary pools and standing waters to permanent and flowing waters such as rivers and lakes. The adults are seen regularly flying around aquaculture ponds.

The larvae are generally ferocious predators and commonly consume rotifers, molluscs, small crustaceans, other aquatic insects and tadpoles. Certain species of anisopteran larvae are major predators of small fish and crayfish in aquaculture ponds. In turn, larger fish will prey on odonate larvae which are often sought by anglers for bait.

There are over 300 species representing 17 families of odonates recorded from Australia (Watson and O'Farrell 1991; Watson *et al.* 1991). However, species that inhabit aquaculture ponds and farm dams generally belong to only five families. The following key is a guide to these families.

Key to pond-inhabiting odonate larvae of south eastern Australia

1. Body slender, bearing three leaf-like gills attached to the tip of the abdomen (Fig. 187)... **ZYGOPTERA**...2

- Body stout, without gills attached to the tip of the abdomen (Figs 188 & 189).....**ANISOPTERA**...3

2. Movable hook of labial palp bearing setae (Fig. 190)........................ **Lestidae** (*Austrolestes*)

- Movable hook of labial palp without setae (Fig. 191)..................................**Coenagrionidae**

3. Prementum without setae; labium flat (Fig. 192) (Fig. 188).. **Aeshnidae**

- Prementum bearing large setae; labium deeply concave; (Fig. 193).. 4

4. Distal margin of labial palps with dentations (Fig. 194)... 5

- Distal margin of labial palps without dentations (Fig. 195)........................... **Libellulidae** (in part)

5. Lateral spines on abdominal segment 9 twice the dorsal length of that segment (Fig. 196).. **Libellulidae** (in part)

- Lateral spines on abdominal segment 9 less than the dorsal length of that segment (Fig. 197) (Fig. 189).. **Corduliidae**

Zygoptera (damselflies)

Pond dwelling damselflies, which belong to the families Coenagrionidae and Lestidae, can be abundant in ponds, particularly those which contain aquatic macrophytes. Eight species of damselfly have been recorded from aquaculture ponds at the MAFRISC, most commonly *Ischnura* spp. (Coenagrionidae) (Plate 6a; Fig. 187).

[***Further reading:*** Hawking (1986); Watson and O'Farrell (1991); Watson *et al.* (1991)].

Anisoptera (dragonflies)

The most common dragonflies encountered in aquaculture ponds are *Hemianax papuensis* (Aeshnidae) (common name: couta) (Plate 6b; Fig. 188), *Hemicordulia tau* (Corduliidae) (common name: spider) (Plate 6c; Fig. 189) and *Orthetrum caledonicum* (Libellulidae) (common name: bumble bee). During summer, dragonfly larvae can become abundant in aquaculture ponds. Densities of *H. tau*, probably the most common species encountered in aquaculture ponds, have often exceeded 2.5 larvae/m^2 in ponds at the MAFRISC. Some of the larger more robust species, such as *H. papuensis, H. tau* and *Pantala flavescens* (Libellulidae), can capture and consume small fish. When these species are abundant in aquaculture ponds they can be a major threat to the survival of fry.

In an experiment to control predatory dragonfly larvae, Ingram and Hawking (*unpub. data*) found that removing marginal vegetation from the perimeter of a pond prevented some species from colonising the pond by eliminating egg deposition sites used by the adults. These species of dragonfly need to implant their eggs into emergent aquatic vegetation. This control measure also considerably reduced the densities of other species of dragonfly which lay their eggs directly into the water.

[***Further reading:*** Hawking (1986); Watson and O'Farrell (1991); Watson *et al.* (1991)].

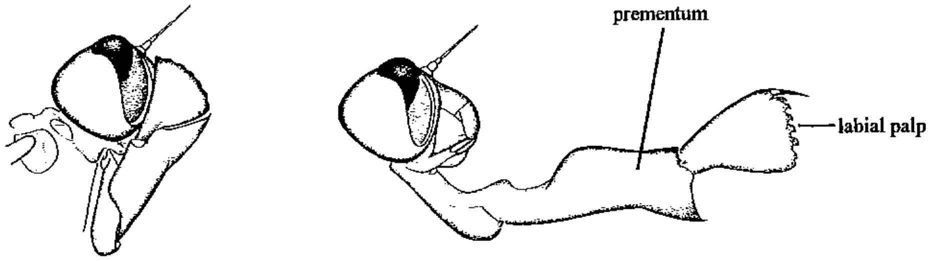


Fig. 186 Labium of an odonate larva, (a) withdrawn, (b) extended

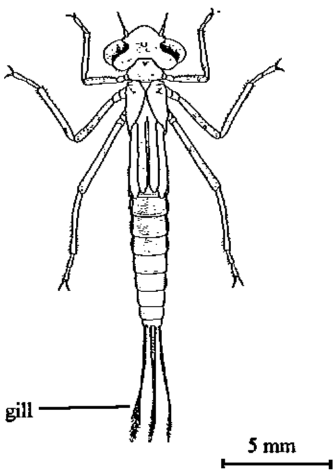


Fig. 187 *Ischnura heterosticta* larva (Coenagrionidae)

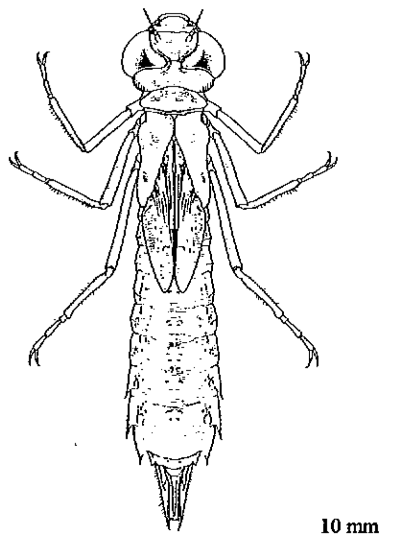


Fig. 188 *Hemianax papuensis* larva (Aeshnidae)

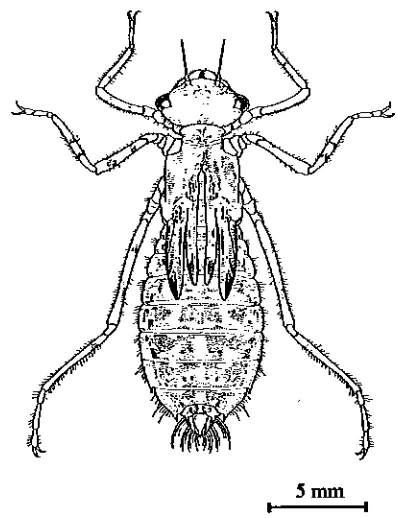


Fig. 189 *Hemicordulia tau* larva (Corduliidae)

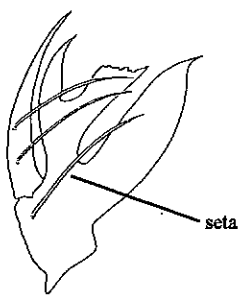


Fig. 190

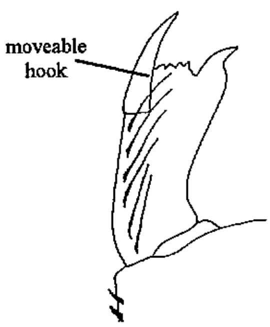


Fig. 191

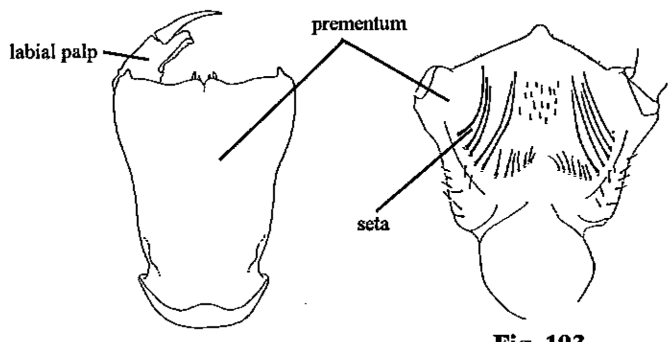


Fig. 192

Fig. 193

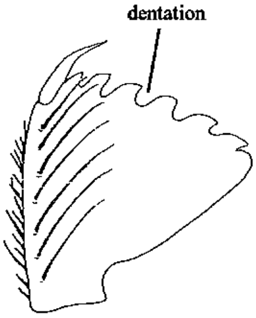


Fig. 194

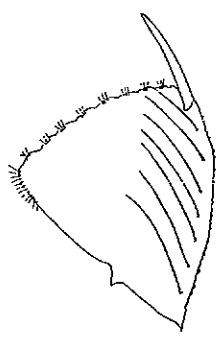


Fig. 195

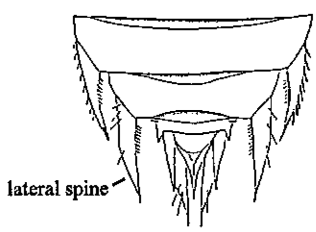


Fig. 196

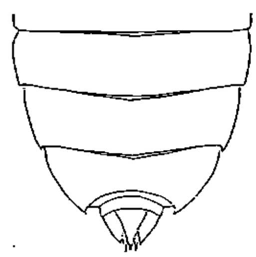


Fig. 197

HEMIPTERA (true bugs)

Biology, ecology and identification

In Australia the Hemiptera is represented by 99 families, which encompasses the true bugs such as aphids, cicadas, leaf hoppers and scale insects. Most of the families are terrestrial, but some 15 families contain species which are either semi-aquatic or aquatic (Carver *et al.* 1991). These hemipterans can be separated into three ecological groups; shore-dwelling semi-aquatic forms (Gelastocoridae, Leptopodidae, Ochteridae and Saldidae), families that dwell on the water surface (Gerridae, Hebridae, Hydrometridae, Mesoveliidae and Veliidae), and fully aquatic families (Belostomatidae, Corixidae, Naucoridae, Nepidae, Notonectidae and Pleidae).

Most aquatic hemipterans are carnivores, feeding by piercing the body of their prey with the stylet of their mouth parts and sucking out the fluids (Carver *et al.* 1991). Hemipterans are important predators in the aquatic environment and their presence can significantly influence populations of other species of aquatic insects (Hilsenhoff 1991). Larger species of hemipterans, especially the Belostomatidae, Nepidae and Notonectidae, can even prey on small fish (Kingsbury 1937; Barr and Huner 1977).

Hemipterans, particularly corixids, are consumed by native fish in ponds and farm dams. Barlow *et al.* (1986) found that 50% (by volume) of the stomach contents of golden perch held in farm dams was composed of corixid nymphs. However, many hemipterans may not be palatable to some fish because they possess scent glands that secrete a noxious substance (Polhemus 1978). This may explain why golden perch held in farm dams preferred *Agraptocorixa eurynome* over other abundant species of corixid (Barlow and Bock 1981; Barlow *et al.* 1986). Small corixids are occasionally eaten by fry in rearing ponds at the MAFRISC, but they are only a minor part of the diet when compared to the amounts of zooplankton and chironomids consumed by these fish.

The following key is a guide to the families of freshwater aquatic and semi-aquatic hemipterans of south eastern Australia. The families Dipsocoridae, Leptopodidae, Ochteridae and Gelastocoridae have not been included in the key because their species are all littoral (or marginal) dwellers and are not expected to occur in aquaculture ponds.

Key to families of pond-inhabiting Hemiptera of south eastern Australia (modified from Williams 1980 and Carver *et al.* 1991)

1. Antennae as long or longer than head (Figs 198-203); animals dwelling on water surface or shore dwelling..2

- Antennae shorter than head; animals fully aquatic, living beneath the water surface (Figs 204-211)..7

2. Head as long as thorax; body long and very slender (Fig. 198)......................**Hydrometridae**

- Head shorter than thorax; body shorter and stouter (Figs 199-203).......................................3

3. Claws (at least on fore legs) inserted before tip of last tarsal segment (Fig. 199b)..........................4

- Claws inserted at tip of tarsal segment (Fig. 203b) 5

4. Middle and hind legs approximately twice as long as the body; beak 4-jointed; body usually longer than 5 mm (Fig. 199a)..........................**Gerridae**

- Middle and hind legs usually less than the length of the body; beak 3-jointed; body usually shorter than 5 mm (Fig. 200)............................ **Veliidae**

5. Eyes large, equal to width of head between eyes; apex of head points down at a 90° angle to body (Fig. 201)...**Saldidae**

- Eyes small, half the width of head between eyes; apex of head down at a 45° angle to body (Figs 202 & 203)...6

6. Body shape broad, length 2 mm or less; tarsi 2-segmented (proximal segment small) (Fig. 202) .... **Hebridae**

- Body shape elongate oval, length over 2 mm; tarsi 3-segmented (proximal segment small) (Fig. 203a)....................................**Mesoveliidae**

7. Tarsal segments of first pair of legs usually flattened or scoop-like; front view of head triangular; swimming with back upper-most (Fig. 204)...**Corixidae**

- Without the above combination of characters......8

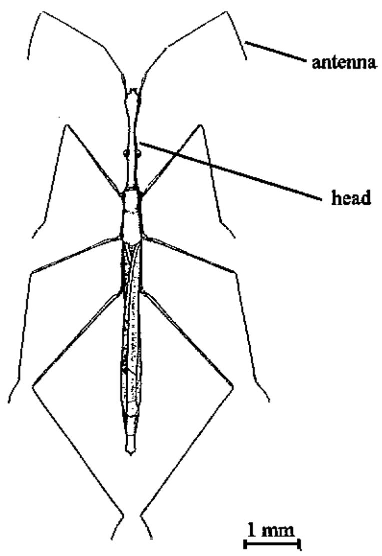


Fig. 198 *Hydrometra strigosa* (Hydrometridae)

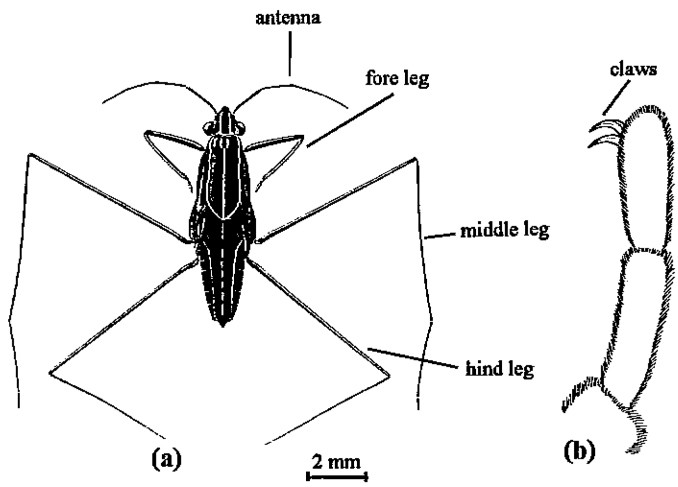


Fig. 199 (a) *Limnogonus luctuosus* (Gerridae), (b) tip of fore leg

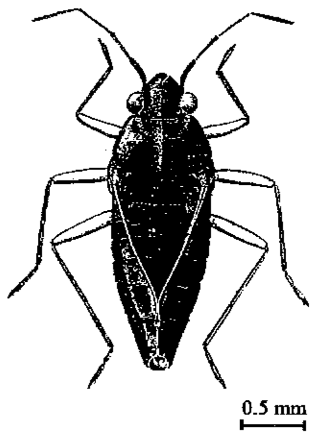


Fig. 200 *Microvelia peramoena* (Veliidae)

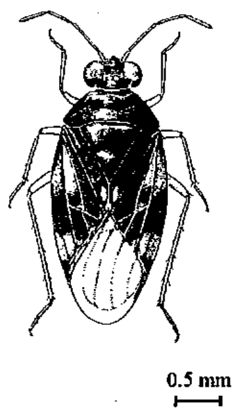


Fig. 201 *Saldula brevicornis* (Saldidae)

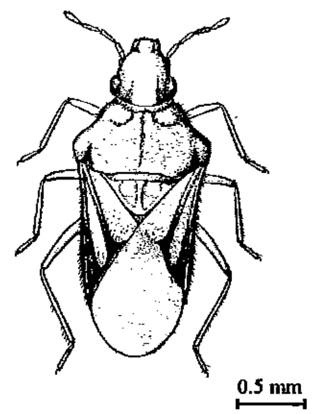


Fig. 202 *Merragata hackeri* (Hebridae)

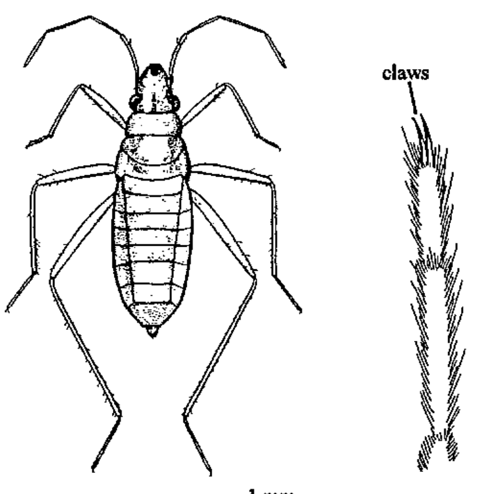


Fig. 203 (a) *Mesovelia hungerfordi* (Mesoveliidae), (b) tip of fore leg

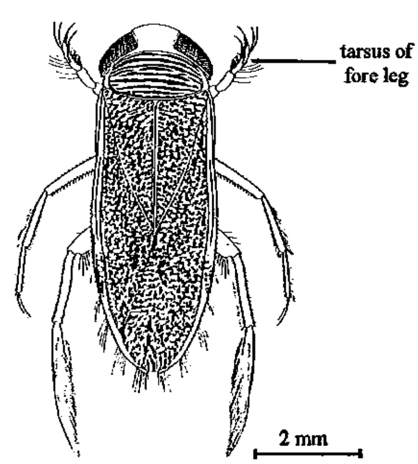


Fig. 204 *Sigara* sp. (Corixidae)

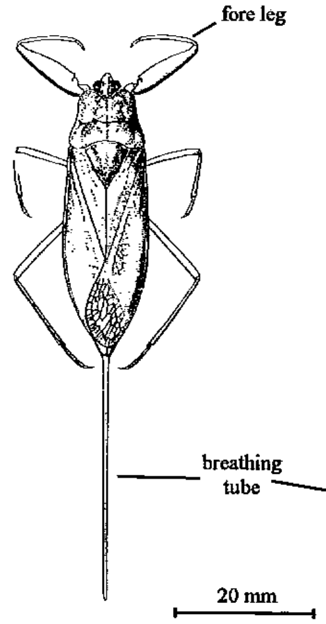


Fig. 205 *Laccotrephes tristis* (Nepidae)

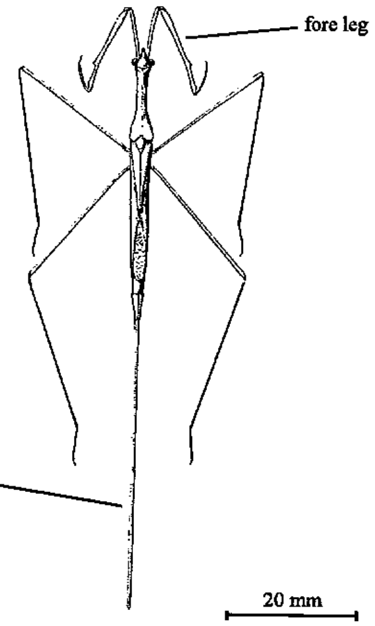


Fig. 206 *Ranatra dispar* (Nepidae)

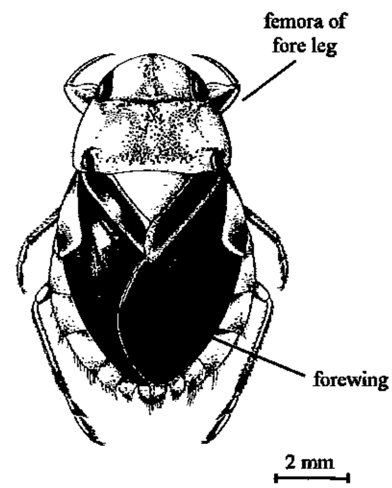


Fig. 207 *Naucoris congrex* (Naucoridae)

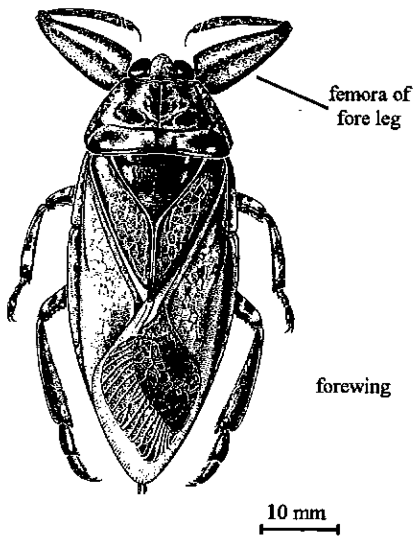


Fig. 208 *Lethocerus insulanus* (Belostomatidae)

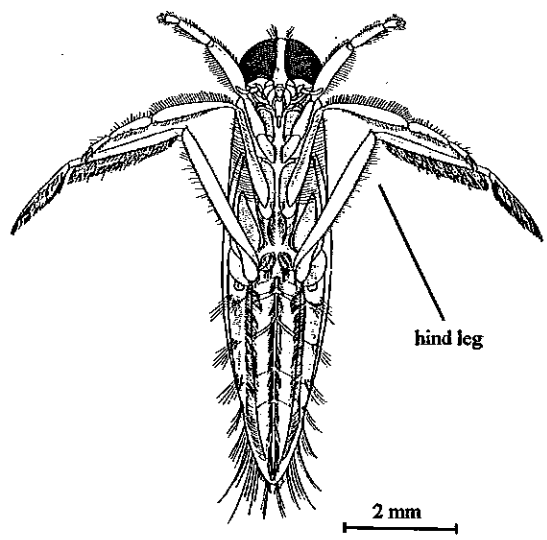


Fig. 210 *Anisops* sp. (Notonectidae) (ventral view)

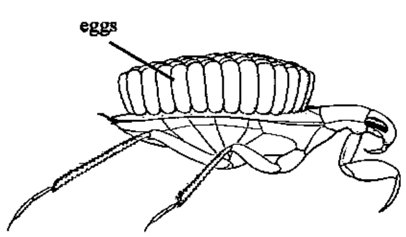


Fig. 209 Male *Diplonychus rusticus* (Belostomatidae) carry eggs

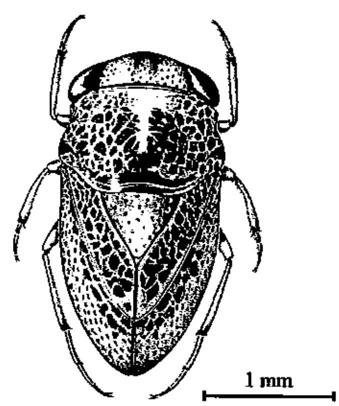


Fig. 211 *Paraplea* sp. (Pleidae)

8. First pair of legs inserted on thorax immediately behind head, and obviously modified for grasping; swimming with back upper-most (Figs 205-209) 9

- First pair of legs inserted near posterior margin of first thoracic segment, and not modified for grasping; swimming ventral surface uppermost (Figs. 210 & 211) 11

9. Apex of abdomen with a long slender breathing tube (Figs 205 & 206) .... **Nepidae**

- Apex of abdomen without a long breathing tube (Figs 207, 208 & 209) 10

10. Membranous part of forewing lacking veins; femora of fore leg triangular and nearly as broad as long; adults < 11 mm long (Fig. 207) .... **Naucoridae**

- Membranous part of forewing with veins; femora of fore leg not triangular and more than twice as long as wide; adults > 11 mm long (Figs 208 & 209) .... **Belostomatidae**

11. Eyes very large; body elongate; hind leg with a single claw; moderately large animals (> 4 mm) (common) (Fig. 210) .... **Notonectidae**

- Eyes small; body oval/globular; hind leg with 2 claws; small animals (< 4 mm) (uncommon) (Fig. 211) .... **Pleidae**

[***Further reading:*** Williams (1980); Lansbury (1981); Carver *et al.* (1991)].

Corixidae (water boatmen)

Species of the Corixidae, especially *Agraptocorixa* (Plate 6f), *Micronecta* and *Sigara* are very common inhabitants of aquaculture ponds. Unlike notonectids, corixids swim with their back uppermost, their body is more flattened and the tarsus of the front leg is scoop-like to aid feeding. Corixids are capable of flight and are often one of the first colonisers of newly filled ponds. Unlike most hemipterans, which are predatory, many corixids feed on detritus and particulate plant and animal matter, but some corixids will eat small aquatic invertebrates. Corixids are reported to be a problem on crayfish farms because they lay their eggs on hard substrates including the carapaces of crayfish. This does not harm the crayfish but does reduce their marketability. Corixids are not known to feed on small fish, however, during harvest of fry rearing ponds the presence of large numbers of corixids may stress the fingerlings, especially since corixids like to cling to objects, including the fish.

Key to common corixid genera of south eastern Australian (modified from Williams 1980)

1. Scutellum exposed, pronotum covering only anterior margin (Fig. 212) .... *Micronecta*

- Scutellum covered by pronotum (Figs 213 & 214) 2

2. Pronotum with transverse markings and without covering of fine setae (Fig. 213) .... *Sigara*

- Pronotum densely punctured, without transverse markings, and with covering of fine setae (Fig. 214) .... *Agraptocorixa*

[***Further reading:*** Williams (1980); Carver *et al.* (1991); *Agraptocorixa*, Knowles (1974); *Micronecta*, Chen (1965); *Sigara*, Lansbury (1970)].

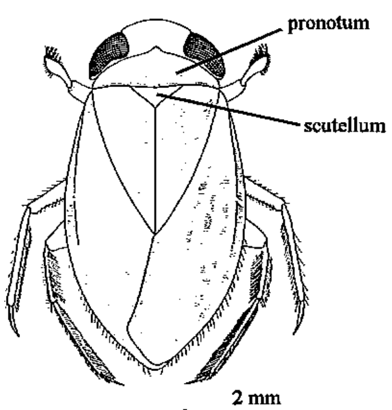


Fig. 212 *Micronecta* sp.

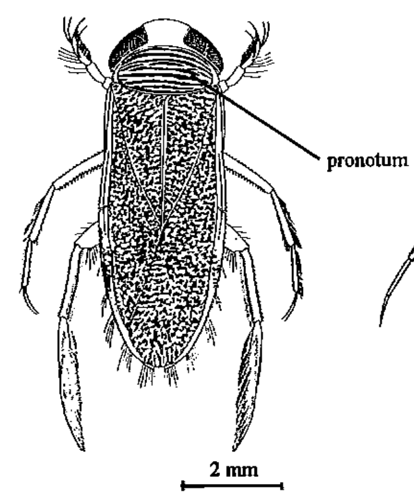


Fig. 213 *Sigara* sp.

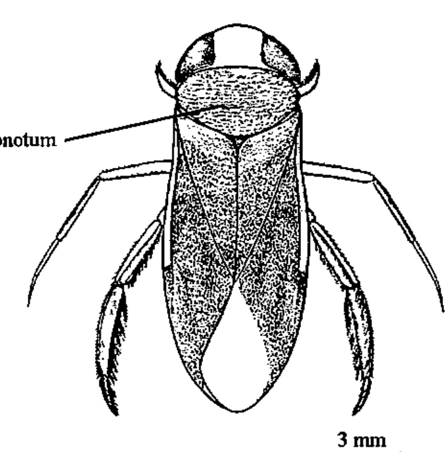


Fig. 214 *Agraptocorixa* sp.

Nepidae (water scorpions)

The nepids are easily distinguished from other bugs by their large size (up to 5 cm) and body shape. *Laccotrephes tristis* (Plate 6h; Fig. 205) is somewhat flattened and broad across the back, and superficially looks like a scorpion, hence the name "water scorpion". Species that belong to the sub-family Ranatrinae such as *Ranatra dispar* (Plate 6g; Fig. 206) are stick-like in appearance. Other features that distinguish the nepids are a long abdominal breathing tube, which is pushed through the water surface to breath, and the raptorial first pair of legs used to catch prey. The nepids are predators, and *R. dispar* has been reported to prey on small fish (Lansbury 1972). Because nepids prefer slow flowing or still waters, particularly where aquatic plants are found, they often occur in aquaculture ponds.

[*Further reading:* Carver *et al.* (1991); Lansbury (1972, 1974)].

Notonectidae (back-swimmers or water boatmen)

Notonectids are very common inhabitants of aquaculture ponds and are easily recognisable as they swim with their ventral side uppermost. Notonectids are capable of flying and can colonise newly filled ponds in a matter of days (Busch 1985), particularly species of *Anisops* (Plate 6j; Fig. 215) which are efficient migrators (Lansbury 1981).

Notonectids are carnivores and will prey on zooplankton, other aquatic insects, tadpoles and small fish (Williams 1980; Reynolds and Geddes 1984). Studies have shown that species of *Anisops* can have a marked impact on the community structure in artificial environments (McDonald and Buchanan 1981); for example, *Daphnia* form enlarged head shields and tail spines to avoid predation in their presence (Grant and Bayly 1981). When notonectids are abundant in fertilised rearing ponds they can become a major problem as they may compete with fish for zooplankton, and even prey directly on small fry. Burleigh *et al.* (1993) showed that the notonectid, *Notonecta indica,* killed at least 10 golden shiner fry (*Notemigonus crysoleucas*) per day in the laboratory. Studies at the NFC have shown that densities of *Anisops* in fertilised rearing ponds are regularly between 5 and 10 ind./m² and that large species, such as *A. stali*, will prey on the fry of golden perch and silver perch (S. Thurstan *pers comm.*). However, if there is an abundance of food (eg. zooplankton) in the ponds, then predation by notonectids is not a problem (S. Thurstan *pers. comm.*).

Notonectids in ponds and tanks can be controlled by covering the water surface with a mixture of oil (8 parts diesel oil to 1 part motor oil) (Brown and Gratzek 1980; Busch 1985; Rowland 1986a) which causes suffocation when they come to the surface to breath. The oil clogs and breaks down the hydrophobic nature of the hydrofuge hairs that retain air around the body. Spraying organophosphate insecticides into pond water has also been used to kill nuisance aquatic insects (Brown and Gratzek 1980; Busch 1985). However, the use of insecticides and oils is ecologically unacceptable because they can be toxic to other beneficial pond fauna and pollute the environment.

Larger fish, on the other hand, may prey on notonectids, for example Barlow *et al.* (1986) found that golden perch held in farm dams consumed notonectids.

Two genera of Notonectidae, *Anisops* and *Enithares*, are widespread in south eastern Australia and species of *Anisops* in particular are very common and abundant in aquaculture ponds and farm dams.

[*Further reading:* Williams (1980); Carver *et al.* (1991); identification Sweeney (1965); Lansbury (1968, 1969)].

Key to notonectid common genera of south eastern Australia

1. Femur of middle leg with an ante-apical pointed protuberance or spur (Fig. 216) .... *Enithares*

- Femur of middle leg without pointed protuberance (Fig. 217) .... *Anisops*

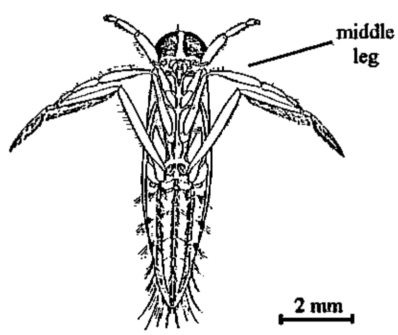


Fig. 215 *Anisops* sp.

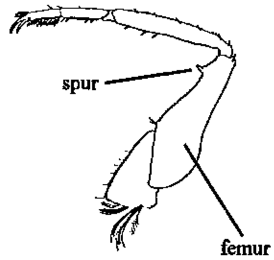


Fig. 216 *Enithares* sp. middle leg

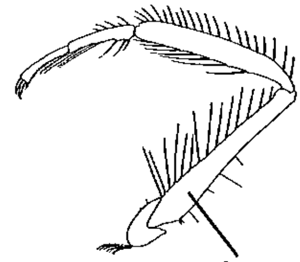


Fig. 217 *Anisops* sp. middle leg

Other hemipteran families

Species of **Belostomatidae** (giant water bugs) are very large bugs (up to 70 mm) which generally prefer slow or standing water and are subsurface dwellers. They are sometimes a nuisance in fish ponds as they can prey on small fish (McLarney 1984). Two genera are encountered, *Lethocerus* (Fig. 208) and *Diplonychus* (Fig. 209). The female of *Diplonychus* lays her eggs on the back of the male which carries them until they hatch (Plate 6i).

The **Gerridae** (water striders or pond skaters) is a family of large (8-12 mm) predatory bugs that skate rapidly over the water surface. They are readily distinguished from other aquatic bugs by the second and third pairs of legs that are almost twice as long as the body (Plate 6d; Fig. 199a).

The **Hebridae** (velvet water-bugs) is represented by two species, *Hebrus axillaris* and *Merragata hackeri* (Fig. 202), in aquatic habitats of south eastern Australia. Hebrids are small stout velvety bugs (1-2 mm) that live on the water surface and vegetation at the edges of water bodies.

One genus of the **Hydrometridae** (water-measurers), the cosmopolitan *Hydrometra* (Fig. 198), occurs in Australia. These stick-like bugs (8-11 mm long) are distinguished by their long narrow head with the eyes placed near the middle. They are slow moving predators that walk on the water surface and rest amongst vegetation at the margins of water bodies.

Only one genus of the **Mesoveliidae** (water treaders), the *Mesovelia* (Fig. 203a) is aquatic. These small (< 5 mm) long-legged predatory bugs occur on the water surface at the edges of standing water-bodies.

Species of **Naucoridae** (creeping water bugs) are broad flat-bodied bugs that are less than 11 mm long. *Naucoris congrex* (Fig. 207) is the most common species in the family which is found throughout south eastern Australia. They are more often associated with aquatic vegetation in standing water-bodies.

The **Pleidae** (pygmy backswimmers) contains only one genus, *Paraplea* (formerly *Plea*) (Plate 6k Fig. 211), which are small (< 2.5 mm) aquatic bugs with a noticeably arched body. Like the notonectids, *Paraplea* swims with its ventral side uppermost. These bugs are poor swimmers and prefer to crawl over submerged plants.

Species of **Saldidae** (shore-bugs) are small, oval-shaped and mottled bugs that live on the water surface. As the name suggests, these bugs mostly occur around the margins of ponds. The family contains 4 genera, and *Saldula* (Fig. 201) has been recorded from aquaculture ponds.

Species of **Veliidae** (water crickets) are small (< 4 mm), dark-coloured bugs which dwell on the water surface (Fig. 200). *Microvelia* spp. (Plate 6e) and *Rhagovelia australica*, are known from freshwater habitats in Australia.

[*Further reading:* Belostomatidae, Lauck and Menke (1961); Gerridae, Hungerford and Matsuda (1960); Hebridae, Lansbury (1990); Hydrometridae, Andersen (1977); Naucoridae, Lansbury (1985); Saldidae, Rimes (1951); Veliidae, Malipatil (1980)].

COLEOPTERA (beetles)

Biology, ecology and identification

The Coleoptera (beetles) is a very large insect order, representing approximately 40% of all insects (Lawrence and Britton 1991). Most beetles are terrestrial but 19 families contain species that are either semi-aquatic or aquatic (Lawrence 1992). The distinguishing feature of adult beetles is the forewings, called elytra, which are hard and shell-like, and protect the hindwings folded beneath them. The ability of adult beetles to fly makes them efficient colonisers of water bodies, particularly newly filled ponds.

Many aquatic beetle larvae are of the general insect form having a distinctly segmented head, thorax and abdomen, and three pairs of segmented legs (eg. Dytiscidae). These larvae are usually active crawlers or swimmers. In contrast, grub-like larvae which have indistinctly segmented bodies, (eg. Chrysomelidae) are fairly inactive.

Both the larvae and adults of aquatic beetles have varied diets. Some species are herbivores or scavengers while others are carnivores. The diet may also change from larva to adult. The grub-like larvae are usually herbivores and feed on plant matter while the more active insect-like larvae tend to be predatory. These carnivorous larvae feed on small crustaceans, oligochaetes and other aquatic insects (Williams 1980). Some species are notorious for their ability to attack and eat small fish (Wilson 1923; Barr and Huner 1977). On the other hand, both adult and larval beetles are eaten by larger fish held in aquaculture ponds and farm dams.

The majority of beetles found in aquaculture ponds belong to two families, the Dytiscidae and Hydrophilidae. Species belonging to the families Haliplidae, Hygrobiidae, Gyrinidae, Scirtidae and Hydraenidae are not as common, but also regularly occur in aquaculture ponds. The following key provides a guide to the identification of these families. Another 12 beetle families, which are not included in this key, have aquatic representatives but are either rare, have not been recorded from aquaculture ponds, or are semi-aquatic and live in marginal habitats. Nevertheless, some of these species may occasionally be collected from ponds and information on their identification can be found in Williams (1980), Mathews (1980, 1982); Lawrence and Britton (1991) and Lawrence (1992).

Key to common aquatic pond-inhabiting beetles of south eastern Australia (modified from Lawrence 1992)

Adults

1. Hind coxae with very large plates concealing basal ventrites and most of the hind femora (Fig. 218) .... **Haliplidae** (*Haliplus*)

- Hind coxae without large plates (Figs 219-223).. 2

2. Eyes completely divided into dorsal and ventral portions; fore legs long and raptorial, middle and hind legs short and paddle-like (Fig. 219) .... **Gyrinidae**

- Eyes not divided; legs not modified as above...... 3

3. Antennae filiform, 11-segmented; maxillary palps shorter than antennae (Figs 220 & 221)............ 4

- Antennae club-shaped 7- to 9-segmented; maxillary palps usually as long or longer than antennae (Figs 222 & 223) 5

4. Body stout and oval; eyes protruding; metasternum with a transverse suture (Fig. 220).. .... **Hygrobiidae** (*Hygrobia*)

- Body boat-like and streamlined; eyes not protruding; metasternum without a transverse suture (Fig. 221)................................ **Dytiscidae**

5. Antennae 9-segmented with 5-segmented club; abdomen with 6 or 7 ventral plates (Fig. 222)...... .... **Hydraenidae**

- Antennae 7- to 9-segmented with 1-, 3- or 4-segmented club; abdomen with 5 ventral plates (Fig. 223) .... **Hydrophilidae**

Larvae

1. Antennae elongate (> 10 segments), at least twice as long as the head (Fig. 224) ....**Scirtidae**

- Antennae short (< 10 segments), less than head length (Figs 225-229)...................................... 2

2. Tip of each leg bearing 2 claws (Fig 227b)......... 3

   Tip of each leg bearing one claw (Figs 225a, 225b & 226)... **Hydrophilidae**

3. Feathery lateral gills on abdominal segments 1 to 10; terminal abdominal segment with four hooks (Fig. 227a) .... **Gyrinidae**

- Abdominal segments without gills (Figs 228 & 229) .... **Dytiscidae**

Dytiscidae

The Dytiscidae is a large family of aquatic beetles with 37 genera (Lawrence 1992). Both the larvae and adults are aquatic. Dytiscids range in size from about 3 to 35 mm in length and are found in a wide variety of aquatic habitats, but they are most abundant in small freshwater ponds (Williams 1980). Adult dytiscids are usually strong swimmers and use their hind legs together like oars.

Both larval and adult dytiscids are predators of other aquatic animals. The larvae have either sucking or chewing mouthparts while the adults have only chewing mouthparts. The larger dytiscid larvae are recognised as predators of small fish (Kingsbury 1937; Barr and Huner 1977). The larvae of *Cybister* and *Homeodytes* (Plate 7j; Fig. 228), for example, are large (up to 85 mm long), excellent swimmers and possess well-developed mandibles which makes them potential predators of fry. However, there are few records, none convincing, of adult dytiscids attacking fish. Genera commonly found in aquaculture ponds include *Allodessus, Antiporus* (Fig. 229), *Chostonectes* (Plate 7k), *Cybister, Eretes, Homeodytes* (Plates 7d & 7j; Fig. 228), *Hydrovatus, Hyphydrus, Lancetes* (Plate 7c) and *Rhantus* (Fig. 221).

[*Further reading:* Watts (1963, 1978); Williams (1980); Lawrence and Britton (1991)].

Hydrophilidae (water-scavenger beetles)

The Hydrophilidae is a large family of beetles. Many species are terrestrial, but the larvae and adults of 19 genera are aquatic. Hydrophilids range in size from less than 3 mm (*Paracymus*) to greater than 45 mm (*Hydrophilus*) in length. Hydrophilids are generally found in standing water bodies and are common in aquaculture ponds. Generally, adult hydrophilids are poor swimmers and are propelled through the water by alternate strokes of the hind legs.

Hydrophilid larvae (Plates 7h & 7i) are carnivores and possess well-developed mandibles for capturing prey such as small crustaceans and other aquatic insects. In contrast, the adults are mainly herbivores or scavengers, feeding on dead and decaying vegetable matter (Anderson 1976).

Berosus is probably the most common hydrophilid beetle found in fish culture ponds. The larvae of *Berosus* are easily recognised by the upturned head and simple abdominal gill filaments along the body (Plate 7h; Fig. 225a). The adults of *Berosus* (Plate 7e; Fig. 223a) are drab mottled brown-coloured beetles with a very convex body, and which make an audible sound when handled. *Hydrochus* (Plate 7f), *Enochrus, Limnoxenous* and *Helochares* are other common hydrophilids in aquaculture ponds and farm dams.

[*Further reading:* Watts (1987, 1988a); Lawrence and Britton (1991); Lawrence (1992)].

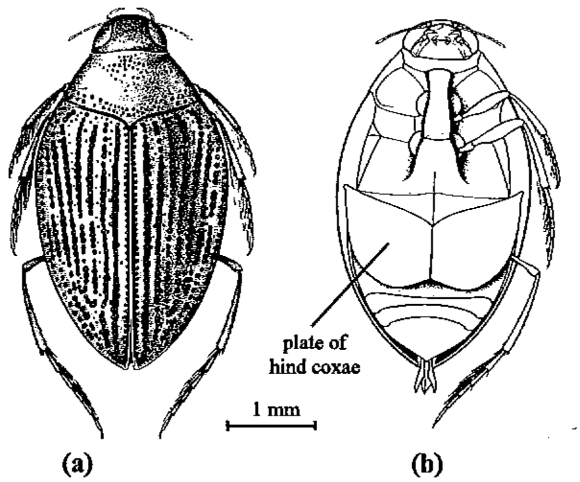


Fig. 218 *Haliplus testudo* (Haliplidae)
(a) dorsal view, (b) ventral view

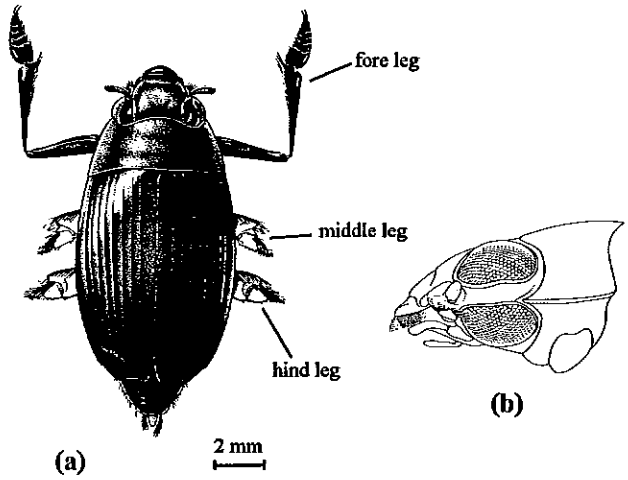


Fig. 219 *Macrogyrus oblongus* (Gyrinidae)
(a) dorsal view, (b) lateral view of head

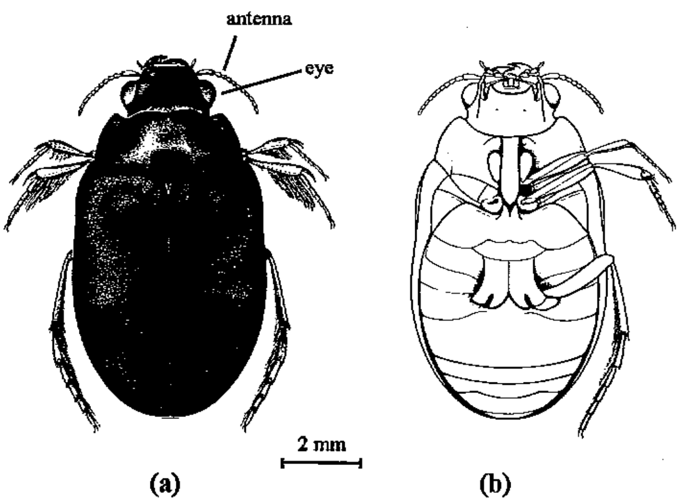


Fig. 220 *Hygrobia niger* (Hygrobiidae)
(a) dorsal view, (b) ventral view

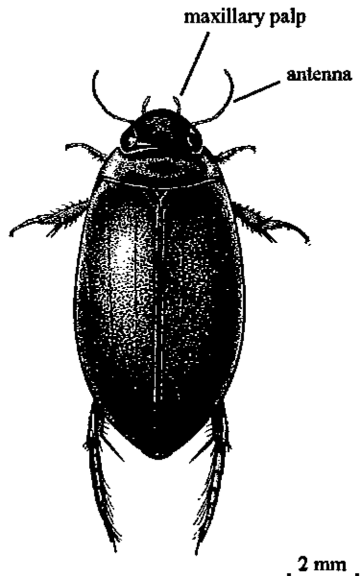


Fig. 221 *Rhantus suturalis*
(Dytiscidae)

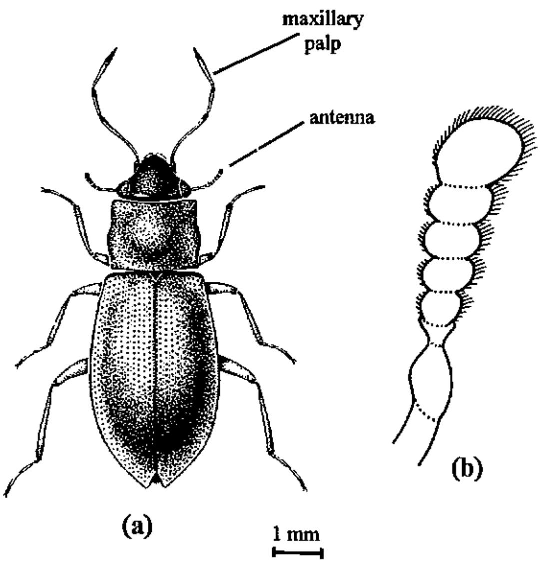


Fig 222 *Hydraena luridipennis* (Hydraenidae)
(a) dorsal view, (b) antenna

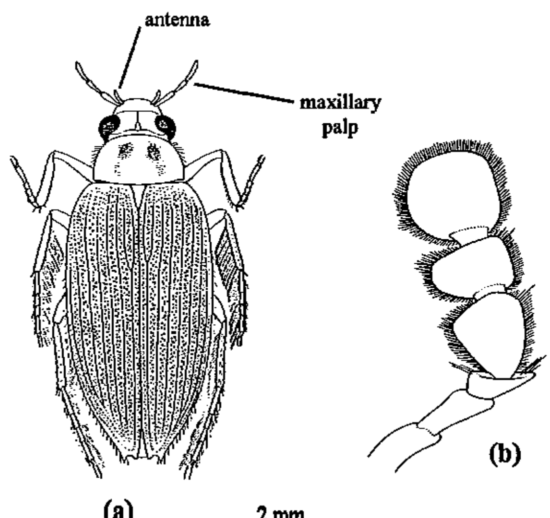


Fig 223 *Berosus* sp. (Hydrophilidae)
(a) dorsal view, (b) antenna

Gyrinidae (whirligig beetles)

Gyrinid beetles are well known and easily recognisable by their habit of rapidly skimming and whirling around on the surface of the water, often in aggregations. Adult gyrinids are usually glossy black in colour and very streamlined in appearance (Plate 7a; Fig. 219a). The eyes, which are completely divided (Fig. 219b) to allow viewing both beneath and above the water surface at the same time, are a distinguishing feature of the family.

Gyrinid larvae can be distinguished from other beetle larvae by the presence of 10 pairs of feathery abdominal gills (Plate 7l; Fig. 227a). Gyrinid larvae are active swimmers and predators, while the adults feed on insects which fall onto the water surface. Gyrinids prefer sheltered, slow moving or still waters. The family contains four genera, *Aulonogyrus, Dineutus, Gyrinus* and *Macrogyrus.*

[***Further reading:*** Ochs (1949); Lawrence and Britton (1991); Lawrence (1992)].

Other coleopteran families

The **Haliplidae** is a small family containing a single genus *Haliplus* (Fig. 218a) in Australia. Species of *Haliplus* are clumsy swimmers found in sheltered environments and amongst aquatic vegetation at the edges of ponds. Both the larvae and the adults of *Haliplus* are aquatic. The adults are characterised by having large post-coxal plates covering the hind legs.

Hygrobia is the only genus in the family **Hygrobiidae**. Both the larvae and adults of *Hygrobia* are aquatic and prefer still waters. Adults of *H. australasiae* and *H. nigra* (Plate 7b; Fig. 220a) are occasionally found in aquaculture ponds, but neither are common and the larvae have not been collected.

Species of **Hydraenidae** are tiny (about 1.5 mm) crawling beetles which usually are found amongst aquatic vegetation in still or slow-flowing water. Of the four genera recorded from Australia, only *Hydraena* (Fig. 222a) has been collected from aquaculture ponds.

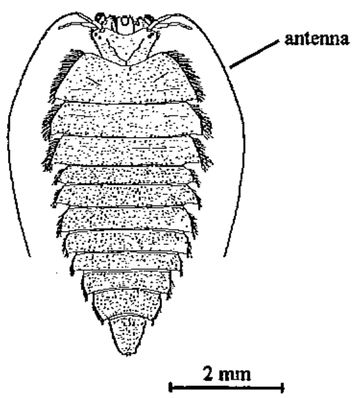


Fig. 224 Scirtidae

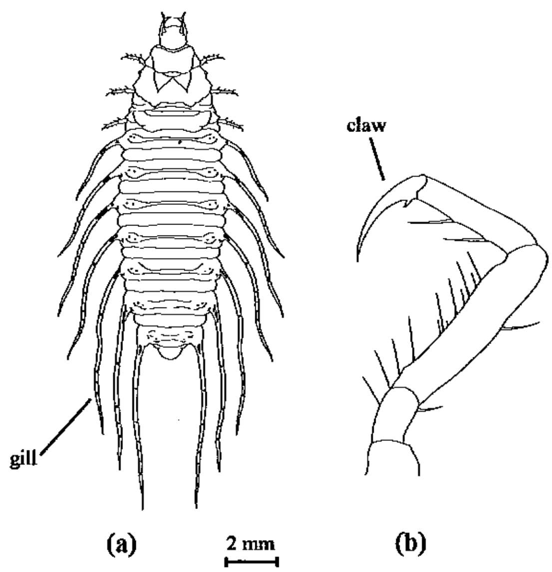


Fig. 225 *Berosus* (Hydrophilidae)
(a) dorsal view, (b) leg

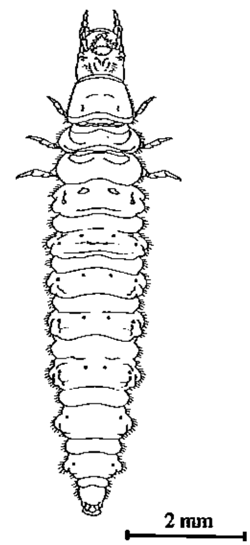


Fig. 226 Hydrophilidae

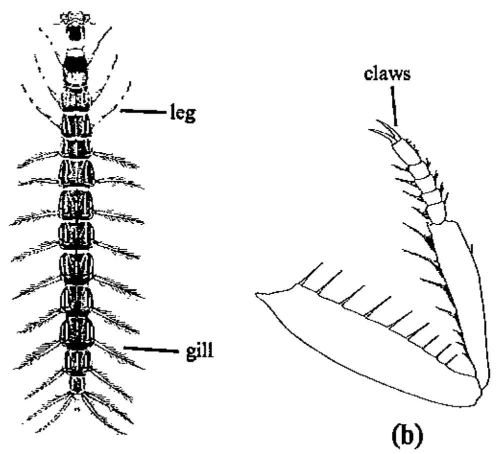


Fig. 227 *Macrogyrus* (Gyrinidae)
(a) dorsal view, (b) leg

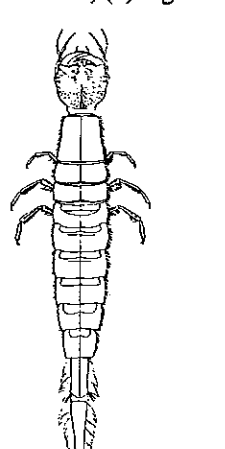


Fig. 228 *Homeodytes* sp.
(Dytiscidae)

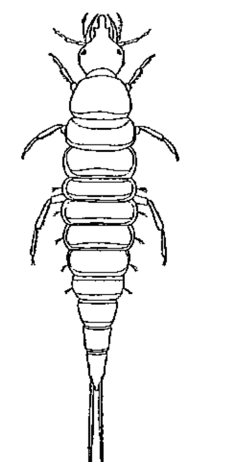


Fig. 229 *Antiporus* sp.
(Dytiscidae)

The aquatic larvae of species of **Scirtidae** (Plate 7g; Fig. 224) are somewhat flattened in appearance with a large head and distinctively long, multi-segmented antennae (> 10 segments). The adults usually are found in marginal vegetation.

The **Carabidae, Chrysomelidae, Limnichidae, Heteroceridae, Microsporidae** and **Staphylinidae** all contain some species that are at least semi-aquatic and which may occur along the margins of streams and ponds.

There are a number of semi-aquatic and aquatic weevils (**Curculionoidae**) in Australia; some species have been introduced from South America to control salvinia. The **Elmidae** and **Psephenidae** contain species that mostly occur in flowing waters and so are rarely collected from standing ponds, but some species of both families have been collected from flowing waters in trout hatchery facilities.

[***Further reading:*** Williams (1980); Lawrence and Britton (1991); Lawrence (1992); Haliplidae Watts (1988b); Hygrobiidae Britton (1981); Hydraenidae Zwick (1977)].

DIPTERA (flies, midges and mosquitos)

Biology, ecology and identification

The Diptera is a large insect order with nearly 8,000 species in Australia (Colless and McAlpine 1991). Some 20 families contain species that are either semi-aquatic or aquatic, but of these, only 9 families have larvae that are predominantly aquatic (Williams 1980). The most abundant and common, and therefore the most important species of dipteran larvae found in aquaculture ponds belong to the family Chironomidae.

Larval dipterans have a wide range of body forms (Plates 8a-h; Figs 230-241). Many dipteran larvae can utilise dissolved oxygen and do not need to return to the surface to breath. Larvae that need to replenish their air supply at the water surface, such as the Syrphidae and some culicids, usually possess breathing spiracles on the posterior end of the body, occasionally at the end of a breathing tube or siphon. Adult dipterans are distinguished from other insects by having only one pair of functional wings, the second pair of wings are reduced to small knobs called halteres.

The lifecycle of dipterans includes eggs, larvae, pupae and adults (complete metamorphosis). Eggs are laid singly or in masses. Culicid eggs are laid into a floating raft while the eggs of chironomids are laid into a jelly-like mass (Colless and McAlpine 1991). The larval stage, which usually has four instars, may last only a few weeks to several years, depending on the species. Most of the lifecycle is spent in the larval stage whereas the pupal and adult stages are relatively short. Some pupae, such as the Stratiomyidae and Ephydridae, retain their last larval skin and so are similar in appearance to the larval stage. Other pupae are dissimilar to the larval stage (eg. Chironomidae, Ceratopogonidae). The pupae may be either active or inactive.

Aquatic dipteran larvae occupy many levels of the trophic web in aquaculture ponds. Some species are detritivores and play a key role in recycling nutrients, many species are herbivores and few are carnivores. Dipteran larvae are eaten by many other species of aquatic animals including other invertebrates and vertebrate predators. In particular, chironomid larvae are the most common aquatic insects eaten by fish in fertilised fry rearing ponds at the MAFRISC (Ingram *unpub. data*).

The following key provides identifications to the more common dipteran larvae found in aquaculture ponds. The pupae of many species of aquatic dipterans are less known or rarely collected and for this reason a key to dipteran pupae is not included here.

Key to common pond-inhabiting dipteran larvae of south eastern Australia (modified from Williams (1980) and Colless and McAlpine (1991))

1. Head distinct and well sclerotised (Figs 230-235). 2

\- Head absent or incomplete (Figs 236-241) 6

2. Head retractile into thoracic segments (Fig. 230). .... **Tipulidae**

\- Head not retractile into thorax segments (Figs 231-235) 3

3. Three thoracic segments fused and enlarged, broader than abdominal segments; head large and highly mobile; active larvae (Figs 231 & 232) .. 4

\- Three thoracic segments nearly always distinctly separated; thorax usually as broad as abdomen (Figs 233 & 235) 5

4. Prominent mouth brush of setae on either side of labrum; thorax and abdomen without air sacs (Fig. 231) .... **Culicidae**

\- Mouth brushes absent; body often nearly transparent; thorax and 7th abdominal each usually with a pair of air sacs (Fig. 232) .... **Chaoboridae**

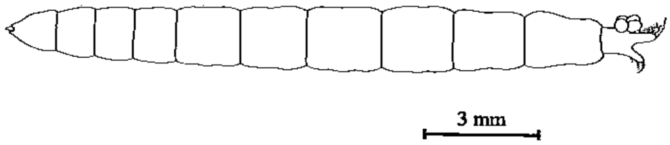


Fig. 230 Tipulidae

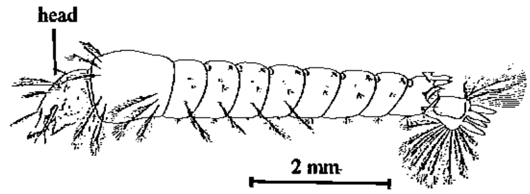


Fig. 231 *Anopheles* sp. (Culicidae)

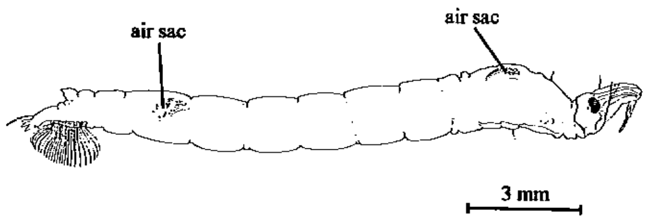


Fig. 232 *Chaoborus* sp. (Chaoboridae)

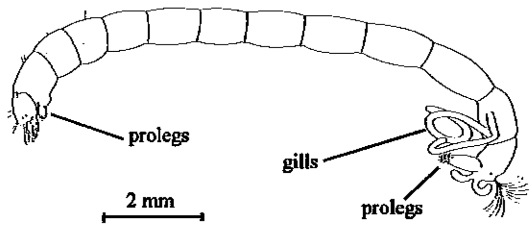


Fig. 233 *Chironomus* sp. (Chironomidae)

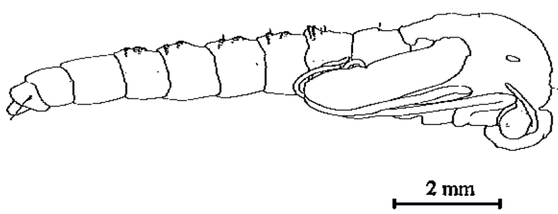


Fig. 234 Chironomidae pupa

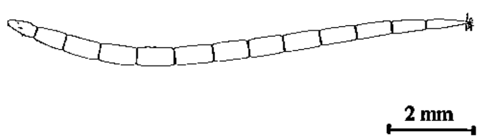


Fig. 235 *Bezzia* sp. (Ceratopogonidae)

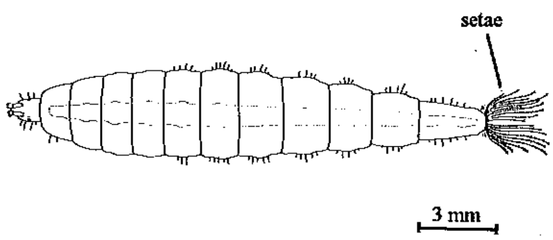


Fig. 236 *Odontomyia* sp. (Stratiomyidae)

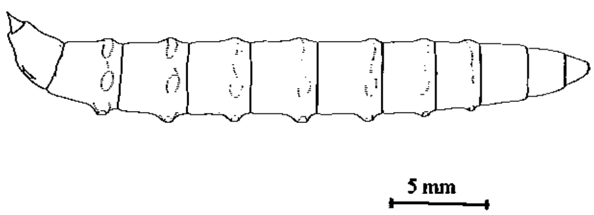


Fig. 237 Tabanidae

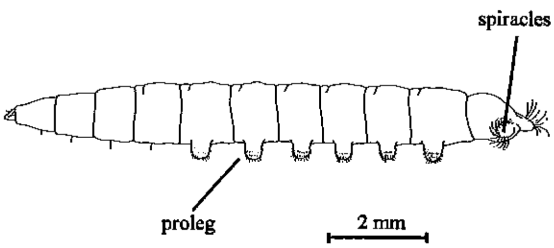


Fig. 238 Empididae

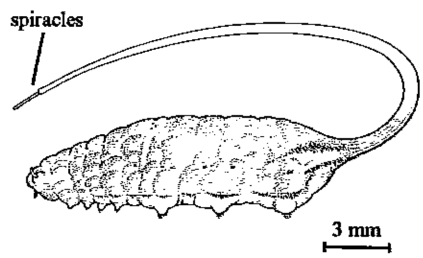


Fig. 239 Syrphidae

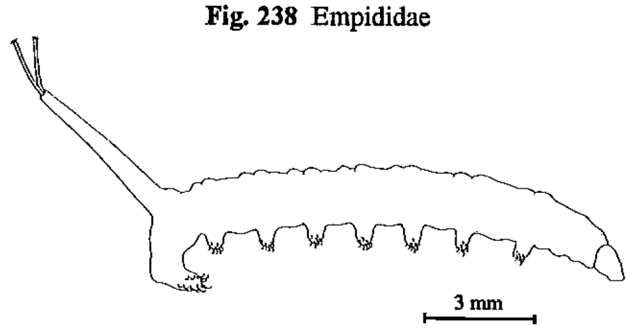


Fig. 240 Ephydridae

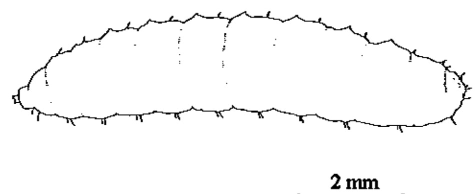


Fig. 241 Muscidae

5. Usually with a pair of partially or completely fused prolegs on thorax and a pair at apex of abdomen; body hairs, if present, not strongly developed (Fig. 233) .... **Chironomidae**

- Without prolegs, or if present, posterior pair completely fused; or head with distinct internal pharyngeal skeleton; or body hairs arising from sclerotised tubercles (Fig. 235) .... **Ceratopogonidae**

6. Head incomplete, usually sclerotized dorsally and retractile; antennae usually well-developed (Figs 236, 237 & 238) 7

- Head vestigial, not sclerotized and permanently retracted; antennae poorly developed or absent (Figs 239, 240 & 241) 9

7. Free part of head not retractile; prolegs absent; body somewhat dorso-ventrally flattened; integument leathery; posterior spiracles surrounded by hydrophobic setae (Fig. 236) .... **Stratiomyidae**

- Free part of head more or less retractile; prolegs present or, if absent, body cylindrical (Figs 237 & 238) 8

8. Anterior and middle segments each with a girdle of prolegs bearing hooks or appearing as fleshy swellings; respiratory organs close together, situated in a vertical cleft (Fig. 237).... **Tabanidae**

- Never more than one pair of prolegs on each abdominal segment; spiracles born on the surface or on distinct raised processes (Fig. 238) .... **Empididae**

9. Posterior spiracles close together at the end of an elongate tube which, when fully extended, is at least half body length; integument transversely wrinkled (Fig. 239) .... **Syrphidae**

- Without the above combination of characters.... 10

10. Apex of abdomen somewhat tapered, sometimes with retractile respiratory tube; posterior abdominal segments covered with setae, spines or setaceous tubercles (Fig. 240) .... **Ephydridae**

- Without the above combination of characters (Fig. 241) .... **Muscidae**

Chaoboridae (phantom midges)

Chaoborid larvae, particularly *Chaoborus* (Plate 8c Fig. 232), are characteristically transparent, hence the popular name "phantom larvae". The larvae, which have benthic and pelagic stages, are predators and will feed on small invertebrates and other aquatic insects. *Chaoborus*, is common and widespread in Australia and often is collected from aquaculture ponds.

[*Further reading:* Merritt and Cummins (1984); Williams (1980); Colless and McAlpine (1991)].

Chironomidae (midges, gnats and bloodworms)

The family Chironomidae contains more than 200 species from 86 genera in Australia (Colless and McAlpine 1991) and is the most widely distributed and often the most abundant group of insects in aquaculture ponds. Almost all species of the Chironomidae have semi-aquatic or aquatic larvae which are commonly called bloodworms. Adult chironomids are similar to, and often confused with, mosquitoes.

The most common and abundant species collected from aquaculture ponds of south eastern Australia belong to the genera *Chironomus* (Plate 8d; Fig. 233), *Procladius* and *Polypedilum*, but species from at least another 17 genera have also been recorded from ponds (Appendix I).

Densities of chironomids in the benthos of fertilised fry rearing ponds at the MAFRISC have reached 20,000 ind./m^2, but are more commonly 2,500-7,500 ind./m^2 (Fig. 242). Higher densities, in excess of 70,000 ind./m^2, have been recorded from other aquatic environments (eg. Maher and Carpenter 1984).

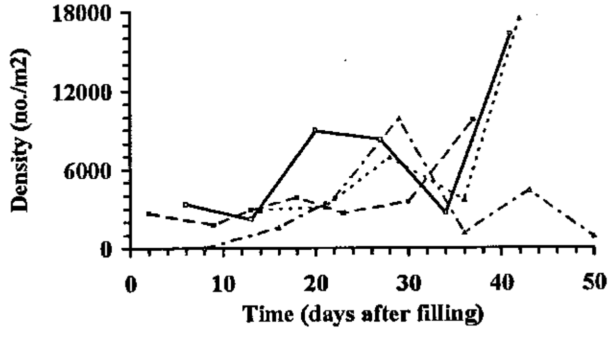


Fig. 242 Densities of chironomid larvae (no./m^2) in four fry rearing ponds at the MAFRISC during the 1992-93 season

The lifecycle of chironomids has been reviewed by Oliver (1971). At times large numbers of both the egg masses and the empty, cast off pupal skins can be seen in ponds. Most of the lifecycle is spent in the larval stage. Adults live for only a few days to weeks and are usually non-feeding. An entire lifecycle can be completed in a matter of weeks. The development of chironomids is influenced by a range of environmental factors including temperature, photoperiod, the amount and quality of food present and competition with other animals.

Chironomids occupy a range of habitats. In aquaculture ponds, chironomids live on or in the substrate with the majority occurring in the top 5 cm of sediment (Ford 1962). Many species live in silken tubes incorporating fine particles constructed by the larvae, while others are free-living. Chironomid larvae also live on hard substrates, submerged timber and aquatic plants. Occasionally chironomid larvae will leave the substrate and may be collected in plankton samples.

The name bloodworm is derived from the distinctive red or brown coloration often seen in species of the Chironominae. This colouration is due to the presence of haemoglobin, which retains oxygen and assists chironomids to tolerate poorly oxygenated waters such as sometimes occur in the bottoms of ponds.

Chironomid larvae are important in aquaculture ponds. Many species are detritivores or herbivores which feed on fine organic matter, bacteria and algae. Carnivorous species, such as *Procladius*, prey on other species of chironomid, oligochaetes, nematodes and other small invertebrates. Studies at the MAFRISC and other studies (Arumugam and Geddes 1987; Fox 1989; Rowland 1992) have shown that chironomid larvae are a major component in the diet of fry reared in aquaculture ponds. The pupae (Plate 8e; Fig. 234) are also eaten by fish. Chironomids are also prey for other animals, including aquatic insects, crustaceans and water birds.

[***Further reading:*** Oliver (1971); Pinder (1986); Colless and McAlpine (1991); Cranston (1994); Armitage *et al.* (1995)].

Culicidae (mosquitoes)

There are some 275 species of culicids that inhabit freshwaters in Australia of which all have aquatic larvae (Colless and McAlpine 1991). The more commonly encountered species in aquaculture ponds in south eastern Australia belong to the genera *Aedes, Anopheles* (Fig. 231) and *Culex* (Plate 8b). Culicid larvae prefer lentic waters, such as ponds and puddles. The larvae and pupae are active swimmers and regularly come to the water surface to replenish their air supply. Many culicid larvae feed on fine organic matter, such as microscopic organisms and detritus, whereas other species are predatory.

[***Further reading:*** Dobrotworsky (1965); Williams (1980); Russell (1993)].

Other dipteran families

The larvae of **Ceratopogonidae** recorded from aquaculture ponds are stiff, narrow, elongate larvae that swim with a rapid serpentine motion (Plate 8f). The adults of some species are best known as blood-sucking sandflies in estuarine areas. The larvae of the aquatic species of ceratopogonid, particularly *Bezzia* (Fig. 235) are often collected from aquaculture ponds, but are not common. Elson-Harris (1990) provides a key to ceratopogonid larvae.

Although most larvae of the **Stratiomyidae** are terrestrial, *Odontomyia* has aquatic larvae, which are collected regularly from aquaculture ponds. These leathery, somewhat dorso-ventrally flattened larvae (Plate 8g; Fig. 236) are slow moving and are found drifting at the water surface in shallow areas of ponds.

Only a few genera of the family **Syrphidae** have aquatic larvae. The larvae of *Eristalis* are well known and easily recognised by their long, telescopic breathing tube (Fig. 239), hence the popular name "rat-tailed maggots". *Eristalis* larvae are found in nutrient rich ponds and stagnant water.

Tabanid larvae are generally semi-aquatic, preferring damp habitats. Those species which are aquatic usually are found in shallow muddy environments such as swamps, ponds, and lakes. Tabanid larvae are typically bullet shaped and tapered at both ends (Plate 8h; Fig. 237). The adults are large flies (6-20 mm) and many species are known to bite humans and stock.

The **Tipulidae** (Plate 8a; Fig. 230) is a large cosmopolitan family that contains nearly 700 species in Australia. Most species of tipulid are described from mountainous areas of south eastern Australia. Tipulid larvae are commonly found in damp soil or boggy marsh areas, however, some are fully aquatic and may reach up to 5 cm long. The adult tipulid typically has a slim body with very long legs.

Species of **Ephydridae** (Fig. 240), **Dixidae, Sciomyzidae, Empididae** (Fig. 238) and **Muscidae** (Fig. 241) have all been recorded from standing waters and it is most likely that these may also occur in aquaculture ponds.

[***Further reading:*** Merritt and Cummins (1984); Williams (1980); Colless and McAlpine (1991)].

TRICHOPTERA (caddisflies)

Biology, ecology and identification

Almost all larvae of the Trichoptera are aquatic. One of the main distinguishing features of many larval caddisflies is their habit of constructing a protective case in which they live These cases are made from either sand particles, vegetable matter or secretions produced by the larvae. Usually these cases are portable, but some species may construct a case fixed to the substrate. The shape and composition of the case can be used as a diagnostic feature for some groups. The larvae of caddisflies inhabit a wide range of aquatic environments from fast flowing streams to freshwater ponds. Many species are found crawling over the substrate, but some species, particularly *Notalina spira*, are active swimmers. The adults are small to moderate-sized, moth-like insects which are active fliers. The order is represented by 25 families in Australia (Neboiss 1991).

Larval caddisflies have a wide range of feeding habits (Neboiss 1991). Case-making caddisflies such as the Leptoceridae and Calamoceratidae are usually herbivores, detritivores or suspension feeders, and consume algae and plant matter (aquatic macrophytes, terrestrial wood and leaves) or fine organic particles. Free-living trichopterans, such as the Ecnomidae, are mostly predators. Some species are omnivorous or change their diet as they grow (Neboiss 1991).

Caddisflies can be an important part of the diet of many fish species. For example juvenile golden perch held in farm dams consume caddisfly larvae (Barlow *et al.* 1986). Although large numbers of leptocerid larvae occur in fry rearing ponds at the MAFRISC, they do not appear in the diet of fry reared in these ponds (Ingram *unpub. data*).

The following key is based mainly on the construction of the case and is designed only as a guide to the more common species found in aquaculture ponds and farm dams. The key in Dean *et al.* (1995) should be used to confirm identifications.

Key to common pond-inhabiting trichopteran larvae of south eastern Australia

1. Larvae construct and live in portable cases (Figs 243-248); abdominal gills present; first abdominal segment with dorsal and/or lateral protuberances (Fig. 243) 2

- Larvae free-living or live in a fixed retreat or a silken purse; first abdominal segment without protuberances; abdominal gills absent (Figs 249 & 250) 4

2. Larval case dorso-ventrally flattened, constructed from two pieces of leaf (Fig. 244)........................ .... **Calamoceratidae** (*Anicentropus*)

- Larval case constructed from sand grains or pieces of plant matter (Figs 243 & 245-248)....... .... **Leptoceridae**...3

3. Larval case box-shaped and constructed from plant matter (Fig. 245), or conical and constructed from sand grains (Fig. 246)....*Oecetis*

- Larval case elongate, conical and constructed from spirally arranged plant matter (Fig. 247)..... .... *Notalina spira*

- Larval case constructed from pieces of organic matter, straw or small twigs (Fig. 248) .... *Triplectides*

4. Final instar larvae construct a portable transparent silk purse-like case (Fig. 249); abdominal segments swollen; abdominal prolegs not well-developed .. **Hydroptilidae** (*Hellyethira*)

- Without silk purse-like case; abdomen not swollen; abdominal prolegs well-developed (Fig. 250) .... **Ecnomidae** (*Ecnomus*)

Leptoceridae

The Leptoceridae, with 83 species known from Australia, is one of the largest groups of caddisfly, and its larvae are by far the most commonly encountered in aquaculture ponds. *Triplectides* (Plate 8j; Fig. 243) utilises hollowed out pieces of wood or grass stems and twigs for its case (Fig. 248) and is the most abundant trichopteran in aquaculture ponds. *Oecetis* larvae construct box-shaped cases from plant material (Plate 8i; Fig. 245) or tubular cases from sand grains (Fig. 246). *Notalina spira* constructs a narrow spiralled case (Fig. 247) from plant matter and is often seen swimming through the water.

[***Further reading:*** Neboiss (1991); St Clair (1991, 1994)]

Other trichopteran families

Species of the family **Hydroptilidae** are small trichopterans which are occasionally collected from ponds. The final instar (5th instar) of species in this family is easily recognised as it has swollen abdominal segments and constructs a laterally flattened, often transparent, purse-shaped silken case (Plate 8k; Fig. 249).

Anicentropus, the only genus in the family **Calamoceratidae**, may be found in permanent aquaculture ponds and farm dams. The case, which is constructed from two pieces of leaf (Fig. 244), and a dense fringe of setae along the lateral margins of the abdomen easily distinguish this genus from other caddisflies.

Ecnomid larvae do not construct a portable case but instead build a silken tube or retreat which incorporates plant and detrital material. Ecnomids feed on organic particles and other aquatic invertebrates. The family contains two genera, but only *Ecnomus* (Plate 8l; Fig. 250) has been collected from aquaculture ponds.

[*Further reading:* Hydroptilidae Wells (1985); Calamoceratidae Dean and Cartwright (1991); Ecnomidae Cartwright (1991)].

LEPIDOPTERA (moths and butterflies)

Most lepidopterans are terrestrial, but moths from the family Pyralidae have larvae and pupae which are aquatic in standing and flowing water. The larvae graze on algae and aquatic plants. Some larvae have filamentous abdominal gills (Plate 8m; Fig. 251) and several species from the genera *Blechroglossa* and *Parapoynx* construct flat cases from the leaves of their food plant.

[*Further reading*: Nielsen and Common (1991)].

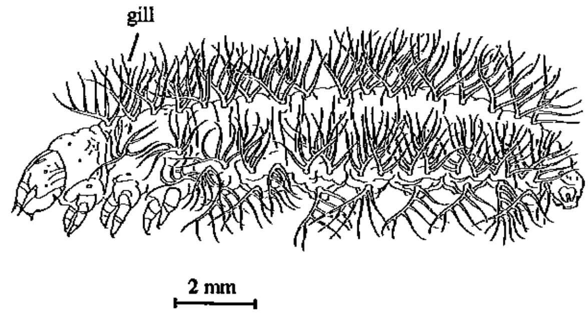


Fig. 251 Larva of a pyralid moth (Lepidoptera)

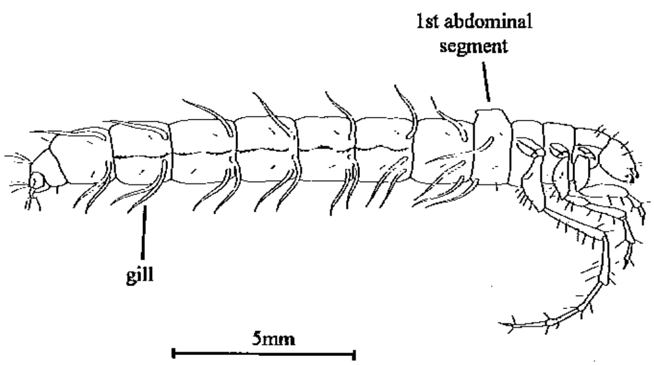


Fig. 243 *Triplectides australis* (Leptoceridae)

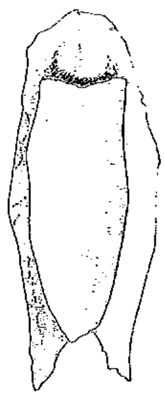


Fig. 244 *Anicentropus* sp. case (Calamoceratidae)

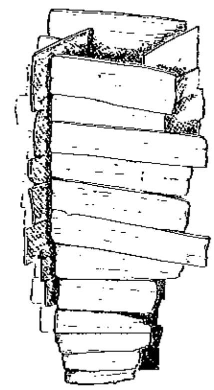


Fig. 245 Case of *Oecetis* sp.

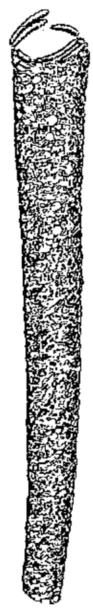


Fig. 246 Case of *Oecetis* sp.

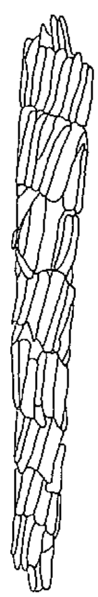


Fig. 247 Case of *Notalina spira*

Fig. 248 Case of *Triplectides australis*

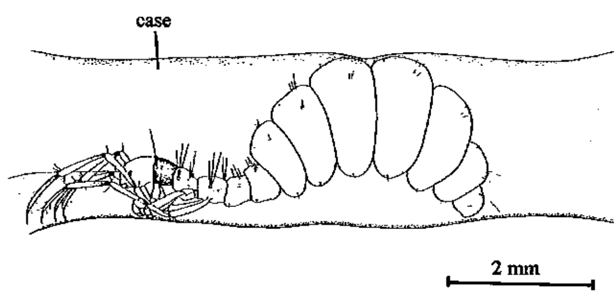


Fig. 249 *Hellyethira* sp. (Hydroptilidae) in case

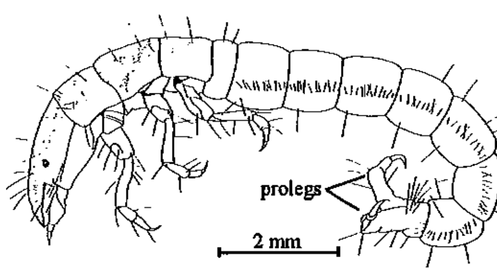


Fig. 250 *Ecnomus* sp. (Ecnomidae)

OTHER INSECT ORDERS

The larvae of the **Megaloptera** (alder flies or dobson flies) are aquatic and usually inhabit well oxygenated, flowing streams (Williams 1980; Theischinger 1991b). Although megalopteran larvae do not occur in aquaculture ponds, the larvae of *Archichauliodes* (Corydalidae) (Fig. 177) have been collected from the flowing waters of the trout hatchery at the MAFRISC.

Most larvae of the **Neuroptera** (lacewings) (Fig. 169) are terrestrial, but some are at least semi-aquatic. Species of the Osmlyidae and Neurorthidae have larvae that are associated with damp environments and stream habitats, and the larvae of the Sisyridae live in, and feed on, freshwater sponges (Williams 1980; New 1991). These larvae have long, needle-like sucking mouth parts.

Only one family of the **Mecoptera** (Scorpionflies), the Nannochoristidae, contains species that have aquatic larvae. All other species of mecopteran are terrestrial. The larvae, such as those of *Nannochorista* (Fig. 179) , occur in accumulations of silt in shallow, slow flowing streams (Byers 1991). The adults are terrestrial.

The majority of the **Hymenoptera** (bees and wasps) are terrestrial, but there are several families in which the larvae of some species parasitise aquatic insects. The adults of *Prestwichia* can swim underwater to deposit eggs on its host, zygopteran larvae (Williams 1980; Naumann 1991).

Some species of **Orthoptera** (grasshoppers and crickets), such as *Bermiella acuta* are adapted to a semi-aquatic life (Norris 1991).

Table 7 Classification of vertebrates associated with aquaculture ponds and farm dams (common names or representatives associated with ponds in brackets)

Subphylum	Class	Order
Vertebrata (vertebrates)		
	Osteichthyes (bony fish)	
		Cypriniformes (carp & goldfish)
		Siluriformes (catfish)
		Salmoniformes (salmon & trout)
		Cyprinodontiformes (mosquito fish)
		Perciformes (bass, perch, cod & gudgeons)
	Amphibia (amphibians)	
		Salientia (Anura) (frogs & toads)
	Reptilia (reptiles)	
		Testudines (turtles & tortoises)
		Squamata (lizards & snakes)
	Aves (birds)	
		Podicipediformes (grebes and dabchicks)
		Pelecaniformes (cormorants, darters & pelicans)
		Ciconiiformes (egrets, ibises & herons)
		Anseriformes (ducks, geese & swans)
	Mammalia (mammals)	
		Monotremata (platypus)
		Rodentia (water-rats)

AQUATIC AND SEMI-AQUATIC VERTEBRATES

The vertebrates are those animals which possess a backbone. Within the vertebrates, there are several major groups which contain species that are aquatic or closely associated with aquatic habitats. These include fish, frogs and toads, turtles (or tortoises), lizards, birds and mammals (Table 7).

OSTEICHTHYES (fish)

Fish are generally cold-blooded (poikilothermic) aquatic vertebrates typically with gills and fins. There are three main classes of fish: the Cephalaspidomorphi, jawless fish with pouched gills (lampreys); Chondrichthyes, fish with cartilaginous skeletons (sharks and rays); and Osteichthyes, fish with bony skeletons (bony fish). In Australian freshwaters there are about 200 species of fish which occur in a wide range of aquatic habitats and, not surprisingly, certain species thrive in aquaculture ponds. Species which are currently being reared in aquaculture ponds of south eastern Australia are listed in the introduction.

Apart from the species of fish intentionally stocked into aquaculture ponds, other species may also find their way into the ponds, particularly if inlets are poorly screened. These fish can cause several problems, especially if they occur in large numbers. They may prey directly on the stocked fish, or compete with them for food. Barlow and Bock (1981) found that there was a 50% reduction in the survival rate of golden perch fry stocked into farm dams that contained mosquito fish (*Gambusia holbrooki*). Despite their small size, mosquito fish can harass larger fish by nipping at their tails. Unwanted fish may also harbour parasites or diseases that may spread to the stocked fish. Rowland and Ingram (1991) suggested that European carp (*Cyprinus carpio*) is a carrier of the anchor worm (*Lernaea* sp.) and may have been responsible for its spread to native fish. The presence of unwanted fish is also a nuisance during pond harvest as added labour is required to separate them from the stocked fish.

The most reliable method of eliminating unwanted fish is to completely drain and dry the pond, then refill through a screened inlet. The screen size may need to be as small as 0.5 mm aperture size to prevent most fish eggs and larvae from entering the pond. Alternatively, ponds which cannot be drained or screened can be treated with a single application of 200 kg/megal. of slaked lime which raises the water pH to a level that is toxic to many aquatic organisms including fish. The treated pond should not be stocked with fish for at least one month, or until the water pH has dropped to normal, and aquatic organisms (zooplankton and insects) have recolonised the pond.

Identification keys and descriptions of Australian native freshwater species and introduced species can be found in Cadwallader and Backhouse (1983), Merrick and Schmida (1984), Allen (1989) and McDowall (1996). Information on stocking farm dams with fish can be found in Anon (1989), MacKinnon (1989), Anon (1990) and Barlow *et al.*(1990).

AMPHIBIA (tadpoles and frogs)

Frogs are cold-blooded (poikilothermic) vertebrates with soft glandular skin and four limbs. They have a lifecycle that typically includes eggs, aquatic larvae (tadpoles), 'metamorphlings' (immature frogs) and adults (Hero *et al.* 1991). The eggs of most species are laid in clear jelly masses which sink whereas those of *Limnodynastes* are laid in a white floating frothy mass. Most tadpoles are aquatic and possess gills through which they breathe. Tadpoles feed mainly on algae and detritus. The duration of the tadpole stage is variable and may last from just a few weeks to over a year, depending on species, water temperature and food supply (Hero *et al.* 1991). Adult frogs are semi-aquatic or terrestrial.

Frogs and tadpoles are often found in and around aquaculture ponds, and are occasionally eaten by fish. For example, tadpoles are a prominent part of the diet of juvenile barramundi (> 40 mm) in freshwater rearing ponds (Barlow *et al.* 1993).

High densities of tadpoles can sometimes develop in fry rearing ponds, as was the case in a 0.3 ha pond at the NFC when over 5,000 tadpoles were harvested (Ingram *unpub. data*). A survey of fish farmers in Florida and Arkansas (USA) found that infestations by tadpoles were considered a serious problem in aquaculture ponds (Kane *et al.* 1992). Tadpoles may reduce primary productivity (Seale 1980), compete with fish for food, and serve as vectors for some fish diseases and parasites. The combined effects of high fish and tadpole biomass can lead to poor water quality, such as low dissolved oxygen. Separating fish from tadpoles during harvest is time consuming and can subject fish to stress and injury (Kane *et al.* 1992).

There are a number of methods to control tadpoles including treating ponds with formalin (Helms 1967) or a lampricide (Kane and Johnson 1989). However, since certain species of frogs are protected by legislation nationally, non-destructive methods of controlling frogs should be used in preference to chemicals. These include removing egg masses from the water, reducing frog habitat (marginal vegetation) from around the ponds, and erecting frog-proof fences.

Species of frog which occur around aquaculture ponds and farm dams belong to two families. The Hylidae (tree frogs) typically have pads on the tips of their fingers and toes which aid climbing. The more common species belong to the genus *Litoria*. In contrast, species of Myobatrachidae (formerly Leptodactylidae) (southern frogs) lack pads on the fingers and toes. The larvae of several species of marsh frog (*Limnodynastes*) have been collected from aquaculture ponds. No reliable key is available to identify tadpoles of Australian frogs, but Martin (1965) and Martin *et al.* (1966) provide keys to the eggs and tadpoles of frogs in the Melbourne area. Adult frogs can be identified from keys in Hero *et al.* (1991) and Cogger (1992).

[*Further reading:* Tyler (1989)].

REPTILIA (turtles)

The reptiles, which includes crocodiles, lizards, snakes, turtles and tortoises, are cold-blooded, air-breathing vertebrates which are mostly terrestrial in habitat. Of these, only the freshwater turtles (also called tortoises) occur in aquaculture ponds and farm dams, although in northern Australia crocodiles are being farmed in ponds.

Australian freshwater turtles mostly belong to the family Chelidae. Species that regularly occur in aquaculture ponds in south eastern Australia include the eastern long-necked turtle (*Chelodina longicollis*), the Murray short-necked turtle (*Emydura macquarii*) (Murray-Darling Basin) and the eastern short-necked turtle (*E. signata*) (coastal areas on northern NSW and southern Queensland). Several other species of turtle occur in south eastern Australia, but these are essentially river-dwelling species. Although turtles spend much of their time in the water, they will leave the water to lay eggs and move to other water bodies. For this reason, they can colonise isolated water bodies.

Turtles are mostly carnivorous, feeding on fish, tadpoles, molluscs and crustaceans, and so are a nuisance in aquaculture ponds. Since all native reptiles, including turtles, are protected by legislation, offending animals should be removed rather than destroyed.

[*Further reading:* Cann (1978); Cogger (1992)].

AVES (birds)

The birds (Aves) are warm-blooded, air-breathing, feathered vertebrates which are adapted to aerial life. Birds that most frequently occur around aquaculture ponds and farm dams are the wading birds (herons and egrets), diving birds (cormorants and darters) and web-footed birds (ducks, grebes etc.). Some of these species are considered a pest in aquaculture ponds.

The cormorants (shags) are notorious fish and crustacean predators. There are five species of cormorants in Australia; the black-faced cormorant (*Leucocarbo fuscescens*), pied cormorant (*Phalacrocorax varius*), little pied cormorant (*P. melanoleucos*) (front cover), black cormorant (*P. carbo*) and little black cormorant (*P. sulcirostris*). The black-faced cormorant is restricted to the coastal regions of southern Australia, while the other species occur throughout much of Australia (Slater *et al.* 1994). Fish are the major item in the diet of these birds, though they will also feed on aquatic insects, crustaceans and amphibians (McNally 1957; Barker and Vestjens 1989).

Cormorants can eat up to 27% of their body weight per day, with daily intake ranging from 125g/day for little pied cormorants to in excess of 500g/day for black cormorants (Barlow 1995). The impact of fishing by flocks of cormorants on fish in aquaculture ponds can be quite devastating. Barlow and Bock (1984) found that cormorants consumed some 50% of the fingerlings stocked into farm dams, and Rowland (1995) reported survival of juvenile silver perch in four ponds frequented by large numbers of cormorants was 0.3-3.5%, and the largest fish swallowed by a black cormorant weighed 373 g. Apart from devouring small fish, cormorants also cause injury and stress. Juvenile silver perch in ponds under attack from cormorants ceased feeding and, at harvest, many of the fish showed signs of injury from bird strikes (Rowland 1995).

The darter (*Anhinga melanogaster*) is another fish-eating diving bird that can be a problem in aquaculture ponds.

Wading birds, particularly the white-necked heron (*Ardea pacifica*) and white-faced heron (*Ardea novaehollandiae*), are common around aquaculture ponds. They may take their toll on fish and crustaceans in ponds, but their impact is not as great as cormorants because they are limited to wading-depth water around the edges of the ponds. Other species that frequent aquaculture ponds include the grebes (*Podicepes* spp.) and ducks and teals (eg. *Anas* spp. and *Chenonetta* spp.), but fish are only a minor part or absent from their diet (Barker and Vestjens 1989).

Controlling bird predation can be costly and time consuming. In the USA, predation on channel catfish by the double-crested cormorant (*Phalacrocorax auritus*) costs the industry about $US 4.0 million annually ($US 2.0 mil. worth of eaten fish and $US 2.0 mil. in management and control costs).

The use of harassment devices such as noise makers (eg. gas cannons) and scarecrows to control bird predation are mostly ineffective because the birds eventually become accustomed to them. More often than not, lethal control measures, namely the use of fire-arms, are used. Although all native birds, including cormorants, are protected by legislation, a permit can be obtained to control pest species. However, the most effective method, though expensive, is to exclude the birds by enclosing the ponds in bird-proof netting.

[***Further reading:*** Frith (1982); Reader's Digest (1986); Cayley (1987); Slater *et al.* (1994)].

MAMMALIA (mammals)

The mammals are warm-blooded, air-breathing, vertebrates which are mostly terrestrial in habitat. Two species, the platypus (*Ornithorhynchus anatinus*) and the water-rat (*Hydromys chrysogaster*) (Plate 8n) have amphibious habits and, although they prefer to live near permanent water bodies such as rivers and streams, they are found occasionally around aquaculture ponds.

The platypus is a well-known monotreme, having a characteristic bill, broad tail, webbed feet and water-repellent fur. The platypus feeds mostly on aquatic invertebrates, but occasionally small vertebrates are eaten.

The water-rat is a native Australian rodent which is about the size of a rabbit and characterised by having broad, partially-webbed hind feet, water-repellent fur and a thick, white-tipped tail. Water rats are active carnivores which prey on large aquatic insects, molluscs, crustaceans, fish and amphibians. Some people consider water-rats to be a pest around aquaculture facilities.

Both the platypus and the water-rat are protected by legislation, so the preferred method of control for these mammals, if they are being a nuisance, is to trap them alive and remove them to a new location away from the ponds. Alternatively, small fences may be constructed around ponds to prevent their entry.

[***Further reading:*** Watts and Aslin (1981); Strahan (1988); Grant (1989)].

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GLOSSARY

Abdomen: posterior part of the body lacking segmented legs.

Abiotic: non-living.

Abundance: total number of individuals in an area, volume, population or community.

Amorphous: of indeterminate or irregular form; with no visible differentiation in structure.

Antenna(e): Jointed feeler on head.

Antennule: a small antenna, specifically first pair of antennae in crustaceans.

Anterior: pertaining to, or situated toward, the head end.

Aperture: hole or opening.

Appendage: a limb (eg. leg, proleg, etc) attached to the body.

Auricle: ciliated lateral protrusion or appendage of some rotifers.

Autotroph: an organism capable of synthesising its own nutritive substances, especially by photosynthesis (primary producer).

Bacterivore: bacteria-eating.

Benthic: pertaining to the pond bottom or floor, bottom dwelling.

Bifurcate: forked or having two prongs.

Binary fission: division into two parts; the most common form of asexual reproduction in protists.

Biomass: a quantitative estimate of the total mass of organisms per unit area; measured as volume, mass (live, dead, dry or ash-free weight) or energy.

Biotic: pertaining to life or living organisms.

Biramous: divided into two branches.

Bivalved: having two valves or shells which are hinged together.

Bloom(s): an explosive increase in the density of, for example, phytoplankton or zooplankton, within an area.

Branchial chamber: chamber produced by the carapace of crustaceans in which the gills are situated.

Brood pouch: space between the body and the carapace in female cladocerans; where eggs are deposited and held during their development (brood chamber).

Calcareous: rich in calcium salts (eg. calcium carbonate).

Carapace: a shield-like extension of the exoskeleton of crustaceans, which arises from a fold of the head.

Carnivore: flesh-eating.

Cell: one of the units consisting of a nucleus and cytoplasm surrounded by a membrane. Make up the building blocks of plant and animal bodies.

Cephalothorax: the body region formed by fusion of head and thorax.

Cerci: paired, often jointed, appendages at end of abdomen.

Chelicerae: first pair of appendages on the head of arachnids.

Chitin (Chitinous): a horny organic substance (mucopolysaccharide) which occurs in the cuticle or exoskeleton of some invertebrates.

Chlorophyll: pigment found in plants which absorbs light energy for photosynthesis.

Chloroplast: cell body (organelle) containing chlorophyll.

Cilia: minute, hair-like outgrowths.

Collagen: the protein contained in connective tissue and bones.

Colony (colonial): collection of organisms living together.

Commensal: an organism living with another and sharing food, both species as a rule benefiting by the association, or one benefiting and the other not being harmed.

Community: a well-defined assemblage of plants and/or animals, clearly distinguishable from other such assemblages.

Conjugation: a type of sexual reproduction during which two cells unite.

Copepodite(s): a larval stage of copepods which has the general adult features but the abdomen is usually unsegmented and there may be only three pairs of thoracic appendages.

Copulation: sexual union.

Corona: disc of cilia on the anterior end of a rotifer; used for locomotion and to create feeding currents. The corona may be composed of one or two ciliated rings.

Coxa: proximal joint an insect leg.

Cyclomorphosis: a cycle of changes in form, such as seasonal changes in morphology.

Cyst: spore-like cell with a resistant protective wall; an enclosing membrane surrounding an organism that has passed into a dormant condition.

Cytoplasm: the living substance of a cell.

Decomposition: degradation of organic matter into simple organic and inorganic compounds.

Desiccation: removal of water; the process of drying.

Detritivore: an organism feeding on detritus.

Detritus: fragmented particles of organic matter derived from the decomposition of plant and animal remains.

Diapause: a resting phase; a period of suspended growth or development.

Dioecious: having male and female reproductive organs on different individuals.

Diploid: having a double set of similar chromosomes.

Distal: end furthest from the body or point of attachment.

Dormant: in a state of rest or inactivity.

Dorso- (dorsal): pertaining to, or situated on the back.

Ecdysis: the shedding or casting off of an outer coat or integument.

Elytra: the pair of hardened shell-like forewings of beetles.

Encrusting: growing like a crust on a surface.

Encystment: to become enclosed in a cyst.

Endopodite: the inner branch of biramous crustacean appendage.

Ephippium: a thickened and sometimes pigmented container derived from the carapace and enclosing "resting eggs" in cladocerans. The ephippium is cast off with the carapace during moulting.

Epibenthic: living on or attached to the pond bottom or floor.

Epiphytic: living on or attached to plant surfaces.

Epizoic: living on or attached to the body of an animal.

Estuarine: found in estuaries.

Eutrophic: having high levels of nutrients.

Exopodite: the outer branch of biramous crustacean appendage.

Exoskeleton: an external hard, supporting, protective covering or integument.

Exuvium: cast off skin or exoskeleton.

Femur (Femora): the third segment of an insect's leg (counting from the base).

Filiform: threadlike.

Flagella: long, minute, hair-like outgrowths.

Foliate: leaf-like covering.

Forewings: the first or anterior pair of wings of insects.

Free-living: living independently of any host organism.

Gelatinous: jelly-like.

Gametes: mature reproductive cells (usually haploid), such as sperm and eggs.

Geniculate: having a knee-like joint or bend.

Gill: feathery, platelike or filamentous aquatic organ used for respiration.

Globular: globe-shaped.

GRC: Grafton Research Centre (N.S.W. Fisheries).

Haemoglobin: protein responsible for the red colour of blood and which carries oxygen to the tissues.

Haploid: having a single set of chromosomes.

Head capsule: the head of an insect, particularly of the larvae.

Headshield: section of exoskeleton which covers the head anterior to the carapace of cladocerans.

Herbivore: plant-eating.

Hermaphrodite(s): an organism having both the male and female reproductive organs.

Heterotroph(s): an organism incapable of synthesising its own nutritive substances, reliant on other organisms, such as plants.

Hydrofuge: water-repelling or non wettable.

ind./l: individuals per litre.

ind./m²: individuals per square metre.

Instar: stage of development or growth between moults.

Integument: a skin, shell or outer layer.

Labial palp: segmented sensory appendage of the labium in insects; used in manipulating and tasting food.

Labium: lower lip of an insect, consisting of paired appendages (ie. labial palps)

larva(e): an early or immature developmental stage of an organism.

Lateral (laterally): pertaining to, or situated on the side.

Littoral: pertaining to the shore-line.

Lorica: a firm, rigid protective external case or shell born by some protozoans and rotifers.

Macroinvertebrates: macroscopic invertebrates.

Macroscopic: visible to the naked eye (> 1.0 mm).

MAFRISC: Marine and Freshwater Resources Institute, Snobs Creek.

Maxillae: mouth parts in insects and crustaceans, lying behind the mandibles.

Maxillary palp: segmented sensory appendage of the maxillae of insects; used in manipulating food.

Membrane: a thin film, skin or layer.

Metamorphosis: a marked structural transformation during the development of an organism.

Metasternum: the third segment of the sternum of an insect thorax.

Microcrustaceans: microscopic crustaceans.

Microscopic: very small; indistinct without the use of a microscope (<1.0 mm).

Mixotroph(ic): an organism capable of being both an autotroph and a heterotroph.

Morphology: form or structure of an organism, especially external features.

Moult: to cast or shed the outer skin or integument.

Nauplius: the earliest larval stage of certain crustaceans.

Neonate(s): newborn cladoceran.

NFC: Narrandera Fisheries Centre (N.S.W. Fisheries).

Nucleus: complex spherical mass within a cell containing genetic codes, essential to growth, metabolism and reproduction.

Ocellus: a simple eye or eye spot, or an eye-like marking.

Omnivore: both flesh- and plant-eating.

Operculum: a hard plate attached dorsally to the foot of some gastropod snails which closes the opening of the shell when the animal is withdrawn.

Ovary: the female reproductive organ.

Parasite: an animal or plant living on or in another organism (the host), from which it derives food, the host usually being harmed by the association.

Parthenogenesis: reproduction and development of a female gamete (egg) without fertilisation by a male gamete (sperm).

Pedipalps: the second pair of appendages on the head of an arachnid.

Pelagic: pertaining to the water column or open waters.

Phagocytosis: the ingestion of solid particulate matter by a cell.

Pharyngeal: pertaining to, or connected with the pharynx.

Pharynx: muscular tube connecting the mouth to the alimentary canal.

Photosynthesis (photosynthetic): the synthesis of complex organic substances by plants from carbon dioxide, water and inorganic substances using sunlight as the source of energy.

Phylum (Phyla): a primary division of the animal or plant kingdom.

Phytoplankton: planktonic plant-life.

Pigment(s): a substance which colours the tissues or cells of animals and plants.

Plankton(ic): small plants and animals which float or drift in the water column or open water.

Poikilothermic: having a poorly developed mechanism or no mechanism for internal regulation of temperature; body temperature fluctuates with that of the environment.

Polymorphism: occurrence of individuals with different body forms within the same species.

Postabdomen: posterior segment(s) of abdomen.

Postabdominal claw: a double claw at the distal end of the abdomen of cladocerans.

Posterior: pertaining to, or situated toward, the rear end.

Ppt: parts per thousand.

Prementum: distal part of the insect labium, bearing the labial palps.

Proboscis: an elongate or snout-like feeding organ.

Proximal: end closest to the body or point of attachment.

Proleg(s): unjointed abdominal leg of some insect larvae.

Pronotum: dorsal part of anterior section of insect thorax.

Pseudopodia: temporary protrusions of the protoplasm of amoebae.

Pupa(e): transformation stage between the larva and adult in the life cycle of an insect.

Radula: a chitinous membrane in the mouth of gastropods, set with numerous minute horny teeth.

Ramus(rami): branch-like structure(s) (eg. antennae).

Rostrum: an acute apex or beak-like extension at the front of the head.

Rudimentary: incompletely developed in size or structure.

Sclerotised: hardened tissue.

Scutellum: small shield-like plate at the posterior part of an insect thorax.

Setae: stiff or bristle-like hairs.

Setose: set with bristles, bristly.

Sheath: closely enveloping part or structure.

Sp.: a single species.

Species: the basic category of biological classification, intended to designate a single kind of animal or plant.

Spp.: more than one species

Spicule(s): minute, needle-like, siliceous or calcareous process.

Spiracle(s): an aperture or orifice used for breathing.

Spore(s): a small, walled reproductive body.

Sternite(s): a ventral plate of an arthropod segment.

Substrate: the bottom or base.

Suture: the line of junction between two plates or bones.

Symbiotic: living closely with another organism, where the union is advantageous or necessary to both.

Tarsus (tarsi): the fifth (distal) segment of an insect leg, often itself divided into segments.

Test: the hard covering of certain invertebrates; shell, lorica.

Thallus: a plant body not differentiated into leaf and stem.

Thorax (thoracic): the portion of the body between the head and the abdomen.

Transverse: lying across or between.

Trophic web: The network of interconnected food chains of a community through which energy is transferred from one level of the web to another.

Trophus (trophi): the complex set of hardened jaws of rotifers.

Tubercle(s): a small rounded projection on the surface of the body.

μm: micrometres, 0.001 millimetre.

Umbos: the protuding point on each valve of a bivalve above the hinge.

Urosome: tail region.

Vacuole: a cavity in a cell or tissue.

Ventral: pertaining to, or situated on the front or belly.

Ventrite(s): ventral chitinous plate of each segment of most arthropods.

Zooplankton: planktonic animal-life, generally <5 mm in freshwaters.

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APPENDIX I

CHECKLIST OF FLORA AND FAUNA KNOWN TO OCCUR IN FRESHWATER AQUACULTURE PONDS AND FARM DAMS OF SOUTH EASTERN AUSTRALIA

The table below provides a checklist of the flora, invertebrate fauna and selected vertebrate fauna collected from aquaculture ponds and farm dams in south eastern Australia (N.S.W., S.A. and Vic.). The checklist has been compiled from samples collected by, or for, the authors, as well as lists produced by Sudzuki and Timms (1980), Barlow and Bock (1981), Arumugam (1986), Barlow *et al.*(1986), Geddes (1986) and Culver and Geddes (1993).

Species names enclosed in "   " refers to a species that either requires revision as it is probably not the nominate species, or is a species complex. Where "?" has been used, the identification is tentative.

Locations referred to in the following table are:

a. Marine and Freshwater Resources Institute, Snobs Creek, Eildon, Victoria (collected by B. Ingram)

b. Koorangie Native Fish Rearing Facility, Kerang, Victoria (collected by B. Ingram & E. McLean).

c. Benalla Native Fish Rearing Facility, Benalla, Victoria. (collected by B. Ingram & A. Walker).

d. NSW Fisheries, Narrandera Fisheries Centre, Narrandera, N.S.W. (*Sources*: Arumugam 1986; Culver and Geddes 1993; samples collected by S. Thurstan).

e. NSW Fisheries, Grafton Research Centre, Grafton, N.S.W. (collected by T. Pontifex, C Mifsud and B. Ingram)

f. Bingara Murray Cod Hatchery, Bingara, N.S.W. (collected by P. Forster)

g. Farm dams near Narrandera, N.S.W. (*Sources*: Barlow and Bock 1981; Barlow *et al.* 1986).

h. Farm dams near Gloucester, N.S.W. (*Source:* Sudzuki and Timms 1980).

i. Farm dams, near Adelaide, S.A. (*Sources:* Arumugam 1986; Geddes 1986; Suter and Bishop 1990).

j. Collected from still waters by R.J. Shiel, Murray-Darling Freshwater Research Centre, Albury, N.S.W.

GROUP	SPECIES	LOCATION
ALGAE		
CHLOROPHYTA		
Characeae	*Nitella* sp.	a
Chlamydomonadaceae	*Sphaerellopsis* sp.	d
Chlorococcaceae	*Characium* sp.	d
	Schroederia sp.	d
	Tetraedron spp.	d
Coccomyxaceae	*Elakatothrix gelatinosa*	d
	Elakatothrix sp.	a
Desmidiaceae	*Arthrodesmus* sp.	a
	Closterium sp.	a
	Cosmarium sp.	a
	Dicidium sp.	a
	Euastrum sp.	a
	Micrasterias sp.	a b c
	Penium sp.	a
	Staurastrum spp.	a d
Dictyosphaeriaceae	*Dictyosphaerium* sp.	d
Gleoecystaceae	*Gloeocystis* sp.	a
Hydrodictyaceae	*Pediastrum duplex*	a c
	Pediastrum sp.	d
	Hydrodictyon sp.	d
Micractiniaceae	*Golenkinia* sp.	a d
Oocystaceae	*Ankistrodesmus ?falcatus*	a
	Ankistrodesmus sp.	d
	Chlorella spp.	a
	Franceia sp.	d
	Kirchneriella obesa	d
	Oocystis sp.	a d
	Treubaria sp.	a d
Palmellaceae	*Sphaerocystis* sp.	d
Phacotaceae	*Pteromonas cruciata*	d
Scenedesmaceae	*Actinastrum* sp.	a d
	Coelastrum spp.	a d
	Crucigenia sp.	d
	Scenedesmus sp.	a d
	Tetrastrum spp.	d
Tetrasporaceae	*Paulschulzia pseudovolvox*	d
Volvocaceae	*Eudorina* sp.	a d
	Pandorina sp.	a
	Volvox sp.	c d
Zygnemataceae	*Spirogyra* sp.	a
Unknown	*Atractomorpha echinata*	d
	Monoraphidium sp.	d
EUGLENOPHYTA		
Euglenaceae	*Euglena acus*	a
	Euglena sp.	d
	Lepocinclis ovata var. def.	d
	Trachelomonas volvocina	a
	Trachelomonas sp.	d
PYRRHOPHYTA		
Ceratiaceae	*Ceratium* sp.	a
Peridiniaceae	*Peridinium* sp.	a
CHRYSOPHYTA		
Bacillariophyceae		
Achnanthaceae	*Acnanthes* sp.	b f
Coscinodiscaceae	*Cyclotella stelligera*	d
	Aulacoseira ?distans	d
	Aulacoseira granulata	d
Fragilariaceae	*?Synedra* sp.	a
	Asterionella sp.	d

GROUP	SPECIES	LOCATION
Rhizosoleniaceae	*Attheya zachariasi*	d
	Rhizosolenia sp.	d
Chrysophyceae		
Dinobryaceae	*Dinobryon* sp.	a
Ochromonadaceae	*Uroglenopsis* sp.	a
Synuraceae	*Mallomonas* sp.	a
	Synura sp.	d
CRYPTOPHYTA		
Cryptochrysidaceae	*Chroomonas* sp.	d
	?*Rhodomonas* sp.	a
Cryptomonadaceae	*Cryptomonas erosa*	d
	?*Cryptomonas* sp.	a
CYANOPHYTA		
Chroococcaceae	*Microcystis* sp.	d
Nostocaceae	*Anabaena spiroides*	a c
	Anabaena sp.	a b d f
	Nostoc sp.	a b f
HIGHER PLANTS		
ANGIOSPERMA		
Dicotyledons		
Haloragaceae	*Myriophyllum variifolium*	a
Scrophulariaceae	*Glossostigma elatinoides*	a
Typhaceae	*Typha* sp.	a
Monocotyledons		
Cyperaceae	*Cyperus* spp.	a
	Eleocharis pusilla	a
	Eleocharis spp.	a
Juncaceae	*Juncus* spp.	a
Hydrocharitaceae	*Ottelia ovalifolia*	a
Lemnaceae	*Spirodela* sp.	a
Potamogetonaceae	*Potamogeton ochreatus*	a
PROTOZOA		
Ciliophora	*Stentor* sp.	a
	Trichonia sp.	a b c
	Vorticella sp.	a
	ciliates	a b c
Sacromastigophora		
Mastigophora	flagellates	a b c
Sacrodina	*Arcella* sp.	a
	Difflugia sp.	a e
	Netzelia sp.	e
PORIFERA	sponge	a d
CNIDARIA	*Hydra* sp.	a e
TURBELLARIA	Tricladida	a
NEMERTEA	nemertean	f
NEMATODA	Dorylaimidae	a
NEMATOMORPHA	Gordiidae	b
ROTIFERA		
Bdelloidea	?*Philodina* sp.	h
	Rotaria neptunia	j
	bdelloid	a e
Collothecacea		
Collothecidae	*Collotheca pelagica*	j
Flosculariacea		
Conochilidae	*Conochilus coenobasis*	j
	C. dossuarius	j
	C. natans	j
	C. unicornis	a i j
	Conochilus sp.	d e h

GROUP	SPECIES	LOCATION
Filiniidae	*Filinia australiensis*	i j
	F. longiseta	d e h j
	F. passa	d
	F. pejleri	d j
	F. terminalis	j
	Filinia spp.	a b c d i
Flosculariidae	*Lacinularia* sp.	a b j
Hexarthridae	*Hexarthra intermedia*	i j
	H. mira	h j
	Hexarthra sp.	a d
Testudinellidae	*Pompholyx complanata*	j
	P. sulcata	h j
	Testudinella patina	i j
	T. ?*amphora*	h
Ploimida		
Asplanchnidae	*Asplanchna brightwelli*	h i j
	A. priodonta	i j
	A. sieboldi	a d h i j
	Asplanchna sp.	b c d e
	Asplanchnopus hyalinus	j
	A. multiceps	j
Brachionidae	*Anuraeopsis navicula*	j
	Brachionus angularis	a d e h i j
	B. budapestinensis	a d i j
	B. calyciflorus	a b c d e h i j
	B. dichotomus	d h
	B. diversicornis	d
	B. falcatus	d e j
	B. lyratus	a i j
	B. ?*nilsoni*	e
	B. quadridentatus	a d h i j
	Brachionus spp.	a b c d j
	Keratella australis	b d j
	K. cochlearis	d e h i j
	K. procurva	d h i j
	K. slacki	a d e h i j
	K. tropica	d e h i j
	Plationus patulus	j
Colurellidae	*Colurella uncinata*	j
	Colurella sp.	h i
	Lepadella patella	j
Epiphanidae	*Epiphanes brachionus*	d j
	E. clavulata	j
	E. macrourus	j
Euchlanidae	*Euchlanis dilatata*	j
	E. oropha	d
	Euchlanis sp.	d h
Gastropodidae	*Ascomorpha* ecaudis	j
	A. saltans	h j
	Gastropus hyptopus	h j
	G. minor	j
	G. stylifer	h j
Lecanidae	*Lecane bulla*	h
	L. closterocerca	i
	L. hamata	d
	L. luna	i j
	L. lunaris	j
	Lecane sp.	a
Lindiidae	*Lindia deridderi*	j
Mytilinidae	*Mytilina mucronata*	j
	M. ventralis	j
Notommatidae	*Cephalodella* sp.	h
Synchaetidae	*Polyarthra dolichoptera*	h j
	P. vulgaris	d h i j
	Polyarthra sp.	a
	Synchaeta longipes	d
	S. oblonga	j
	S. pectinata	j
	Synchaeta sp.	d h i

GROUP	SPECIES	LOCATION
Trichocercidae	*Ascomorphella volvocicola*	d j
	Trichocerca birostris	h
	T. capucina	h
	T. pusilla	d j
	T. similis	h j
	T. stylata	d
Trichotriidae	*Macrochaetus collinsi*	h
	Trichotria tetractis	j
MOLLUSCA		
Gastropoda		
Ancylidae	*Ferrissia* sp.	c
Lymnaeidae	*Austropeplea* sp.	e
Physidae	*Physa acuta*	a b c d g
Planorbidae	*Gyraulus* sp.	f
unidentified	unidentified snails	d e g
Bivalvia		
Hyriidae	*Velesunio ambiguus*	e
ANNELIDA		
Oligochaeta		
Enchytraeidae	unidentified enchytraeid	a
Lumbriculidae	*Lumbriculus variegatus*	a
Naididae	*Dero* sp.	a
	Pristinella jenkinae	a
Tubificidae	*Branchiura sowerbyi*	e
	Limnodrilus hoffmeisteri	a
	Tubifex tubifex	a
Hirudinea		
?Glossiphonidae	unidentified leeches	a b c e
ARACHNIDA		
Acarina		
Hydracarina		
Eylaidae	*Eylais* sp.	a b c d
Pionidae	*Piona* sp.	a
unidentified	unidentified mites	a b c d e g
Araneae		
Pisauridae	*?Dolomedes* sp.	a b
CRUSTACEA		
Anostraca		
Thamnocephalidae	*Brachinella* sp.	d
Branchiopoda (Cladocera)		
Bosminidae	*Bosmina meridionalis*	a b d e i j
	Bosminopsis dietersi	j
Chydoridae	*Alona guttata*	i
	A. diaphana	j
	Alona sp.	i e
	Biapertura rigidicaudis	j
	Camptocercus australis	a j
	Chydorus eurynotus	j
	C. "sphaericus"	i j
	Chydorus sp.	a b e j
	Dunhevedia crassa	i
	Graptoleberis testudinaria	j
	Leydigia australis	i j
	Pleuroxus jugosus	i
Daphniidae	*Ceriodaphnia "quadrangula"*	d i j
	C. "cornuta"	d e i j
	C. "pulchella"	e
	Ceriodaphnia sp.	a b e i j
	Daphnia carinata	a b c d i j
	D. cephalata	j
	D. lumholtzi	a d e i j
	Scapholeberis kingi	a c d i j
	Simocephalus exspinosus	j
	S. vetulus	i j
	Simocephalus sp.	a c j
Ilyocryptidae	*Ilyocryptus "sordidus"*	j

GROUP	SPECIES	LOCATION
Macrothricidae	*Macrothrix spinosa*	d i j
	Pseudomoina lemnae	j
Moinidae	*Moina micrura*	a b c d e i j
	M. tenuicornis	j
	Moinodaphnia macleayi	j
Sididae	*Diaphanosoma excisum*	d
	D. unguiculatum	j
	Diaphanosoma sp.	e
	Latonopsis australis	j
Ostracoda		
Cyprididae	*Cypretta* sp.	i
	Heterocypris sp.	a b
	Newnhamia fenestrata	i
	Newnhamia sp.	a
	unidentified ostracods	d e i f
Conchostraca	*Cyzicus* sp.	d f
Copepoda		
Calanoida	*Boeckella minuta*	c j
	B. fluvialis	a d e j
	B. symmetrica	i j
	B. triarticulata	a b d i j
	Calamoecia ampulla	i j
	C. lucasi	d i j
Cyclopoida	*Acanthocyclops robustus*	j
	Australocyclops australis	b j
	Eucyclops euacanthus	i j
	M. ?thermocyclopoides	d
	Mesocyclops spp.	a c d i j
	Microcyclops spp.	b d e j
	Tropocyclops sp.	i
	unidentified cyclopoids	f
Harpacticoida	*Canthocamptus* sp.	a j
Amphipoda		
Ceinidae/Hyalellidae	*Austrochiltonia australis*	i
	unidentified amphipod	b
Decapoda		
Atyidae	*Paratya australiensis*	a b c d e g
Hymenosomatidae	*Amarinus laevis*	e
Palaemonidae	*Macrobrachium australiense*	a b c d
Parastacidae	*Cherax destructor*	a b c d g
INSECTA		
Collembola	hypogastrurid	a
	isotomid	a b
	sminthurid	a
	unidentified springtail	e
Ephemeroptera		
Baetidae	*Cloeon* spp.	a b c d e f
	unidentified ephemeropteran	g
Caenidae	*Tasmanocoenis* sp.	a c d e
Leptophlebiidae	*Atalophlebia* sp.	a c
Siphnuridae	*Tasmanophlebia* sp.	a
Odonata		
Zygoptera		
Coenagrionidae	*Austroagrion watsoni*	a
	Ischnura aurora aurora	a
	I. heterosticta	a b d
	Ischnura sp.	e
	Xanthagrion erythroneurum	a b c d e
Lestidae	*Austrolestes analis*	a
	A. annulosus	a b
	A. leda	a
Megapodagrionidae	*Argiolestes icteromelas*	a

GROUP	SPECIES	LOCATION
Anisoptera		
Aeshnidae	*Aeshna brevistyla*	a
	Hemianax papuensis	a b c d f
Corduliidae	*Hemicordulia tau*	a b c d f
Gomphidae	*Austrogomphus australis*	d
	A. ochraceus	a
Libellulidae	*Diplacodes bipunctata*	a c d
	D. haematodes	a
	Orthetrum caledonicum	a b c e f
	Pantala flavescens	a c
unidentified	unidentified odonate	g
Plecoptera		
Gripopterygidae	*Dinotoperla evansi*	i
	D. serricauda	a
Notonemouridae	?*Notonemoura* sp.	e
unidenified	unidenified plecopteran	g
Hemiptera		
Belostomatidae	*Diplonychus* sp.	a c d g
Corixidae	*Agraptocorixa eurynome*	b c d e f g
	A. hirtifrons	b
	A. parabiopunctata	g
	A. parvipunctata	a c d
	Micronecta annae	g
	Micronecta spp.	a b c d e i
	Sigara sp.	a b c d e g
Gerridae	?*Tenagogerris*	a
Hebridae	*Hebrus axilaris*	a
	unidentified hebrid	e g
Hydrometridae	*Hydrometra risbeci*	a c
Mesoveliidae	*Mesovelia* sp.	a c e
Naucoridae	*Naucoris congrex*	a
Nepidae	*Laccotrephes tristis*	a b c e f
	Ranata dispar	a b c g f
Notonectidae	*Anisops calcaratus*	a c f
	A. hackeri	a d
	A. stali	a c d
	A. thienemanni	a b c d e
	Anisops spp.	a b c d e f i
	Enithares sp.	a b c e f
Pleidae	*Paraplea* sp.	a e
Saldidae	*Saldula* sp.	e
Veliidae	*Microvelia* sp.	a e
Coleoptera		
Chrysomelidae	chrysomelid larva	a
Dytiscidae	*Allodessus bistrigatus*	a b c d g
	Antiporus gilberti	a b c d g
	A. femoralis	a g
	Chostonectes gigas	a c g
	Cybister tripunctatus	d e f g
	Copelatus sp.	a
	Eretes australis	a b c d g
	Homeodytes scutellaris	a b c d g
	?*Hydaticus* sp.	a
	Hydrovatus armstrongi	g
	Hyphydrus elegans	a c d e f g
	Laccophilus religatus.	e
	Lancetes lanceolatus	a b c d g
	Liodessus shuckhardi	g
	Megaporus ?hamatus	a
	M. howitti	a c d g
	Megaporus sp.	e
	Necterosoma wallastoni	g
	Necterosoma sp.	a
	Paroster ?sharpi	g
	Rhantus suturalis	a b c g
	Sternopriscus multimaculatus	g
	Sternopriscus sp.	a e g
Gyrinidae	*Macrogyrus* sp.	a b c
	unidentified gyrinid larvae	a b c d
Haliplidae	unidentified haliplid	g

GROUP	SPECIES	LOCATION
Helminthidae	*Coxemis V-fasciata*	g
Heteroceridae	*Heterocerus* sp.	b
Hydraenidae	*Hydraena ?acutipennis*	g
	Hydraena sp.	e g
	Ochthebiinae	a
	"*Ochthebius*" sp.	g
Hydrophilidae	*Berosus* spp.	a b c d e g
	Enochrus laevigatus	g
	Enochrus sp.	c g
	Helochares tristis	a c
	Helochares sp.	d g
	Hydrochus sp.	d e g
	Hydrophilus albipes	d
	H. latipalpus	b
	Hydrophilus sp.	a
	Laccobius sp.	g
	Limnoxenous sp.	a c
	?*Notohydrus* sp.	a
	Paracymus pygmaeus	g
	Paracymus sp.	a c
	Spercheus sp.	g
	unidentified hydrophilid larvae	a c d g
Hygrobiidae	*Hygrobia australiae*	a c
	H. nigra	c g
Scirtidae	unidentified scirtid larvae	a c
Staphylinidae	unidentified staphylinid	g
Diptera		
Ceratopogonidae	*Bezzia* sp.	a b e
Chaoboridae	*Chaoborus* sp.	a c
Chironomidae	*Ablabesmyia* sp.	a b
	Chironomus sp.	a b c d e f
	Cladopelma sp.	a
	Cladotanytarsus sp.	a
	Clinotanypus sp.	c
	Coelopynia pruinosa	a
	Cryptochironomus griseidorsum	b
	Cryptochironomus sp.	a b
	Dicrotendipes sp.	a b
	Kiefferulus martini	a
	Kiefferulus sp.	a b c d e
	?*Mesosmittia/Parasmittia*	a
	Parachironomus sp.	b
	Paracladopelma sp.	a b
	Polypedilum nubifer	a b c e
	Polypedilum sp.	f
	Procladius paludicola	a b c
	Procladius sp.	d f
	Reithia sp.	a
	Tanytarsus belaivensis	a
	Tanytarsus sp.	a b d e
	Thienemanniella sp.	a
	unidentified chironomids	i g
Culicidae	*Anophelus annulipes*	a c
	Culex annulirostris	a c
	C. australicus	c
	culicids	g
Tipulidae	Limoniinae	a
Stratiomyidae	*Odontomyia* sp.	a b c
Ephydridae	ephydrids	a c
Tabanidae	tabanids	a
Syrphidae	?*Eristalis* sp.	a c
Muscidae	muscids	a e
Trichoptera		
Ecnomidae	*Ecnomus* sp.	e
Hydroptilidae	*Hellyerthira* sp.	a
	hydroptilids	e
Leptoceridae	*Notalina spira*	a c d
	Oecetis spp.	a b c d e
	Triplectides australis	a b c d e

GROUP	SPECIES	LOCATION
Lepidoptera		
Pyralidae	pyralids	a g
VERTEBRATA		
Amphibia		
Hylidae	*Litoria peroni*	a b c
Leptodactylidae	*Limnodynastes dumerili*	a b c
	L. tasmaniensis	c
unidentified	unidentified tadpoles	a b c f g

GROUP	SPECIES	LOCATION
Reptilia		
Chelidae	*Chelodina longicollis*	a b c
	Emydura macquarii	b c
	E. signata	e
Pisces		
Cyprinidae	*Cyprinus carpio*	b
	Carassius auratus	b
Eleotridae	*Hypseleotris galii*	e
	H. klunzingeri	d
	Philypnodon grandiceps	a b
Percidae	*Perca fluviatilis*	b
Poeciliidae	*Gambusia holbrooki*	b g
Retropinnidae	*Retropinna semoni*	b

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