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SELECTED ASPECTS OF THEIR ECOLOGY.

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THE OSTRACODA OF GULL LAKE, MICHIGAN:
SELECTED ASPECTS OF THEIR ECOLOGY

By

DON L. MCGREGOR

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ABSTRACT

THE OSTRACODA OF GULL LAKE, MICHIGAN:
SELECTED ASPECTS OF THEIR ECOLOGY

By

Don L. McGregor

This study presents both qualitative and quantitative description of selected aspects of the ecology of the free-living ostracods inhabiting littoral and sublittoral areas of Gull Lake, Michigan. Most data reported were collected over a period of one year.

Twenty-four species representing 10 genera of the superfamilies Cypridacea, Darwinulacea and Cytheracea were identified from samples totalling nearly 33,000 ostracods. Twelve species are reported from Michigan, and one from North America, for the first time. Seventeen species are non-swimmers and seven are free-swimmers; of the latter, all but one were restricted to the littoral region (0-9 m). Almost 98 percent of the ostracods collected from sediment cores were found in the top five cm sediment interval.

Most species of ostracods from Gull Lake reproduce sexually, all are dioecious and all but two are oviparous. *Cypridopsis vidua*, *Darwinula stevensoni* and *D. pagliolii* are known to be parthenogenetic and the last two species carry their young through embryological development to the first, and occasionally second, instar. The maximum number of uterine eggs and/or young, recorded for different species from a sample of 7,533 females, ranged from three (*Darwinula pagliolii*) to 69 (*Candona crogmaniana*). The maximum number of eggs and young

reported for each species is believed to be a more realistic estimate of the actual reproductive performance of most females than were the reported means.

A majority of the free-swimming species reproduce during the summer months, but some have more than one generation per year. *Cyprinotus glaucus* was found only from May to September. Many non-swimming species, excepting those of *Darwinula* and two species of *Candona*, reproduce during the Fall, Winter and Spring. Most species of *Candona* had an annual reproductive cycle; *Candona ohioensis* had an annual reproductive cycle in the littoral areas and a biannual cycle in the sublittoral. The reproductive cycles of free- and non-swimming species exhibited little overlap.

Ostracod diversity, in number of species and individuals was greatest in the littoral areas of Gull Lake. *Candona* was the dominant genus, in number of species, and undoubtedly accounted for most of the standing crop biomass of non-swimming species. Free-swimming species appeared to account for most of the standing crop biomass in the littoral areas during the summer months, whereas, in the late Fall and Winter non-swimming species presumably were dominant in biomass and number of species. Statements regarding ostracod biomass, based upon visual observation, are supported by information on species size, composition, and density.

For those species of *Candona* whose life histories were studied in sufficient detail, the proportion of males always was greatest during the initial phase of the reproductive cycle. Most evidence indicated that males have a shorter life span than females. Greater mortality rates of males resulting from predation by fish was strongly indicated by analyses of stomach and gut contents of the yellow perch, *Perca* flavescens. Percentages of males of two species of Candona found in the stomach contents of perch were much higher than those ever encountered in sediment core or dredge samples. Ostracods representing 13 species and six genera, were found in three species of fish, P. flavescens (yellow perch), Lepomis macrochirus (bluegill), and Osmerus mordax (smelt) from Gull Lake.

Detailed information is presented on the life history, reproductive performance and cycle(s), temporal and spatial distribution, population density, size and age structure, sex and juvenile-adult ratio, parasites, and predators of most species of the ostracod fauna of Gull Lake. Literature reviewed on the above topics focuses attention on our limited knowledge of the biology of freshwater Ostracoda.

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INTRODUCTION

The Ostracoda are among the most widespread and common groups of Crustacea in aquatic environments and have one of the best documented geological histories of any invertebrate group. Ironically, the ecology and most other aspects of the biology of freshwater ostracods are scarcely known compared to a wealth of information available on other entomostracans.

In recent years, increased attention has been focused on the trophic structure, population dynamics and energetics of many groups of benthic organisms in diverse types of aquatic ecosystems. Yet, when one peruses the literature relating to studies of this nature on the Ostracoda, the paucity of information is indeed striking. The small size of most freshwater ostracods, difficulty in making specific determinations, and the general disregard of this group by benthic ecologists may account for the limited number of ecological studies on the freshwater Ostracoda.

The objectives of the present work were 1) to investigate the life history and population dynamics of two or more species of Gull Lake Ostracoda and 2) to complete a taxonomic survey of the ostracod fauna of this lake. This study presents both qualitative and quantitative description of selected aspects of the ecology of free-living ostracods inhabiting the littoral and sublittoral areas of Gull Lake. Though limited in scope and based almost entirely upon field studies, this investigation represents a preliminary attempt to establish a basic framework for identifying and formulating more detailed, experimental approaches to the study of ostracod populations.

HISTORICAL REVIEW

General

Literature on fossil and Recent Ostracoda is extremely voluminous but widely scattered in many journals throughout the world. No attempt is made to review the major publications on freshwater ostracods or even those on a given genus.

Much of the information of concern to ecologists is published in taxonomic reports or in the paleontological literature. Freshwater ostracods often are reported in studies principally concerned with marine or brackish-water faunas or in the diverse array of ecological, limnological, and oceanographical literature. Some papers cited in this study are related only indirectly to the problems investigated. However, these publications have been invaluable in directing me to other important literature and in most every instance have provided greater insight to the more general biological and paleontological features of the Ostracoda from which future questions will be generated.

Many problems exist in identifying and classifving both living and fossil freshwater ostracods. Zoologists have devised hierarchial classifications based largely upon appendage and reproductive structure morphology. Detailed studies of the carapace have been limited. Paleontologists, on the other hand, generally are obliged to scrutinize the carapace of ostracods in considerable detail, in the absence of preserved soft parts. Consequently, rather divergent hierarchic classifications are used in the study of fossil and living Ostracoda. Much of the work on living ostracods, however, has been compiled by paleontologists.

In 1942, Hoff described the ostracod fauna of Illinois. He presented a review of pertinent European literature and a rather comprehensive discussion of earlier studies of freshwater ostracods to that date in North America. Later, the classic study by Kesling (1951a) contributed additional information in this area and provided the most thorough description of the anatomy and biology of a freshwater ostracod that has been made in the United States.

Because much of the classic and other important literature has been reviewed by the above authors the primary intent here is to cite those studies that have been most useful in this investigation. Additional studies are reviewed, where appropriate, in subsequent sections of this thesis.

During the taxonomic phase of this study I relied heavily on the works of the following authors: Alm (1915), Brady and Norman (1889), Delorme (1967a, 1967b, 1967c), Dobbin (1941), Ferguson (1957 to 1968), Furtos (1933, 1935, 1936a, 1936b), Hoff (1942), Klie (1938), Müller (1900, 1912), Pinto and Sanguinetti (1958), Pinto and Kotzian (1961), Sars (1922-1928), Sharpe (1918), Swain (1962), Tressler (1959), and Turner (1895). Studies by Hartmann (1964, 1965a, 1965b) and Klie (1935a, 1933, 1939) also were useful. The following general references were used extensively in many aspects of this study and are recommended to beginning students, non-specialists, and others desiring detailed or general information on many aspects of the biology and paleontology of living and fossil Ostracoda: Howe (1962), Moore (1961), and Van Morkhoven (1962, 1963).

A taxonomic study usually requires much more than simply a thorough understanding of the anatomical features used for identification. In fact, many taxonomic works assume some acquaintance with the principal biological features of a given group of organisms and cannot be used or readily interpreted without previous reference to such related literature. The studies on carapace terminology (Kesling 1951b), carapace structure (Kesling 1951a; Sylvester-Bradley 1941), muscle scars (Van Morkhoven 1963; Smith 1965; Benson 1967), cuticle development (Harding 1965), anatomy, morphology, histology, (Kesling 1951a, 1957, 1965, Smith 1965; Rome 1947a; Cannon 1926, 1931, 1940), and larval development (Schreiber 1922; Scheerer-Ostermeyer 1940; Kesling 1951a, 1953; Fox 1964a) have been indespensable aids.

Paleontological literature has been consulted in many instances for taxonomic and paleoecologic information. Although the fossil records of most Gull Lake Ostracoda are not considered in detail at this time, the value of the following works is not to be minimized (e.g., Triebel 1941; Swain 1947; Winkler 1960, 1962; Diebel 1961; Gutentag and Benson 1962; Benson and MacDonald 1963; Staplin 1963a, 1963b; Grundel 1964; Gutentag 1964; Frey 1964; Lüttig 1965; Schmidt and Sellman 1966; Benson 1967; Klassen et al. 1967; and Delorme 1968).

Ecological studies on freshwater ostracods are limited in number and most present few data that are directly comparable with those data presented here. The investigations of Hoff (1942, 1943a, 1943b), Ferguson (1944, 1958b), Moore (1939), and Kenk (1949) perhaps are most relevant to the present work. Other studies (i.e., Alm 1915; Pinto and Purper 1965; Neale 1965; Latour et al. 1966; Sywula 1966; de Vos 1954) have provided data of a more general nature as pointed out in subsequent discussion.

Numerous authors, e.g., Benson (1959, 1966), Elofson (1941), Hagerman (1966, 1967), Hulings (1967), Iles (1953), Kornicker (1959, 1961, 1963, 1965), Kornicker and Wise (1960), McHardy and Bary (1965), McKenzie (1965), Puri (1966), Puri et al. (1965), Reys (1963), Theisen (1966), and Tressler (1948, 1957b) have reviewed work or have investigated various aspects of the ecology of benthonic and planktonic Ostracoda. Most of these studies are concerned with marine and brackish-water ostracods but provide information pertinent to several general biological features of the Ostracoda (refer to discussion). The symposium edited by Puri (1965) represents a particularly valuable reference on the ecology and paleoecology of ostracods.

Several investigators have reported ostracods from Michigan during the past 30 years. Moore (1939) investigated the ostracod fauna of Douglas Lake and found 11 species. Later, Tressler (1947) published a checklist of Michigan Ostracoda which included 14 species belonging to 10 genera. Kenk (1949), Cole (1953), Ferguson (1957), and Winkler (1960), also reviewed the distribution of numerous living and fossil ostracods. In 1959 Tressler published a taxonomic key for the ostracods of the United States and listed 18 species from the state of Michigan. Tressler's (1959) key was published several years following its preparation; thus, the checklists of Ferguson (1957, 1958c) represented the most complete faunal lists for Michigan ostracods through the year 1959. In 1968, Ferguson listed United States distribution records for 91 new species and 31 previously described species for the period from 1957 to 1966. No additional species were recorded for Michigan.

Both Tressler (1959) and Ferguson (1957, 1958c) omitted certain species from their respective distribution records that were recorded in these publications. The following list represents the ostracod fauna of Michigan recorded by Tressler and Ferguson through 1959.

Darwinula stevensoni (Brady and Robertson)
Eucypris crassa (O.F. Müller)
Eucypris fuscata (Jurine)
Candona crogmaniana Turner
Candona exilis Furtos
Candona simpsoni Sharpe (= C. reflexa Sharpe)
Candona indigena Hoff
Candona decora Furtos
Candona truncata Furtos
Cypria turneri Hoff
Cypria obesa Sharpe
Cypria opthalmica (Jurine)
Cypria lacustris Sars
Cypris subglobosa Sowerby
Physocypria pustulosa (Sharpe)
Cyclocypris serena (Koch)
Cypridopsis obesa Brady and Robertson
Cypridopsis vidua (O. F. Müller)
Cypricercus tuberculatus (Sharpe)
Cypricercus tincta Furtos
Cypricercus cheboyganensis Ferguson
Cyprinotus incongruens (Ramdohr)
Cyprois marginata (Strauss)
Limnocythere sancti-patrici (Brady and Robertson)

Recent investigations by McGregor (1967, 1969), McGregor and Wetzel (1968), McGregor and Kesling (1969a, 1969b) and Wetzel and McGregor (1968) report the only published records of Gull Lake Ostracoda. These studies, excepting McGregor (1969), involved research topics other than those discussed here, and are not considered in further detail. This thesis presents the first and only complete record of the ostracods of Gull Lake.

Genus Darwinula

A significant portion of the time and effort devoted to fulfilling the ecological objective of this thesis involved a study of the ostracod Darwinula stevensoni (Brady and Robertson)[1]. The widespread distribution, unique morphological characteristics, geologic

[1]A somewhat revised version of the study on D. stevensoni has been published (McGregor 1969). This study was, however, an integral part of the work reported here and is included for the purpose of completeness.

history, parthenogenetic reproduction, retention of young through the first instar, and high incidence of parasitism in this species afforded the opportunity to investigate several ecological aspects of the type species of the genus Darwinula, of potential interest to both zoologists and paleontologists. Much of the historical information on this species is scattered throughout the world literature. I believe such information is most useful in this section of the thesis in contrast to that presented for other species in subsequent pages.

Darwinula stevensoni and other species of this genus are unique among the freshwater Ostracoda because they are the only freshwater representatives in the United States which retain the young through embryological development to the first instar. Members of this genus are characterized by weakly calcified, unornamented valves, with muscle scars arranged in a rosette pattern differing from that found in all other extant or fossil Ostracoda. The furca is rudimentary, and the morphologically similar second and third pairs of thoracic appendages are dissimilar to the first pair. Additional morphologic and taxonomic characteristics of the genus Darwinula may be found in Swain (1961), Howe (1962), Van Morkhoven (1963), and Hartmann (1965b).

Brady (1870) was the first to report on Darwinula stevensoni (Brady and Robertson). He figured the carapace and mentioned that the species would be named and described later in collaboration with David Robertson. Polycheles stevensoni was described (Brady and Robertson, 1870) later the same year, but was changed (Brady and Robertson, 1872) to Darwinella stevensoni due to preoccupation of the former name. Descriptions based upon dried specimens in the 1872 publication were later emended (Brady and Robertson, 1874). Darwinella, however, also was preoccupied and the name Darwinula was erected in 1885 (Brady and

Robertson). In 1889, Brady and Norman presented another description and designated _Darwinula stevensoni_ as the genotype.

Subsequent descriptions of _D. stevensoni_ or its synonyms have been given by various workers including Vávra (1909), Müller (1912), Alm (1915), Sars (1922-28), Turner (1895), Furtos (1933), Hoff (1942), Swain and Gilby (1965), and Staplin (1963). Pinto and Sanguinetti (1958) presented a redescription of the genotype of _Darwinula_ in order to clarify some of the nomenclatural problems in the literature.

Darwinula stevensoni is one of the most widely distributed species of freshwater ostracods. Some of the distribution records for _D. stevensoni_ are summarized below:

United States	
Ohio	Furtos (1933)
Illinois	Hoff (1942)
Michigan	Tressler (1947), Moore (1939), McGregor and Wetzel (1968), McGregor (1969)
Massachusetts	Furtos (1935)
Georgia	Turner (1895)
Tennessee	Cole (1966)
Kentucky	Cole (1966)
Mississippi	McGregor (1969)
Florida	McGregor (this thesis)
South Carolina	McGregor (this thesis)
Virginia	Elliott et al. (1966), Nichols and Ellison (1967)
Texas	Cole (1966)
Mexico	Furtos (1936b)
Nicaragua	Swain and Gilby (1965), Hartmann (1959, from Swain and Gilby, 1965)
Great Britain	Brady (1870), Brady and Robertson (1872), Brady and Norman (1889)
Austria	Löffler (1963)
Germany	Klie (1938)
France	Sars (1922-28)
Sweden	Alm (1915), Sars (1922-28)
Norway	Sars (1922-28)
Switzerland	Sars (1922-28)
The Netherlands	de Vos (1954)
Italy	Fox (1965, 1966)
Poland	Sywula (1965)
Yugoslavia	Klie (1941), Petkovski (1960, 1961), Stanković (1960)
Turkey	Hartmann (1964)
U.S.S.R.	Bronstein (1947), Hartmann (1964)

Iran	Hartmann (1964)
Sumatra	Klie (1933)
Java	Klie (1933)
Africa	Hartmann (1964), Klie (1935a, 1939)

The type locality of Darwinula stevensoni is the East Anglian Fen District in England (Brady and Norman, 1889). Brady (1870) first reported D. stevensoni from the Meuse and Scheldt rivers of England and Holland, respectively. Additional distribution records for the East Anglian Fen District (Brady and Robertson, 1870, 1872) were summarized by Brady and Norman (1889). Other areas inhabited by D. stevensoni include: Lakes Ohrid, Prespa, Dojran (Yugoslavia); Maggiore, Mergozzo, Varese, Comabbio, Monate (Italy); Ijssel (The Netherlands); Van (Norway); Pereslavskoye (U.S.S.R.); Ngebel, Bedali (Java); Toba (Sumatra); Lothing and many others (Great Britain); Nicaragua, Managua (Nicaragua); Erie, Douglas, Gull (United States). Several river habitats include the Nene, Cam, Ouse, Deben (Great Britain), Warta (Poland) and Rappahannock (United States).

The seasonal and spatial distribution of D. stevensoni has received limited study. Alm (1915, p. 225) stated that this species should be found throughout the entire year on the basis of its 'viviparous' reproduction.

Pinto and Purper (1965) illustrated the seasonal occurrence of Darwinula in a recent study, but did not specify the species. Moore (1939) collected D. stevensoni at depths of from 4-9 meters in Douglas Lake, Michigan. Klie (1933) reported specimens from depths of approximately 4 meters and Cole (1966) found them at depths of about 0.3 meter. I have collected adults and late instar juveniles at depths ranging from a few millimeters, near Saline, Michigan, to 12 meters in Gull Lake.

The geologic range of the genus Darwinula extends from the Upper Carboniferous (Pennsylvanian) to Recent according to Swain (1961) and Van Morkhoven (1963). Swain (1961) also reported a questionable record from the Ordovician Period. Several authors, notably, Brady et al. (1874), Wagner (1957), and Staplin (1963b) have recorded D. stevensoni from Quaternary deposits.

Other extant species of Darwinula have been reported from Romania (Danielopol and Vespremeanu, 1964), Brazil (Pinto and Kotzian, 1961), Africa (Klie, 1935a, 1939; Menzel, 1916), Java (Menzel, 1923; Klie, 1933), Patagonia (Daday, 1902), Uruguay (Klie, 1935b), Holland (Delachaux, 1928), and Rennell Island, Pacific Ocean (Harding, 1962). Sohn (1965), Pinto and Purper (1965), and Sandberg (1965) reported Darwinula, respectively, from Lake Tiberias, Israel, Brazil, and Mexico, but did not mention the species encountered. Fossil species have been described, for example, from the Miocene (Méhes, 1908), and Jurassic (Bate, 1967).

Darwinula stevensoni is presumably a parthenogenetic species. Brady and Robertson (1870) briefly described and figured the copulatory apparatus of a male specimen, and later restated the description (1874). Brady and Norman (1889) incorporated the above description and figure in their monograph on the marine and freshwater Ostracoda of the North Atlantic and North-western Europe. Male characteristics other than the copulatory apparatus were not described in these papers nor have any subsequent investigators reported finding male D. stevensoni.

I have isolated and reared numerous late instar individuals through at least one reproductive cycle and on all occasions only females were produced. In addition, no males have been encountered in more than 10,000 specimens collected from Gull Lake and other localities in the present study. The validity of the record by Brady and Robertson (1870) must be considered highly suspect until adequate evidence is provided to prove the existence of males in this species.

In 1953 Kesling noted some of the causes for variation in form within an instar, such as diet, effects of temperature, sexual dimorphism and individual variation. He also stated (1953, p. 101) that:

> The number of instars in the ontogeny of an ostracod appears to be constant for a genus. Insofar as is known, it is constant for certain families, but relatively few species have been studied and there may be exceptions.

Later, Sandberg (1964) reviewed several systems of instar designation used by different authors and some of the problems encountered in their use when working with living and fossil species. In the present discussion the first instar is number one and later instars are numbered consecutively.

The ontogenetic development of _Darwinula stevensoni_ has been discussed by Scheerer-Ostermeyer (1940). Some of the apparent differences in the ontogenetic development of _D. stevensoni_ from that reported in other freshwater ostracods may be due, as Kesling noted (1951a, p. 94), to different interpretations of appendages. Because the principle concern here is the total number and relative size of the instar stages in this species, the sequence of ontogenetic development and relative size described by Scheerer-Ostermeyer (1940, p. 366) is presented in Table 1. I have followed the style of Kesling (1951a, pp. 94-95) in portraying the developmental process of _D. stevensoni_ described by Scheerer-Ostermeyer (1940). Some modification was necessary owing to a different interpretation of appendages.

Table 1. Ontogenetic development and relative size range of instars of Darwinula stevensoni. Modified from Scheerer-Ostermeyer (1940, p. 366) in the style of Kesling (1951a, pp. 94 -95).

Instar										Length (microns)	Height (microns)
1	A1	An	Md	Mx	___	___	___		(Fc)		
2	A1	An	Md	Mx	(L1)	___	___		(Fc)	160-175	90-100
3	A1	An	Md	Mx	(L1)	___	___		(Fc)	223(R)-217(L)	126(R)
4	A1	An	Md	Mx	(L1)	___	___		(Fc)	250(R)	133(R)
5	A1	An	Md	Mx	L1	(L2)	___		(Fc)	290(R)-270(L)	130(R)
6	A1	An	Md	Mx	L1	L2	(L3)		(Fc)	350(R)-320(L)	168(R)
7	A1	An	Md	Mx	L1	L2	L3		(Fc)	440(R)-431(L)	245(R)
8	A1	An	Md	Mx	L1	L2	L3	(Rp)	(Fc)	518(R)-508(L)	250(R)
9	A1	An	Md	Mx	L1	L2	L3	Rp	___	700	

A1 = Antennule
An = Antenna
Md = Mandible
() = Anlagen, incomplete
(R)= Right valve
(L)= Left valve
Mx = Maxilla
L1 = First thoracic leg
L2 = Second thoracic leg
L3 = Third thoracic leg
Fc = Furca
Rp = Reproductive organs

METHODS AND MATERIALS

Collecting Methods

An Ekman dredge, free-fall corer with removable plastic inner-liner, modified Glemacher frozen core sampler (Gleason and Ohlmacher, 1965), and a modified aquatic sweep net were used for sample collection. The modified aquatic net was used in areas suitable for wading or for manipulation from a boat. Ekman samples generally were collected from depths of three meters or greater. Transect and individual sample localities are shown in Figure 1.

Sediment cores obtained using the free-fall corer were removed from a plastic inner-liner, 4.3 cm in diameter. This corer was allowed to free-fall from approximately 3 meters above the sediment-water interface. The liner was marked for separation of the top 5 cm of sediment from the underlying 10 cm sediment interval. Retrieval of cores was dependent upon a clay plug to hold the sediment in the liner. After removing the liner, water was siphoned off to a point about 4 cm above the substrate-water interface and the core was allowed to slide slowly out the coring end. Sediment below the 15 cm interval was discarded and that between the 5 cm and the 15 cm interval was collected in a labelled container. The upper 5 cm of sediment, and the water above, were collected in a second container. Both samples were immediately frozen in dry ice and were later thawed and sieved in the laboratory.

The modified Glemacher frozen core sampler employs a mixture of dry ice and acetone in the freezing compartment for *in situ* freezing of the sediment. The dry ice and acetone, separated prior to penetration of the sediment, are released by a lever and spring tripping mechanism when a messenger is lowered. Complete freezing of the 3 cm diameter sediment core occurs within three minutes following messenger release. The frozen cores, ranging in length from 18-23 cm, were sectioned at 5 cm intervals and sieved in the laboratory.

All Ekman and net samples were sieved in the field using the modified aquatic net. This net accommodated a second, finer mesh, detachable nylon net for retention of ostracods. Samples were examined in the laboratory immediately following collecting or stored temporarily at 4°C. No preservatives were added as separation and examination of living animals proved to be more satisfactory.

Additional methods of collecting ostracods included stomach and gut analyses of several species of fish from Gull Lake. This method occasionally yielded rather large numbers of identifiable ostracods. Crayfish also were collected and examined for commensal ostracods of the family Entocytheridae. The latter, however, are not considered in this thesis. Numerous samples were collected by hand or in light traps for taxonomic purposes.

Separation Techniques

Samples were hand sorted and all non-swimming ostracods visible to the unaided eye were separated from the sediment by employing the water surface tension technique. The sediment is drained and exposed to air; the non-wettable ostracod valves are held by the water surface tension when the sediment is again immersed. On several occasions, a sample was first hand sorted and then sorted again using other techniques, including treatment with weak acids and bases, differential heating, saturated sugar and salt solutions, wet sieving through graded sieve series, behavioral responses to light quality and quantity, elutriation, and microscopic examination of sediment.

The surface tension technique works extremely well for quantitative separation of smooth shelled, non-swimming ostracods, such as Darwinula and Candona. However, ostracods which have highly ornamented and sculptured valves usually cannot be separated adequately, at least quantitatively, from the sediment. This is also true for most of the free-swimming ostracods. The latter often are caught in the water surface film, but usually manage to free themselves through rapid movements of their antennules.

No attempt was made to quantify the numbers of free-swimming and highly ornamented burrowing ostracods in most samples. However, small numbers of these animals were removed for investigation of reproductive cycles, sex ratios and other life history characteristics.

Collecting methods and organism-sediment separation techniques also have been described by other authors (e.g., Kesling 1956; Tressler 1959; Van Morkhoven 1962; Fox 1964b; Delorme 1967b).

Dissection and Preservation

Most of the above sorting techniques induced gravid females to release their young or eggs and were, therefore, unsatisfactory. Screening or hand sorting ostracods held in the water surface film facilitated removal of females, with eggs and young intact, and provided many opportunities for observing various behavioral traits of different species.

The ostracods were sorted beneath a dissecting microscope to remove the remaining debris and other organisms. Adult and juvenile Darwinula were isolated from other species and placed in another container.

The former were separated into size categories, counted, anesthetized with Tricaine Methanesulfonate (MS 222) and dissected under highest power of a dissecting microscope. All other species were treated in the manner above but were killed with a 1:1, by volume, solution of 95% ethyl alcohol and water. Individuals in each of these species were separated into juvenile and adult categories, counted and preserved. The preservative contained 70:20:10 parts, respectively, of 95% ethyl alcohol, distilled water, and glycerol.

The number of young or eggs within the carapace, parasites, developmental stage of the young, and several other observations were recorded for each individual of Darwinula stevensoni and D. pagliolii Pinto and Kotzian.

Later, individuals of all other species were cleared in glycerine. The sex and reproductive state of each specimen and the number of eggs within the uterus of females were recorded. Counts were made in transmitted and reflected light for females with few eggs; however, several thousand females required dissection before accurate counts could be made.

Several hundred whole mounts and needle dissections suitable for permanent mounts of Gull Lake Ostracoda were prepared for taxonomic study. Approximately 1,000 ostracods were dissected in temporary glycerine mounts, but most were used for purposes not discussed here. Permanent mounts were made in balsam, diaphane, and CMC-S non-resinous stain mountant. The latter, distributed through the General Biological Supply Incorporated, Chicago, Illinois, is an excellent medium for needle dissections of ostracods (refer to Darby, 1965). Minuten nadeln insect pins mounted on long, slender wooden rods were used in most needle dissections.

Many details concerning techniques and procedures for dissection, preservation, staining, serial sectioning and photography of freshwater ostracods have been expertly described by Smith (1965). Other interesting and useful techniques are discussed by Hoff (1942), Ferguson (1944) Kesling (1956), Fox (1964b), and Darby (1965).

STUDY AREA

Gull Lake (Fig. 1) is located in the southwestern corner of the Southern Peninsula of Michigan, in Kalamazoo and Barry counties, between latitudes 42°20'-42°30' N and longitudes 85°20'-85°30' W. The lake basin, of glacial ice block origin, was formed during retreat of the Wisconsin glacier which had covered Barry and Kalamazoo counties (Martin, 1957).

The lake drainage basin is small and most water comes from springs and a few small streams. Gull Lake drains into the Kalamazoo River which, in turn, empties into Lake Michigan. The lake covers an area of 821.5 hectares and has a maximum depth of 33.5 meters (Taube and Bacon, 1952). Major physiographic features, morainic highlands and dissected glacial outwash plains in the area surrounding Gull Lake, reflect the impact of the recession of the Wisconsin glacier (Deutsch et al., 1960). The regional soils are the well-drained, Grey-Brown Podzolic or Brunizem Great Soil Groups described by Whiteside et al. (1963).

Preliminary studies on nutrient cycling and primary production rates in Gull Lake have been initiated only recently and no detailed chemical or physical measurements have been published. Yet, the lake may be classified generally as oligotrophic, possibly mesotrophic, on the basis of its physiographic and chemical-physical properties, when compared with other lakes nearby.

Gull Lake is well oxygenated at all depths throughout the year

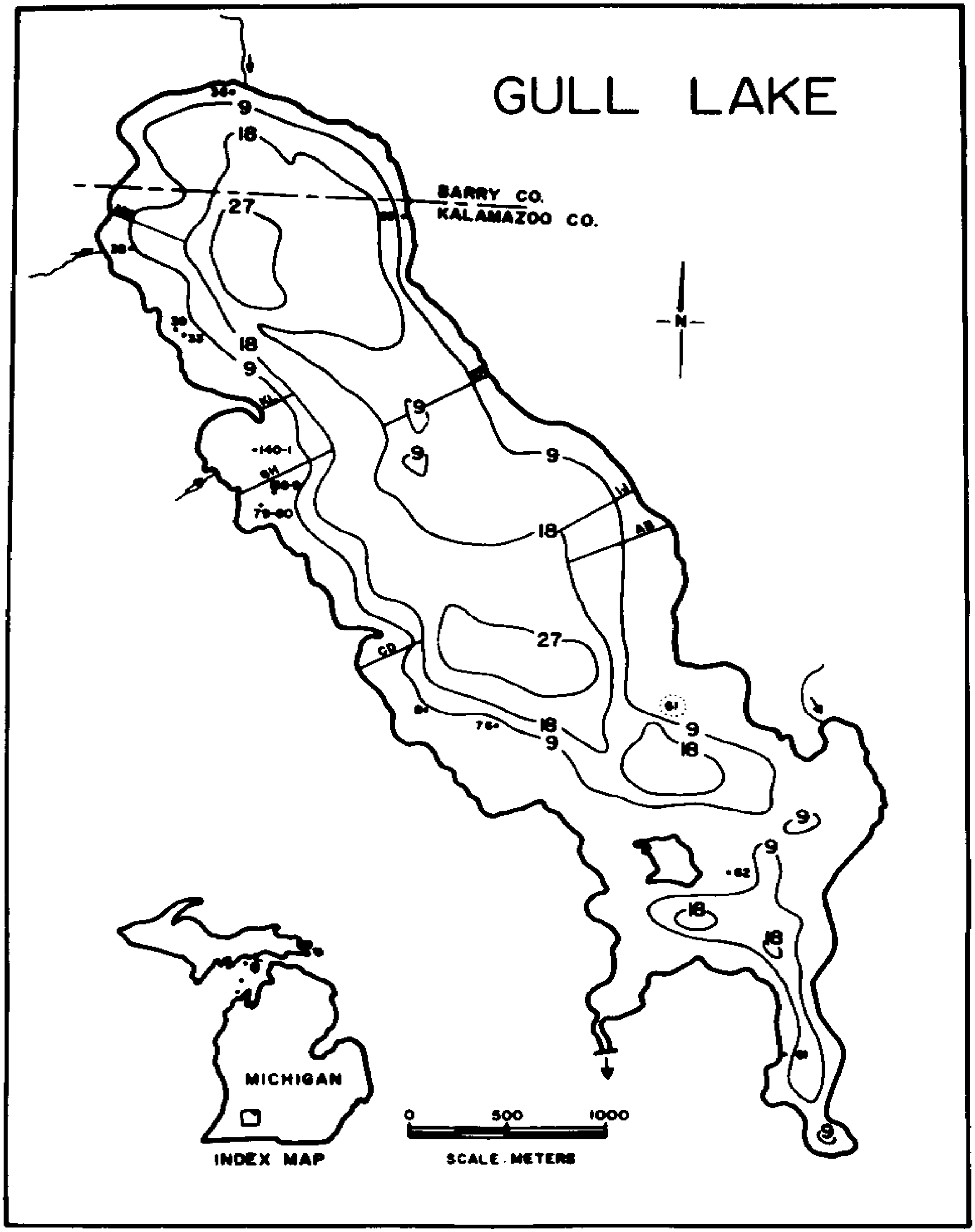

Figure 1. Map of Gull Lake showing sample localities and general lake morphometry. Depth contour interval is 9 meters.

except in the deepest portions of the hypolymnion during the latter phase of summer and fall stratification. Alkalinity, measured as mg/l $CaCO_3$, generally ranges between 140-160, and the pH, between 7.5-8.5. The lake stratifies thermally by late May or early June and begins the fall turnover sometime in November. By mid-January the lake usually freezes over and remains ice-covered through most of March and, occasionally, early April. Secchi disc readings reach a maximum of about 10 meters and calcium carbonate deposits cover most of the littoral areas. Steep slopes on all sides of the lake reflect its glacial origin and a majority of the surface area is more than nine meters in depth.

RESULTS

General

Most data reported below represent studies undertaken during the period from August, 1965 to August, 1966. Data collected on other dates are noted in the text. All samples were collected at depths ranging from 0-18 meters and the majority from 0-12 meters.

A total of 262 samples collected on 38 dates were analyzed. The former total includes 142 Ekman, 84 aquatic net, 25 free-fall core, 7 frozen core and 4 fish samples. The few samples representing other collecting periods are not included in the above total. About 150 additional samples from Gull Lake and other areas were used in studies not reported here.

Most of the sampling was accomplished without assistance and often was dependent on equipment available for use, wind velocity over Gull Lake, or character of ice cover. Perhaps the most serious problem was the limitation on sampling at scheduled intervals due to the generally unpredictable weather in the study area.

A total of 32,726 free-living ostracods were collected from Gull Lake. Excluding ostracods collected from fish stomachs, 23,325 adults and juveniles were identified to species; 7,765 early instar individuals of the genus Candona could not be identified to species, at least with certainty, and are used only for density estimates discussed later. Most of the 1,636 ostracods retrieved from fish stomachs were identified to species. About 50,000 ostracods collected before and subsequent to the present work have been preserved for later study or used in investigations cited above.

Aliquot samples were examined from large samples of certain free-swimming species. Therefore, adult-juvenile percentages were calculated from a total of 21,685 individuals. Of 11,835 adults in the latter, the sex of 11,060 individuals was determined. The number of uterine eggs or young carried in the carapace were recorded for 7,533 females. Parasites were investigated in 4,192 individuals of the genus *Darwinula*.

Gull Lake Ostracoda

Twenty-four species of ostracods, excluding the commensal Entocytheridae, were identified from Gull Lake. All were collected from depths reported above. Seventeen species are non-swimmers, restricted to burrowing or crawling over the substrate and rooted aquatic plants. Seven species are free-swimmers, but remain near the substrate and only rarely are found in plankton samples. The latter also are capable burrowers.

The following species were found in Gull Lake:

Darwinula stevensoni (Brady and Robertson)

Darwinula pagliolii Pinto and Kotzian

Candona ohioensis Furtos

Candona rawsoni Tressler

Candona acuta Hoff

Candona inopinata Furtos

Candona elliptica Furtos

Candona porteri sp. nov.

Candona aff. *caudata* Kaufmann

Candona scopulosa Furtos

Candona crogmaniana Turner

Candona aff. *suburbana* Hoff

Candona decora Furtos

Candona distincta Furtos

Candona sp.

Cypridopsis vidua (O. F. Müller)

Physocypria pustulosa (Sharpe)

Cypria turneri Hoff

Cyclocypris ampla Furtos

Cyclocypris cruciata Furtos

Cyprinotus glaucus Furtos

Potamocypris smaragdina (Vávra)

Limnocythere verrucosa Hoff

Cytherissa lacustris (Sars)

Only one of the above species, *Candona porteri* sp. nov., is undescribed. This species will be properly described, along with emendations of certain other species, in a future report. *Darwinula pagliolii* is reported for the first time in North America and represents one of the two species of the family Darwinulidae known on this continent. Living representatives of *Candona acuta*, *C. elliptica*, *C.* aff. *caudata*, *C. scopulosa*, *C.* aff. *suburbana*, *C. distincta*, *Candona* sp., *Cyclocypris cruciata*, *Cyprinotus glaucus*, *Potamocypris smaragdina*, *Limnocythere verrucosa* and *Cytherissa lacustris* are reported from Michigan for the first time. *Candona ohioensis*, *C. rawsoni*, *C. inopinata* and *Cyclocypris ampla* were recorded previously in reports by this writer and others.

Species of the genera Darwinula and Candona were the only species quantitatively sampled in this study. Darwinula, Candona, Limnocythere and Cytherissa are non-swimmers; however, the latter two genera are characterized by sculptured, variously ornamented valves unsuited for the ostracod separation technique described earlier. Species belonging to the remaining genera are free-swimmers.

Candona is among the most dominant genera of ostracods in number of species and individuals in most freshwater habitats. Because of the large number of species (over 200) presently assigned to this genus, however, identification of individual species is extremely difficult. Sexual dimorphism is pronounced in most species of Candona; the valves and certain appendages on opposite sides of the body often differ in one individual more than they differ from the same structures in closely related species. This genus has nine instar stages including the adult instar. Thus, considering the valves alone, one is confronted with 36 different characteristic sizes and shapes for a single species. There are numerous taxonomically important characteristics of the carapace, in addition to a large number of internal structures, used for identification.

The point here is that much information of potential value in a life history or population study (i.e., age and size structure, growth rate, mortality, sex ratio and other characteristics) is lost when one neglects or cannot identify immature individuals of a given species. I regret that such is true in this study for the earliest instars of the genus Candona. Perhaps one of the benefits of this study has been recognition of certain genera and species of ostracods which have life history characteristics suited for more detailed population studies than accomplished here.

Depth Distribution in Sediment

Seven sediment cores were collected *in situ*, employing the modified Glemacher frozen core sampler, at a depth of 5 meters along Transect MN on 15 October, 1965. One of the 71 ostracods recovered was below the top 5 cm.

On 19 January, 1966, five free-fall cores ranging in length from 34-42 cm were collected at depths of 9-15 meters along Transect IJ. Each core was sectioned at 5 cm intervals; 25 ostracods were found in the top 5 cm of these cores. Later, on 5 June, 1966, 20 free-fall sediment cores more than 20 cm in length were collected at depths of 3, 6, 9, 12, and 15 meters along Transect AB. Ostracods were absent from only one core. Sixty-five adult and juvenile ostracods, representing 10 species and 6 genera, were found in the upper 5 cm of sediment; 3 were below the top 5 cm. The latter, however, were in two cores which had been labelled for possible contamination of the 5-15 cm sediment interval.

The species collected from sediment cores were *Darwinula stevensoni*, *Candona ohioensis*, *C. inopinata*, *C. crogmaniana*, *C.* aff. *caudata*, *C. elliptica*, *C. porteri*, *Cypridopsis vidua*, *Cypria turneri*, *Physocypria pustulosa*, and *Cyclocypris ampla*.

Of 164 ostracods removed from the free-fall and frozen core samples only 4 or 2.4 percent were found below the top 5 cm of sediment. These data indicate that many species of Gull Lake Ostracoda normally burrow in sediment at depths less than 5 cm and may be sampled adequately with the Ekman dredge or other bottom dredges suitable for use in loosely consolidated sediments.

Although no data are available on the vertical distribution of other Gull Lake species, I do not believe it unreasonable to assume their burrowing habits are similar to the above species.

Life History Studies

Darwinula stevensoni

A total of 6,274 adult and juvenile Darwinula stevensoni from Gull Lake and nearby localities were studied. The number of specimens examined for parasites or young is summarized below:

	Total Examined	No. Adults	No. Juveniles	Reproductive Potential	Parasites Adults	Parasites Juveniles
Gull Lake	5993	2906	3087	2590	2169	1879
Other Areas	281	68	213	53	53	84

This species was present in eighty-seven Ekman, 15 core, and 22 net samples from Gull Lake, and 7 net and hand samples from other areas. Only one adult of 12 juvenile and 10 adult D. stevensoni present in cores obtained using the free-fall corer was found at depths below 5 cm. This specimen, however, was in one of two cores which previously had been labelled for possible contamination. Three cores at 3 meters, four cores at 6 meters and one at 9 meters contained D. stevensoni. Thirteen adults and twenty-seven juveniles were present in the frozen core samples; one juvenile was found below the 5 cm interval.

The secondary nylon monofilament screen cloth used with the modified aquatic net had a mesh opening of 202 microns. Consequently, only those instars with length and height dimensions greater than 202 microns were retained. Good agreement with expected instar development and size was observed in all juvenile samples. Generally, only the seventh, eighth and adult instars were present; earlier instar individuals always comprised less than one percent of the sample. Measurements of a limited number of eighth and ninth instar animals were somewhat greater than those reported by Scheerer-Ostermeyer (1940), but were in general agreement. Further discussion of juvenile-adult percentages will be in reference to the seventh and eighth juvenile instars and the ninth or adult instar.

Darwinula stevensoni was abundant in the littoral areas of Gull Lake and reached a maximum density at a depth of about 6 meters throughout the year. The population density decreased markedly between 6 and 9 meters and only a few individuals were found at depths greater than 9 meters. Although an unequal number of samples were collected from different depths the majority of specimens were from depths of 3 and 6 meters.

Variation in number of individuals sampled at a given depth and date, or at different times during one month, probably represented a reasonable degree of sample bias. Much of the variability, however, reflected the geographic variation in population density and the number of late instar juveniles that had reached the size necessary for retention by the collecting process discussed above.

The percentages of adult and juvenile ostracods in replicated and non-replicated samples from Gull Lake at depths of <3, 3, 6, 9, and 12 meters are presented in Tables 2 and 3. At <3, 3, and 6 meters the percentage of adults was maximal during the summer months and was followed by a sharp decline in the early fall. The percentage of adults continued to decrease through the fall and winter seasons and generally reached a minimum by early or late spring depending upon the depth from which samples were collected. More than 90 per cent of the total number of ostracods collected from all depths, in August of 1965-66, were adults. The adult component of most samples collected at depths of <3, 3, and 6 meters during late March, 1966 ranged between about

Table 2. Percentage of adult and juvenile *Darwinula stevensoni* from samples collected at depths of <3 and 3 meters in Gull Lake.

Date	Sample No.	Transect	N	% Adult	% Juvenile
		<3 meters			
1965					
7- 9	33		42	100.0	0.0
7-19	36		4	100.0	0.0
8- 2	39		8	100.0	0.0
8- 2	40	KL	49	98.0	2.0
8- 3	44	MN	2	50.0	50.0
8- 3	45	KL	43	95.4	4.6
9-14	61		13	100.0	0.0
9-14	62		8	37.5	62.5
9-14	60,64	GI	99	77.8	22.2
9-22	65	GI	86	62.8	37.2
9-27	66		22	54.5	45.5
10- 4	70,71	GI	164	57.3	42.7
10-13	72,73	GI	64	60.9	39.1
10-18	78	GI	105	60.0	40.0
10-18	79,80		98	55.1	44.9
11- 1	81	GI	75	49.3	50.7
12- 2	102	GI	46	58.7	41.3
1966					
1- 4	109	GI	18	50.0	50.0
1-11	111	GI	24	58.3	41.7
2-11	117	AB	1	00.0	100.0
2-21	124	AB	6	33.3	67.7
2-24	129	AB	1	00.0	100.0
3-21	134,135	AB	3	33.3	67.7
3-26	138,139		67	25.4	74.6
3-26	140,141		36	30.6	69.4
5-31	172	GI	59	74.6	25.4
6-15	186	GI	9	66.7	33.3
7- 2	207	AB	35	97.1	2.9
		3 meters			
1965					
8- 3	41	MN	61	100.0	0.0
8- 3	46	KL	38	97.4	2.6
8- 5	50,53	AB	17	100.0	0.0
11- 4	82	AB	137	35.0	65.0
11- 4	92	EF	184	47.3	52.7
11- 4	97	GH	365	31.8	68.2
11- 4	87	CD	167	62.3	37.7

Table 2. (cont'd.)

Date	Sample No.	Transect	N	% Adult	% Juvenile
1966					
2-24	131,132	AB	241	23.2	76.8
3-30	142	AB	159	24.5	75.5
4-29	156	AB	50	18.0	82.0
5-19	164	AB	36	27.8	72.2
6- 1	174,180	AB	89	29.2	70.8
6-15	187,188	AB	121	24.0	76.0
7- 1	197,198	AB	2	100.0	0.0
7-15	212,213	AB	152	88.8	11.2
8- 1	223,224	AB	29	89.7	10.3

Table 3. Percentage of adult and juvenile *Darwinula stevensoni* from samples collected at depths of 6, 9, and 12 meters in Gull Lake.

Date	Sample No.	Transect	N	% Adult	% Juvenile
			6 meters		
1965					
*7-27	8		1	100.0	0.0
8- 2	38		33	100.0	0.0
8- 3	47	KL	35	97.1	2.9
8- 5	51-54	AB	56	87.5	12.5
10-13	76		28	46.4	53.6
11- 4	83	AB	123	55.3	44.7
11- 4	93	EF	63	49.2	50.8
11- 4	98	GH	98	52.0	48.0
12- 8	105	EF	511	12.9	87.1
1966					
2-21	125	IJ	82	24.4	75.6
3-30	148,149	IJ	248	28.2	71.8
4-29	157	AB	54	38.9	61.1
5-19	165	AB	44	56.8	43.2
6- 1	175,181	AB	79	74.7	25.3
6-15	189,190	AB	189	47.1	52.9
7- 1	199,200	AB	338	47.6	52.4
7-15	214,215	AB	177	76.8	23.2
8- 1	225,226	AB	185	76.8	23.2
			9 meters		
1965					
8- 3	48	KL	61	96.7	3.3
8- 5	55,56	AB	7	100.0	0.0
11- 4	84	AB	6	100.0	0.0
11- 4	94	EF	24	87.5	12.5
11- 4	89	CD	7	85.7	14.3
12- 8	106	EF	93	24.7	75.3
1966					
2- 5	114	IJ	4	75.0	25.0
3-30	144	AB	1	100.0	0.0
5-19	166	AB	7	100.0	0.0
6- 1	182	AB	9	100.0	0.0
6-15	192	AB	3	66.7	33.3
7-15	216,217	AB	10	100.0	0.0
8- 1	227,228	AB	14	100.0	0.0

Table 3. (cont'd.)

Date	Sample No.	Transect	N	% Adult	% Juvenile
		12 meters			
1965					
11- 4	100	GH	1	100.0	0.0
12- 8	107	EF	1	100.0	0.0
1966					
2-21	126	IJ	1	0.0	100.0

*1964

25-30 percent. By late May and early June the percentage of adults in the population again began to increase (Tables 2 and 3).

The seasonal change in the adult-juvenile ratio may be expressed more clearly, for example, using data from samples collected at depths of <3 meters. The combined numbers of adult D. stevensoni collected each month were divided by the total monthly sample to obtain the following adult precentages. In August of 1965, adults comprised 96 percent of 102 collected; in September, 70 percent (N = 42); October, 61 percent (N = 262); January, 1966, 55 percent (N = 42); March, 27 percent (N = 106); May, 75 percent (N = 59), and July, 97 percent (N = 135).

Many of the overwintering juveniles had molted to the ninth or adult instar by mid-May, 1966, and contributed to the high percentage of adults reported at depths of <3 meters. Development and molting proceeded less rapidly at greater depths owing, in part, to the lower temperatures. Consequently, the adult component at 3 meters (Table 2) was low until the eighth instar juveniles completed the final molt in early June. At 6 meters the percentage of adults remained somewhat higher during the winter months as a smaller fraction of the overwintering juveniles had attained the size of those juveniles at shallower depths. The high adult percentages at 6 meters during May and early June (Table 3) probably represented an overestimation in light of the reproductive potential data discussed later.

The small number of specimens collected from depths of 9 and 12 meters made comparison of adult-juvenile percentages difficult (Table 3). This portion of the total population also is considered later in the discussion of reproductive potential.

Estimates of ostracod density per square meter presented in Table 4 are useful in predicting the contribution of young by adults and assist in understanding the life cycle of Darwinula stevensoni in Gull Lake. Only data from replicated samples collected along Transect AB during the summer of 1966 are considered (Refer to Tables 2 and 3 and Fig. 1).

The percentages of adults and juveniles collected on 15 June-1 July and 15 July-1 August at 6 meters depth, were almost identical (Table 3). Yet, when one considers the density estimates on these dates, changes in the size structure of the population become more evident. The number of adults and juveniles per square meter was almost double, on 1 July, the corresponding estimates for 15 June (Table 4).

The small number of replicated samples may account for some of the variation in density. I believe the major difference in density is due, however, to the number of newly molted overwintering juveniles that were contributing to the adult and late instar classed by 1 July. This explanation also is tenable for estimates on 1 July and 1 August at 6 meters. The abrupt decrease in juvenile density is believed to result from the rapid contribution of juveniles to the adult class by mid-July and early August. The slight decrease in adult density from 1 July to 15 July may reflect a replacement of second reproductive season adults by first reproductive season adults during the latter part of the summer.

Study of the reproductive cycle, discussed below, indicated that at least two adult age groups were represented in the summer collections. The adult age structure exhibited marked changes in 15 July and 1 August samples and was comprised primarily of first reproductive season adults. The juvenile density, on 1 June, at 6 meters, was much lower than expected and is believed to reflect considerable

Table 4. Estimates of the mean number of adult and juvenile <u>Darwinula stevensoni</u> per square meter at depths of 3, 6 and 9 meters along Transect AB during the period from 1 June - 1 August 1966 (A = adult; J = juvenile).

	1 June		15 June		1 July		15 July		1 August	
	A	J	A	J	A	J	A	J	A	J
3 meters	562	1363	627	1990	43	---	2921	367	562	65
6 meters	1277	432	1926	2164	3484	3831	2943	887	3073	931
9 meters	195	---	43	22	---	---	216	---	303	---

sampling bias.

The variable nature of the substrate and the small number of ostracods at depths of 3 and 9 meters, respectively, renders density estimates less reliable in terms of absolute numbers. Yet, high juvenile densities in June and an abrupt reversal of adult-juvenile densities later in the summer correspond to the general trend noted at 6 meters. The decrease in density at 9 meters compared with that at 6 meters is obvious.

The reproductive potential and cycles of freshwater ostracods have received limited study. Observations of the number of eggs or young in one or a few specimens of *D. stevensoni* are scattered throughout the literature. However, I know of no study on the reproductive preformance of *D. stevensoni* over a single reproductive cycle.

Some difficulty was encountered in studying the reproductive potential of *Darwinula stevensoni* from field samples. When the population reproductive cycle is initiated, successive addition and development of eggs within the carapace and ultimate release of first instar young proceeds at varying rates. The difficulty arises in distinguishing adults exhibiting the maximum production of young from those which are adding or losing young.

The thin, translucent carapace of *D. stevensoni* premits direct observation of the developing young during most of the reproductive season. However, eggs and young become so closely packed prior to release of the first individuals that accurate counts cannot be made without dissection of each animal. In addition, parasites attached to the hypodermis in the area in which the young are carried are easily confused with the developing eggs. Consequently, each adult ostracod was anesthetized and dissected alive, in order to obtain accurate counts of the number of eggs or young and parasites.

The annual reproductive cycle of D. stevensoni and number of eggs and young in the carapace of each dissected female are presented in Fig. 2. These data represent combined monthly counts of 2587 individuals collected from Gull Lake. One specimen from 1964, two animals which died before young were counted, and several young released during observation were not included in Fig. 2.

In Gull Lake the reproductive period of D. stevensoni begins in May and is effectively completed by October. Only 8 adults examined in late fall and early winter were found with young or eggs. The number of developing young per individual increased from a maximum of 3 in May to 15 in August. The sharp decrease in the number of young per individual from August to September reflects widely spaced sampling periods.

Information derived from study of the reproductive cycle and reproductive potential assists in understanding the juvenile-adult percentages and density data presented earlier. On the other hand, the generalized reproductive potential and reproductive cycle presented in Fig. 2 do not reveal certain variables which are important in estimating population growth rates and the changing size and age structure in various components of the population.

The differential rates at which eggs were released into the carapace of adults at depths of 3, 6 and 9 meters during the summer of 1966, are shown in Fig. 3. These histograms show the retarded development and addition of young at increasing depths. At a depth of 3 meters the number of eggs and young per individual progressed from a maximum of 4, on 1 June, to 13 on 15 July. By 15 July, a large number of the 3 and 6 meter adults had begun to release their young whereas those adults

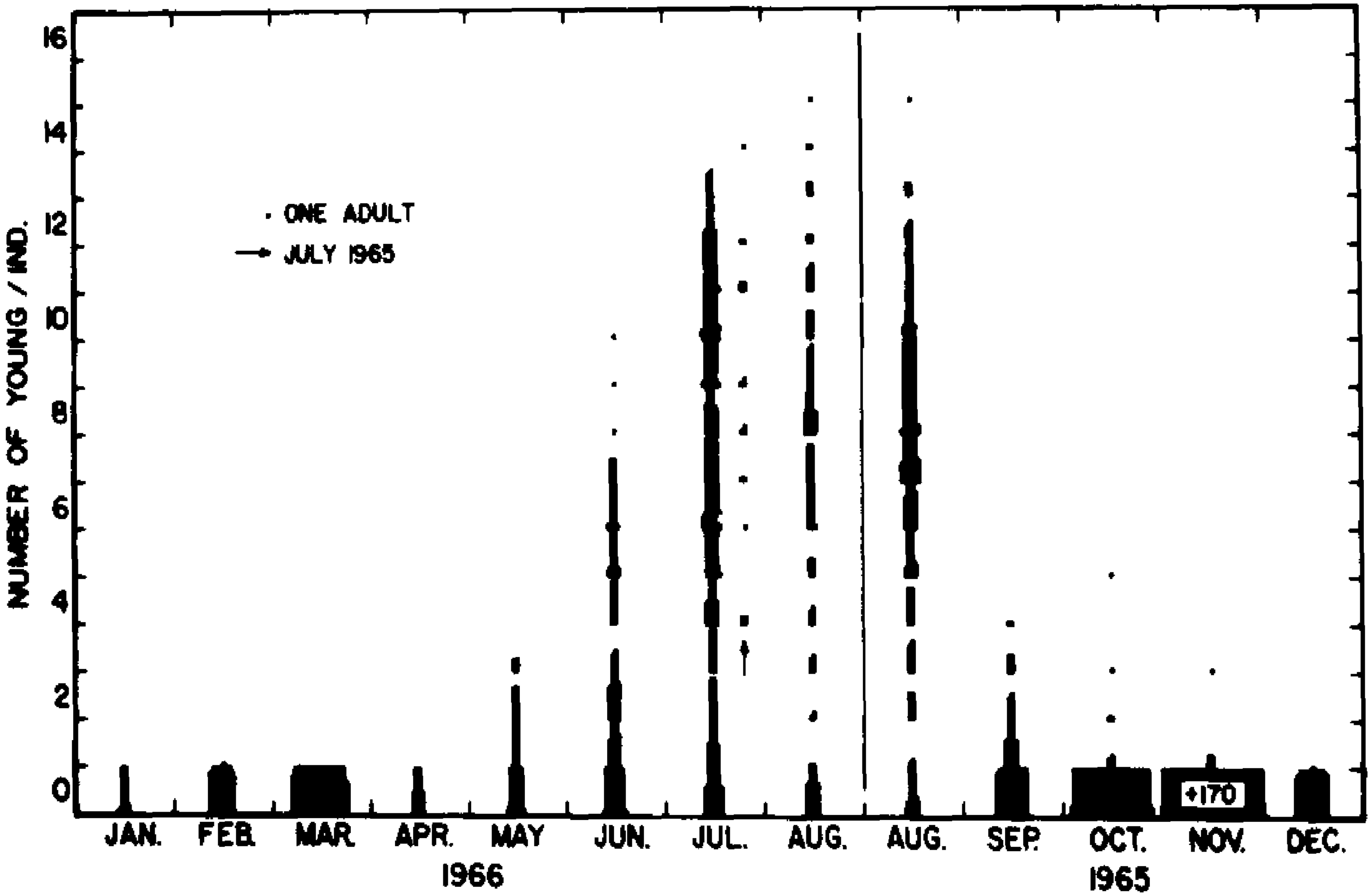

Figure 2. Annual reproductive cycle and reproductive potential of _Darwinula stevensoni_ in Gull Lake. The total number of specimens examined each month, from left to right, are: Jan. (23), Feb. (79), Mar. (175), Apr. (30), May (83), June (217), July (475 and 20), Aug. (181), Aug. (324), Sept. (152), Oct. (252), Nov. (477), Dec. (99).

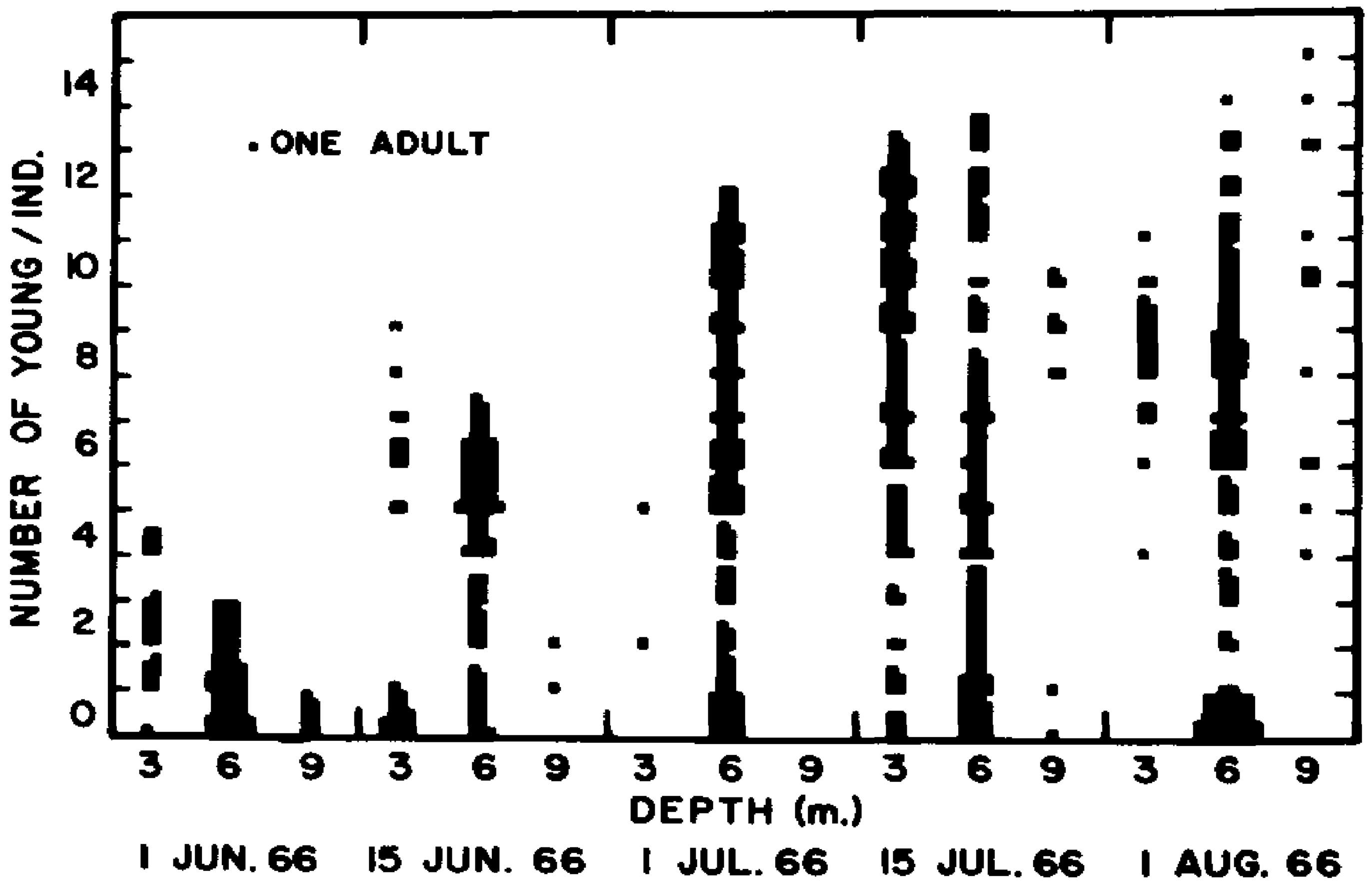

Figure 3. Differential rates of egg deposition and development of young along Transect AB depth gradient during the summer of 1966. Number of animals represented by histograms at each depth, on consecutive dates, may be found in Tables 2 and 3.

collected at depths of 9 meters had no first instar young in the carapace. Although samples from depths of 3 and 9 meters were small or absent on certain dates, the maximum number of young, per adult, increased by 5 individuals about every 15 days at depths of 3 and 6 meters. The corresponding increase at 9 meters depth occurred over a period of about one month.

The presence of both adults and juveniles through the winter and spring of 1966 suggested the possibility of determining the contribution of young by at least two age classes of adults during the following reproductive season.

Overwintering adults from the summer of 1965 were observed to begin yolk deposition as early as November 1965. These individuals were suspected to begin releasing eggs into the carapace during the following reproductive period prior to the molting and production of young by overwintering juveniles. Thus, one would have a means of separating first and second year adult age classes early in the reproductive season. Once the juveniles matured and began producing young, recognition of this age class would be dependent on some other criteria.

The relative maximal developmental state of the young carried by each adult was perhaps the most useful single criterion for distinguishing first and second reproductive season adults. The number of parasites within the carapace proved to be an additional aid in recognizing first and second reproductive season individuals, at least during the early part of the summer. Recently molted adults generally had few parasites, if any, whereas many of the older ostracods were found with three or more parasites. Another criterion which aided was the pigmentation of the hepatopancreas. Although pigmentation varied with depth and was measured only qualitatively, recently molted individuals usually exhibited much less pigment than older animals. Detailed records were kept on the qualitative changes in pigmentation of both adults and juveniles but are not considered in the present study.

Adults examined for parasites and young from 1 June through 1 August 1966 were grouped and placed into three major categories. Group 1 consisted of adults with at least one young, with movable appendages, in the first instar stage. Group 2 included adults with developing embryos having no movable appendages, and Group 3 was comprised of adults with no eggs or young free within the carapace.

The number of first and second reproductive season adults comprising Groups 1, 2, and 3 are presented in Table 5. On 1 June 1966, all adults in Groups 2 and 3 at depths of 3 and 6 meters were considered second reproductive season adults, based upon yolk deposition, developmental state of young, degree of parasitism and pigmentation of the hepatopancreas. Ostracods in Group 3 at 9 meters depth were also second reproductive season, or possibly older, adults. By 15 June more than half of the individuals from 3 meter samples consisted of recently molted ostracods; greater than 90 percent on 15 July and 100 percent of the animals on 1 August were considered first reproductive season adults.

The change in percentage dominance of first and second reproductive season adults from 6 meter samples, occurred approximately 15 days later than the change at 3 meters depth. Less than 10 percent of the ostracods collected on 15 July and 1 August were second reproductive season adults.

These data indicated an almost complete turnover of the adult portion of the population, at depths of 6 meters or less, each year. Juveniles produced by first and second reproductive season adults are

Table 5. Age structure and reproductive potential of adult Darwinula stevensoni in Groups 1, 2, and 3. Samples collected along Transect AB at depths 3, 6, and 9 meters during the summer of 1966. Group I includes only those adults having at least one first instar young with movable appendages; Group 2 includes adults with young which have no movable appendages; Group 3 includes adults with no young or eggs free in the carapace. Percentages with totals more or less than 100 percent result from rounding to nearest tenth.

Date	Group	N	Per-centage	$\overline{X}$ No. young/ adult	Range No. young	First Reprod. season Adults	Second Reprod. season Adults
				3 meters			
	1	0	0.0	0.0	---	0	0
6- 1	2	24	96.0	2.3	1-4	0	24
	3	1	4.0	0.0	---	0	1
	1	0	0.0	0.0	---	0	0
6-15	2	14	48.3	6.3	1-10	1	13
	3	15	51.7	0.0	---	15	0
	1	0	0.0	0.0	---	0	0
7- 1	2	2	100.0	3.5	2-5	0	2
	3	0	0.0	0.0	---	0	0
	1	92	68.7	8.0	3-13	84	8
7-15	2	36	26.9	4.4	1-7	32	4
	3	6	4.5	0.0	---	6	0
	1	25	96.2	8.2	4-11	25	0
8- 1	2	1	3.9	7.0	7	1	0
	3	0	0.0	0.0	---	0	0
				6 meters			
	1	0	0.0	0.0	---	0	0
6- 1	2	35	59.3	1.4	1-2	0	35
	3	24	40.7	0.0	---	0	24
	1	0	0.0	0.0	---	0	0
6-15	2	76	87.4	4.4	1-7	0	76
	3	11	12.6	0.0	---	6	5
	1	73	45.3	9.0	4-12	0	73
7- 1	2	65	40.4	4.4	1-9	64	1
	3	23	14.3	0.0	---	23	0
	1	68	50.0	8.4	1-13	65	3
7-15	2	49	36.0	3.1	1-7	48	1
	3	19	14.0	0.0	---	16	3

Table 5. (cont'd.)

Date	Group	N	Per-centage	$\overline{X}$ No. young/adult	Range No. young	First Reprod. season Adults	Second Reprod. season Adults
	1	89	63.1	7.9	2-14	82	7
8- 1	2	18	12.8	4.6	1-8	17	1
	3	34	24.1	0.0	---	33	1
				9 meters			
	1	0	0.0	0.0	---	0	0
6- 1	2	0	0.0	0.0	---	0	0
	3	9	100.0	0.0	---	0	9
	1	0	0.0	0.0	---	0	0
6-15	2	2	100.0	1.5	1-2	0	2
	3	0	0.0	0.0	---	0	0
	1	0	0.0	0.0	---	0	0
7-15	2	9	90.0	8.2	1-10	1	8
	3	1	10.0	0.0	---	1	0
	1	10	71.4	11.7	8-15	0	10
8- 1	2	4	28.6	5.3	4-6	4	0
	3	0	0.0	0.0	---	0	0

released during the summer and early fall and overwinter as juveniles. The following summer these young mature and reproduce. Surviving members of this age class overwinter as adults during their second winter and reproduce for a second time the following summer. The data presented in Table 5 indicate that most second reproductive season adults die following release of young and are replaced by maturing offspring produced during their first reproductive season. Juveniles produced by the second reproductive season adults of the previous year also contribute to the replacement of the two-year-old adults. Most adults of both age classes produce only one brood of young per year.

Overwintering juveniles mature during mid-July and early August at depths of 9 meters. Overwintering adults did not begin releasing their young until early August. This study was terminated in August of 1966; consequently, no data are available concerning the potential contribution of young by adults in their first reproductive season. The development and release of young by second reproductive season adults suggests that the contribution of young by late maturing first reproductive season adults may be limited or entirely lacking. Several of the early maturing adults had from 4-6 eggs within the carapace by 1 August. Second reproductive season adults at 9 meters appear to have a slightly higher reproductive potential than animals at shallower depths. At 9 meters, egg development is much slower than that of animals living under higher temperature regimes at shallower depths. The generally smaller and more uniform size of eggs and the retarded development of first instar young apparently provides space for a greater number of young than is possible for adults at lesser depths.

The mean number of young per adult shown for Group 1 on successive dates (Table 5) represents an underestimation of the reproductive potential of ostracods from all three depths. The means of 8.0 and 8.2 young per individual on 15 July and 1 August at 3 meters depth represent, at best, only minimal estimates. The mean number of young per individual would have been higher had sampling intervals been more closely spaced.

Six meter samples on 1 July show a mean maximum of 9.0 young per individual. When adults with three or more parasites and those which had obviously begun releasing young are excluded, the reproductive potential is 10.1 young per individual (N = 45). At 9 meters the mean maximum of 11.7 young per individual for second reproductive season adults represents the highest and possibly most accurate reproductive potential estimate.

Ostracods that had not produced the maximum number of young, those with maximal production, and those which had released some portion of the brood were included in calculating the mean number of young per individual from the Group 1 category. A more realistic estimate of the mean reproductive potential of D. stevensoni would be about 11 young per individual at 3 and 6 meters, and 13 young per individual at 9 meters. The latter estimates are based upon observations of the probable maximal development of young in several hundred adults from depths of 3, 6, and 9 meters.

A second density estimate is made possible by differentiating adult age classes. The estimated number of first and second reproductive season adults, per square meter along Transect AB, during the summer of 1966, is presented in Table 6. Density estimates presented in Table 4 were calculated from the mean number of adults and juveniles in replicated Ekman dredge samples. First and second

Table 6. Mean number of first and second reproductive season adults per square meter calculated from data presented in Table 5. Density estimates for second reproductive season adults are given on second line; first line gives estimates for first reproductive season adults.

1 June	15 June	1 July	15 July	1 August
		3 meters		
0	346	0	2640	562
563*	281	43	260	0
		6 meters		
0	130	1883	2792	2857
1277	1753	1601	151	195
		9 meters		
0	0	0	43	87
195	43	0	173	216

* One adult added to total adults examined (N = 26).

reproductive season adults were not considered separately in the latter estimates.

The estimated number of second reproductive season adults per square meter at 6 meters depth was 1277, 1753, 1601, 151, and 195, respectively, on the dates shown in Table 6. These estimates differ somewhat from those presented in Table 4, because the number of ostracods dissected often was less than the total collected. Yet the point here is to show the decreased variability in second reproductive season adult estimates for June and early July compared with total adult estimates in Table 4, and the rapid decline of second reproductive season adults following release of young. The first estimate (Table 4) gives a clearer representation of the size structure of the population; however, the second estimate assists in understanding the turnover in age structure of the adult segment of the population.

Darwinula stevensoni harbors an unidentified parasitic rotifer on which work is currently in progress. The parasite is almost always found in the posterior region of the carapace where the ostracod eggs are carried, and is presumed to be strictly ectoparasitic.

More than 4,000 adult and juvenile ostracods were dissected and examined for parasites. Only 41 or 2.1 per cent of 1,963 juveniles were infected. The infected animals were generally in the penultimate instar and the greatest incidence of infection occurred in a relatively shallow, sheltered bay area on the west side of Gull Lake (sample localities 138, 140-1).

Parasitism varies with water depth, size and age of individuals, number of young, and geographically. Variation in the percentage of parasitized adults collected along four transects in Gull Lake on the same date is shown in Table 7. Here, the number of parasitized

Table 7. Geographic and depth variation in the number of parasitized adult Darwinula stevensoni collected along four transects on 4 November 1965.

Transect	No. Adults	% Parasitized	$\bar{X}$ Parasites/ Infected Ind.	Range No. Parasites
		3 meters		
AB	47	31.9	1.7	0-3
EF	87	23.0	1.7	0-5
GH	99	6.1	1.7	0-3
CD	103	25.2	1.8	0-5
		6 meters		
AB	21	42.9	2.4	0-4
EF	9	0.0	0.0	---
GH	51	0.0	0.0	---
CD	--	----	---	---

9 meters
No Parasites (N = 24)

12 meters
No Parasites (N = 1)

individuals varies both geographically and with depth.

Approximately 26 percent or 562 specimens of a total 2,169 adults examined had at least one parasite within the carapace. A total of 1400 parasites were found in infected ostracods and the maximum number per individual ostracod was nine. More than 200 ostracods had three or more parasites within the carapace.

The seasonal, geographic, and depth variation in parasitized adults from Gull Lake is presented in Table 8. Although the incidence of infection varied geographically at a given depth, the percentages of parasitized individuals generally were highest at depths of 6 meters. About 40 percent of the ostracods were infected at 6 meters; less than 10 percent of the ostracods, in most <3 meter samples, were parasitized. Only 3 of 105 ostracods from depths of 9 meters were infected.

The low incidence of infection in juveniles compared with that in adults illustrates the variation in parasitism in relation to the size structure of the population. Parasitism of mature and immature ostracods produced during the same reproductive season was much greater in recently matured individuals, even though the age of both groups was essentially the same.

Parasitism also varies with the age structure of the population. The percentages of infected ostracods comprising adult age classes discussed above (Table 5) are presented in Table 9. These data are presented in the manner of construction used for Table 5; Groups 1, 2, and 3 were explained in the latter table and may be compared with the two right-hand columns for age class composition (Table 5) not repeated in Table 9.

Only second reproductive season adults were parasitized at 3 meters

Table 8. Seasonal, geographic, and depth variation in the number of parasitized adult Darwinula stevensoni collected along Transect AB, Station GI, and other localities in Gull Lake.

Date	Locality	No. Adults	% Infected	$\bar{X}$ No. Parasites/ Infected Ind.	Range No. Parasites
			<3 meters		
2-21-66	AB	2	0.0	---	---
3-21-66		1	0.0	---	---
7- 2-66		34	0.0	---	---
9-22-65	GI	54	11.1	3.7	0-8
10- 4-65		94	0.0	0.0	---
10-13-65		39	10.3	2.0	0-4
10-18-65		63	6.4	1.3	0-2
11- 1-65		35	2.9	2.0	0-1
12- 2-65		27	3.7	1.0	0-1
1- 4-66		9	0.0	0.0	---
1-11-66		14	7.1	3.0	0-3
5-31-66		41	4.9	1.5	0-3
6-15-66		4	0.0	0.0	---
9-14-65	62	3	0.0	---	---
9-27-65	66	12	0.0	---	---
10-18-65	79-80	43	48.8	2.3	0-6
3-26-66	138	17	47.1	2.3	0-5
3-26-66	140-1	11	36.4	1.3	0-2
			3 meters		
11- 4-65	AB	47	31.9	1.7	0-3
2-24-66		56	42.9	3.0	0-7
3-30-66		25	64.0	2.8	0-8
4-29-66		9	0.0	---	---
5-19-66		10	40.0	3.8	0-7
6- 1-66		25	32.0	2.5	0-5
6-15-66		29	13.8	5.0	0-6
7- 1-66		2	0.0	---	---
7-15-66		134	22.4	2.3	0-5
8- 1-66		26	26.9	2.0	0-4

Table 8. (cont'd.)

Date	Locality	No. Adults	% Infected	$\overline{X}$ No. Parasites/ Infected Ind.	Range No. Parasites
			6 meters		
11- 4-65	AB	21	42.9	2.4	0-4
2-21-66		18	55.6	3.4	0-7
3-30-66		50	30.0	1.7	0-3
4-29-66		21	61.9	3.2	0-7
5-19-66		25	44.0	2.1	0-6
6- 1-66		59	45.8	2.1	0-8
6-15-66		87	43.7	2.4	0-5
7- 1-66		161	36.7	3.2	0-9
7-15-66		136	38.2	2.6	0-9
8- 1-66		141	53.2	2.6	0-7
10-13-65	76	13	0.0	---	---
12- 8-65	EF	48	33.3	2.4	0-7
3-30-66	IJ	70	31.4	3.0	0-7

on 1 June and 15 June. More than one-half of the individuals were first reproductive season adults in the 15 June samples, yet none of these ostracods was infected. Data from 15 July to 1 August, at 3 meters, indicate that first reproductive season adults were parasitized soon after reaching maturity. Older individuals within the same year class (Groups 1 and 2) were more heavily parasitized than the more recently molted adults (Group 3). Mid-July and August samples, at 6 meters, also indicated progressively increased infection of older individuals. First reproductive season adults comprised more than 90 percent of the latter samples. The high incidence of parasitized adults in Groups 2 and 3 during June, at 6 meters, reflects the fact that over 95 percent of the animals were second reproductive season adults. On 1 July, Group 1 included only second reproductive season adults whereas Groups 2 and 3 were almost exclusively first reproductive season adults; the percentage of infected Group 1 adults was twice that of Group 2.

The mean number of young per individual in parasitized adults (Table 9) compared to the mean number of young per individual in the total sample (Table 5) does not appear to reflect a reduction of the reproductive potential in infected animals. However, no comparison with the reproductive potential of non-parasitized adults is given. Reduction of reproductive potential resulting from parasitism is currently being investigated experimentally under controlled laboratory conditions and will be reported later (McGregor and Esch, in preparation).

Table 9. Parasites of Darwinula stevensoni in Groups 1, 2 and 3, collected at depths of 3 and 6 meters along Transect AB, during the summer of 1966. Explanation of Group designations given in Table 5.

Date	Group	N	% Parasitized	Range Parasites	Adults with $\bar{X}$ Para./Ind.	Parasitized $\bar{X}$ young/Ind.
				3 meters		
	1	0	0.0	---	0.0	0.0
6- 1	2	24	33.0	0-5	2.5	2.1
	3	1	0.0	---	0.0	0.0
	1	0	0.0	---	0.0	0.0
6-15	2	14	28.6	0-6	5.0	5.8
	3	15	0.0	---	0.0	0.0
	1	0	0.0	---	0.0	0.0
7- 1	2	2	0.0	---	0.0	0.0
	3	0	0.0	---	0.0	0.0
	1	92	20.7	0-5	2.1	8.5
7-15	2	36	30.6	0-5	2.7	5.0
	3	6	0.0	---	0.0	0.0
	1	25	28.0	0-4	2.0	7.7
8- 1	2	1	0.0	---	0.0	0.0
	3	0	0.0	---	0.0	0.0
				6 meters		
	1	0	0.0	---	0.0	0.0
6- 1	2	35	45.7	0-3	1.6	1.3
	3	24	45.8	0-8	3.0	0.0
	1	0	0.0	---	0.0	0.0
6-15	2	76	42.1	0-5	2.3	3.8
	3	11	54.6	0-5	3.2	0.0
	1	73	53.4	0-9	3.9	9.7
7- 1	2	65	26.2	0-4	1.9	4.7
	3	23	8.7	0-1	1.7	0.0
	1	68	50.0	0-9	2.8	7.1
7-15	2	49	28.6	0-5	1.9	2.9
	3	19	21.1	0-6	3.5	0.0
	1	89	69.7	0-7	2.7	7.2
8- 1	2	18	44.4	0-5	2.6	4.3
	3	34	14.7	0-4	2.0	0.0

Darwinula pagliolii

Darwinula pagliolii is the smallest free-living ostracod species of the Gull Lake fauna. Adults reach a maximum length of about .56 mm. This ostracod is similar in appearance to juveniles of D. stevensoni, but it is not as laterally compressed or anteriorly-posteriorly tapered as the latter. D. pagliolii is the only species of the family Darwinulidae, other than D. stevensoni, reported from North America and presently is known only from Gull Lake and other areas investigated in this study. The species was described from southern Brazil in 1961 and had not been reported elsewhere.

The spatial and depth distributions of D. pagliolii were more restricted than any other species in the lake. Living animals were found only at Station GI at depths of <3 meters. Empty carapaces were found in other shallow, marl-encrusted shelf areas of Gull Lake.

This species is parthenogenetic and the young are carried by the parent through the first and occasionally the second instar. Early instar juveniles isolated and reared in the laboratory completed one reproductive cycle and produced only females. No males were found in field collections from Gull Lake or other areas. D. pagliolii appeared to have the smallest number of offspring per year of all Gull Lake species.

All specimens were collected using the modified aquatic net from the sand, marl, cobblestone substratum at Station GI. The single juvenile found during the study reflected the small size of immature individuals and the inability to retain them in the 202 micron mesh openings of the aquatic net. Forty-four samples were collected on 9 sampling dates. The number of ostracods examined is presented below.

	Total No.	No. Adults	No. Juveniles	No. Females	No. females exam. for young	No. females exam. for parasites
Gull Lake	195	194	1	194	162	144

Adults were found in samples from August to December 1965, and again in May 1966(Table 10). However, *D. pagliolii* was present throughout the year as evidenced by samples collected for studies not reported here.

The reproductive cycle, based on available field data and laboratory observations, was similar to that of *D. stevensoni*. Basic similarity of the reproductive biology, behavior, parasitism and seasonal distribution leave no doubt, in my belief, that many aspects of the population ecology described for *D. stevensoni* were common to *D. pagliolii*.

Data presented in Table 10 indicate that gravid females began releasing first or second instar young by late summer 1965. A maximum of 3 young were found in one female on 13 October 1965. The eggs released in the carapace of the latter individual were small and showed no evidence of appendage or carapace differentation. The parent may have been one of the early summer juveniles that had matured and begun to reproduce. Other gravid females had no yolked folicles and carried 1-2 fully developed first or second instar young. This indicated that the latter adults had overwintered from the previous fall as juveniles, matured early in the summer of 1965, and were in the last stages of their reproductive cycle by early fall of 1965. Surviving members of this age group and some of their offspring may have been represented by the non-gravid adults collected in November and December (Table 10).

Table 10. Percentage of adults and average number of young in gravid females of Darwinula pagliolii collected at Station GI in Gull Lake. Depth is <3 meters.

Date	No. Samples	Total No.	Percent Adult	Females exam.	Percent Gravid	Gravid Females Avg. No. Eggs/Ind.	Range
1965							
9-14	4'	14	100.0	10	50.0	1.2	0-2
9-22	10'	15	100.0	15	20.0	1.3	0-2
10- 4	3'	12	100.0	12	8.3	1.0	0-1
10-13	2'	15	100.0	15	6.7	3.0	0-3
10-18	5'	25	100.0	25	9.0	1.5	0-2
10-20	4'	1	100.0	--	---	---	---
11- 1	7'	2	100.0	2	0.0	---	---
12- 2	4'	107	99.1	79	0.0	---	---
1966							
5-31	5'	4	100.0	4	75.0	1.0	0-1

' Aquatic Net

Adults overwintering from the fall of 1965 had begun releasing eggs into the carapace by May 1966. Three of 4 adults collected on 31 May were gravid and each had one newly deposited egg in the carapace. Three, or possibly four, eggs and first instar young are about the maximum number that a female can carry because of space limitations at the time first instar young are released. The maximum number of young and eggs found in a single individual was 3. Two or three developing young, together with rotifers attached to the hypodermis, completely fill the posterior region of the carapace. Occasionally, dead females were found with large, active juveniles still inside closed valves; some young appeared to be in third or possibly fourth instar.

A rotifer, presumably the same species found in *D. stevensoni*, was present in the carapace of *D. pagliolii*. The incidence of infection was much greater in the latter; 86.8 percent (N = 144) of the ostracods had one or more rotifers attached to the hypodermis in the posterior region of the carapace. Table 11 shows the percentages of infected adults in samples from Station GI. These data do not indicate if the rotifer caused a reduction in the average number of young produced by *D. pagliolii*.

All of the gravid females (Table 10) had released some young or were just beginning the reproductive cycle. Thus, data on the number of rotifers in the carapace of individual ostracods with maximum numbers of young and eggs are lacking. Observations of *D. pagliolii* in 1967 indicated that fewer young were produced by females with four or more rotifers in the carapace. This problem still is being investigated. If the rotifer definitely is shown to reduce the number of offspring produced by infested ostracods, *D. pagliolii* certainly will

Table 11. Variation in the number of parasitized adult *Darwinula pagliolii* collected at Station GI in Gull Lake.

Date	No. Adults	Percent Infected	$\bar{X}$ No. Parasites/ Infected Ind.	Range No. Parasites
1965				
9-14	1	100.0	4.0	4
9-22	12	91.7	2.1	0-6
10- 4	12	66.7	2.3	0-5
10-13	14	100.0	2.1	1-4
10-18	20	95.0	3.6	0-6
11- 1	2	100.0	3.5	3-4
12- 2	79	91.1	3.2	0-7
1966				
5-31	4	75.0	2.0	0-3

have the highest incidence of parasitism (in the sense used here, see discussion) of any ostracod known.

No rotifers were found in any Gull Lake ostracods except *D. stevensoni* and *D. pagliolii*. Both of these species are slow, creeping benthic forms which do not have a modified third pair of thoracic legs for keeping debris and other organisms out of the carapace. The furcae also are rudimentary. The absence of appendages suited for forcibly removing the rotifers and the space available in the posterior region of the carapace where the young ostracods develop probably explains why the ostracod-rotifer relationship is found only in *Darwinula*.

Candona ohioensis

Candona ohioensis was collected from 96 Ekman, 5 free-fall core, 8 aquatic net, and 3 fish samples. The number of specimens examined is summarized below.

	Total No.	No. Adults	No. Juve-niles	No. Male	No. Female	No. Females Examined for eggs
Gull Lake	2833	361	2472	121	240	226
Fish Analysis	166	166	---	13	153	---

C. ohioensis was the largest ostracod species examined from Gull Lake, reaching a maximum length of slightly more than 2 mm. This species was collected at depths ranging from <1-18 meters during the study period, but was found at depths of 32 meters on other dates.

Tabular data for C. ohioensis and other Candona species are arranged first by depth and then by date of collection. This was done to show differences in the reproductive cycle(s) of species populations living in the littoral and sublittoral areas of the lake. C. ohioensis, for example, had two generations per year in the sub-littoral and one generation per year in the littoral region of Gull Lake.

Scanning of data in the tables below is made easier by first considering the data for a given date at <3, 3, 6 and 9 meters and then those data for 12 meters or greater.

In early August, 1965, 100 percent of 1065 specimens collected at depths of <3, 3, 6 and 9 meters were middle to late instar juveniles. By mid-September most <3 meter individuals had molted to the adult instar, but no females (N = 22) were gravid (Table 12). On 13 October non-gravid females were found at 6 meters, whereas, by 18 October, 100 percent of the females from <3 meters were gravid and averaged 11.4 eggs per individual (Table 13).

Samples were collected along four transects on 4 November at depths of 3, 6, 9, 12 and 15 meters. In littoral samples (0-9 m) all C. ohioensis were mature and most females were gravid. One individual from 6 meters had 35 eggs; 4 females from 9 meters averaged 24.5 eggs per individual. Density estimates on 5 August and 11 November at depths of 3, 6 and 9 meters indicate high mortality of late instar juveniles and early maturing adults (Table 14). August estimates represent replicated samples along Transect AB and November estimates, the means of 4 transects. Reductions in the mean number of individuals per square meter on the latter date were marked.

The reproductive cycle of C. ohioensis in the littoral region apparently ended by early December as no adult or juvenile individuals were present in December samples. Additional evidence supporting this conclusion was the absence of C. ohioensis in all littoral samples through March of 1966. Early instars, abundant in 3-9 meter samples on 15 May 1966, were presumed to be offspring of the November 1965 adults. All C. ohioensis collected from 0-6 meter depths through the summer of 1966 were immature. Recently molted adult males were collected at a depth of 9 meters on 15 June 1966. One non-gravid and 2 gravid females were collected on 15 July and 1 August, respectively, from the latter depth. Most juveniles, at depths less than 9 meters, had molted to the seventh or eighth instar by 1 August 1966; presumably, these individuals would have entered their reproductive cycle by October or November as was found in 1965.

In contrast to the annual fall generation of adults in the

Table 12. Percentage of adult and juvenile Candona ohioensis from Gull Lake samples collected at depths of <3, 3, 6, 9, 12, 15, and 18 meters.

Date	Sample No.	Transect or Location	N	Percent Adult	Percent Juvenile
		<3 meters			
1965 8- 2	39	39	14	0.0	100.0
	40	KL	20	0.0	100.0
8- 3	44	MN	19	0.0	100.0
	45	KL	110	0.0	100.0
8- 5	49	AB	6	0.0	100.0
9-14	61	61	17	94.1	5.9
	62	62	12	100.0	0.0
10-18	80	80	19	100.0	0.0
1966 7- 2	207	AB	2	0.0	100.0
		3 meters			
1965 8- 3	41	MN	113	0.0	100.0
	46	KL	97	0.0	100.0
8- 5	50	AB	153	0.0	100.0
	53	AB	80	0.0	100.0
11- 4	82	AB	4	100.0	0.0
	87	CD	2	100.0	0.0
	92	EF	1	100.0	0.0
	97	GH	1	100.0	0.0
1966 5-19	164	AB	50	0.0	100.0
6- 1	174, 180	AB	69	0.0	100.0
6-15	187, 188	AB	58	0.0	100.0
7- 1	197	AB	1	0.0	100.0
7-15	212, 213	AB	90	0.0	100.0
8- 1	223, 224	AB	16	0.0	100.0
		6 meters			
1965 8- 2	38	38	76	0.0	100.0
8- 3	42	MN	75	0.0	100.0
	47	KL	24	0.0	100.0
8- 5	51	AB	192	0.0	100.0
	54	AB	17	0.0	100.0
10-13	76	76	4	100.0	0.0
11- 4	83	AB	4	100.0	0.0
	88	CD	11	100.0	0.0
	93	EF	4	100.0	0.0
	98	GH	3	100.0	0.0
1966 5-19	165	AB	17	0.0	100.0
6- 1	175, 181	AB	60	0.0	100.0
6-15	189, 190	AB	67	0.0	100.0
7- 1	199, 200	AB	79	0.0	100.0
7-15	214, 215	AB	43	0.0	100.0
8- 1	225, 226	AB	45	0.0	100.0

Table 12. (cont'd.)

Date	Sample No.	Transect or Location	N	Percent Adult	Percent Juvenile
		9 meters			
1965 8- 3	48	KL	30	0.0	100.0
8- 5	52	AB	2	0.0	100.0
	55	AB	37	0.0	100.0
11- 4	84	AB	5	100.0	0.0
	94	EF	6	100.0	0.0
1966 5-19	166	AB	6	0.0	100.0
6- 1	176, 182	AB	49	0.0	100.0
6-15	191, 192	AB	6	16.7	83.3
7- 1	201, 202	AB	19	10.5	89.5
7-15	216, 217	AB	13	15.4	84.6
8- 1	227, 228	AB	27	7.4	93.6
		12 meters			
1965 11- 4	85	AB	14	85.7	14.3
	90	CD	10	80.0	20.0
	95	EF	4	50.0	50.0
	100	GH	14	7.1	92.9
12- 8	107	EF	54	7.4	92.6
1966 2-21	126	AB	11	0.0	100.0
3-30	145	AB	27	0.0	100.0
	150	IJ	10	0.0	100.0
4-29	159	AB	60	0.0	100.0
5-19	167	AB	31	0.0	100.0
	169	IJ*	7	0.0	100.0
6- 1	177, 183	AB	142	27.4	72.6
6-15	193, 194	AB	50	32.0	68.0
7- 1	203, 204	AB	67	38.8	61.2
7-15	218, 219	AB	96	66.7	33.3
		15 meters			
1965 10-13	75	75	6	0.0	100.0
11- 4	86	AB	2	100.0	0.0
	91	CD	2	100.0	0.0
	96	EF	17	94.1	5.9
	101	GH	21	38.5	61.5
1966 3-30	146	AB	3	0.0	100.0
	151	IJ	11	9.9	90.1
5-19	168	AB	2	0.0	100.0
6- 1	178, 184	AB	63	4.8	95.2
6-15	195, 196	AB	59	10.2	89.8
7- 1	205, 206	AB	65	23.1	76.9
7-15	220, 221	AB	51	54.9	45.1
		18 meters			
1966 6- 1	179-185	AB	59	6.8	93.2

* Core sample

littoral region, data from 12 and 15 meter samples strongly indicate a biannual turnover rate in the sublittoral population of C. ohioensis.

No samples were collected at depths of 12 and 15 meters before November, 1965. Thus, data indicating the period in which the late fall-early winter reproductive cycle began are lacking. By early November, however, many juveniles had molted to the sixth-eighth instar and 66.7 percent (N = 84) of the individuals collected were mature (Table 12). Gravid and non-gravid females were present in samples from depths of 12 and 15 meters and the number of uterine eggs per gravid female averaged, respectively, 15.4 and 8.9 (Table 13).

The rather low densities at depths of 12 and 15 meters on 4 November 1965 (Table 14) possibly reflect high juvenile and adult mortality, but also could mark the early stages of the reproductive cycle. Of 54 individuals collected on 8 December 93 percent were immature; three of the four gravid females had from 27-34 eggs in the uterus (Table 13). No Ekman samples were taken in January, but analysis of fish stomachs of the yellow perch, Perca flavescens (Mitchill), yielded over 100 adult C. ohioensis. The perch were caught in gill nets at a depth of 15 meters. The condition of ostracods in the stomachs of most fish suggested that many had been eaten shortly before the fish were captured. The latter results are discussed in greater detail in other sections of this thesis.

From late February, 1966 through 19 May, almost 100 percent of the specimens in 12 and 15 meter samples were early instar juveniles. A single adult male found on 30 March had just molted to the adult instar, indicated by the soft, flexible, incompletely calcified carapace. By 1 June, 27.4 percent (N = 142), 4.8 percent (N = 62) and 6.8 percent (N = 59) of the ostracods, respectively, were mature in

Table 13. Percentage of males and females in adult <u>Candona ohioensis</u> and average number of eggs present in the uterus of adult females. Sample number and location corresponding to dates are presented in Table 12.

Date	Number Adults	% Male	% Female	Number Female Exam. for eggs	% Gravid	Gravid Females Avg. No. eggs per female	Range No. eggs
				<3 meters			
9-14-65	28	21.4	78.6	22	0.0	0.0	-
10-18-65	19	10.5	89.5	17	100.0	11.4	4-20
				3 meters			
11-4-65	8	0.0	100.0	8	87.5	7.7	0-12
				6 meters			
10-13-65	4	33.3	66.7	3	0.0	0.0	-
11-4-65	22	15.8	84.2	17	70.6	13.3	0-35
				9 meters			
11-4-65	11	9.1	90.0	4	100.00	24.5	20-28
6-15-66	1	100.0	0.0	-	---	---	-
7-1-66	2	100.0	0.0	-	---	---	-
7-15-66	2	50.0	50.0	1	0.0	0.0	-
8-1-66	2	0.0	100.0	2	100.0	4.5	4-5
				12 meters			
11-4-65	23	13.0	87.0	19	57.9	15.4	0-26
12-8-65	4	0.0	100.0	4	100.0	22.8	1-34
6-1-66	39	56.4	43.6	16	37.5	5.8	0-14
6-15-66	16	31.3	68.7	11	81.8	10.6	0-20
7-1-66	26	61.5	38.5	10	60.0	26.2	0-33
7-15-66	64	35.9	64.1	41	63.4	10.7	0-31
				15 meters			
11-4-65	33	6.1	93.9	27	85.2	8.9	0-20
3-30-66	1	100.0	0.0	-	---	---	-
6-1-66	3	33.0	67.0	2	50.0	1.0	0-2
6-15-66	6	50.0	50.0	3	33.3	17.0	0-17
7-1-66	15	80.0	20.0	3	33.3	5.0	0-5
7-15-66	28	53.6	46.4	13	61.5	6.4	0-13
				18 meters			
6-1-66	4	25.0	75.0	3	33.3	16.0	0-16

Table 14. Estimates of the mean number of adult and juvenile *Candona ohioensis* per square meter on 5 August and 4 November 1965. August estimates from replicated samples along Transect AB; November estimates represent means of samples from four transects (A = adult; J = juvenile).

Depth (meters)		August	November
3	A	---	87
	J	5064	---
6	A	---	238
	J	4523	---
9	A	---	119
	J	844	---
12	A		249
	J		206
15	A		357
	J		97

12, 15 and 18 meter samples. Greater than 50 percent of the animals collected on 15 July were mature (Table 12). Combined estimates of the mean number of adults and juveniles per square meter generally were of the same order of magnitude as juvenile densities at lesser depths (Table 15). Ostracod densities at 9 meters generally were less than at other depths.

The largest number of eggs recorded for a single female was 35. Many females lived beyond periods of egg laying as evidenced by one or a few eggs in the uteri of females collected late in the reproductive cycle. The size and location of uterine eggs and condition of the ovaries clearly indicated whether or not individual females had already released the majority of their eggs.

The maximum number of eggs recorded for *C. ohioensis* does not necessarily represent the maximum number of eggs that individuals may lay during a single reproductive cycle. However, these data may indicate differences in the relative importance of certain ostracod species in the benthic food web of Gull Lake.

Females outnumbered males in most large samples of adults (Table 13). On November 4, 1965, more than 75 percent of the adults from all depths were females. During the summer of 1966, males were more abundant than females in some samples. Of 55 eighth instar juveniles examined from 12-15 meter samples on 1 June-15 June 1965, 30 or 54.5 percent were males. This indicated that the sex of immature ostracods did not differ significantly from a 1:1 ratio during the early phase of the summer reproductive cycle. However, males of most *Candona* species mature earlier and have a shorter life span than females. Of the total number of adult *C. ohioensis* examined, 33.5 percent were males. Large numbers of males in the population at the onset of the reproductive

Table 15. Estimates of the mean number of adult and juvenile Candona ohioensis per square meter at depths of 3-18 meters along Transect AB from 1 July - 1 August 1966 (A = adult; J = juvenile).

Depth	June 1		June 15		July 1		July 15		August 1	
(meters)	A	J	A	J	A	J	A	J	A	J
3	---	1493	---	1255	---	22	---	1948	---	346
6	---	1298	---	1450	---	1710	---	931	---	974
9	---	1060	22	108	43	368	43	238	43	541
12	844	4393	346	736	563	887	1385	692		
15	65	1298	130	1234	325	1082	606	498		
18	87	1190								

cycle may have some selective advantage in insuring fertilization of females soon after the latter mature.

Feeding habits, involving size discrimination, by predators of ostracods may account for the rapid reduction of males in certain species populations in Gull Lake. Data relating to this assumption are discussed later.

C. ohioensis also were collected from Lawrence Lake, Barry County, Michigan and from Pretty Lake, Indiana.

Candona rawsoni

Candona rawsoni was perhaps the most easily recognized species of Candona in Gull Lake. The female has a prominent posterior flange on the left valve in the adult instar. Juveniles lack this flange, but have other distinctive carapace features which permit rapid identification. Late instar males were not easily identified. Candona scopulosa is very similar in shape and in external appearance to C. rawsoni. Males and late instar juveniles often had to be dissected to verify a tentative identification based on carapace morphology. Males and females are little more than 1 mm in length and exhibit considerable variation in size. The male is larger than the female.

Juveniles or adults were collected in every month of the study period but not at all depths on a given date. C. rawsoni was found in 64 Ekman, 40 aquatic net and 2 fish samples. The number of individuals examined is recorded below.

	Total No.	No. Adults	No. Juveniles	No. Male	No. Female	No. Females exam. for eggs
Gull Lake	1887	557*	1330	122	423	326
Fish Analysis	28	1	27	1	---	---

* Sex of 12 adults not recorded

C. rawsoni had a single reproductive cycle in both the littoral and sublittoral regions of Gull Lake. The reproductive period, however, did not span the same time interval. There appeared to be two distinct or at least effective breeding populations in the area of Transect AB. Sampling was insufficient to indicate whether this was true in other areas of Gull Lake. Large numbers of individuals were found on the sandy, cobblestone substrates in shallow water near shore. The other zone of high ostracod density was at depths of 12 and 15 meters. Although *C. rawsoni* exhibited a highly clumped distribution in the littoral region of Gull Lake, I believe the total number of samples taken in this study was sufficient to indicate very limited exchange of individuals between the shallow water and 12-15 meter depths. Only 1 adult and 14 juveniles were collected at depths between 3 and 12 meters during the entire study. Almost 1900 individuals were collected from the 0-3 and 12-15 meter depths.

One hundred percent (N = 823) of the ostracods collected from the littoral region during August through November 1965 were immature (Table 16). Adults were found on 8 December, but no record was made of the sex or reproductive condition of these specimens.

Only 2 of 434 individuals were immature in 0-9 meter samples collected from 11 February to 1 June 1966. The reproductive cycle ended by early June 1966, and small juveniles were again abundant on 1 July. No adults were found in the littoral areas of the lake after 1 June.

Gravid females were abundant in February with a maximum of 40 eggs in some individuals. By late February, 93 percent (N = 185) of the females were gravid; from March through 1 June all females were gravid, but most had released the major portion of their eggs. At depths of 3 and 6 meters gravid females were found only during February and March. One late maturing female had 40 eggs in the uteri on 31 May 1966; however, this individual was the only specimen collected beyond March which had not released most of its eggs (Table 17).

C. rawsoni was not found in 12 and 15 meter samples until February 1966. Gravid females were present in all samples from February-15 June at 12 meters depth. Females which had completed egg laying were present

Table 16. Percentage of adult and juvenile *Candona rawsoni* in samples collected from Gull Lake at depths of <3 to 15 meters.

Date	No. Samples	Transect or Location	N	% Adult	% Juvenile
		<3 meters			
1965					
8- 2	2	39, KL	40	0.0	100.0
8- 3	1	KL	1	0.0	100.0
8- 5	1	AB	189	0.0	100.0
8-28	2'	AB	14	0.0	100.0
9-14	3'	GI, 62 AB	274	0.0	100.0
9-27	11'	66, 67 68	238	0.0	100.0
10- 4	1'	GI	4	0.0	100.0
10-13	8'	GI, 74	39	0.0	100.0
10-18	7'	GI, 80	10	0.0	100.0
1966					
2-11	4	AB	19	89.5	10.5
2-21	2	AB	3	100.0	0.0
2-24	7	AB	356	100.0	0.0
3-21	4	AB	18	100.0	0.0
3-26	4	138-141	19	100.0	0.0
5-31	5'	GI	1	100.0	0.0
6- 1	1	AB	10	100.0	0.0
7- 2	3'	GI	1	0.0	100.0
		3 meters			
1965					
8- 3	1	MN	1	0.0	100.0
11- 4	2	EF, GH	5	0.0	100.0
12- 8	1	EF	16	75.0	25.0
1966					
2-24	4	AB	4	100.0	0.0
3-30	2	AB, IJ	3	100.0	0.0
7- 1	2	AB	200	0.0	100.0
7-15	2	AB	2	0.0	100.0
		6 meters			
1965					
8- 3	1	MN	1	0.0	100.0
11- 4	2	AB, EF	7	0.0	100.0
1966					
3-30	1	IJ	1	100.0	0.0
7- 1	1	AB	3	0.0	100.0
7-15	1	AB	1	0.0	100.0

' Aquatic net samples

Table 16. (cont'd.)

Date	No. Samples	Transect or Location	N	% Adult	% Juvenile
		9 meters			
1966					
7-15	1	AB	1	0.0	100.0
		12 meters			
1966					
2-21	1	AB	1	100.0	0.0
3-30	1	AB	43	32.6	67.4
4-29	1	AB	23	47.8	52.2
5-19	1	AB	8	0.0	100.0
6- 1	2	AB	94	23.4	76.6
6-15	2	AB	57	36.8	63.2
7- 1	2	AB	22	13.6	86.4x
7-15	2	AB	12	0.0	100.0x
		15 meters			
1966					
3-30	1	AB	64	35.9	64.1
4-29	1	AB	26	69.2	30.8
5-19	1	AB	22	27.3	72.7
7- 1	2	AB	34	0.0	100.0

x Early instar

in 1 July samples, but all of these individuals were feeble and emaciated. Many dead, incompletely deteriorated specimens of C. rawsoni were present in June and July samples, indicating that physiological death was a major mortality factor.

During the Fall of 1965, immature individuals were particularly abundant in well sorted sandy subtrates and in many samples constituted the only species of Candona present. The early molting of juveniles to the adult instar at depths of <3 and 3 meters during February and March, 1966 also was in marked contrast to the development of immature ostracods in the sublittoral populations. In the latter, late instar individuals comprised more than 50 percent of the total C. rawsoni collected from March through 15 June, 1966. Early instars collected on 1 July indicated the initiation of a new generation. This supposition was further supported by the absence of adult and late instar individuals of the parent generation by mid-July.

Difficulties of sampling in shallow water, cobblestone substrates, through a thick ice cover, prevented accurate quantification of adult population densities in such areas. Although a large number of individuals were collected from depths of <3 meters, no adequate measure of population density could be made for comparison with that estimated for adult Candona rawsoni at 12-15 meter depths. This species was, nevertheless, one of the conspicuous numerical dominants during February and March at depths of <3, 3, and 12-15 meters.

Density estimates at 12 meters depth illustrated the rapid reduction of adults during June 1966. On 1 June the estimated mean number of adults per square meter was 2034, on 15 June, 1234 and 1 July, 476. By 15 July adults were absent and the estimated number of early instar juveniles was 260. The latter apparently represented newly hatched offspring of the expired adult population.

In the early stages of the reproductive cycle, at both <3 and 12-15 meter depths, sex ratios were near a 1:1 ratio. Males, in fact, were more numerous than females in all the larger samples. Throughout the remainder of the reproductive cycle, however, females comprised about 70 percent, or more, of the adults. Less than 15 percent of the specimens from May and June were males (Table 17). This corresponds closely to results presented for *C. ohioensis*.

Table 17. Sex ratios of adult Candona rawsoni and average number of eggs present in the uterus of adult females. Number and location of samples corresponding to dates are presented in Table 16.

Date	No. Adults	% Male	% Female	No. females exam. for eggs	% Gravid	Gravid females Avg. No. eggs/ female	Range No. eggs
				<3 meters			
1966							
2-11	17	52.9	47.1	8	62.5	22.2	0-40
2-21	3	0.0	100.0	3	66.7	11.5	0-17
2-24	350	19.4	80.6	185	93.0	8.0	0-25
3-21	18	16.7	83.3	15	100.0	10.0	2-24
3-26	19	31.7	68.3	13	100.0	9.6	4-20
5-31	1	0.0	100.0	1	100.0	40.0	40
6- 1	10	10.0	90.0	9	100.0	4.9	1- 8
				3 meters			
12- 8*	12	---	---	---	---	---	---
2-24	4	0.0	100.0	4	100.0	8.5	4-14
3-30	3	0.0	100.0	3	66.7	14.3	0-27
				6 meters			
3-30	1	0.0	100.0	1	100.0	9.0	9
				12 meters			
2-21	1	0.0	100.0	1	100.0	4.0	4
3-30	14	78.6	21.4	3	66.7	9.5	0-14
4-29	11	18.2	81.8	9	100.0	8.4	5-12
6- 1	22	13.6	86.4	19	100.0	6.7	2-13
6-15	21	4.8	95.2	20	100.0	7.8	1-14
7- 1	3	0.0	100.0	3	0.0	---	---
				15 meters			
3-30	23	56.5	43.5	10	60.0	6.7	0-17
4-29	18	27.8	72.2	13	100.0	10.2	6-15
5-19	6	0.0	100.0	6	100.0	10.2	3-17

* 1965

Candona acuta

Candona acuta was collected from 32 Ekman dredge and 2 fish samples on 10 sampling dates. Results of fish stomach analyses are not included in the tables below; however, data from one Ekman dredge sample on 23 January 1965 are included to supplement other information on reproductive cycles.

This species is similar to Candona rawsoni in size, ranging from about 1.1 to 1.3 mm in length. The males are larger than females and sexually dimorphic. Juvenile C. acuta were difficult to identify; therefore, only the late instar totals are recorded in the following tables. Early instar individuals may have been present in other samples, but could not be identified. Adult males were dissected for positive identification. The number of specimens examined is shown below.

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	454	360	94	51	309	283
Fish Analyses	180	180	--	100	80	---

C. acuta was collected at depths ranging from <3 to 15 meters. The first specimens were found on 4 November 1965. Density estimates of 844 (3m), 649 (6m), 573 (9m) and 390 (15m) ostracods per square meter showed greatest densities at shallower depths. Adults comprised over 75 percent of the individuals at 3 and 6 meters whereas 25 percent, or less, were mature in samples from depths of 9-15 meters (Table 18). No females were gravid.

Development rates of C. acuta appeared to be strongly influenced

Table 18. Percentage of adult and juvenile <u>Candona acuta</u> in samples collected from depths of <3 to 15 meters in Gull Lake.

Date	No. Samples	Transect or Location	N	% Adult	% Juvenile
		<3 meters			
1966					
2-21	1	AB	1	100.0	0.0
3-26	1	138	6	100.0	0.0
		3 meters			
1965					
11- 4	4	AB, CD EF, GH	78	76.9	23.1
1966					
2-24	4	AB	3	100.0	0.0
3-30	1	AB	4	100.0	0.0
		6 meters			
1965					
11- 4	4	AB, CD EF, GH	60	85.0	15.0
12- 8	1	EF	28	100.0	0.0
1966					
2-21	1	AB	1	100.0	0.0
3-30	1	AB	3	100.0	0.0
		9 meters			
1965					
11- 4	4	AB, CD EF, GH	53	13.2	86.8
12- 8	1	EF	12	100.0	0.0
		12 meters			
1965					
1-23	1	IJ	46	100.0	0.0
12- 8	1	EF	60	100.0	0.0
1966					
2-21	1	AB	2	100.0	0.0
		15 meters			
1965					
11- 4	3	AB, CD EF	36	25.0	75.0
1966					
3-30	2	AB, IJ	51	100.0	0.0
4-29	1	AB	9	100.0	0.0
5-19	1	AB	1	100.0	0.0

by temperature. By 8 December all females (N = 35) from 6-9 meters were gravid, but only 30 percent (N = 54) were oviferous in 12 meter samples. Females from 6 meter samples had 3-11 eggs and averaged 11.8 eggs per individual (N = 24). At 9 meters the number of eggs ranged from 4-16, but the average was 9.1 (N = 11) per female. A maximum of 13 uterine eggs was recorded for 12 meter adults; however, the latter averaged only 4.9 (N = 14) eggs per individual. Forty non-gravid females in the 12 meter samples had just matured and most had incompletely calcified valves. The size and position of eggs within the uteri, condition of ovaries and recently molted appearance of many adults clearly indicated that females from the above depths had not begun laying eggs by early December (Table 19).

The number of adults per square meter had decreased markedly by February 1966, and all oviferous females, except one from <3 meters, had released a majority of their eggs. The lag in egg development at lower temperatures again was indicated by the larger number of eggs in females from 12 and 15 meter samples compared to individuals from lesser depths. No adults were found at depths less than 15 meters beyond March 1966. Only 10 adults were collected from 15 meters during April and May.

Males were most abundant in the first phase of the reproductive cycle, but never constituted more than 35 percent of the adults in any sample (Table 19). After November 1965, males comprised 10 percent, or less, of the adults sampled. Slightly more than 14 percent (N = 360) of the adults examined were males. In contrast, 56 percent (N = 180) of the adults eaten by the perch, *Perca flavescens*, were males. These differences in sex ratios strongly indicate size discriminate feeding by the yellow perch. Males are probably more active than females

Table 19. Sex ratio of adult <u>Candona acuta</u> and average number of eggs present in the uterus of adult females. Number and location of samples corresponding to dates are presented in Table 18.

Date	No. Adults	% Male	% Female	No. Females exam. for eggs	% Gravid	Gravid Females Avg. No. eggs/Ind.	Range No. eggs
				<3 meters			
1966							
2-21	1	0.0	100.0	1	100.0	23.0	23
3-26	6	0.0	100.0	6	100.0	2.8	1-6
				3 meters			
1965							
11- 4	60	26.7	73.3	44	0.0	---	---
1966							
2-24	3	0.0	100.0	3	100.0	1.7	1-2
3-30	4	0.0	100.0	4	100.0	2.0	1-4
				6 meters			
1965							
11- 4	51	35.3	64.7	33	0.0	---	---
12- 8	28	7.1	92.9	24	100.0	11.8	3-11
1966							
2-21	1	0.0	100.0	1	100.0	4.0	4
3-30	3	0.0	100.0	3	100.0	3.7	1-7
				9 meters			
1965							
11- 4	13	23.1	76.9	5	0.0	---	---
12- 8	12	8.3	91.7	11	100.0	9.1	4-16
				12 meters			
1965							
1-23	46	2.2	97.8	26	96.2	6.0	0-11
12- 8	60	10.0	90.0	54	25.9	4.9	0-13
1966							
2-21	2	0.0	100.0	2	100.0	8.0	8
				15 meters			
1965							
11- 4	9	33.3	66.7	6	0.0	---	---
1966							
3-30	51	2.0	98.0	50	100.0	6.3	1-13
4-29	9	0.0	100.0	9	100.0	6.6	1-15
5-19	1	0.0	100.0	1	100.0	8.0	8

during the reproductive period and may be more abundant at the substrate-water interface. The reproductive behavior of males coupled with apparent size discriminate feeding by the yellow perch may result in higher predation on male *C. acuta.*

Candona inopinata

Candona inopinata was one of the most common species of *Candona* encountered in Gull Lake. This ostracod was easily recognized in adult and late instars. Only the early instars posed a problem of identification. Females are about 1 mm in length and males somewhat larger. The sexes are strongly dimorphic, but the posteriorly truncate carapace of the female and highly arched dorsum of the male readily distinguished this species from others in Gull Lake. Closely related species in lakes surrounding Gull Lake were not present.

Adults show a definite temporal distribution although juveniles or adults are present throughout the year. Early instars, present in summer and early fall samples, were not included in tables because of difficulties in distinguishing between tiny juveniles of many species. *C. inopinata* is an able climber as well as burrower and often was found in large numbers on highly organic substrates and occasionally on the surfaces of rooted aquatic plants.

Fifty-eight Ekman, 34 aquatic net, 1 free-fall core and 2 fish samples contained *C. inopinata*. The number of ostracods examined is presented below.

	Total No.	No. Adults	No. Juvenile	No. Males	No. Females	No. females exam. for eggs
Gull Lake	975*	730	245	188	539	478
Fish Analyses	15	15	---	7	8	---

* Sex of three adults undetermined

The depth distribution of C. inopinata ranged from extremely shallow water to 15 meters. Most specimens were collected from depths of 6 meters or less; 95 individuals or 9.7 percent of the total were collected from depths greater than 6 meters.

Juveniles from 0-3 meter depths matured earlier than those in deeper waters. The first late instar juveniles were collected from <3 meter depths in mid-October 1965 (Table 20). By 1 November, 11.5 percent (N = 26) were mature, but non-gravid. On 2 December, about 80 percent (N = 46) of the specimens from <3 meters were mature and females contained from 0-26 uterine eggs. From January to May 1966 adults were abundant and constituted between 84 and 100 percent of the individuals sampled on the dates listed (Table 20). The latter juvenile-adult ratios may be misleading because of my inability to identify the smallest instars. Greater than 80 percent of the adult females were gravid, but the average number of eggs per individual declined steadily after mid-February. The maximum number of eggs in a single ostracod was 36.

Samples from 3 meter depths had a higher proportion of late instar juveniles than collections from <3 meters during November 1965 through March 1966. The estimated number of juveniles per square meter was 173 on 4 November. Later on 24 February 1966, the estimated number of adults and late instar juveniles was, respectively, 1006 and 368. The November estimate represented the mean of four transects; the latter estimate, four replicates from Transect AB. A two transect sample mean on 30 March gave an estimate of 1234 adults and 390 juveniles per square meter. All ostracods in April-June samples were mature and most females were gravid (Table 21). The number of adult C. inopinata in 3 meter samples decreased rapidly after March 1966. A single adult was

Table 20. Percentage of adult and juvenile *Candona inopinata* in samples collected from depths of <3 to 18 meters in Gull Lake.

Date	No. Samples	Transect or Location	N	% Adult	% Juvenile
		<3 meters			
1965					
10-18	7'	GI, 80	15	0.0	100.0
11- 1	7'	GI	26	11.5	88.5
12- 2	4'	GI	46	80.4	19.6
1966					
1- 4	5'	GI	58	94.8	5.2
1-11	6'	GI	49	98.0	2.0
2-11	4	AB	89	95.5	4.5
2-21	2	AB	40	85.0	15.0
2-24	7	AB	80	83.8	16.2
3-21	3	AB	108	95.4	4.6
3-26	3	139-141	32	100.0	0.0
5-31	5'	GI	1	100.0	0.0
		3 meters			
1965					
11- 4	4	AB, CD			
		EF, GH	17	5.9	94.1
12- 8	1	EF	5	60.0	40.0
1966					
2-24	4	AB	127	73.2	26.8
3-30	2	AB, IJ	75	76.0	24.0
4-29	1	AB	17	100.0	0.0
5-19	1	AB	12	100.0	0.0
6- 1	1	AB	1	100.0	0.0
		6 meters			
1965					
10-13	1	76	1	0.0	100.0
11- 4	4	AB, CD			
		EF, GH	51	0.0	100.0
12- 8	1	EF	6	66.7	33.3
1966					
2-21	1	AB	2	50.0	50.0
3-30	2	AB, IJ	22	100.0	0.0
		9 meters			
1965					
11- 4	4	AB, CD			
		EF, GH	21	0.0	100.0
12- 8	1	EF	13	92.3	7.7

' Aquatic Net

Table 20. (cont'd.)

Date	No. Samples	Transect or Location	N	% Adult	% Juvenile
1966					
2- 5	1	IJ	1	100.0	0.0
3-30	1	AB	4	100.0	0.0
4-29	1	AB	1	100.0	0.0
6- 1	1	AB	1	100.0	0.0
		12 meters			
1965					
11- 4	3	CD, EF, GH	14	0.0	100.0
12- 8	1	EF	23	82.6	17.4
1966					
2-21	1	AB	9	100.0	0.0
3-30	1	IJ	2	100.0	0.0
1-19	2*	IJ	5	100.0	0.0
		15 meters			
1965					
11- 4	1	CD	1	0.0	100.0

* Free Fall Cores

collected on 1 June.

Density estimates, calculated from means of four transect samples, on 4 November at depths of 6, 9, 12, and 15 meters were 551, 227, 151, and 11, respectively. All individuals were late instar juveniles. By 8 December, greater than 50 percent of the ostracods collected from each of these depths were mature and more than one half of the females were gravid. The maximum number of uterine eggs in one female was 15.

Females had deposited the majority of their eggs by February, but several eggs remained in the uterus of specimens collected in late March. Only 2 adult C. inopinata were collected from depths of 6-15 meters after March 1966.

Sex ratios of adult C. inopinata followed the general pattern described for other species. Males began maturing somewhat earlier than females. Eighty percent of the 45 eighth instar juveniles sexed in mid-October-early November were males. In most samples with more than 10 adults, males constituted less than 35 percent of the total. Toward the end of the reproductive cycle the percentage of males had declined further. No males were present in April-August samples, but probably would have been found in early April had samples been taken.

Table 21. Sex ratio of adult Candona inopinata and average number of eggs in the uterus of adult females. Number and location of samples corresponding to dates are presented in Table 20.

Date	No. Adults	% Male	% Female	No. Females exam. for eggs	% Gravid	Gravid females Avg. No. eggs/ Ind.	Range No. eggs
			<3 meters				
1965							
11- 1	3	100.0	0.0	---	---	---	---
12- 2	37	5.4	94.6	31	77.4	10.6	0-26
1966							
1- 4	55	27.3	72.7	40	100.0	9.8	3-19
1-11	48	10.9	89.1	34	97.1	9.9	0-21
2-11	85	45.9	54.1	48	93.8	11.2	0-23
2-21	34	26.5	73.5	25	84.0	9.7	0-22
2-24	67	29.9	70.1	44	84.1	8.2	0-30
3-21	103	27.2	72.8	75	89.3	7.3	0-36
3-26	32	15.6	84.4	27	85.2	5.3	0-13
5-31	1	0.0	100.0	1	100.0	21	21
			3 meters				
1965							
11- 4	1	100.0	0.0	---	---	---	---
12- 8	3	---	---	---	---	---	---
1966							
2-24	93	31.2	68.8	24	79.2	4.3	0-9
3-30	57	24.6	75.4	43	83.7	5.6	0-25
4-29	17	23.5	76.5	13	100.0	4.5	1-10
5-19	12	0.0	100.0	7	71.4	6.4	0-16
6- 1	1	0.0	100.0	1	100.0	6	6
			6 meters				
1965							
12- 8	4	25.0	75.0	3	33.3	13	0-13
1966							
2-21	1	100.0	0.0	---	---	---	---
3-30	22	18.2	81.8	17	94.2	4.4	0-11
			9 meters				
1965							
12- 8	12	9.1	90.9	8	87.5	9.7	0-15
1966							
2- 5	1	0.0	100.0	1	100.0	7	7
3-30	4	25.0	75.0	3	100.0	2.0	1-3
4-29	1	0.0	100.0	1	100.0	3	3
6- 1	1	0.0	100.0	1	100.0	3	3

Table 21. (cont'd.)

Date	No. Adults	% Male	% Female	No. Females exam. for eggs	% Gravid	Gravid females Avg. no. eggs/ Ind.	Range No. eggs
				12 meters			
1965							
12- 8	19	21.1	78.9	15	46.7	4.6	0-9
2-21	9	0.0	100.0	9	100.0	4.3	2-6
3-30	2	0.0	100.0	2	100.0	2	2
1966							
1-19	5	0.0	100.0	5	80.0	3.5	0-5

Candona elliptica

Candona elliptica is an elongated, laterally compressed ostracod .8-1.0 mm in length. Males are slightly larger than females and do not exhibit the extreme sexual dimorphism characteristic of many other Gull Lake Candona. C. elliptica was perhaps the most agile of all the burrowing ostracods and often was associated with the phytobenthos.

This species is capable of walking or climbing on the smooth glass surfaces of culture dishes and moves much more rapidly than other species of Candona. Consequently, microscopic sorting of ostracods often was delayed to remove C. elliptica from the sides of the sorting tray or from species already sorted.

Forty-eight Ekman, 1 free-fall core, 58 aquatic net and 1 fish sample contained C. elliptica. Data from the sediment core and fish samples are not included in the following tables. The number of ostracods investigated is summarized below.

	Total No.	No. Adults	No. Juvenile	No. Males	No. Females	No. females exam. for eggs
Gull Lake	503*	374	129	104	264	264
Fish Analyses	1	1	---	1	---	---

* Sex of 6 adults not recorded

C. elliptica was one of the few Candona species whose reproductive cycle spanned the summer months with little overlap into other seasons. This is not surprising when considering the animals' close association with rooted aquatic plants. Locomotive behavior and anatomy of the mouth parts indicate that this ostracod is an epistrate feeder that probably grazes on the attached periphyton of rooted plants. The spatial and depth distributions of C. elliptica also support this assumption. Large numbers of adults were present in shallow reed beds and 6 meter depths where rooted plants were abundant. No specimens were collected from depths greater than 9 meters; this depth corresponds generally to the lower limit of the littoral region, the depth to which rooted aquatics extend. I do not infer that food resource is the only factor which controls the spatial distribution of *C. elliptica*.

The life history of *C. elliptica* is not easily interpreted from data presented in Tables 22-23. The reproductive cycle is clearly indicated, but the growth and development of juveniles and consequent changes in the size and age structure of the population are not readily delineated. Higher temperatures and longer growing seasons at shallower depths may account for the major differences in the size structure of the population at the depths sampled (see Table 22).

The life history of *C. elliptica* is discussed more easily by noting that the reproductive cycle begins in May and ends in September. In August of 1965, adult *C. elliptica* were collected from depths of <3, 3, 6 and 9 meters (Table 22). A majority of the females were gravid and the maximum number of uterine eggs in a given individual was 24. By mid-September, 55 percent (N = 11) of the females from <3 meter samples were oviferous, but presumably near the end of their egg laying period. Most of their eggs were large and located in the posterior portion of the uterus. Fifty-two non-gravid adults collected from late September to mid-October indicated that the reproductive cycle had ended in September (Table 23). I could not determine if the latter adults represented offspring produced during the summer of 1965 or ostracods that had completed their first reproductive cycle.

Immature ostracods were found on 1 November, 4 November, and

Table 22. Percentage of adult and juvenile <u>Candona</u> <u>elliptica</u> in samples collected from Gull Lake.

Date	No. Samples	Transect or Location	N	% Adult	% Juvenile
		<3 meters			
1965					
8- 2	1	KL	1	100.0	0.0
8- 3	2	MN, KL	13	100.0	0.0
9-14	4'	GI, 61, 62, GI	23	100.0	0.0
9-22	10'	GI	6	100.0	0.0
9-27	4'	66	24	100.0	0.0
10- 4	3'	GI	12	100.0	0.0
10-13	4'	GI	2	100.0	0.0
10-18	4'	GI	14	100.0	0.0
11- 1	7'	GI	10	50.0	50.0
1966					
1- 4	5'	GI	12	100.0	0.0
1-11	6'	GI	12	100.0	0.0
2-21	1	AB	4	100.0	0.0
3-26	1	AB	3	100.0	0.0
5-31	5'	GI	46	100.0	0.0
6- 1	1	AB	1	100.0	0.0
6-15	3'	GI	12	100.0	0.0
7- 2	3'	GI	36	30.6	69.4
		3 meters			
1965					
8- 3	2	MN, KL	9	100.0	0.0
8- 5	1	AB	3	100.0	0.0
11- 4	2	AB, EF	5	0.0	100.0
1966					
2-24	4	AB	2	100.0	0.0
3-30	2	AB, IJ	5	80.0	20.0
4-29	1	AB	1	100.0	0.0
5-19	1	AB	3	0.0	100.0
6- 1	2	AB	8	100.0	0.0
6-15	2	AB	9	88.9	11.1
7- 1	1	AB	1	100.0	0.0
7-15	2	AB	8	50.0	50.0
8- 1	2	AB	7	71.4	28.6
		6 meters			
1965					
8- 3	1	KL	7	100.0	0.0
8- 5	1	AB	2	100.0	0.0
11- 4	1	AB	21	23.8	76.2

' Aquatic Net

Table 22. (cont'd.)

Date	No. Samples	Transect or Location	N	% Adult	% Juvenile
		6 meters			
1966					
2-21	1	AB	3	100.0	0.0
3-30	2	IJ	15	13.3	86.7
4-29	1	AB	7	0.0	100.0
5-19	1	AB	15	26.7	73.3
6- 1	2	AB	43	97.7	2.3
6-15	2	AB	45	88.9	11.1
7- 1	1	AB	3	100.0	0.0
7-15	2	AB	12	33.3	66.7
8- 1	2	AB	33	42.4	57.6
		9 meters			
1965					
8- 3	1	KL	2	100.0	0.0
12- 8	1	EF	1	0.0	100.0
1966					
5-19	1	AB	2	0.0	100.0

8 December, respectively, in samples from 0-3, 6, and 9 meters. Adults were in some samples but none had eggs. All of the ostracods collected at depths of <3 meters from early January to mid-June 1966 were mature, but gravid females were not found until 31 May (Table 23).

Non-gravid females, adult males and late instar juveniles were collected throughout the winter and spring of 1966 from 3-9 meter samples. Gravid females were found on 19 May and 1 June, respectively, in 6 and 3 meter samples. Overlapping age classes of juveniles and adults were impossible to differentiate during the summer of 1966. Some juveniles from the previous fall had not matured before the first young of the summer generation began to appear. Most early to mid-summer adults were offspring of the preceding year, but toward the end of the study some adults probably represented early maturing individuals of the summer generation. The maximum number of eggs in gravid females was 30.

Sex ratios were highly variable in most samples because of the small number of adults. Males were more abundant in late summer and early fall than in other seasons at depths of <3 and 3 meters. In samples with over 40 adults less than 35 percent were males.

Table 23. Sex ratio of adult <u>Candona elliptica</u> and average number of eggs in the uterus of adult females. Number and location of samples corresponding to dates are presented in Table 22.

Date	No. Adults	% Male	% Female	No. Females exam. for eggs	% Gravid	Gravid Females Avg. No. eggs/ Ind.	Range No. eggs
				<3 meters			
1965							
8- 2	1	0.0	100.0	1	100.0	6.0	6
8- 3	13	30.8	69.2	9	77.8	3.7	0-6
9-14	23	52.2	47.8	11	54.5	10.7	0-12
9-22	6	---	---	--	---	---	---
9-27	24	29.2	70.8	17	0.0	---	---
10- 4	12	16.7	83.3	10	0.0	---	---
10-13	2	50.0	50.0	1	0.0	---	---
10-18	14	42.9	57.1	8	0.0	---	---
11- 1	5	40.0	60.0	3	0.0	---	---
1966							
1- 4	12	16.7	83.3	10	0.0	---	---
1-11	12	0.0	100.0	12	0.0	---	---
2-21	4	0.0	100.0	4	0.0	---	---
3-26	3	0.0	100.0	3	0.0	---	---
5-31	46	17.4	82.6	38	94.7	6.1	0-23
6- 1	1	0.0	100.0	1	100.0	9.0	9
6-15	12	16.7	83.3	10	90.0	5.8	0-13
7- 2	11	45.4	54.6	6	66.7	9.0	0-18
				3 meters			
1965							
8- 3	9	55.6	44.4	4	100.0	10.0	4-24
8- 5	3	33.3	66.7	2	50.0	8.5	0-17
1966							
2-24	2	0.0	100.0	2	0.0	---	---
3-30	4	25.0	75.0	3	0.0	---	---
4-29	1	0.0	100.0	1	0.0	---	---
6- 1	8	12.5	87.5	7	100.0	6.6	1-13
6-15	8	50.0	50.0	4	100.0	9.8	6-14
7- 1	1	0.0	100.0	1	100.0	28.0	28
7-15	4	75.0	25.0	1	100.0	16.0	16
8- 1	5	40.0	60.0	3	100.0	6.3	4-9
				6 meters			
1965							
8- 3	7	0.0	100.0	7	100.0	10.3	2-18
8- 5	2	0.0	100.0	2	50.0	8.5	0-17
11- 4	5	20.0	80.0	4	0.0	---	---

Table 23. (cont'd.)

Date	No. Adults	% Male	% Female	No. Females exam. for eggs	% Gravid	Gravid Females Avg. No. eggs/ Ind.	Range No. eggs
1966							
2-21	3	0.0	100.0	3	0.0	---	---
3-30	2	50.0	50.0	1	0.0	---	---
5-19	4	25.0	75.0	3	100.0	11.3	8-14
6- 1	42	31.0	69.0	29	69.0	10.4	0-24
6-15	40	32.5	67.5	27	74.1	6.3	0-10
7- 1	3	33.3	66.7	2	100.0	10.5	8-13
7-15	4	0.0	100.0	4	100.0	10.3	4-21
8- 1	14	35.7	64.3	9	88.9	9.0	0-30
				9 meters			
1965							
8- 3	2	50.0	50.0	1	0.0	---	---

Candona porteri

An undescribed species in the Gull Lake ostracod fauna is Candona porteri. I assigned the name C. porteri for convenience of discussion; the new species will be named and described in a future report. C. porteri is one of the larger species of Candona and reaches a maximum length of nearly 2 mm. The male is similar in shape and slightly larger than the female. Late instar juveniles resemble the adult, but the first four instars are not easily identified.

C. porteri was collected from 28 Ekman dredge samples and 8 free-fall sediment cores. Two adults and 2 juveniles from 4 of the sediment cores are not considered in the tables below. The number of specimens examined is presented in the following summary.

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	921*	416	505	126	288	282

* Sex of two adults not recorded

The summer reproductive cycle of C. elliptica in the littoral region of Gull Lake had its closest sublittoral counterpart in C. porteri. This species essentially was restricted to depths greater than 9 meters. Only 1.2 percent (N = 921) of the ostracods were found at depths less than 12 meters; 3 were adults (Table 24).

Early instar juveniles were collected on 19 January 1966 at a depth of 15 meters, but were not encountered again until 19 May. Four gravid females were found in late May and April samples from the above depth. These females presumably were among the earliest

Table 24. Percentage of adult and juvenile *Candona porteri* in samples collected from Gull Lake.

Date	No. Samples	Transect or Location	N	% Adult	% Juvenile
		6 meters			
1966					
7-15	1	AB	1	100.0	0.0
		9 meters			
5-19	1	AB	1	100.0	0.0
6-15	2	AB	9	11.1	89.9
		12 meters			
5-19	1	AB	49	36.7	63.3
6- 1	2	AB	184	57.6	42.4
6-15	2	AB	123	94.3	5.7
7- 1	2	AB	90	54.4	45.6
7-15	2	AB	151	67.5	32.5
		15 meters			
1-19	2*	IJ	11	0.0	100.0
3-30	1	AB	2	100.0	0.0
4-29	1	AB	2	100.0	0.0
5-19	1	AB	4	50.0	50.0
6- 1	2	AB	34	0.0	100.0
6-15	2	AB	28	14.3	85.7
7- 1	2	AB	94	6.4	93.6
7-15	2	AB	73	0.0	100.0
		18 meters			
6- 1	2	AB	61	6.6	93.4

* Free Fall Cores

to mature as no specimens were found in samples from other depths until 19 May.

Data in Table 24 indicate that the reproductive cycle of C. porteri began before 19 May. However, most specimens were immature and males were more abundant than females at the 12 meter depth. In every other species of Candona studied, the proportion of the males was always highest during the initial phase of the reproductive cycle. Table 25 shows the marked change in adult sex ratios during the early summer. Of 26 eighth instar juveniles sexed on 19 May, 54 percent were males; 56 percent of the adults collected on this date were males. The latter comprised 51 percent (N = 106) of the adults on 1 June, but the percentage of males decreased markedly thereafter. Estimates of the number of males per square meter at 12 meter depths on 1 June-15 June and 1 July-15 July were, respectively, 1169, 693, 238, 346.

The percentage of gravid females in 12 meter samples increased during June and July and all females from 15 meter depths were oviferous. The number of adults per square meter, estimated from replicated 12 meter samples, ranged between about 2200-2500 in June and July. A low estimate of 1060 on 1 July may be strongly biased, but this cannot be stated with certainty.

No samples were collected from depths of 12 and 15 meters after 15 July 1966. However, the absence of C. porteri in October and November 1965 samples suggests that the 1966 reproductive cycle probably ended by September or early October.

Table 25. Sex ratio of adult <u>Candona porteri</u> and average number of eggs in the uterus of adult females. Number and location of samples corresponding to dates are presented in Table 24.

Date	No. Adults	% Male	% Female	No. Females exam. for eggs	% Gravid	Gravid Females Avg. No. eggs/ Ind.	Range No. eggs
				6 meters			
1966							
7-15	1	0.0	100.0	1	100.0	3.0	3
				9 meters			
5-19	1	0.0	100.0	1	100.0	4.0	4
6-15	1	0.0	100.0	1	100.0	14.0	14
				12 meters			
5-19	18	55.6	44.4	8	50.0	6.0	6
6- 1	106	50.9	49.1	52	75.0	4.7	0-9
6-15	116	27.6	72.4	84	95.2	6.5	0-11
7- 1	49	22.4	77.6	38	97.4	6.1	0-12
7-15	102	15.7	84.3	80	100.0	7.7	1-13
				15 meters			
3-30	2	0.0	100.0	2	100.0	4.5	4-5
4-29	2	0.0	100.0	2	100.0	3.4	2-5
5-19	2	50.0	50.0	1	100.0	8.0	8
6-15	4	0.0	100.0	4	100.0	7.5	2-12
7- 1	6	33.3	66.7	4	100.0	3.0	2-4
				18 meters			
6- 1	4	0.0	100.0	4	100.0	3.0	1-6

Candona aff. caudata

Male C. caudata were not reported in the original species description or in most subsequent papers. In addition, several morphologic features of the carapace in specimens from Gull Lake differ slightly from those described by other investigators. Assignment of the specific name, therefore, is tentative, but recognition of ostracods that I call C. aff. caudata is positive. Males are larger than females and strongly dimorphic. This species is intermediate in size between C. acuta and C. porteri.

Thirty-two Ekman, 7 free-fall core and 2 fish samples contained C. aff. caudata. Five sediment cores and the fish samples are not considered in Tables 26 and 27; however, data from one Ekman dredge sample collected on 23 January 1965 are included. The number of specimens examined is presented below.

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	880*	581	294	102	479	374
Fish Analyses	476	476	---	398	78	---

* Sex of 5 individuals undetermined

Excluding 4 specimens from 9 meter depths, C. aff. caudata was found only in the sublittoral areas of Gull Lake. This species was first collected on 4 November 1965 from depths of 12 and 15 meters (Table 26). Less than 25 percent (N = 326) of the ostracods were mature, and the females were non-gravid. Almost one-half of the individuals had weakly calcified valves. In addition, males constituted 45 and 39 percent of the adult totals, respectively, in 12 and 15

Table 26. Percentage of adult and juvenile <u>Candona</u> aff. <u>caudata</u> in samples collected from Gull Lake.

Date	No. Samples	Transect or Location	N	% Adult	% Juvenile
		9 meters			
1966					
5-19	1	AB	2	50.0	50.0
6- 1	1	AB	2	100.0	0.0
		12 meters			
1965					
1-23	1	IJ	134	100.0	0.0
11- 4	3	AB, CD, GH	246	22.4	77.6
12- 8	1	EF	27	81.5	18.5
1966					
2-21	1	AB	32	100.0	0.0
3-30	2	AB, IJ	58	100.0	0.0
4-29	1	AB	27	77.8	21.2
5-19	1	AB	7	100.0	0.0
6- 1	2	AB	20	100.0	0.0
6-15	2	AB	5	100.0	0.0
		15 meters			
1965					
11- 4	3	AB, EF, GH	86	15.1	84.9
1966					
3-30	2	AB, IJ	109	90.8	9.2
4-29	1	AB	50	84.0	16.0
5-19	1	AB	18	100.0	0.0
6- 1	2	AB	14	100.0	0.0
6-15	2	AB	16	100.0	0.0
7- 1	2	AB	8	100.0	0.0
7-15	1	AB	1	100.0	0.0
		18 meters			
1-19	2*	IJ	2	100.0	0.0
6- 1	2	AB	11	100.0	0.0

* Free Fall Cores

meter samples. Based on evidence above and knowledge of the general reproductive patterns of other Candona species, I believe it reasonable to conclude that C. aff. caudata was just beginning the reproductive cycle in early November.

Nearly 82 percent of the ostracods were mature in one 12 meter sample on 8 December and 58 percent of the females were gravid. The average number of uterine eggs per individual was 4.7 and the maximum number was 9 (Table 26). Two adults collected in January 1966 were not sexed.

Data from one 12 meter sample collected on 23 January 1965 indicate that the annual reproductive cycle of C. aff. caudata began about the same time in both years. Twenty-five females from the above sample had an average of 7.0 eggs per individual with a range of 3-11 (Table 27). Males comprised only 12 percent (N = 134) of the sample.

Oviferous females must have deposited the majority of their eggs between mid-December 1965 and late February 1966. The average number of uterine eggs was less than 6.0 in females collected from February through mid-July. The maximum number of eggs in a given individual was 18. Every gravid female examined from 12 and 15 meter samples had either released most of her eggs or was just beginning to reproduce.

Data on the average and maximum number of eggs found in samples of C. aff. caudata accurately represent the reproductive condition of the individuals examined. However, these data reveal almost nothing about the actual number of eggs laid by individuals of this species. The size of adult females and the space occupied by uterine eggs in those individuals examined indicate that at least 30 eggs could be held in the uteri of a single female. In other species of Candona studied the uterus on each side of the body was greatly distended before the first eggs were released.

Most ostracods collected from February to 15 July were mature. The number of individuals and the maximum and average number of eggs in gravid females gradually decreased during this period. No _C_. aff. _caudata_ were collected from 12 meter samples after 15 June; 9 adults were found in 15 meter samples from 15 June-15 July. About 30 dead females were sampled from May-July, and in June-July most living adults were inactive, emaciated, and obviously near physiological death.

The percentage of males in the population was greatest in the initial stages of the reproductive cycle. On 4 November, 45 percent of the 12 meter adults were males, but by 8 December they had decreased to about 16 percent. From February through 15 June females constituted a minimum of 87 percent of the adults in each sample. The percentage of males in 15 meter samples decreased less abruptly, but followed the same pattern observed in 12 meter samples.

Table 27. Sex ratio of adult Candona aff. caudata and average number of eggs in the uterus of adult females. Number and location of samples corresponding to dates are presented in Table 26.

Date	No. Adults	% Male	% Female	No. Females exam. for eggs	% Gravid	Gravid Females Avg. No. eggs/ Ind.	Range No. eggs
			9 meters				
1966							
5-19	1	0.0	100.0	1	100.0	18.0	18
6- 1	2	0.0	100.0	2	100.0	9.0	4-14
			12 meters				
1965							
1-23	134	11.9	88.1	25	100.0	7.0	3-11
11- 4	55	45.4	54.6	30	0.0	---	---
12- 8	22	15.8	84.2	19	57.9	4.7	0-9
1966							
2-21	32	12.5	87.5	21	100.0	5.8	2-11
3-30	58	8.6	91.4	53	96.2	3.6	0-7
4-29	21	9.5	90.5	19	89.5	4.5	0-9
5-19	7	0.0	100.0	6	66.7	5.8	0-6
6- 1	20	5.0	95.0	19	84.2	2.7	0-4
6-15	5	0.0	100.0	5	100.0	2.6	1-5
			15 meters				
1965							
11- 4	13	38.5	61.5	8	0.0	---	---
1966							
3-30	99	28.3	71.7	71	98.6	4.9	0-10
4-29	42	16.7	83.3	31	100.0	5.9	1-11
5-19	18	11.1	88.9	16	93.8	4.7	0-8
6- 1	14	0.0	100.0	14	100.0	4.3	1-7
6-15	16	0.0	100.0	16	93.8	4.4	0-7
7- 1	8	12.5	87.5	7	57.1	3.3	0-4
7-15	1	100.0	0.0	--	---	---	---
			18 meters				
1-19	2	100.0	0.0	--	---	---	---
6- 1	11	0.0	100.0	11	100.0	4.3	2-7

Other Non-Swimming Species

The eight species of ostracods discussed below accounted for 5.9 percent of the total number of non-swimming animals identified to species. A summary of the number of ostracods investigated is followed by a brief discussion of each species. No results are presented in tabular form, but certain observations are supported by emperical data.

Candona scopulosa

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	377	314	63	112	202	189

Aside from a single juvenile collected on 8 December 1965, *C. scopulosa* was found only in February and March of 1966, at depths of <3 meters. Seventy-seven percent (N = 167) of the February specimens were mature and about 68 percent (N = 77) of the females were gravid. The latter averaged 10.8 eggs per individual, but the maximum number was 26. In March 89 percent (N = 209) of the ostracods were mature and 94 percent (N = 112) of the females were oviferous. The average number of eggs per gravid individual was 8.2 and the maximum, 21. Males were relatively abundant; in February they constituted slightly more than 35 percent (N = 128) of the adults and in March 36 percent (N = 186).

This species may have more than one generation per year as indicated by the presence of several gravid females in <3 meter samples in the summer of 1967.

Candona aff. suburbana

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	274	63	211	30	33	33

This species was found in the littoral areas of Gull Lake. Five ostracods were from 9 meter samples, but over 75 percent came from depths of 0-3 meters. One hundred percent (N = 274) of the ostracods collected from August-December 1965 were juveniles.

The reproductive cycle of C. aff. suburbana apparently began by January 1966 as all February specimens (N = 60) were mature and more than one-half of the females were gravid. The average number of eggs in oviferous females was about 12 and the maximum 25. Two females and 1 male were collected in March and April; each female had 10 uterine eggs. The sex ratio was essentially equal in February with 29 males and 31 females.

Hundreds of gravid females not considered here were collected from organic rich substrates in March and April of 1967.

Candona decora

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	131	131*	2	22	89	13
Fish Analyses	1	1	-	1	--	--

* Sex of 20 adults undetermined

C. decora was found in 1 fish, 5 aquatic net and 2 Ekman samples. Two specimens were collected from 9 meters, 1 from 12 meters and 130 at depths of <3 meters. Non-reproductive adults were first encountered in early December 1965. By January 1966, females were gravid and all individuals were mature. On 11 February, 8 gravid females averaged 23.8 eggs per individual; the maximum number of eggs was 32. Several oviferous females were sampled in early April. Males constituted less than 35 percent of the adults in all samples.

Candona crogmaniana

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	64	21	43	8	13	13
Fish Analyses	3	3	--	-	3	--

C. crogmaniana was collected from depths of 0-15 meters. Juveniles were found in October. By 4 November late instar juveniles, non-gravid adults and a few gravid females were present; six gravid ostracods had a mean of 9.0 eggs and a maximum of 13. In February, 1 female carried 67 eggs and another, 69. Three oviferous females had a mean of 24.3 and a maximum of 41 uterine eggs in late March.

Candona sp.

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	45	2	43	1	1	--

This species was collected in late March 1966 from depths of 1-2 meters. Early to late instar juveniles and two recently molted adults indicated that the reproductive cycle of _C_. sp. had just begun.

Candona distincta

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	2	2	--	--	2	--

Two gravid females were collected from a depth of 9 meters in June of 1966.

Limnocythere verrucosa

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	26	4	22	1	3	--

This species was found in August-September 1965 and June-July 1966, at depths of <1-15 meters. _L. verrucosa_ was more abundant than indicated by the summary above, but was not easily separated from sediment using the water surface tension technique. Empty carapaces were abundant in the lake sediment.

Cytherissa lacustris

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	3	3	--	--	3	--

No living representatives of this species were collected. Three specimens apparently had died shortly before they were collected because all appendages were intact and soft tissues such as muscles had not decomposed. Empty carapaces were abundant in 12 and 15 meter samples.

Free-Swimming Species

Cypridopsis vidua

Free-swimming ostracods were not sampled quantitatively and in many instances not in relation to their numerical dominance over other species. Nevertheless, these ostracods often were extremely abundant and surely accounted for a large share (if not most) of the standing crop of ostracods in the littoral areas during the summer months.

Cypridopsis vidua is perhaps the most cosmopolitan of all freshwater ostracods and is found in a great variety of aquatic habitats. This ostracod is easily identified and probably is the best known species in the United States. Few investigators, however, have studied populations in nature. An excellent account of the anatomy and biology of *C. vidua* was given by Kesling in 1951. *C. vidua* reproduces parthenogenetically, but young are not retained by the parent as in *Darwinula*.

Seventy-one Ekman, 66 aquatic net, and 5 sediment cores contained *C. vidua*. Results of fish stomach analyses are not included in Table 28, but data collected in July 1965 are incorporated. The number of specimens examined is presented below.

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	1143	742	401	--	742	596
Fish Analyses	120	120	---	--	120	---

C. vidua inhabited the littoral region of Gull Lake; one adult from 12 meters and one juvenile from 18 meters were the only exceptions. Juveniles and adults, including gravid females, were collected in every month of the study. Overlapping age groups were impossible to differentiate. Some juveniles were recruited into the adult size group each month and, when gravid, could not be distinguished from older adults.

There were three rather vaguely defined generations produced during the study period. The first reproductive period was in November and December of 1965. This generation of adults likely represented offspring of the preceding summer. The maximum number of uterine eggs in one adult was 17. A second reproductive period occurred in March and April. The third and most distinct reproductive cycle was in the summer of 1966. Almost 90 percent (N = 244) of the ostracods were mature and 86 percent (N = 93) of those examined were gravid (Table 28). The largest number of eggs per individual was observed in the summer months with a maximum of 21 eggs in several females.

Table 28. Adult-juvenile ratio and reproductive state of adult *Cypridopsis vidua* in composite monthly samples from Gull Lake. Samples include individuals collected at depths of from <1 to 9 meters on different dates and from different localities.

Month	No. Samples Ekman	Net-Core	Total No.	% Adult	% Juvenile	No. exam. for eggs	% Gravid	Range No. eggs
1965								
July	11	2	430	46.0	54.0	200	64.0	0-13
Aug.	5	3	35	51.4	48.6	14	50.0	0-4
Sept.	--	12	43	62.8	37.2	37	48.6	0-6
Oct.	1	17	121	74.4	25.6	80	45.0	0-4
Nov.	6	7	16	93.8	6.2	11	36.4	0-5
Dec.	2	4	19	84.2	15.8	4	100.0	2-17
1966								
Jan.	--	12	19	89.5	10.5	17	11.8	0-1
Feb.	12	--	19	78.9	21.1	15	20.0	0-2
Mar.	10	--	52	84.6	15.4	44	65.9	0-6
Apr.	2	--	3	66.7	33.3	--	---	---
May	2	8	41	75.6	24.4	29	96.6	0-9
June	7	3	92	51.1	48.9	46	37.0	0-9
July	9	3	244	88.9	11.1	93	86.0	0-21
Aug.	4	--	9	66.7	33.3	6	16.7	0-10

Physocypria pustulosa

Physocypria pustulosa was extremely abundant in or near thick growths of rooted plants such as Najas or Potamogeton. Although density estimates were not calculated for this species, means of quantitative samples would have resulted in estimates of about 100,000 individuals, or more, per square meter.

P. pustulosa was collected from depths of <1-15 meters, but less than 2 percent (N = 522) were from depths greater than 9 meters. The number of ostracods examined is presented below.

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	522*	464	55	215	215	146

* Sex of 34 adults not recorded

Juveniles or adults were present throughout the study. No specimens were collected in January 1966 (Table 29), but this was a bias in sampling and did not denote the absence of P. pustulosa in Gull Lake.

The major reproductive cycle occurred in the summer months. In August 1965, gravid females carried an average of nearly 6 eggs per individual, but in October and November all females were non-gravid. The latter possibly represented the early maturing offspring of the summer adults (Table 30). By December some females were oviferous. I do not know if a second egg laying cycle began before the summer of 1966. The range in the number of eggs observed in February and March (Table 30) may indicate that some females deposited their eggs in March. The maximum number of eggs in July and August adults was 10.

The proportion of males was lowest in summer samples and highest in February and March. Males also were more abundant than females in April samples, but those specimens collected were used in other studies and are not enumerated in Table 30.

Table 29. Percentage of adult and juvenile Physocypria pustulosa from Gull Lake. Samples represent composite monthly collections from different localities and depths.

Date	No. Samples'	Total No.	% Adult	% Juvenile
1965				
Aug.	2	18	100.0	0.0
Sept.	6'	29	75.9	24.1
Oct.	2, 1'	23	73.9	26.1
Nov.	10	73	87.7	12.3
Dec.	4	25	64.0	36.0
1966				
Jan.	--	--	---	---
Feb.	6	197	97.5	2.5
Mar.	7	38	81.6	18.4
Apr.	2	7	---	---
May	2, 1'	4	100.0	0.0
June	10	54	77.8	22.2
July	7	24	100.0	0.0
Aug.	5	30	90.0	10.0

' Aquatic Net and Core Samples

Table 30. Sex ratio and reproductive cycle of adult <u>Physocypria pustulosa</u> collected from Gull Lake.

Date	N	% Male	% Female	No. Females exam.	% Gravid	Gravid Females Avg. No. eggs/ Ind.	Range No. eggs
1965							
Aug.	18	44.4	55.6	10	70.0	5.6	0-10
Sept.	22	40.9	59.1	4	75.0	3.0	0-6
Oct.	17	47.1	52.9	7	0.0	---	---
Nov.	64[1]	51.4	48.6	18	0.0	---	---
Dec.	16	31.3	68.7	11	27.3	3.0	0-6
Jan.	--	---	---	--	---	---	---
Feb.	192	61.5	38.5	17	17.6	3.7	0-8
Mar.	31	71.0	29.0	8	37.5	2.0	0-2
Apr.	7[2]	---	---	--	---	---	---
May	4	25.0	75.0	3	66.7	5.0	0-6
June	42	23.8	76.2	30	86.7	5.8	0-9
July	24	25.0	75.0	18	83.3	5.9	0-10
Aug.	27	25.9	74.1	20	65.0	3.8	0-6

1 Sex not recorded for 27 adults
2 Sex not recorded for 7 adults

Cypria turneri

This ostracod was one of the most abundant species in Gull Lake. No other ostracod was as uniformly dispersed, geographically or with depth, as C. turneri. The latter was found at depths of a few millimeters to 32 meters and was present in every major substrate sampled. Ten sediment core, 29 aquatic net and 116 Ekman samples contained C. turneri. Fish stomach analyses are not considered in the following tables. The number of ostracods studied is presented below.

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	4006	2325[1, 2]	44	500	1585	1555
Fish Analyses	29	29	--	---	---	---

1 Aliquot of 460 individuals represents estimate for 2097 animals collected on 4 February.
2 Sex undetermined for 240 adults.

The number of C. turneri collected each month (Table 31) did not reflect its actual abundance. C. turneri usually was the numerically dominant species at 9 meters, but was more numerous at other depths. Juveniles were collected only in the summer months (Table 31) which indicated a single generation per year and possibly an annual turnover of the population.

The average and maximum number of eggs in gravid females is not presented in Table 32, but the reproductive state of females is noted. Most females were oviferous in November-January, but a few gravid individuals were collected in February and early March.

Juveniles of the summer generation, 1965, matured and reproduced in November-December and laid their eggs before February 1966 (except those noted in Table 32*). The first juveniles of the next generation began to appear in June. These young had not completely replaced the parental stock by August 1966. In late July and early August samples, recently molted adults were less pigmented than older ostracods and were easily detected. About 70 percent of the animals were newly recruited adults. The high percentage of males in October of 1965 also indicated that most were new recruits from the preceding summer generation.

Table 31. Percentage of adult and juvenile *Cypria turneri* in composite monthly samples collected from different localities and depths in Gull Lake.

Date	No. Samples	Total No.	% Adult	% Juvenile
1965				
Aug.	6, 1'	235	99.1	0.9
Sept.	4'	2	100.0	0.0
Oct.	2, 3'	64	100.0	0.0
Nov.	20, 7'	269	100.0	0.0
Dec.	4, 4'	301	100.0	0.0
1966				
Jan.	13	21	100.0	0.0
Feb.	15	125	100.0	0.0
*	4	2097	100.0	0.0
Mar.	15	180	100.0	0.0
Apr.	5	47	100.0	0.0
May	3, 7'	27	100.0	0.0
June	20	219	89.5	10.5
July	16	298	94.0	6.0
Aug.	6	121	100.0	0.0

' Aquatic Net and Core Samples

* Four samples from small shallow man made lagoon with outlets directly to Gull Lake along Transect AB. Total represents aliquots from 4 samples and adult-juvenile percentages derived from an aliquot of 460 adults from the sample.

Table 32. Sex ratio and reproductive state of _Cypria turneri_ collected from Gull Lake.

Date	N	% Male	% Female	No. Females Examined	With eggs
1965					
Aug.	233	---	---	---	--
Sept.	2	---	---	---	--
Oct.	64	43.8	56.2	35	No.
Nov.	268	17.2	82.8	200	Yes
Dec.	301	21.6	78.4	236	Yes
1966					
Jan.	21	23.8	76.2	16	Yes
Feb.	125	14.4	85.6	107	No
*	460	35.4	64.6	297	Yes
Mar.	180	16.1	83.9	151	No[1]
Apr.	47[2]	21.4	78.6	33	No
May	27	14.8	85.2	16	No
June	196	24.0	76.0	149	No
July	280	17.5	82.5	231	No
Aug.	121	30.6	69.4	84	No

* See Table 31 for explanation. Aliquot of 460 adults from larger sample.

1 Three of 180 females with eggs

2 Sex of 5 adults not recorded

Other Free-Swimming Species

Cyclocypris ampla

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	474	393	81	---	---	226
Fish Analyses	4	4	--	---	---	---

The sex ratio of *Cyclocypris ampla* is not recorded in Table 33. Many individuals died with their valves completely closed and could not be dissected without destroying the carapace.

Non-reproductive adults were collected from August through December 1965 (Table 33). The reproductive cycle began by February 1966 and continued to June. Gravid females carried a maximum of 10 uterine eggs. Early instar individuals had hatched by June and passed through successive molts to the adult instar by August 1966. All but 9 *C. ampla* were collected from depths of 0-3 meters. This ostracod is a powerful swimmer and capable burrower.

Cyprinotus glaucus

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females
Gull Lake	1569	842	727	260	582
Fish Analyses	7	---	7	---	---

C. glaucus had the most restricted temporal distribution of any ostracod in Gull Lake and probably the most rapid population growth rate. Individuals of this species passed through 8 successive molts to the adult instar and began reproducing within about one month

Table 33. Percentage of adult and juvenile *Cyclocypris ampla* in composite monthly samples from Gull Lake. Only 3 individuals from depths greater than 9 meters.

Date	No. Samples	Total No.	% Adult	% Juvenile	Females Gravid
1965					
Aug.	2, 2'	18	100.0	0.0	No
Sept.	9'	3	100.0	0.0	No
Oct.	1'	1	100.0	0.0	No
Nov.	4	6	100.0	0.0	No
Dec.	2	2	100.0	0.0	No
1966					
Feb.	15	44	100.0	0.0	Yes
Mar.	8	63	100.0	0.0	Yes
Apr.	1	4	100.0	0.0	Yes
May	1, 1'	21	100.0	0.0	Yes
June	4	33	36.4	63.6	Yes
July	6	184	67.4	32.6	No
Aug.	2	95	100.0	0.0	No

' Aquatic Net

Maximum eggs is 10 during February.

from the time of hatching. Juveniles were abundant in May 1966, and had matured and begun to reproduce by 1 June (Table 34). The life cycle ended in September of 1965; this also was true in 1967. The maximum number of eggs observed in gravid females was 15. This ostracod may be the most abundant free-swimmer in the littoral region during the summer period; in biomass, I am certain that *C. glaucus* is one of the littoral dominants. Most data concerning *C. glaucus* are not yet analyzed.

Potamocypris smaragdina

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	31	30	1	--	--	--
Fish Analyses	1	1	-	--	--	--

P. smaragdina was collected in July and August 1965 and July 1966 from depths less than 3 meters. Some females were gravid in August 1965, but eggs were not counted.

Cyclocypris cruciata

	Total No.	No. Adults	No. Juveniles	No. Males	No. Females	No. females exam. for eggs
Gull Lake	15	15	--	2	7	3

Cyclocypris cruciata was collected from depths of 3-12 meters, but most were found at depths less than 9 meters. Females were gravid in the summer, but not in October or February.

Table 34. Sex ratio and juvenile - adult percentages of <u>Cyprinotus glaucus</u> collected from Gull Lake.

Date	No. Samples	N	% Adult	% Juvenile	No. Adult	% Male	% Female
1965							
July	3'	1189	63.7	36.3	757	30.1	69.9
Aug.	3'	32	71.9	28.1	23	13.0	87.0
Sept.	8'	16	100.0	0.0	16	50.0	50.0
1966							
May	5'	91	0.0	100.0	--	---	---
June	2, 3'	36	47.2	52.8	17	23.5	76.5
July	1, 3'	205	14.1	85.9	29	58.6	41.4

' Aquatic Net Samples

All less than 6 meters
Majority at 3 meters or less

Fish Stomach Anaylses

Ostracods were found in the stomach and intestines of three species of fish from Gull Lake. The yellow perch, *Perca flavescens* (Mitchill), bluegill, *Lepomis macrochirus* Rafinesque, and smelt, *Osmerus mordax* (Mitchill), were the only species examined.

Four perch were captured in one inch gill nets from depths of 6-9 meters, along Transect IJ, on 2 December 1965. They were killed immediately following capture; the standard length of each individual was less than 100 mm. Two male and one female *Candona ohioensis* and one male *C. decora* were found in the stomach of one fish. The stomachs and intestines of the other fish were empty.

On 9 January 1966, 15 perch were collected in gill nets from a depth of 15 meters. These specimens were caught near the base of the net shortly before it was retrieved. The perch ranged in length from 91-143 mm; only one was longer than 116 mm. The stomach and gut contents of each individual were carefully examined under a dissecting microscope.

A total of 1322 ostracods representing 7 species and 2 genera were collected. Of this number 760 were identified to species and the remainder to genus. All of the ostracods were mature; most individuals identified only to genus could have been identified to species had time permitted. The concentration of ostracods and other organisms in discrete groups in the stomachs and intestines of most fish clearly indicated selective feeding for each food organism. In addition, the ostracods were completely free of debris even though most were non-swimmers. Males were dominant numerically in those species identified only to genus, but accurate counts of each sex were not recorded.

Ostracods were found in 13 perch and were dominant, in number and biomass, in 7. Cladocera and tendipedid larvae were dominant food organisms in eight fish. Table 35 shows the number of ostracods of each species, sex, and percentage of males. Candona ohioensis, C. aff. caudata and C. acuta were the most abundant species; males of the last two species comprised more than 50 percent of the total sample.

Three perch were examined on 13 February 1966. These specimens were collected in gill nets along Transect IJ at a depth of 16 meters. Two perch contained ostracods, but the third had only 2 tendipedid larvae in its stomach. One fish yielded 136 ostracods representing 5 species in two genera: Candona ohioensis, C. acuta, C. aff. caudata, C. inopinata and Cypria turneri. C. aff. caudata was most abundant with C. acuta second and C. ohioensis third. Males comprised nearly 64 percent of the 69 C. aff. caudata, a much higher percentage than was ever found in sediment core or Ekman dredge samples. Only 14.3 percent of 28 C. acuta and 25 percent of the 4 C. ohioensis were male. Thirty-three specimens were identified only to genus but all belonged to Candona. The second perch had 4 male C. aff. caudata and 40 tendipedid larvae in the intestine. The fish ranged in length from 91-95 mm.

Thirteen bluegill (L. macrochirus) were captured and dissected on 19 July 1966. The animals were collected from gill nets in the shallow water littoral areas along Transect AB. Four fish had no organisms in the stomach or gut and only three fish contained ostracods. One hundred sixty-seven ostracods were found in the stomachs of the three fish. There were 120 adult Cypridopsis vidua, 4 Cyclocypris ampla, 7 C. cruciata, 1 Potamocypris smaragdina, 7 juvenile Cyprinotus *glaucus*, 27 juvenile *Candona rawsoni* and 1 *C. elliptica*.

The stomach and intestines of most fish contained appreciable quantities of plant debris, small sand grains and other organisms. The latter included amphipods, beetle larvae, tendipedid larvae, tricopteran larvae, water mites, snails, annelids and small minnows. The bluegills obviously were far less discriminate in their feeding behavior than were the perch. Nevertheless, they demonstrate that fish predators contribute to the mortality of juvenile ostracods as well as adults.

Three adult *Cypria turneri* were found in the stomachs of 2 smelt (*O. mordax*) collected in September and October 1966. These fish were collected in an Issacs Kidd trawl from depths of 12 and 20 meters.

Table 35. Summary of the number, sex, and percentage of male ostracods removed from 15 yellow perch (*Perca flavescens*) collected in Gull Lake on 9 January 1966.

Species	Total No.	Male	Female	Percent Male
Candona ohioensis	159	10	149	6.3
Candona acuta	152	96	56	63.2
Candona aff. *caudata*	403	350	53	86.8
Candona inopinata	14	6	8	42.9
Candona crogmaniana	3	0	3	0.0
Candona rawsoni	1	1	0	100.0
Candona spp.	562	--	--	---
Cypria turneri	28	--	--	---

DISCUSSION

Distribution

The geographic distribution of many freshwater ostracods in the United States is scarcely known. This is particularly true in regard to the burrowing, non-swimming species. Several species of the Gull Lake ostracod fauna are widely dispersed or have fossil records which indicate more expansive distribution than currently known. Most of the difficulty in assessing the distribution of a given species results from the limited number of investigations of the Ostracoda in the United States.

The ostracod faunas of relatively few states have been studied. Among those works which deserve special note are studies by Furtos (1933) Ohio, (1935) Massachusetts, (1936a) Florida and North Carolina; Hoff (1942) Illinois; Dobbin (1941) Washington; Danforth (1948) Iowa; Tressler (1954) Texas; Ferguson (1954, 1958a) South Carolina, (1957) Michigan, (1962) Louisiana; and Cole (1965, 1966) Tennessee. Other authors (e.g. Moore 1939; Hoff 1943b) have studied the ostracod faunas of more restricted areas.

Some problems arise from taxonomic error. A good example is the ostracod *Candona rawsoni*. This species was described by Tressler (1957a) from the Great Slave Lake, Canada. Unfortunately, Tressler erred in the description of an important taxonomic feature of the carapace. Thus, Gutentag and Benson (1962) described the same species from Pleistocene deposits in Kansas as *C. nyensis*. Later, Benson and

MacDonald (1963) reported _C. nyensis_ in sediments of Lake Erie, and Staplin (1963a) described it (_C. swaini_) from Pleistocene deposits of Illinois. Swain (1947) had reported this species from Pleistocene deposits of Utah and Bronstein (1947) described the ostracod from the U.S.S.R. under the name _C. obtusa_. Finally, Delorme (1967c) examined the collections of Tressler and clarified the taxonomic status of _C. rawsoni_. He found (1967b) _C. rawsoni_ in Canadian lakes and later (1968) in Pleistocene sediments from the Yukon.

Most of the free-swimming species in Gull Lake also have a wide geographic range. _Cyprinotus glaucus_ and _Cyclocypris ampla_ recently were reported from Canada (Delorme 1967b) and from Pleistocene deposits in the Yukon (Delorme 1968). These two species formerly were known only in the midwestern United States.

Some distribution records of fossil and living ostracods representing certain Gull Lake species are summarized below.

Candona ohioensis

Ohio-(Lake Erie) Furtos (1933); (Pleistocene) Winkler (1962)
Indiana-(Pretty Lake) McGregor (this thesis)
Michigan-(Gull Lake) McGregor and Wetzel (1968)
Canada-(Saskatchewan) Delorme (1967a, 1967b); (Manitoba-Pleistocene) Klassen et al. (1967)

Candona inopinata

Ohio-Furtos (1933)
Michigan-McGregor and Wetzel (1968)

Candona rawsoni

Utah-(Pleistocene) Swain (1947)
Kansas-(Pleistocene) Gutentag and Benson (1962)
Illinois-(Pleistocene) Staplin (1963a)
Ohio-(Holocene) Benson and MacDonald (1963)
Michigan-(Gull Lake) McGregor and Wetzel (1968); (Lake Michigan) McGregor (this thesis)
Canada-(Great Slave Lake) Tressler (1957a); (Saskatchewan) Delorme (1967a, 1967b); (Manitoba-Pleistocene) Klassen et al. (1967); (Yukon-Pleistocene) Delorme (1968)

Candona acuta

Illinois-Hoff 1942
Michigan-McGregor (this thesis)
(Lake Michigan) McGregor (this thesis)
Canada-(Manitoba-Pleistocene) Klassen et al. (1967); (Saskatchewan) Delorme (1967b)

Candona crogmaniana

Ohio-Furtos (1933)
Michigan-Moore (1939); Kenk (1949); (Holocene) Winkler (1960); (Lake Michigan) McGregor (this thesis)
Illinois-Hoff (1942); (Pleistocene) Staplin (1963a)
Iowa-Danforth (1948)
Kansas-(Pliocene-Pleistocene) Gutentag and Benson (1962)
Georgia-Turner (1895)
Canada-(Great Slave Lake) Tressler (1957a)

Candona elliptica

Ohio-Furtos (1933)
Iowa-Danforth (1948)
Michigan-McGregor (this thesis)
Massachusetts-Furtos (1935)
Tennessee-Hoff (1943a)
S. Carolina-Ferguson (1954, 1958a)

Candona caudata

Massachusetts-Furtos (1935)
Illinois-Hoff (1942)
Ohio-(Pleistocene) Winkler (1962); (Lake Erie-Holocene) Benson and MacDonald (1963)
Kansas-(Pleistocene) Gutentag and Benson (1962)
Washington-Dobbin (1941); Scheffer and Robinson (1939)
Canada-(Recent and Pleistocene) Delorme (1967a, 1967b, 1968)

Ferguson reviewed the taxonomy and distribution of several species common to Gull Lake. In 1944, he reported *Potamocypris smaragdina* from Missouri and later (1954, 1958a) from S. Carolina. The following year Ferguson (1959b) published a synopsis of the genus including description of a new species. Still later he recorded *P. smaragdina* from Louisiana (1962) and Wyoming (1966) and listed it as one of 10 United States species in his (1967b) taxonomic key. Ferguson (1959a, 1967a) also studied the taxonomy and distribution of *Cypridopsis* and *Cyprinotus*.

Freshwater ostracods are more widely distributed, geographically and ecologically, than most aquatic biologists are aware. Many species tolerate a broad range of chemical and physical conditions and are associated with a diverse array of aquatic organisms. For example, freshwater ostracods have been reported from saline ponds and brackish-water habitats (deVos 1954; Neale 1965; Latour et al. 1966; Hulings 1967), caves and subterranean waters (Klie 1934, 1936; Löffler 1963), hot springs (Moniez 1893; Castenholtz 1967), bromeliad leaves (Tressler 1941, 1956; Furtos 1936b), crayfish burrows (Creaser 1931), and semiterrestrial forest litter habitats (Chapman 1960). Many species are common in shallow vernal ponds and other temporary waters whereas some occur in the profundal regions of deep lakes or in streams and rivers. Endemic species are known in some of the older lakes, as Lake Baikal (Kozhov 1963) and Lake Ohrid (Stanković 1960).

Ostracods were collected at depths from 0-33 meters in Gull Lake. Fox (1965) reported a depth range of 0-311 meters for ostracods in Lago Maggiore, Italy, and Tressler (1957a) studied specimens from 600 meters in Great Slave Lake, Canada. The depth distribution of a given species may vary greatly in different lakes. For example, Candona crogmaniana was reported from temporary ponds by Kenk (1949), from 4-12 meters in Douglas Lake, Michigan (Moore 1939), <1-15 meters in Gull Lake (this study; 29 meters in 1967), 37 meters in Lake Michigan (this study), and 5-183 meters in Great Slave Lake, Canada (Tressler 1957a).

The depth distribution of Candona rawsoni ranged from 11-37 meters in Great Slave Lake (Tressler 1957a). This species was collected from depths of 0-3 and 12-15 meters in Gull Lake and 37 meters in Lake Michigan. Candona decora was found largely at depths of 1-2 meters in Gull Lake, but Tressler reported a range of 12-600 meters in Great Slave Lake. Marine ostracods are known from depths of 5,000 meters (Benson 1966).

Reference to D. stevensoni as a representative of the freshwater Ostracoda has been emphasized in this study. This species, however, has been reported to occur in waters of varying salinity (Brady and

Robertson, 1872; deVos, 1954; Neale, 1965; Hagerman, 1967). Neale (1965) listed a maximum salinity range of about $0.8^{o}/oo$, but Hagerman (1967) recently reported this species in water with a salinity of $2.3^{o}/oo$.

Gofman (1966) found small numbers of D. stevensoni at salinities up to $13^{o}/oo$ in the Caspian Sea; however, the population density was much higher at lower salinities. Lerner-Seggev recently (1968) noted that D. stevensoni was the most abundant species in Lake Tiberias, Israel.

Swain (1961) and Van Morkhoven (1963) recorded the genus Darwinula in both fresh and mixohaline water. Sohn (1951) listed the inferred salinity habitats of two fossil species of Darwinula and reported (In Wagner, 1965) culturing an unidentified species of Darwinula from Lake Tiberias in varying salinity solutions of up to 20 percent of normal marine water. Sandberg (1965) found mixed assemblages of ostracod valves, including Darwinula, in the Lagunda de Tamiahua, Veracruz, Mexico, and suggested the presence of freshwater faunas at times of high outflow from the lagoon. Harding (1962) described a new species of Darwinula from Lake Te-Nggano, Rennell Island, Pacific Ocean; this lake was reported to have a salinity of $4.56^{o}/oo$.

Hulings (1967) presented a summary of the ecological distribution of freshwater and marine ostracods in and adjacent to the Gulf of Mexico and recorded several species of Candona, Cypridopsis, Cyprinotus, Limnocythere, and Darwinula. More specifically, Darwinula stevensoni (=D. aurea B. & R.), Candona rawsoni (= Candona obtusa Bronstein), Candona caudata, Cypridopsis vidua, and Physocypria pustulosa were reported at depths less than 2 meters on the Gulf Coast.

Many species of the primarily freshwater Cypridacea were abundant in shallow waters of low salinity in the Tvärminne area, Gulf of Finland. Hagerman (1967) recorded species of the genera Candona, Cypridopsis, Cyprinotus, Cyclocypris, Potamocypris, Cypria, Limnocythere and Darwinula. The two latter genera belong, respectively, to the superfamilies Cytheracea and Darwinulacea. Earlier authors (Hirschmann 1912, others cited by Hagerman 1967) also reported typically freshwater ostracods from the above region.

Neale (1965) reviewed the salinity and temperature ranges reported for many freshwater and marine ostracods and found that certain species of Candona, Cypridopsis, and Cyprinotus tolerate salinities up to 14^{o}/oo. Benson (1959), for example, found living Cypridopsis vidua in brackish-water, marsh grass habitats in the Rio San Miguel lagoon of Baja California, Mexico. He stated (1959, p. 40), however, that their presence might have been due to the "fresh upper bay of water that overrides the denser more saline brackish layer". Löffler (1967) recently summerized the geographic and ecologic distribution of European freshwater Ostracoda.

Substrate

Many authors have studied ostracod-substrate interrelationships, but their results have been somewhat conflicting and inconclusive. Elofson (1941), Hoff (1942), Swain (1955), Benson (1959), Kornicker (1959, 1961, 1963, 1965), Puri et al. (1965), Rome (1965), and Löffler (1968) should be consulted for detailed discussion of this subject.

Benson (1959, p. 37) concluded that the distribution of certain sediment types was correlated with the abundance and character of some /ostracod, brackets mine/ biofacies in Todos Santos Bay, California. Grossman (1965) attributed certain substrate preferences to two species of the marine genus Loxoconcha on the basis of differences in their appendage morphology.

Hoff (1942) found no definite correlation between substrate type and ostracod distribution in Illinois. Löffler (1968) also found no clear correlation of substrate and ostracod distribution in his study of East African high-mountain lakes. Rome (1965), however, reported that some marine species were restricted to well defined substrates whereas others were distributed irrespective of the sediment type.

Neale (1965) discussed some pertinent findings relating substrate type to ostracod distribution. He concluded (1965, p. 277) that grain size alone probably does not exert a particularly strong influence on ostracod distribution, but exercises a rather subtle role linked to availability of food, rates of sedimentation and other factors.

Studies on the relationship of substrate texture, composition and stability to the microdistribution of Gull Lake Ostracoda were not completed. I became aware of the difficulty of distinguishing between cause and effect relationships soon after the initial work began. Whatever correlations could have been drawn would have been dependent upon some knowledge of the population dynamics of the species investigated. The latter proved a formidable task in itself, even when restricted to problems studied here.

Moore (1939) studied the vertical distribution of Cypria spp. and Candona spp. in the sediments of Douglas Lake, Michigan, and found, respectively, 97 and 66 percent of the specimens in the upper four centimeter stratum. Some Candona spp. were found about 17 cm below the sediment surface. Cole (1953) reported finding approximately 93 percent of macrobenthic organisms between the substrate surface and the

14 cm sediment interval in Douglas Lake; only the general depth distributions of several ostracod species were considered. Greater than 97 percent of the juvenile and adult ostracods in sediment cores from Gull Lake were present in the upper five cm of sediment. Neale (1965, p. 277) stated that most evidence suggests that ostracods are essentially distributed in the top 2 cm of the substrate.

Reproduction, Development, Life History

Most ostracod species in Gull Lake reproduce syngamically and all are dioecious. Cypridopsis vidua, Darwinula stevensoni and Darwinula pagliolii are parthenogenetic. All species of Gull Lake Ostracoda, except those of Darwinula, are oviparous. The latter carry their young through embryological development to the first instar, occasionally the second. Males often are not reported for species known to reproduce syngamically.

I have used the term "population" for sexual and parthenogenetic species in the context stated by Cole (1957, p. 2); "... to use the word where it is meaningful to speak of a birth rate, a death rate, a sex ratio, and an age structure in describing the properties of the unit."

Kesling (1951a, 1953, 1961b), Van Morkhoven (1962) and Sandberg (1964) have reviewed some of the early studies on embryological development, egg laying, and instar growth and development in freshwater and marine ostracods. Kesling (1961a) presented a general account of reproduction in the Ostracoda and Pokorný (1952) reviewed several examples of possible parthenogenetic reproduction in fossil ostracods.

The number of eggs or nauplii produced by different ostracod species may vary from two to sixty, with some young maturing before the last eggs or larvae are released (Van Morkhoven, 1962). Kesling

(1951a) reported a maximum of 53 young produced by one individual of the parthenogenetic ostracod Cypridopsis vidua (O. F. Müller). The eggs were released over a 35-day period in laboratory culture. Sandberg (1964) found a maximum of 11 eggs and nauplii, with a range between 6 and 11, in the 'brood chamber' of Cyprideis castus Benson. Elofson (1941) and Weygoldt (1960) reported a maximum of 42 and 30 eggs, plus nauplii, respectively, in Cyprideis torosa (Jones).

In this study, the number of uterine eggs recorded for females of oviparous species represented static counts that did not necessarily reflect the actual reproductive capacity of the individuals or populations investigated. I believe the maximum number of eggs reported for each species is far more realistic estimate of the reproductive performance of most females than are the means of any samples. The latter always included individuals that had released some portion of their brood or had just begun reproducing. In laboratory cultures one can easily count the eggs of individual specimens when the uteri are packed. In contrast, field samples usually contain individuals in all stages of development and reproduction and if the life cycle of the species in unknown, one is more likely to miss the period of greatest egg production. The maximum number of uterine eggs observed in females of Gull Lake species are listed below.

Darwinula stevensoni	15-(See text)	Candona decora	32
Darwinula pagliolii	3	Candona crogmaniana	69
Candona ohioensis	35	Candona sp.	--
Candona rawsoni	40	Candona distincta	--
Candona acuta	23	Cypridopsis vidua	21
Candona inopinata	36	Physocypria pustulosa	10
Candona elliptica	30	Cypria turneri	8
Candona porteri	14	Cyclocypris ampla	10
Candona aff. caudata	18	Cyprinotus glaucus	15
Candona scopulosa	26		
Candona aff. suburbana	25		

Wohlgemuth (1914) studied the rate of egg development of *Cyprinotus* /*Heterocypris*/ *incongruens* at different temperatures. Eggs cultured at 28-30°C developed about twice as rapidly as those incubated at 17-19°C and almost four times more rapidly than those at 9-11°C in the natural habitat. Kesling (1951a, p. 87) stated that for *Cypridopsis vidua* development from the egg stage to sexually mature individuals lasted approximately one month at room temperature.

Some investigators (i.e., Elofson 1941, Alm 1915, Theisen 1966) found that larval development through early instars generally was completed soon after hatching or, in species which retain their eggs, after release from the carapace. Development of later instars extended over a considerably longer period. This was true for all Gull Lake species whose early instars could be identified.

Theisen (1966, p. 268) stated that egg development lasted from 4 to about 30 days, respectively, in the brackish-water species *Elofsonia baltica* (Hirschmann) and *Cyprideis torosa* (Jones). Larval development, in above order, lasted about 11 and 63 days at 18-24°C in laboratory cultures. Hagerman (1966, p. 15) reported an annual life cycle for the marine ostracod *Hirschmannia viridis* (O. F. Müller). The first larval stages were of short duration and juveniles over-wintered as late instar larvae. The adults died soon after reproducing.

Ferguson (1944) studied the life histories of *Cypridopsis vidua*, *Physocypria pustulosa* and *Potamocypris smaragdina*. *C. vidua* reached peak abundance in summer months and was believed to have two generations per year: April-September and August-April. Development from nauplial instar to adult required about 106 days in the April-September brood and 70 days in the August-April brood.

From laboratory studies of _Cypridopsis vidua_ Kesling (1951a, p. 90) stated:

> ...(1) the female lays eggs at intervals, and not all at one time; (2) the complete cycle of growth can be completed in thirty-five days; (3) a female may survive beyond her capacity to lay eggs; and (4) under favorable laboratory conditions, ostracods will reproduce during the winter, although in nature they do not normally produce young during that season.

After reviewing other laboratory and field studies (i.e., Schreiber 1922; Ferguson 1944) and his own work, Kesling (op. cit., p. 91) concluded:

> It would seem that reproduction takes place the year around in nature, but the survival rate is much greater during the favorable spring and summer months than during the rigorous late fall and winter.

Gravid _C. vidua_ were present throughout the year in Gull Lake, but I could not differentiate adult age classes. Females did not lay all their eggs at one time.

Ferguson (1944) reported 2 broods per year and an adult life span of about 2 months for _Physocypria pustulosa_. The latter is common in many areas of the United States (Ferguson 1957) and probably has a variable number of generations per year depending upon the duration of the growing season. Hoff (1943b) noted that the life span of most ostracods in temporary ponds may be limited to 45 days or less.

Theisen (1966) studied the life histories of seven species of 'brackish-water' ostracods. Four species had seasonal life cycles. Two of thirteen species studied by Tressler and Smith (1948), one of 45 species reported by Elofson (1941) and apparently none of those species studied by Kornicker (1965) were seasonal forms. Twenty-two of about 50 freshwater species reported by Klie (1938) had seasonal life cycles.

According to Alm (1915) and Theisen (1966) seasonal species are those which do not occur as larvae or adults during certain periods of the year, but remain in the egg stage or latent in the sediment as eggs, larvae, or adults. Perennial species are those which are active as juveniles or adults through the entire year.

The only obvious, seasonally restricted species in Gull Lake was *Cyprinotus glaucus*. However, there may have been others, such as *Potamocypris smaragdina*. The first three to four instars of most *Candona* species were identified only to genus; thus, some species may not have been represented by juveniles immediately following the adult reproductive cycle. Generalized life cycles of the numerically dominant species in Gull Lake are presented in Figure 4.

A detailed description of the annual temperature cycle of Gull Lake has not been published and is not the intent of this paper. However, a few general temperature characteristics of the lake are reviewed below in relation to the general depth and density distribution of *D. stevensoni*. The water temperature at depths of 3, 6, 9 and 12 meters increases from about 1.9°C in early February to a maximum of approximately 27°C by early July. In February, water temperatures are almost identical at the above depths and generally range between 1.8°-2.0°C, but temperature maxima at 3, 6, 9 and 12 meters, respectively, are; about 27°C, early July; 24°C, mid-July; 22°C, mid-August; and 15°C, early September.

The general time lag at which temperature maxima are reached at the above depths corresponds closely to a similar time lag in development and release of eggs and first or second instar young at these

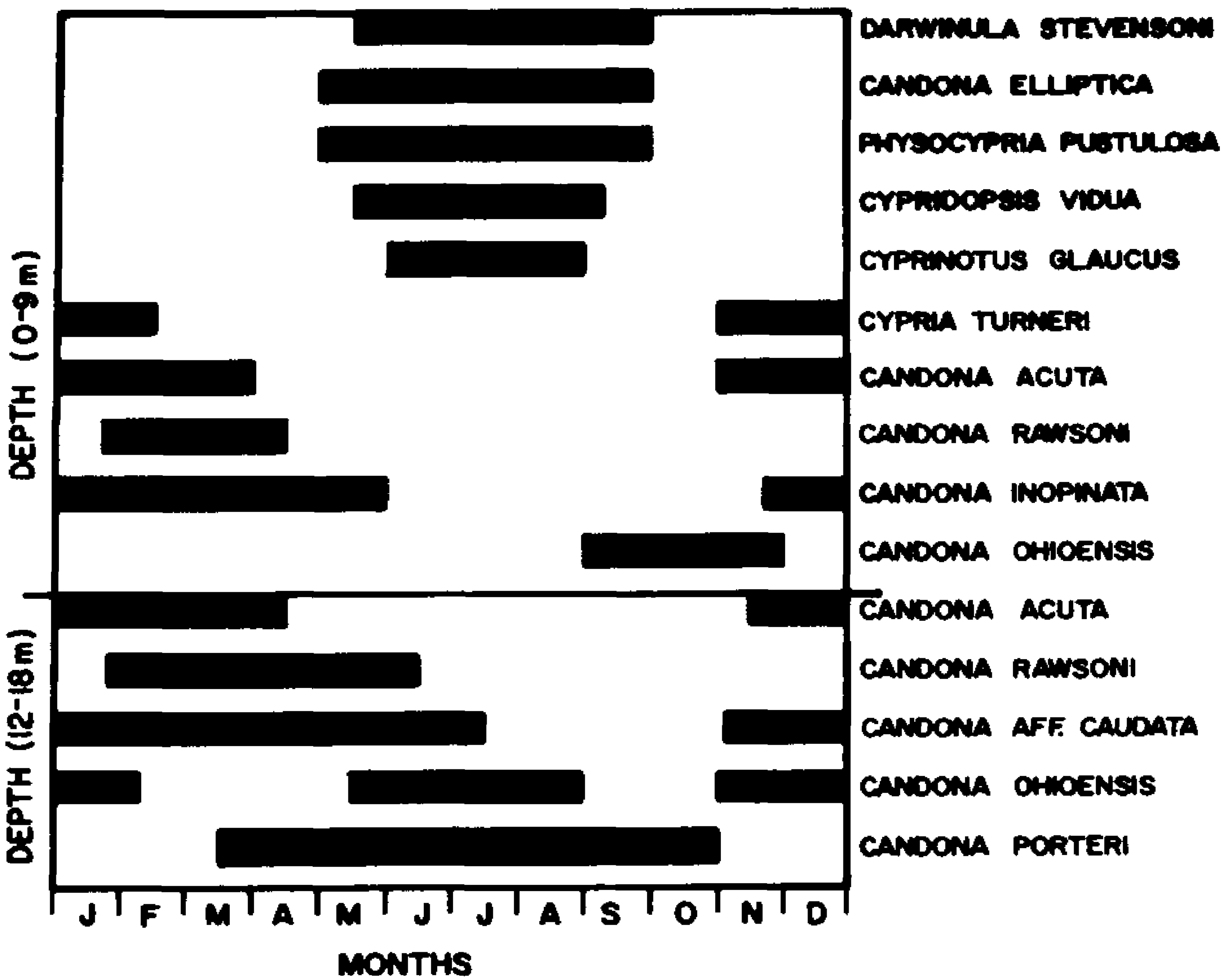

Figure 4. Highly generalized reproductive cycles of numerically dominant species in Gull Lake.

respective depths during the reproductive season of Darwinula stevensoni.

Second reproductive season adults began releasing young by mid- and late June whereas first reproductive season adults did not begin until early July at 3 meter depths. Second and first reproductive season adults at 6 meters were releasing young, respectively, by 1 July and 15 July (Table 5). Maximal reproductive potentials and initial release of first instar individuals at 9 meters were observed for second reproductive season adults on 1 August. The release of first, or occasionally second, instar juveniles by second reproductive season adults generally begins about 15 days before that in first reproductive season adults; release of young by the latter begins during approximately the same periods of the month that maximum temperatures are reached at the depths stated above.

Temperature may be one of the more, if not most, important environmental factors which regulates the general distribution pattern and density of D. stevensoni in Gull Lake. I believe the low temperatures and consequent shortened growing seasons at depths greater than 9 meters may account for the marked decrease in density. This species may be entirely unable to replace itself at these depths due to the time necessary for production of a single brood of young. Other factors such as substratum, food availability, predation, et cetera, may be important geographically in regulating the densities and patterns of distribution within the more general limits influenced by temperature. I believe that this generalization also is valid for D. pagliolii.

Elofson (1941), Kesling and Takagi (1961) and Neale (1965) discussed the influence of temperature on ostracods at different latitudes where, in some invertebrate groups, a decrease in temperature is accompanied by an increase in size. Elofson (1941, p. 399) found populations of Philomedes globosus (Lilljeborg) from cold waters near Greenland to be about 20 percent larger than those living in warmer waters. Winter specimens of Cytherura nigrescens (Baird) were larger than those collected in summer (op.cit., p. 396-397).

Kesling and Takagi (1961, p. 50) suggested that Elofson's observations indicated slower growth but greater size at maturity for ostracods in cold water compared to those of the same species in warmer water. Neale (1965, p. 274) stated that such a "trend has not been convincingly established in the Ostracoda".

Dispersal

Dispersal mechanisms of aquatic organisms have been discussed by many authors (see Proctor and Malone 1965; deVlaming and Proctor 1968). Until recently, however, data supporting earlier suppositions regarding passive dispersal of ostracods by birds were non-existent.

According to Hagerman (1967, p. 1), Purasjoki (1948) proposed that dispersal of ostracods by birds was responsible for the presence of the freshwater ostracod Potamocypris (Cyprilla) humilis Sars in the Tvärminne area, Gulf of Finland. This species formerly had been known only from Central and South Africa. Other authors (i.e., Klie 1926, Sandberg 1964, Puri 1966) also have commented on passive dispersal of ostracods by birds. (Refer to Sandberg 1964 for detailed discussion.)

Proctor (1964) recovered viable eggs of five species of ostracods from the intestinal tract and droppings of migratory waterfowl. Cypridopsis vidua, and species belonging to Cyprinotus, Physocypria and Potamocypris were cultured from gut and fecal material of the green-winged teal (*Anas carolinensis*), mallard duck (*Anas platyrhynchos*), and gadwall (*Anas strepera*). Viable eggs of *C. vidua* were recovered from two waterfowl species, whereas eggs of the other ostracods were reared from single species cultures.

Later, Procter et al. (1967) reported retention periods in which both eggs and adult ostracods remained viable in the intestinal tract of two species of waterfowl. They found that living adult ostracods can be dispersed over short distances via the intestinal tract of the killdeer, *Charadrius vociferus*, the distance being that in which the killdeer could fly in 15-30 minutes. Ostracod eggs remained viable for longer periods.

Density

Few estimates of density per unit area have been recorded in studies on freshwater ostracods. Kozhov (1963) reported estimates of more than 10,000 individuals per square meter for *Candona unguiculata* Bronstein in littoral areas of Lake Baikal, U.S.S.R. On the other hand, Tressler (1957a) reported an average of only 57 ostracods per square meter with a range from 4 to 152 per square meter in the Great Slave Lake, Canada.

Bronstein (1947) and Sandberg (1964) reviewed some of the density estimates of the 'brackish-water' ostracod *Cyprideis torosa* in various areas of the Soviet Union. Values ranging from about 1,000-50,000 individuals per square meter were common. The maximum estimate was 670,900 per square meter on which Sandberg (1964, pp. 19-20) commented:

> Even though the extreme values given by some of those workers may be misleading, it is evident that the ostracods are quite numerous in the bottom sediments of brackish-water bodies.

The above densities, excepting Tressler (1957a), represent estimates based upon the combined number of adults and juveniles of a given species. The highest combined density estimate for adult and late instar juveniles of D. stevensoni from Gull Lake was 7,325 per square meter, on 1 July, 1966. Had all instar stages been sampled, the latter estimate, undoubtedly, would have been much higher. Considerably higher densities of D. stevensoni have been found in small lakes in the area surrounding Gull Lake, but cannot be considered in detail at this time.

Estimates of ostracod density per square meter in Gull Lake are presented in Table 36. The first series of estimates represent the combined densities of all non-swimming adult and juvenile ostracods collected on a given date; juvenile Candona that were not identified to species are included. The second series of estimates represent both non-swimming and free-swimming species. August 1965 and June-August 1966 densities were calculated from means of replicated samples collected along Transect AB, whereas, estimates for 4 November represent means of four transects. Values for 30 March were calculated from sample means of two transects; samples from 3 transects were used for 6 meter estimates.

Ostracod density was greatest in the littoral region of Gull Lake, but decreased sharply at the 9 meter depth. Had free-swimming species been sampled quantitatively, estimates of the total ostracod density per square meter would have been much higher, for both littoral and sublittoral areas, than those values reported in Table 36. The increase would have been particularly marked in the littoral zone during the summer months.

Data on the standing crop biomass of Gull Lake Ostracoda are not available. From observation alone, however, there were obvious

Table 36. Estimates of the number of ostracods per square meter in Gull Lake. Juveniles identified only to genus were included in calculating densities. (See text for additional explanation).

		Depth (meters)					
		3	6	9	12	15	18
		Non-Swimmers					
1965	8- 5	9890	7054	3700	----	----	----
	11- 4	12162	5508	1796	3528	2090	----
1966	3-30	7402	9011	----	3138	5194	----
	6- 1	8285	6363	1753	9544	2402	2835
	6-15	13093	10063	822	5042	2229	----
	7- 1	9804	14868	1277	3874	4372	----
	7-15	19087	7076	2769	5605	2706	----
	8- 1	9718	7791	2727	----	----	----
		Non-Swimmers and Free-Swimmers					
1965	8- 5	10215	9032	7054	----	----	----
	11- 4	12573	6243	2975	4578	2501	----
1966	3-30	9069	10370	----	3399	5670	----
	6- 1	8960	7034	2662	9760	3311	3528
	6-15	14067	10367	2294	5258	2381	----
	7- 1	13050	15041	5886	3939	4826	----
	7-15	20169	7595	3894	5778	2706	----
	8- 1	12120	8181	5367	----	----	----

differences in the total biomass of non-swimming species in littoral and sublittoral samples. Although the number of non-swimming ostracods generally was higher in littoral samples their total biomass was conspicuously less than that of ostracods in sublittoral samples, especially those from the 12 meter depth. The difference was most obvious during the summer months. During the latter period free-swimming species clearly were dominant, in density and biomass, in the littoral areas of Gull Lake.

The low standing crop biomass of non-swimming ostracods in most littoral areas of Gull Lake during the summer may reflect, in part, interspecific competition for resources brought about by greatly increased population densities of free-swimming species. This, however, cannot be concluded at the present time.

Hagerman (1966) presented some interesting data concerning population densities of ostracods and other animals on the higher aquatic, marine plant communities of _Fucus serratus_ L. Ostracods were the most numerous organisms throughout most of the year and reached a maximum density of slightly more than 6,000 individuals on a single _Fucus_ plant.

Wieser (1952) and Coleman (1940) also studied ostracods associated with higher aquatic plants. Coleman reported a maximum density of 50,530 ostracods per square meter on two species of plants, but found only 246 per square meter on _Fucus serratus_. Chapman (1955) reported a density of 2,200 per square meter in the coralline algae zone in the Azores.

Estimates of the maximum number of ostracods per square meter in several marine and brackish-water habitats are presented below. These data were compiled by Hagerman (1967, p. 7) and references are cited in his paper. Some estimates include typical freshwater species.

Öresund	1,600	(Krogh and Spärck, 1936)
Öresund, _Fucus_, per plant	6,000	(Hagerman, 1966)
Loch Head, Clyde Sea area	12,500	(Moore, 1931)
Danish Wadden Sea	24,000	(Smidt, 1951)
Tvärminne area, Gulf of Finland	46,020	(Hagerman, 1967)
Öresund, extremely shallow water	380,000	(Muus, in print)
Bristol Channel, tidal area	790,000	(Rees, 1940)

In Gull Lake the maximum density estimate was 20,169 ostracods per square meter on 15 July 1966 (Table 36).

Rome (1965) found that ostracod densities increased with increasing depth from shore to a depth of about 30 meters; however, below 50 meters ostracod abundance decreased with increasing depth. Hagerman (1967, p. 6) also found generally higher densities of ostracods with increased depth and salinity in the Gulf of Finland. However, he recorded the highest ostracod densities from relatively shallow depths (3-7 meters) in water of low salinity (2-3^{o}/oo). _Darwinula stevensoni_, _Candona_ spp. and other freshwater ostracods were abundant at the latter depths.

Trophic Relations

Little is known about trophic relationships of freshwater or marine Ostracoda. Often, the Ostracoda are referred to simply as detritus feeders. Trophic relationships of Gull Lake ostracods have not been studied, but from cursory examination of stomach and gut contents I believe that most Gull Lake species feed on living, benthic diatoms, other algae and bacteria. The literature on ostracod nutrition reviewed below illustrates the need for research in this area.

Hoff (1942, p. 32) stated that most species of freshwater ostracods feed on diatoms, bacteria and minute particles of organic material, and detritus. He remarked (p. 39) further:

> Many species, as some of the Candona species, apparently ingest large numbers of diatoms which they seem to be able to digest, since the cytoplasm within the test of the diatoms stains when the plant is first ingested, but only the empty test may be observed in the food balls in the posterior part of the intestine.

Kesling (1956, p. 84) also found that laboratory cultures of Candona thrive best on diatoms and algae, but "most do well on dead leaves".

Ferguson (1959a, p. 60) cited a study by Deschiens et al. (1953) in which the ostracod Cypridopsis hartwigi Müller was observed preying upon two species of snails, Bullinus contortus Michaud and Planorbis glabratus Say. Neale (1965, p. 36) noted that Cypridopsis hartwigi also is known to attack infusorians, rotifers, and insect larvae. Recently, Lo (1967) reported that Cypridopsis vidua and Cypricercus reticulatus (Zaddach) prevented successful snail culture by 1) active predation of snail eggs, 2) physical contact with snails and consequent inactivation of the latter, and 3) laying eggs in snail apertures which inhibits their feeding and locomotion. C. vidua maintained rather low population densities in 16 liter aquaria with no snails, but reached densities of almost 50,000 individuals when snails were abundant (Lo, 1967, p. 403). The ostracods limited the population growth of snails belonging to nine genera. Both ostracods also were cultured successfully on a diet of lettuce leaf, dead snails and their feces, and snail eggs.

Klugh (1927) examined stomach contents of Potamocypris smaragdina, Cyprinotus incongruens, Cypris fuscata, Cyclocypris castanea and Cypria turneri (=Cypria exsculpta). Several genera of algae were identified; Scenedesmus quadricauda was found in C. castanea. Kesling (1951a) reported that Cypridopsis vidua fed on diatoms of the genera Pinnularia, Brebissonia and Amphora, desmids (Tetmemorus, Gymnozyga), and a flagellate Trachelomonas, whereas, Klugh (1927) reported the algae Chaetophora elegans and Conferva bombycina tenuis. Kesling, Klugh, and Wohlgemuth (1914) also cultured C. vidua on diets of algae, boiled egg yolk, leaves, detritus, raw meat, crushed snails and potato.

The algae Elaeophyton cf. E. coorangiana Thiessen was found to be part of the diet of certain ostracods (i.e., Physocypria granadae Hartmann) in Lake Nicaragua (Swain and Gilby, 1965). According to the latter authors (1965, p. 368), Darwinula stevensoni apparently fed on settled plankton and copropelic substances.

Straškraba (1963) measured the variation in standing crop of zooplankton in two fishponds in southern Bohemia. Notodromus monacha (O. F. Müller) and "other Ostracoda" were dealt with in his estimates. N. monacha was considered a fine filtrator along with certain cladocerans. In Hunter's Hot Springs, Oregon, Castenholz (1967) reported an ostracod of the genus Potamocypris which grazes on the surface of the Phormidium and Pleurocaspa mat at temperatures between 30° and 47°C. Rome (1947a, p. 53) stated that Herpetocypris reptans Baird feeds on diatoms, green algae, remains of gastropods and other animals in aquarium cultures.

Elofson (1941), Hagerman (1966) and Puri (1966) discussed the trophic relationships of numerous genera and species of marine and 'brackish-water' ostracods. For instance, Hagerman (1966) found that all the ostracods of Fucus serratus communities, excepting species of the genus Paradoxostoma, were herbivorous on diatoms and other algae. The mandibles of the Paradoxostoma species are modified for sucking juices from algae and possibly higher aquatic plants. According to Puri (1966), Cytherois, Paracytherois, and Sclerochilus also have modified feeding appendages for sucking nutrients from plants. Certain species of the genus Cytheropteron are carnivores (Elofson 1941); whereas, others are apparently herbivores (Hagerman 1966). Elofson (1941) found diatoms common in stomach contents of 45 ostracod species.

Cannon (1940), Elofson (1941) and Iles (1961) described the preda-tory habits of several planktonic marine ostracods. Conchoecia bispinosa is known to ingest copepods, some larger than its own body (Iles 1961). Cannon (1940) reported chaetognaths (Sagitta), free-swimming copepods, Pleuremamma robusta Dahl, Heterorabdus spp., and young fish in the huge ostracod Gigantocypris mulleri. Müller (1890, in Neale 1965) reported finding a heteropod in the stomach of Pyrocypris.

Kornicker (1967) found a harpacticoid copepod in Sarsiella zostericola Cushman and S. disparalis Darby. Other arthropod appendages and free living nematodes also were present in the latter species. Darby (1965) reported that diatoms were the principal items in stomach contents of Euconchoecia chiercheiae Müller. In Rutiderma mollita Darby, remains of annelids, diatoms and nearly whole copepods were found and in the ostracod Philomedes lilljeborgi (Sars), diatoms and a Foraminifera. Cannon (1933) reported filter feeding of various sized detrital particles by species of the genera Asterope, Cytherella, and Cypridina.

Predators

Scant knowledge exists on the importance of ostracods in the diet of other animals. Results of fish stomach analyses reported above indicate that certain ostracods in Gull Lake constitute a significant part of the diet of the yellow perch, Perca flavescens and bluegill, Lepomis macrochirus Rafinesque. Predation by the yellow perch clearly had a pronounced effect in reducing the proportion of males in populations of several species of Candona during their respective reproductive cycles. The sex ratio is an important parameter in predicting natality and population growth rates from density estimates. In addition, significant changes in the sex ratio of adults also may alter the size and age structure of the population.

Tharrett (1959) investigated the food organisms of P. flavescens in Saginaw Bay, Lake Huron. Immature insects, principally tendipedid larvae and pupae and mayfly nymths, were the dominant food, but small numbers of unidentified ostracods were found in the stomachs of fish at four stations. Partiarche and Ball (1949) found chironomids, ostracods, and small mayfly nymphs to be the chief items in the diet of small bluegills (L. macrochirus) in several Michigan ponds.

Hunt and Carbine (1951) reported that ostracods were a consistent, though quantitatively small, part of the diet of young pike (Esox lucius L.) up to 70 millimeters in length. Ostracods also were found in stomachs of the common whitefish Coregonus clupeaformis and cisco Leucichthys spp. in the Great Slave Lake (Rawson, 1951, in Tressler 1957, p. 417). In 1902, Scott enumerated the ostracod species removed from 12 of 56 fish species examined. Lowndes (1942) reported the stickleback (Gasterosteus aculeatus) a predator of ostracods.

Hoff (1942) found 6 species of ostracods in fish stomachs but listed only Candona acuta and C. caudata from the fish Catostomus commersonii. These two species of ostracods were eaten by the yellow perch in Gull Lake. Later, Hoff (1943a) found the stomachs of 3 out of 6 specimens of the grourdhead or common buffalo fish, Megastomatobus cyprinella, packed with "millions of individuals" of the ostracod Physocypria pustulosa. Hoff suggested that the presence of only one species in such abundance in these fish indicated some selectivity in feeding.

The ostracod Stenocypris archoplites Ferguson was described from specimens taken from stomachs of the Sacramento perch, Archoplites interruptus (Ferguson 1964). Harding (1962) described five new species of ostracods, Mungava munda, Pontoparta wolfii, Paracypria eleotridis, Candonopsis calva and Darwinula daps, taken from the stomachs of Eleotris fusca (Bloch and Schneider) in Lake Te-Nggeno, Rennell Island, Pacific Ocean. Another species, Ilyodromas pectinatus Sharpe, also was described from specimens found in the gut of the fish Spatula clypeata (L.) (Sharpe 1908).

In 1939 Tressler reported Cypria opthalmica and Onychocythere alosa Tressler in stomach contents of the shad Alosa sapidissima. Fox (1965) noted the occurrence of Isocypris nocentiniae Fox in the fish Eupomatus gibbosus.

Several animals other than fish also have been reported as predators of ostracods. For example, Zinn (1940) found a maximum of 129 ostracods in the stomach of a single Triturus v. viridescens. Almost 600 specimens of Cypria elegantula (probably C. turneri) were recovered from 5 salamanders on one sample date; ostracods were collected from other individuals over a six month period.

Proctor et al. (1967) found several hundred adult ostracods in the stomachs of two Least Sandpipers (Erolia minutilla) collected from the field. Several dozen ostracods were viable and were observed swimming a short time after the gut contents of the birds were placed in water. Klugh (1927, p. 49) stated that *Hydra oligactis*, a predator of the ostracod *Cyprinotus incongruens*, contained as many as 5 specimens in the gastrovascular cavity at one time. Rees (1940, in Neale 1965) suggested that the polychaete *Nereis diversicolor* preyed on certain marine ostracods.

Parasitism

The term 'parasitism' has been used in this study in the broad sense discussed by Allee et al. (1949, p. 253).

> Parasitism is a form of symbiosis in which a small organism lives on or in or with and at the expense of a large animal or plant.

The 'expense' in the instance of *Darwinula stevensoni* and *D. pagliolii* involves a reduction, indicated by evidence not reported here, of the reproductive capacity of those ostracods infested with rotifers.

Parasitism of ostracods by several groups of invertebrates was reviewed recently by Neale (1965). Ostracods have been reported to be parasitized by acanthocephalans (Hoff, 1942; Ward, 1940; Baer, 1952, p. 115), isopods, (Neale, 1965), copepods (Kornicker, 1967), cestodes (Scott, 1891; Rome, 1947b, in Kesling, 1953), and trematodes (Macy and Demott, 1957).

Mrázek (1890, cited by Kesling 1951) reported cercocysts of *Taenia coronula* Dujardin in the ostracod *Cyclocypris ovum* Jurine, and Klie (1926) reviewed a report of the larvae of *Drepanidotaenia gracilis* Keal in *Candona*, *Dolerocypris*, and *Cypria*. Ward (1940) found the ostracod *Physocypria pustulosa* (Ward's *Cypria globula*) to be the second intermediate host of the acanthocephalan *Neoechinorhynchus* *cylindratus*. The trematode *Halipegus occidualis* parasitized laboratory cultures of *Cypridopsis vidua* (Macy and Demott 1957). According to Neale (1965) an encysted protozoan *Foettingeria actiniorum* and the copepod *Sphaeronellopsis littoralis* are known to parasitize ostracods.

In 1889 Sars reported that the marine ostracod *Cypridina norvegica* was parasitized by the isopod *Cyproniscus cypridinae*. Later, Monod (1932) also reported ostracods of the genus *Cypridina* parasitized by a copepod larvae of the family Choniostomatidae and the isopod *Cyproniscus*. Kornicker (1967) found a parasitic copepod of the family Choniostomatidae in *Sarsiella disparalis* Darby.

Wilson (1911) described an ostracod, *Cypridina parasitica* (=*Vargula*), infesting the gills and nasal tubes of a hammerhead shark and two other fish. Harding (1966) reported ostracods of the marine genera *Vargula* and *Sheina*, respectively, from the gills and nostrils of the hammer-headed shark, *Sphyrna zygaena*, ray *Taeniura lymna*, and shark *Hemiscyllium oscellatus*. The species involved presumably are parasitic, but definitive evidence, clearly demonstrating parasitism by the Ostracoda, is presently lacking. Commensal ostracods have been reported by many authors (i.e., de Vos and Stock 1956; Elofson 1941; and Hart 1962).

SUMMARY AND CONCLUSIONS

(1) This study presents a taxonomic survey and both qualitative and quantitative description of selected aspects of the ecology of the free-living ostracods inhabiting littoral and sublittoral areas of Gull Lake, Michigan.

(2) Twenty-four species representing 10 genera of the superfamilies Cypridacea, Darwinulacea and Cytheracea were identified from a sample of nearly 33,000 ostracods. All species belong to the order Podocopida.

(3) Living representatives of twelve species are reported from Michigan for the first time; *Darwinula pagliolii* is reported in North America for the first time and one species is undescribed.

(4) Almost 98 percent of the ostracods collected from sediment cores were found in the top 5 cm sediment interval.

(5) In Gull Lake, *D. stevensoni* reached a maximum density at a depth of about 6 meters throughout the year. The population density decreased markedly between 6 and 9 meters. No specimens were found at depths greater than 12 meters.

(6) The reproductive period of *D. stevensoni* in Gull Lake begins in May and is effectively completed by October. The number of young per individual increased from a maximum of 3 in May to 15 in August, 1966. Although the reproductive potential of a given individual is strongly correlated with temperature and may vary with depth, most adults produce only one brood of

young per year. The mean reproductive potential of D. stevensoni at depths of 3 and 6 meters is about 11 young per individual; that at 9 meters depth is about 13.

Eggs are released and develope within the carapace of the parent. Juveniles produced by first and second reproductive season adults are released during the summer and early fall and overwinter as juveniles. These young mature and reproduce the following summer. Surviving members of this age class overwinter as adults during their second winter and reproduce again the following summer. Most second reproductive season adults die following release of young and are replaced by overwintering juveniles entering their first reproductive season. Thus, an almost complete turnover of the adult portion of the population occurs each year at depths of 6 meters or less. The precentage of second year adults that survive and produce young in a third reproductive season is not known.

(7) Darwinula stevensoni harbors an unidentified rotifer which is presumed to be strictly ectoparasitic. Parasitism varies with water depth, size and age of individuals, number of young, and geographically. Only 2.1 percent of 1,963 juveniles were infected whereas, 26 percent of 2,169 adults were parasitized. The greatest incidence of infection occurred at depths of 6 meters. Older individuals within the same year class were more heavily parasitized than the recently molted adults.

(8) Darwinula pagliolii had the most restricted spatial distribution and presumably the lowest reproductive potential of the ostracods studied. This species is parthenogenetic and carries the young through development to the first, sometimes the second,

instar. *D. pagliolii* had a summer reproductive cycle and young were released in late summer and early fall. Many aspects of the behavior, life cycle, and reproductive biology of *D. pagliolii* were similar to those described for *D. stevensoni*. Data were not sufficient to determine the age structure of overwintering adults or the number of reproductive cycles and life span of a given generation.

(9) An unidentified rotifer, presumably the same species infesting *D. stevensoni*, was present in the carapace of *D. pagliolii*. Almost 87 percent of the adults were parasitized. The mode of locomotion and reproduction, availability of space in the posterior region of the carapace, and lack of modified appendages to dislodge attached organisms may account for the fact that *Darwinula* was the only genus which harbored the rotifer.

(10) Temperature appears to be the most important environmental factor which regulates the general distribution pattern and density of *D. stevensoni* and *D. pagliolii* in Gull Lake. It is hoped that laboratory experiments currently in progress will provide additional information regarding the effects of temperature, nutrition, and parasitism on the reproductive performance, growth and development of these species.

(11) *Candona* was the dominant genus, in number of species, in Gull Lake and accounted for most of the standing crop biomass of non-swimming ostracods. Ostracod biomass was not determined in this study, but I have absolutely no doubt that the latter statement is correct.

(12) *Candona ohioensis* was the largest species studied. This ostracod was collected at depths from 0-18 meters, but is

known to occur in the deepest areas of Gull Lake. C. ohioensis was characterized by an annual reproductive cycle in the littoral region and biannual cycle in the sublittoral.

The reproductive cycle of C. ohioensis in the littoral region extended roughly from September to December. In the sublittoral, adults reproduce from November through early February, and die soon after the eggs are laid. The new generation of young pass through eight molts to the ninth or adult instar by late May or early June and reproduce during the summer months. The sex ratio of late instar juveniles and early maturing adults was essentially equal. The proportion of males decreased markedly during later stages of the reproductive cycle.

(13) Candona rawsoni had a highly clumped spatial distribution in the area of Transect AB. There appeared to be two distinct breeding populations, one at depths of from 0-3 meters and the other at 12-15 meters. This species had an annual reproductive cycle extending from late January to mid-April, and mid-June, respectively, in the littoral and sublittoral regions. The sex ratio in both littoral and sublittoral populations was near 1:1 only in the early stages of the reproductive cycle. Females predominated at all other times.

(14) Candona acuta was collected at depths ranging from <1-15 meters. The annual reproductive cycle begins some time in November and extends through May and early April, respectively, in the littoral and sublittoral areas. Population densities were the highest in the littoral region during the early phase of the reproductive cycle, but had decreased sharply by

February, 1966. Males were most abundant in the first phase of the reproductive cycle, but constituted less than 36 percent of adults in all samples.

(15) Adult Candona inopinata were temporally distributed from late November to June, but juveniles or adults were present throughout the year. This species was collected at depths from 0-15 meters but 90 percent of all specimens were collected from 6 meters or less. The reproductive cycle began in November and, in the majority of individuals, was completed by April. Some females lived beyond egg laying but population densities decreased rapidly from March to June. Males matured more rapidly than females; however, they constituted progressively smaller percentages of the adult population as the reproductive cycle proceeded.

(16) Candona elliptica was restricted to the littoral region of Gull Lake and was the only Candona species, in the latter area, whose reproductive cycle spanned the summer months. Often, C. elliptica was abundant in areas of rooted aquatic plants. The reproductive cycle began in May and ended in September, but non-gravid females were present in other seasons. Overlapping age groups could not be differentiated in most late-summer samples.

(17) The only undescribed species studied was Candona porteri. Three other species of Candona are tentatively identified at this time. C. porteri essentially was found at depths greater than 9 meters and was characterized by an annual reproductive cycle which began about mid-May and spanned the summer months. The period in which the reproductive cycle was completed is

unknown but, at the depths sampled, it definitely ended before November.

(18) Almost 100 percent of all *Candona* aff. *caudata* were collected from depths greater than 9 meters. The annual reproductive cycle began in early November 1965, and ended in July 1966. Oviferous females had released a majority of their eggs by March. Dead or inactive and emaciated females collected from May through July indicated that physiological death may have been a major mortality factor. High mortality through fish predation also was indicated from analyses of fish stomach contents.

(19) In species of *Candona* studied in enough detail to determine general life cycle characteristics, the proportion of males always was highest during the initial phase of the reproductive cycle. Most evidence indicated that males mature more rapidly than females, but have a shorter life span. Greater mortality rates of males resulting from predation by fish was strongly indicated by analyses of stomach contents of the yellow perch, *Perca flavescens*. Percentages of males of two ostracod species found in stomach contents of perch were much higher than those ever encountered in dredge or sediment core samples.

(20) Eight of the 17 species of non-swimming ostracods comprised less than 6 percent of the total number collected. Data on these species were insufficient to describe the principal features of their life histories. *Candona scopulosa*, *C.* aff. *suburbana* and *C.* sp. were found primarily at depths <6 meters, whereas, *C. decora*, *C. crogmaniana*, and *Limnocythere verrucosa*

were collected at depths from 0-15 meters. Candona distincta was found only at a depth of 9 meters. Candona crogmaniana is known to inhabit the deepest areas of Gull Lake. No living Cytherissa lacustris were collected, but undecomposed soft parts in several specimens indicated that living representatives of this species were present in Gull Lake.

(21) Free-swimming ostracods were not sampled quantitatively but probably account for most of the standing crop biomass in the littoral areas of the lake during the summer months.

All free-swimming species, excepting Cypria turneri, essentially were restricted to the littoral region. C. turneri was found at all depths and in every major substrate examined.

(22) Cypridopsis vidua had three, rather vaguely defined generations per year; overlapping adult age classes could not be differentiated. The first reproductive period was in November-December, the second in March-April, and third in June-July. Other free-swimming species, with the possible exception of Physocypria pustulosa, had annual reproductive cycles. The latter species reproduces during the summer but may have a second reproductive period from December to March.

(23) Cypria turneri was the most uniformly and widely dispersed species, temporally, geographically and with depth, of all ostracods studies. Most females were oviferous in November-January, but a few gravid individuals were collected in February and early March. Juveniles hatch in the summer months, mature and reproduce in November-December and lay their eggs by about mid-February.

(24) Cyprinotus glacus exhibited the most clearly delineated

seasonal life cycle of any species. Individuals of this species pass through 8 molts to the adult instar and begin reproducing within one month from the time of hatching. The first juveniles were found in May; the seasonal life cycle ended in September. _C_. _glaucus_ is one of the littoral dominants, in number and biomass, during the summer months.

(25) Ostracods were found in the stomachs and intestines of the three species of fish examined, the yellow perch _Perca flavescens_, bluegill _Lepomis macrochirus_ and smelt _Osmerus mordax_. The ostracods _Candona ohioensis_, _C_. _rawsoni_, _C_. _acuta_, _C_. aff. _caudata_, _C_. _inopinata_, _C_. _crogmaniana_ and _Cypria turneri_ were eaten by the yellow perch. _C_. _ohioensis_, _C_. aff. _caudata_ and _C_. _acuta_ were the most abundant species; males of the last two species comprised more than 50 percent (N = 760) of the total January sample.

Cypridopsis vidua, _Cyclocypris ampla_, _C_. _cruciata_, _Potamocypris smaragdina_, _Cyprinotus glaucus_, _Candona rawsoni_ and _C_. _elliptica_ were found in _L_. _macrochirus_. The latter species contributes to the mortality of both adult and juvenile ostracods but is a far less discriminate predator, in terms of apparent size discrimination, than _P_. _flavescens_. Three specimens of _Cypria turneri_ were collected from stomach contents of _C_. _mordax_.

(26) Most Gull Lake ostracod species probably have a more expansive geographic distribution and geologic history than presently known. Such information as exists for most species should not be strongly relied upon for purposes of species identification. Fossil records indicate that some species (i.e., _Candona rawsoni_, _C_. _ohioensis_, _Cyprinotus glaucus_)

may have been more widely distributed, geographically during the Pleistocene. However, the limited number of studies on living or fossil freshwater ostracods in the United States precludes such a conclusion at this time.

(27) Several freshwater genera and species common to Gull Lake (i.e., Darwinula stevensoni, Cypridopsis vidua, Candona spp. Limnocythere spp.) are known to reproduce in waters of low salinity. D. stevensoni may tolerate salinities up to 14°/oo.

(28) Ostracod-substrate interrelationships are rather vaguely defined at present but most evidence indicates that ostracods are generally restricted to the upper few centimeters of the bottom sediment.

(29) Most ostracod species studied reproduce by sexual means and all are dioecious. Three species, Cypridopsis vidua, Darwinula stevensoni and D. pagliolii, are known to be parthenogenetic, and all but the last two species are oviparous.

(30) The number of eggs and/or young observed for Gull Lake ostracods ranged from 3 (Darwinula pagliolii) to 69 (Candona crogmaniana). The maximum number of eggs reported for each species is believed to be a more realistic estimate of the reproductive performance of most females than were the recorded means.

(31) Ostracod diversity, in number of species and individuals, is greatest in the littoral areas of Gull Lake. Free-swimming species appear to account for most of the standing crop biomass in the littoral zone during summer months. During the late fall and winter, non-swimming ostracods appeared to be dominant, in biomass as well as number of species, based upon observation

alone. Non-swimming ostracods in the sublittoral region had a greater standing crop biomass, per square meter, during most periods of the year than their counterparts in littoral areas. Again, the latter statement was based upon observation rather than actual dry or ash-free weight data but the differences, even from visual observation, were usually marked.

(32) The literature reviewed on dispersal, trophic relationships, predators, and parasites of ostracods probably describes the limitations of our knowledge, relating to the overall biology of freshwater and marine ostracods, as adequately as the obviously limited coverage of these topics in this study.

(33) Future work, integrating laboratory and field observation and experimentation, on several species of freshwater ostracods currently is being planned. The effect of parasitism on reproductive potential, and life table information can best be obtained under controlled laboratory conditions and hopefully will strengthen field observations discussed herein. Greater emphasis on quantification and replication of future field and laboratory experiments will perhaps aid in better understanding the ecological aspects of ostracod populations stated briefly in the introductory remarks. More quantitative and experimental approaches are not only desirable, but are essential in elucidating the importance of freshwater ostracods in population, community and trophic interactions in aquatic ecosystems.

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