

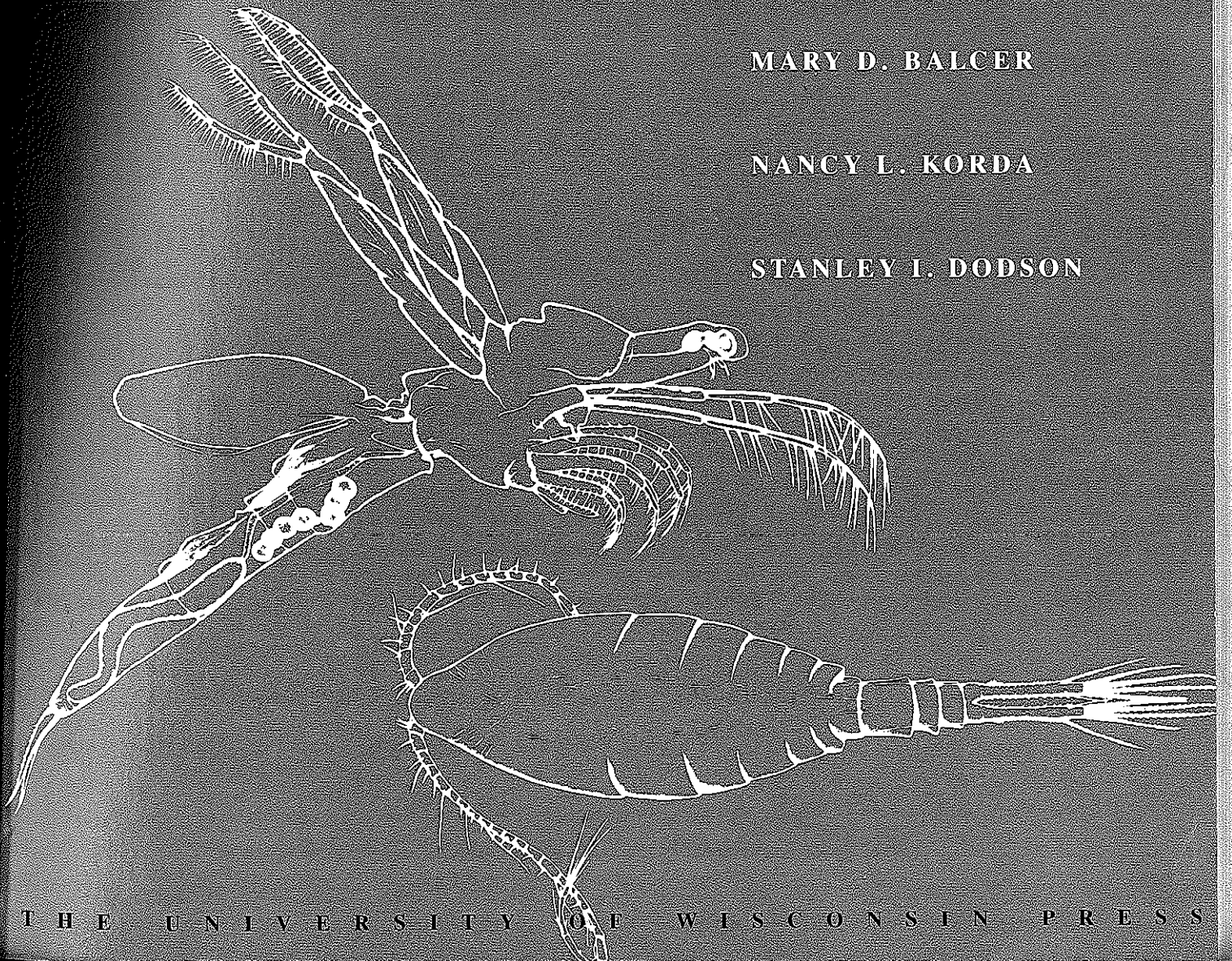
ZOOPLANKTON OF THE GREAT LAKES

*A Guide to the
Identification and Ecology
of the Common
Crustacean Species*

MARY D. BALCER

NANCY L. KORDA

STANLEY I. DODSON



THE UNIVERSITY OF WISCONSIN PRESS

Zooplankton of the Great Lakes

Researchers, instructors, and students will appreciate this compilation of detailed information on the crustacean zooplankton of the Great Lakes. The authors have gathered data from more than three hundred sources and organized it into a useful laboratory manual. The taxonomic keys are easy to use, suitable for both classroom and laboratory identifications. Detailed line drawings are provided to help confirm the identification of the major species. Zoologists, limnologists, hydrobiologists, fish ecologists, and those who study or monitor water quality will welcome this dependable new identification tool.

A concise summary of pertinent information on the ecology of these zooplankton is provided in the main body of the text. A checklist of all species reported from each of the Great Lakes and notes on the distribution and abundance of more than a hundred species were compiled from an extensive search of existing literature. In addition, the authors collected samples from several locations on Lake Superior, in order to provide information on the abundance and life histories of the major crustacean species.

For the thirty-four most common cladocerans and copepods, the authors also include sections on the taxonomy of each species, its description and size, life history, habitat, migration pattern, feeding ecology, and role as prey for other organisms. Tables provide information on the amount and type of zooplankton sampling conducted on each of the Great Lakes from the late nineteenth century to the present. Changes in major species abundance in each lake during the past hundred years may also be determined from the tabular data.

The text is carefully documented so that readers may easily find additional information on most topics by consulting the bibliography, which includes most of the articles on Great Lakes zooplankton written between 1871 and 1982. *Zooplankton of the Great Lakes* will at once become a standard guide for researchers, instructors, and students at both the high school and college levels.

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The University of Wisconsin Press
114 North Murray Street, Madison, Wisconsin 53715

ISBN 0-299-09820-6

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OF
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143
B35
1984

Published 1984

The University of Wisconsin Press
114 North Murray Street
Madison, Wisconsin 53715

The University of Wisconsin Press, Ltd.
1 Gower Street
London WC1E 6HA, England

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Work on this book was funded in part by the University of Wisconsin Sea Grant College Program under a grant from the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and by the State of Wisconsin (federal grant number NA80AA-D-00086, project number R/LR-12). The U.S. government is authorized to produce and distribute reprints for government purposes notwithstanding any copyright notation that may appear hereon.

First printing

Printed in the United States of America

For LC CIP information see the colophon

ISBN 0-299-09820-6

Plates drawn by Nancy L. Korda

Figures 3b, 17-19, 22, 24-26, 28-33, 38-43, 45-50, 55, 71, 77, and 78 are redrawn after the second edition of Ward and Whipple's *Freshwater Biology*, edited by W. T. Edmondson, published by John Wiley and Sons, Inc., 1959, and used here with their kind permission.

Figures 73, 83, 84, 88, and 90-93 are from K. Smith and C. H. Fernando, 1978, *A guide to the freshwater calanoid and cyclopoid copepod Crustacea of Ontario*, University of Waterloo Biology Series 18.

Figures 23 and 27 are redrawn after C. L. Herrick and C. H. Turner, 1895, *Synopsis of the Entomostraca of Minnesota*, in *2nd Report of State Zoologist*.

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Acknowledgments

We would like to thank the following individuals and public agencies for their assistance in sampling the zooplankton of Lake Superior: Gary Curtis and Jim Selgeby of the U.S. Fish and Wildlife Service in Ashland, WI; Gary Fahnenstiel and Dr. Robert Keen of Michigan Technological University-Houghton; Mort Purvis of the Ontario Ministry of Natural Resources; Arthur Lasanen, captain of the fishing vessel *Atomic*; Dr. William Swenson, Dave Anderson, Sue McDonald, Sue Medjo, Lynn Goodwin, Lisa Schmidt, Gloria Berg, and Tom Markee of the University of Wisconsin-Superior's Center for Lake Superior Environmental Studies; Lt. Commander Lundberg of the U.S. Coast Guard Cutter *Mesquite* and Frank Johnson of Sivertson's Fishery Company.

Additional samples of zooplankton species from Lake Erie were provided by Roberta Cap of the Great Lakes Laboratory, Buffalo, NY.

Assistance in analyzing the zooplankton samples was provided by Tim Linley and Carolyn Lie.

Sections of this manuscript were edited by E. Bousfield, S. Czaika, J. Gannon, J. Havel, S. Gresens, D. Krueger, C. Lie, and A. Robertson.

We would especially like to thank Linda McConnell, Grace Krewson, Denise Rall, Jacque Rust, and Doris Brezinski for typing several drafts of this manuscript and Cheryl Hughes for preparing several of the illustrations used in the taxonomic key.

Introduction

When studying an aquatic system, it is necessary to identify the individual components of the ecosystem and examine their relationships. In the Great Lakes, the crustacean zooplankton play an important role in the transfer of energy from the primary producers, the algae, to the higher order consumers such as aquatic insects, larval fish, and some adult fish. Any disturbance, such as nutrient enrichment, fish introductions, thermal discharges, or toxic effluents, that alters the composition of the zooplankton community could ultimately affect the rest of the system.

This taxonomic key and accompanying information were prepared to facilitate the identification and study of crustacean zooplankton communities of the Great Lakes. The key is designed so that students and researchers with only a limited knowledge of crustacean taxonomy can learn to identify the common Great Lakes zooplankton, primarily using a dissecting microscope. The life history and ecology section summarizes information on the major crustacean species to help readers determine the ecological role of each species.

At the present time, approximately 100 species of crustacean zooplankton have been reported from the Great Lakes. Most of these organisms are restricted to littoral or benthic habitats and seldom occur in plankton collections. In this report, we emphasized the life history and ecology of 34 species most frequently collected from the nearshore and limnetic environments. The key covers 42 Great Lakes spe-

cies and references other published information to identify the remaining species.

The taxonomic key is based largely on zooplankton collected from Lake Superior. Samples of some Great Lakes species not found in Lake Superior were obtained from other investigators. We examined several adult males and females of each of the common species to determine species-specific characteristics that are readily visible at 50 \times magnification, then used these characteristics to construct a dichotomous key. Although the key is primarily concerned with the common species, you can identify most organisms to family or genus. Dissections and greater magnification are often needed to identify the less common species. In these cases, you are directed to other works with more detailed species descriptions. To assist in the identification process, detailed composite drawings of the dominant zooplankton species found in the Great Lakes are also provided (see plates).

The scientific names used here are consistent with those in the 2nd edition of Ward and Whipple's *Freshwater Biology* (Edmondson 1959a), except in cases of changes since its publication. The more current names are referenced in our list of "Species of Crustacean Zooplankton Found in the Great Lakes" and in the taxonomic history sections for individual species.

Common names of fish are in accordance with the American Fisheries Society (1980).

Information on the distribution, abundance, life histo-

ries and ecology of the Great Lakes crustacean zooplankton was obtained through an extensive literature search. This information was supplemented by data collected during a year-round sampling program conducted on Lake Superior.

A 0.5-meter diameter, 80 μm mesh net was towed vertically to obtain plankton samples from several nearshore and pelagic stations located in the United States waters of Lake Superior. Samples were collected weekly in the Duluth-Superior region during the ice-free seasons of 1978–

1980 and at monthly intervals during the winter. Monthly samples were also collected at the Sault Ste. Marie outfall of the Great Lakes Power Co. and around the Keweenaw Peninsula during 1979 and 1980. Other stations in the western half of the lake were sampled once a year during the summer months.

All samples were preserved in 4% formalin and returned to the lab for analysis.

General Morphology and Ecology of the Crustacean Zooplankton

CLADOCERANS

ANATOMY

Cladocerans, commonly known as water fleas, are generally 0.2–3.0 mm long. The body is not distinctly segmented and is enclosed in a folded shell-like structure, the carapace, that opens ventrally (Fig. 1). The shape of the carapace varies. In some species it terminates in a spinule or spine, referred to as a mucro in the Bosminidae. In *Leptodora* and *Polyphemus* the carapace is greatly reduced and restricted to the brood chamber.

The head, which contains a single, darkly pigmented compound eye, is not enclosed by the carapace but is protected by a separate, hardened head shield. In some species a tiny pigmented light-sensitive organ, the ocellus, is located below the eye. Small, often inconspicuous antennules (first antennae) are attached to the ventral surface of the head. The antennules often have olfactory setae. Projecting from the sides of the head are the large antennae (second antennae), which are the principal appendages used in swimming. Most cladocerans have segmented, biramous antennae with a variable number of setae or swimming hairs located on each branch. At the base of each antenna, the head shield is modified into a strengthening ridge, or fornix.

In many cladocerans a pointed beak, or rostrum, projects from the head near the antennules. The anterior portion of the head may also be elongated to form a helmet.

Cladoceran mouthparts are small and difficult to see. They are generally located slightly posterior to the junction of the head and body. The darkly pigmented mandibles, which are used to crush and grind food particles, can be seen in constant motion in live animals. Ingested food moves into a tubular intestine that passes through the body and terminates at the anus located on the postabdomen. The intestine of some species is looped or convoluted, while in others it contains blind pouches, or caeca, to aid in digestion by increasing gut passage time.

The central portion of the body, the thorax, bears 4 to 6 pairs of flattened legs covered with finely spaced setae. In some species the first two pairs of legs may be modified to aid in scraping or clinging to vegetation. In *Leptodora* and *Polyphemus* the thoracic legs are cylindrical, which enables these animals to feed raptorially.

Cladocerans carry their eggs in a brood chamber, a space located between the body wall and the dorsal surface of the carapace. Developing embryos are held in this chamber by the fingerlike abdominal processes. Occasionally, embryos may be released from the brood chambers of preserved animals. The embryos do not have well-developed carapaces or appendages (Fig. 4) and should not be confused with free-living juveniles and adults.

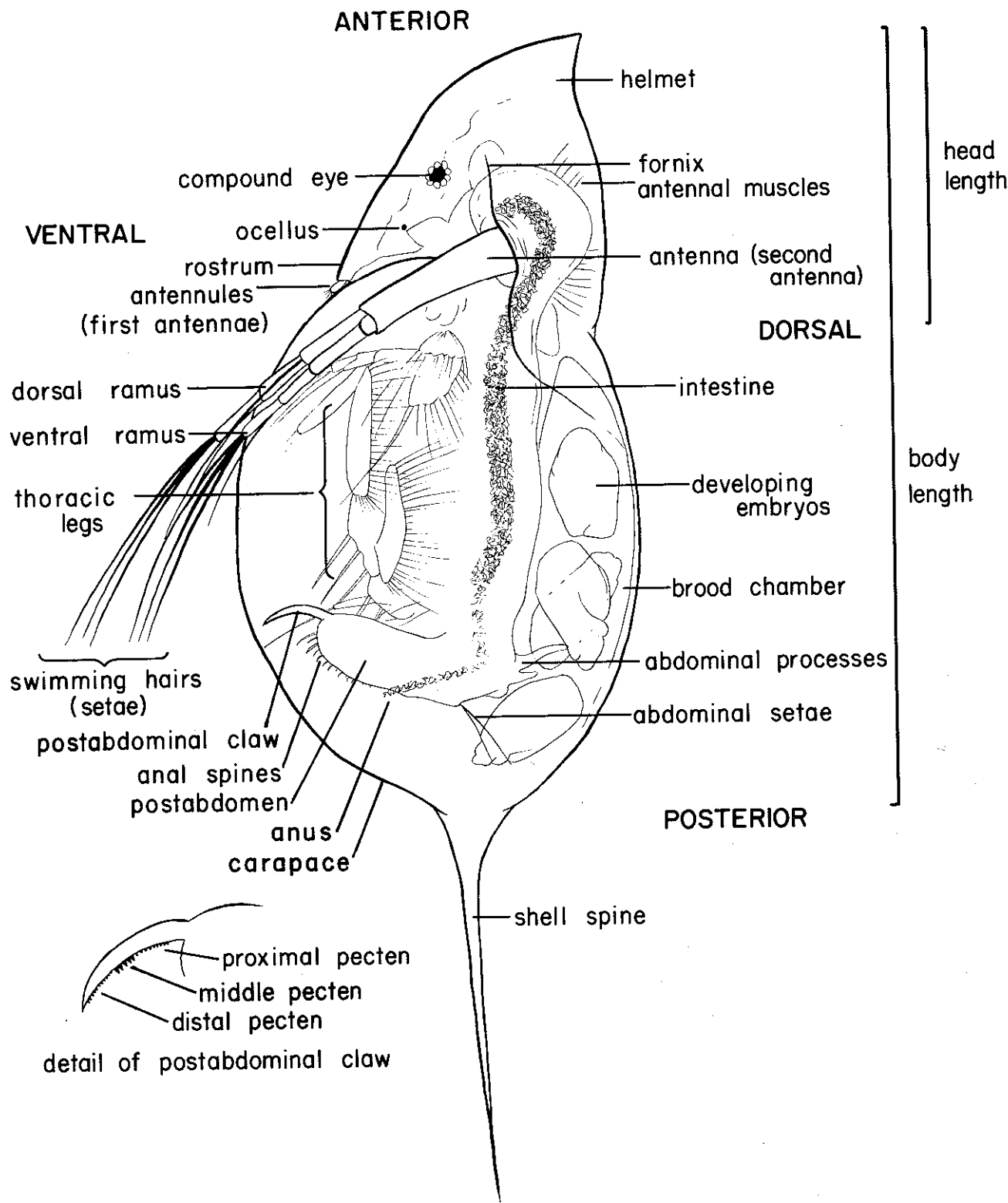


Figure 1 Morphology of a generalized cladoceran

The most posterior region of the body, the postabdomen, terminates in two hooklike cuticular claws. In many species the shape of the fine teeth or pecten located on the postabdominal claws is used in species identification. The teeth of the pecten often differ in size in the proximal, middle, and distal portions of the claw. The postabdomen may also bear rows of spines that aid in removing debris from the thoracic legs.

Male cladocerans (Fig. 58) are usually smaller than females. They have longer antennules and modified postabdomen; some may also possess stout, hooklike claspers on the first legs.

FEEDING BEHAVIOR

Most cladocerans are primarily filter feeders. Movement of the thoracic legs creates water currents that bring suspended food particles into the area between the valves of the carapace. The setae on the thoracic legs strain the particles out of the water and move them towards the mouth. Algae, protozoa, bacteria, and organic detritus of a suitable size are ingested. Large particles and undesirable material can be removed from the filtering appendages and rejected by the modified first legs or by the postabdomen with its terminal claw and lateral spines.

The Chydoridae and Macrothricidae are adapted for feeding in vegetated areas or among the bottom detritus. Their modified first and second legs enable these animals to cling to and scrape food particles off of the vegetation and detritus.

Polyphemus and *Leptodora* possess cylindrical prehensile limbs that allow them to grasp larger prey including protozoans, rotifers, small cladocerans, and copepods.

GROWTH AND REPRODUCTION

In order to increase in size, cladocerans must shed their exoskeletons. After each molt, the animal takes up water and rapidly increases in volume before the newly developed exoskeleton can harden. Cladocerans molt from two to five times before reaching maturity and 6 to 25 times after.

During most of the year, cladocerans reproduce asexually (parthenogenetically). After each molt, mature females deposit 2 to 20 eggs in the dorsal brood chamber. The eggs develop without fertilization into juvenile females that look like miniature adults. At the next molt, the parent females release the free-swimming juveniles, which begin feeding, grow, and mature quickly. This parthenogenetic pattern of reproduction permits a rapid increase in population size under favorable conditions.

When conditions become less favorable due to over-

crowding, accumulation of metabolic wastes, decreasing food availability, decreasing water temperatures, or changes in light intensity, some females begin to produce parthenogenetic eggs that hatch into males instead of females. If the adverse conditions continue, some mature females then produce one or two sexual or resting eggs. After copulating with a male, the female releases the fertilized eggs into a specialized brood chamber. The walls of this brood chamber are thick and dark-colored, forming a saddlelike case, known as an ephippium, around the eggs. When the female molts, the ephippium and its enclosed eggs are released; they may sink to the bottom, attach to the substrate, or float at the surface. Ephippial eggs are resistant to freezing and drying. When favorable conditions return, the eggs hatch into females that begin to reproduce parthenogenetically. Most cladoceran populations overwinter as ephippial eggs.

CYCLOMORPHOSIS

Many cladocerans show changes in their morphology as the population develops through the year. This cyclomorphosis may affect helmet shape, eye size, and length of antennules or shell spines. For example, in *Daphnia*, many populations have short, round helmets during the late fall, winter, and early spring. As the population begins to increase in the spring, individuals with more elongated helmets appear (Fig. 59). The helmets of each succeeding generation become increasingly larger until late summer. The head shape of each generation then begins to revert to the rounded form. The causes of cyclomorphosis are not well understood. Water temperature, turbulence, variations in light intensity, genetic variability, and selective vertebrate and invertebrate predation may all be involved in this phenomenon.

VERTICAL MIGRATION

Many cladocerans undergo diurnal vertical changes in position in the water column. Most populations tend to concentrate at the surface at dusk and then move downward again at dawn. Some species rise and sink twice during the night, while others display a pattern of reverse migration, with the greatest surface concentration occurring at dawn. Vertical movement varies from about 1 to 25 m for freshwater cladocerans.

Although changing light intensity appears to be a cue for movement, the migration patterns are also affected by age and size of the animals, food supply, day length, oxygen concentration, turbulence, and several other factors. The adaptive value of this diurnal movement is not yet well understood, but it may be involved in increasing metabolic efficiency and avoiding predators.

More information on the ecology and life histories of cladocerans can be found in Hutchinson (1967), Pennak (1978), and Kerfoot (1980).

COPEPODS

ANATOMY

Adult copepods, commonly known as oarsmen, of the suborders Calanoida, Cyclopoida, and Harpacticoida are 0.3–3.2 mm long. Their elongate cylindrical bodies are clearly segmented (Fig. 2).

The head segments are fused and covered by the carapace. A single, small, pigmented eyespot is usually present along with several paired appendages. The uniramous first antennae (antennules) consist of 8 to 25 segments used in locomotion and chemo- and mechanoreception. The right antennule of adult male calanoids is geniculate (bent) and may possess a lateral projection on the antepenultimate (second from the last) segment (Fig. 2f). Adult male cyclopoids (Fig. 2b) and harpacticoids have both antennules geniculate. The second antennae (Fig. 2c) are generally shorter than the antennules. They are uniramous in cyclopoids, biramous in calanoids, and prehensile in harpacticoids. Copepod mouthparts consist of the paired mandibles, maxillules, and maxillae.

The first thoracic segment is usually fused to the head. This fused body region is termed the cephalic segment and it bears the maxillipeds which are used for feeding. The second through sixth thoracic segments each bear one of the five pairs of swimming legs. Some of these segments may be fused to the cephalic segment or to each other. The first four pairs of thoracic legs are biramous and similar in appearance (Fig. 2d), the inner branch known as the endopod and the outer branch termed the exopod. The fifth pair of legs is usually quite different from the preceding pairs. It is greatly reduced in both sexes of the cyclopoids and harpacticoids. In adult female calanoids, the symmetrical fifth legs are usually modified. They are often reduced in size (Fig. 2h) and may be uniramous or absent in some species. Adult male calanoids generally have asymmetrical fifth legs, and in diaptomids the right exopod terminates in a hooklike claw (Fig. 2g). The shape of this claw and the position of the lateral spine located on the last segment of the exopod are useful in determining species.

The genital segment of adult copepods is often larger than the following abdominal segments. In cyclopoids and harpacticoids, the genital segment may bear a pair of ves-

tigial sixth legs that are more developed in males than females.

The abdominal segments lack jointed appendages. The first abdominal segment may fuse with the genital segment and is followed by one to four additional distinct segments. The last segment bears two cylindrical caudal rami that terminate in hairlike caudal setae. The number, position, and length of these setae (Fig. 2a) are useful in species identifications.

The cephalic and thoracic segments are commonly referred to as the metasome; the genital segment and the abdominal segments make up the urosome. The body of calanoid copepods is constricted between the metasome and the urosome while the cyclopoid and harpacticoid body is constricted between the segments bearing the fourth and fifth legs. In the calanoids and cyclopoids, the segments posterior to the constriction are much narrower than the anterior segments (Figs. 2a and e), but in harpacticoids (Fig. 2i) the urosome is not noticeably narrower than the metasome. The last segment of the metasome of calanoids may be expanded laterally into metasomal wings.

FEEDING BEHAVIOR

Calanoid copepods are primarily filter feeders (Richman et al. 1980). Movements of the second antennae and mouthparts create water currents that carry food particles past the sensory first antennae and into the reach of the feeding appendages. The setae on the maxillae are used to filter these particles out of the water. The feeding current is maintained during feeding, but filtration probably occurs only when a food particle is within reach of the mouthparts. Recent studies have shown that calanoids are capable of selectively filtering certain sizes and types of algae. Some species also use their modified maxillipeds to grasp algae or smaller zooplankton.

Cyclopoids lack developed filtering setae but have mouthparts modified for grasping and chewing. These raptorial cyclopoids may be herbivores, omnivores, or carnivores with different species showing preferences for detritus, algae, protozoans, cladocerans, or other copepods.

Harpacticoids are benthic organisms. They crawl about the bottom and use their modified mouthparts to select edible particles out of the detritus.

GROWTH AND REPRODUCTION

Reproduction in all copepods is sexual. The male clasps the female with his modified first antennae and/or fifth legs, then transfers a packet of sperm, the spermatophore, from his genital pore to her genital segment. The sperm are

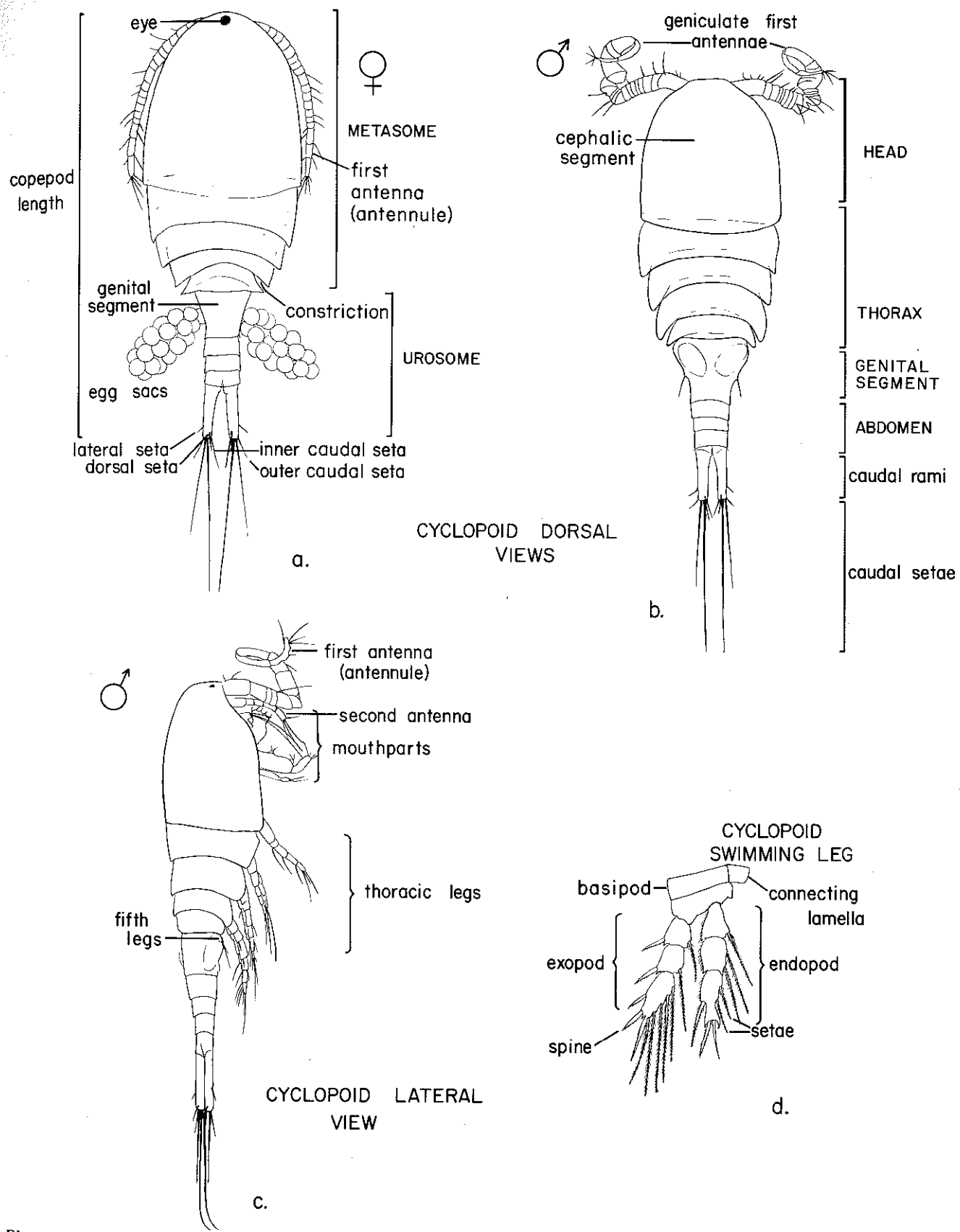


Figure 2a-d General morphology of copepods. The body divisions labeled in 2a and 2b apply to either sex.

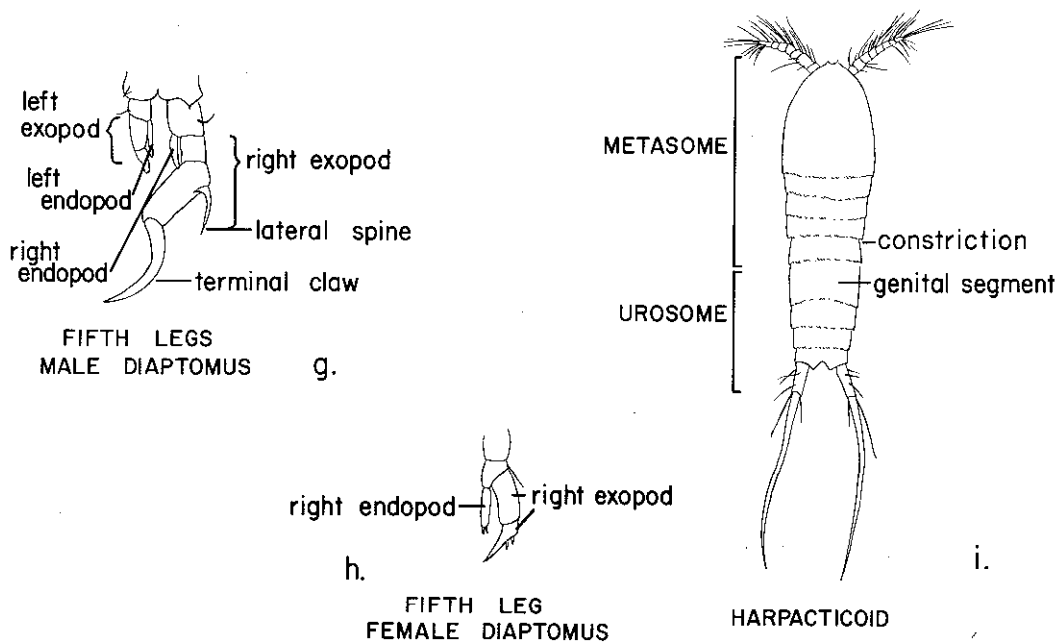
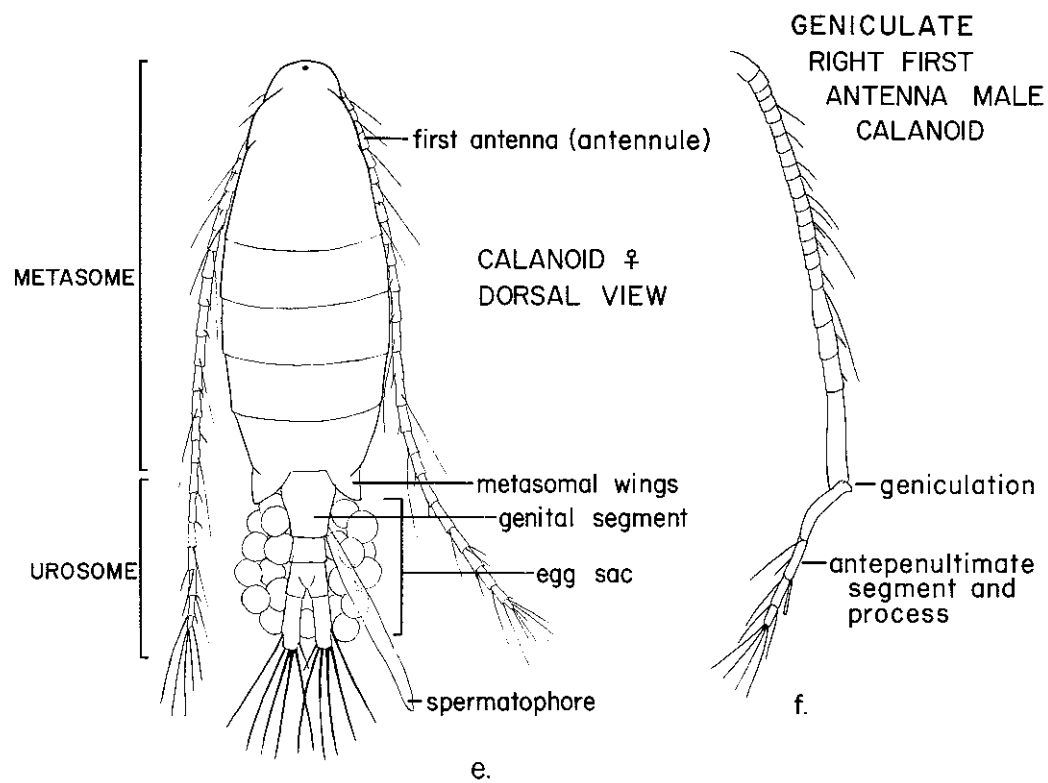


Figure 2e-i General morphology of copepods

stored in a seminal receptacle located in the female's genital segment. When the female releases eggs from her genital tract, they are fertilized by the stored sperm. Females of most species brood the eggs in one (calanoids) or two (cyclopoids and harpacticoids) egg sacs attached to the genital segment. A few species of calanoid copepods do not brood their fertilized eggs but release them directly into the water, where they sink to the bottom before hatching.

After the first clutch of eggs has hatched, some females fertilize a second and third clutch utilizing more of the sperm stored from their first mating.

Copepod eggs hatch into small, active larvae known as nauplii (Fig. 5). The first nauplius stage (NI) is characterized by three pairs of appendages. The animals grow rapidly and molt to the second nauplius stage (NII), which is slightly longer and, in cyclopoids, possesses a rudimentary fourth appendage. The animals continue to grow and add appendages as they pass through six naupliar stages. The next molt is to the first copepodid stage (CI). At this point the young copepods have the general body shape of the adult but are smaller and lack several of the swimming legs (Fig. 6). Growth, addition of swimming legs, and modification of the limbs continue at each molt until the adult (CVI) stage is reached. The animals then mate and produce the next generation.

The length of copepod life cycles and the number of egg clutches produced by females are quite variable. Some species grow and mature rapidly, producing several generations each year. Others require up to a year to reach maturity. Growth is generally slowed in cold temperatures. Some copepods become dormant and diapause near the bottom during the winter, while others diapause during warm water conditions.

ECOLOGY

Copepods are more common and show a greater diversity in marine systems than in freshwater. In limnetic regions of the Great Lakes, one or two calanoids and one cyclopoid generally dominate. In the littoral areas where there is a greater variety of habitats, more copepod species are encountered. Although some cyclopoids are found among the bottom debris of the littoral and benthic zones, these areas are usually occupied by harpacticoids.

Some copepods are strong swimmers and may undergo diurnal vertical migrations up to 100 m. As in the cladocerans, the stimuli and adaptive significance of this movement are not yet well understood.

MALACOSTRACANS

Order Mysidacea

ANATOMY

Adult mysids, commonly known as opossum shrimp, are 15–25 mm long and superficially resemble shrimp or crayfish. A thin carapace covers most of the thorax but is not fused posteriorly to the thoracic segments (Fig. 3a).

The large compound eyes are located on stalks. Two pairs of antennae also extend from the head; the first pair is biramous while the second pair is uniramous with an elongated basal projection, or scale.

The head contains the paired mandibles, first maxillae, and second maxillae, which are used in food handling. The first two pairs of thoracic appendages, the maxillipeds, are modified for straining zooplankton, phytoplankton, and detritus from the water and moving the particles forward to the mouth. The first pair of maxillipeds is also involved in respiration. Mysids lack gills and respire through the thin lining of the carapace. The first maxillipeds direct a current of water under the carapace to increase the potential for gas exchange.

The posterior six pairs of thoracic appendages are known as swimming legs, or pereopods. The outer branch (exopod) of each leg projects to the side of the body and is responsible for the smooth, rapid swimming pattern of the animal. The inner branch (endopod) of each pereopod is used to create a water current that brings food particles to the maxillipeds.

The abdomen of mysids consists of six segments. The first five pairs of abdominal appendages are often reduced in size and are known as pleopods. The last abdominal segment terminates in a flattened telson and a pair of uropods. An equilibrium organ, the statocyst, is located at the base of each uropod.

Mature male mysids are distinguished by their greatly elongated fourth pleopods and the shape of the third pleopods, which are modified for copulation (Fig. 8). Adult females have a set of plates known as oostegites projecting ventrally from the last two thoracic segments. These plates enclose the ventral brood chamber. Juvenile mysids resemble the adults but do not have fully developed reproductive appendages as mentioned above.

Only one member of the Order Mysidacea is common in the Great Lakes. The life history, feeding behavior, and ecology of *Mysis relicta* are described in more detail in a later section.

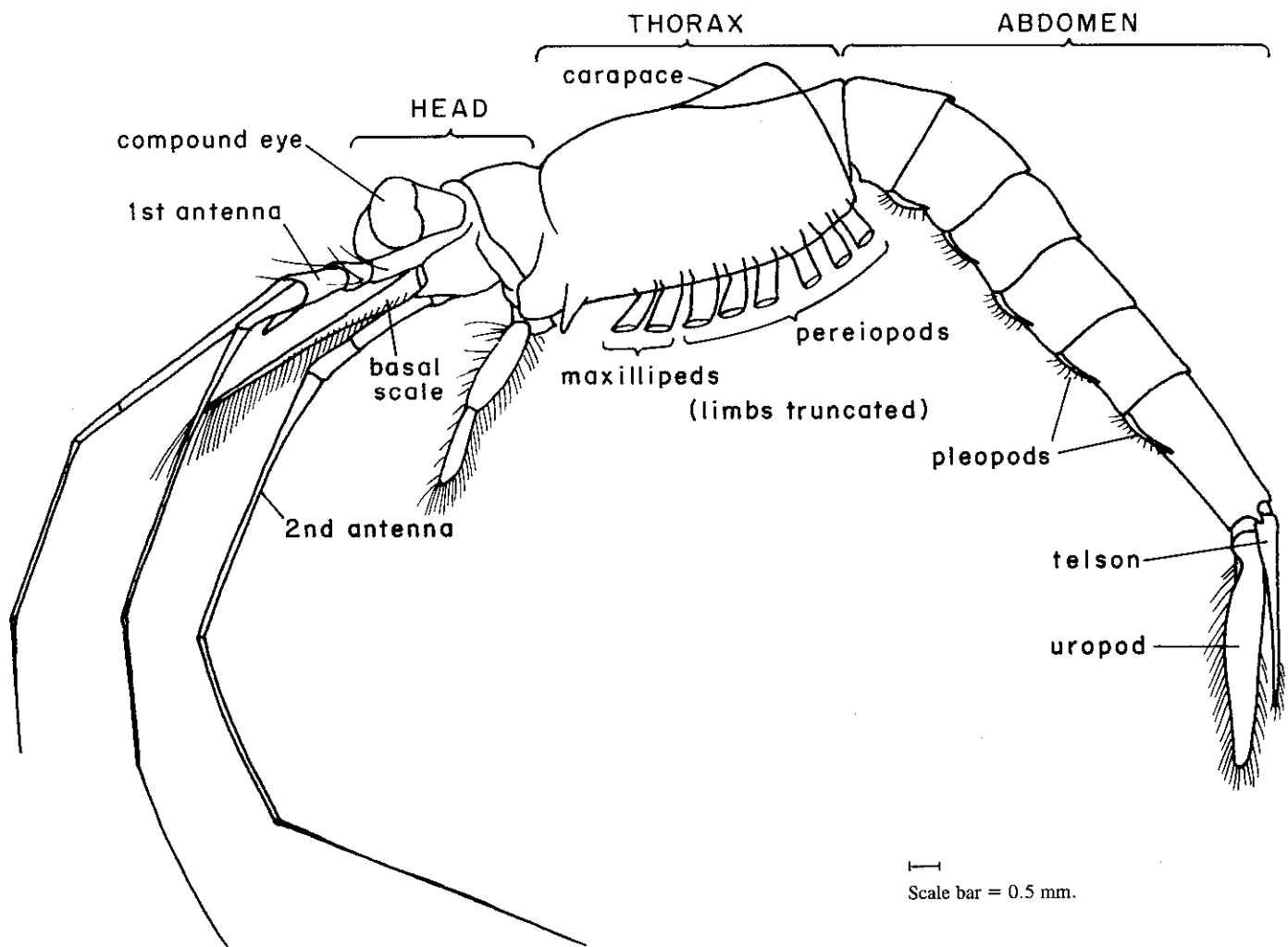


Figure 3a General morphology of a malacostracan, Order Mysidacea, lateral view

Order Isopoda

ANATOMY

The aquatic pill bugs or sow bugs of the order Isopoda are not generally planktonic but are occasionally found in samples collected near breakwalls or from the bottom of vegetated areas of the Great Lakes.

The 5–20 mm long adults are dorsoventrally flattened and lack a carapace (Fig. 3b). The head possesses two pairs of antennae; the second pair longer than the first. The compound eyes are not stalked and are located on the dorsal surface of the head. The remaining ventrally located head appendages—the mandibles, first maxillae, and second maxillae—are used for feeding.

The first thoracic segment is fused to the head and has paired, flattened ventral appendages, the maxillipeds, which

are used in food handling. The next seven thoracic segments are expanded laterally. Each possesses a pair of uniramous walking legs, the pereiopods. The first pair, gnathopods, may be modified for grasping and are more specialized in males than in females.

The first two abdominal segments are reduced in size; the succeeding four segments are larger and fused together. The modified appendages, the pleopods, of the first five segments are hidden beneath the abdomen and aid in respiration. In males, the second pair of pleopods are modified into copulatory stylets and are used for sperm transfer. The last abdominal segment bears the paired uropods, which project posteriorly from the body.

FEEDING BEHAVIOR

Isopods are scavengers and crawl along the bottom mainly in shallow water searching under rocks and among vegeta-

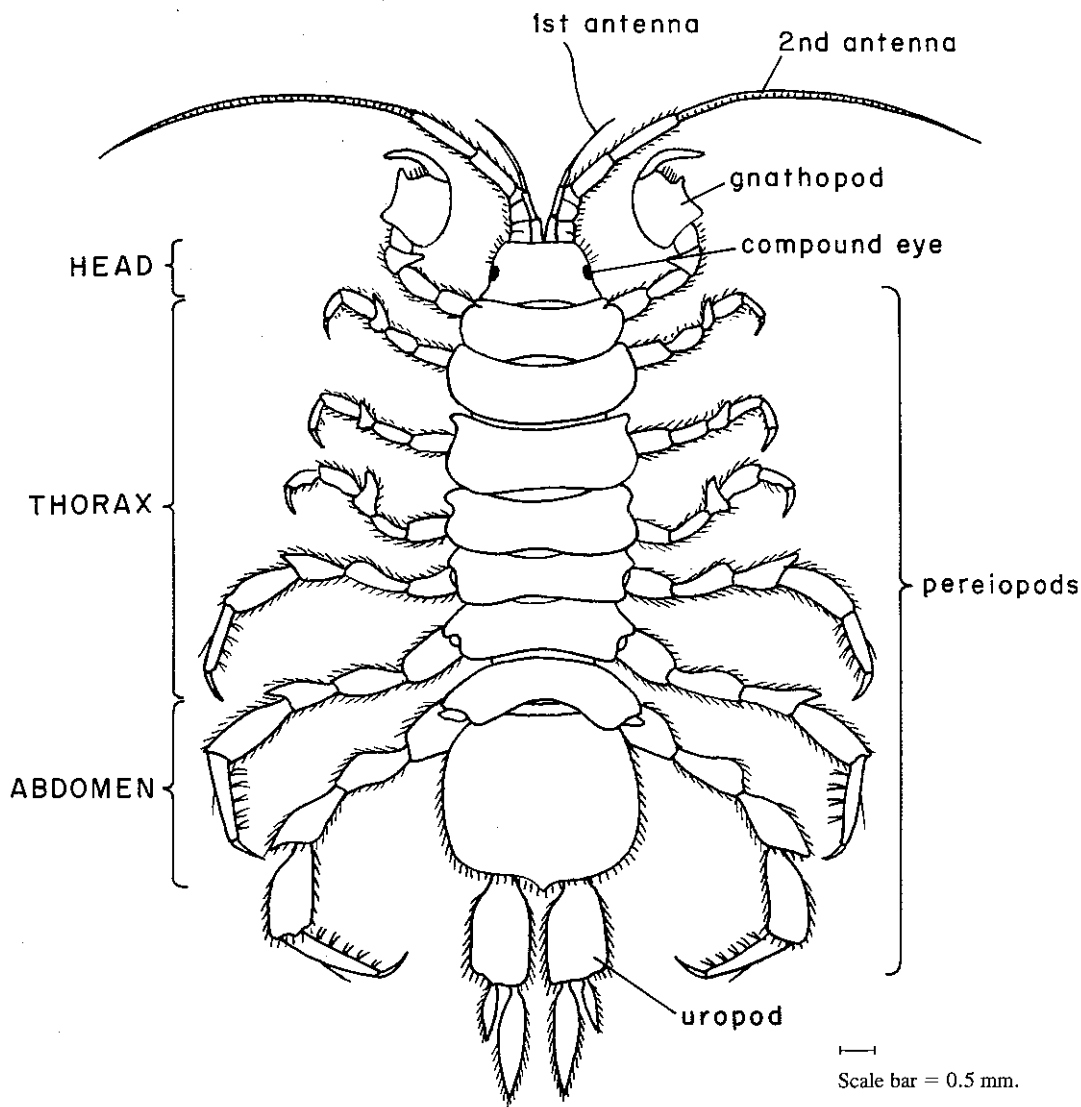


Figure 3b General morphology of a malacostracan, Order Isopoda, dorsal view

tion and debris for dead and injured animals. They also consume leaves, grass, and aquatic vegetation.

The ecology and life history of the isopods are described in more detail by Pennak (1978).

Order Amphipoda

ANATOMY

Commonly known as scuds (suborder Gammaridea) these animals typically lack a carapace, and the body segments are laterally compressed. Scuds from the Great Lakes are 5–20 mm long when mature. Bousfield (1982) is an excellent source for the anatomy and taxonomy of amphipods.

The head (to which the first thoracic segment is fused) has paired, unstalked, sessile compound eyes located laterally (Fig. 3c). Two pairs of antennae are present. The first antenna consists of a three-segmented basal penduncular portion and a longer, more slender multisegmented flagellum; a shorter accessory flagellum is present on Great Lakes scuds. The second antenna is longer, with a peduncle of 5 segments, the second bearing the excretory gland cone. The mouthparts are clustered in a compact mass directly beneath the head. They consist of the unpaired and fused upper and lower lips, the paired movable mandibles, first and second maxillae, and the maxillipeds, the latter pair fused basally.

The seven free segments of the thorax each bear a pair of seven-segmented uniramous “walking” legs, pereopods. The first two pairs are usually modified for grasping, often

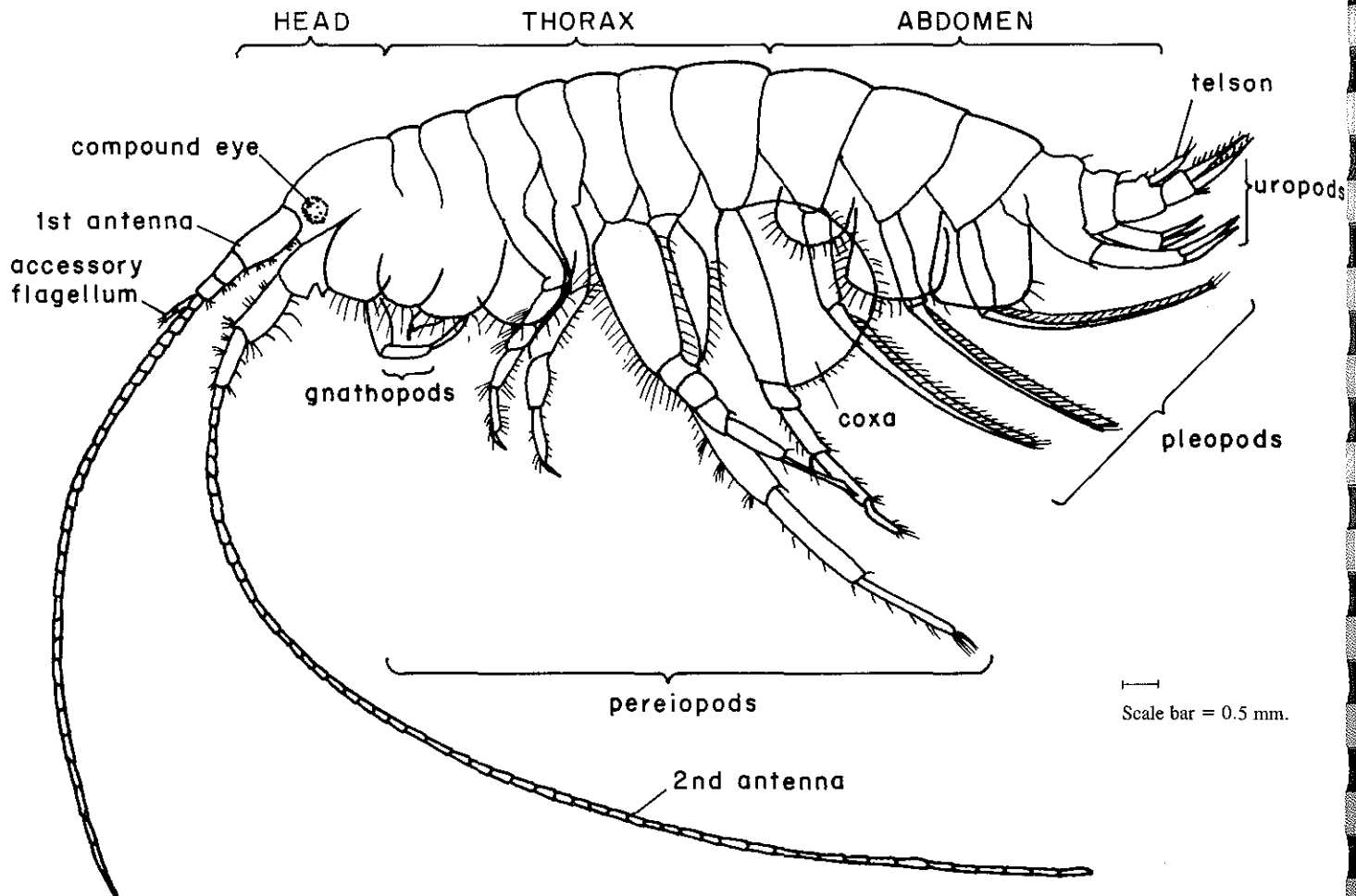


Figure 3c General morphology of a malacostracan, Order Amphipoda, lateral view

strongly so in the male, and are termed gnathopods. The basal segment, coxa, of each leg is enlarged and flattened into an outer protective plate. Attached to the inner surface of coxae 2–7 (often lacking on 7) are flattened respiratory sacs, coxal gills. Slender, fingerlike accessory gills are attached to the sternum in some groups, including *Pontoporeia* and *Hyalabella*.

In mature females (Fig. 9), the coxae of pereopods 2–5 bear large, thin interlocking brood plates (oostegites) that form a ventral brood chamber. In mature males, the short, paired penis papillae are located near the coxae of pereopod 7.

The abdomen consists of six segments and terminates in a short, usually bilobate or platelike telson. The first three segments have paired biramous flexibly multisegmented pleopods used in swimming and maintaining a respiratory current. The posterior three abdominal segments (occasionally fused together) bear stiff biramous uropods, which aid in pushing, swimming, and burrowing.

FEEDING BEHAVIOR

Amphipods are voracious feeders but only a few groups are predaceous on live animals. When consuming detritus or plant material, they use the gnathopods to grasp and hold the material while the mouthparts chew off portions. Some amphipods are filter feeders, and some, mostly marine, are external parasites or commensals on fishes or colonial invertebrates.

GROWTH AND REPRODUCTION

Many species of scuds become sexually mature at about the 9th or 10th molt stage or instar. In gammarids, a sexually mature male often pairs with a subadult (8th instar) female and clings to her for 1–7 days until she molts. The animals then mate. The female extrudes the eggs into her ventral brood chamber where they are fertilized by sperm strings

from the male. Eggs are incubated for 1-3 weeks. The newly hatched young may be retained in the chamber for an additional 1-8 days, then released when the female molts. Adults molt every 3-40 days and may molt several times after they reach sexual maturity.

It is difficult to determine the sex of the very immature instars. Sixth or seventh instar females begin to form small oostegites, and developing eggs may be observed in the ovaries. In some amphipods (such as *Gammarus* and *Hyalolella*) males are distinguished by their modified, enlarged gnathopods, which begin to differentiate from the fe-

male form at about the sixth instar. All later immature males may be identified by the small penis papillae at the bases of the 7th pereopods.

ECOLOGY

Most scuds are generally benthic organisms with a negative response to light. They hide among rocks, vegetation, and detritus in shallow water. Pennak (1978) and Bousfield (1973) give more information on the ecology of the amphipods.

General Procedures for Collecting and Identifying Crustacean Zooplankton

Zooplankton may be collected with water samplers, plankton traps, plankton nets, Clarke-Bumpus samplers, and pumps. Edmondson and Winberg (1971) describe each of these methods and discuss their advantages and disadvantages. In the Great Lakes, most investigators collect zooplankton by taking a vertical tow with a 0.5-m diameter plankton net. Samples are usually concentrated and preserved in a solution of 4% neutralized formaldehyde (equals 10% formalin solution).

Subsamples are counted when the total number of organisms in a sample is too large to be counted easily. In these cases, measure the sample volume and thoroughly mix it before using a wide mouth pipette to remove a known volume of the sample. Place the subsample in a Sedgewick-Rafter cell, a plankton counting cell, or a small gridded Petri dish for examination.

Most organisms can be identified to major taxonomic group and the common plankton can be identified to species with a dissecting microscope (25–50× magnification) and the following key. Dissections and higher magnification (100–200×) are needed to confirm the identity of some organisms.

Cladocerans are commonly identified from the lateral view (Fig. 1). Use small needles or insect pins mounted on wooden dowels or inserted into the eraser of a pencil to manipulate the animals into the proper position. In some cla-

docerans you must examine the pecten of the postabdominal claw to confirm the identification. In this case, place the organism on a glass slide in a small drop of water. Use the probes to reach into the carapace, pull the postabdomen out, and cut it off. Then place a cover glass over the postabdomen and observe it under a compound microscope.

Copepods are often identified from the dorsal view. Probes must be used to hold the animals since the position of the legs tends to roll them over onto their sides. Note that legs are omitted or drawn in an ideal location in the following illustrations of copepods. You must examine the fifth leg of some copepods to identify them correctly. In calanoids the fifth legs can be examined by pulling them to the side of the animal (Figs. 79–82) or cutting them off (Fig. 83). The fifth legs of cyclopoid copepods (Fig. 2c) are very tiny and are best observed by cutting the animal in half between the segments with the fourth and fifth legs and mounting the posterior half, ventral side up, on a slide.

When examining a sample of zooplankton, it is a good idea to look through the sample, key out several of the organisms, and examine them carefully. When you become familiar with the organisms, you can then begin counting the sample by moving the dish or slide slowly, without splashing, and identifying the organisms you see in each grid. More information on subsampling and counting samples is provided by Edmondson and Winberg (1971). It is a good

idea to preserve some of the organisms in small vials or to make permanent slides of them (see Edmondson 1959b) so that the identification can be confirmed.

The following key identifies the common Great Lakes zooplankton to species. Many of the less common animals are keyed only to family or genus because accurate species identification would require dissections and use of high magnification. While figures of representative organisms in the family or genus are provided, we caution you against identifying an animal solely on the basis of the figure and advise you to consult the more detailed taxonomic works listed.

DISTINGUISHING LIFE STAGES

This key is applicable for all free-living life stages of the common Great Lakes cladocerans. Except where the key refers specifically to males or females, either sex can be used to identify a species. Occasionally, embryos (Fig. 4) will be released from the brood chambers of preserved females. These immature forms lack developed appendages and carapaces and cannot be identified correctly by the following key; they should not be counted as free-living organisms.

Characteristics of adult copepods (stage VI copepodids: CVI) are used for species identification in this key. Although they resemble adults, immature copepodids often lack the necessary characteristics for identification and should be separated from the adults before applying the key. The copepod nauplii are generally small (100–400 μm

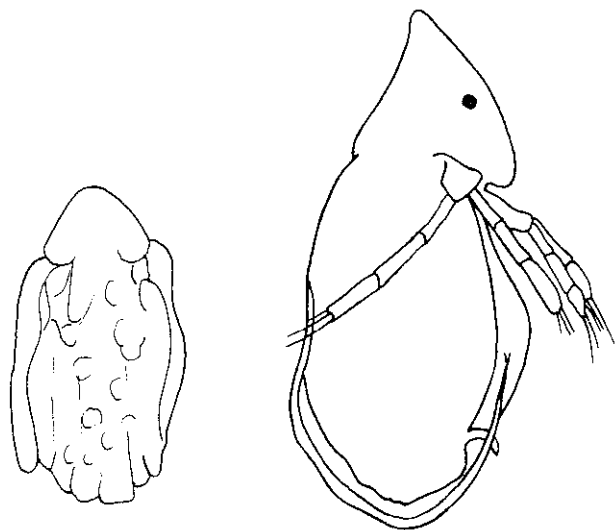


Figure 4 Cladoceran (*Daphnia*) embryos

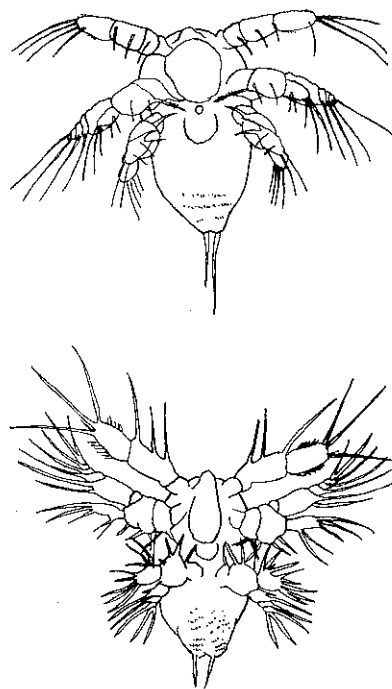


Figure 5 Copepod nauplii

long) and resemble the animals shown in Fig. 5. The body shape and number of appendages vary in the different species and naupliar stages.

Adult (CVI) male cyclopoids are recognized by their geniculate first antennae (Fig. 2b) while adult females usually are found carrying paired egg sacs. Adults of both sexes have an enlarged genital segment that is longer than any of the posterior abdominal segments. The number of abdominal segments depends on the developmental stage and sex of the animal. Adult males have four segments posterior to the genital segment while adult females have only three. In immature cyclopoid copepodids (CI–CV), the genital segment is similar in size to the succeeding segment, and the terminal abdominal segment is the longest since it hasn't yet divided transversely (Fig. 6).

Adult male calanoids have only the right first antenna geniculate (Fig. 2f). In preserved specimens the first antennae may be extended, but the geniculation (joint) is still evident (Figs. 80–81). CVI males have five abdominal segments; fewer segments are present in stages CI–CV. Adult females are more difficult to distinguish from immature stages since the number of adult abdominal segments varies between species. They are most easily recognized when carrying eggs or spermatophores. The genital segment is usually expanded slightly and, in a lateral view, is seen

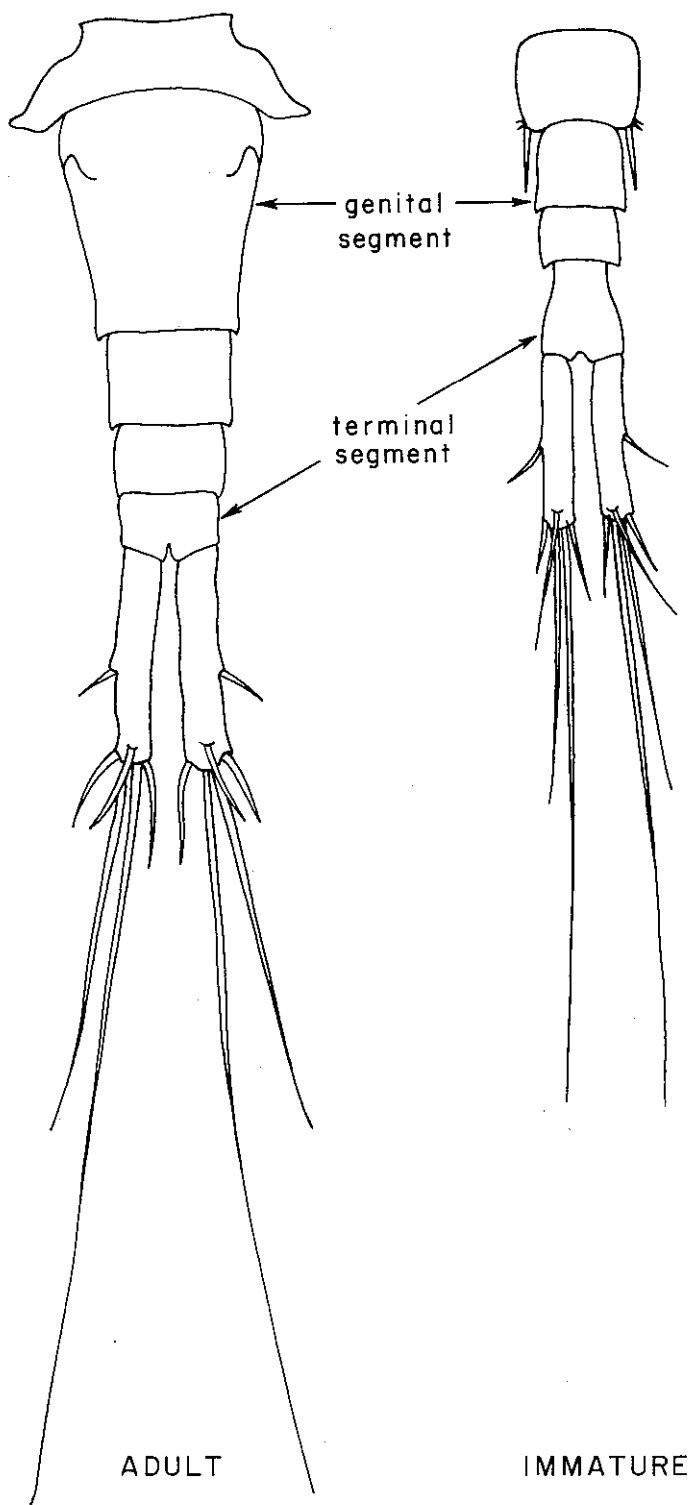


Figure 6 Abdomen of cyclopoid copepods (*Diacyclops*), dorsal view

to bulge ventrally (Figs. 61, 63). Immature calanoid copepodids are smaller than the adults and lack the above characteristics.

Detailed keys to the nauplii (NI–NVI) and copepodids (CI–CVI) of all common Great Lakes species of cyclopoids and calanoids (Czaika 1982) and to the immature diaptomid copepodids (Czaika and Robertson, 1968) are available but require dissection of appendages and high magnification. Torke (1974) describes the naupliar and copepodid stages of *Limnocalanus macrurus*, diaptomid spp., and *Diacyclops thomasi*, and Katona (1971) describes the immature stages of *Eurytemora affinis*, but neither provides species keys.

USING A TAXONOMIC KEY

A taxonomic key provides a simplified method to differentiate organisms from each other. Most keys are arranged in couplets consisting of a pair of phrases that give alternative choices; i.e., an organism either does or does not have a certain characteristic. To use the following taxonomic key to the Great Lakes crustacean zooplankton, begin at couplet 1. Decide whether the organism you want to identify is best described by phrase 1a or 1b. Pointers on figures point out major features described by the phrases. Then go to the couplet indicated by the number to the far right of the phrase you selected. Again determine which phrase of the couplet best describes your unknown organism. Continue to move to the couplets indicated by your choice of phrases until you come to the name of an organism or group of organisms. Read the additional descriptive notes that may be present and compare your unknown animal with the figures indicated. If they agree, you now know the identity of the animal. If your animal does not resemble the figure and description, you most likely selected the wrong phrase in one of the preceding couplets. Go back and decide where you may have been mistaken and then continue along from the alternative phrase until you learn the identity of your unknown animal. You may also wish to consult the more detailed descriptions and life history information provided for the major species after the key. Page numbers for this information are provided in the key at the point of identification for the species covered.

Note: This key is designed for the more common species of crustacean zooplankton. Some rare species will not be accurately described by any of the couplets and will not resemble the accompanying figures. In these cases more detailed keys should be consulted. Appendages have been omitted from some of the figures in order to show underlying body features.

Classification
of Great Lakes
Crustacean
Zooplankton

PHYLUM ARTHROPODA

Class Crustacea

SUBCLASS BRANCHIOPODA

ORDER CLADOCERA

Suborder Haplopoda

Family Leptodoridae—*Leptodora*

Suborder Eucladocera

SUPERFAMILY POLYPHEMOIDEA

Family Polyphemidae—*Polyphemus*

SUPERFAMILY SIDOIDEA

Family Sididae—*Diaphanosoma*,
Latona, *Latonopsis*, *Sida*

Family Holopedidae—*Holopedium*

SUPERFAMILY CHYDOROIDEA

Family Daphnidae—*Ceriodaphnia*,
Daphnia, *Scapholeberis*,
Simocephalus

Family Moinidae—*Moina*

Family Bosminidae—*Bosmina*,
Eubosmina

Family Macrothricidae—*Acantholeberis*,
Drepanothrix, *Ilyocryptus*,
Macrothrix, *Ophryoxus*,
Wlassicsia

Family Chydoridae—*Acroperus*, *Alona*,
Alonella, *Alonopsis*, *Anchistropus*,
Camptocercus, *Chydorus*, *Dispar-*
alona, *Eurycercus*, *Graptoleberis*,

Kurzia, *Leydigia*, *Monospilus*,
Pleuroxus, *Rhynchotalona*

SUBCLASS COPEPODA

ORDER EUCOPEPODA

Suborder Calanoida

Family Pseudocalanidae—*Senecella*

Family Centropagidae—*Limnocalanus*,
Osphranticum

Family Temoridae—*Epischura*,
Eurytemora

Family Diaptomidae—*Leptodiaptomus*,
Skistodiaptomus

Suborder Cyclopoida

Family Cyclopidae—*Acanthocyclops*,
Cyclops, *Diacyclops*, *Eucyclops*,
Macrocyclops, *Mesocyclops*, *Para-*
cyclops, *Tropocyclops*

Suborder Harpacticoida

Family Canthocamptidae—*Bryocamp-*
tus, *Canthocamptus*, *Epacto-*
phanes, *Mesochra*, *Moraria*

Family Ameiridae—*Nitocra*

SUBCLASS MALACOSTRACA

ORDER MYSIDACEA

Family Mysidae—*Mysis*

ORDER AMPHIPODA

Family Pontoporeiidae—*Pontoporeia*

ORDER ISOPODA

Species of
Crustacean Zooplankton
Found in
the Great Lakes

<i>Species Name</i> ^a	<i>Identification Level</i> ^b	<i>Page Reference</i>	<i>Location</i> ^c				
			<i>Erie</i>	<i>Huron</i>	<i>Michigan</i>	<i>Ontario</i>	<i>Superior</i>
CLADOCERANS							
<i>Acantholeberis curvirostris</i> (O. F. Müller) 1776	F	32, 112		x			
<i>Acroperus harpae</i> Baird 1843	F	28, 112	x		x		x
<i>Alona affinis</i> (Leydig) 1860	F	28, 112	x	x	x	x	x
<i>Alona circumfimbriata</i> Megard 1967	F	28, 112			x		
<i>Alona costata</i> Sars 1862	F	28, 112	x		x		x
<i>Alona guttata</i> Sars 1862	F	28, 113	x		x		x
<i>Alona lepida</i> Birge 1893	F	28, 113					[x]
<i>Alona quadrangularis</i> (O. F. Müller) 1785	F	28, 113	x		x		
<i>Alona rectangula</i> Sars 1861	F	28, 113	x		x		
<i>Alonella excisa</i> (Fisher) 1854	F	28, 113	x				
<i>Alonella nana</i> (Baird) 1850	F	28, 113	x				x
<i>Alonopsis elongata</i> Sars 1861	F	28, 113					x
<i>Anchistropus minor</i> Birge 1893	F	28, 113		x	x		x
<i>Bosmina longirostris</i> (O. F. Müller) 1785	S	31, 66	x	x	x	x	x
<i>Camptocercus macrurus</i> (O. F. Müller) 1785	F	28, 113	x				
<i>Camptocercus rectirostris</i> Schödler 1862	F	28, 113	x	x	x	x	
<i>Ceriodaphnia lacustris</i> Birge 1893	G	33, 58	x	x	x	x	
<i>Ceriodaphnia laticaudata</i> P. E. Müller, 1867	G	33, 58	x				
<i>Ceriodaphnia pulchella</i> Sars 1862	G	33, 58	x				
<i>Ceriodaphnia quadrangula</i> (O. F. Müller) 1785	G	33, 58	x	x	x		
<i>Ceriodaphnia reticulata</i> (Jurine) 1820	G	33, 58	x				
<i>Chydorus faviformis</i> Birge 1893	F	28, 71		x			
<i>Chydorus gibbus</i> Sars 1890 (<i>Chydorus gibbus</i> Lilljeborg 1880)	F	28, 71	x				x

Species Name ^a	Identification Level ^b	Page Reference	Location ^c				
			Erie	Huron	Michigan	Ontario	Superior
CLADOCERANS (continued)							
<i>Chydorus globosus</i> Baird 1850	F	28, 71	x	x			x
<i>Chydorus latus</i> Sars 1862	F	28, 71	x				
<i>Chydorus sphaericus</i> (O. F. Müller) 1785	F	28, 71	x	x	x	x	x
<i>Daphnia ambigua</i> Scourfield 1947	S	35, 111	x	x	x		
<i>Daphnia galeata</i> Sars 1864 <i>mendotae</i> Birge 1918	S	36, 60	x	x	x	x	x
<i>Daphnia longiremis</i> Sars 1861	S	37, 64	x	x	x	x	
<i>Daphnia parvula</i> Fordyce 1901	S	34, 111			x		
<i>Daphnia pulex</i> Leydig 1860 emend. Richard 1896	S	35, 111	x	x	x	x	x
<i>Daphnia retrocurva</i> Forbes 1882	S	38, 62	x	x	x	x	x
<i>Daphnia schödleri</i> Sars 1862	S	35, 111			x		
<i>Diaphanosoma brachyurum</i> (Liéven) 1848	G	27, 54	x	x	x		x
<i>Diaphanosoma birgei</i> Kofinck 1981 (<i>D. leuchtenbergianum</i> Fischer 1850)	G	27, 54	x	x	x	x	x
<i>Disparalona acutirostris</i> (Birge) 1878 (<i>Alonella acutirostus</i> (Birge) 1878)	F	28, 113					x
<i>Disparalona rostrata</i> (Koch) 1841 (<i>Alonella rostrata</i> (Koch) 1841)	F	28, 113			x		x
<i>Drepanothrix dentata</i> (Eurén) 1861	F	32, 112		x			x
<i>Eubosmina coregoni</i> (Baird) 1850	S	31, 69	x	x	x	x	x
<i>Eubosmina longispina</i> (Leydig) 1860	G	31, 66	[x]	[x]			[x]
<i>Eurycercus lamellatus</i> (O. F. Müller) 1785	F	28, 113	x	x	x	x	x
<i>Graptoleberis testudinaria</i> (Fischer) 1848	F	28, 114	x	x	x		
<i>Holopedium gibberum</i> Zaddach 1855	S	26, 56	x	x	x	x	x
<i>Ilyocryptus acutifrons</i> Sars 1862	F	32, 112			x		
<i>Ilyocryptus sordidus</i> (Liéven) 1848	F	32, 112	x		x		
<i>Ilyocryptus spinifer</i> Herrick 1884	F	32, 112	x			x	x
<i>Kurzia latissima</i> (Kurz) 1874	F	28, 114	x	x			
<i>Latona setifera</i> (O.F. Müller) 1785	S	27, 110	x	x	x		x
<i>Latonopsis occidentalis</i> Birge 1891	S	28, 110	x				
<i>Leptodora kindtii</i> (Focke) 1844	S	25, 49	x	x	x	x	x
<i>Leydigia acanthocercoides</i> (Fischer) 1854	F	28, 114	x				
<i>Leydigia leydigi</i> (Schödler) 1863 (<i>L. quadrangularis</i> (Leydig) 1860)	F	28, 114	x	x	x		
<i>Macrothrix laticornis</i> (Jurine) 1820	F	32, 112	x		x	x	x
<i>Moina micrura</i> Kurz 1874	S	33, 111			x		
<i>Monospilus dispar</i> Sars 1861	F	28, 114	x	x			x
<i>Ophryoxus gracilis</i> Sars 1861	F	32, 112		x	x		
<i>Pleuroxus aduncus</i> (Jurine) 1820	F	28, 114	x				
<i>Pleuroxus denticulatus</i> Birge 1878	F	28, 114	x		x		
<i>Pleuroxus hastatus</i> Sars 1862	F	28, 114					x
<i>Pleuroxus procurvus</i> Birge 1878	F	28, 114	x		x		x
<i>Pleuroxus striatus</i> Schödler 1863	F	28, 114	x				
<i>Polyphemus pediculus</i> (Linné) 1761	S	26, 52		x	x	x	x
<i>Rhynchotalona falcata</i> (Sars) 1861	F	28, 114					x
<i>Scapholeberis aurita</i> (Fischer) 1849	G	34, 111	x		x		x
<i>Scapholeberis kingi</i> Sars 1903	G	34, 111	x		x		x
<i>Sida crystallina</i> (O.F. Müller) 1875	S	28, 110	x	x	x	x	x
<i>Simocephalus exspinosus</i> (Koch) 1841	G	34, 111					x
<i>Simocephalus serrulatus</i> (Koch) 1841	G	34, 111	x		x		
<i>Simocephalus vetulus</i> Schödler 1858	G	34, 111	x				x
<i>Wlassicsia kinistinensis</i> Birge 1910	F	32, 112			x		

Species Name ^a	Identification Level ^b	Page Reference	Location ^c				
			Erie	Huron	Michigan	Ontario	Superior
CYCLOPOID COPEPODS							
<i>Acanthocyclops vernalis</i> (Fischer) 1893 (<i>Cyclops vernalis</i> Fischer 1893)	S	47, 93	x	x	x	x	x
<i>Cyclops scutifer</i> Sars 1863	S	47, 115		x			
<i>Cyclops strenuus</i> Fischer 1851	S	47, 115					x
<i>Diacyclops nanus</i> (Sars) 1863 (<i>Cyclops nanus</i> Sars 1863)	S	46, 115	x	x			
<i>Diacyclops thomasi</i> (S. A. Forbes) 1882 (<i>Cyclops bicuspidatus thomasi</i> S. A. Forbes 1882)	S	48, 96	x	x	x	x	x
<i>Eucyclops agilis</i> (Koch) 1838	S	47, 115	x		x		x
<i>Eucyclops prionophorus</i> Kiefer 1931	S	46, 115			x		
<i>Eucyclops speratus</i> (Lilljeborg) 1901	S	47, 115	x				x
<i>Macrocyclus albidus</i> (Jurine) 1820	S	45, 115	x		x		x
<i>Mesocyclops edax</i> (S. A. Forbes) 1891	S	46, 98	x	x	x	x	x
<i>Paracyclops fimbriatus poppei</i> (Rehberg) 1880	S	46, 116	x		x		
<i>Tropocyclops prasinus mexicanus</i> Kiefer 1938	S	46, 101	x	x	x	x	x

CALANOID COPEPODS

<i>Epischura lacustris</i> S. A. Forbes 1882	S	41, 77	x	x	x	x	x
<i>Eurytemora affinis</i> (Poppe) 1880	S	40, 79	x	x	x	x	x
<i>Leptodiaptomus ashlandi</i> (Marsh) 1893 (<i>Diaptomus ashlandi</i> March 1893)	S	42, 44, 82	x	x	x	x	x
<i>Leptodiaptomus minutus</i> (Lilljeborg) 1889 (<i>Diaptomus minutus</i> Lilljeborg 1889)	S	43, 44, 84	x	x	x	x	x
<i>Leptodiaptomus sicilis</i> (S. A. Forbes) 1882 (<i>Diaptomus sicilis</i> S. A. Forbes 1882)	S	42, 44, 87	x	x	x	x	x
<i>Leptodiaptomus siciloides</i> (Lilljeborg) 1889 (<i>Diaptomus siciloides</i> Lilljeborg 1889)	S	41, 45, 89	x	x	x	x	x
<i>Limnocalanus macrurus</i> Sars 1863	S	38, 74	x	x	x	x	x
<i>Osphranticum labronectum</i> S. A. Forbes 1882	N	114			x		[x]
<i>Senecella calanoides</i> Juday 1923	S	40, 73		x	x		x
<i>Skistodiaptomus oregonensis</i> (Lilljeborg) 1889 (<i>Diaptomus oregonensis</i> Lilljeborg 1889)	S	42, 43, 91	x	x	x	x	x
<i>Skistodiaptomus pallidus</i> (Herrick) 1879 (<i>Diaptomus pallidus</i> Herrick 1879)	S	42, 43, 115	x			x	
<i>Skistodiaptomus reighardi</i> (March) 1895 (<i>Diaptomus reighardi</i> March 1895)	S	42, 45, 115	x	x	x		

HARPACTICOID COPEPODS

<i>Bryocamptus nivalis</i> (Willey) 1925	SO	38, 116					x
<i>Bryocamptus zschokkei</i> (Schmeil) 1893	SO	38, 116					x
<i>Canthocamptus robertcokeri</i> M. S. Wilson 1958	SO	38, 116	x		x		x
<i>Canthocamptus staphylinoides</i> Pearse 1905	SO	38, 116	x		x		x
<i>Epactophanes richardi</i> Mrazek 1893	SO	38, 116					x
<i>Mesochra alaskana</i> M. S. Wilson 1958	SO	38, 116					x
<i>Moraria cristata</i> Chappuis 1929	SO	38, 116					x

Species Name ^a	Identification Level ^b	Page Reference	Location ^c				
			Erie	Huron	Michigan	Ontario	Superior
HARPACTICOID COPEPODS (continued)							
<i>Nitocra hibernica</i> (Brady) 1880	SO	38, 116				x	
<i>Nitocra spinipes</i> Bueck 1864	SO	38, 116				x	
MALACOSTRACANS							
<i>Mysis relicta</i> Lovén 1861	S	24, 103	x	x	x	x	x
<i>Pontoporeia</i> Krøyer 1842	G	25, 106	x	x	x	x	x

^a The names in this list are consistent with those in Ward and Whipple's *Freshwater Biology* (Edmondson 1959a). Where names have changed since its publication, the Edmondson (1959a) name is given in parentheses below the new name.

^b Identification level

SO = Suborder F = Family G = Genus S = Species N = Not in Key

^c Where location is bracketed, the animals given the indicated name were probably misidentified.

Key to
Common Great Lakes
Crustacean
Zooplankton

- 1a. Two large, paired lateral compound eyes; each body segment with a pair of appendages; large animals (6–25 mm), shrimp- or scudlike (Figs. 3b, 7–10)..... Subclass MALACOSTRACA, 2
- 1b. Compound eye single (median) or absent; appendages lacking on several abdominal segments; small animals (most < 5 mm); waterfleas and oarsmen..... 4
- 2a. Eyes on stalks; body shrimplike, with carapace (Figs. 7, 8) ... Order MYSIDACEA, *Mysis relicta*, ... p. 103
Adults 13–25 mm, young 3 mm.
- 2b. Eyes not stalked; body lacking carapace 3
- 3a. Body segments flattened dorsoventrally; abdomen with 5 pairs of pleopods, 1 pair of uropods (Fig. 3b) Order ISOPODA

Isopods are rarely planktonic but are common in some bottom samples. Consult keys by Chace et al. (1959) or Pennak (1978) for species identification.

Scale bars = 0.5 mm.

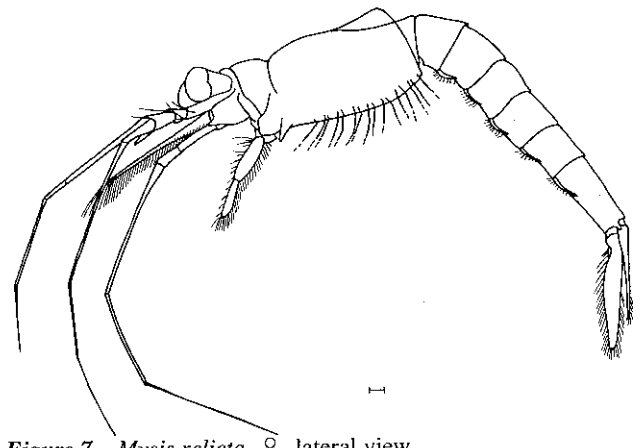


Figure 7 *Mysis relicta*, ♀, lateral view

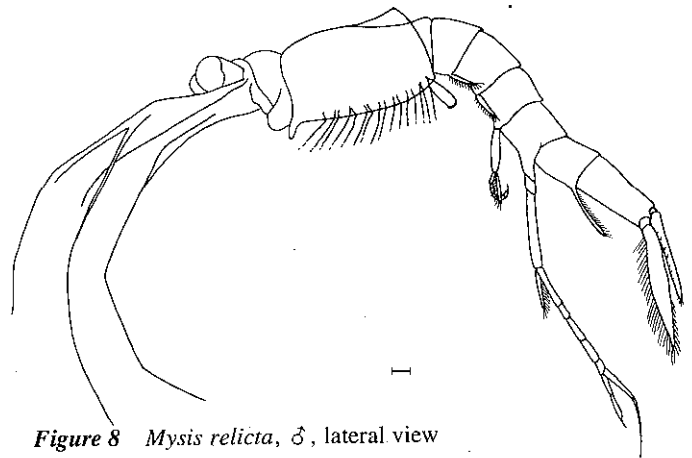


Figure 8 *Mysis relicta*, ♂, lateral view

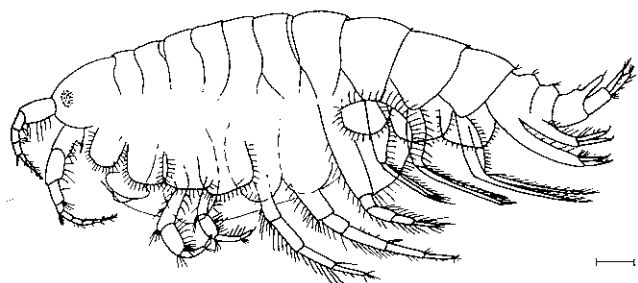


Figure 9 *Pontoporeia*, ♀, lateral view

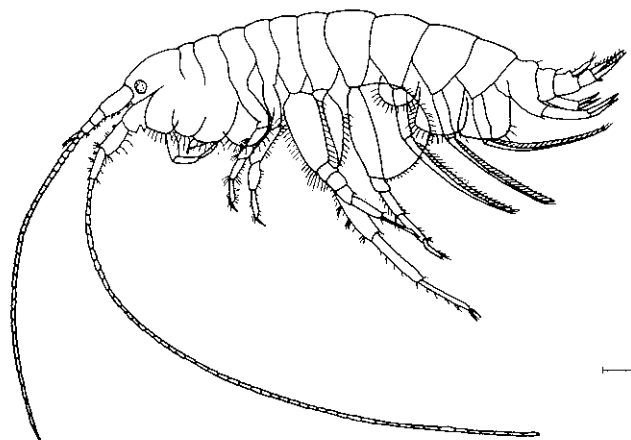


Figure 10 *Pontoporeia*, ♂, lateral view

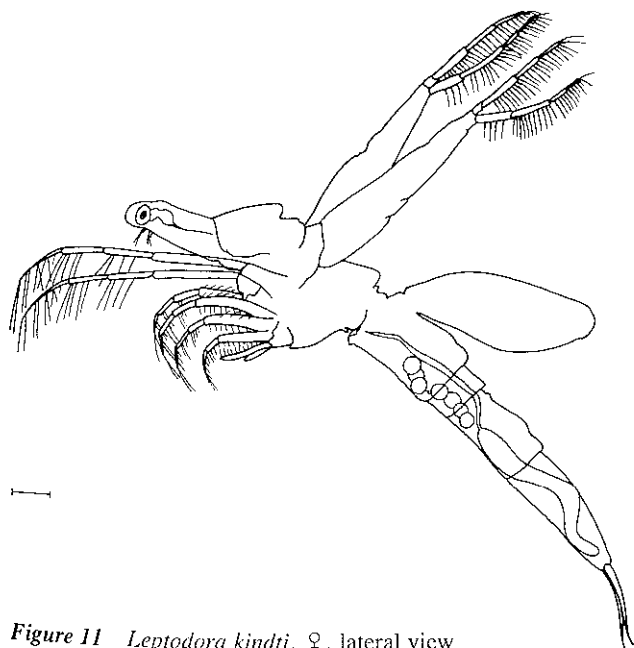


Figure 11 *Leptodora kindtii*, ♀, lateral view

3b. Body segments compressed laterally; abdomen with 3 pairs of pleopods, 3 pairs of uropods (Figs. 9, 10). Adults 6–9 mm. Order AMPHIPODA, p. 106

Pontoporeia (pelagic males) occur seasonally (late fall to spring) in the plankton. Chace et al. (1959), Pennak (1978) and Bousfield (1982) describe the other members of this order.

4a. Single compound eye present; longest head appendage (2nd antenna) usually with 2 branches (Figs. 1, 11, 13).
 Subclass BRANCHIOPODA, ORDER CLADOCERA, 5

4b. Compound eye absent; longest head appendage (1st antenna) with only 1 branch (Fig. 2)
 Subclass COPEPODA, 26

5a. Body and thoracic appendages enclosed in a shell-like carapace 7

5b. Carapace reduced, only covers brood chamber; appendages exposed 6

6a. Body long and slender (up to 18 mm long); eye small, less than half as wide as head (Figs. 11, 12)
 *Leptodora kindtii*, p. 49

Scale bars = 0.5 mm.

- 6b. Body rounded (< 2 mm long) with elongate "tail"; eye large, almost as wide as head (Fig. 13)
 *Polyphemus pediculus*, p. 52
- 7a. Second antennae of females with 1 branch; a large gelatinous sheath often covers the humpbacked animals (Fig. 14). *Holopedium gibberum*, p. 56
 Adults 0.5–2.2 mm long. Males are similar to females in shape but have biramous 2nd antennae. The sheath may be lost in preserved animals.
- 7b. Second antennae with 2 branches; no gelatinous covering; back not humped 8
- 8a. Many (> 14) setae arranged in a row along one side of the dorsal (longer) branch of the 2nd antennae (Figs. 15–19). Family SIDIDAE, 9
 Preserved animals often have 2nd antennae extended as in figure 15.
- 8b. Few (< 10) setae on dorsal branch of 2nd antennae, not arranged in a row along one side of the branch (Figs. 21, 41, 49). 12

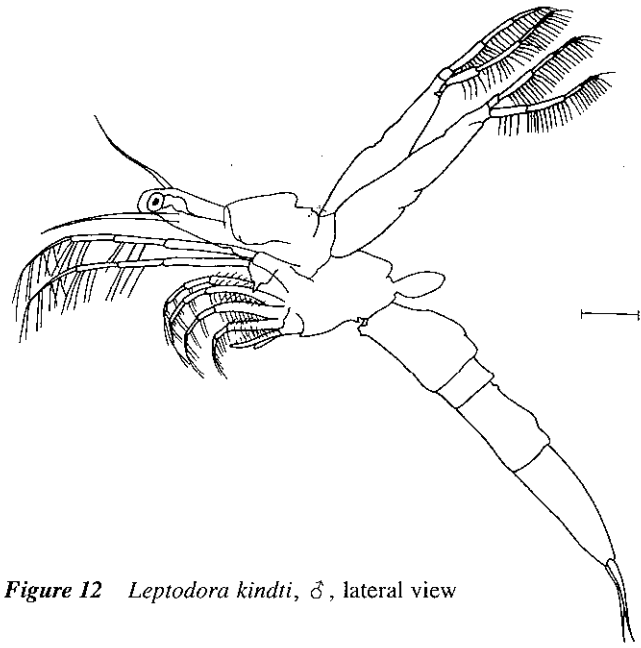


Figure 12 *Leptodora kindti*, ♂, lateral view

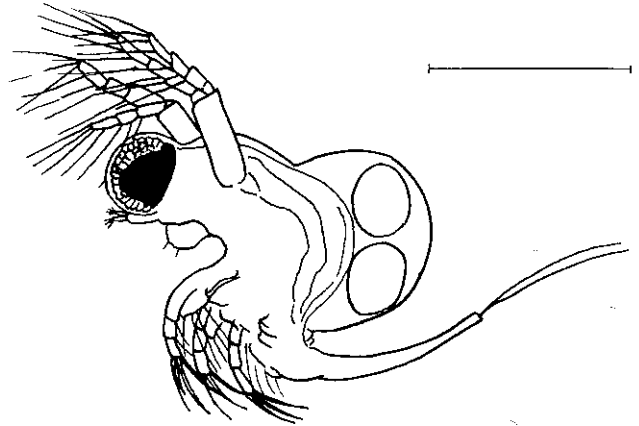


Figure 13 *Polyphemus pediculus*, lateral view

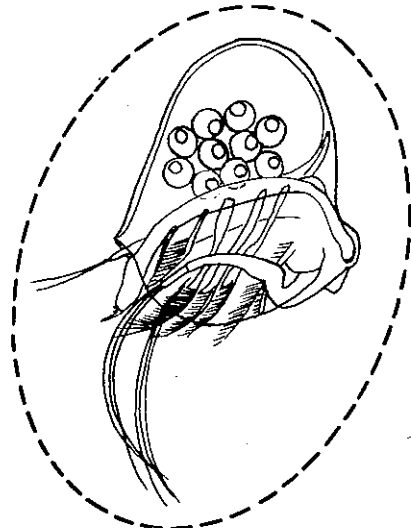


Figure 14 *Holopedium gibberum*, ♀, lateral view

Scale bars = 0.5 mm.

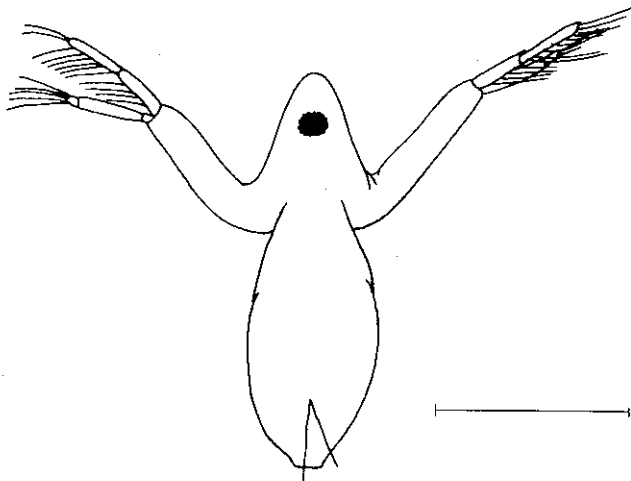


Figure 15 *Diaphanosoma birgei*, ♀, ventral view

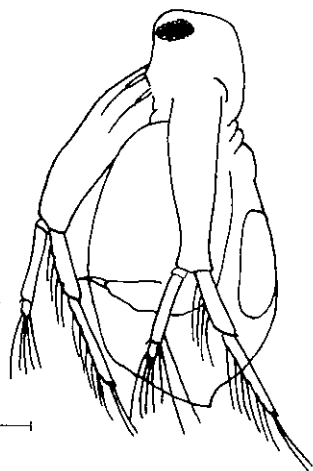


Figure 16 *Diaphanosoma birgei*, ♀, lateral view

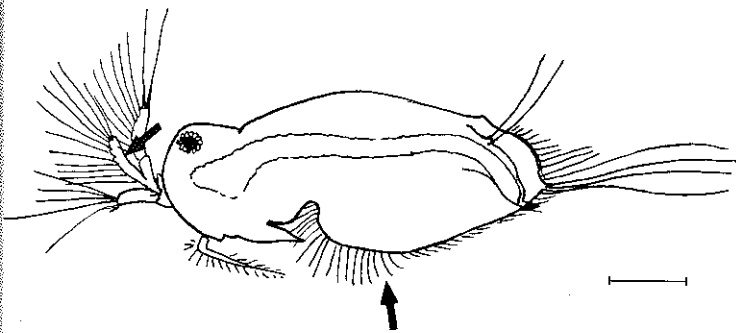


Figure 17 *Latona setifera*, lateral view

9a. Basal segment of 2nd antennae longer than head; no ocellus present (Figs. 15, 16) *Diaphanosoma*, p. 54

Both *D. birgei* and *D. brachyurum* occur in the Great Lakes. See Kořínek (1981) for identification.

9b. Basal segment of 2nd antennae shorter than head; ocellus may be present 10

The following group of littoral sidids is not commonly found in the Great Lakes.

10a. Second antennae with 3 branches, the middle branch an extension from the 1st segment of the dorsal (longest) branch (Fig. 17) *Latona setifera*, p. 110

Length 2–3 mm; margin of carapace covered with hairs; antennules elongate; ocellus absent.

10b. Second antennae with only 2 branches. 11

Scale bars = 0.5 mm.

- 11a.** Margin of carapace with long setae, some almost $\frac{1}{2}$ height of carapace; ocellus present; length 1.8 mm. two segments in longer (dorsal) branch of 2nd antenna (Fig. 18). . . . *Latonopsis occidentalis*, p. 110
- 11b.** Margin of carapace with very inconspicuous setae, < 10 μ m long; no ocellus; length 3–4 mm; three segments in longer branch of 2nd antenna (Fig. 19). . . . *Sida crystallina*, p. 110
- 12a.** First antennae covered by a beaklike structure; shell spine rarely present (Figs. 20–33). . . . Family CHYDORIDAE pp. 71, 112
 Adult length 0.3–3.0 mm. Second antennae with 3 segments in both branches. *Chydorus* and *Alona* are the most common genera of this family in the Great Lakes, but *Acroperus*, *Alonopsis*, *Alonella*, *Anchistropus*, *Camptocercus*, *Disparalona*, *Eurycercus*, *Kurzia*, *Graptoleberis*, *Leydigia*, *Monospilus*, *Pleuroxus*, and *Rhynchotalona* are occasionally found. Higher magnification and keys by Brooks (1959) should be used to identify members of this family to species.
- 12b.** First antennae exposed, not covered by a beaklike structure (first antennae inconspicuous in some species; Figs. 36, 38, 50); shell spine may be present . . . 13
- 13a.** Paired 1st antennae are fixed, pointed, tusklke structures as long as the head or longer (Figs. 34–37). . . . Family BOSMINIDAE . . . 14

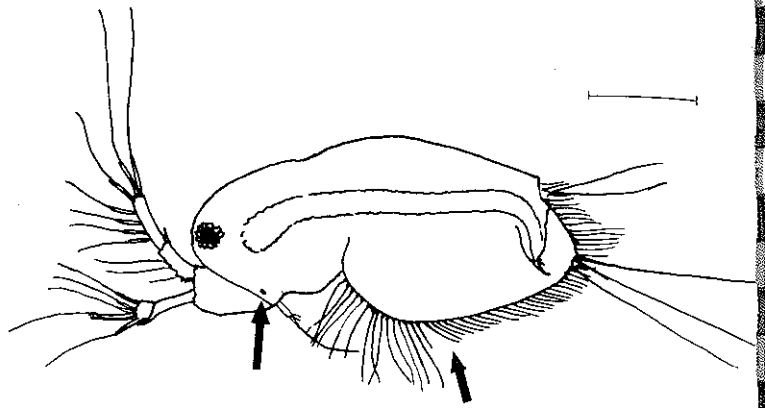


Figure 18 *Latonopsis occidentalis*, lateral view

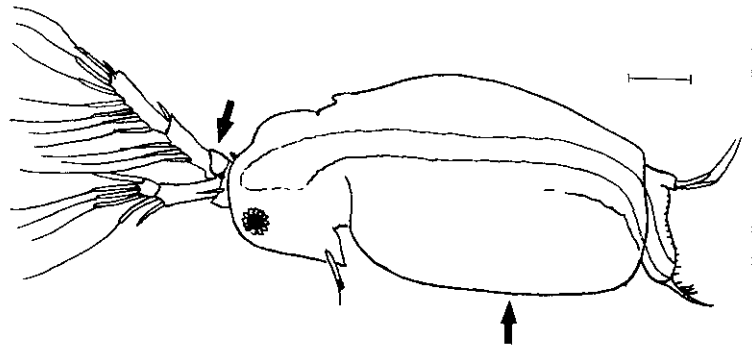


Figure 19 *Sida crystallina*, lateral view

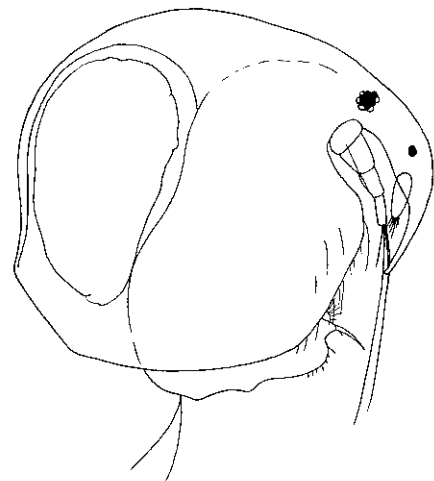


Figure 20 *Chydorus sphaericus*, ♀, lateral view

Scale bars = 0.5 mm.

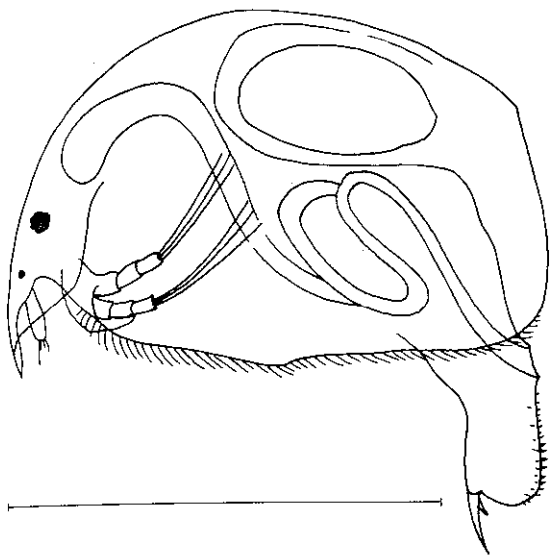


Figure 21 *Alona* sp., ♀, lateral view

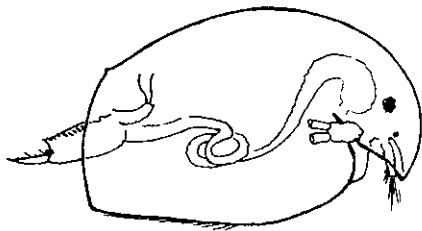


Figure 22 *Acroperus harpae*, lateral view

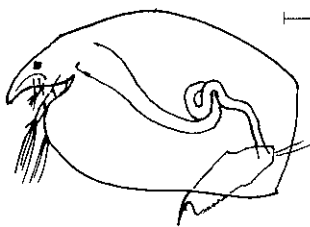


Figure 23 *Alonopsis elongata*, lateral view

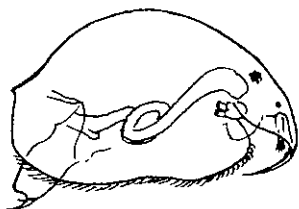


Figure 24 *Alonella* sp., lateral view

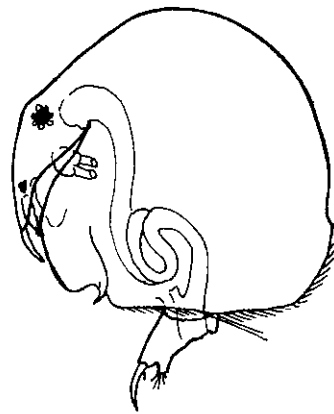


Figure 25 *Anchistropus minor*, lateral view

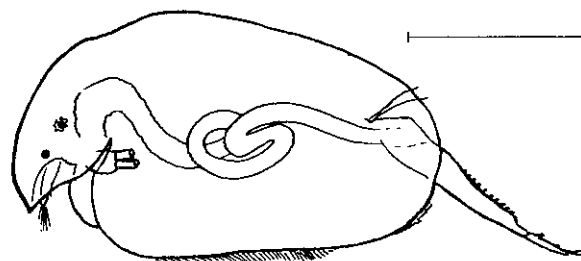


Figure 26 *Camptocercus* sp., lateral view

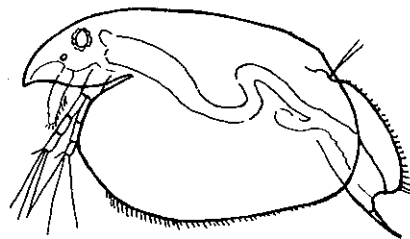


Figure 27 *Eurycercus lamellatus*, lateral view

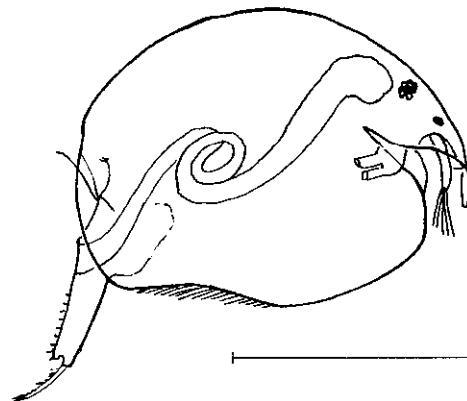


Figure 28 *Kurzia latissima*, lateral view

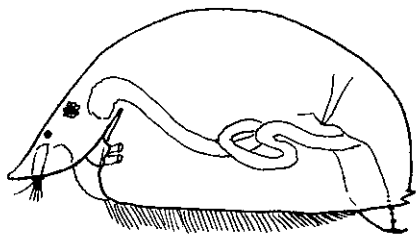


Figure 29 *Graptoleberis testudinaria*,

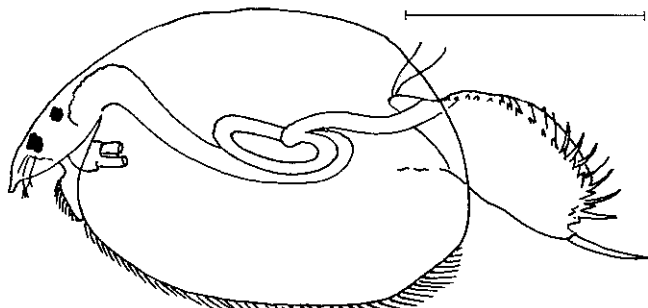


Figure 30 *Leydigia* sp., lateral view

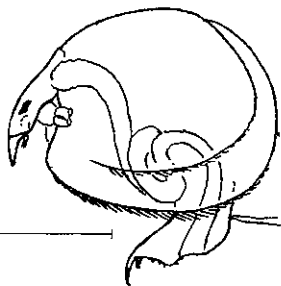


Figure 31 *Monospilus dispar*, lateral view

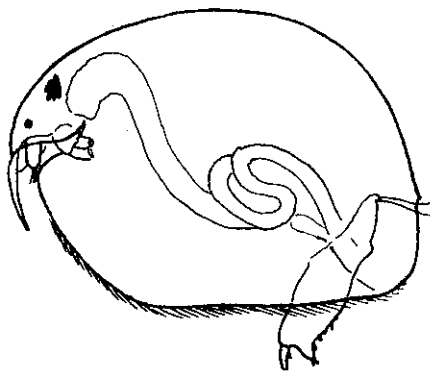


Figure 32 *Pleuroxus* sp., lateral view



Figure 33 *Rhynchotalona falcata*, lateral view

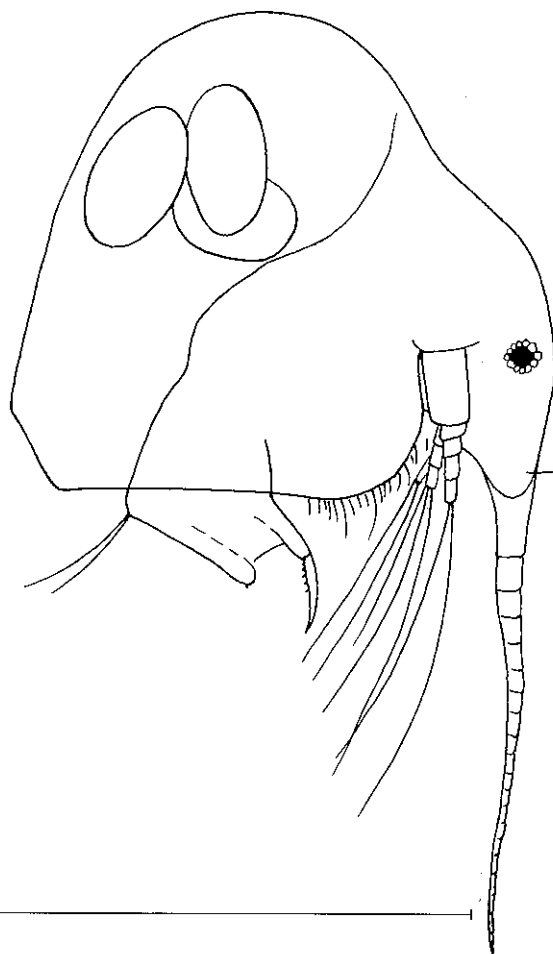


Figure 34 *Eubosmina coregoni*, ♀, lateral view

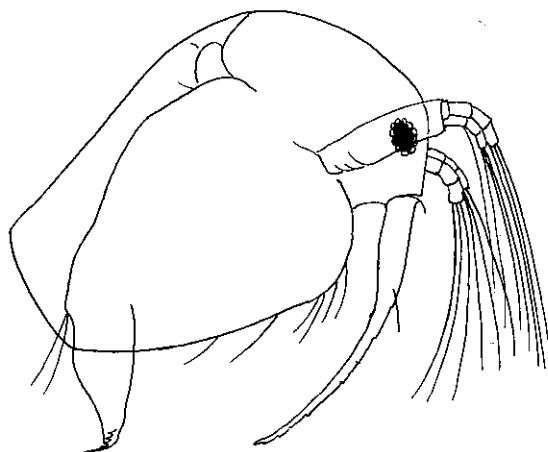


Figure 35 *Eubosmina coregoni*, ♂, lateral view

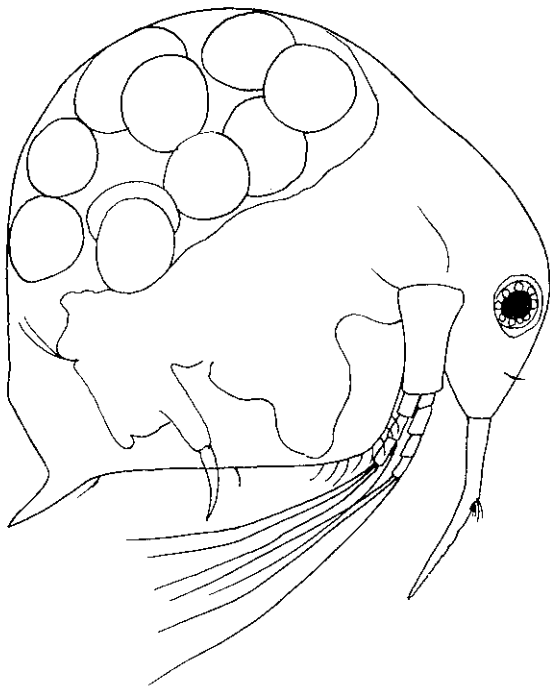


Figure 36 *Bosmina longirostris*, ♀, lateral view

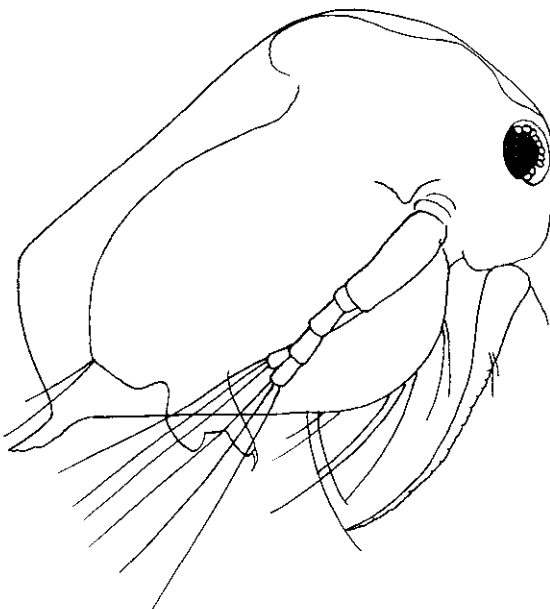


Figure 37 *Bosmina longirostris*, ♂, lateral view

- 13b. First antennae flexible, tips blunt, bearing setae 15
- 14a. No shell spine (mucro) present on posterior margin of carapace (Figs. 34, 35)
Eubosmina coregoni, p. 69
- 14b. Shell spine (mucro) present on posterior margin of carapace (Figs. 36, 37)
Bosmina longirostris, p. 66

Length 0.20–0.56 mm. Some populations from Lake Ontario may have a very small shell spine (false mucro). Higher magnification is needed to observe the sensory bristle on the rostrum near the base of the 1st antennae and the pecten located only on the proximal portion of the postabdominal claw. Deevey and Deevey (1971) provide keys to *Eubosmina*.

Length 0.4–0.6 mm. Most mucronate bosminids in the Great Lakes are *B. longirostris*. The *Eubosmina longispina* of the older Great Lakes literature is probably a long-featured morph of this species (Torke 1975). Identity can be confirmed by examining, under high magnification, the sensory bristle, located on the rostrum halfway between the eye and the base of the 1st antennae, and the pecten of the postabdominal claw. Both a large proximal pecten and a smaller distal pecten are present. Some mucronate eubosminids with sensory bristles and pecten similar to those of *E. coregoni* may occasionally be found in the Great Lakes. Deevey and Deevey (1971) provide keys to *Bosmina* and *Eubosmina*.

Scale bars = 0.5 mm.

- 15a. First antennae almost as long as head, attached near front of head (Figs. 38–43)
 Family MACROTHRICIDAE, p. 112

Length 0.5–2.0 mm. The littoral genera *Acantholeberis*, *Drepanothrix*, *Ilyocryptus*, *Macrothrix*, *Ophryoxus*, and *Wlassicsia* are not commonly found in the Great Lakes. Consult Brooks (1959) for generic and species identifications, which often require higher magnifications.

- 15b. First antennae variable in length, not attached at front of head 16

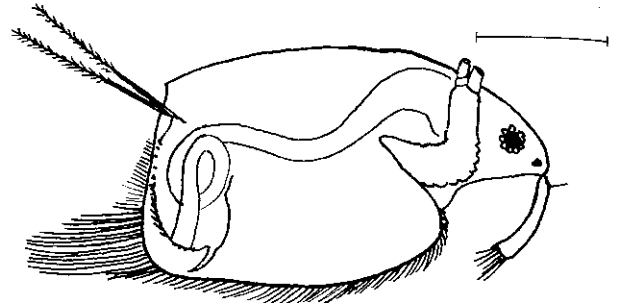


Figure 38 *Acantholeberis curvirostris*, lateral view

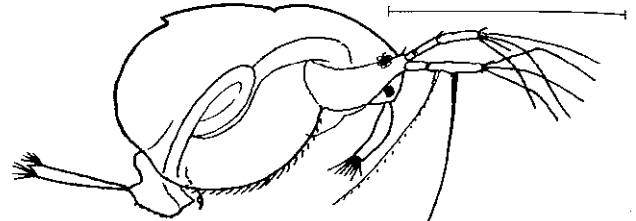


Figure 39 *Drepanothrix dentata*, lateral view

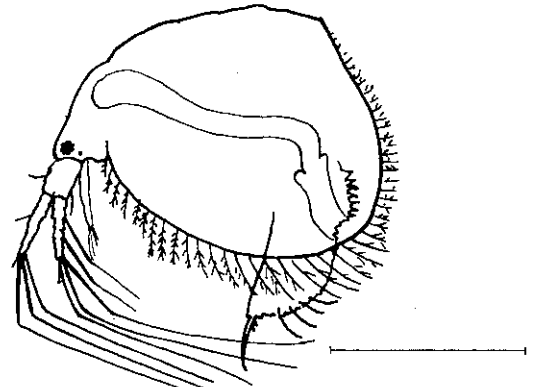


Figure 40 *Ilyocryptus*, lateral view

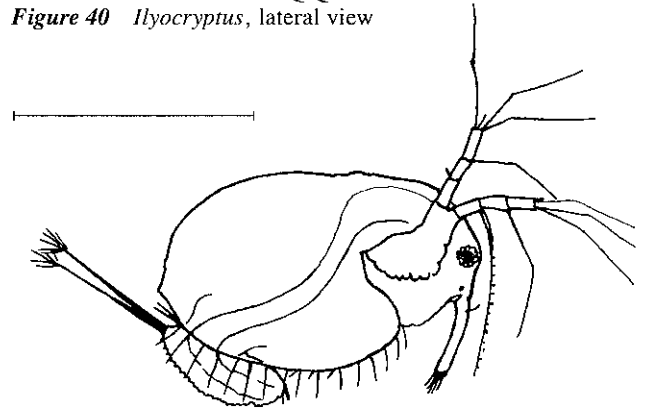


Figure 41 *Macrothrix*, lateral view

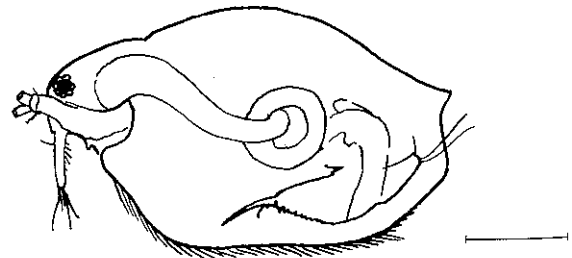


Figure 42 *Ophryoxus*, lateral view

Scale bars = 0.5 mm.

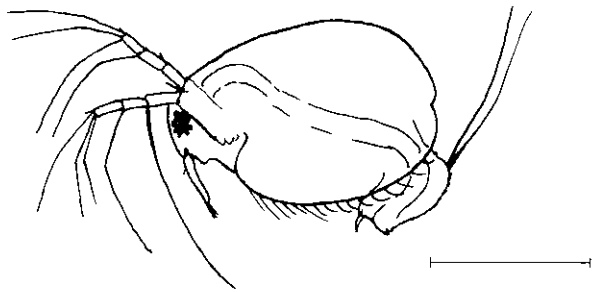


Figure 43 *Wlassicsia kinistinensis*, lateral view

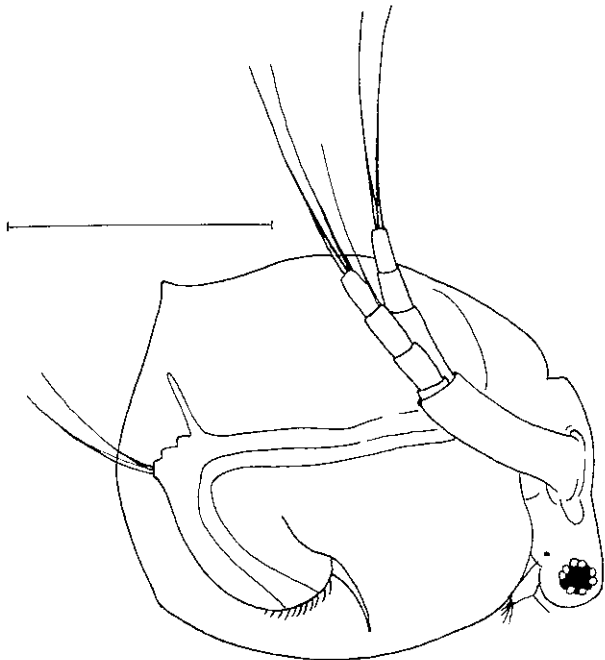


Figure 44 *Ceriodaphnia* sp., lateral view

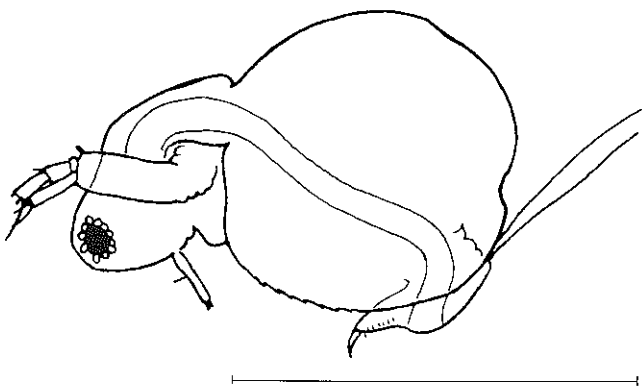


Figure 45 *Moina micrura*, lateral view

- 16a. Rostrum absent; head curved ventrally (Figs. 44, 45) 17
- 16b. Rostrum present; head not curved ventrally (Figs. 47, 49). Family DAPHNIDAE (in part) 18
- 17a. Head small, $\frac{1}{6}$ as long as carapace; ocellus present; 1st antennae short, not freely moveable (Fig. 44). Family DAPHNIDAE, *Ceriodaphnia*, p. 58
Length 0.4–1.4 mm. Five species of *Ceriodaphnia* are found in the Great Lakes. Species identification requires greater magnification to examine features described by Brooks (1959) and Brandlova et al. (1972).
- 17b. Head large, $\frac{1}{2}$ as long as carapace; ocellus absent; 1st antennae long, flexible (Fig. 45)
..... Family MOINIDAE, *Moina micrura*, p. 111
Length 0.5 mm; rare in the Great Lakes.

Scale bars = 0.5 mm.

- 18a. Shell spine present 19
- 18b. Shell spine absent (Fig. 46). . . *Simocephalus*, p. 111
 Length 3–4 mm. *Simocephalus vetulus*, *S. serulatus*, and *S. exspinus* are uncommon in the Great Lakes. Species keys using characteristics of the pecten of the postabdominal claw are available in Brooks (1959) and Pennak (1978).
- 19a. Posterior shell spine located near ventral margin of carapace, ventral margin straight (Fig. 47)
 *Scapholeberis*, p. 111
 Length 1.0 mm. *S. kingi*, with a dark-colored carapace, and *S. aurita*, with a more transparent, white to green carapace, have been reported from the Great Lakes. Brooks (1959) describes both species in greater detail.
- 19b. Posterior shell spine located near midline of carapace, ventral margin of carapace convex (Figs. 48–59)
 *Daphnia*, 20
- 20a. Shell spine short, < 1/3 carapace length; front of head concave (Figs. 48–50) 21
- 20b. Shell spine long, > 1/3 carapace length; head shape variable 23
- 21a. Ocellus present 22
- 21b. Ocellus absent (Fig. 48). . . *Daphnia parvula*, p. 111
 Adults 0.75–1.0 mm. Rostrum short, “pugnosed.” The middle pecten of the postabdominal claw is slightly larger than the proximal pecten (seen only under high magnification). Rare in Great Lakes.

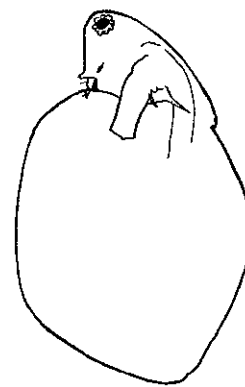


Figure 46 *Simocephalus*, lateral view

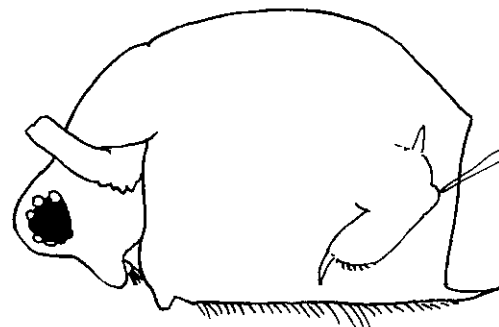


Figure 47 *Scapholeberis*, lateral view

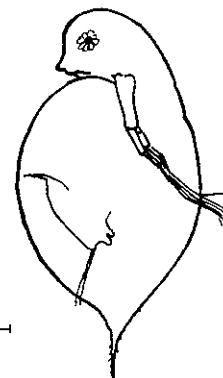


Figure 48 *Daphnia parvula*, lateral view

Scale bars = 0.5 mm.

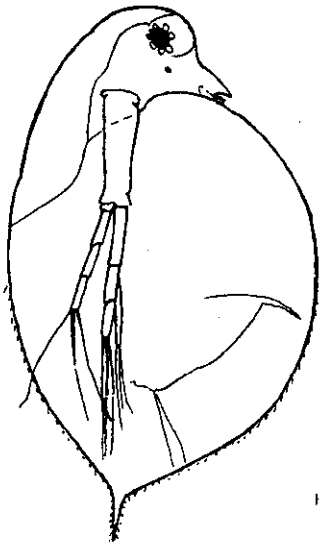


Figure 49 *Daphnia pulex*, lateral view

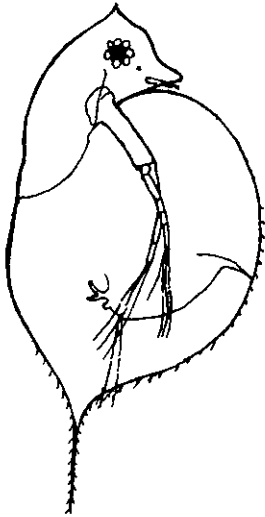


Figure 50 *Daphnia ambigua*, lateral view

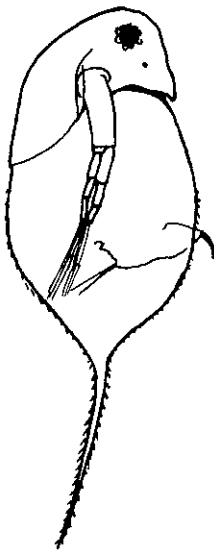


Figure 51 *Daphnia schødleri*, lateral view

- 22a. Large adults, 1.3–2.2 mm long (Fig. 49)
 *Daphnia pulex*, p. 111
 Uncommon in Great Lakes. High magnification shows that the middle pecten of the postabdominal claw is twice as large as the proximal pecten.
- 22b. Small adults, < 1 mm long (Fig. 50)
 *Daphnia ambigua*, p. 111
 Uncommon in Great Lakes. Pecten on postabdominal claw uniformly fine.
- 23a. Ocellus present 24
- 23b. Ocellus absent 25
- 24a. Head rounded at apex (Fig. 51)
 *Daphnia schødleri*, p. 111
 Adults 1.2–2.0 mm. High magnification reveals enlarged middle pecten of postabdominal claw. Rare in Great Lakes.

Scale bars = 0.5 mm.

24b. Head shape variable, peak located near midline of body (Figs. 52-54).....

.....*Daphnia galeata mendotae*, p. 60

Adults 1.3-3.0 mm. High magnification shows uniformly fine pecten on postabdominal claw. Common in Great Lakes.

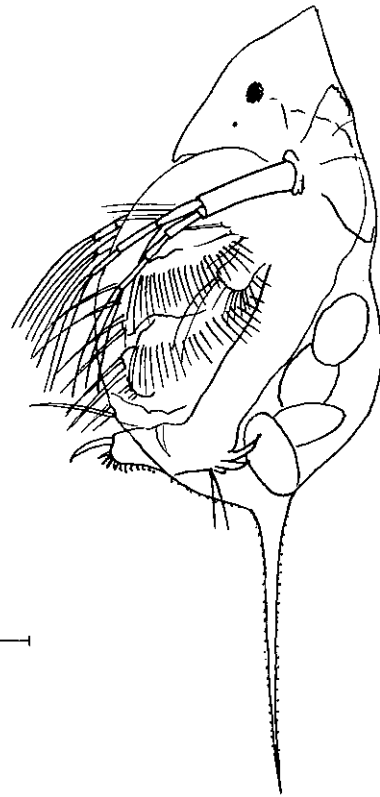


Figure 52 *Daphnia galeata mendotae*, ♀, lateral view

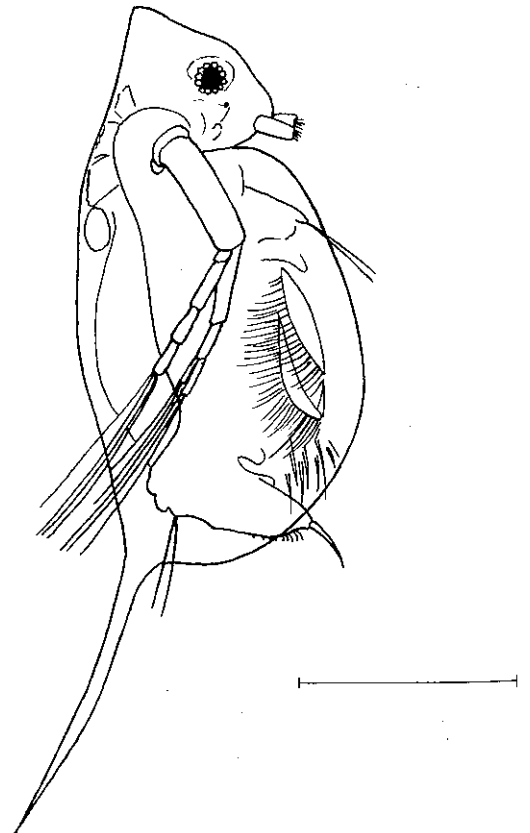


Figure 53 *Daphnia galeata mendotae*, ♂, lateral view

Scale bars = 0.5 mm.

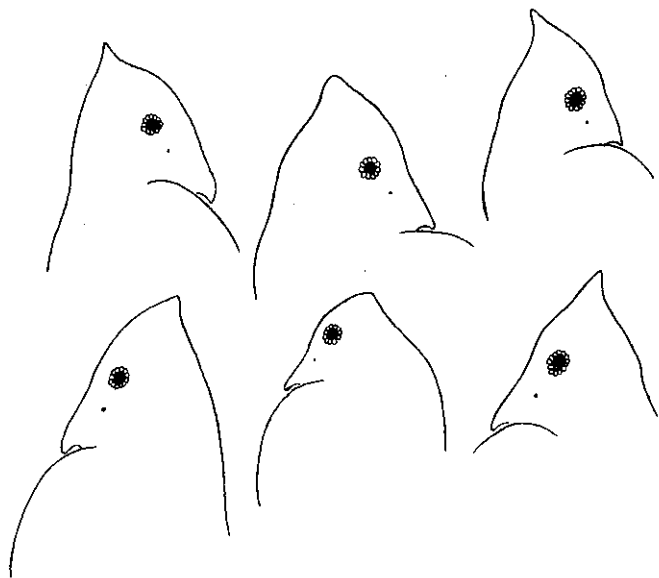


Figure 54 Variation in helmets of *Daphnia galeata mendotae*

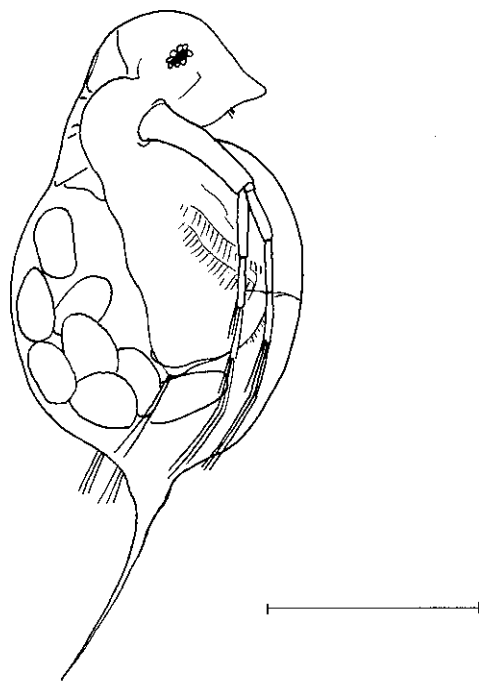


Figure 55 *Daphnia longiremis*, ♀, lateral view

25a. Setae of second antennae reach posterior margin of carapace. (Figs. 55, 56)
 *Daphnia longiremis*, p. 64

Length 0.8–1.2 mm. Pecten on postabdominal claw uniformly small. High magnification also shows that the seta at the base of the second segment of the dorsal ramus of the antennae is shorter than the ramus. Common species.

Scale bars = 0.5 mm.

25b. Setae of second antennae do not reach to end of carapace (Figs. 57–59) *Daphnia retrocurva*, p. 62

Length 1.2–1.8 mm. High magnification shows enlarged, thickened middle pecten of postabdominal claw. Seta at base of 2nd segment of dorsal ramus of antennae extends beyond end of ramus. Common species.

26a. Metasome and urosome not distinctly separate; 1st antennae shorter than cephalic segment (Fig. 60). Suborder HARPACTICOIDA, p. 116

Harpacticoid copepods are mainly benthic and littoral organisms and rarely occur in plankton samples. Consult Wilson and Yeatman (1959b) to identify the 9 species occurring in the Great Lakes.

26b. Urosome noticeably narrower than metasome; 1st antennae generally as long or longer than cephalic segment 27

27a. First antennae often reaching to or beyond caudal rami. Body narrows between segment with 5th legs and genital segment (Fig. 2e). Suborder CALANOIDA, 28

Mature males have geniculate right 1st antennae; adult females often carry a single egg sac.

27b. First antennae usually not reaching past genital segment; body narrows between segments with 4th and 5th legs (5th legs are vestigial) (Figs. 2a, 2b). Suborder CYCLOPOIDA, 43

Mature males have both 1st antennae geniculate while adult females may carry 2 egg sacs.

28a. Caudal rami elongate, at least 3 times as long as wide 29

28b. Caudal rami not elongate, length less than 3 times width 30

29a. Animals large, up to 3.0 mm; maxillipeds elongate, almost twice body width in lateral view; adult females lack metasomal wings; CVI males have fairly straight 5th legs (Figs. 61, 62) *Limnocalanus macrurus*, p. 74



Figure 56 Variation in body shape of immature *Daphnia longiremis*

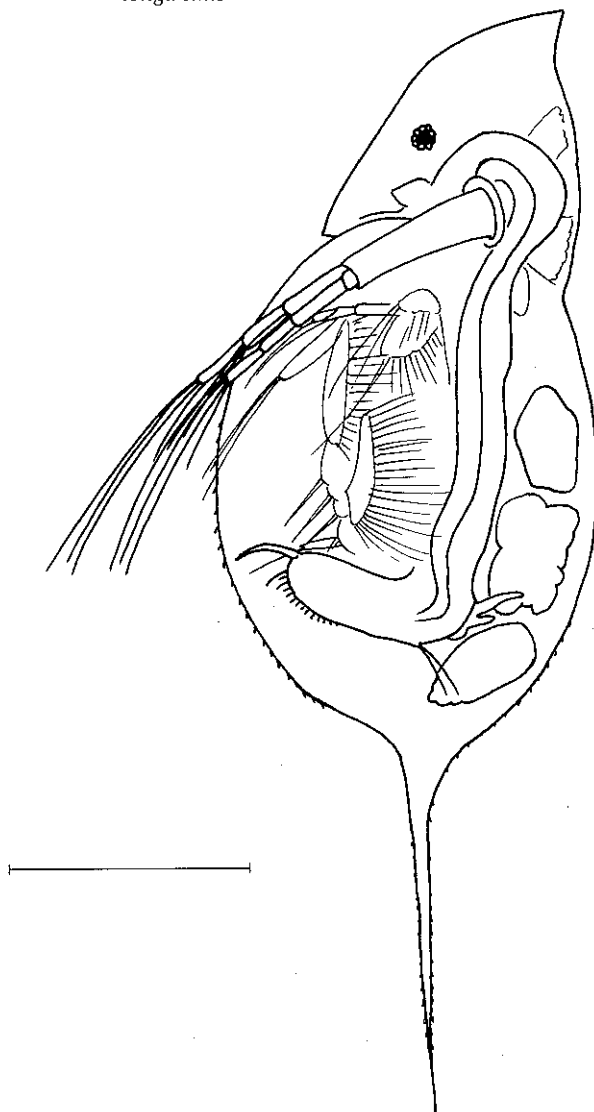


Figure 57 *Daphnia retrocurva*, ♀, lateral view

Scale bars = 0.5 mm.

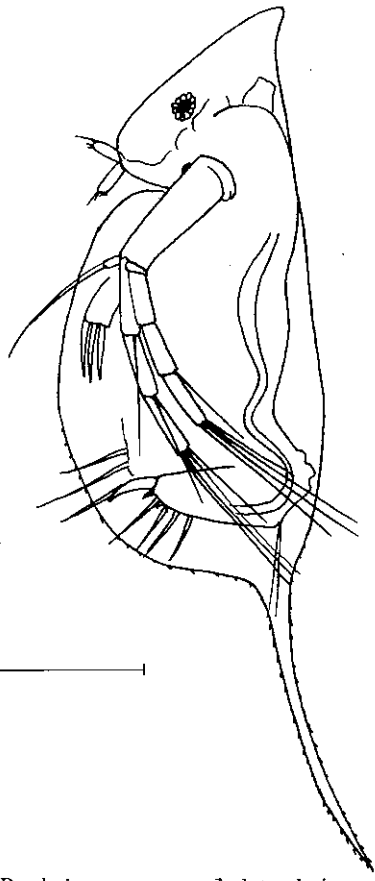


Figure 58 *Daphnia retrocurva*, ♂, lateral view

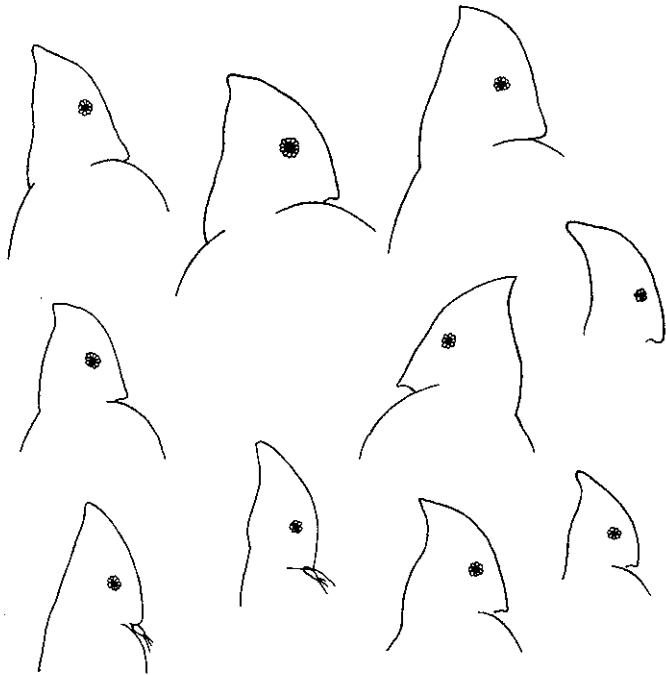


Figure 59 Variation in helmets of *Daphnia retrocurva*

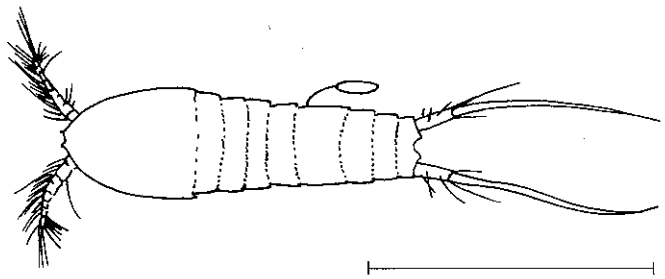


Figure 60 Harpacticoid copepod with spermatophore, ♀, dorsal view

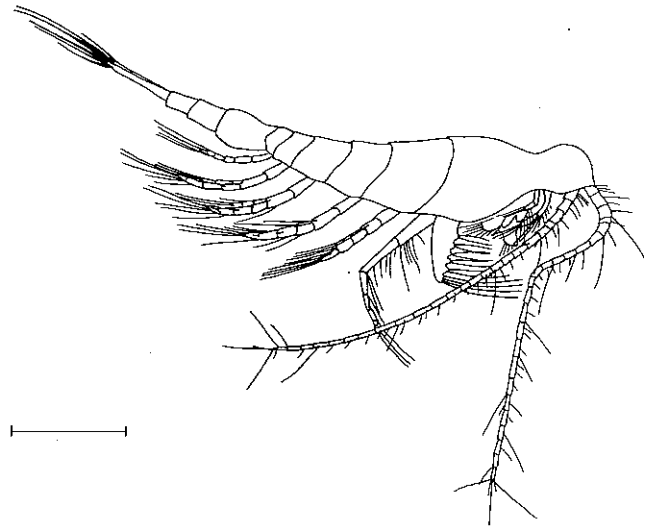


Figure 61 *Limnocalanus macrurus*, ♀, lateral view

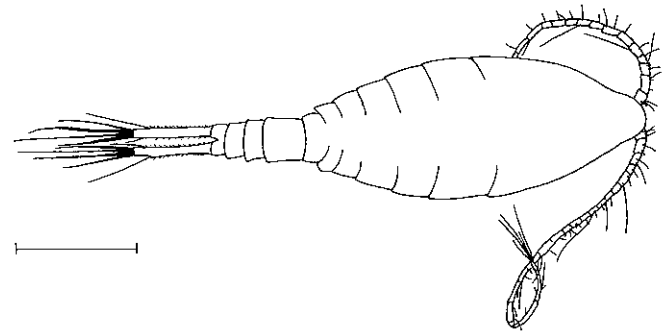


Figure 62 *Limnocalanus macrurus*, ♂, dorsal view

29b. Animals small, up to 1.5 mm; maxillipeds not elongate, subequal to body width in lateral view; adult females have enlarged, pointed metasomal wings; CVI males have bent, hooklike 5th legs (Figs. 63, 64) *Eurytemora affinis*, p. 79

30a. Caudal rami with 4 stout terminal setae and a thinner outer seta that is hard to see; large animals, up to 2.9 mm (Figs. 65, 66) *Senecella calanoides*, p. 73

Unlike most other calanoids, adult females lack 5th legs and do not carry their eggs in egg sacs, and adult males do not have geniculate right 1st antennae.

30b. Caudal rami with 3 or 5 well-developed terminal setae; animal less than 2.5 mm long 31

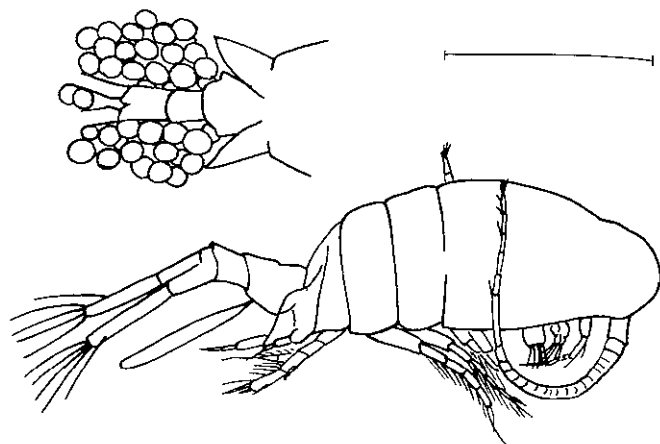


Figure 63 *Eurytemora affinis*, ♀, lateral view

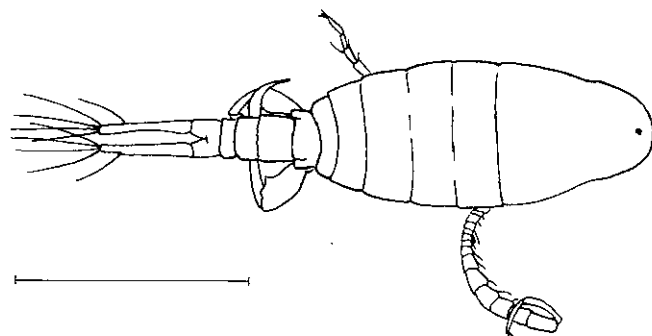


Figure 64 *Eurytemora affinis*, ♂, dorsal view

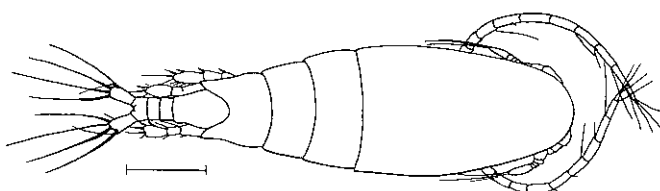


Figure 65 *Senecella calanoides*, ♀, dorsal view

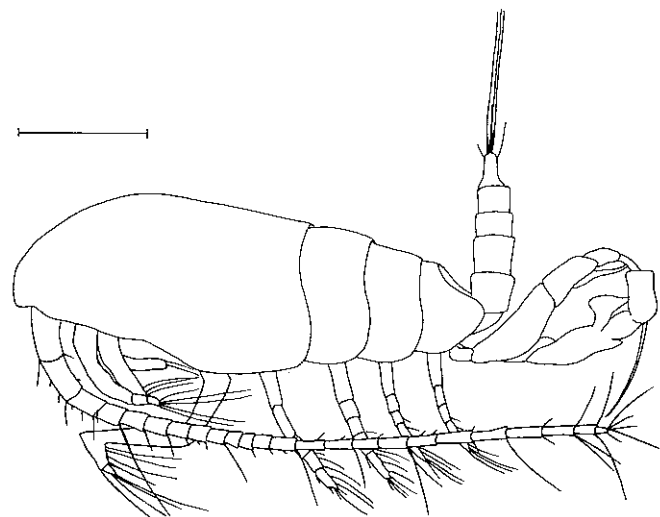


Figure 66 *Senecella calanoides*, ♂, lateral view

Scale bars = 0.5 mm.

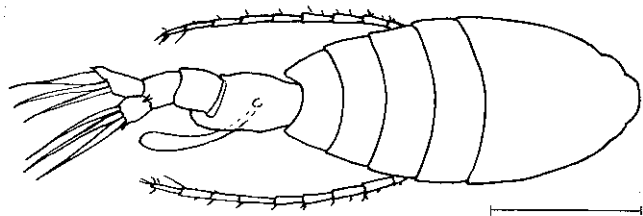


Figure 67 *Epischura lacustris*, ♀, dorsal view

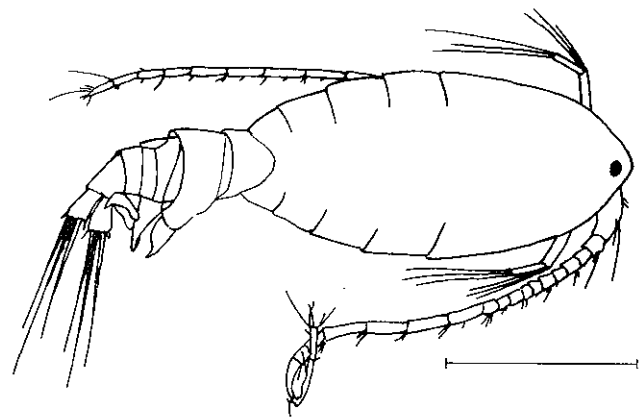


Figure 68 *Epischura lacustris*, ♂, dorsal view

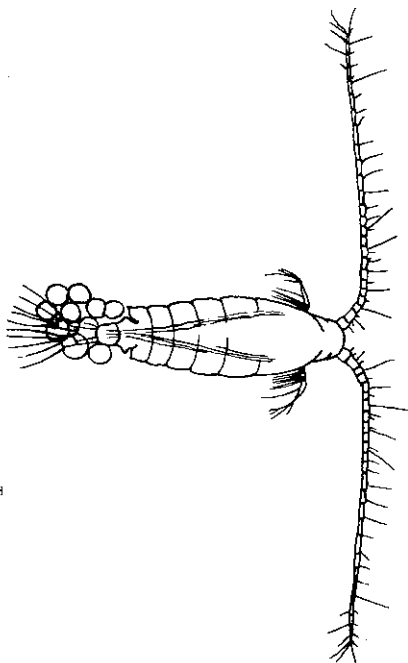


Figure 69 *Leptodiaptomus siciloides*, ♀, dorsal view

31a. Caudal rami with 3 broad terminal setae (Figs. 67, 68). *Epischura lacustris*, p. 77

Adult females have twisted urosomes with short, thick spines on the outer corner of the caudal rami. Adult males have smaller spines on the rami and enlarged lateral processes on the right side of the urosome.

31b. Caudal rami with 5 terminal setae and often a slender, dorsally placed inner seta. (Fig. 2e).
 Family DIAPTOMIDAE, ♂ 38, ♀ 32

Females do not have twisted urosomes, and males lack lateral urosomal processes.

32a. Three urosomal segments 33

32b. Two urosomal segments 37

33a. Genital segment expanded laterally into pointed projections (Fig. 69).
 ♀ *Leptodiaptomus siciloides*, p. 89

Length 1.0–1.3 mm; 2nd urosomal segment shorter than 3rd; metasomal wings pointed.

33b. Genital segment not expanded laterally; small spines may be present on sides of genital segment 34

Scale bars = 0.5 mm.

- 34a. Sides of last metasomal segment extended posteriorly into metasomal wings (Figs. 70, 71) 35
- 34b. Sides of last metasomal segment not extended into wings (Figs. 72, 73) 36
- 35a. Metasomal wings pointed, triangular (Fig. 70).
..... ♀ *Leptodiaptomus sicilis*, p. 87
Length 1.4–1.9 mm.
- 35b. Metasomal wings rounded (Fig. 71)
..... ♀ *Skistodiaptomus pallidus*, p. 115
Uncommon in Great Lakes; length 1.0–1.2 mm.
- 36a. Posterior corners of last segment of metasome rounded (Fig. 72) ♀ *Skistodiaptomus oregonensis*, p. 91
Length 1.25–1.50 mm; common in Great Lakes.
- 36b. Posterior corners of last segment of metasome with slight points (Fig. 73).....
..... ♀ *Skistodiaptomus reighardi*, p. 115
Length 1.00–1.57 mm; uncommon in Great Lakes
- 37a. Metasomal wings asymmetrical, left wing longer than right (Fig. 74)
..... ♀ *Leptodiaptomus ashlandi*, p. 82

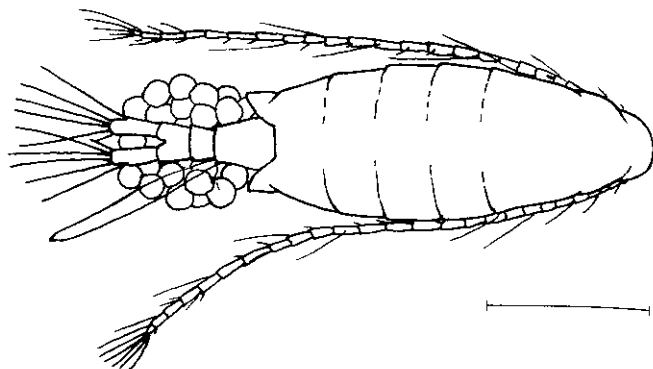


Figure 70 *Leptodiaptomus sicilis*, ♀, dorsal view

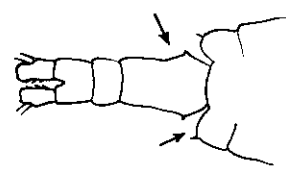


Figure 71 *Skistodiaptomus pallidus*, ♀, urosome, dorsal view

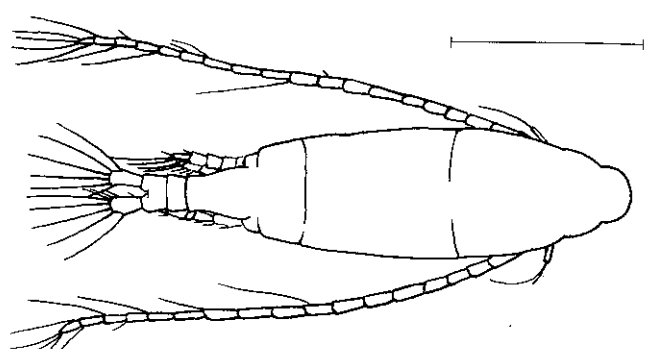


Figure 72 *Skistodiaptomus oregonensis*, ♀, dorsal view

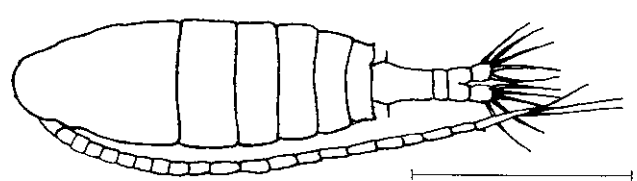


Figure 73 *Skistodiaptomus reighardi*, ♀, dorsal view

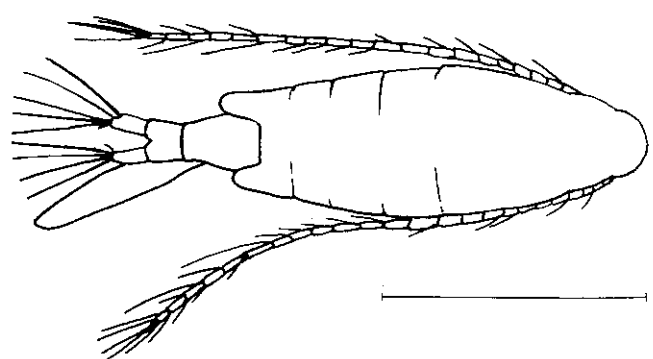


Figure 74 *Leptodiaptomus ashlandi*, ♀, dorsal view

Scale bars = 0.5 mm.

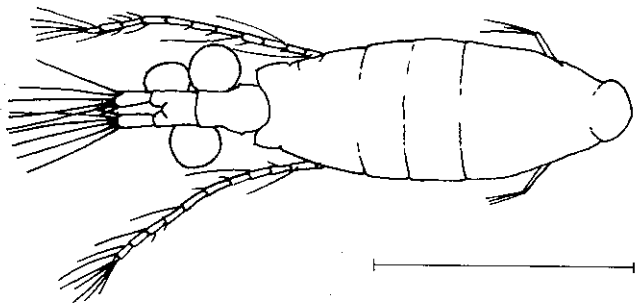


Figure 75 *Leptodiptomus minutus*, ♀, dorsal view

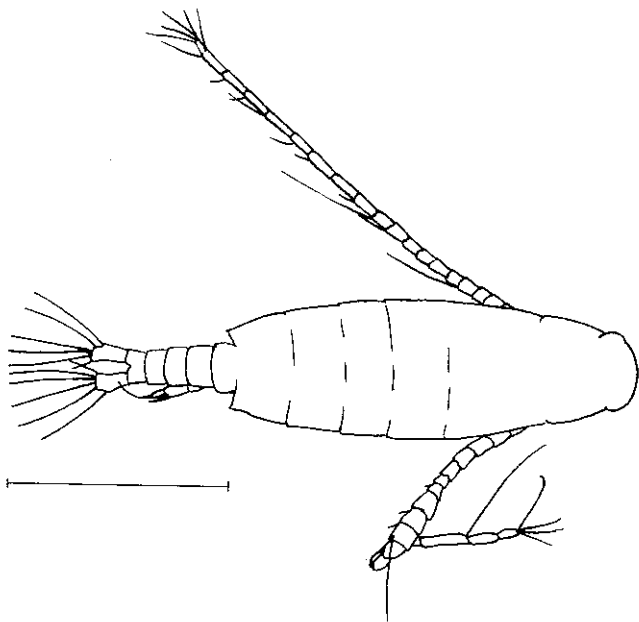


Figure 76 *Skistodiptomus oregonensis*, ♂, dorsal view



Figure 77 Exopod of left fifth leg of ♂ *S. pallidus*



Figure 78 Exopod of left fifth leg of ♂ *S. oregonensis*

37b. Metasomal wings symmetrical, rounded, with small spines at corners (Fig. 75)
 ♀ *Leptodiptomus minutus*, p. 84

38a. Lateral spine on terminal segment of exopod of right 5th leg subterminal in position (Fig. 76).
 ♂ *Skistodiptomus*, pp. 91, 115

High magnification should be used to distinguish the common *S. oregonensis* from the rare *S. pallidus*. The terminal segment of the exopod of the left 5th leg of male *S. pallidus* (fig. 77) has a hooklike process not present in *S. oregonensis* (Fig. 78).

38b. Lateral spine not subterminal in position 39

Scale bars = 0.5 mm.

- 39a. Lateral spine of terminal segment of exopod of right 5th leg large, located on the proximal $\frac{1}{3}$ of the segment (Fig. 79) . . . ♂ *Leptodiaptomus ashlandi*, p. 82
- 39b. Lateral spine located between middle and distal $\frac{1}{3}$ of the segment; lateral spine large or small 40
- 40a. Lateral spine of terminal segment of exopod of right 5th leg small, less than $\frac{1}{2}$ width of exopod segment (Fig. 80) ♂ *Leptodiaptomus minutus* p. 84
- 40b. Lateral spine large, at least as long as width of exopod 41
- 41a. Metasomal wings expanded, triangular (Fig. 81) ♂ *Leptodiaptomus sicilis*, p. 87
- 41b. Metasomal wings not expanded 42

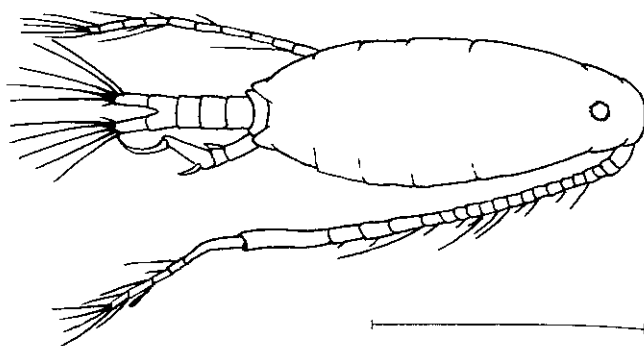


Figure 79 *Leptodiaptomus ashlandi*, ♂, dorsal view

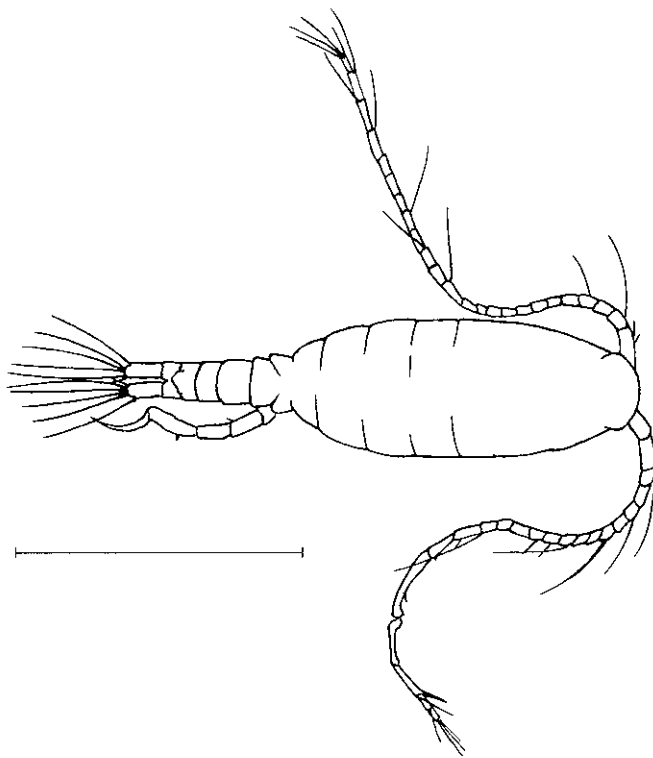


Figure 80 *Leptodiaptomus minutus*, ♂, dorsal view

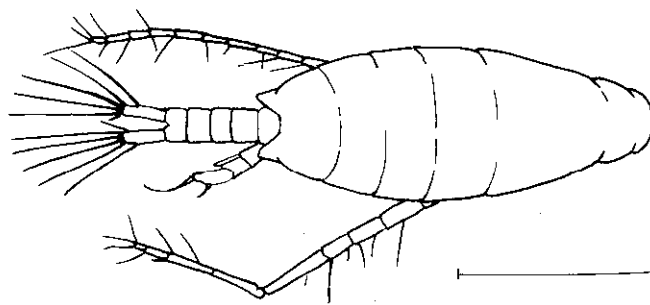


Figure 81 *Leptodiaptomus sicilis*, ♂, dorsal view

Scale bars = 0.5 mm.

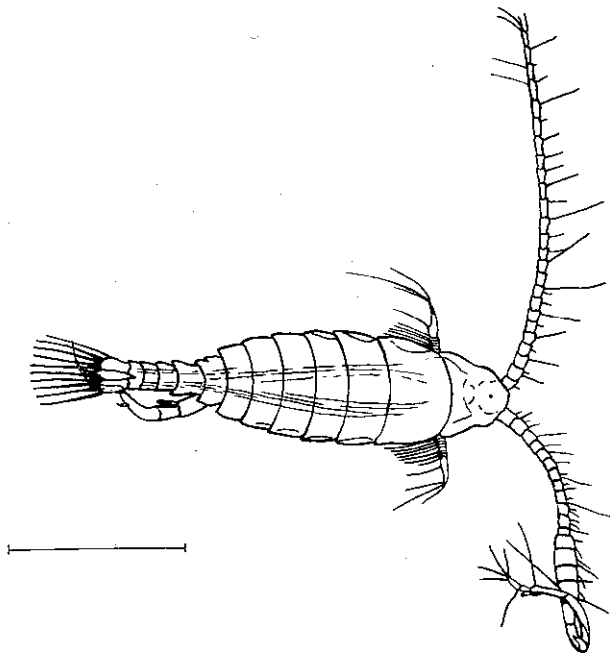


Figure 82 *Leptodiaptomus siciloides*, ♂, dorsal view

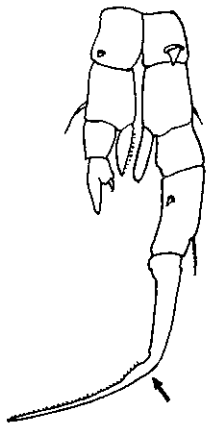


Figure 83 Fifth leg of ♂ *Skistodiaptomus reighardi*

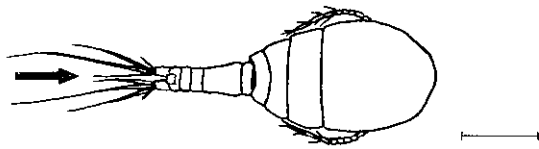


Figure 84 *Macrocyclus albidus*, dorsal view

- 42a. Terminal claw on exopod of right 5th leg smoothly curved; short process located on antepenultimate segment of right 1st antenna (Fig. 82)
..... ♂ *Leptodiaptomus siciloides*, p. 82
- 42b. Terminal claw of exopod of right 5th leg bent, angular. No process on antepenultimate segment of right 1st antenna (Fig. 83).....
..... ♂ *Skistodiaptomus reighardi*, p. 115
- 43a. Inner seta of caudal ramus long, at least twice the length of the ramus (Fig. 85) 44
- 43b. Inner seta short, less than twice length of ramus (Fig. 94)..... 45
- 44a. Inner seta of caudal ramus less than 1/2 length of longest caudal seta (Fig. 84)
..... *Macrocyclus albidus*, p. 115
Length 1–2.5 mm; uncommon in Great Lakes;
no hairs on inner margin of rami.

Scale bars = 0.5 mm.

- 44b. Inner seta longer than $\frac{1}{2}$ length of longest caudal seta. (Figs. 85, 86) *Mesocyclops edax*, p. 98
Length 0.7–1.5 mm. Common. High magnification shows hairs on inner margin of rami.
- 45a. First antennae short, less than $\frac{3}{4}$ length of cephalic segment (uncommon species). 46
- 45b. First antennae at least $\frac{3}{4}$ length of cephalic segment 48
- 46a. First antennae of female with 12 segments (use high magnification).
. *Eucyclops prionophorous*, p. 115
Length 0.7–0.9 mm.
- 46b. First antennae of female with 11 or fewer segments 47
- 47a. First antennae of female with 8 segments (use high magnification) (Fig. 87)
. *Paracyclops fimbriatus poppei*, p. 116
Length 0.7–0.9 mm; uncommon
- 47b. First antennae of female with 11 segments (use high magnification) (Fig. 88) . . *Diacyclops nanus*, p. 115
Length ♀ 0.45–0.9 mm; uncommon.
- 48a. Small animals (0.5–0.8 mm); extended 1st antennae reach genital segment (Fig. 89)
. *Tropocyclops prasinus mexicanus*, p. 101
- 48b. Animals longer than 0.7 mm; 1st antennae do not reach genital segment 49
- 49a. Outer seta of caudal ramus modified into a spine, thicker than inner seta *Eucyclops*, 50
High magnification shows a row of fine spinules on outer margin of caudal rami of females; 5th leg with only 1 segment.
- 49b. Outer seta not thicker than inner seta 51
High magnification shows no spinules on outer margin of caudal rami; 5th leg with 2 segments.

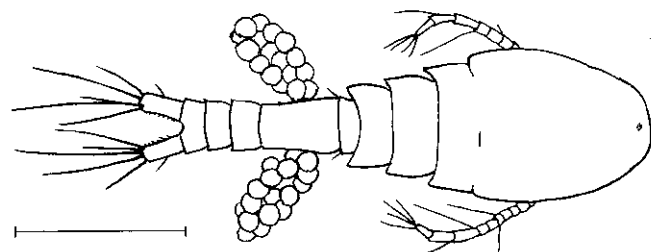


Figure 85 *Mesocyclops edax*, ♀, dorsal view

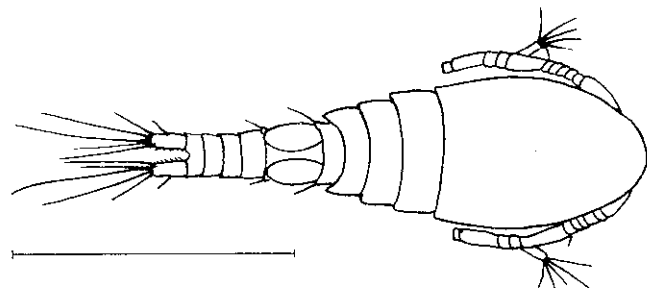


Figure 86 *Mesocyclops edax*, ♂, dorsal view

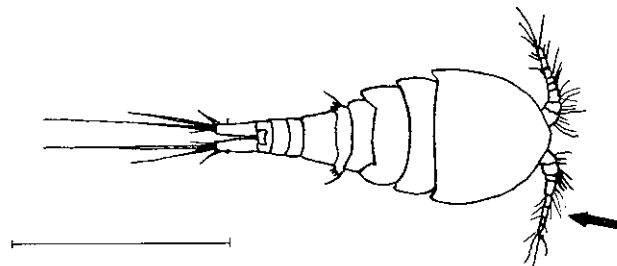


Figure 87 *Paracyclops fimbriatus poppei*, dorsal view

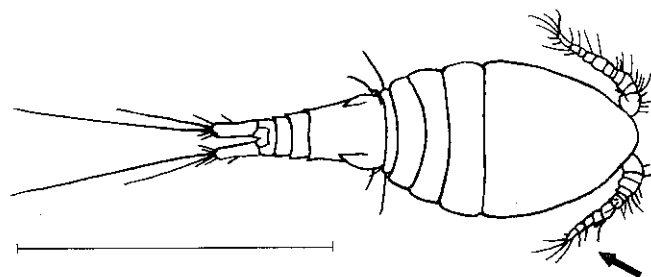


Figure 88 *Diacyclops nanus*, dorsal view

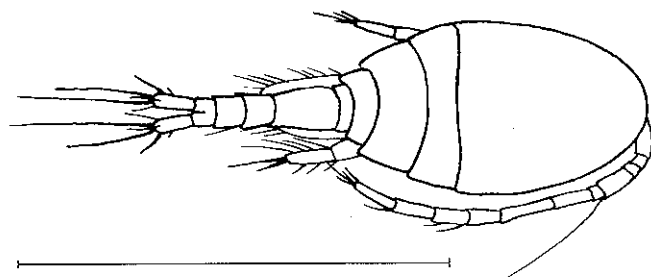


Figure 89 *Tropocyclops prasinus mexicanus*, dorsal view

Scale bars = 0.5 mm.

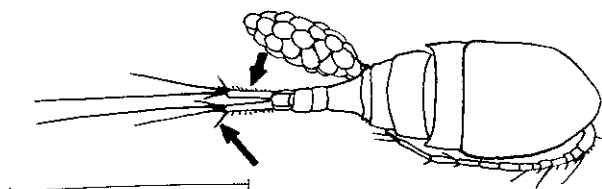


Figure 90 *Eucyclops speratus*, dorsal view

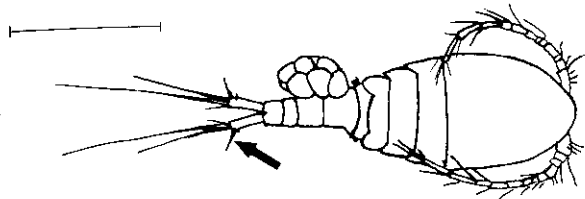


Figure 91 *Eucyclops agilis*, dorsal view

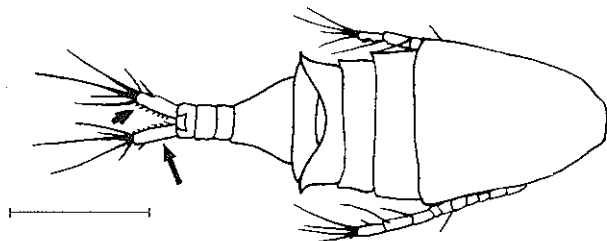


Figure 92 *Cyclops scutifer*, dorsal view

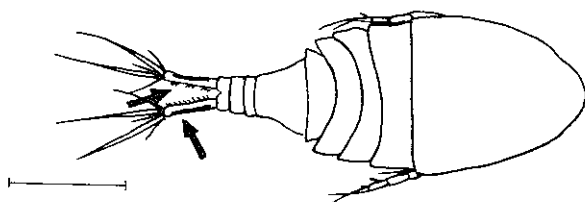


Figure 93 *Cyclops strenuus*, dorsal view

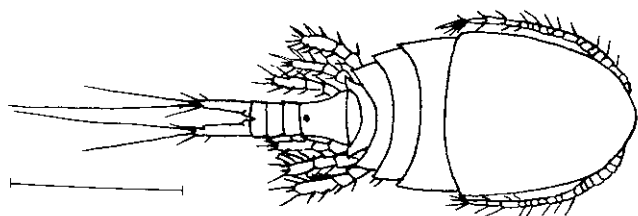


Figure 94 *Acanthocyclops vernalis*, ♀, dorsal view

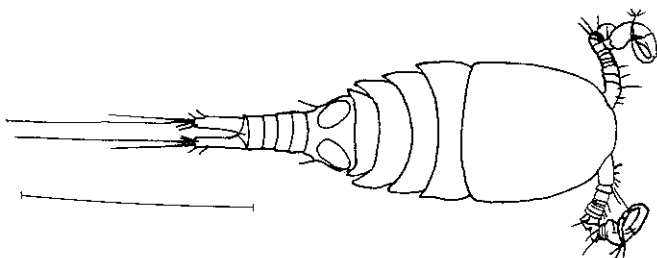


Figure 95 *Acanthocyclops vernalis*, ♂, dorsal view

- 50a. Caudal rami elongate, length 4–5 times width (Fig. 90)..... *Eucyclops speratus*, p. 115
- 50b. Caudal rami not elongate, length less than 4 times width (Fig. 91)..... *Eucyclops agilis*, p. 115
- 51a. Inner margin of caudal rami with fine hairs (use high magnification; uncommon species) 52
- 51b. Inner margin of caudal rami without hairs (use high magnification; common species) 53
- 52a. Caudal rami 4 times as long as wide; 4th and 5th metasomal segments expanded into pointed wings (Fig. 92)..... *Cyclops scutifer*, p. 115
Length 0.97–1.29 mm. Smith and Fernando (1978) may also be used to separate this species from *C. strenuus* based on characteristics of the 4th legs.
- 52b. Caudal rami 5–7 times as long as wide; tips of 4th and 5th metasomal segments with small points, not expanded into wings (Fig. 93) *Cyclops strenuus*, p. 115
Length 1.2–2.3 mm. See Smith and Fernando (1978) for details on the 4th legs.
- 53a. Lateral seta located on the posterior ¼ of the caudal ramus (Figs. 94, 95)..... *Acanthocyclops vernalis*, p. 93
Length 0.8–1.8 mm. Body more robust than *D. thomasi*. Yeatman (1959) illustrates the 5th legs, which are different than those of *D. thomasi*.

Scale bars = 0.5 mm.

53b. Lateral seta located between the middle and posterior $\frac{1}{3}$ of the caudal ramus (Figs. 96, 97).....
..... *Diacyclops thomasi*, p. 96
Length 0.9–1.4 mm; body thinner than *A. vernalis*; 5th legs distinct (see Yeatman 1959).

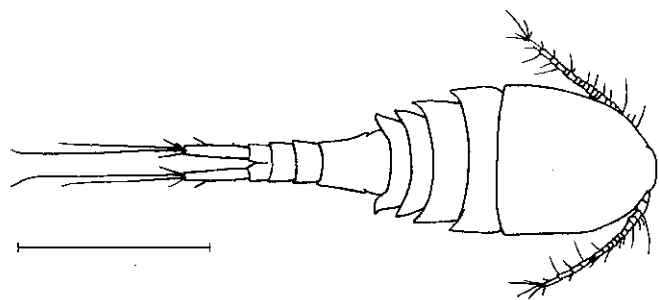


Figure 96 *Diacyclops thomasi*, ♀, dorsal view

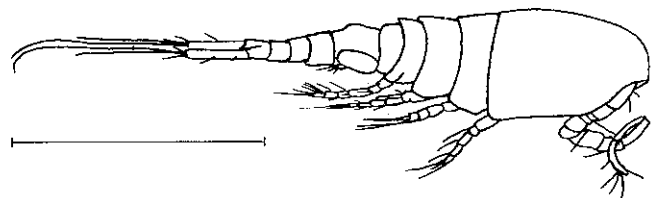


Figure 97 *Diacyclops thomasi*, ♂, lateral view

Scale bars = 0.5 mm.

*Life History and
Ecology
of the Major
Crustacean Species*

CLADOCERANS

Leptodora kindti (Focke 1844)

TAXONOMIC HISTORY

This species was first reported in Germany in 1838 as *Polyphe-mus kindtii* by Focke and Kindt. It was independently described as *Leptodora hyalina* by Lilljeborg (1860) and as *Hyalasoma dux* by Wagner (1870). The sexual dimorphism of this organism and a limited exchange of information among the investigators resulted in the use of all three names for almost two decades.

In 1867 Muller described both sexes of this cladoceran, leading Sars (1873) to conclude that the three names were synonymous. The taxonomic status of this species was settled in 1880 when Pope renamed it *Leptodora kindtii* Focke. The change in spelling to *Leptodora kindti* is in accordance with the ruling of the 15th International Congress of Zoology (1964).

DESCRIPTION

Unlike most cladocerans, the body of this large, transparent zooplankter is not completely enclosed in a bivalved car-

apace, and the thoracic legs are not flattened for use in filtering food. *L. kindti* uses its jointed, tubular limbs to grasp prey. Females (Plate 1) possess an enlarged brood pouch that is covered by the reduced carapace. In males (Plate 2) the brood pouch is rudimentary, and the first antennae are elongated.

More detailed descriptions of this organism have been published by Forest (1879), Forbes (1882), Gerschler (1911), and Brooks (1959).

SIZE

The parthenogenetically produced females often grow to over 13 mm while the sexually produced animals are generally less than 9 mm. In Lake Michigan, females produce their first clutch of eggs when they reach a length of 5 to 6.5 mm (Andrews 1949).

In Lake Superior (this study), females average 7.4 mm long (range 6.8–8.7 mm), while males are considerably smaller (average 5.4 mm, range 5.2–6.0 mm).

Leptodora from Lake Michigan have a dry weight of 3.0–19.1 µg (Hawkins and Evans, 1979).

DISTRIBUTION AND ABUNDANCE

L. kindti is found in freshwater lakes, ponds, and occasionally rivers in the northern hemisphere. It is generally re-

TABLE 1
Reports of *Leptodora kindti* in the Great Lakes

	Sampling Date	Abd ^a	Reference		Sampling Date	Abd ^a	Reference		
LAKE ERIE	1918	P	Langlois 1954	LAKE HURON	1903, 1905, 1907	P	Bigelow 1922		
	1918-1920	F	Clemens and Bigelow 1922		1907	C	Sars 1915		
	1928-1930	P	Wright 1955		1967-1968	P	Patalas 1972		
	1928	F	Sibley 1929		1970-1971	P	Carter 1972		
	1928-1929	P	Wilson 1960		1974	P	Basch et al. 1980		
	1929	F	Ewers 1933		1974-1975	P	McNaught et al. 1980		
	1929	F	Kinney 1950						
	1938-1939	P	Chandler 1940		LAKE ONTARIO	1919, 1920	U	Clemens and Bigelow 1922	
	1946-1948	P	Andrews 1949			1939-1940	U	Tressler et al. 1953	
	1950-1951	P	Davis 1954			1967	P	Patalas 1969	
	1956-1957	C	Davis 1962			1967-1968	P	Patalas 1972	
	1961	P	Britt et al. 1973			1969-1970, 1975	P	McNaught and Hasler 1966	
	1962	CF	Wolfert 1965			1970	C	Watson and Carpenter 1974	
	1967-1968	P	Davis 1968			1972	U	Czaika 1974a	
	1967	P	Patalas 1972			1972-1973	U	Czaika 1978a	
	1970	A	Watson and Carpenter 1974						
	1971-1972	P	Rolan et al. 1973						
LAKE MICHIGAN	1881	P	Forbes 1882	LAKE SUPERIOR	1871	F	Smith 1874b		
	1887-1888	U	Eddy 1927		1889	P	Forbes 1891		
	1926-1927	R	Eddy 1934		1893	P	Birge 1893		
	1954-1955, 1958	—	Wells 1960		1964	P	Olson and Odlaug 1966		
	1954-1961	UF	Wells and Beeton 1963		1967-1969	P	Swain et al. 1970b		
	1966, 1968	P	Wells 1970		1967-1968	P	Patalas 1972		
	1969-1970	P	Gannon 1972a		1971-1972	P	Selgeby 1975a		
	1969-1970	P	Gannon 1974		1971	P	Selgeby 1974		
	1969-1970	U	Gannon 1975		1973	P	Watson and Wilson 1978		
	1971	C	Howmiller and Beeton 1971		1973	P	Upper Lakes Ref. Group 1977		
	1971-1972	P	Beeton and Barker 1974		1974	P	Basch et al. 1980		
	1971-1977	P	Evans et al. 1980		1979-1980	P	This study		
	1973	P-C	Stewart 1974						
	1973-1974	U	Torke 1975						
	1975-1977	—	Hawkins and Evans 1979						

^aAbundance Code

R = rare U = uncommon P = present C = common A = abundant F = found in fish stomach contents
 — = abundance ranking not appropriate

stricted to water bodies located between 35 degrees and 60 degrees north latitude.

L. kindti is commonly found in all of the Great Lakes (Table 1) but in relatively low numbers. Abundance estimates are variable due to this animal's patchy horizontal distribution (Chandler 1940) and its ability to avoid plankton traps and small nets (Tressler et al. 1953). Abundance is generally less than 100 m⁻³ (McNaught and Buzzard 1973; Howmiller and Beeton 1971; present study). In Lake Superior the average annual density is less than 1 m⁻³ (Selgeby

1975a), but swarms of 200 m⁻³ (Stewart 1974) and 2449 m⁻³ (Rolan et al. 1973) have been reported from lakes Michigan and Erie, respectively.

LIFE HISTORY IN THE GREAT LAKES

In the Great Lakes *L. kindti* is commonly seen from May through November or December (Chandler 1940; Andrews 1949; Rolan et al. 1973; Stewart 1974; Selgeby 1974). Abundance peaks in midsummer or early fall (Andrews

1949; Davis 1954; Wells 1960; Beeton and Barker 1974; Gannon 1974; Watson and Carpenter 1974).

In the fall males and females mate and a resting egg is formed, which overwinters. In the spring, generally in April or May, a 1-mm nauplius hatches from each egg (Warren 1901). The nauplii grow to 1.5–2.0 mm and then molt to an immature female form. These sexually produced females possess a secondary eyespot located behind and below the compound eye. As the animals mature the eyespot fades. This first generation is not very numerous, and adults are smaller and produce fewer clutches with fewer eggs than the succeeding generations.

The sexually produced females reproduce parthenogenetically and deposit 0.38- to 0.40-mm diameter eggs into the brood sac on their back. The eggs develop directly into immature females (no naupliar stages are present in parthenogenetically produced animals), which are released from the brood chamber when the parent molts. The first parthenogenetically produced females usually mature in June, and reproduce parthenogenetically throughout the summer.

In the fall, some of the females produce eggs that hatch into males. The stimulus for male production is not known, but it may be linked to blue-green algae abundance (Andrews 1948). The males mate with females to produce the resting eggs.

Females usually outnumber males, except during October and November when sexual reproduction is taking place.

Andrews (1949) constructed a size-frequency distribution curve of 1300 parthenogenetically produced females collected over a two-year period. The curve displayed extreme irregularity and lacked distinct modes, thus failing to indicate the number of adult instars produced in a natural population.

ECOLOGY IN THE GREAT LAKES

Habitat. *L. kindti* occurs in both the littoral and limnetic zones of most lakes. It has an uneven horizontal distribution and has been observed forming large patches or swarms (Andrews 1948; Wilson 1960; Swain et al. 1970a; Beeton and Barker 1974; Gannon 1975).

This species may be temperature limited (Andrews 1948). Its abundance declines steadily in October and November as the water cools, even though the food supply remains at a relatively high level for several more weeks.

Diurnal Migrations. *L. kindti* migrates upward as light intensity decreases, arriving at the surface at or just after sunset. The animals remain near the surface until early morning

(Andrews 1949; Wells 1960). Immature forms precede the adults to the surface at night and remain there later in the morning.

Andrews (1949) was unable to collect any organisms during the day, possibly because they were able to see and avoid his net. Further work by Wells (1960) showed that many *Leptodora* are located near the lake bottom during the day, although some animals tend to remain in the metalimnion. The depth of daytime distribution seems dependent on the depth of the water column.

Feeding Ecology. Although *L. kindti* is a large zooplankter with legs modified for raptorial feeding, it is a feeble swimmer and waits for prey to happen by instead of actively pursuing it. Andrews (1949) conducted laboratory feeding trials and discovered that this species captures the slowest-moving prey items first when offered a choice of prey. To be utilized as a food source, fast-moving prey must be very numerous. The most common zooplankters eaten include cyclopoids, diaptomids, *Epischura*, daphnids, and *Eurycerus*.

As a group, cladocerans may be the major food item of *L. kindti* (Mordukhai-Boltovskoi 1958). Stewart (1974) found that the peak abundance of *L. kindti* coincided with the dominance of *Daphnia* and high abundance of other larger cladocerans. Andrews (1949) showed that the abundance of *L. kindti* decreased concurrently with a decrease in abundance of other cladocerans and an increase in phytoplankton density.

McNaught et al. (1980) found that *Leptodora* filters nannoplankton in Lake Huron at the slow rate of 0.004–0.006 ml · animal⁻¹ · hour⁻¹.

As Food for Fish. Its large size and tendency to swarm make *L. kindti* an ideal food for fish. It is a major item in the diet of bass, trout-perch, shiners, crappie, sauger, wall-eye, perch, cisco, and freshwater drum (Clemens and Bigelow 1922; Sibley 1929; Ewers 1933; Kinney 1950; Wolfert 1965; Engel 1976). Without its extreme transparency and pattern of vertical migration, *Leptodora* would probably be eliminated from most lakes.

LIFE HISTORY AND ECOLOGY IN OTHER LAKES

L. kindti is common in many large lakes (Carl 1940) and generally has a life history similar to that described previously (Marsh 1897; Birge 1897). The occurrence of large swarms and patchy distribution patterns reported from Green Lake in Wisconsin (Marsh 1897) are similar to those observed in the Great Lakes. However, there are some exceptions to the generalized pattern of vertical migration

described previously. Forbes (1891) occasionally found *L. kindti* at the surface during the day, while in clear, shallow lakes the animals were sometimes found in the mud.

These organisms can be difficult to culture in the laboratory (Engel 1976). It is important to provide the animals with an abundant food supply and to prevent injuries due to contact with the aquarium sides. Temperature, light, pH, aeration, and circulation of culture media are not primary factors responsible for laboratory die-offs (Andrews 1949).

Young *L. kindti* are voracious feeders immediately after release from the brood pouch. In feeding studies, Birge (1897) observed that *L. kindti* seemed to squeeze out and swallow the interior of the prey items, particularly *Cyclops* and *Daphnia*. Cannibalism may occur in some lab cultures when food is limiting (Andrews 1949).

Polyphemus pediculus (Linné 1761)

TAXONOMIC HISTORY

Polyphemus pediculus is the sole freshwater representative of the family Polyphemidae in North America. This family is represented by several other genera and species in the Caspian Sea region.

DESCRIPTION

Ischregt (1933), Scourfield and Harding (1941), Brooks (1959), and Buttorina (1968) provide detailed descriptions of this unusual cladoceran. *Polyphemus* is easily recognized by its reduced carapace, large eye, globular brood chamber, and elongate abdomen terminating in two long caudal setae (Plate 3). Males are distinguished from females by a hook on the inner surface of the first leg (Fig. 98) (Mordukhai-

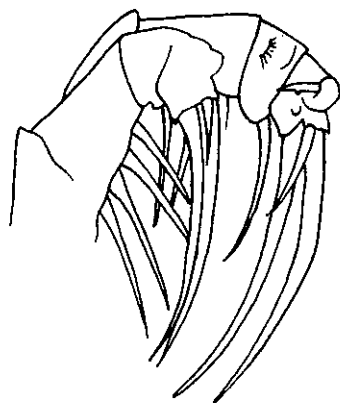


Figure 98 First leg of *Polyphemus pediculus*

Boltovskoi 1965), although this feature is difficult to see even under high magnification.

SIZE

Females may reach a length of 1.5–2 mm while males are smaller, generally reaching only 0.8 mm (Scourfield and Harding 1941; Brooks 1959). In Lake Superior, we found female *Polyphemus* to be fairly small (0.74–1.08 mm), averaging 0.89 mm. This cladoceran has a dry weight of 2.2–4.1 μg (Hawkins and Evans 1979).

DISTRIBUTION AND ABUNDANCE

P. pediculus is characteristic of northern or Arctic water bodies (Gurney 1923), occurring in pools, marshes, and along lake margins throughout the northern hemisphere. It has been collected from all of the Great Lakes (Table 2). It generally occurs in low densities ($< 20 \text{ m}^{-3}$) although abundance may increase for a brief period in July or August to 170–1000 organisms m^{-3} (Olson and Odlaug 1966; Wells 1970; Stewart 1974). Recent changes in relative abundances led Gannon (1970) to speculate that *P. pediculus* is replacing *Leptodora kindti* (another predatory cladoceran) in Lake Michigan.

LIFE HISTORY IN THE GREAT LAKES

Most Great Lakes investigators have only observed *P. pediculus* in their mid-to-late summer samples (Wells 1960; Patalas 1969; Carter 1972; Gannon 1972a, 1974, 1975; Selgeby 1974; Czaika 1974a; Stewart 1974; Torke 1975).

Polyphemus produces two generations each year. The summer population of females in Lake Superior hatches from resting eggs that overwintered (Selgeby 1974). These females mature and produce parthenogenetic eggs that develop into sexual males and females. The ephippial or resting eggs are produced by the matings of this generation.

ECOLOGY IN THE GREAT LAKES

Habitat. This cladoceran is generally most abundant in inshore areas (Stewart 1974), where it may exhibit a patchy distribution pattern (Swain et al. 1970b). *P. pediculus* shows a preference for the upper water strata a few meters below the surface but has been found to depths of 40 m (Wells 1960; Olson and Odlaug 1966).

Diurnal Migration. Migration studies of this species are limited by its sparse abundance in most areas. Wells (1960) found evidence of migration towards the surface at sunset or slightly before. A slight evening descent may precede a sec-

TABLE 2
Reports of *Polyphemus pediculus* in the Great Lakes

	Sampling Date	Abd ^a	Reference		Sampling Date	Abd ^a	Reference
LAKE ERIE	—	—	Reighard 1894	LAKE HURON (continued)	1970–1971	P	Carter 1972
	—	—	Price 1963		1974	P	Basch et al. 1980
LAKE MICHIGAN	1954–1955, 1958	P	Wells 1960		1974–1975	P	McNaught et al. 1980
	1954–1961	U	Wells and Beeton 1963	LAKE ONTARIO	1967	U	Patalas 1969
	1966, 1968	P	Wells 1970	1967–1968	P	Patalas 1972	
	1969–1970	U	Gannon 1972a	1972	R	Czaika 1974a	
	1969–1970	U	Gannon 1975	LAKE SUPERIOR	1889	P	Forbes 1891
	1971–1972	P	Beeton and Barker 1974	1893	P	Birge 1893	
	1972–1977	P	Evans et al. 1980	1964	P	Olson and Odlaug 1966	
	1973	P–C	Stewart 1974	1967–1968	U	Patalas 1972	
	1973–1974	U	Torke 1975	1969	P	Swain et al. 1970b	
	1974	P	Evans and Stewart 1977	1971	P	Selgeby 1974	
	1975–1979	—	Hawkins and Evans 1979	1971–1972	U	Selgeby 1975a	
LAKE HURON	1903, 1905, 1907	C	Bigelow 1922	1973	P	Watson and Wilson 1978	
	1907	C	Sars 1915	1973	P	Upper Lakes Ref. Group 1977	
	1967–1968	U	Patalas 1972	1974	P	Basch et al. 1980	
				1979–1980	P	This study	

^aAbundance Code

R = rare U = uncommon P = present C = common A = abundant F = found in fish stomach contents
— = abundance ranking not appropriate

ondary peak near the surface just before dawn. The animals then descend to their daytime depths of a few meters below the surface.

Feeding Ecology. *P. pediculus* is a predatory cladoceran. Its modified thoracic appendages enable it to grasp small prey items including protozoans, rotifers, and other cladocerans (Brooks 1959; Pennak 1978). Laboratory studies (Anderson 1970) show no evidence that it consumes nauplii of diaptomid or cyclopoid copepods. The food items consumed are broken down by enzymes capable of digesting fats, carbohydrates, and proteins (Hasler 1937).

The distribution of *P. pediculus* may be affected by its food habits. In Lake Michigan, it is found concentrated in inshore areas where the zooplankton populations are dominated by small prey organisms such as rotifers and *Bosmina longirostris* (Stewart 1974).

It was also found to consume nannoplankton in Lake Huron (McNaught et al. 1980). A yearly average of algae equivalent to 22.7% of its body weight is consumed each day, with filtering rates varying from 0.0015–0.044 ml · animal⁻¹ · hour⁻¹.

As Food for Fish and Other Organisms. *P. pediculus* does not appear to be a common prey item for most fish. It has only been found in small quantities in the stomachs of young bloater (Wells and Beeton 1963) and arctic char (Langland 1978). Although cyclopoid copepods consume other cladocerans, there is no indication that they attack *P. pediculus* (Anderson 1970).

LIFE HISTORY AND ECOLOGY IN OTHER LAKES

The distribution and ecology of this species have been studied in lakes in British Columbia (Carl 1940) and southern Saskatchewan (Moore 1952).

Laboratory experiments (Hutchinson 1967) show that *P. pediculus* is negatively phototactic in a strong horizontal light beam but becomes positively phototactic when the intensity of the beam is decreased. The nutritional needs and development of its embryos in the brood chamber have also been investigated (Patt 1947).

Diaphanosoma (Fischer 1850): *D. birgei* and *D. brachyurum*

TAXONOMIC HISTORY

The animals in this group were originally described as members of the genus *Diaphanosoma* but were changed to the genera *Sida* and *Daphnella* before *Diaphanosoma* was reestablished as a true genus (Herrick 1884; Richard 1895). Two of the 11 species in this genus, *D. leuchtenbergianum* (Fischer 1850) and *D. brachyurum* (Liéven 1848) are reported from the Great Lakes. These two forms have been considered ecotypic varieties of a single species (Brooks 1959), with *D. leuchtenbergianum* being the more limnetic variety.

Recent work by Kořínek (1981) shows that, based on its original description, the name *D. leuchtenbergianum* is synonymous with *D. brachyurum*, but there are two species of *Diaphanosoma* in North America. He proposes the name *D. birgei* for American specimens of the more limnetic species and retains the name *D. brachyurum* for the more littoral species. We follow this name change.

DESCRIPTION

This genus is distinguished from other members of the family Sidae by characteristics of the second antennae (Brooks 1959). The two Great Lakes species are recognized by their enlarged second antennae, elongate bodies that lack terminal shell spines, and rounded heads without crests (Plates 4, 5). The more limnetic species, now called *D. birgei* has previously been distinguished from *D. brachyurum* by its larger head (head equals $\frac{2}{3}$ length and $\frac{1}{2}$ width of carapace), smaller eye, which is located near the midventral margin of the head, and more transparent body color (Figs. 99, 100). The second antennae of *D. birgei*, which reach the posterior margin of the carapace when reflexed, are longer than those of *D. brachyurum* (Fordyce 1900; Brooks 1959; Brandlova et al. 1972; Pennak 1978). These features are somewhat variable, and Kořínek (1981) proposes using the spine on the distal margin of the first segment on the exopod (longer branch) of the second antennae to differentiate the species. The spine extends past the tip of the segment in *D. birgei* but not in *D. brachyurum*.

Males of both species are distinguished from females by their elongate antennules and hooked first legs.

SIZE

Brooks (1959) reported that *D. brachyurum* was slightly smaller than *D. birgei*:

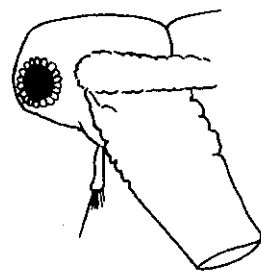


Figure 99 Head shape of *Diaphanosoma birgei*

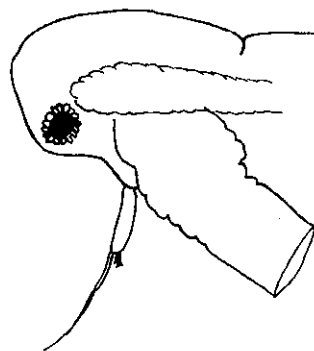


Figure 100 Head shape of *Diaphanosoma brachyurum*

<i>D. brachyurum</i>	♀ 0.8–0.9 mm	♂ 0.4 mm
<i>D. birgei</i>	♀ 0.9–1.2 mm	♂ 0.8 mm

The female *D. birgei* we collected from Lake Superior averaged 1.02 mm long (range 0.92–1.12 mm).

Hawkins and Evans (1979) found that *Diaphanosoma* from lake Michigan have a dry weight of 1.2–3.6 µg.

DISTRIBUTION AND ABUNDANCE

D. birgei has been collected in North America from the Arctic Circle south to Louisiana. It is common in northern Europe and Asia (Scheffer and Robinson 1939; Scourfield and Harding 1941; Pennak 1949; Moore 1952; Comita 1972; Binford 1978; and Kořínek 1981). *D. brachyurum* has a similar distribution pattern but is also found in Africa and Central and South America (Birge 1897; Gurney 1923; Brandlova et al. 1972; Lewkowicz 1974).

D. birgei is more widely distributed in the Great Lakes than the littoral *D. brachyurum* (Table 3). The former species is generally found in low numbers ($< 1 \text{ m}^{-3}$) in Lakes Ontario, Michigan, and Superior (Patalas 1969; Czaika 1974a; Gannon 1974; Stewart 1974; Selgeby 1975a) although peaks of 300 m^{-3} were found in Lake Superior's Chequamegon Bay (Selgeby 1974). It is fairly common in Lake Huron's Georgian Bay (Carter 1972) and in Lake Erie, where average summertime densities of 400 m^{-3} and peaks of 2400 m^{-3} have been recorded (Davis 1954).

TABLE 3
Reports of *Diaphanosoma* in the Great Lakes

	Sampling Date	Abd ^a	Reference		Sampling Date	Abd ^a	Reference	
LAKE ERIE	1919-1920	F	Wickliff 1920	LAKE MICHIGAN (continued)	1971-1972	1U	Beeton and Barker 1974	
	1919-1920	2F	Clemens and Bigelow 1922		1971-1973	1U	Stewart 1974	
	1928-1929	IP-C, 2P	Wilson 1960		1972-1977	1P	Evans et al. 1980	
	1928-1930	1P	Wright 1955		1973-1974	1P	Torke 1975	
	1929	1F	Ewers 1933		1975-1977	—	Hawkins and Evans 1979	
	1938-1939	1P	Chandler 1940					
	1948-1949, 1959	1C	Bradshaw 1964		LAKE HURON	1903, 1905, 1907	1U, 2U	Bigelow 1922
	1950-1951	1C	Davis 1954		1968	1U	Patalas 1972	
	1956-1957	1P	Davis 1962		1970-1971	1C	Carter 1972	
	1961	1P	Britt et al. 1973		1970	1R	Watson and Carpenter 1974	
	1967	1P	Davis 1968		1974-1975	1U	McNaught et al. 1980	
	1967-1968	1P	Davis 1969					
	1968, 1970	1P	Heberger and Reynolds 1977		LAKE ONTARIO	1967	1U	Patalas 1969
	1968	1P	Patalas 1972		1967	1P	Patalas 1972	
	1970	1C	Watson and Carpenter 1974		1972	1R	Czaika 1974a	
	1971-1972	1C	Rolan et al. 1973		1972-1973	1R	Czaika 1978a	
LAKE MICHIGAN	1888	1C	Eddy 1927	LAKE SUPERIOR	1928	2R	Eddy 1934	
	1954-1955, 1958	2P	Wells 1960		1968	1U	Patalas 1972	
	1954, 1966, 1968	2R	Wells 1970		1971	1P	Selgeby 1974	
	1969-1970	1P	Gannon 1972a		1971-1972	1U	Selgeby 1975a	
	1969-1970	1P, 2P	Gannon 1974		1973	1U	Upper Lakes Ref. Group 1977	
	1969-1970	1P	Gannon 1975		1979-1980	1P	This study	

^aAbundance Code

1 = *D. birgei* 2 = *D. brachyurum* R = rare U = uncommon P = present C = common A = abundant
F = found in fish stomach contents — = abundance ranking not appropriate

LIFE HISTORY IN THE GREAT LAKES

In Lake Erie *D. birgei* is commonly collected between May and October (Chandler 1940; Wright 1955; Davis 1962; Britt et al. 1973; Watson and Carpenter 1974). In the other Great Lakes this species is generally found only in the fall (Beeton and Barker 1974; Czaika 1974a; Watson and Carpenter 1974; Gannon 1975). Abundance peaks have usually been reported during the fall months (Eddy 1927; Davis 1954 and 1962; Bradshaw 1964; Patalas 1969; Rolan et al. 1973; Britt et al. 1973; Stewart 1974).

The life history of this genus in the Great Lakes is not well documented. Summer reproduction appears to be parthenogenetic. Small numbers of males appear only in the fall. In Lake Michigan (Stewart 1974) males have been collected during the September population peak.

ECOLOGY IN THE GREAT LAKES

Habitat. *D. brachyurum* is found in littoral areas while *D. birgei* is more limnetic (Brooks 1959). In the Great Lakes *D. birgei* is usually found in the open waters of sheltered bays, harbors, and island areas rather than in the deep offshore regions (Patalas 1969; Gannon 1972a; Carter 1972; and Selgeby 1974). In Ohio lakes this species was most common at a depth of 3-6 m and was seldom collected at the surface (Winner and Haney 1967).

In Lake Erie *Diaphanosoma* is most abundant in the western basin in July and in the eastern and central basins during the fall (Davis 1968, 1969). It is not known if eutrophication and high temperatures are responsible for this seasonal change in distribution.

Diurnal Migrations. Wells (1960) reported that *D. brachyurum* was found at all depths in Lake Michigan but preferred the upper layers, with the animals more concentrated at the surface at night than during the day.

Feeding Ecology. Although the feeding behavior of this genus has not been studied in the Great Lakes, Gliwicz (1969) found that other populations of *D. brachyurum* are filter feeders capable of ingesting particles from 5–154 μ m. The smallest particles (1–5 μ m) are consumed in the greatest quantities while very few particles greater than 18 μ m are ingested. Stomach analysis showed chlorophytes (7–15 μ m) and diatoms (12 μ m) are the principal items consumed.

As Food for Fish. In the Great Lakes *Diaphanosoma* are consumed by largemouth bass, cisco, crappie, logperch, shiners, yellow perch, and other fish (Wickliff 1920; Clemens and Bigelow 1922; Ewers 1933; Wilson 1960).

LIFE HISTORY AND ECOLOGY IN OTHER LAKES

D. birgei has been studied in Lake Washington (Scheffer and Robinson 1939), British Columbia (Carl 1940), Colorado (Pennak 1949), the midwestern United States (Birge 1897; Marsh 1897; Comita 1972), and in the Atchafalaya River in Louisiana (Binford 1978). Most studies reported seasonal abundance patterns similar to those of the Great Lakes.

Diaphanosoma species have been found to prefer epilimnetic waters (Marsh 1897; Engel 1976) and migrate to the surface at night in several lakes (Marsh 1897; Brandlova et al. 1972).

Field studies employing grazing chambers (Lane 1978) showed that *D. birgei* is readily preyed upon by omnivorous zooplankton including *Diacyclops thomasi*, *Chaoborus*, *Mesocyclops edax*, *Leptodora kindtii*, *Tropocyclops prasinus mexicanus*, *Skistodiaptomus oregonensis*, and *Leptodiaptomus minutus*. In a separate study, Anderson (1970) found that *Diaphanosoma leuchtenbergianum* (*D. birgei*?) was the most common prey item of *Diacyclops thomasi* in Patricia Lake, Alberta.

Holopedium gibberum (Zaddach 1855)

TAXONOMIC HISTORY

Holopedium gibberum was first described in 1855 by Zaddach. It is one of the two species of the genus *Holopedium*

of the family Holopedidae. The distinct characteristics of this family, genus, and species have resulted in very few changes in the taxonomy of this organism.

DESCRIPTION

H. gibberum is easily recognized by the large gelatinous mantle covering its humped carapace. This mantle is often twice as long as the body, thus increasing the animal's volume by eight times. In live plankton samples, the mantle generally appears as a small glob of jelly; in preserved samples it is often lost. *H. gibberum* swims upside down with its second antennae and filtering appendages projecting through a T-shaped opening in the ventral surface of the mantle. The second antennae are uniramous in females (Plate 6) and biramous in males.

SIZE

Brooks (1959) reports females from 1.5–2.2 mm (excluding mantle) and males from 0.5–0.6 mm. In Lake Superior we found the females to be a bit smaller (1.0–1.7 mm). Without the mantle, *Holopedium* from Lake Michigan have a dry weight of 1.9–10.9 μ g (Hawkins and Evans 1979).

DISTRIBUTION AND ABUNDANCE

H. gibberum occurs in northern and arctic lakes of Europe and North America. In the United States it is restricted to the northern states and the mountainous areas from California to Colorado (Gurney 1923; and Brooks 1959). Carpenter (1931) regarded this species as a glacial relict. It has been found in brackish water, but it is less abundant and shows limited reproduction there.

H. gibberum is found in low numbers in all the Great Lakes (Table 4). Davis (1968) and Patalas (1972) reported this species from the Eastern and Central basins of Lake Erie but not from the Western Basin. It exhibits a very patchy distribution, generally numbering less than 6 m⁻³ but occasionally concentrating in numbers over 4000 m⁻³ (Wells 1970; Stewart 1974; McNaught et al. 1980). Abundance is generally high in Georgian Bay of Lake Huron (Sars 1915; Bigelow 1922; Carter 1972; Watson and Carpenter 1974) but is lower along the western side of Lake Huron (7–17 m⁻³), (Basch et al. 1980) and in Lake Superior (35 m⁻³) (Selgeby 1975a).

LIFE HISTORY IN THE GREAT LAKES

This cladoceran is usually absent from winter and spring plankton samples (Wells 1960; Davis 1969; Beeton and Bar-

TABLE 4
Reports of *Holopedium gibberum* in the Great Lakes

	Sampling Date	Abd ^a	Reference		Sampling Date	Abd ^a	Reference
LAKE ERIE	1919-1920	F	Clemens and Bigelow 1922	LAKE HURON (continued)	1967-1968	P	Patalas 1972
	1928-1929	U	Wilson 1960		1970-1971	A	Carter 1972
	1967	C	Davis 1968		1970	P	Watson and Carpenter 1974
	1967-1968	P	Davis 1969		1974	P	Basch et al. 1980
	1967-1968	P	Patalas 1972		1974-1975	P	McNaught et al. 1980
	1970	P	Watson and Carpenter 1974				
LAKE MICHIGAN	1881	P	Forbes 1882	LAKE ONTARIO	1967	P	Patalas 1969
	1954-1955, 1958	C	Wells 1960		1967-1968	U	Patalas 1972
	1954-1961	PF	Wells and Becton 1963		1970	P	Watson and Carpenter 1974
	1966, 1968	P	Wells 1970		1972	U	Czaika 1974a
	1969-1970	P	Gannon 1975	1973	R	Czaika 1978a	
	1969-1970	C	Gannon 1972a	LAKE SUPERIOR	1889	P	Forbes 1891
	1969-1970	P	Gannon 1974		1893	P	Birge 1893
	1971-1972	A	Beeton and Barker 1974		1967-1968	U	Patalas 1972
	1972-1977	P	Evans et al. 1980		1970-1971	P	Conway et al. 1973
	1973	P	Stewart 1974		1971-1972	P	Selgeby 1975a
	1973-1974	P	Torke 1975		1971	P	Selgeby 1974
	1975-1977	—	Hawkins and Evans 1979		1973	P	Watson and Wilson 1978
					1973	P	Upper Lakes Ref. Group 1977
			1974		C	Basch et al. 1980	
			1979-1980		P	This study	
LAKE HURON	1903, 1905, 1907	A	Bigelow 1922				
	1907	C	Sars 1915				

^aAbundance Code

R = rare U = uncommon P = present C = common A = abundant F = found in fish stomach contents
 — = abundance ranking not appropriate

ker 1974). Abundance increases during the summer, with population peaks occurring between June and October (Wells 1960; Patalas 1969; Gannon 1972a; Stewart 1974; Torke 1975; Selgeby 1975a).

The reproductive pattern of this species is not well documented for the Great Lakes. Selgeby (1974, 1975a) found very few ovigerous females in Lake Superior even though the population increased from July to August. He observed one male and a few ephippial females in October. In Lake Michigan, males have been found to comprise 25% of the fall population (Torke 1975). These data suggest that female *H. gibberum* hatch from resting eggs and produce a sexual generation. Those animals mate and produce ephippial eggs that overwinter.

ECOLOGY IN THE GREAT LAKES

Habitat. *H. gibberum* has been found in both the littoral (Forbes 1891) and pelagic (Birge 1893) regions of lakes. Carter (1972) found greatest numbers inshore in June with

the population peaking offshore during the summer. This may be due to its preference for cold water. It is considered a cold water stenotherm (Pennak 1978) and occurs primarily in oligotrophic soft-water lakes (Thienemann 1926, Pejler 1965). However, it is often abundant in the relatively hard waters of Lakes Huron and Michigan.

Diurnal Migration. The vertical distribution of *Holopedium* has been studied in Lake Michigan (Wells 1960). This cladoceran remains in the upper 20 m of the water column above the metalimnion during the day, moving toward the surface beginning in late afternoon. Greatest abundance at the surface was observed two hours before sunset in July and at sunset in October. The animals descend slightly for the night.

Feeding Ecology. *H. gibberum* is an omnivorous filter feeder, consuming several species of planktonic algae as it swims about upside down (Stenson 1973). Although considered a generalist (Allan 1973), *Holopedium* in Lake

Huron was found to consume only nanoplankton approximately 22 μm long during August and October (McNaught 1978). This animal is a very effective grazer at low densities of phytoplankton and may be adapted for feeding in areas of dispersed phytoplankton (McNaught 1978). In Lake Huron, *Holopedium* filters nanoplankton at a rate of 0.129–0.147 ml \cdot animal⁻¹ \cdot hour⁻¹ (McNaught et al. 1980) and ingests an average of 0.8% of its body weight each day.

As Food for Fish. *H. gibberum* is occasionally eaten by cisco (Clemens and Bigelow 1922; Wilson 1960), bloater (Wells and Becton 1963), the Arctic char (Langeland 1978), and coho salmon (Engel 1976). The small actual body size of this animal helps it avoid most vertebrate predation, while its large invisible gelatinous mantle offers protection from invertebrate predation (Allan 1973). McNaught (1978) reported that *H. gibberum* may taste bad to fish, possibly due to the chemical composition of the mantle.

LIFE HISTORY AND ECOLOGY IN OTHER LAKES

The mantle, which covers most of the body of *Holopedium*, is composed of one or more acid muco-polysaccharides (Hamilton 1958). It is believed to be secreted by the outer epithelium of the carapace and may have other functions besides protecting the animal from predation. Hamilton (1958) suggested that the mantle may reduce the animal's density and help retard its rate of sinking.

In most areas female *Holopedium* hatch from resting eggs in the spring when the water temperature reaches 4–7 degrees C (Hamilton 1958; Tash 1971; and Stenson 1973). The animals mature in approximately 6 weeks and reproduce parthenogenetically in June and July. Each female can carry up to 20 eggs that develop into males and sexual females by August. These animals mate and produce the ephippial eggs. In most areas this species disappears between September and November. In warmer lakes *Holopedium* may produce several parthenogenetic generations before sexual animals are produced (Tash 1971).

H. gibberum is usually found in slightly acidic waters with a pH of 6.0–6.8 (Carpenter 1931) although it can withstand a pH of 4.0–7.5 (Hamilton 1958). It is restricted to soft-water lakes with less than 20 mg/l Ca⁺⁺ and temperatures less than 25 degrees C (Hamilton 1958). This species is often found in large swarms (Hamilton 1958; Stenson 1973) swimming about in the epilimnion (Engel 1976; Langford 1938).

In most lakes *Holopedium* shows a regular pattern of diurnal migration. However in one lake in Colorado, Penak (1944) found the maximum abundance occurring at the surface at noon.

Ceriodaphnia spp. (Dana 1853)

TAXONOMIC HISTORY

Five species of *Ceriodaphnia* have been collected from the Great Lakes: *C. lacustris* Birge 1893, *C. laticaudata* P. E. Müller 1867, *C. pulchella* Sars 1862, *C. quadrangula* (O. F. Müller) 1785 and *C. reticulata* (Jurine) 1820. A sixth species, *Ceriodaphnia sciutula*, was reported in Lake Huron by Sars (1915). However, the description Sars gave of this new species conformed to that of *C. lacustris*.

DESCRIPTION

All species of *Ceriodaphnia* possess spherical carapaces without an elongate posterior spine (Plate 7). The small but distinct head is bent ventrally and contains a large compound eye. The antennules are reduced in size. Males are distinguished from females by their modified first legs and long, stout setae on the antennules.

Brooks (1959) and Brandlova et al. (1972) should be consulted when identifying *Ceriodaphnia* to species. High magnification may be necessary to determine the characteristics of the postabdominal claw and anal spines that are used in species identification.

SIZE

Brooks (1959) lists the size ranges of these small cladocerans as follows:

<i>C. reticulata</i>	♀ 0.6–1.4 mm	♂ 0.4–0.8 mm
<i>C. lacustris</i>	♀ 0.8–0.9 mm	♂ unknown
<i>C. pulchella</i>	♀ 0.4–0.7 mm	♂ to 0.5 mm
<i>C. quadrangula</i>	♀ to 1.0 mm	♂ to 0.6 mm
<i>C. laticaudata</i>	♀ to 1.0 mm	♂ to 0.7 mm

DISTRIBUTION AND ABUNDANCE

Most species of *Ceriodaphnia* are found throughout the United States and Canada (Brooks 1959). *C. quadrangula* is also found in Europe, Asia, and South America (Pennak 1978).

One or more of the *Ceriodaphnia* have been reported from each of the Great Lakes (Table 5). In our summer and fall samples the Duluth-Superior nearshore region of Lake Superior, we found *C. lacustris* present in low numbers. Lake Erie contains all five species. *C. lacustris* is the most limnetic of the five species, and peak abundances of 200–3500 m⁻³ have been reported from Lake Erie (Rolan et al. 1973; Watson and Carpenter 1974). This species is also

TABLE 5
Reports of *Ceriodaphnia* in the Great Lakes

	Sampling Date	Abd ^a	Reference		Sampling Date	Abd ^a	Reference
LAKE ERIE	1929	4F	Ewers 1933	LAKE HURON	1903, 1905, 1907	3, 5U	Bigelow 1922
	1938-1939	4U	Chandler 1940		1967-1968	5P	Patalas 1972
	unknown	2, 4U	Langlois 1954		1970	5R-P	Watson and Carpenter 1974
	1928-1929	1, 2, 3, 4F	Wilson 1960		1970-1971	5C, 3P	Carter 1972
	1950-1951	4U	Davis 1954		1974	6P	Basch et al. 1980
	1966-1967	5U	Patalas 1972		1974-1975	5P	McNaught et al. 1980
	1967-1968	6U	Davis 1969				
	1970	5P	Watson and Carpenter 1974				
	1971-1972	2, 4, 5U; 3R	Rolan et al. 1973		LAKE ONTARIO	1967	5P
1973-1974	5P	Czaika 1978b	1967-1968	6P		Patalas 1972	
			1970	5P		Watson and Carpenter 1974	
LAKE MICHIGAN	1926	5U	Eddy 1927	1971-1972	5P	Wilson and Roff 1973	
	1969-1970	5P	Gannon 1972a	1972	5P	McNaught and Buzzard 1973	
	1969-1970	3, 5P	Gannon 1974	1972	5C	Czaika 1974a	
	1971	5P	Howmiller and Beeton 1971	1972-1973	5U	Czaika 1978a	
	1971-1972	5P	Beeton and Barker 1974				
	1972	3P	Stewart 1974	LAKE SUPERIOR	1967-1969	6U	Swain et al. 1970b
	1972-1977	3P	Evans et al. 1980		1970-1971	6U	Conway et al. 1973
	1973-1974	5R	Torke 1975		1979-1980	5U	This study

^aAbundance Code

1 = *C. laticaudata* 2 = *C. pulchella* 3 = *C. quadrangula* 4 = *C. reticulata* 5 = *C. lacustris* 6 = *Ceriodaphnia* spp.
R = rare U = uncommon P = present C = common A = abundant F = found in fish stomach contents

common in Lakes Ontario, Huron, and Michigan where abundance peaks of 80-10,000 organisms m⁻³ have been reported (Howmiller and Beeton 1971; Carter 1972; Watson and Carpenter 1974). *C. quadrangula* is found in low numbers in Lakes Ontario and Huron and in moderate numbers (up to 2000 m⁻³) in Lake Michigan (Johnson 1972; Stewart 1974).

LIFE HISTORY IN THE GREAT LAKES

Life history information for this genus in the Great Lakes is very limited. *C. lacustris* is generally found only in the summer and fall, with abundance peaks occurring between August and October (Patalas 1969; Carter 1972; Gannon 1972a; Wilson and Roff 1973; Rolan et al. 1973; Czaika 1974a, 1978b; Watson and Carpenter 1974; Torke 1975). Dramatic fluctuations in abundance were observed in Lake Erie from July to October 1971 (Rolan et al. 1973) instead of the usual slow increase in abundance to a peak followed by a sharp decline in numbers.

Reproduction is parthenogenetic during the summer, with males and ephippial females appearing in September and October (Czaika 1974a). Like most cladocerans, this species overwinters as resting eggs.

ECOLOGY IN THE GREAT LAKES (AND OTHER AREAS)

Habitat. *Ceriodaphnia* have been found in both the littoral and limnetic zones of lakes (Brooks 1959). In the Great Lakes these organisms are usually found nearshore (Rolan et al. 1973) or in the warmer upper layers of the water column (Wilson and Roff 1973).

Diurnal Migrations. Wilson and Roff (1973) observed a limited vertical migration of *C. lacustris* in Lake Ontario. The mean depth of the population was closer to the surface after sunset than during the afternoon and evening. The mean population depth was not correlated with the intensity of the incident radiation at that depth. Juday (1904) and