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Postglacial ostracod distribution and paleoecology, Devils Lake basin, northeastern North Dakota

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POSTGLACIAL OSTRACOD DISTRIBUTION AND PALEOECOLOGY, DEVILS LAKE BASIN, NORTHEASTERN NORTH DAKOTA

by

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This dissertation submitted by James B. Van Alstine in partial fulfillment of the requirements for the Degree of Doctor of Philosophy from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

(Chairman)

This dissertation meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Dean of the Graduate School

Permission

Title: POSTGLACIAL OSTRACOD DISTRIBUTION AND PALEOECOLOGY, DEVILS LAKE BASIN, NORTHEASTERN NORTH DAKOTA

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ABSTRACT

Sediment cores were taken from Main Bay and Creel Bay of Devils Lake (in 1975 and 1976) and East Devils Lake (in 1978), within the Devils Lake basin, and from Red Willow Lake (in 1979), a control lake outside of the Devils Lake basin, northeastern North Dakota. The cores were sampled, for the recovery of the ostracods, at 10-cm intervals. Fifteen species of ostracods were present in the studied cores: 8 candonids, 1 cyclocyprid, 3 cyprids, and 3 limnocytherids. Two distinct faunas are recognized. The Devils Lake-East Devils Lake fauna consists of Candona lactea, C. rawsoni, Cyprinotus glaucus, Potamocypris smaragdina, Limnocythere (Limnocytherina) ceriotuberosa, and L. staplini. The Red Willow Lake fauna consists of Candona acutula, C. candida, C. caudata, C. decora, C. ohioensis, C. lactea, C. pronopa, C. rawsoni, Cypridopsis vidua, Cyclocypris ampla, and Limnocythere (Limnocytherina) itasca. Only two species are in common in the two faunas. Variations of diversity, similarity, and equitability indices, and abundance of species with depth are used to interpret major episodes of environmental disruption. The faunas do not increase in complexity with time. The Devils Lake-East Devils Lake fauna indicates that the lakes have remained saline with time, but episodes of greatly increased salinity or desiccation have occurred at several intervals. Using sedimentation rates determined by Callender (1968) for Main Bay, major disruptive

events are interpreted at 7,000, 1,500, 1,200, and 900 years BP. Sedimentation rates have not been determined for the other cores. The Red Willow Lake fauna indicates that the lake has remained relatively fresh with time, but periods of environmental disruption have occurred. The changing environments through time of Main Bay of Devils Lake, as interpreted on the basis of ostracod distribution patterns, correlates only generally with interpretations based on diatom succession and geochemical analysis of the sediments.

INTRODUCTION

The Devils Lake Basin, northeastern North Dakota, has undergone several drastic changes in salinity and depth during its recorded history, as well as during the Pleistocene Epoch. These changes have been recognized in the geochemistry of the lake sediment (Callender 1968) and in the diatoms (Stoermer et al. 1971).

The primary purposes of this study are:

(1) to determine the vertical distribution and paleoecology of ostracod populations in the postglacial sediments of Devils Lake, East Devils Lake (both within the Devils Lake basin), and a control lake, Red Willow Lake (outside of the basin);

(2) to calculate and interpret the diversity coefficients of the populations in each sample, and the similarity coefficients of the populations of consecutive samples, to determine if significant breaks in distribution patterns occurred, indicating periods of major environmental disruption;

(3) to compare any distribution patterns with those reported by Callender (1968) and Stoermer et al. (1971); and

(4) to test the hypothesis that diversity or complexity of a community increases with time or with increased stability of the environment.

These goals were accomplished by:

(1) obtaining sediment cores from Main Bay and Creel Bay of Devils Lake, from East Devils Lake, and from Red Willow Lake;

(2) sampling the cores at 10-cm intervals, and extracting, identifying, and counting all individuals of each species of ostracod in the samples;

(3) calculating, plotting, and interpreting the diversity, similarity, and equitability indices for each sample;

(4) comparing the paleoecology of the fauna as it changed through time, to the sedimentological changes observed by Callender (1968); and

(5) relating the changes in the ostracod fauna to the inferred stability of the environment of deposition.

PREVIOUS WORK

The first published description of Devils Lake was that of Nicollet (1843). He named the lake "Minnewakan," and published a map of the region. The first geological description of the Devils Lake area was that of Upham (1895). He included observations on previous lake levels as interpreted from strand lines. Fluctuations of lake levels, changes in salinity, and general glacial geology and hydrology of the Devils Lake region were reported by Babcock (1902). Simpson (1912) described the geography of the Devils Lake and Stump Lake regions, and, in a report on the Geology of North Dakota (1929), described the geology of the Devils Lake area. Works by Aronow (1955, 1957, 1963) and Aronow et al. (1953) described the detailed Pleistocene geology and the Post-Pleistocene history of the Devils Lake region.

Limnological studies of the lake were carried out by Young (1924) and Metcalf (1931). Studies of the chemistry of Devils Lake were reported by Pope (1909), Nehrus (1920), and Swenson and Colby (1955). Precipitation of carbonate minerals in Devils Lake was reported by Callender and Armstrong (1966), and the primary productivity of the lake was reported by Armstrong et al. (1966) and Anderson and Armstrong (1966).

Callender (1968) undertook an extensive study of the Devils Lake region, including the hydrology of the region, the limnology of Devils Lake, including a discussion of the present sedimentary environments,

and an interpretation of the sedimentary history of the lake basin.

Stoermer et al. (1971), utilizing a sediment core from Main Bay of Devils Lake, studied the diatom succession in the lake, and used the information to summarize the Holocene history of the lake basin.

Recent studies of the Devils Lake basin were prompted, for the most part, by the proposed Garrison Diversion Project. This project would use the Devils-Stump Lake chain as a route for the movement of irrigation water to the southeastern part of the state. Because of the high salinity of the lakes, and the potential damage this water could do if introduced into other lakes and rivers, several studies were initiated. Neel et al. (1970) reported on the limnobiochemistry of the lake. Larson (1968, 1972) studied the salamander population of the lake. Owen et al. (1973) reported on the biogeochemistry of the lake, including a discussion of the evolution of the lake system.

Shubert (1976, 1978) and Mercil et al. (1980) discussed the algal growth potential of Devils Lake, as related to the eutrophic conditions in the lake.

GEOLOGIC SETTING

Devils Lake and East Devils Lake are part of a series of lakes within a drainage basin of about 10,000 square kilometers. Red Willow Lake is south of this basin, outside of the Devils Lake drainage. All of the lakes are in the glaciated plains of northeastern North Dakota (Figure 1).

The major glacial landforms in the study area are the well developed Kensdal, North Viking, and Heimdal Moraines, bordering the lake basin on the south, and the poorly developed Sweetwater Moraine north of Devils Lake. Gently rolling ground moraine is present between the "end" moraines, and outwash occurs distal to them (Callender 1968). Several large meltwater trenches are present in the study area, both in the surface and subsurface. The entire Devils Lake-Stump Lake chain is considered by some authors to occupy an old meltwater trench (Paulson and Akin 1964, Fig. 9). The largest surface trench in the study area is the Sheyenne River Valley (Figure 1). This trench was formed by the draining of Glacial Lake Souris, and cuts entirely through surficial deposits exposing bedrock in places along the valley walls (Callender 1968, p. 13).

Surficial deposits in the study area consist of the Pleistocene Coleharbor Group and late Pleistocene and Holocene Oahe Formation, directly overlying the Cretaceous Pierre Shale (Bluemle et al. 1980).

The Coleharbor Group consists of up to 300 m of glacial sediment and glacier-related sediment. There are two facies of this group

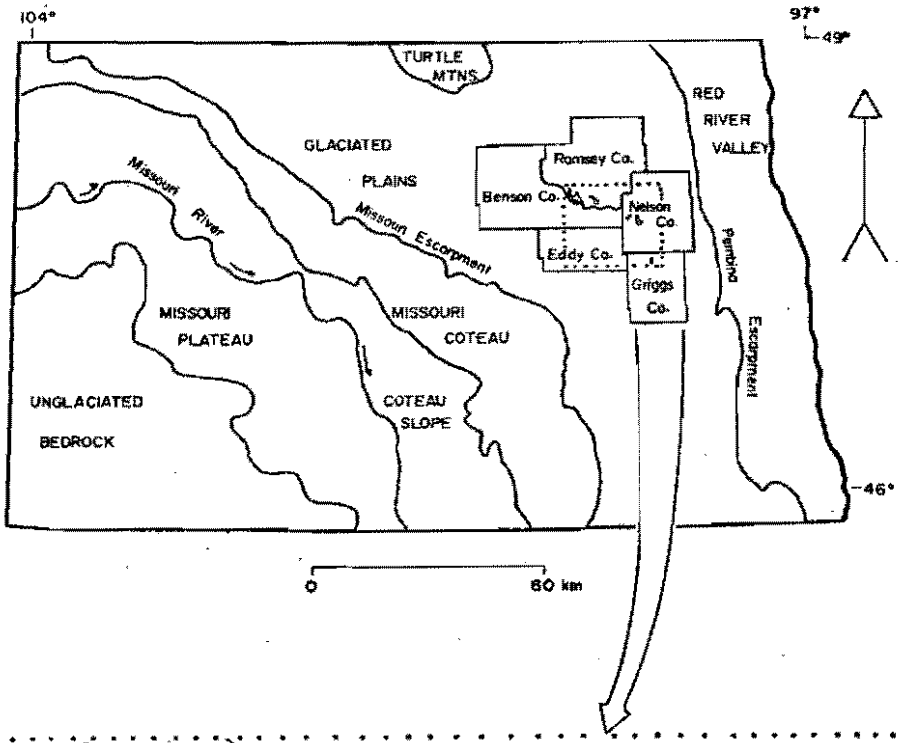
recognized in the study area: a till facies, consisting of unsorted, unstratified material deposited in contact with the ice, and a sand and gravel facies consisting of material deposited by glacial meltwater (Bluemle 1975).

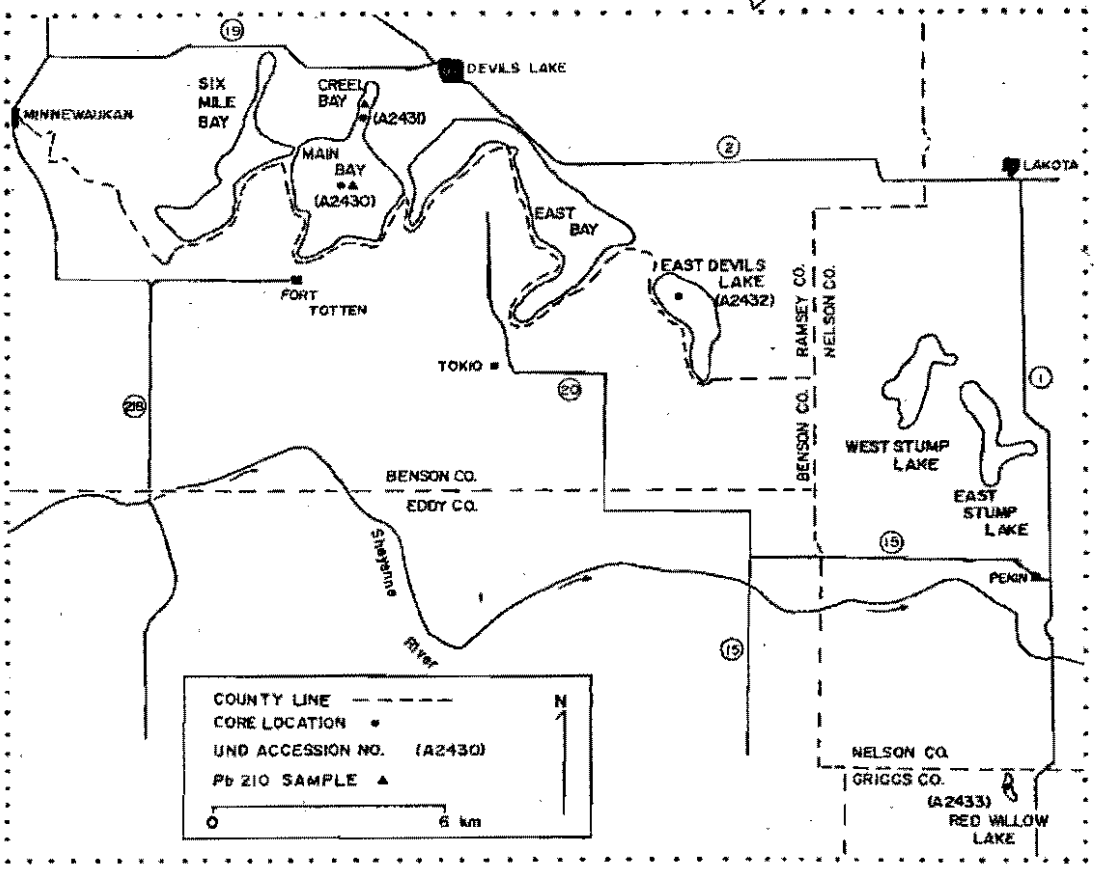
The till facies constitutes "ground moraine" (lodgment deposits), "collapse moraine" (material "let down" as the ice melted), and "end moraines" (ice marginal deposits) or thrust features. Several areas of Benson and Griggs Counties exhibit linear ridges with associated depressions. These ridges have internal linearity, and were formed when large blocks of Pierre Shale and till were excavated by large-scale sub-ice shearing and transported short distances. The resulting topography, a hill and related depression, is well illustrated by Sully's Hill and related hills in Benson County, and several areas in northwestern Griggs County. Devils Lake, East Devils Lake, and Red Willow Lake occupy depressions left by this shearing process (Bluemle 1975 and 1977; Clayton et al. 1980). The till facies of the Coleharbor Group in the study area contains large amounts of fragmented Pierre Shale, as well as Paleozoic carbonates derived from outcrops in the Winnipeg area of Manitoba (Callender 1968; and Clayton et al. 1980).

The sand facies of the Coleharbor Group consists of glacial outwash. This material was deposited in depressions and on top of the rolling topography in northern Griggs and Ramsey Counties (Bluemle 1975, p. 24). The outwash in the study area consists predominantly of Pierre Shale fragments, or mixed shale, limestone, and crystalline rock fragments (Callender 1968, p. 7).

The Oahe Formation consists of sediment of fluvial, lacustrine, eolian, mass-movement, or slopewash origin. It is considered to include all material deposited after 10,000 years B.P., or during the end of the Pleistocene and the Holocene (Bluemle et al. 1980). Much of the Devils Lake region, including the Devils Lake-Stump Lake chain, is located on the clay facies of the Oahe Formation. This material had been deposited during higher still-stands of Devils Lake (Clayton et al. 1980). All cores taken in this study are from the Oahe Formation.

Fig. 1. Physiographic map of North Dakota illustrating the relationship between the major physiographic subdivisions of the state and the study area (adapted from Bluemle 1977), and a detailed map of the study area showing the location of the lakes, nearest towns, and the sediment cores. Cores are indicated by name and UND Accession number. All location descriptions are given in Appendix V.


104°
97°
49°
TURTLE MTNS.
RED RIVER VALLEY
GLACIATED PLAINS
Missouri River
Missouri Escarpment
Ramsey Co.
Benson Co.
Nelson Co.
Eddy Co.
Griggs Co.
Sheyenne
Escarpment
MISSOURI PLATEAU
MISSOURI COTEAU
UNGLACIATED BEDROCK
COTEAU SLOPE
46°
0
60 km


DEVILS LAKE
MINNEWAUKAN
SIX MILE BAY
CREEL BAY
(A2431)
MAIN BAY
(A2430)
EAST BAY
LAKOTA
FORT TOTTEN
EAST DEVILS LAKE (A2432)
TOKIO
RAMSEY CO.
NELSON CO.
BENSON CO.
WEST STUMP LAKE
EAST STUMP LAKE
BENSON CO.
EDDY CO.
Sheyenne River
PEKIN
NELSON CO.
GRIGGS CO.
(A2433)
RED WILLOW LAKE
COUNTY LINE
CORE LOCATION
UND ACCESSION NO. (A2430)
Pb 210 SAMPLE
N
0
6 km

QUATERNARY GEOLOGIC HISTORY

The understanding and interpretation of the glacial geologic history of North Dakota has changed considerably in the last ten years. The summary below is a brief synthesis of the very detailed works of Bluemle (1975) and Clayton et al. (1980).

There is evidence for pre-Wisconsinan glaciation in several counties in northeastern North Dakota. Bluemle (1967a) reported multiple tills separated by gravel horizons north of Griggs and Steele Counties that were interpreted to be possibly pre-Wisconsinan. Two other tills of pre-Wisconsinan age are recognized along Lake Sakakawea, but have not been dated (Bluemle 1975; and Clayton et al. 1980). These do not correlate with tills found in northeastern North Dakota (Bluemle 1975).

The late Wisconsinan glaciation advanced through North Dakota 25,000-20,000 years B.P. (Clayton et al. 1980, p. 65). From about 13,000-11,000 years B.P. there were seven advances into east-central North Dakota (advances 9 through 15 of Clayton et al. 1980, fig. 8). The Kensdal moraine and younger material have not been dated, but stratigraphic and geomorphic evidence indicate a significant period of advancement at about 12,700 years B.P. Thrust masses of the Kensdal, Heimdal, and North Viking moraines also indicate an active ice advance. It was this sub-ice thrusting that excavated the basins that now contain the Devils-Stump Lake chain, and Red Willow Lake.

The detailed glacial geology of the Devils Lake area is very complex, consisting of pre-glacial channel sediment, thrust blocks, and overridden lake sediment (Clayton et al. 1980, p. 70), and post-glacial channel sediment (Callender 1968, p. 11-13). A detailed chronology of the study area has yet to be thoroughly worked out and published (Hobbs personal communication).

Devils Lake has been in existence since the end of the Late Wisconsinan glaciation (Aronow 1957). Since the Holocene, it has been a closed basin lake, fluctuating in level from its highest stage of 443 m to a low of 427 m during recorded history (1940 A.D.) (Clayton et al. 1980, p. 24). Aronow (1957) speculated that Devils Lake and Stump Lake were connected during the Late Wisconsinan. Clayton et al. (1980) disagreed because there is no evidence that water had flowed through the area.

Throughout the Holocene, water levels and salinity of Devils Lake have fluctuated dramatically. Callender (1968, fig. 45) recognized five major and several minor fluctuations of lake level from 6,000 years B.P. to the present. Stoermer et al. (1971, fig. 2) recognized seven periods of low water and brackish conditions.

Analysis of the ostracod fauna indicates that the Devils Lake environment has always been unstable, with four major fluctuations of level and salinity recognized (Analysis of Fauna and Discussion sections).

MATERIALS AND METHODS

Field Work

Field work was carried out during 1975-1979. Cores were recovered as follows: Creel Bay, during the summer of 1975; Main Bay, during the winter of 1976; East Devils Lake, during the summer of 1978; and Red Willow Lake during the winter of 1979. Bottom sediment samples from Main Bay and Creel Bay, for the purpose of determining a sedimentation rate for recent deposits, were collected during the summer of 1979 (Figure 1).

The Main Bay core was taken in the deepest portion of the lake so a maximum record of uninterrupted sedimentation would be obtained. The Creel Bay core was taken in a rather shallow arm of the lake, so a record of maximum change would be obtained. Small changes in water level would more likely affect benthic organisms in a shallow bay. The East Devils Lake core was taken for the purpose of comparing another lake in the basin to Devils Lake. This core was taken in a shallow bay, again to record maximum change. Red Willow Lake was used as a control lake, outside of the Devils Lake drainage basin. This core was taken from deeper water, again to record maximum sedimentation.

All cores were recovered with a piston coring apparatus modified from that of Colinvaux (1964). This apparatus allowed recovery of a continuous, relatively undisturbed section of core from the sediment

surface to a depth of about 9 m. A moveable piston was secured in the end of a disposable plastic core liner, which was contained in an aluminum core barrel. The piston, attached to a cable, served to prevent sediment from entering the core barrel before reaching the position where the core was to be taken, and provided a vacuum to prevent loss of the core (Figure 7). The cable was run through the back of the core barrel and through a pulley and winch on the surface. The core barrel assembly was lowered through a PVC plastic casing to the sediment surface by a system of extension rods. Once in position, the cable was secured, thereby fixing the piston, and the core barrel was driven past the piston by means of a pile-driver. When the maximum length of the core (1 or 2 m, depending on the length of the core barrel) was obtained, the depth of penetration was marked on the extension rods by clamping a vise grip pliers on the rod at the top of the casing, and the entire assembly was extracted from the sediment with the winch and cable. The core liner containing the sediment was removed from the barrel, capped on both ends, labeled and stored for later analysis, and a new liner was installed. The entire operation was then repeated by lowering the coring apparatus to the depth marked on the rods, securing the cable, and again driving the core barrel and liner over the piston.

The major problem in the entire field operation was maintaining a stable coring platform. Winter coring, using ice as a stable surface, was the easiest, but access to the lakes was, at times, impossible. A pontoon raft was used for summer coring, and when secured on four corners with anchors, provided a suitable platform. The maximum workable water depth was about 10 m. The maximum length of core was determined

by the difficulty of driving the core barrel into the sediment. At a core depth of about 8-9 m, the extension rods would bend, the couplings would fail, and the operation was halted.

The sections of core were stored upright, excess water was siphoned off, and they were allowed to compact before transport. Appendix I gives a complete description of the coring apparatus.

Preparation of Samples

The sediment cores were measured, and either frozen immediately (if taken in the winter) or as soon as returned to the laboratory. The cores were kept frozen until sectioned to prevent acidification of the sediment by decomposition of organic material.

The frozen cores were sectioned while in the liners. A 1-cm-thick slice was taken from the top of the core and from every 10 cm throughout the length of the core. The remaining segments were capped, labeled, and kept frozen.

Each 1-cm slice was removed from the liner section, thoroughly scraped to remove any contamination, placed in a jar and covered with a solution of 10% Calgon (sodium hexametaphosphate) and deionized water to deflocculate the clays. Prior to washing, the sample jars were placed in a sonic bath for 15 minutes to assure the complete breakdown of the sediment. At times, a second soaking was required for maximum deflocculation. Minimum agitation was used to avoid breakage of the ostracod valves.

Once deflocculation was complete, the entire sample was washed through a 250-mesh sieve to remove the silt and clay sediment fraction. All material remaining on the wet sieve was washed with deionized water

onto filter paper in a Buchner vacuum funnel apparatus, and the excess water evacuated. The residue in the funnel was washed twice with acetone to remove as much moisture as possible to prevent cohesion of any remaining clay. The samples were finally placed in an air curculating drying oven, set at 25° C, for two hours to remove the remaining moisture and acetone.

The dry samples were sieved through 20-, 50-, and 60-mesh Tyler hand sieves. These size fractions of the prepared samples were scanned under a binocular microscope, and all ostracod valves picked. The material on the pan was ignored, as anything passing through the 60-mesh sieve would be immature and unable to be identified positively (Van Morkhoven 1963). All ostracod valves observed were picked with a 00-size brush, or when exceptionally abundant, with a micropipette vacuum aparatus designed for the purpose (Appendix II). Using the vacuum system, all valves could be picked up rapidly with a minimum of breakage. If the original sample contained abundant ostracods, it was split with a microsplitter before picking. The ostracods were loose mounted in micropaleontological slides for later identification and counting. Each valve was counted, with the final number divided by two for the true number of individuals in the sample. If a sample had been split, the number of individuals was multiplied by the number of splits for the final count.

Statistical Methods

One of the major goals of this study was to determine if there were significant changes in the ostracod fauna of the lakes through time, and to determine whether the paleoecology of the fauna could be used to determine changing environments within the lake basins. In order to assess the significance of variations observed in the fauna, four quantitative aspects of the ostracod distribution were studied: faunal diversity; faunal equitability; faunal similarity; and abundance of various species through time (depth of sample). Each of these parameters provides a different view of the changes observed in communities over a large geographic area, or through time.

Faunal Diversity

Diversity within a community is one of the major factors which gives an indication of the complexity of the community structure, at one geographic location, or one point in time (Lister 1974, p. 4). This index is a measure of the number of species present in the community without regard to which species they are. The greater the index, the greater the biologic complexity of the community (MacArthur 1955). Biological complexity has been considered to be a function of the following factors: time (older communities have more species than younger communities); heterogeneity of the environment (the more complex the environment, the more complex the biota of the environment); and climatic stability (a more stable environment yields a more complex community than an unstable environment) (Pianka 1966).

The purposes of assessing faunal diversity in this study was to determine whether periods of environmental instability (interpreted to

be periods of desiccation and increased salinity) could be recognized by using the ostracod fauna contained in the cores; to determine whether the diversity of the fauna increased with time, indicating maturity of the community; and to compare the lakes with each other through time.

Four diversity indices of two basic types were calculated. The simplest diversity measure is the number of species present in a sample. This index does not take into consideration the number of individuals of the species present, and tends to weight rare and common species equally. This measure is an advantage if the absolute numbers of individuals in the sample is unknown. If, however, one species fluctuated greatly in numbers throughout time, but was never eliminated from the fauna, this measure would not convey that information. The other measures of diversity take into consideration the relative species abundance versus the numbers of individuals in the sample.

Simpson's Index ($D= N(N-1)/\sum^{i}(n_i(n_i-1))$) (Simpson 1949), Brillouin's Index ($D= 1/N\log(N!/n_1!\ n_2!.....n_s!)$) (Brillouin 1962), and Margalef's Index ($D= S-1/(\mathrm{Ln}(N))$) (Margalef 1958) where D= Diversity, N= total number of individuals, n= n_i individuals in the i^{th} species, and S= total number of species, are of this type. These indices were calculated for every sample in every core and were plotted versus depth. Plots of all indices proved to be very close. Margalef's index exhibited the most variability with depth and was chosen to be illustrated along with simple diversity on figures 2-6.

Faunal Equitability

Equitability (E) of a fauna is an expression of dominance by one or more taxa. If equitability is 0, there is a total dominance of the

fauna by one taxon. A value of 1 represents perfect equitability where each taxon is represented by equal numbers of individuals. The equitability index used in this study was that of Donahue (Shaak 1975) where E= Simpson's Index/ number of taxa. This index was calculated and plotted versus depth on figures 2-6.

Variations in equitability can be directly related to species diversity and to environmental stability. Lister (1974) proposed that severe drops in equitability, as well as in simple diversity through time, indicate large-scale disturbances that drastically disrupt the community structure, exterminating most of the species.

Faunal Similarity

Similarity is a measure of the "sameness" of two faunas. Similarity indices have been used to correlate widely separated faunas of the same age to establish biogeographic zones (Raup and Crick 1979).

Similarity indices were calculated in this study to compare every two consecutive samples in all cores. The purpose was to determine whether there was a noticable change in the similarity curve at points of inferred environmental stability. Similarity indices were also used to assess the similarity of the lakes to each other.

Three similarity indices were calculated: Simpson's Index (S=K/B) (Simpson 1943), Jaccard's Index (S= K/A+B-K) (Jaccard 1908), and Dice's Index (S= 2K/A+B) (Sokal and Sneath 1963), where K= the number of taxa in common to the two samples, B = the smaller of the two assemblages, and A = the larger of the two assemblages. All indices were plotted versus depth. Simpson's Index was useless in this study. The number of taxa in any one sample was always very small, and consecutive samples

usually differed only by one taxon. For this reason, K and B were often the same, and the similarity index would be a perfect 1, even though the assemblages were not equal. Plots of the Jaccard and Dice indices were very similar and the Jaccard index was chosen for illustration on figures 2-6.

Species Abundance

The final attempt to quantify the data was to plot the abundance (number of individuals) of selected species versus depth for each core. The species that exhibited greatest fluctuation with depth, yet the greatest persistence throughout the core, were chosen. This information was plotted for two reasons: to compare the distribution of individual species to the plots of diversity and equitability, and to aid in determining the changing environments of the lakes through time. The environment preferred by individual species can be inferred to have fluctuated as the abundance of the species varied throughout the core.

Computer Methods

Three different computer programs were written to aid in the analysis of the raw data. These programs form a significant portion of this study, and are easily adapted to any study where species diversity or similarity indices of samples must be calculated. Because of the usefulness of these programs, they are briefly described here, with a complete listing including users' documentation and technical information in Appendix III.

Program DATALIST

This program is designed to read a data file and output the following for each species found in the study:

(1) every location and every interval that contains that species;

(2) the number of individuals of that species in each interval;

(3) the total of individuals of that species found in the study; and

(4) the total number of individuals of all species in the study.

Program DIVERSITY

This program is designed to read a data file and output the following for each sample or sampling interval:

(1) the location and interval sampled;

(2) the species present in the sample, listed by name;

(3) the number of individuals present for each species; and

(4) the total number of individuals present in the sample.

The program then calculates and outputs the Brillouin, Simpson, and Margalef Diversity Indices, and the Donahue Equitability Index for the species in the sample.

Program SIMILARITY

This program is designed to read a data file, and output the following for every two consecutive samples in a core or section:

(1) the location of the samples and the intervals being compared; and

(2) the Simpson, Jaccard, and Dice Similarity Indices for the two intervals being compared.

The above programs could be combined into one run on a computer, but for convenience sake they were entered individually for this study.

Photographic Methods

All photographs were taken with a scanning electron microscope at the Geology Department of the University of North Dakota, Grand Forks. The fossils were coated with gold, and photographed at magnifications of 24X to 50X. Polaroid negatives were used to make contact prints from which the final plates were composed.

SEDIMENTATION RATE

Sedimentation rates were used to attempt to determine the amount of time represented by the Main Bay core, and to help determine when periods of environmental disruption occurred.

Callender (1968, p. 178) reported a depositional rate of 50-146 $mg/cm^2/yr$ for Main Bay of Devils Lake. These rates were calculated from two cores, using radiocarbon dates determined by the total organic carbon method. Callender used the mass-per-unit area expression of rates instead of an expression of length-per-unit time, because he considered it to be more precise. Considering that the sedimentation rate in Main Bay was greater in the lower portion of the core (Callender, 1968, p. 178), an average sedimentation rate in terms of length/unit time would be approximately 0.1 cm/yr. Because the dates were not established on the basis of woody tissue, they are considered tenuous.

Attempts were made to determine a recent sedimentation rate for Main Bay and Creel Bay. One meter cores were taken from both bays (Figure 1), and analyzed by the University of Minnesota Geochronology Lab using ^{210}Pb. The cores were sampled every centimeter to assure maximum coverage. The results were mixed. In the Main Bay core there was no increase in activity of ^{210}Pb below 0.75 cm. This would indicate that there has been very little sedimentation in this part of the lake in recent history. Either no sediment was introduced into this area, or the rather continuous wave action during ice-free months redistributed

the sediment that had been deposited and diluted the ^{210}Pb, preventing an accurate reading. The Creel Bay core exhibited large fluctuations in the activity of ^{210}Pb. This could be related to the fluctuating water levels in recent history, but a positive correlation can not be made at this time. A tenuous sedimentation rate of 0.26-0.4 cm/year was established for Creel Bay, for the last 80-100 years. Much more work has to be done in this area before a recent sedimentation rate can be established with certainty.

ANALYSIS OF FAUNA

General

In attempting to use the ostracods of Devils Lake to determine changing environments, several factors influencing the fauna must be considered.

Rarely in paleontology does a fossil population completely represent that living at any point in time. Not only is there lack of preservation of forms without hard parts, but there is selective representation of those forms that are preservable. This is true with the ostracods. Not all species will be represented in a fossil sample as they were in the living population. Those with a carapace more resistant to destruction will appear to be more abundant (Kontrovitz 1967), as will those with a more rapid succession of generations (Lister 1974).

Ostracods representing several habitats will be brought together by reworking of the surface sediment by wave action. This prevents interpretation of microhabitats, but is an advantage when trying to interpret the history of an entire lake based on one or two cores. Each sediment sample (a 1-cm thick slice of the core) probably represents several years accumulation. This minimizes the problem of spatial heterogeneity of the environment, as well as seasonal differences in abundance of various species.

In attempting to use absolute numbers of individuals to calculate diversity and similarity indices, other factors must be considered. Even though a constant volume of sediment was taken with each sample, the number of individuals preserved in that sample will be diluted or concentrated depending on the sedimentation rate. The sedimentation rate in Devils Lake has been variable through time (Callender 1968) and is presently negligible. The effect of sedimentation rate on the numbers of ostracods counted in each sample is unknown.

Composition of Faunas

Fifteen species of ostracods in four families were present in cores from the lakes in the study area. The composition of the faunas, with the numbers of individuals of each species in the study is listed below.

Family Candonidae

Genus Candona

C. acutula	90 individuals
C. candida	10
C. caudata	10
C. decora	106
C. ohioensis	3278
C. lactea	5904
C. pronopa	22
C. rawsoni	4882

Family Cyclocyprididae

Genus Cyclocypris

C. ampla	624

Family Cyprididae	
Genus *Cyprinotus*	
C. glaucus	66
Genus *Cypridopsis*	
C. vidua	219
Genus *Potamocypris*	
P. smaragdina	1
Family Limnocytheridae	
Genus *Limnocythere*	
L. ceriotuberosa	1993
L. itasca	230
L. staplini	203

Faunal Diversity

The ostracod fauna of Devils Lake and East Devils Lake is small, consisting of only six species. No macrofossils were found.

The Main Bay and East Devils Lake faunas exhibit perfect similarity, each containing the same five species: *Candona lactea*, *C. rawsoni*, *Cyprinotus glaucus*, *Limnocythere ceriotuberosa*, and *L. staplini*. The Creel Bay fauna contains the above listed species, with the addition of *Potomocypris smaragdina*. Only one individual of this species was found in the Creel Bay core and this species is not considered to be a significant addition to the Creel Bay fauna.

Red Willow Lake exhibits a more diverse fauna, consisting of eleven species of ostracods: *Candona acutula* *C. candida*, *C. caudata*, *C. decora*, *C. ohioensis*, *C. lactea*, *C. pronopa*, *C. rawsoni*, *Cyclocypris ampla*,

Cypridopsis vidua, and Limnocythere itasca. In addition to the greater numbers of ostracod species, seven species of pill clams and gastropods were recognized.

There is little similarity between the Red Willow Lake fauna and the fauna of the lakes in the Devils Lake basin. Only two of the eleven species in Red Willow Lake (Candona lactea, and Candona rawsoni) are in common with the other lakes.

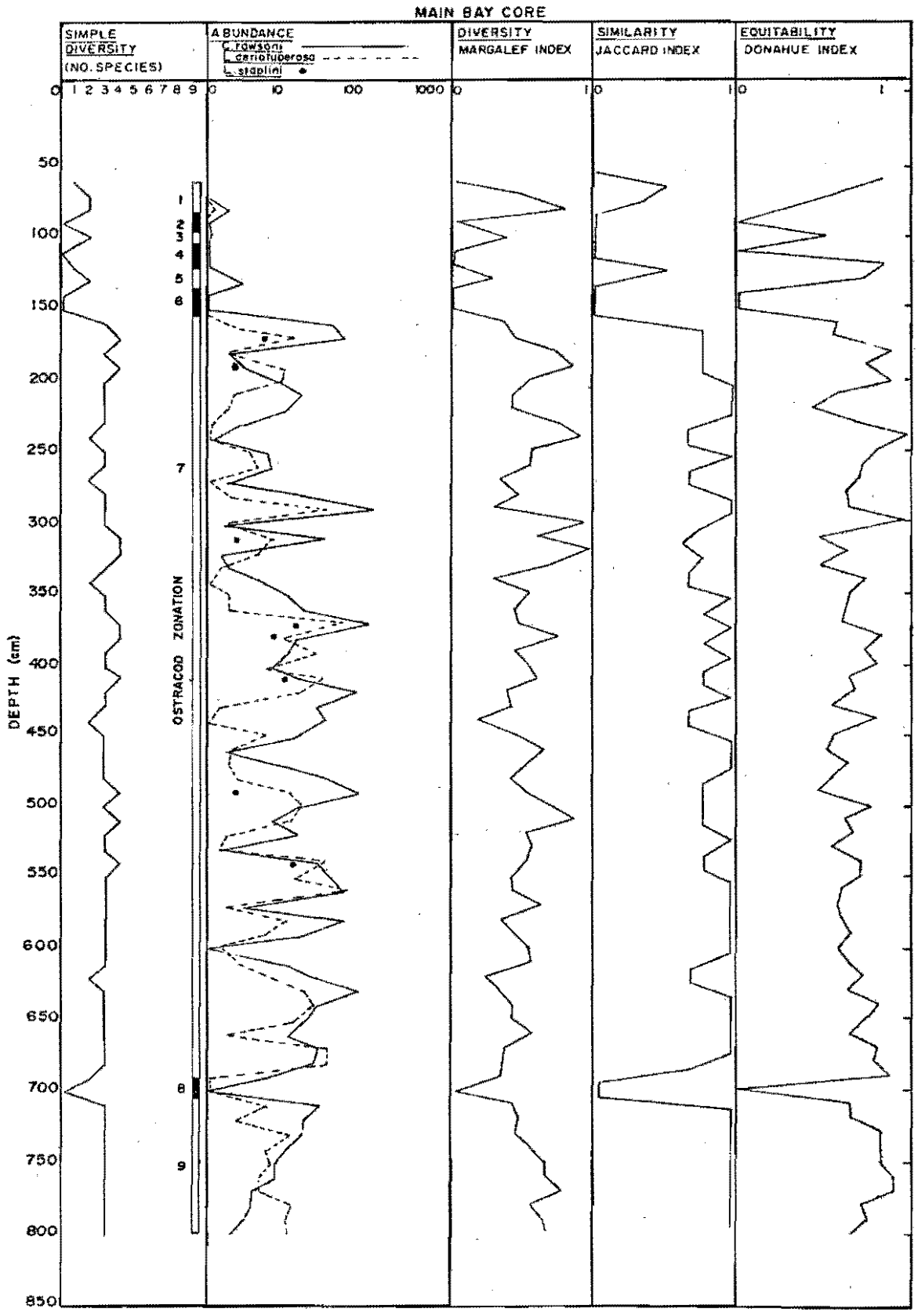
Biostratigraphy

The use of diversity and equitability indices to determine periods of drastic environmental change is useful in this study. All parameters discussed in the above sections, and plotted against depth on figures 2-6 fluctuated widely throughout the length of the cores. No species can be considered an index for a particular set of conditions existing at any point in time. The entire fauna fluctuates almost in unison. Green (1969) reported that regular or cyclical variability of the environment will both decrease or increase community structure, but erratic, irregular or catastrophic variability only destroys community structure. Catastrophic change is interpreted to have occurred in all lakes in this study through time. Periods of dramatic change, inferred to be total desiccation or hypersalinity, are represented by major decreases in all indices. These periods of change are indicated by solid bars in figures 2-6 designated as "OSTRACOD ZONATION".

Main Bay core (Figure 2)

All major indices fluctuate widely in the top 150 cm of the core. The total diversity is also low, with a maximum of two species found.

Fig. 2. Distribution with depth of simple diversity, species abundance (number of individuals of indicated species), Margalef diversity, Jaccard similarity, and Donahue equitability indices of the ostracod fauna contained in the Main Bay core (UND Accession number A2430). Also indicated is the ostracod zonation. A solid bar indicates periods of environmental change, with total elimination of the ostracod fauna. Distribution of the ostracod species with depth is given in Appendix IV.


MAIN BAY CORE
SIMPLE DIVERSITY (NO. SPECIES)
ABUNDANCE
C. rawsoni
C. reticulata
C. stapilini
DIVERSITY MARGALEF INDEX
SIMILARITY JACCARD INDEX
EQUITABILITY DONAHUE INDEX
0 1 2 3 4 5 6 7 8 9
0 10 100 1000
0 1
0 1
0 1
DEPTH (cm)
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
OSTRACOD ZONATION
1
2
3
4
5
6
7
8
9

The abundance of the indicated species is also very low, under five individuals per sample. All major indices decrease to zero at 100, 110, and 150 cm. These points, represented by zones 2, 4, and 6, represent periods of dramatic environmental change.

At 150-690 cm the overall diversity of the fauna increases to a maximum of four species per sample. There is fluctuation in all indices, but at no point do they drop to zero. The abundance of the indicated species also fluctuates greatly throughout zone 7.

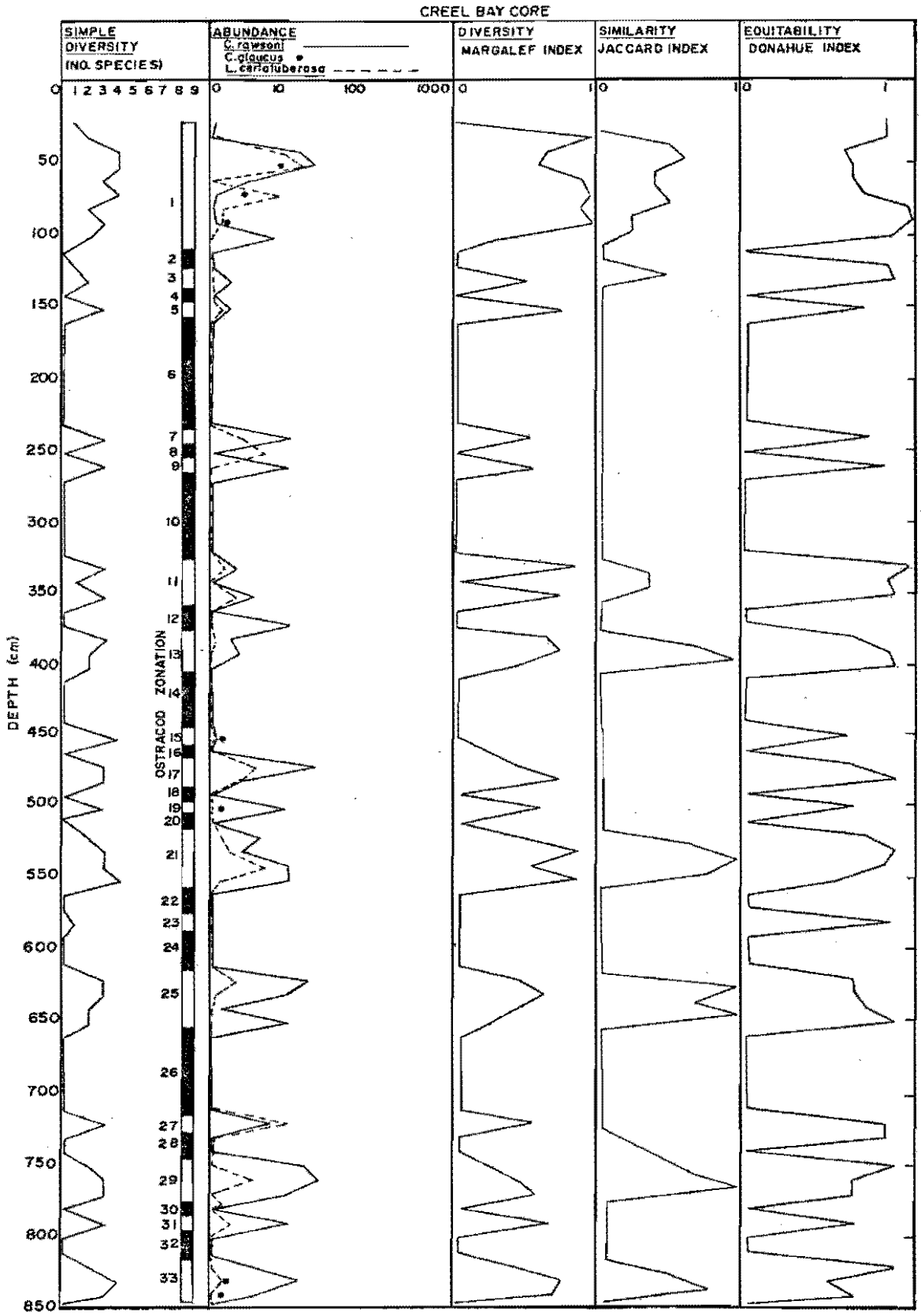
A major change occurs at 700 cm. All indices decrease to near zero. This zone (8) represents a period of major disruption. From 700 cm to the bottom of the core at 800 cm, all major indices rose.

Creel Bay core (Figure 3)

The Creel Bay core was taken from a shallow arm of the lake so a record of maximum fluctuation of the water level was obtained. Minor fluctuations of water level that had no drastic affect on the deeper portions of Main Bay are very noticeable in Creel Bay. There are many more periods of major disruption than were evident in the Main Bay core. All indices decrease to zero in zones 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, and 32. Major long-term disruptions occur at zones 6, 10, and 26. Zones 6 and 26 correlate with episodes of disruption recognized in zones 6 and 8 in the Main Bay core.

The species diversity and abundance of the indicated species rose rapidly in zones 7, 9, 17, 25, and 29. Also of interest is the distribution of Cyprinotus glaucus, which is only found in zones 1, 15, 19, and 33. This species prefers shallow water conditions.

Fig. 3. Distribution with depth of simple diversity, species abundance (number of individuals of indicated species), Margalef diversity, Jaccard similarity, and Donahue equitability indices of the ostracod fauna contained in the Creel Bay core (UND Accession number A2431). Also indicated is the ostracod zonation. A solid bar indicates periods of environmental change, with total elimination of the ostracod fauna. Distribution of the ostracod species with depth is given in Appendix IV.


CREEL BAY CORE
SIMPLE DIVERSITY (NO. SPECIES)
ABUNDANCE
C. rawsoni
C. glaucus
L. cerratuberosa
DIVERSITY MARGALEF INDEX
SIMILARITY JACCARD INDEX
EQUITABILITY DONAHUE INDEX
DEPTH (cm)
OSTRACOD ZONATION

East Devils Lake core (Figure 4)

All major indices remain fairly constant, without major fluctuations, from the top of the core to 390 cm. The abundance of the indicated species fluctuates, but no major episode of disruption is recognized in zone 1. In zones 2, 4, and 6, major periods of disruption are recognized. All indices drop to zero, and no species of ostracod are present. Diversity and species abundance increase rapidly in zones 3 and 5.

The episodes of environmental instability in this lake do not correspond with those recognized in the Main Bay or Creel Bay cores. This substantiates the statement by Clayton et al. (1980) that the lakes were never part of one large system, at least during the Holocene. The similarity of the faunas in East Devils Lake and Devils Lake, however, indicate that the same factors influenced the populations of ostracods in both lakes.

Red Willow Lake core (Figure 5)

In the upper half of the Red Willow Lake core, several periods of environmental instability are recognized. At zones 2, 4, 6, and 8, all major indices drop to zero. Below 430 cm there is relative stability. The fauna of Red Willow Lake is considerably different than those of the other lakes, which would indicate that the factors controlling the fauna may have been different. The only two species in common between Devils Lake-East Devils Lake and Red Willow Lake are present below the 430 cm level in zone 9. This may indicate that during the early history of Red Willow Lake, it was more similar to Devils Lake than it is today.

Fig. 4. Distribution with depth of simple diversity, species abundance (number of individuals of indicated species), Margalef diversity, Jaccard similarity, and Donahue equitability indices of the ostracod fauna contained in the East Devils Lake core (UND Accession number A2432). Also indicated is the ostracod zonation. A solid bar represents periods of environmental change, with total elimination of the ostracod fauna. Distribution of the ostracod species with depth is given in Appendix IV.

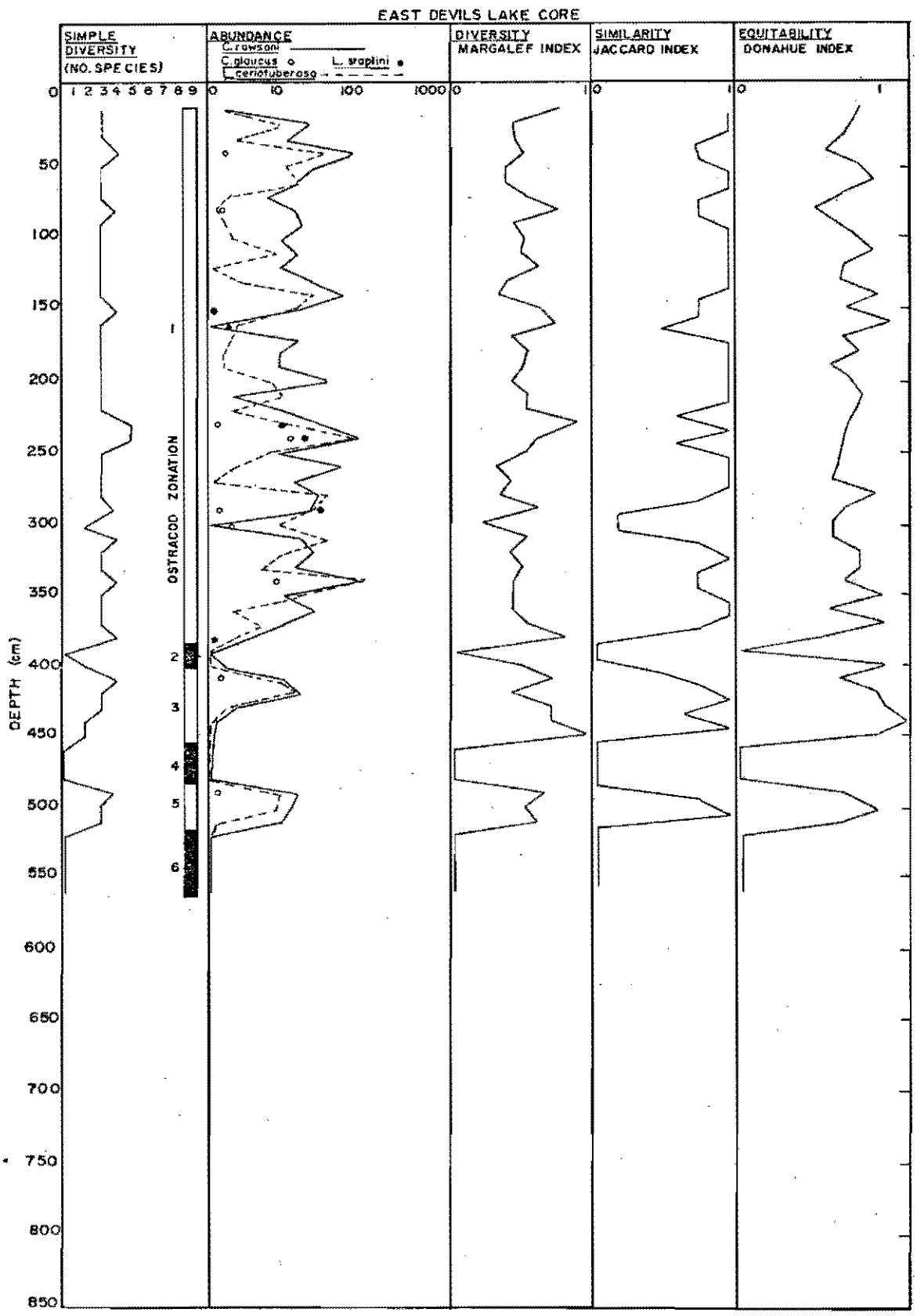
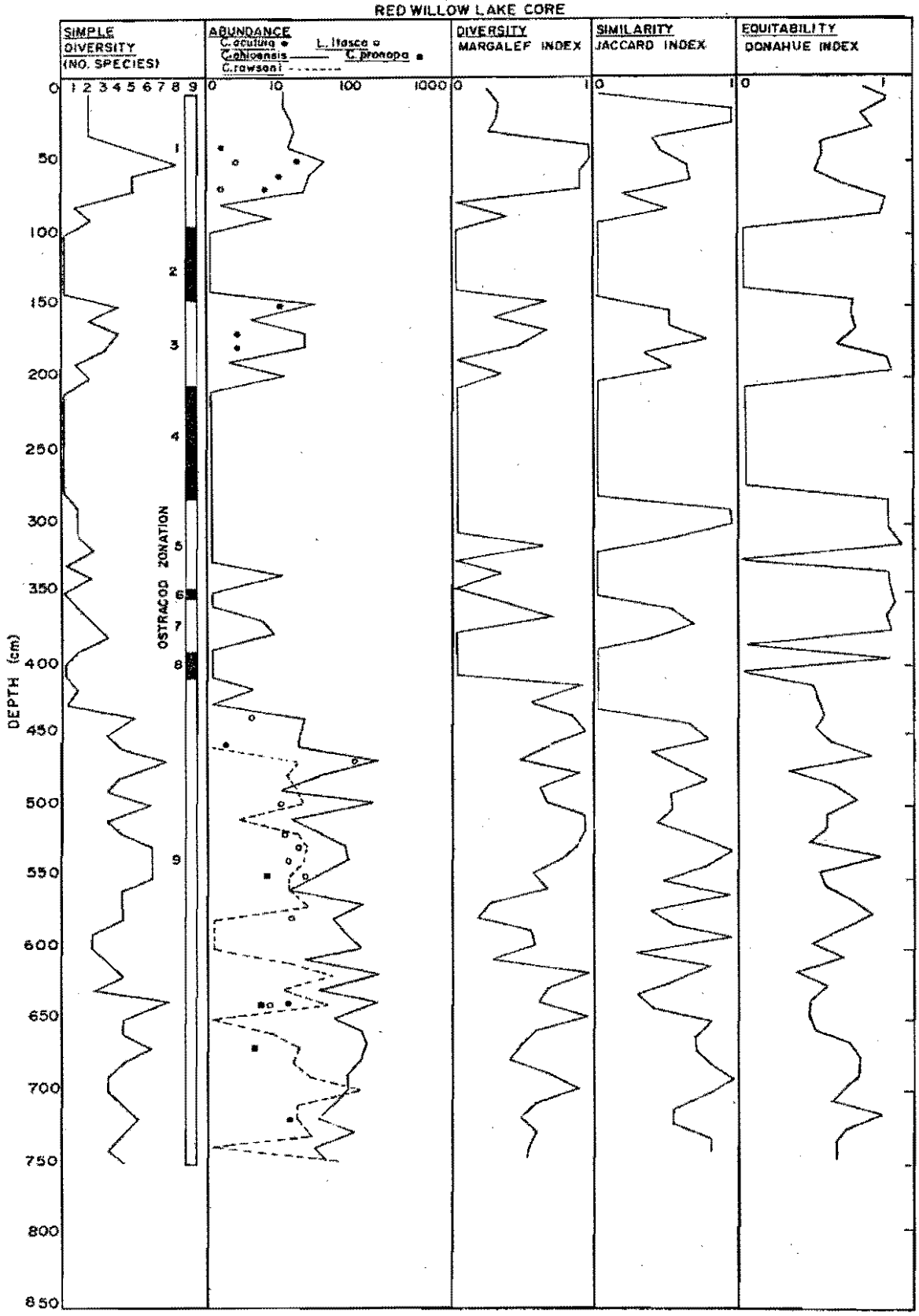

EAST DEVILS LAKE CORE
SIMPLE DIVERSITY (NO. SPECIES)
ABUNDANCE
C. rawsoni
C. glaucus
L. spaltini
C. ceriotuberosa
DIVERSITY MARGALEF INDEX
SIMILARITY JACCARD INDEX
EQUITABILITY DONAHUE INDEX
OSTRACOD ZONATION
DEPTH (cm)

Fig. 5. Distribution with depth of simple diversity, species abundance (number of individuals of indicated species), Margalef diversity, Jaccard similarity, and Donahue equitability indices of the ostracod fauna of the Red Willow Lake core (UND Accession number 2433). Also indicated is the ostracod zonation. A solid bar represents periods of environmental change, with total elimination of the ostracod fauna. Distribution of the ostracod species with depth is given in Appendix IV.

RED WILLOW LAKE CORE



There are no geochemical data on the sediment in Red Willow Lake, which limits the interpretations that can be made.

The greatest diversity of the fauna is recognized in zone 1.

Paleoecology

Fresh water ostracods have been utilized by several authors, notably Delorme (1969, 1971a), for paleoenvironmental interpretations.

The limiting factors in ostracod populations seems to be temperature and total dissolved solids (Delorme 1969). The composition of the faunas indicate that total dissolved solids is the primary limiting factor, at least in the Devils Lake basin.

According to Delorme (1969), the ionic makeup of the water of lakes depends on where the lakes are situated. The presence of vegetation around the lake is also significant; vegetation changes the acidity of surface water and regulates the leaching of carbonates. In a prairie region, more sulfates are leached because of the absence of acidic forest litter. Delorme (1971) was able to classify lakes on their chemical makeup, and to relate the ostracod fauna to this chemical composition. This allowed him to make detailed, specific paleoecological interpretations of the ostracods contained in sediment cores.

Benson and MacDonald (1963) noted that breaks in sedimentation in cores was indicated by the rapid increase and decrease of the abundance of ostracod carapaces. It is evident that the benthonic ostracod population depends in large part on the stability of the bottom, and that rapid changes in effective wave base on rates of sedimentation affects the size of the living population, as well as dilutes or concentrates

their paleontologic record (Benson and MacDonald 1963, p. 10). Increasing water depth results in a greater or more diverse population. Increased population levels also result from forms becoming acclimatized to overall changes in the environment. This can occur very rapidly with the reintroduction of species into an area.

Candona is the most common and widespread genus in this study. It can not tolerate acidic waters and proliferates in alkaline lakes and ponds. Up to a point, Candona shows a progressive increase in numbers with increasing salinity (Klassen et al. 1967, p. 440). Candona is a large genus and the carapace is heavily calcified. Staplin (1963) reported that ostracods of this type are indicators of alkaline waters. Hoff (1942) also associated this genus with alkaline lakes. The genus is not common in streams, as it can not tolerate the current (Hoff 1942).

The species whose abundances are tabulated on figures 2-6, are considered to be the most diagnostic species in the study for paleoenvironmental interpretations. Each of these species is listed below, along with a description of their preferred habitat. In addition, several species that are found only in Red Willow Lake are listed to allow comparison of it to other lakes in the study.

Candona acutula

This species is found throughout the Red Willow Lake core, but is most common in the upper 180 cm. Klassen et al. (1967, p. 444) indicated that this species is indicative of a shallow, moderately eutrophic lake rather high in total dissolved solids, specifically magnesium sulfate.

Candona ohioensis

This species is found throughout the Red Willow Lake core, but is most abundant in the lower half of the core, below 450 cm. C. ohioensis is considered to be a permanent lake form, found along weedy margins in slightly alkaline water (Staplin 1963a). Klassen et al. (1967, p. 442) reported that the presence of this species indicates a freshening of lake water, with the magnesium sulfate content of the water decreasing, and the magnesium bicarbonate content increasing. Delorme (1969, Fig. 1) indicated that this species prefers water at least 20 feet deep, and can tolerate total dissolved solids of 72-1584 ppm.

Candona rawsoni

This species is the most abundant and widely distributed species in this study. It is found throughout the Main Bay, Creel Bay, and East Devils Lake cores, but only occurs below 460 cm in the Red Willow Lake core. Staplin (1963a) reported this species as being common in cool, alkaline, permanent lakes, with little vegetation. It is a bottom dweller, preferring muddy bottoms. Delorme (1971, Fig. 1) indicated that C. rawsoni was the only species in his study able to tolerate over 10,000 ppm $SO_4^{=}$, and widely fluctuating chemical conditions.

Cyclocypris ampla

This species was not plotted in the text figures, but occurs throughout the Red Willow Lake core. Delorme (1969) indicated that it prefers permanent ponds of moderate salinity at least 20 feet deep. C. ampla can tolerate total dissolved solids of 72-1584 ppm, but can not tolerate $SO_4^{=}$ concentrations greater than 1000 ppm (Delorme 1971, Fig. 1).

Cyprinotus glaucus

This species has a limited occurrence in the Main Bay, Creel Bay and East Devils Lake cores. It prefers shallow water of moderate salinity (Staplin 1963a).

Limnocythere (*Limnocytherina*) *itasca*

This species was found in eleven samples from the Red Willow Lake core. It is noticeably more abundant below the 400-cm level. Delorme (1971) reported that this species prefers shallow to moderately deep lakes and ponds. It can tolerate total dissolved solids of 165-5900 ppm. This species is less tolerant of elevated levels of $SO_4^=$ than other species of the genus, and can not tolerate rapidly fluctuating environmental conditions (Delorme 1971, Fig. 1).

Limnocythere (*Limnocytherina*) *staplini*

This species was found in seventeen samples from the Main Bay, Creel Bay, and East Devils Lake cores. Delorme (1969) said it prefers permanent lakes of extremely high salinity. It can tolerate total dissolved solids of up to 199,000 ppm. In Main Bay, this species was found to increase slightly in numbers as other species declined.

Paleoenvironmental Interpretations

General

The low diversity of the ostracod fauna in the Devils Lake and East Devils Lake cores is a reflection of the general instability of the environment in terms of water level and salinity. This low diversity was also reported in the diatom flora by Stoermer et al. (1971). Fluctuations of the salinity in an ecosystem leads to the exclusion of many species because their physiology can not cope with the variation. This

yields a low diversity community (Valentine 1973, p. 291).

The use of diversity indices to determine maturity of the environment (Margalef 1963; Shaak and Franz 1977) is invalid in this study. The faunal diversity of Devils Lake and East Devils Lake does not increase appreciably throughout the length of the cores. The diversity indices in Creel Bay are highly variable, and in Main Bay they actually decrease in the upper 150 cm of the core (Fig. 2, 3, and 6). East Devils Lake exhibits a period of stability from 400 cm to the top of the core (Fig. 4). There is no increase in diversity, only a reduction of the fluctuations of the indices. The diversity indices would indicate that rather harsh conditions have existed in these lakes throughout their histories, preventing diversification of the fauna.

Red Willow Lake, the control lake in this study, has not experienced the drastic salinity changes affecting the Devils Lake system, even though the diversity indices indicate it has experienced environmental disruption. The diversity indices of the fauna in Red Willow Lake did not increase with time, indicating that Red Willow Lake has not been able to stabilize and come to maturity. The faunas of Devils Lake and East Devils Lake and Red Willow Lake are very different, but both fluctuate widely throughout the length of the cores. This indicates that even though the lakes had very different environments through time, they were all affected by environmental disruptions.

The amount of time represented by the cored interval in Devils Lake is probably no more than 8,000 years, as determined by using the sedimentation rate of Callender (1968). Sedimentation rates have not been determined for the other lakes, but a rate of 0.1 cm/year, similar

to that in Devils Lake, would not be unrealistic. Using this sedimentation rate, the other cores probably do not represent more than 7,000 to 8,000 years. This is not enough time for the selection and evolution of new species of ostracods (Guttentag and Benson 1962). The low diversity of the ostracod faunas could be related in part to their youthfulness. This time factor could also explain why the Red Willow Lake fauna, while almost twice as large as that in Devils Lake, is still small compared to other post-Pleistocene lakes (Lister 1974; Delorme 1969).

The paleoecology of the ostracod fauna of Devils Lake and East Devils Lake indicates that the lakes have been saline throughout their histories. All species contained in the cores are able to tolerate elevated salinity. Major exterminations, as indicated by decreases in all indices, as well as the abundance of individual species, occurred with changing environmental conditions. With moderation of the environmental conditions, the same species would re-populate the lakes. Species unable to tolerate even moderate levels of salinity were prevented from inhabiting the lakes.

The ostracod fauna of Red Willow Lake contains species that are able to tolerate cool conditions, but not high levels of salinity. The fauna is typical of a temperate lake in a prairie region (Delorme 1971). Fluctuations of the diversity and similarity indices suggest major periods of environmental disruption in the history of Red Willow Lake. There is no evidence of re-population of Red Willow Lake with salinity tolerant species after the periods of elimination. This indicates that salinity must not have been the limiting factor in this lake. The

presence of Candona rawsoni in the early history of the lake (below 450 cm) indicates that the early environments of Red Willow Lake may have been closer to those of the other lakes. Candona rawsoni can also be considered a pioneer species, but unable to compete with later inhabitants of the lake.

The salinity changes in Devils Lake and East Devils Lake have been attributed to fluctuating lake levels. The fluctuating lake levels are a direct result of fluctuating climate and precipitation (Callender 1968, p. 56). Red Willow Lake is of the same age as the other lakes, and is situated on the same glacial material. The same climatic variations that affected the Devils Lake system must have affected the Red Willow Lake system. The faunal diversity of Red Willow Lake indicates that disruptions occurred but that they did not result in elevated salinities. Red Willow Lake does not have major streams or rivers entering the drainage basin, and is considered a closed basin lake, similar to the Devils Lake system. Residents along the lake report the presence of springs in the lake bottom. This has not been confirmed, but the influence of fresh ground water entering the lake in this manner would moderate the fluctuations of salinity resulting from climatic change. The ground water in the Red Willow Lake area may also be of different quality than that in the Devils Lake region, which would be a factor contributing to the overall quality of the surface water. Much more work in the Red Willow Lake region must be done before a reason for the difference in the fauna can be determined.

The paleoenvironments of the lakes interpreted below are based on the paleoecology of the ostracod fauna contained in the sediment cores.

Each core is discussed by zone. The discussions of the Main Bay and Creel Bay cores are combined with a discussion comparing this study with those of Callender (1968) and Stoermer et al. (1971).

With the exception of two zones in the Main Bay and Creel Bay cores (at 150 and 700 cm), none of the variations of the indices measured correlate between the cores.

East Devils Lake

(Fig. 4)

The East Devils Lake fauna consists entirely of salinity-tolerant species, indicating that the environment of the lake has always prevented population by less tolerant forms. Because of the uniformity of the fauna, only a general environmental interpretation can be made.

It could be interpreted that zone 6 represents the beginning of sedimentation in the lake, but there is insufficient evidence to substantiate this. For this reason, zone 6 is interpreted to represent only a period of environmental disruption and elimination of ostracods.

Zone 5 represents moderation of the environmental conditions, allowing population of the lake by salinity-tolerant species. The presence of Candona rawsoni indicates salinity in the range of 10,000 ppm or greater. The presence of Cyprinotus glaucus implies shallow water conditions.

Zone 4 represents a period of drastic change and elimination while zone 3 represents moderation of the environment, with the lake returning to conditions similar to those represented by zone 5. Zone 2 represents the last period of elimination recognized in this core.

Zone 1 represents a moderation and stabilization of environment. The lake remains saline, with total dissolved solids of perhaps 10,000 ppm or greater. There were minor fluctuations of the environment throughout zone 1, as indicated by the fluctuation of abundances of individual species, but at no time was a major period of elimination represented. The presence of Cyprinotus glaucus in zone 1 indicates continuous shallow water conditions, and the appearance of Limnocythere staplini confirms a saline environment.

Red Willow Lake

(Fig. 5)

The Red Willow Lake fauna consists almost entirely of species unable to tolerate concentrations of total dissolved solids greater than 5,000 ppm. Of the eleven species of ostracods present in this core, the six most diagnostic species were used for paleoenvironmental interpretation.

Zone 9 represents the longest period of stability during the history of the lake. The overall diversity of the ostracod population is high, and most of the species are represented by large numbers of individuals. Candona pronopa and C. rawsoni are restricted to this zone. C. rawsoni is interpreted to represent a pioneer species in this lake, and not to be an indicator of elevated salinity. The presence of Candona ohioensis and Limnocythere itasca, neither of which can tolerate levels of total dissolved solids greater than 5,000 ppm, with Candona rawsoni, substantiate this.

The presence of Cyclocypris ampla and Candona acutula throughout the length of the core indicates that the lake was always relatively low in salinity.

Major periods of environmental disruption occur at zones 8, 6, 4, and 2. The cause of the disruption is unknown. Each episode is followed by a period of moderation, allowing re-population of the lake by species representing cool conditions and total dissolved solids less than 5,000 ppm.

Limnocythere itasca is present in zones 9 and 1. This species indicates periods of general environmental stability. The overall species diversity is greatest in these zones as well. This is an additional indication of stability.

The abundance of Candona ohioensis throughout the core indicates that aquatic vegetation was always abundant in the lake.

Devils Lake

(Fig. 2, 3, and 6)

The fauna of the Main Bay and Creel Bay cores

same conditions interpreted for East Devils Lake. The lake has always been saline, with total dissolved solids greater than 10,000 ppm, and very high levels of $SO_4^{=}$.

A major period of environmental disruption is recognized in zone 8 in Main Bay. This correlates with zone 26 in Creel Bay.

Zone 7 in Main Bay represents a long period of moderating conditions, yet only salinity tolerant species were able to populate the lake (Candona rawsoni and Limnocythere staplini). There were many periods of minor environmental fluctuation throughout zone 7, but no major period of elimination. The many periods of major faunal disruption recognized in the portion of the Creel Bay core corresponding to zone 7 in the Main Bay core illustrate the much more tenuous position of

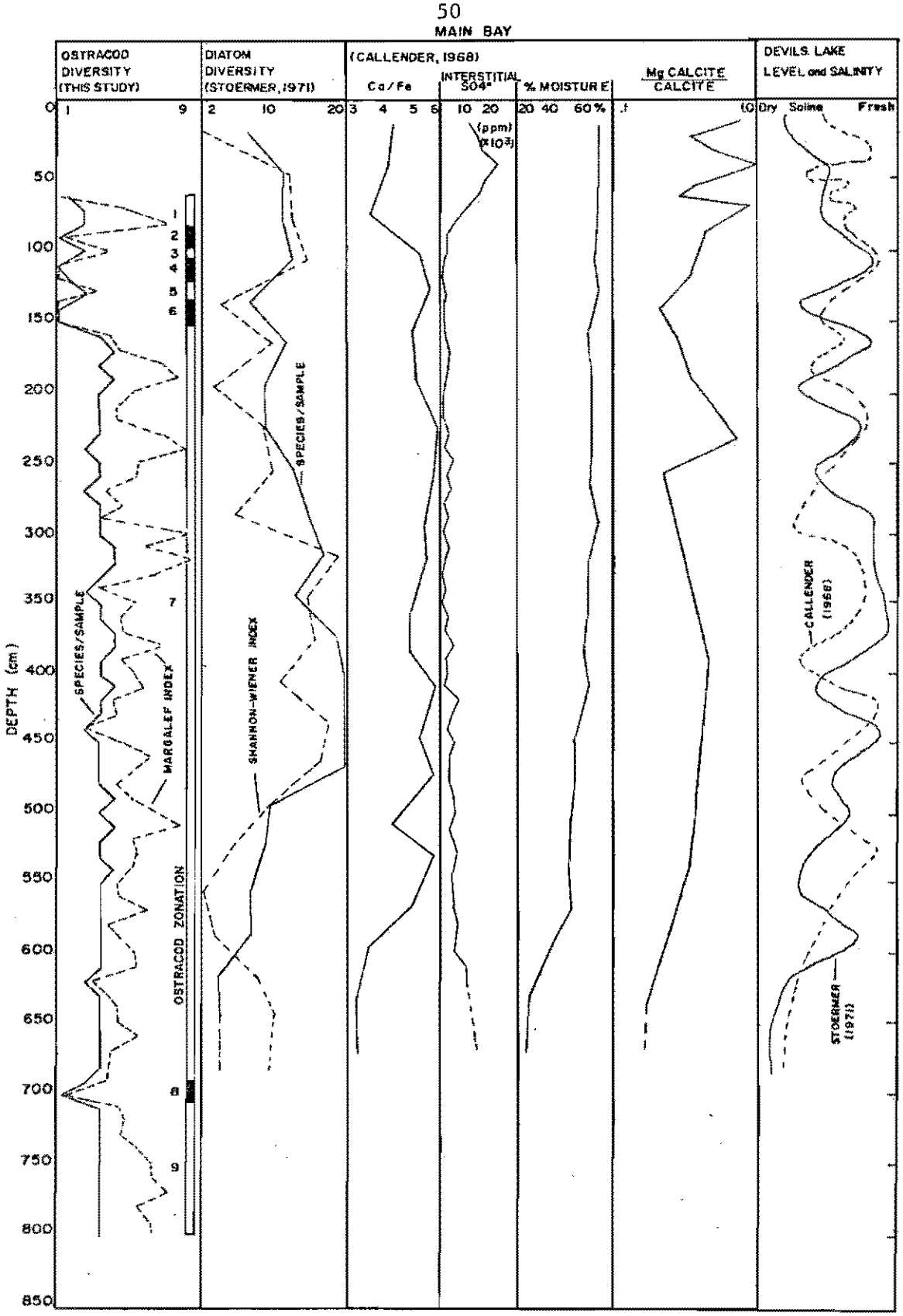
shallow water faunas. Minor fluctuations that are barely noiceable in deep water are devastating to a fauna in shallow water.

Each period of disruption in either the Main Bay core or the Creel Bay core is followed by a period of rapid re-population of the lakes by salinity-tolerant species.

Callender (1968) interpreted the Holocene history of Devils Lake based on the geochemical parameters and on the abundance of diatoms. Figure 6 illustrates the major geochemical parameters used in his interpretation. The calcium/iron ratio of the sediment is an indication of changing salinity. A higher ratio indicates a brackish environment. The amount of interstitial $SO_4^{=}$ in the cores is another measure of salinity. An increase in $SO_4^{=}$ in the sediment indicates brackish conditions. The percentage of moisture in the core is an indication of desiccation. The drop in the percentage of moisture at 650 cm is interpreted by Callender to represent dry conditions. The high magnesium calcite/calcite ratio is also used to interpret lake level fluctuations. A lower lake level would be represented by a lower ratio of Mg calcite/calcite preserved in the sediment. Based on this evidence, Callender interpreted five major and several minor periods of hypersalinity or desiccation: at 680, 475, 400, 300, 180, 150, and 50 cm (Fig. 6).

Stoermer et al. (1971) interpreted seven periods of saline or dry conditions based on the diatom flora contained in the cores. Figure 6 illustrates the diatom diversity indices (simple diversity and the Shannon-Wiener index) plotted versus depth, as well as their interpretation of the changing conditions of Devils Lake.

Fig. 6. Comparison of ostracod diversity (this study), diatom diversity (Stoermer et al. 1971), and chemical parameters (Callender 1968) with depth in Main Bay. Also indicated is the ostracod zonation (solid bars representing periods of environmental change with total elimination of the ostracod fauna) and the interpretations of changes in the Devils Lake environment by Stoermer et al. (1971) and Callender (1968).


MAIN BAY
OSTRACOD DIVERSITY (THIS STUDY)
DIATOM DIVERSITY (STOERMER, 1971)
(CALLENDER, 1968)
Ca / Fe
INTERSTITIAL SO4=
(ppm) (x10³)
% MOISTURE
Mg CALCITE / CALCITE
DEVILS LAKE LEVEL and SALINITY
Dry
Saline
Fresh
DEPTH (cm)
SPECIES/SAMPLE
MARGALEF INDEX
SHANNON-WIENER INDEX
OSTRACOD ZONATION
CALLENDER (1968)
STOERMER (1971)

The periods of hypersalinity as interpreted by Stoermer et al. are very close to those of Callender. It is not clear whether Stoermer et al. and Callender used the same or different cores. There is one deviation between the two studies at 550 cm; the diatoms indicate desiccation, the chemical parameters do not.

The interpretations of changing conditions of Devils Lake based on the ostracods agree, in part, with those of the above authors. Major periods of environmental disruption, as based on ostracod evidence, are indicated between 80 and 150 cm. These episodes are indicated by zones 2, 4, and 6, in the Main Bay core, and can be tentatively dated at 900, 1200, and 1500 years B. P. Zone 6 is the only episode that correlates with the other studies.

Zone 7 is interpreted to represent a period of relative stability, or at least not a period representing major disruption of the ostracod population. This disagrees with evidence presented in the above studies, which indicate several periods of major change throughout this zone.

Possible explanations for the discrepancies might be that the core obtained for this study represented slightly deeper water, less affected by minor fluctuations in water level, or that the ostracods are less sensitive indicators. The ostracods in this core are very tolerant of salinity. It could be that anything short of total desiccation would create only minor fluctuations in diversity. The diatoms may be better indicators of subtle changes in the environment.

The major period of disruption represented at 680-700 cm can be correlated throughout all studies. The cores used by Callender (1968) and Stoermer et al. (1971) ended at about 680 cm. They interpreted this

period to represent total dryness, and the ostracod evidence would substantiate this conclusion. This period is indicated by zone 8 (Fig. 6), and is tentatively dated at about 7000 years B. P.

The Main Bay core in this study is longer than those used in the other studies, by about a meter. The lowest part, zone 9, is interpreted to represent a period of relatively stable, but saline conditions.

CONCLUSIONS

The following conclusions are based on the quantitative and paleoecological analyses of the ostracod fauna contained in sediment cores from Main Bay and Creel Bay of Devils Lake, from East Devils Lake, and from Red Willow Lake:

1. Fifteen species of ostracoda were present in the studied cores: 8 candonids, 1 cyclocyprid, 3 cyprids, and 3 limnocytherids.

2. The ostracod species are distributed in two distinct faunas. The Devils Lake-East Devils Lake fauna consists of six species: Candona lactea, C. rawsoni, Cyprinotus glaucus, Potamocypris smaragdina, Limnocythere ceriotuberosa, and L. staplini. The Red Willow Lake fauna consists of eleven species: Candona acutula, C. candida, C. caudata, C. decora, C. ohioensis, C. lactea, C. pronopa, C. rawsoni, Cypridopsis vidua, Cyclocypris ampla, and Limnocythere itasca. Candona rawsoni and Candona lactea are the only species in common in the two lakes.

3. Quantitative analyses of the fauna through time (diversity, similarity, equitability, and abundance of individuals) can be used to interpret dramatic changes in the environment resulting in periods of total elimination of the ostracod fauna.

4. Four periods of environmental change, interpreted to be hypersalinity or desiccation, are recognized in the Main Bay core, in zones 2, 4, 6, and 8, and have been tentatively dated at 900, 1200, 1500, and 7000 years B. P. Sixteen periods of instability are recognized in the

Creel Bay core, in zones 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, and 32. These zones have not been dated. The greater instability of Creel Bay through time is interpreted to be the result of shallower water conditions through time in this bay. Two periods of major, long-term environmental disruption can be correlated between these cores, at about 1500 and 7000 years B. P. (zones 6 and 26).

5. Three major episodes of disruption are recognized in East Devils Lake, in zones 2, 4, and 6. These episodes have not been dated, and do not correlate with episodes recognized in the other cores.

6. Four periods of environmental disruption are recognized in Red Willow Lake, in zones 2, 4, 6, and 8. These episodes have not been dated, and do not correlate with episodes recognized in the other cores. The cause of the disruptions in Red Willow Lake are unknown. There is no evidence that the salinity increased in this lake through time.

7. The quantitative indices do not indicate that the ostracod communities in the cores became more complex (mature) with time. This is a result of the instability of all of the lakes in the study area through time, and the youthfulness of the fauna.

8. The paleoecology of the Devils Lake-East Devils Lake fauna indicates that the lakes have remained shallow, with little aquatic vegetation, through time. Elevated levels of sulfate have always been present, with levels of total dissolved solids always being greater than perhaps 10,000 ppm. The ostracod populations are useful in this study to document periods of environmental disruption, interpreted to represent hypersalinity. In Devils Lake, only two periods of major environmental change, at 1500 and 7000 years B. P., correlate with

evidence from diatoms and the geochemistry of the lake sediment.

9. The paleoecology of the Red Willow Lake fauna indicates that the lake has remained cool and relatively deep, with abundant aquatic vegetation through time. The sulfate concentration has always been low, and the levels of total dissolved solids have always remained below perhaps 6,000 ppm.

10. Candona rawsoni is interpreted to represent a pioneer species in the early history of Red Willow Lake.

SYSTEMATIC PALEONTOLOGY

The classification of the Ostracoda used here follows that of Scott (1961), Delorme (1970a, b, c, d, 1971), and Lister (1975).

The generic diagnoses are adapted from the above sources and are rearranged where necessary to follow a more consistent, logical order. The species descriptions were edited to remove generic characteristics. Only the morphological features of the carapace are described. Generic synonymies are not included, and only the original reference for each genus is included. Species synonymies only indicate name changes. Localities are indicated by core name, with the accession numbers corresponding to those in Appendices IV and V.

All specimens are stored at the University of North Dakota Department of Geology, Grand Forks, North Dakota.

Subclass Ostracoda Latreille, 1806

Order Podocopida Müller, 1894

Suborder Podocopina Sars, 1866

Superfamily Cypridacea Baird, 1845

Family Candonidae Kaufmann, 1900

Genus Candona Baird, 1845

Original reference.--Baird, 1845, p. 152.

Type species.--Cypris candida Müller, 1776, p. 199.

Diagnosis.--Shape variable, reniform, triangular or elongate-ovate; maximum height posterior or medial; carapace elliptical in dorsal view, moderately inflated to compressed; ventral margin concave; surface of valves smooth, to faintly roughened; normal pores simple and scattered; inner lamella narrow to moderately wide; anterior and posterior vestibulum present, anterior larger than posterior; marginal pore canals numerous, simple, regularly spaced; hinge adont; muscle scars prominent, consisting of a group of five closely spaced scars, topped by an elongate sixth scar; two mandibular scars present anteroventrally from group; several dorsal muscle scars visible near dorsal margin; sexual dimorphism generally pronounced (adapted from Lister 1975, p. 5).

Remarks.--The geologic range of Candona is Tertiary to Holocene. It is an exclusively fresh water genus (Benson et al. 1961, p. Q233).

Candona acutula Delorme, 1967

Pl. 1 Figs. 1-4

Candona acutula Delorme, 1967b, p. 358, Pl. 1, Figs. 3-6.

Diagnosis.--Carapace subreniform to subtriangular in side view; greatest height posterior to the middle, greater than half the length; dorsal margin arched, meeting anterior margin without interruption; ventral margin with pronounced anteroventral notch in male; anterior margin evenly rounded; posterior margin evenly rounded in male, acutely pointed at 45° angle in female; prominent hinge flap on posterodorsum of right valve of female; in dorsal view, sides convex with greatest width posterior of center; anterior extremity acutely pointed, posterior

extremity bluntly rounded; valves translucent; normal pores numerous; inner lamella broad in anterior and posterior, sloping inward in mid-ventral region; vestibulum widest in anterior; marginal pore canals straight (adapted from Lister 1975, with reference to Delorme 1970c).

Description of material.--Two specimens collected with conjoined valves. The rest of the material was for the most part unbroken and well preserved.

Material and occurrences.--Ninety individuals (180 separate valves) were collected from ten intervals within the Red Willow Lake core (Appendix IV).

Remarks.--Sexual dimorphism is prominent in this species, and both males and females were recognized in the samples. All specimens in each sample were counted.

Hypotypes.--Univ. N. Dak. Cat. Nos. 14372-14375.

Measurements.--The following are dimensions of the figured hypotypes:

Material	Length(mm)	Height(mm)	UND cat. no.	Fig.
Female right	1.20	0.65	14372	1
Female left	1.21	0.71	14373	2
Male right	1.21	0.70	14374	3
Male left	1.30	0.70	14375	4

Discussion.--This species was first described from Canadian transition zones between prairie and forest (Delorme 1970c). It favors shallow water with abundant aquatic vegetation, and is restricted to North America. For a more complete discussion of the environmental conditions preferred by this species, see the Paleoecology section.

Candona candida (Müller), 1776

Pl. 1 Figs. 5-6

Cypris candida Müller, 1776, p. 199.

Cypris lucens Baird, 1835, p. 100, Pl. 3, Fig. 15.

Cypris pellucida Koch, 1837, Species 5.

Cypris lucida Koch, 1838, Species 18.

Candona candida (Müller), [1776]. Liljeborg, 1853, p. 127, Pl. 11, Figs. 19, 20; Pl. 25, Figs. 13-15.

Eucandona candida (Müller), [1776]. Swain, 1961, p. 604, Figs. 2-3.

Candona candida (Müller), 1776. Delorme, 1970c, p. 1103, Figs. 51-65.

Diagnosis.--Carapace reniform in side view; greatest height posteromedial to medial, greater than half the length; dorsal margin arched; ventral margin moderately concave; anterior margin broadly and evenly rounded; posterior margin acutely rounded; posteriodorsum convex; broadly elliptical in dorsal view, sides convex with greatest width posterior of center; anterior extremity pointed, posterior extremity narrowly rounded; valves translucent; left valve overlaps right along posterodorsal margin; inner lamella broad anteriorly, narrow ventrally; inner margin semicircular in outline anteriorly, acutely rounded posteriorly (adapted from Staplin 1963, with reference to Delorme 1970c).

Description of material.--Few complete valves found, none conjoined. Only females of the species were recognized.

Material and occurrences.--Ten individuals (20 separate valves) were counted from two intervals within the Red Willow Lake core (Appendix IV).

Remarks.--Males of this species are rare in North America and Europe (Delorme, 1970c). There is no significant sexual dimorphism, and no males of the species were identified. All specimens in each sample were counted.

Hypotypes.--Univ. N. Dak. Cat. Nos. 14376-14377.

Measurements.--The following are dimensions of the figured hypotypes:

Material	Length(mm)	Height(mm)	UND cat. no.	Fig.
Female right	1.11	0.65	14376	5
Female left	1.10	0.63	14377	6

Discussion.--This species was described by Delorme (1970c) from the Canadian prairies. It prefers shallow water ponds and lakes, but is also found in streams. It has a worldwide distribution.

Candona caudata Kaufmann, 1900

Pl. 1 Figs. 7-8

Candona elongata Brady and Norman, 1889, p. 100, Pl. 10, Figs. 24-27.

Candona acuminata [Non Fischer, 1854]. Brady and Norman, 1889, p. 104, Pl. 9, Figs. 9, 10; Pl. 10, Figs. 5, 6.

Candona caudata Kaufmann, 1900, p. 365, Pl. 24, Figs. 16-20; Pl. 26, Figs. 17-23.

Candona novocaudata Benson and MacDonald, 1963, p. 15, Pl. 2, Figs. 1-4.

Candona caudata Kaufmann, 1900. Delorme, 1970c, p. 1103, Figs. 66-75.

Diagnosis.--Carapace reniform to subreniform in side view; greatest height posterior of middle, less than half the length; dorsal margin arched; anterior margin rounded; posterior margin inflexed dorsally, convex posteriorly; ventral margin forms a rounded point with an angle of about 80°, forming a blunt posteroventral hooklike projection; sides convex in dorsal view, with greatest width posterior of center; both extremities acutely pointed; valves translucent; normal pores numerous; left valve slightly overlaps right; inner lamella moderately broad, widest in anterior, sloping steeply inward in the midventral region; vestibulum present, but does not extend around the dorsal margin; inner margin semicircular in anterior, acutely rounded in posterior (adapted from Lister 1975, with reference to Delorme 1970c).

Description of material.--One set of conjoined valves found, few complete single valves found. Only females recognized.

Material and occurrences.--Ten individuals (20 separate valves) were counted from two intervals within the Red Willow Lake core (Appendix IV).

Remarks.--Sexual dimpophism is present in this species, with the males of the species exhibiting a more rounded, blunt posterior margin. Males are rare in North America (Delorme 1970c, p. 1104), and were not recognized in the material available. All specimens in each sample were counted.

Hypotypes.-- Univ. N. Dak. Cat. Nos. 14378-14379.

Measurements.--The following are dimensions of the figured hypotypes:

Material	Length(mm)	Height(mm)	UND cat. no.	Fig.
Female right	1.30	0.60	14378	7
Female left	1.31	0.61	14379	8

Discussion.--Delorme (1970c) described this species from the southern edge of the boreal forest and mixed zone of the Canadian Provinces. It commonly occurs in streams and at depth in lakes. This species was common in the late Pleistocene, and has a world wide distribution today.

Candona decora Furtos, 1933

Pl. 1, Figs. 9-10

Candona decora Furtos, 1933, p. 477, Pl. 8, Figs. 4, 5; Pl. 9, Figs. 21-22; Pl. 11, Figs. 5-6.

Candona fossulensis Hoff, 1942, p. 92, Pl. 5, Figs. 58-64.

Candona fossulensis Hoff, 1942. Tressler, 1959, p. 687, Figs. 28, 73.

Candona decora Furtos, 1933. Delorme, 1970c, p. 1106, Figs. 99-111.

Diagnosis.--Carapace subtriangular to subrectangular in side view; greatest height posterior of middle, about half of the length; dorsal margin nearly straight to slightly convex; ventral margin slightly concave, with anteroventral notch in male; anterior margin evenly rounded; posterior margin truncated, with convex portion of dorsal margin forming an obtuse angle; sides convex in dorsal view with greatest width posterior of center; anterior extremity acutely pointed, posterior

extremity bluntly rounded; valves translucent, with faint reticulations on posterior of female; normal pores numerous; inner lamella broad in anterior, narrow in ventral and posterior regions; inner margins semi-circular in anterior, acutely rounded in posterior; vestibulum well developed in anterior, less well developed in posterior (adapted from Delorme 1970c).

Description of material.--Two individuals collected as conjoined valves. Most single valves were partially broken. Only females of the species recognized.

Material and occurrences.--One hundred and six individuals (212 single valves) were counted from nine intervals within the Red Willow Lake core (Appendix IV).

Remarks.--Sexual dimorphism is not prominent in this species, and no males were recognized in the material. All specimens in each sample were counted.

Hypotypes.--Univ. N. Dak. Cat. Nos. 14380-14381.

Measurements.--The following are the dimensions of the figured hypotypes:

Material	Length(mm)	Height(mm)	UND cat. no.	Fig.
Female right	1.11	0.61	14380	9
Female left	1.28	0.69	14381	10

Discussion.--Delorme (1970c) reported this species from the mixed woods zone and southern fringes of the boreal forest of Canada. It is rarely found in the true prairie. This species most commonly inhabits temporary ponds, but is found in lakes. It is restricted to North America.

Candona ohioensis Furtos, 1933

Pl. 1, Figs. 11-14

Candona ohioensis Furtos, 1933, p. 475, Pl. 9, Figs. 19-20; Pl. 10, Figs. 8-12.

Diagnosis.--Carapace elongate-reniform in side view; greatest height posterior of middle, less than half of the length; dorsal margin slightly convex; ventral margin with anteroventral notch in male; anterior margin evenly curved; posterior margin acuminate, broadly rounded in male, subtruncate in female forming an agle of about 35° to the horizontal; narrowly elliptical in dorsal view; sides convex, greatest width slightly anterior of center in female, posterior of center in male; anterior extremity acutely pointed, posterior extremity bluntly rounded; valves transparent to translucent, thin; faint reticullations on posterior of female, gonad traces often present on male; normal pores scattered, inconspicuous; left valve slightly overlaps the right; inner lamella broad in anterior and posterior, narrow in ventral margin; inner margins semicircular in anterior, acutely rounded in posterior; vestibulum strongly developed in anterior and posterior; marginal pore canals moderate in length (adapted from Staplin 1963, with reference to Delorme 1970c).

Description of material.--Many individuals were collected as conjoined valves. Most single valves were unbroken, and well preserved. Both males and females were recognized in the material.

Material and occurrences.--Three thousand, two hundred and seventy eight individuals (6556 single valves) were counted from throughout the Red Willow Lake core (Appendix IV).

Remarks.--Sexual dimorphism is prominent in this species, and both males and females were recognized. All specimens in each sample were counted.

Hypotypes.-- Univ. N. Dak. Cat. Nos. 14382-14385.

Measurements.--The following are the dimensions of the figured hypotypes:

Material	Length(mm)	Height(mm)	UND cat. no.	Fig.
Female right	1.70	0.80	14382	11
Female left	1.70	0.82	14383	12
Male right	1.71	0.81	14384	13
Male right	1.70	0.75	14385	14

Discussion.--This is the most abundant species in the Red Willow Lake core, but it is not found in any of the other lakes. Delorme (1970c) reported this species from the mixed woods zone and southern fringes of the boreal forest of the Canadian prairies. It is most commonly found in lakes of moderate alkalinity and vegetation (Staplin, 1963). The species is restricted to North America. For a complete discussion of the environmental conditions preferred by this species, see the Paleoecology section.

Candona lactea Baird, 1850

Pl. 1, Figs. 15-16

Candona lactea Baird, 1850, p. 225, Pl. 18, Figs. 25-27

Candona detecta Brady, 1868b, p. 384, Pl. 24, Figs. 55-58.

Candona cf. C. lactea Baird, 1850. Staplin, 1963, p. 775, Pl. 19, Fig. 1.

Candona lactea Baird, 1850. Lister, 1974, p. 69, Fig. 12.

Diagnosis.--Carapace elongate-ovate in side view; greatest height medially, about half the length; dorsal margin broadly arched, almost flat; anterior and posterior margins broadly rounded, of the same shape; ovate in dorsal view; sides convex, greatest width slightly posterior to middle; extremities acutely rounded, anterior more roumded than posterior; valves relatively thick, translucent; left valve slightly overlaps right; inner lamella narrow, sloping inward steeply in midventral region; vestibulum narrow, but wider in anterior than posterior; marginal pore canals slightly funnel shaped; inner margin circular in anterior and posterior (adapted from Lister 1974).

Description of material.--Most specimens found as separate valves, generally unbroken and well preserved. Only females of the species were recognized.

Material and occurrences.--Five thousand, nine hundred, and four individuals (11808 separate valves) were counted from throughout all four cores (Appendix IV).

Remarks.--Sexual dimorphism has not been reported in this species, so all specimens are considered to be female. Males are unknown in many species of ostracods, and without soft parts to aid in the identification of C. lactea, are considered to be absent in this study.

Hypotypes.--Univ. N. Dak. Cat. Nos. 14386-14387.

Measurements.--The following are the dimensions of the figured hypotypes:

Material	Length(mm)	Height(mm)	UND cat. no.	Fig.
Female right	1.1	0.58	14386	15
Female left	1.0	0.50	14387	16

Discussion.--This species is the most abundant species in the study, being found throughout all the cores. It was apparently very common throughout the Pleistocene (Lister 1974). C. lactea has been considered to be an immature instar of Candona rawsoni, or some other species of Candona (Lister 1974). It was always found with C. rawsoni in this study, in approximately the same numbers. It differs from C. rawsoni in having thicker, and more elongate valves. For lack of better evidence, or soft parts, C. lactea will be considered a distinct species in this study. Staplin (1963) reported this species from the Pleistocene lake deposits of Illinois, and considers it to have preferred a cold water lake environment.

Candona pronopa Lister, 1975

Pl. 1 Figs. 17-18

Candona pronopa Lister, 1975. Lister, 1975, p. 8, Pl. 1, Figs. 10-11.

Diagnosis.--Carapace subtriangular to subreniform in side view; greatest height posterior to middle, about half the length; dorsal margin strongly arched; ventral margin concave medially; anterior margin rounded; posterior margin narrowly rounded; anterodorsal and posterodorsal margin distinctly concave; sides convex in dorsal view, greatest width at about the center; anterior extremity pointed; posterior extremity bluntly pointed; valves transparent to translucent; inner lamella narrow, sloping inward along midventral margin; vestibulum present, wider in anterior than posterior; inner margins circular to semicircular (adapted from Lister 1975).

Description of material.--One specimen was collected with conjoined valves, and most single valves well preserved and unbroken. Only females recognized in the material.

Material and occurrences.--Twenty two individuals (44 separate valves) were counted from three sample intervals within the Red Willow Lake core (Appendix IV).

Remarks.--Sexual dimorphism was not reported for this species by Lister (1975). Without soft parts, all individuals are considered to be female. Females are commonly more abundant than males, and males are often absent from ostracod populations.

Hypotypes.--Univ. N. Dak. Cat. Nos. 14388-14389.

Measurements.--The following are the dimensions of the figured hypotypes:

Material	Length(mm)	Height(mm)	UND cat. no.	Fig.
Female right	1.0	0.50	14388	17
Female left	1.0	0.52	14389	18

Discussion.--This species is morphologically similar to Candona distincta Furtos (1933), but is generally smaller. The specimens in this study are more similar to C. pronopa as described by Lister (1975). The preferred environmental conditions of this species have not been reported.

Candona rawsoni Tressler, 1957

Pl. 1, Figs. 19-22

Candona sp. Bronstein, 1930, p. 144. Pl. 4, Figs. 17-21.

Candona obtusa [Non C. welterni obtusa Müller, 1900] Bronstein, 1947, p. 252 and 321, text Fig. 157.

Candona sp. aff. Cypris pubera Müller, 1776. Swain, 1947, Pl. 76, Figs. 14-16.

Candona rawsoni Tressler, 1957, p. 420, Figs. 5-11.

Candona nyensis Gutentag and Benson, 1962, p. 37, Fig. 10; Pl. 2, Figs. 1-3.

Candona swaini Staplin, 1963a, p. 785, Pl. 91, Figs. 4-7.

Candona obtusa Bronstein, 1947, (Non Müller, 1900). Delorme, 1967a, p. 792, Pl. 1.

Candona rawsoni Tressler, 1957. Delorme, 1970a, p. 1115, Figs. 229-243.

Diagnosis.--Carapace subreniform to subquadrate in side view; greatest height about middle, more than half the length; dorsal margin broadly arched; ventral margin with an anteroventral notch in male; anterior margin evenly rounded; posterior margin truncated in female; left valve of female meets ventral margin at an obtuse angle, with a prominent posterodorsal flange extended to the posterior; right valve of female more evenly rounded in posterior; posterior margin of male more evenly rounded; sides convex in dorsal view, greatest width posterior of center; anterior extremity pointed; posterior extremity blunt, especially in the female; valves translucent, gonad traces often present in the male; inner lamella broad, sloping steeply inward in midventral region; vestibulum present, widest in anterior, also prominent in posterior; inner margins semicircular; (adapted from Lister (1975) with reference to Delorme (1970c).

Description of material.--Many individuals were collected with conjoined valves, and most single valves were well preserved and

complete. Males and females were recognized in the material, with females being far more common.

Material and occurrences.--Four thousand, eight hundred and eighty two individuals (9764 individual valves) were counted from throughout all four cores (Appendix IV).

Remarks.--Sexual dimorphism is very prominent in this species, and both males and females were collected. All specimens in each sample were counted.

Hypotypes.--Univ. N. Dak. Cat. Nos. 14390-14393.

Measurements.--The following are the dimensions of the figured hypotypes:

Material	Length(mm)	Height(mm)	UND cat. no.	Fig.
Female right	1.12	0.62	14390	19
Female left	1.20	0.65	14391	20
Male right	1.25	0.71	14392	21
Male left	1.40	0.80	14393	22

Discussion.--This is the second most abundant species in this study, being found throughout all cores. C. rawsoni is always found with C. lactea, which has been considered by some authors to be an immature instar of C. rawsoni. Delorme (1970c) reported this species from throughout the Canadian prairies, and it has an Holarctic distribution. It prefers permanent ponds and lakes, but is found in temporary water bodies. For a complete discussion of the environmental conditions preferred by this species, see the Paleoecology section.

Family Cyclocyprididae Kaufmann, 1900

Genus Cyclocypris Brady and Norman, 1889

Original reference.--Brady and Norman, 1889, p. 70.

Type species.--Cypris globosa (Sars), 1863, p. 27.

Diagnosis.--Subovate in side view; maximum height medial, about two-thirds the length; dorsal margin strongly convex; anterior and posterior margins broadly rounded; subspherical in dorsal view, inflated; valves thin, small, subequal; surface of valves smooth; normal pores moderately numerous, simple and scattered; inner lamella widest anteriorly; anterior and posterior vestibulum present, anterior wide, posterior narrow; inner lamella meets margin at two places ventromedially; marginal pore canals moderately numerous, simple, regularly spaced; hinge adont; dorsal margin of smaller valve fits into groove of larger valve; muscle scars prominent, consisting of an anterior row of three scars, two others located posterior to these, the group being capped by one elongate scar; two mandibular scars present anterodorsally from group; several dorsal muscle scars visible near the dorsal margin; sexual dimorphism unknown in the genus (adapted from Lister 1975, p. 10).

Remarks.--The geologic range of Cyclocypris is Tertiary to Holocene. It is a fresh water genus. (Benson et al. 1961, p. Q234).

Cyclocypris ampla Furtos, 1933

Pl. 1, Figs. 23-24

Cyclocypris ampla Furtos, 1933, p. 461, Pl. 14, Figs. 1-7.

Diagnosis.--Carapace subcircular to ovate in side view; greatest height medially, two thirds or more of the length; dorsal margin evenly

arched; ventral margin flat to slightly convex; anterior and posterior margins evenly curved or rounded; subcircular in dorsal view; sides convex, greatest width at center; anterior extremity acutely pointed, posterior extremity broadly rounded; valves transparent to translucent; inner lamella narrow to moderately broad, striated, sloping inward everywhere except along anterior margin; vestibulum present, widest in anterior, but over all small; inner margins semicircular; marginal pore canals numerous, straight; hinge simple (adapted from Lister 1975 with reference to Delorme 1970b).

Description of material.--Many individuals were collected with conjoined valves. Most single valves were well preserved and complete.

Materials and occurrences.--Six hundred and twenty four individuals (1248 separate valves) were counted from throughout the Red Willow Lake core (Appendix IV).

Remarks.--Sexual dimorphism is unknown in this species, and no attempt has been made in the literature to sex the individuals (Delorme 1970b). For this reason, the specimens of this species are not listed by sex, but only by right or left valves. All specimens in each sample were counted.

Hypotypes.--Univ. N. Dak. Cat. Nos. 14394-14395.

Measurements.--The following are the dimensions of the figured hypotypes:

Material	Length(mm)	Height(mm)	UND cat no.	Fig.
Right valve	0.62	0.50	14394	23
Left valve	0.61	0.50	14395	24

Discussion.--This species was reported by Delorme (1970b) from throughout the interior plains of Canada. It is the most abundant species of the genus, readily recognized by its shape, size, and sepia brown color. It is a cosmopolitan species, usually found in lakes, but is able to live in other habitats. For a more complete discussion of the environmental conditions preferred by this species, see the Paleoecology section.

Family Cyprididae Baird, 1845

Subfamily Cypridinae Baird, 1845

Genus Cyprinotus Brady, 1886

Original reference.--Brady, 1886, p. 301.

Type species.--Cyprinotus cingalensis Brady, 1886

Diagnosis.--Subovate to subtriangular in side view, greatest height medially to posteriormedially; dorsal margin arched; ventral margin concave; anterior and posterior margins broadly rounded; right valve smaller than left; smaller valve commonly with small tubercles along anterior and posterior margins; elliptical in dorsal view, somewhat compressed; sides convex, greatest width at center; valves thin, smooth, or with punctae; normal pores numerous, small and simple; inner lamella wide, with concentric striae; vestibulum present, wider in anterior than posterior; marginal pore canals numerous, simple and straight; hinge adont, dorsal margin of smaller valve fits into a groove in larger valve; muscle scars prominent, consisting of an anterior vertical row of four scars and two posterior scars; two mandibular scars are located anteroventrally of main group; one frontal scar is located anterodorsally of main group; several dorsal muscle scars visible near

dorsal margin; sexual dimorphism unknown in genus (adapted from Lister 1975, p. 13).

Remarks.--The geologic range of Cyprinotus is ?Tertiary to Holocene. It is a fresh water genus (Benson et al. 1961, p. Q217).

Cyprinotus glaucus Furtos, 1933

Pl. 2, Figs. 25-26

Cyprinotus glaucus Furtos, 1933, p. 444. Pl. 5, Figs. 9-16.

Diagnosis.--Carapace subovate to subtrapezoidal in side view; greatest height medial, greater than half the length; dorsal margin obtusely rounded, more angular in the right valve; ventral margin concave in right valve, flat in left valve; posterior margin acutely rounded; sides moderately convex in dorsal view, with greatest width posterior to center, anterior of right valve compressed; anterior extremity acutely pointed, posterior extremity bluntly rounded; left valve extends past right valve in anterior; anterior of right valve nodose; tubercular knobs present on anterior and posterior free margins of right valve; inner lamella moderately wide, sloping inward; vestibulum present, widest in anterior of left valve, narrowest in posterior of right valve; inner margins semicircular; marginal pore canals straight to funnel shaped; flange developed on left valve (adapted from Lister 1975 with reference to Delorme 1970b).

Description of material.--Individuals rarely collected as conjoined valves. Most separate valves were well preserved and complete.

Material and occurrences.--Sixty six individuals (132 separate valves) were counted from two samples within the Main Bay core, seven

samples within the Creel Bay core, and from nine samples within the East Devils Lake core (Appendix IV).

Remarks.--Sexual dimorphism is unknown in this species. Males recognized on the basis of soft parts are rare (Delorme 1970b). For this reason the individuals in this study are considered to be female. All specimens in each sample were counted.

Hypotypes.--Univ. N. Dak. Cat. Nos. 14396-14397.

Measurements.--The following are the measurements of the figured hypotypes:

Material	Length(mm)	Height(mm)	UND cat. no.	Fig.
Female right	1.08	0.61	14396	25
Female left	1.10	0.69	14397	26

Discussion.--Delorme (1970b) reported this species from throughout the interior plains of Canada. It is a cosmopolitan species, and can occupy any aquatic environment, but prefers lakes. For a complete discussion of the environmental conditions preferred by this species, see the Paleoecology section.

Subfamily Cypridopsinae Kaufmann, 1900

Genus Cypridopsis Brady, 1868a

Original reference.--Brady, 1868a, p. 117.

Type species.--Cypris vidua Müller, 1776.

Diagnosis.--Subcircular to elongate-ovate in side view, greatest height medially; dorsal margin arched; ventral margin straight to weakly concave; anterior and posterior margins rounded; elliptical in dorsal view, inflated, anterior and posterior extremities rounded to bluntly pointed; valves thin, smooth or punctate; left valve larger

than right; normal pores numerous, small and simple; inner lamella wide; vestibulum present, wider in anterior than posterior; marginal pore canals numerous, short, straight; hinge adont, with dorsal margin of right valve fitting into a groove in left valve; muscle scars prominent, consisting of an anterior row of four scars of ventrally decreasing size, with two other scars posterior to these; two mandibular scars are located anteroventrally of the central group; one frontal scar is located anterodorsally to central group. Several dorsal muscle scars visible near dorsal margin; sexual dimorphism is unknown for the genus (adapted from Lister 1975, p. 15).

Remarks.--The geologic range of Cypridopsis is ?Permian, Upper Cretaceous to Holocene. It is a fresh to brackish water genus (Benson et al. 1961, p. Q230).

Cypridopsis vidua (Müller, 1776)

Pl. 2, Figs. 27-28

Cypris vidua Müller, 1776, p. 199.

Monoculus vidua Müller, [1776]. Jurine, 1820, p. 175, Pl. 19, Figs. 5-6.

Cypris strigata Koch, 1841, Species 19.

Cypris sella Baird, 1846, p. 414, Pl. 9, Fig. 3.

Cypridopsis vidua (Müller), [1776]. Brady, 1868b, p. 375, Pl. 24, Figs. 27-30, 46.

Cypridopsis obesa Brady and Robertson, 1869, p. 364, Pl. 18, Figs. 5-7.

Cypridopsella tumida Kaufmann, 1900b. Kaufmann, 1900c, p. 313, Pl. 19, Figs. 10-13; Pl. 22, Figs. 15-19.

Pionocypris vidua (Müller), 1785. Scott, 1906, p. 272.

Cypridopsis concolor Dady, 1900. Müller, 1912, p. 212.

Cypridopsis pustulosa Furtos, 1933, p. 431, Pl. 6, Figs. 5-9.

Cypridopsis canadensis Ferguson, 1959, p. 64, Figs. 1-4.

Cypridopsis vidua (Müller), 1776. Delorme, 1970b, p. 254, Figs. 11-17.

Diagnosis.--Carapace subtriangular to subovate in side view; greatest height medially, two thirds or more of the length; dorsal margin obtusely arched; ventral margin straight to slightly concave; anterior and posterior margins evenly and broadly rounded; elliptical in dorsal view; sides moderately inflated, greatest width anterior of center; anterior extremity acutely pointed, posterior extremity bluntly rounded; valves appear pitted, translucent; normal pores numerous, small, simple, located at bottom of pits; inner lamella wide, striated, sloping inward; vestibulum prominent, widest in the anterior; inner margins broadly rounded; marginal pore canals conspicuous, short, simple; flange present; hinge simple, adont, as in genus; muscle scars as in genus (adapted from Delorme 1970b, with reference to Lister 1975).

Description of material.--Few individuals were collected as conjoined valves. Many single valves were broken and poorly preserved.

Material and occurrences.--Two hundred and nineteen individuals (438 separate valves) were counted from throughout the Red Willow Lake core (Appendix IV).

Remarks.--Sexual dimorphism is unknown in this species. Males have not been reported in the literature (Delorme, 1970b). For this reason all individuals in this study are not identified by sex, only by

right or left valves. All specimens in each sample were counted.

Hypotypes.--Univ. N. Dak. Cat. Nos. 14398-14399.

Measurements.--The following are the dimensions of the figured hypotypes:

Material	Length(mm)	Height(mm)	UND cat. no.	Fig.
Right valve	0.65	0.40	14398	27
Left valve	0.70	0.45	14399	28

Discussion.--Delorme (1970b) reported this species from throughout the interior plains of Canada. It is the most common Canadian ostracode, and is common throughout the Northern Hemisphere. It can be found in any aquatic environment.

Genus Potamocypris Brady, 1870

Original reference.--Brady, 1870, p. 365.

Type species.--Bairdia fulva Brady, 1868b.

Diagnosis.--Reniform in side view; greatest height anteromedially; dorsal margin broadly rounded; ventral margin very concave; anterior and posterior margins broadly rounded; carapace elliptical, but compressed in dorsal view; valves thin, smooth or with punctae; normal pores numerous, small, simple; right valve higher than left, left valve longer than right; inner lamella wide to narrow, anterior vestibulum wider than posterior; marginal pore canals numerous, short, simple, straight; hinge adont, dorsal margin of right valve fits into shallow groove of left valve; muscle scars prominent, consisting of a group of five to six diagonally elongate scars, two anteroventral mandibular scars, and two anterodorsal frontal scars; dorsal muscle scars visible near the dorsal margin. Sexual dimorphism negligible (adapted from Lister 1975, p. 16).

Remarks.--The geologic range of Potamocypris is Upper Cretaceous to Holocene. It is a fresh water genus (Benson et al. 1961, p. Q230).

Potamocypris smaragdina (Vavra), 1891

Pl. 2, Fig. 29

Cypridopsis smaragdina Vavra, 1891, p. 80, Fig. 26.

Potamocypris smaragdina (Vavra), 1891. Sharpe, 1903, p. 992, Pl. 65, Figs. 5-7.

Diagnosis.--Carapace reniform to crescent-shaped in side view; greatest height medially, more than half the length; dorsal margin broadly rounded, sloping gently towards anterior margin; ventral margin flat to slightly concave; anterior margin rounded; posterior margin broadly rounded; sides convex, compressed in dorsal view, greatest width anterior of center; anterior and posterior extremities acutely pointed; valves translucent; inner lamella moderately wide, sloping gently inward in anterior and posterior, sloping steeply inward in ventral region; vestibulum prominent in the left valve, widest in the anterior; inner margins rounded (adapted from Delorme 1970b with reference to Lister 1975).

Description of material.--Few individuals recovered, mostly poorly preserved and incomplete.

Material and occurrences.--One complete left valve and two partial right valves were collected from one interval within the Red Willow Lake core (Appendix IV).

Remarks.--This species can be distinguished from others of the genus by its crescent shape. Positive assignment was made even with limited material.

Hypotypes.--Univ. N. Dak. Cat. No. 14400.

Measurements.--The following are the measurements of the figured hypotype.

Material	Length(mm)	Height(mm)	UND cat. no.	Fig.
Left valve	0.90	0.60	14400	29

Discussion.--Delorme (1970b) reported this species from throughout the interior plains of Canada. It is present throughout the Northern Hemisphere in most aquatic environments. Because of the limited occurrence of this species in the study, no attempt was made to use it for paleoecological interpretation.

Family Limnocytheridae Sars, 1925

Genus Limnocythere Brady, 1868

Original reference.--Brady, 1868a, p. 121.

Type specimen.--Cythere inopinata Baird, 1843.

Diagnosis.--Subquadrate to subreniform in side view; greatest height anterior or posterior of middle; dorsal margin straight; ventral margin concave; anterior and posterior margins rounded to square; carapace ovate to elliptical in dorsal view; compressed anteriorly and posteriorly, extremities usually pointed; valves thin, often reticulate, but may be smooth or pitted, translucent; anterior subcentral sulcus present, and laterally projecting hollow tubercles or spines often present; normal pores numerous, small, sieve type; left valve slightly larger than right; inner lamella wide, with faint striae; marginal pore canals few, straight or weakly sinuous, simple; hinge lophodont, weekly developed, with smooth terminal teeth in right valve,

connected by a shallow groove; muscle scars prominent, consisting of a vertical row of four subequal scars, a single frontal scar anterior to topmost adductor scar, and an anteroventral mandibular scar; dorsal muscle scars are visible near the dorsal margin. Sexual dimorphism is often prominent (adapted from Lister 1975, p. 23).

Remarks.--The geologic range of Limnocythere is Jurassic to Holocene. It is a fresh to brackish water genus (Benson et al. 1961, p. Q309).

Limnocythere (Limnocytherina) ceriotuberosa Delorme, 1967

Pl. 2, Figs. 30-33

Limnocythere ceriotuberosa Delorme, 1967b, p. 360, Pl. 2, Figs. 9-12.

Limnocythere (Limnocytherina) ceriotuberosa Delorme, 1967. Delorme, 1971, p. 44, Figs. 7-9, 83-86.

Diagnosis.--Carapace subrectangular to subtrapezoidal in side view; greatest height anterior in female, posterior in male, more than half of the length; ventral margin straight to weakly concave in female, concave in male; anterior margin broadly rounded; posterior margin rounded in female, angular in male; posteroventral margin in male pronouncedly down warped; elliptical in dorsal view; sides straight to slightly convex, greatest width posterior of center; anterior extremity acutely pointed, posterior extremity rounded; valves strongly reticulate, bisulcate; sulci deep, with major sulcus posterior of center; well developed elongate alae on ventrolateral surface; normal pores few; inner lamella broad, slightly striate, inward sloping; vestibulum absent; inner margins semicircular; marginal pore canals simple, straight;

(adapted from Lister 1975, with reference to Delorme 1971).

Description of material.--Many individuals collected with conjoined valves. Separate valves most often complete, well preserved.

Material and occurrences.--One thousand nine hundred and ninety three individuals (3986 separate valves) were counted from throughout the Main Bay core, the Creel Bay core, and the East Devils Lake core (Appendix IV).

Remarks.--Sexual dimorphism is prominent in this species, and both males and females were recognized in the material. All specimens in each sample were counted.

Hypotypes.--Univ. N. Dak. Cat. Nos. 14401-14404.

Measurements.--The following are the dimensions of the figured hypotypes:

Material	Length(mm)	Height(mm)	UND cat. no.	Fig.
Female right	0.70	0.40	14401	30
Female right	0.70	0.41	14402	31
Male right	0.90	0.50	14403	32
Male left	0.81	0.40	14404	33

Discussion.--Delorme (1971) reported this species as being common in lakes of the prairie regions of the plains of Canada. It appears to be more able to withstand increased salinity than others of the genus. It is restricted to the Devils Lake chain.

Limnocythere (Limnocytherina) itasca Cole, 1949

Pl. 2, Figs. 34-37

Limnocythere itasca Cole, 1949, p. 351, Figs. 1-7.

Limnocythere trapeziformis Staplin, 1963b, p. 1199, Pl. 160, Figs. 15-16.

Limnocythere (Limnocytherina) itasca Cole, 1949. Delorme, 1971a, p. 48, Figs. 68-80, 100-101.

Diagnosis.--Carapace subtrapezoidal in side view; greatest height anterior of middle in female, posterior in male, about half of the length; dorsal margin straight to slightly concave; ventral margin concave, more so in male; anterior margin broadly rounded; posterior margin subtruncate in female, broadly rounded in male; elliptical in dorsal view, sides slightly convex, compressed in anterior, greatest width posterior of center; anterior extremity acutely pointed, posterior extremity rounded; valves reticulate, bisulcate, with major sulcus posterior of minor sulcus; well developed posteriorly projecting spine or sharp alae on ventrolateral surface; inner lamella moderately broad, sloping inward; vestibulum absent; inner margin semicircular; (adapted from Lister 1975, with reference to Delorme 1971).

Description of material.--Few individuals collected with joined valves. Many separate valves were well preserved, but incomplete.

Material and occurrences.--Two hundred and thirty individuals (460 separate valves) were counted from eleven samples from within the Red Willow Lake core (Appendix IV).

Remarks.--Sexual dimorphism is present in this species, but not as pronounced as in L. ceriotuberosa. Both males and females were recognized in the material. All specimens present in the samples were counted.

Hypotypes.--Univ. N. Dak. Cat. Nos. 14405-14408.

Measurements.--The following are the dimensions of the figured hypotypes:

Material	Length(mm)	Height(mm)	UND cat. no.	Fig.
Female right	0.63	0.33	14405	34
Female right	0.60	0.30	14406	35
Male right	0.71	0.40	14407	36
Male left	0.70	0.38	14408	37

Discussion.--Delorme (1971) reported this species as being common in the lakes of the boreal forest and parkland areas of the interior plains of Canada. It was found only in the Red Willow Lake core, and may be interpreted as being less tolerant of salinity or salinity changes than other species of the genus. For a more complete discussion of the environmental conditions preferred by this species, see the Paleoecology section.

Limnocythere (Limnocytherina) staplini Gutentag and Benson, 1962

Pl. 2, Figs. 38-41

Limnocythere staplini Gutentag and Benson, 1962, Pl. 51, Fig. 15; Pl. 1, Figs. 1-3.

Limnocythere (Limnocytherina) staplini Gutentag and Benson, 1962. Delorme, 1971, p. 56, Figs. 213-223, 267-268.

Diagnosis.--Carapace reniform in side view; greatest height anterior of middle in both male and female; dorsal margin strongly arched in female, straight in male; ventral margin moderately concave in female, concave in male; anterior margin broadly rounded; posterior margin narrowly rounded; sides convex in dorsal view, greatest width slightly anterior of center; anterior extremity acutely pointed, posterior extremity bluntly pointed; valves slightly reticulate, very thin, transparent to translucent, bisulcate, with major sulcus posterior of minor sulcus; no alae or spines present; inner lamella narrow;

vestibulum absent; inner margins semicircular, (adapted from Lister 1975, with reference to Delorme 1971).

Description of material.--Few individuals collected with conjoined valves. Because of the thinness of the carapace, few valves were complete.

Material and occurrences.--Two hundred and three individuals (406 separate valves) were counted from eight samples within the Main Bay core, two samples from the Creel Bay core, and from six samples from within the East Devils Lake core (Appendix IV).

Remarks.--Sexual dimorphism is prominent in this species. Both males and females were recognized in the material. All specimens in the samples were counted.

Hypotypes.--Univ. N. Dak. Cat. Nos. 14409-14412.

Measurements.--The following are the dimensions of the figured hypotypes:

Material	Length(mm)	Height(mm)	UND cat. no.	Fig.
Female right	0.58	0.31	14409	38
Female left	0.56	0.31	14410	39
Male right	0.58	0.30	14411	40
Male left	0.59	0.30	14412	41

Discussion.--Delorme (1971) reported this species from the littoral area of lakes on the prairie of the interior plains of Canada. It is most often found in permanent lakes, and seems to be tolerant of the increased salinity of the Devils Lake chain. For a complete discussion of the environmental conditions preferred by this species, see the Paleoecology section.

PLATES

Accession numbers correspond to those in Fig. 1 and in Appendix IV and V.

Explanation of Plate 1

Figure

1,2,3,4. Candona acutula. 1, side view of right valve of female (hypotype, Univ. N. Dak. Cat. No. 14372); 2, side view of left valve of female (hypotype, Univ. N. Dak. Cat. No. 14373); 3, side view of right valve of male (hypotype, Univ. N. Dak. Cat. No. 14374); 4, side view of left valve of male (hypotype, Univ. N. Dak. Cat. No. 14375). UND Accession Number A2433.05. SEM photos, X24.

5,6. Candona candida. 5, side view of right valve of female (hypotype, Univ. N. Dak. Cat. No. 14376); 6, side view of left valve of female (hypotype, Univ. N. Dak. Cat. No. 14377). UND Accession Number A2433.05. SEM photos, X24.

7,8. Candona caudata. 7, side view of right valve of female (hypotype, Univ. N. Dak. Cat. No. 14378); 8, side view of left valve of female (hypotype, Univ. N. Dak. Cat. No. 14379). UND Accession Number A2433.06. SEM photos, X24.

9,10. Candona decora. 9, side view of right valve of female (hypotype, Univ. N. Dak. Cat. No. 14380); 10, side view of left valve of female (hypotype, Univ. N. Dak. Cat. No. 14381). UND Accession Number A2433.06. SEM photos, X24.

Figure

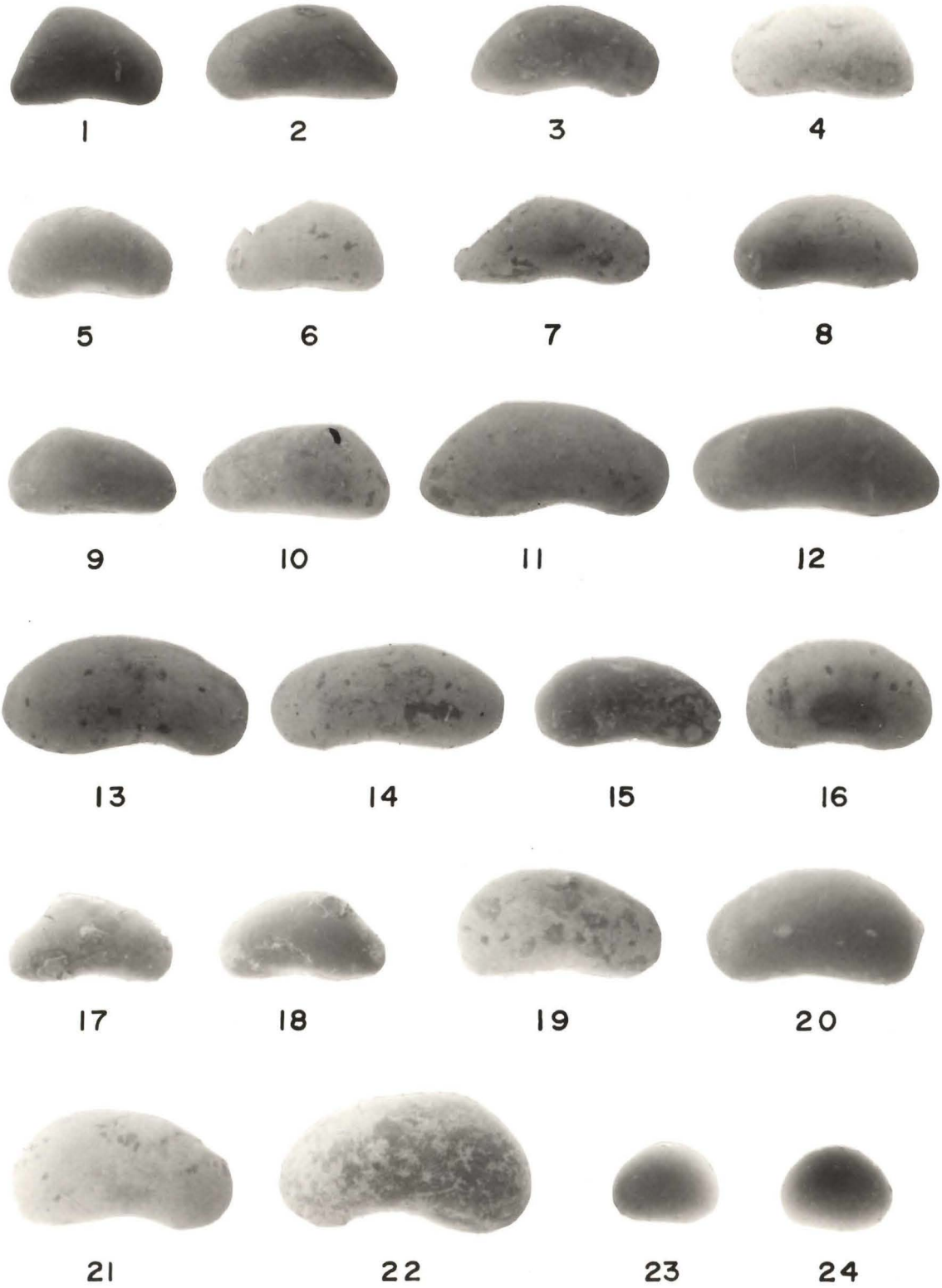
11,12,13,14. Candona ohioensis. 11, side view of right valve of female (hypotype, Univ. N. Dak. Cat. No. 14382); 12, side view of left valve of female (hypotype, Univ. N. Dak. Cat. No. 14383); 13, side view of right valve of male (hypotype, Univ. N. Dak. Cat. No. 14384); 14, side view of left valve of male (hypotype, Univ. N. Dak. Cat. No. 14385). UND Accession Number A2433.05. SEM photos, X24.

15,16. Candona lactea. 15, side view of right valve of female (hypotype, Univ. N. Dak. Cat. No. 14386); 16, side view of left valve of female (hypotype, Univ. N. Dak. Cat. No. 14387). UND Accession number A2433.05. SEM photos, X24.

17,18. Candona pronopa. 17, side view of right valve of female (hypotype, Univ. N. Dak. Cat. No. 14388); 18, side view of left valve of female (hypotype, Univ. N. Dak. Cat. No. 14389). UND Accession number A2433.08. SEM photos, X24.

19,20,21,22. Candona rawsoni. 19, side view of right valve of female (hypotype, Univ. N. Dak. Cat. No. 14390); 20, side view of left valve of female (hypotype, Univ. N. Dak. Cat. No. 14391); 21, side view of right valve of male (hypotype, Univ. N. Dak. Cat. No. 14392); 22, side view of left valve of male (hypotype, Univ. N. Dak. Cat. No. 14393). UND Accession Number A2433.05. SEM photos, X24.

23,24. Cyclocypris ampla. 23, side view of right valve (hypotype, Univ. N. Dak. Cat. No. 14394); 24, side view of left valve (hypotype, Univ. N. Dak. Cat. No. 14395). UND Accession Number A2433.05. SEM photos, X24.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Explanation of Plate 2

Figure

25,26. Cyprinotus glaucus. 25, side view of right valve of female (hypotype, Univ. N. Dak. Cat. No. 14396); 26, side view of left valve of female (hypotype, Univ. N. Dak. Cat. No. 14397). UND Accession Number A2432.34. SEM photos, X30.

27,28. Cypridopsis vidua. 27, side view of right valve of (hypotype, Univ. N. Dak. Cat. No. 14398); 28 side view of left valve of (hypotype, Univ. N. Dak. Cat. No. 14399). UND Accession Number A2433.50. SEM photos, X30.

29. Potamocypris smaragdina. 29, side view of left valve of (hypotype, Univ. N. Dak. Cat. No. 14400). UND Accession Number A2431.02. SEM photos, X30.

30,31,32,33. Limnocythere (Limnocytherina) ceriotuberosa. 30, side view of right valve of female (hypotype, Univ. N. Dak. Cat. No. 14401); 31, side view of right valve of female (hypotype, Univ. N. Dak. Cat. No. 14402); 32, side view of right valve of male (hypotype, Univ. N. Dak. Cat. No. 14403); 33, side view of left valve of male (hypotype, Univ. N. Dak. Cat. No. 14404). UND Accession No. A2430.08. SEM photos, X50.

34,35,36,37. Limnocythere (Limnocytherina) itasca. 34, side view of right valve of female (hypotype, Univ. N. Dak. Cat. No. 14405); 35, side view of right valve of female (hypotype, Univ. N. Dak. Cat. No. 14406); 36, side view of right valve of male (hypotype, Univ. N. Dak. Cat. No. 14407); 37, side view of left valve of male (hypotype, Univ. N. Dak. Cat. No. 14408). UND Accession Number A2433.30. SEM photos, X50.

38,39,40,41. Limnocythere (Limnocytherina) staplini. 38, side view of right valve of female (hypotype, Univ. N. Dak. Cat. No. 14409); 39, side view of left valve of female (hypotype, Univ. N. Dak. Cat. No. 14410); 40, side view of right valve of male (hypotype, Univ. N. Dak. Cat. No. 14411); 41, side view of left valve of male (hypotype, Univ. N. Dak. Cat. No. 14412). UND Accession Number A2432.24. SEM photos, X50.

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APPENDICES

APPENDICES

APPENDIX I

DESCRIPTION OF CORING APPARATUS

DESCRIPTION OF CORING APPARATUS

The coring apparatus utilized in this project was constructed at the University of Minnesota Physics machine shop, Minneapolis, MN., with funds provided by the Legislative Commission on Minnesota Resources and the U.S. Department of the Interior as authorized under the Water Research and Development Act of 1978, P.L. 95-467.

The basic design of the corer is after that of Colinvaux (1964), with several modifications. Similar coring devices have been reported by Kullenberg (1947), Livingstone (1955), Vallentyne (1955), Brown (1956), and Rowley and Dahl (1956).

The parts of the corer (Figure 7) are listed and described below, including trade names of various materials where appropriate.

Extension Rods

The extension rods are designed after those of Lichtwardt (1952). They consist of 1-or-2 m rods (1.8 cm od) made of high strength Reynolds Aluminum, Alloy 6061-T6. The couplers are stainless steel covered by close-fitting brass sleeves held in place by spring-loaded pins. The rods are lightweight, very strong, and easily manipulated in all weather. The sleeves must be kept clean to allow rapid uncoupling. Stainless steel couplers were chosen over aluminum to minimize expansion of the joint while the corer was driven into the sediment with the pile driver.

Core Barrel

The core barrel assembly consists of a 1-or-2 m barrel, a cap, and a bit. The barrels are Alcoa schedule 40 pipe, made of 6061-T6 Alloy, 4.0 cm id, and 4.8 cm od. The bit is made of hardened stainless steel

and is threaded to fit the barrel. The bit has a slightly smaller inside diameter, so that it forms a shoulder to hold the liner and core catcher in the barrel. The cap was milled from a solid block of stainless steel, and slides into the top of the barrel where it is held in place by two flush-fitting threaded bolts. The top of the cap has four holes drilled in it to allow a 3mm steel cable to be passed through as well as to allow the escape of air and water as the corer is being lowered to the sediment. A coupler on the top of the cap allows attachment of the extension rods.

Piston

The piston consists of two cylindrical laboratory washers attached to a threaded eyebolt (12 cm long) separated by an aluminum collar. The design is such that by tightening the bottom bolt, the washers expand to fit tightly in the liner. The piston is attached to the cable by a cable clamp and a stainless steel snap to allow rapid removal.

Liners

The core liners are transparent, rigid PVC plastic tubes, 3.75 cm od and 3.4 cm id. The liners are commercially available in 2.4-m lengths. The liners are cut 1.12 or 2.12 m long to accomodate 1-or-2 m of core and the piston. Plastic tube caps that are easily secured to the liner with plastic electricians tape are also commercially available.

Pile Driver

The pile driver consists of a solid stainless steel rod with a coupler on one end and a fixed 10-kg mass attached to the middle of the rod. A sliding 25-kg mass serves as the pile driver to force the corer into the sediment. The mechanism serves the purpose very well,

but can result in damage to the couplers and rods if too much force is exerted.

Cable and Winch

Any 3 mm cable can be used, but a plastic coated cable is much easier on the hands and does not kink as readily as an uncoated cable. A tripod with a winch and pulley (while on ice) or a boom with a winch and pulley (while on the raft) was used to secure the cable during coring and to raise the apparatus after the core had been taken.

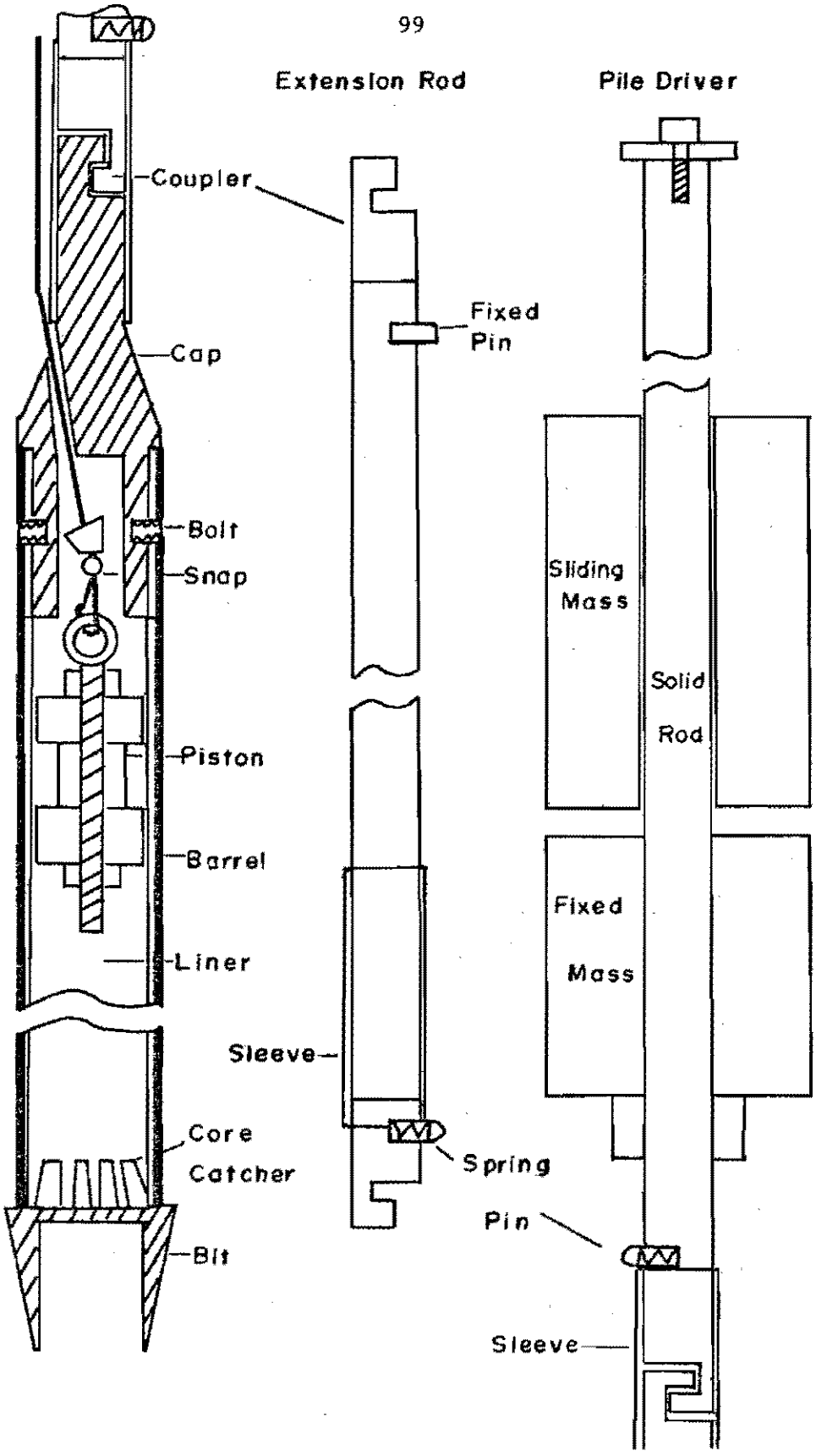
Casing

The casing consists of various lengths of schedule 40, 6.5 cm PVC plastic electrical conduit, with threaded couplers. This material served very well in water depths up to 10 m. In depths greater than 10 m, the conduit would flex while the corer was being driven into the sediment.

Cost

The cost for the entire apparatus, including casing, liners, and caps, was less than $2500, with most of the cost being labor. The entire assembly fits into two boxes, 2.1 m long, that fit easily into the bed of a standard pick-up truck.

Fig. 7. Diagram of the coring apparatus used in this study. All features are illustrated without scale. Dimensions are given in Appendix I for all parts.


Extension Rod
Pile Driver
Coupler
Fixed
Pin
Cap
Bolt
Snap
Piston
Barrel
Liner
Sleeve
Core
Catcher
Bit
Spring
Pin
Sleeve
Sliding
Mass
Solid
Rod
Fixed
Mass

APPENDIX II

MICROFOSSIL VACUUM PICK

DESCRIPTION OF MICROFOSSIL VACUUM PICK

When ostracods were exceptionally abundant in the prepared samples, a vacuum picking apparatus (Figure 8) was used to segregate the valves from sediment.

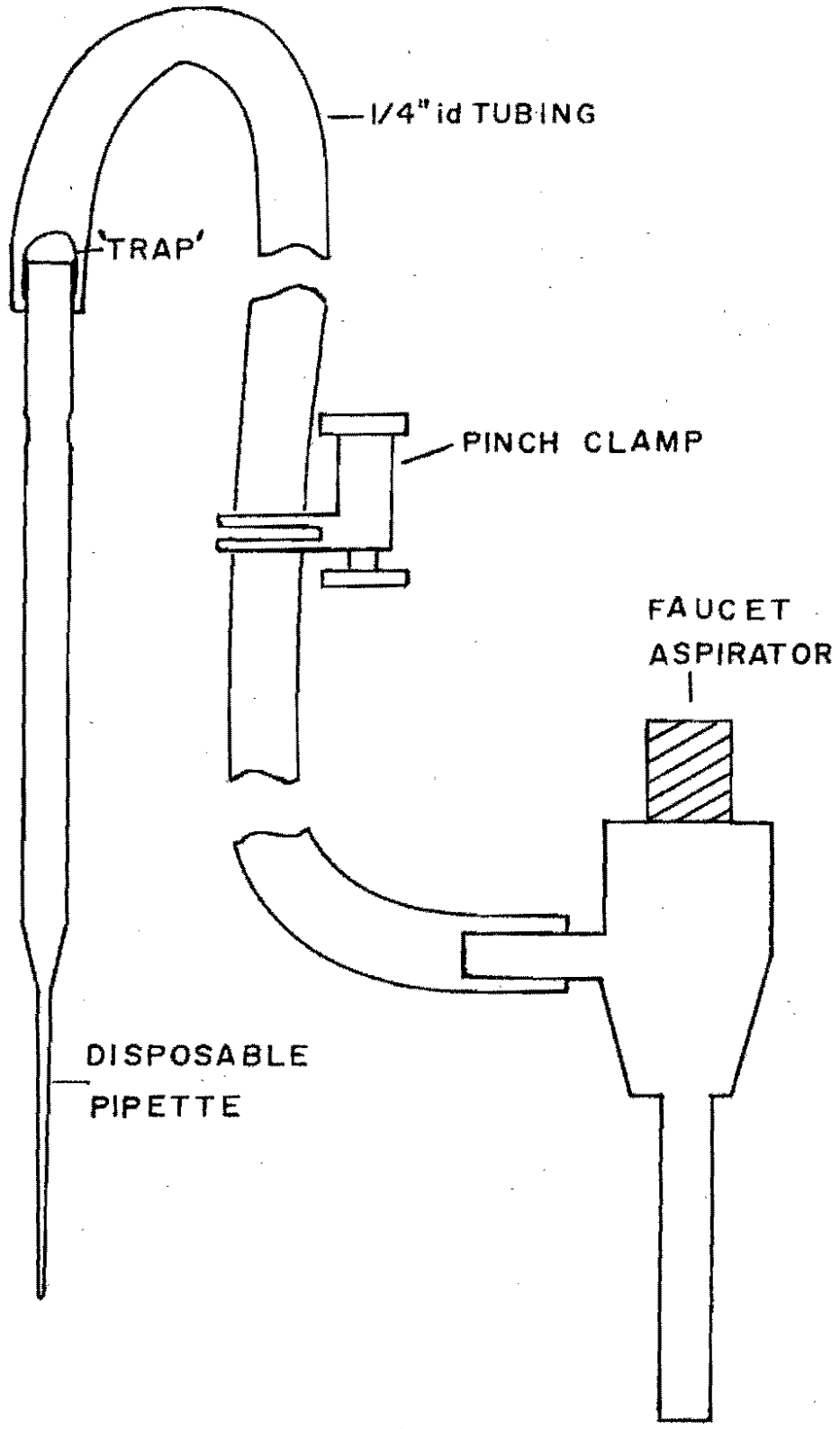
The idea of the apparatus is basically that of Stinemeyer (1965). The apparatus described here, however, does not require expensive vacuum pumps or hypodermic needles, and can be constructed in about 5 minutes with no tools.

The vacuum is provided by a faucet aspirator, and the needle is a disposable glass pipette. The only other required equipment is an in-line moisture trap, a small diameter flexible vacuum hose, and a spring loaded hose clamp.

The maximum vacuum is controlled by the water velocity through the aspirator. The vacuum available to the pipette is controlled by the hose clamp. The size of particle able to be picked up is determined by the diameter of the pipette. This can readily be changed by breaking the tip of the pipette at the desired diameter. A cotton filter is placed over the base of the pipette to prevent loss of the ostracode valves.

This apparatus costs next to nothing to construct, and provides a rapid means of extracting ostracods with little breakage from the unwanted sediment.

Fig. 8. Diagram of microfossil vacuum pick.


1/4" id TUBING
'TRAP'
PINCH CLAMP
FAUCET
ASPIRATOR
DISPOSABLE
PIPETTE

APPENDIX III

PROGRAM LISTING AND DOCUMENTATION

General Information

The following computer programs were written and tested on a Terak Microcomputer. The final complete runs were made on the University of Minnesota Computer Center's Cyber 74. To use these programs on the Cyber system, a library package (*$'IOAIDS' Input,Output AIDS*) had to be inserted at the beginning of the program to allow reading of a text data file. The End Of Line (EOLN) and End of File (EOF) statements also had to be changed to (EOLNS) and (EOFS). This is a University of Minnesota solution to a Control Data Corporation Cyber System characteristic. Because every large system has its own idiosyncrasies, the programs are listed as they would be run on a microcomputer with a PASCAL Compiler and a data file attached. The user must realize that for these programs to run in a large computer system modifications of the input/output statements would have to be made.

The programs are written in PASCAL, a strongly typed and structured computer language. For this reason, all constants, variables, and data types must be declared at the beginning of the program, as illustrated in the listings. The data types used in these programs are integer numbers; real numbers; characters; and Boolean (true/false) variables.

The programs are broken down into procedures, with each procedure accomplishing basically one task. Comments, within the listings, are indicated by lines of text enclosed by parentheses and asterisks. These statements are listed for information only, and are not executed within the program.

The main program is at the end of the listing. It consists of the procedures, listed in order of execution and write statements. Loops and

iterations can also be implemented within the main program, but for readability are usually defined as separate procedures.

Input Data

All the programs are designed to read from the same data file, a text file, to simplify data entry. The data are read in the following order: location; interval number (in the case of a section or core), species, and number of individuals. The species and number of individuals can be repeated as many times as necessary. Information for each sample is represented on one card. If enough species are present in a sample to fill one card, two or more cards can be read consecutively for each sample. The location and species names are entered as integers and are decoded and written by the program. These programs decode fifteen species of ostracods and four core locations. This can be very easily modified to fit any sampling situation.

The following is a sample of input data:

Location	Sample Interval	Species Code	Number of Individuals	Species Code	Number of Individuals	Species Code	Number of Individuals
1	010	1	5	2	10	3	4

The data are entered as integers without commas or periods separating the numbers.

User Documentation and Technical Information

PROGRAM DATALIST

This program reads from an attached data text file, and outputs the following for every species in the study: (1) every core or section location and sample that contains the species; (2) the number of individuals of the species in each occurrence; (3) the total number of individuals of the species in the study, and (4) the total number of all individuals in the study.

The maximum number of species (in this case 15) is listed as a constant. This constant determines the number of times the data file will be searched.

"Idname" is defined as a packed array (character string) of 26 characters. This number represents the longest species name in the study. "Idname" is referenced by the variable "name" to identify the species being searched for during each loop of the main program.

"Infil" is defined as a file of characters and represents the data. Each read statement specifies this data file. "Infil" is reset after the search for each species, so the next search is started at the beginning of the data file.

Procedure "Initialize" sets all counters to zero. This procedure is implemented before the search loop is entered in the main program.

Procedure "Speciesid" decodes the species name in preparation for printing the headings. A case statement is used with the number of species readily changed to fit any study.

Procedure "Check" is the main procedure of the program. It searches the data for each species, and prints the location, interval, and

abundance every time the species is encountered. The locations are referenced by a case statement, and can be easily changed to fit any situation. This procedure also increments a counter for the number of individuals of the species in the study.

The main program consists of a loop, 1 to maxspecies, which calls the various procedures in order of their use, prints headings, and increments the total individual counter for the study.

An example of the output of DATALIST is as follows:

```
**********************************************************

SPECIES NAME:  Candona acutula

Redwillow Lake      550 cm      8 individuals
Redwillow Lake      640 cm      8 individuals
Redwillow Lake      670 cm      6 individuals

Total Number of Individuals:        22

**********************************************************
```

DATALIST Program Listing

```
PROGRAM DATALIST (Input, Output, Infil);

(* This program reads from a data file and outputs for every species
   present in the data the following:  (1) every location and every
   sample containing the species; (2) the number of individuals of the
   species in each sample and; (3) the total number of individuals of
   that species in the data. *)

CONST       Maxspecies = 15;

TYPE        Idname              = packed array[1..26] of CHAR;

VAR         Species,
            Location,
            Interval,
            Speciesname,
            Individuals,
            Coreindividuals,
            Totalindividuals    :  INTEGER;
```

```
            Infil                 :  file of CHAR;

            Name                  :  Idname;

 PROCEDURE Initialize; (* Initialize counters to 0. *)
  Begin
   Coreindividuals := 0;
   Totalindividuals := 0;
  End; (* of initialize *)

 PROCEDURE Speciesid; (* Decode and print the species names. *)
  Begin
   Case Species of
    1:  Name  := 'Candona acutula           ';
    2:  Name  := 'Candona candida           ';
    3:  Name  := 'Candona caudata           ';
    4:  Name  := 'Candona decora            ';
    5:  Name  := 'Candona ohioensis         ';
    6:  Name  := 'Candona lactea            ';
    7:  Name  := 'Candona pronopa           ';
    8:  Name  := 'Candona rawsoni           ';
    9:  Name  := 'Cyclocypris ampla         ';
   10:  Name  := 'Cyprinotus glaucus        ';
   11:  Name  := 'Cypridopsis vidua         ';
   12:  Name  := 'Potamocypris smaragdina   ';
   13:  Name  ;= 'Limnocythere ceriotuberosa';
   14:  Name  ;= 'Limnocythere itasca       ';
   15:  Name  ;= 'Limnocythere staplini     ';
   End
 End; (* of speciesid *)

 PROCEDURE Check; (* Check locations and numbers for each species. *)
  Begin
   Reset (Infil);
   Coreindividuals := 0;
   While not(eof(Infil)) do
    Begin
    Read (Infil, Location, Interval);
     While Not EOLN(Infil) do
     Begin
     Read (Infil, Speciesname, Individuals);
     If Speciesname = Species then
      Begin
       Case Location of
        1:  Write (' Main Bay        ');
        2:  Write (' Creel Bay       ');
        3:  Write (' East Devils Lake');
        4:  Write (' Redwillow Lake  ')
       End; (* of case *)
       Write (Interval:4, ' cm');
       Writeln (Individuals:4, ' individuals');
```

```
      Coreindividuals := Coreindividuals + Individuals;
     End (* of if *)
    End (* of While*)
  End; (* of while *)
 End; (* of procedure *)

Begin (* Main program, DATALIST *)
 Initialize;
 For Species  := 1 to Maxspecies do
  Begin
   Writeln('*************************************************************');
   Writeln;
   Speciesid; (* procedure speciesid *)
   Writeln (' SPECIES NAME:   ', Name);
   Writeln;
   Check; (*procedure check *)
   Writeln;
   Writeln (' TOTAL NUMBER OF INDIVIDUALS:  ',Coreindividuals:4);
   Writeln;
   Totalindividuals := Totalindividuals + Coreindividuals
  End; (* of For *)
  Writeln;Writeln;
  Write (' Total number of individuals in the study: ',Totalindividuals:
    5);
  Writeln
END. (* of main program *)
```

User Documentation and Technical Information

PROGRAM DIVERSITY

This program reads from an attached data file, and outputs the following for each sampling interval in each core: (1) the core location; (2) the sampling interval; (3) the number of species and the number of individuals of each species present in the sample; and (4) the total number of individuals in the sample. The Brillouin, Simpson, and Margalef diversity indices, and the Donahue equitability index are calculated and output as well.

As in DATALIST, all variables must be declared before being used. "Indexflag" is a Boolean variable, initiated to false. If no ostracods are found in the sample, the variable remains false, and prevents the printing of species names, and the calculation of meaningless values for the indices.

Function factorial is used in defining Brillouins diversity index. Brillouins index calls for the factorial of the total number individuals in the sample, as well as the product of the factorials of the number of individuals of each species in the sample. To save computer time, as well as to avoid exceeding maximum integer limitations, Function Factorial was designed. This function, when called, is passed the number of individuals, and calculates the factorial of the number by using natural logarithms to yield the same results as a standard factorial. The results are then passed back to the main program.

Procedure "Initialize" sets all the counters to zero.

Procedure "Sampleid" identifies the core and sample interval and prints the headings.

Procedure "Speciesid" identifies the species present, if any, and uses a case statement to print the species names and the number of individuals of each species in the sample. The calculations required for the various indices are initiated, and counters for various indices are incremented.

Procedure "Writeindices" completes the calculations of the indices and writes the headings and values.

The main program consists of an initial reset of the data file, and a call to each of the procedures as required.

As in DATALIST, this program can be modified, by changes in the case statements, to handle any number of locations or species.

An example of the output of DIVERSITY is as follows:

****

CORE LOCATION: MAIN BAY

SAMPLE INTERVAL: 190cm

SPECIES PRESENT	INDIVIDUALS
Candona lactea	17
Candona rawsoni	5
Limnocythere ceriotuberosa	14
Limnocythere staplini	4
TOTAL	40

DIVERSITY INDICES

Brillouin Index:	0.474
Simpson Index:	3.210
Margalef Index:	0.813

EQUITABILITY INDEX

Donahue Index: 0.802

****

DIVERSITY Program Listing

```
PROGRAM DIVERSITY (Input, Output,Infil);

 (*This is a program to decode and print the names of species of
 ostracodes found during the analysis of sediment cores.  The output
 includes the location of the core, the sample interval, the names of
 species present, if any, the number of individuals of each species,
 and the total number of individuals.  The Brillouin, Simpson, and
 Margalef Diversity indicies are also printed for each sample, as well
 as the Donahue Equitability Index.  The input is from a data file.
 Please refer to the USERS DOCUMENTATION for the format required for
 the data.  This program will only read characters from the data file,
 and the only data that will be accepted by the program is integer.*)

VAR Corelocation,      (*Define all variables.*)
    Sampleinterval,
    Speciesname,
    Numindividuals,
    Numspecies,
    Totalindividuals,
    Counter             : INTEGER;

   Infil                : file of CHAR;

   Brillouinseries,
   Simpsonsum,
   Indexbrillouin,
   Indexsimpson,
   Indexmargalef,
   Indexdonahue,
   Sumloss              : REAL;

   Indexflag            : BOOLEAN;

FUNCTION Factorial (Num: INTEGER)   : REAL; (* For use in defining
                                                        Brillouins*)
  Begin                                        (* Index of Diversity. *)
   Sumloss:= 0.0;
   For Counter:= 1 to Num Do
    Sumloss:= LN(Counter) + Sumloss;
   Factorial:= Sumloss
  End;  (*of function factorial*)

PROCEDURE Initialize;                (*Set variables to zero*)
 Begin
  Numspecies:= 0;
  Totalindividuals:= 0;
  Brillouinseries:= 0;
  Simpsonsum:= 0;
  Indexflag:= false;
```

```
  Writeln; Writeln;
  Writeln ('*************************************************************');
  Writeln
 End; (*of Initialize*)

PROCEDURE Sampleid;  (* To identify the core, and print headings. *)
 Begin
  Read (Infil,Corelocation);
  Write (' CORE LOCATION :  ');
   Case Corelocation of
    1: Writeln (' Main Bay');
    2: Writeln (' Creel Bay');
    3: Writeln (' East Devils Lake');
    4: Writeln (' Redwillow Lake')
   End; (*End of the Case.*)
  Read (Infil,Sampleinterval);
  Writeln (' SAMPLE INTERVAL :  ', Sampleinterval:4, 'cm');
  Writeln; Writeln;
  Writeln (' SPECIES PRESENT                    INDIVIDUALS')
 End; (* of Sampleid *)

PROCEDURE Speciesid; (* To identify the species present, and print the
                                                              names.*)
 Begin
  If (eoln(Infil))
   Then
    Begin
     Writeln;
     Writeln (' NO OSTRACODES IN SAMPLE. ')
    End
   Else while not(eoln(Infil)) do
    Begin
     Indexflag := true;
     Read (Infil,Speciesname);
      Case Speciesname of
        1: Write(' Candona acutula                ');
        2: Write(' Candona candida                ');
        3: Write(' Candona caudata                ');
        4: Write(' Candona decora                 ');
        5: Write(' Candona ohioensis              ');
        6: Write(' Candona lactea                 ');
        7: Write(' Candona pronopa                ');
        8: Write(' Candona rawsoni                ');
        9: Write(' Cyclocypris ampla              ');
       10: Write(' Cyprinotus glaucus             ');
       11: Write(' Cypridopsis vidua              ');
       12: Write(' Potamocypris smaragdina        ');
       13: Write(' Limnocythere ceriotuobesa      ');
       14: Write(' Limnocythere itasca            ');
       15: Write(' Limnocythere staplini          ')
      End; (* of case *)
          (*Count the number of species*)
```

```
      Numspecies := Numspecies + 1;
           (*Read and count the number of individuals*)
      Read (Infil,Numindividuals);
      Writeln (Numindividuals:4);
      Totalindividuals := Totalindividuals + Numindividuals;
           (*Set up the equations required to determine the Diversity
                                                              indices*)
      Brillouinseries := Factorial(Numindividuals) + Brillouinseries;
      Simpsonsum := Numindividuals * (Numindividuals - 1) + Simpsonsum;
     End; (* of while not(eoln) *)
    Writeln('                                   TOTAL ', Totalindividuals:3)
   End; (* of Speciesid *)

  PROCEDURE Writeindicies; (* Calculate and print the diversity indices.*)
   Begin
    Writeln; Writeln;
    Writeln(' DIVERSITY INDICIES'); Writeln;
    Indexbrillouin:=(( Factorial(TotalBndividuals)- Brillouinseries)/LN(10))
                                                    /(Totalindividuals);
    Writeln (' Brillouin Index: ',Indexbrillouin:6:3);
    If( Totalindividuals = Numspecies) Then Indexsimpson:= Numspecies
     Else
        Indexsimpson:= ( Totalindividuals/Simpsonsum)*(Totalindividuals-1);
    Writeln (' Simpson Index: ', Indexsimpson:6:3);
    If( Totalindividuals = 1) Then Indexmargalef:= (Numspecies-1)/ 1
     Else
        Indexmargalef:= (Numspecies-1)/ LN(Totalindividuals);
    Writeln (' Margalef Index:', Indexmargalef:6:3);
    Indexdonahue:= Indexsimpson/ Numspecies;
    Writeln;
    Writeln (' EQUITABILITY INDEX'); Writeln;
    Writeln (' Donahue Index: ', Indexdonahue:6:3);
    Writeln;
   End; (* of Writeindicies *)

BEGIN (*Main program*)
 Reset (Infil);
  While not (eof(Infil))do
  Begin
   Initialize;
   Sampleid;
   Speciesid;
   If (Indexflag) then Writeindicies
  End
END. (* of Ostracoda *)
```

User Documentation and Technical Information

PROGRAM SIMILARITY

This program reads from an attached data file, and outputs for every two consecutive samples in a core, the following: (1) the core location; (2) the intervals being compared; and (3) the Simpson, Jaccard, and Dice similarity coefficients for the samples.

As in previous programs, the variables must be declared prior to use or reference. In this program, two arrays (ArrayA and ArrayB) are used to store the number code of the species present in the two consecutive samples. ArrayA represents the first sample, and ArrayB represents the second sample.

Procedure "FillA" fills the first array from the first sample, after the elements of the array are initialized to zero.

Procedure "FillB" fills the second array from the second sample, again after initialization to zero.

Procedure "ABIncommon" searches both arrays for species that are incommon, and increments a counter to record that number.

Procedure "Headings" uses a case statement to print the core location and intervals being compared. This can be readily changed to fit any study.

Procedure "Indexsimilarity" determines whether ostracods were present in the samples, calculates the indices, and prints the values if valid to do so.

Procedure "BforA" exchanges the values of ArrayA and ArrayB, so ArrayA becomes the next 'first sample', and ArrayB can be filled with new values from the next consecutive sample in the data.

The main program begins with a reset of the data file, and fills the first array. The rest of the procedures are within a loop, and are repeated, in order, as long as there are data to be read.

An example of the output of SIMILARITY is as follows:

```
**************************************************************

CORE LOCATION:      Main Bay

COMPARING INTERVALS: 230 and 240cm


SIMPSON INDEX:  100.00

JACCARD INDEX:  0.667

DICE INDEX:  0.800

**************************************************************
```

SIMILARITY Program Listing

```
PROGRAM SIMILARITY (Input,Output,Infil);

 (*This program is designed to compare the species present in two con-
 secutive samples in a core of any length.  The Simpson, Jaccard, and
 Dice Similarity Coefficients are calculated, and output.  Please refer
 to the USERS DOCUMENTATION for the format required for the data.*)

 (*Define the variables.*)

CONST     Maxspecies        =  15;

TYPE      ARRAYNAME         =  ARRAY [1..Maxspecies] of INTEGER;

VAR       ArrayA, ArrayB     : ARRAYNAME;

          Interval,
          ALocation, BLocation,
          CountA, CountB,
          CounterA, CounterB,
          Species,
          Num,
          Incommon,
          Index              : INTEGER;
```

```
            Simpson,
            Jaccard,
            Dice                : REAL;

            Infil               : file of CHAR;

PROCEDURE FillA;  (* Fill the first array, from the first sample.*)
 Begin
  CountA := 0;
  For Index := 1 to Maxspecies do
   ArrayA [Index] := 0;
  Read (Infil,ALocation, Interval);
  While not(eoln(Infil)) do
   Begin
    Read (Infil, Species,Num);
    CountA := CountA + 1;
    ArrayA [CountA] :=Species;
   End (*of While not(eoln(Infil))*)
  End; (*of FillarrayA*)

PROCEDURE FillB;  (*Fill the second array, from the second sample.*)
 Begin
  CountB := 0;
  For Index := 1 to Maxspecies do
   ArrayB [Index] := 0;
  Read (Infil, BLocation, Interval);
  While not(eoln(Infil)) do
   Begin
    Read (Infil, Species, Num);
    CountB := CountB + 1;
    ArrayB [CountB] := Species;
   End (*of While not(eoln(Infil))*
  End; (*of FillB*)

PROCEDURE ABIncommon; (*Check to see how many species are incommon to the
                        two sampes.*)
 Begin
  Incommon := 0;
  If ((CountA = 0) or (CountB = 0))
   Then Incommon := 0
  Else
   Begin
    For CounterA := 1 to CountA do
     Begin
      For CounterB := 1 to CountB do
       If (ArrayA [CounterA] = ArrayB [CounterB])
        Then Incommon := Incommon + 1
   End;
 End (*of Else*)
End; (*of ABIncommon*)
```

```
PROCEDURE Headings; (*Print the headings for the output.*)
 Begin
  Writeln (' ************************************************************');
  Writeln;
  Write (' Core location:  ');
  Case Blocation of
   1:  Writeln (' Main Bay');
   2:  Writeln (' Creel Bay');
   3:  Writeln (' East Devils Lake');
   4:  Writeln (' Red Willow Lake')
  End; (*of case*)
  Writeln;
  Writeln (' Comparing intervals:  ',(Interval- 10):4,' and ',Interval,
                                                              'cm')
 End; (* of Headings*)

PROCEDURE Indexsimilarity; (*Calculate and print the indices of
                                                        similarity.*)
 Begin
  If Incommon = 0
   Then
    Begin
     If ((CountA = )) and (CountB = 0 ))
      Then
       Writeln (' No Ostracodes found.  Similarity indices are invalid.')
     Else
      Begin
       Simpson := 0;
       Writeln;Writeln (' Simpson Index:',Simpson :6:3);
       Jaccard := 0;
       Writeln;Writeln (' Jaccard Index:',Jaccard :6:3);
       Dice := 0;
       Writeln; (' Dice Index:',Dice :6:3);
       Writeln
      End; (*of else*)
    End
   Else
    Begin
     If (CountA<= CountB)
      Then Simpson := 100*(Incommon/CountA)
      Else Simpson := 100*(Incommon/CountB)
     Writeln;Writeln;
     Writeln (' Simpson Index:',Simpson :6:3);
     Jaccard := Incommon/(CountA=CountB-Incommon);
     Writeln;
     Writeln (' Jaccard Index:',Jaccard :6:3);
     Dice := 2*Incommon/(CountA=CountB);
     Writeln;
     Writeln (' Dice Index:',Dice :6:3);
     Writeln;
     Writeln;
    End
 End; (*of Indexsimilarity*)
```

```
PROCEDURE BforA; (*Exchanges Array B for Array A, so the next comparison
                                                    can be made.*)
 Begin
  For Index := 1 to Maxspecies do
   ArrayA [Index] := ArrayB [Index];
   CountA := CountB
 End; (*of BforA*)

BEGIN  (*main program  Similarity*)
 Reset (Infil);
 While not(eof(Infil)) do
  Begin
   FillA;
   Repeat
    FillB;
    ABIncommon;
    Headings;
    Indexsimilarity;
    BforA;
   Until (eof(infil)) or (ALocation<>BLocation);
  End (*of While not(eof(Infil))*)
END. (*of Similarity*)
```

APPENDIX IV

FOSSIL OCCURRENCES

The following pages contain a list of the abundance of ostracod species present in each sample studied. Each sample represented a 1-cm thick slice of a 3.4-cm diameter core. The number of occurrences of each species refers to the actual number of individuals (two valves per individual) contained in the sample. The depth of sample numbers refer to the depth in each core where samples were taken. A University of North Dakota accession number indicates that ostracods were collected or counted. Accession numbers correspond to those in Fig. 1, and Appendix V.

The species names are coded as follows:

Name	Code
Candona acutula	1
Candona candida	2
Candona caudata	3
Candona decora	4
Candona ohioensis	5
Candona lactea	6
Candona pronopa	7
Candona rawsoni	8
Cyclocypris ampla	9
Cyprinotus glaucus	10
Cypridopsis vidua	11
Potamocypris smaragdina	12
Limnocythere ceriotuberosa	13
Limnocythere itasca	14
Limnocythere staplini	15

MAIN BAY

OSTRACODE OCCURRENCES
MAIN BAY

Depth of Sample	UND Accession Number	Species Code 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0cm																
10cm																
20cm																
30cm																
40cm																
50cm																
60cm	A2430.01						1									
70cm	A2430.02						6							1		
80cm	A2430.03						2		1							
90cm																
100cm	A2430.04						11		1							
110cm																
120cm	A2430.05						1									
130cm	A2430.06						14		5							
140cm																
150cm																
160cm	A2430.07						96		72					4		
170cm	A2430.08						84		96					24		8
180cm	A2430.09						7		3					4		
190cm	A2430.10						17		5					14		4
200cm	A2430.11						13		10					10		
210cm	A2430.12						58		32					4		
220cm	A2430.13						58		12					3		
230cm	A2430.14						7		5					1		
240cm	A2430.15						2		1							
250cm	A2430.16						15		8					6		
260cm	A2430.17						20		9					7		
270cm	A2430.18						10		3							
280cm	A2430.19						27		25					3		
290cm	A2430.20						282		212					50		
300cm	A2430.21						3		2					3		

OSTRACODE OCCURRENCES
MAIN BAY

Depth of Sample	UND Accession Number	Species code 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
310cm	A2430.22						86		43					9		4
320cm	A2430.23						10		2		1			7		
330cm	A2430.24						12		1					3		
340cm	A2430.25						24		7							
350cm	A2430.26						20		14					3		
360cm	A2430.27						28		36					3		
370cm	A2430.28						214		200					86		16
380cm	A2430.29						17		20					13		9
390cm	A2430.30						24		13					37		
400cm	A2430.31						17		9					8		
410cm	A2430.32						45		23					60		13
420cm	A2430.33						82		102					22		
430cm	A2430.34						89		51					2		
440cm	A2430.35						40		64							
450cm	A2430.36						57		22					8		
460cm	A2430.37						16		3					3		
470cm	A2430.38						23		15					3		
480cm	A2430.39						85		41					4		
490cm	A2430.40						199		115					16		4
500cm	A2430.41						70		35					35		
510cm	A2430.42						7		9		1			17		
520cm	A2430.43						18		21					3		
530cm	A2430.44						22		8					2		
540cm	A2430.45						91		53					60		20
550cm	A2430.46						76		47					21		
560cm	A2430.47						60		57					3		
570cm	A2430.48						16		5					3		
580cm	A2430.49						134		82					14		
590cm	A2430.50						50		31					8		
600cm	A2430.51						25		16					1		

OSTRACODE OCCURRENCES
MAIN BAY

Depth of Sample	UND Accession Number	Species code 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
610cm	A2430.52						21		17					2		
620cm	A2430.53						18		49							
630cm	A2430.54						198		115					29		
640cm	A2430.55						61		49					31		
650cm	A2430.56						69		35					29		
660cm	A2430.57						23		14					3		
670cm	A2430.58						74		51					43		
680cm	A2430.59						88		48					42		
690cm	A2430.60						9		8							
700cm																
710cm	A2430.61						66		56					8		
720cm	A2430.62						34		28					4		
730cm	A2430.63						36		29					18		
740cm	A2430.64						16		13					8		
750cm	A2430.65						4		9					9		
760cm	A2430.66						6		9					7		
770cm	A2430.67						3		6					7		
780cm	A2430.68						7		6					18		
790cm	A2430.69						6		5					13		
800cm	A2430.70						3		3					13		

CREEL BAY

OSTRACODE OCCURRENCES
CREEL BAY

Depth of Sample	UND Accession Number	Species Code 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0cm																
10cm																
20cm	A2431.01								1							
30cm	A2431.02						1							1		
40cm	A2431.03						39		26				1	16		
50cm	A2431.04						63		44		10			28		
60cm	A2431.05						2		6							1
70cm	A2431.06						6		1		5			10		
80cm	A2431.07						1							2		
90cm	A2431.08								1		1			2		
100cm	A2431.09						9		9							
110cm																
120cm	A2431.10						1									
130cm	A2431.11						4		3							
140cm																
150cm	A2431.12						8		3					2		
160cm																
170cm																
180cm																
190cm																
200cm																
210cm																
220cm																
230cm																
240cm	A2431.13						19		17					5		
250cm																
260cm	A2431.14						22		15					8		
270cm																
280cm																
290cm																
300cm																

OSTRACODE OCCURRENCES
CREEL BAY

Depth of Sample	UND Accession Number	Species Code 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
310cm																
320cm																
330cm	A2431.15						4		4					2		
340cm	A2431.16						5									
350cm	A2431.17						7		6					3		
360cm																
370cm																
380cm	A2431.18						9		14					1		
390cm	A2431.19						1		3							
400cm	A2431.20						6		4							
410cm																
420cm																
430cm																
440cm																
450cm	A2431.21						5		1		1			1		
460cm																
470cm	A2431.22						41		33					7		
480cm	A2431.23						6		5					5		
490cm																
500cm	A2431.24						15		11		1					
510cm																
520cm	A2431.25								7					2		
530cm	A2431.26						3		5					3		
540cm	A2431.27						8		14					8		
550cm	A2431.28						15		16					2		2
560cm																
570cm																
580cm	A2431.29						1									
590cm																
600cm																

OSTRACODE OCCURRENCES
CREEL BAY

Depth of Sample	UND Accession Number	Species Code 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
610cm																
620cm	A2431.30						34		30					4		
630cm	A2431.31						12		12					1		
640cm	A2431.32						7		2							
650cm	A2431.33						18		13							
660cm																
670cm																
680cm																
690cm																
700cm																
710cm																
720cm	A2431.34						17		9					15		
730cm																
740cm																
750cm	A2431.35						23		28							
760cm	A2431.36						42		32					6		
770cm	A2431.37						18		11					2		
780cm																
790cm	A2431.38						6		15					3		
800cm																
810cm																
820cm	A2431.39						5		6							
830cm	A2431.40						17		23		1			2		
840cm	A2431.41						12		6		1					
850cm																

EAST DEVILS LAKE

OSTRACODE OCCURRENCES
EAST DEVILS LAKE

Depth of Sample	UND Accession Number	Species code 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0cm																
10cm	A2432.01						7		3					2		
20cm	A2432.02						52		43					11		
30cm	A2432.03						31		19					5		
40cm	A2432.04						199		106		3			58		
50cm	A2432.05						52		53					18		
60cm	A2432.06						45		35					26		
70cm	A2432.07						20		9					4		
80cm	A2432.08						17		23		1			2		
90cm	A2432.09						21		33					3		
100cm	A2432.10						20		15					2		
110cm	A2432.11						21		22					10		
120cm	A2432.12						9		13					1		
130cm	A2432.13						53		49					5		
140cm	A2432.14						75		92					55		
150cm	A2432.15						36		32					31		1
160cm	A2432.16						5							5		3
170cm	A2432.17						30		27					4		
180cm	A2432.18						13		14					3		
190cm	A2432.19						30		12					3		
200cm	A2432.20						44		47					9		
210cm	A2432.21						11		4					14		
220cm	A2432.22						18		13					4		
230cm	A2432.23						30		16		2			22		14
240cm	A2432.24						135		140		20			158		40
250cm	A2432.25						18		12					9		
260cm	A2432.26						95		86					4		
270cm	A2432.27						45		31					1		
280cm	A2432.28						42		59					52		
290cm	A2432.29						29		44		2			43		
300cm	A2432.30													12		63

OSTRACODE OCCURRENCES
EAST DEVILS LAKE

Depth of Sample	UND Accession Number	Species code 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
310cm	A2432.31						42		30		2			78		
320cm	A2432.32						43		48					15		
330cm	A2432.33						20		25					8		
340cm	A2432.34						126		176		10			198		
350cm	A2432.35						18		16					24		
360cm	A2432.36						27		56					2		
370cm	A2432.37						13		13					8		
380cm	A2432.38						17		19					2		1
390cm																
400cm	A2432.39						4		3							
410cm	A2432.40						31		15		2			14		
420cm	A2432.41						34		34					23		
430cm	A2432.42						5		5					4		
440cm	A2432.43						2		2							
450cm	A2432.44						1		1							
460cm																
470cm																
480cm																
490cm	A2432.45						27		29		2			15		
500cm	A2432.46						22		21					10		
510cm	A2432.47						12		13					1		
520cm																
530cm																
540cm																
550cm																
560cm																

RED WILLOW LAKE

OSTRACODE OCCURRENCES
Red Willow Lake

Depth of Sample	UND Accession Number	Species code 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0cm	A2433.01					12						30				
10cm	A2433.02					12						12				
20cm	A2433.03					18						6				
30cm	A2433.04					20						12				
40cm	A2433.05	2	2			18	2					12				
50cm	A2433.06	22		8	6	60	46			22		8			4	
60cm	A2433.07	10		2		40	4			12						
70cm	A2433.08	8				34	17			22					2	
80cm	A2433.09					2										
90cm	A2433.10					9				4						
100cm																
110cm																
120cm																
130cm																
140cm																
150cm	A2433.11	10				46				26		16				
160cm	A2433.12					6				22						
170cm	A2433.13	4				30				36		20				
180cm	A2433.14	4				36				16						
190cm	A2433.15					3										
200cm	A2433.16					12				8						
210cm																
220cm																
230cm																
240cm																
250cm																
260cm																
270cm																
280cm																
290cm	A2433.17									6						
300cm	A2433.18									6						

OSTRACODE OCCURRENCES
RED WILLOW LAKE

Depth of Sample	UND Accession Number	Species Code 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
310cm	A2433.19									10						
320cm	A2433.20					2				3						
330cm																
340cm	A2433.21					10				8						
350cm																
360cm	A2433.22									10						
370cm	A2433.23					7				5						
380cm	A2433.24					9				5		3				
390cm	A2433.25									2						
400cm																
410cm																
420cm	A2433.26					6										
430cm																
440cm	A2433.27				4	36				6		4			6	
450cm	A2433.28					30				4		3				
460cm	A2433.29	2				24				10		3				
470cm	A2433.30				32	284	48		20	80		24			102	
480cm	A2433.31					50	14		12	8						
490cm	A2433.32					10	28		20							
500cm	A2433.33				4	194	32		28	6					10	
510cm	A2433.34					19			4	3						
520cm	A2433.35					58	32		20						12	
530cm	A2433.36					86	22		32	4		10			20	
540cm	A2433.37					72	22		30	14		4			12	
550cm	A2433.38					172		8	16	68		8			36	
560cm	A2433.39					15	15		15	6						
570cm	A2433.40					120	14		28	14						
580cm	A2433.41					70				12		8			18	
590cm	A2433.42					84				20						
600cm	A2433.43					104				48						

OSTRACODE OCCURRENCES
RED WILLOW LAKE

Depth of Sample	UND Accession Number	Species code 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
610cm	A2433.44					33	6		10							
620cm	A2433.45				4	229	34		62							
630cm	A2433.46					56			10							
640cm	A2433.47	12				218	40	8	56	16					8	
650cm	A2433.48					64	12			16		8				
660cm	A2433.49					112			8	24		6				
670cm	A2433.50					154	20	6	20	34		22				
680cm	A2433.51					118	24		18	8						
690cm	A2433.52					84	16		32							
700cm	A2433.53					84	16		102							
710cm	A2433.54				16	64	32		20							
720cm	A2433.55	16	8			48	12		20							
730cm	A2433.56				18	96	36		36							
740cm	A2433.57				16	40	28									
750cm	A2433.58				6	58	40		72							

APPENDIX V

CORE LOCATIONS

CORE LOCATIONS

All locations in this appendix are indicated on Figure 1, and correspond to the accession numbers in Appendix IV.

Main Bay Core

Core located in NE¼ NW¼ sec. 35, T. 153 N., R. 65 W., center of Main Bay of Devils Lake, 7 mi SW of Devils Lake, Ramsey Co., North Dakota. Univ. N. Dak. accession numbers A2430.01-A2430.70, J. B. Van Alstine, 26 January 1976. Ostracods collected from throughout 800-cm-long core (Appendix IV).

Creel Bay Core

Core located in SE¼ SW¼ sec. 12, T. 153 N., R. 65 W., center of Creel Bay of Devils Lake, 7 mi SW of Devils Lake, Ramsey Co., North Dakota. Univ. N. Dak. accession numbers A2431.01-A2431.41, J. B. Van Alstine. 29 August 1975. Ostracods collected from throughout 805-cm-long core (Appendix IV).

East Devils Lake Core

Core located in NE¼ SE¼ sec. 19, T. 152 N., R. 62 W., center of bay of East Devils Lake, 6 mi S of Crary, Ramsey Co., North Dakota. Univ. N. Dak. accession numbers A2432.01-A2432.47, J. B. Van Alstine. 17 August 1978. Ostracods collected from throughout 560-cm-long core (Appendix IV).

Red Willow Lake Core

Core located in SE¼ SE¼ sec. 12, T. 148 N., R. 61 W., center of Red Willow Lake, 6.0 mi N of Binford, Griggs Co., North Dakota. Univ. N. Dak. accession numbers A2433.01-A2433.58, J. B. Van Alstine. 30 December 1979. Ostracods collected from throughout 750-cm-long core (Appendix IV).

REFERENCES

REFERENCES

Anderson, D. W., and Armstrong, R., 1966, Zooplankton-phytoplankton relationships in Devils Lake, North Dakota: North Dakota Academy of Science Proceedings, v. 20, p. 158-168.

Armstrong, R., Anderson, D. W., and Callender, E., 1966, Primary productivity measurements at Devils Lake, North Dakota: North Dakota Academy of Science Proceedings, v. 20, p. 136-149.

Aronow, S., Dennis, P. E., and Akin, P. D., 1953, Geology and ground-water resources of the Minnewaukan area, Benson County, North Dakota: North Dakota Ground-water Studies 19, 125 p.

_____1955, Problems in Late Pleistocene and recent history of the Devils Lake region, North Dakota: University of Wisconsin unpublished Ph.D. dissertation, 123 p.

_____1957, On the postglacial history of the Devils Lake region, North Dakota: Journal of Geology, v. 65, p. 410-427.

_____1963, Late Pleistocene glacial drainage in the Devils Lake region, North Dakota: Geological Society of America Bulletin, v. 74, p. 859-874.

Babcock, E. J., 1902, Water resources of the Devils Lake region: North Dakota Geological Survey 2d Biennial Report, p. 208-250.

Baird, W., 1835, List of Entomostraca found in Berwickshire: Berwickshire Naturalist's Club, v. 1, p. 95-100.

_____1843, Notes on British Entomostraca: Zoologist, p. 193-197.

_____1845, Arrangement of British Entomostraca, with a list of species, particularly noticing those which have as yet been discovered within the bounds of the club: Berwickshire Naturalists Club (History), Proceedings 2.

_____1846, Description of some new genera and species of British Entomostraca: Annual Magazine of Natural History, Ser. 1, v. 17, p. 410-416.

_____1850, Description of several new species of Entomostraca: Proceedings of the Zoological Society of London, v. 18, p. 254-257.

Benson, R. H., and Berdan, W., 1961, The Treatise on Invertebrate Paleontology, Part Q, Arthropoda 3, Crustacea, Ostracoda: Geological Society of America and the University of Kansas Press, 422 p.

Benson, R. H., and MacDonald, H. C., 1963, Postglacial (Holocene) ostracods from Lake Erie: University of Kansas Paleontology Contributions, Article 4, p. 1-26.

Bluemle, J. P., 1967a, Multiple drifts in northeast North Dakota: North Dakota Geological Survey Miscellaneous Series, v. 30, p. 133-136.

_____1971, Geology and groundwater resources of McLean County, North Dakota, Part 1, Geology: North Dakota Geological Survey Bulletin, v. 60, 65 p.

_____1975, Geology and groundwater resources of Griggs and Steele Counties, North Dakota, Part 1, Geology: North Dakota Geological Survey Bulletin, v. 64, 50 p.

_____1977, The face of North Dakota. The geological story: North Dakota Geological Survey Educational Series 11, 73 p.

_____Anderson, S. B., and Carlson, C. G., 1980, North Dakota Stratigraphic column: North Dakota Geological Survey.

Brady, G. S., 1868a, A synopsis of the recent British Ostracoda: Intellectual Observer, v. 12, p. 110-130.

_____1868b, A monograph of the recent British Entomostraca: Linnean Society Transactions 46, pt. 2, sec. 9, p. 353-495.

_____1870, Notes on Entomostraca taken chiefly in the Northumberland and Durham District: Transactions of the Society of Natural History Northumberland and Durham, v. 3, p. 316-373.

_____1886, Notes on Entomostraca collected by Mr. A. Haly in Ceylon: Linnean Society of Zoology 19, no. 114, pt. 2, v. 2, p. 293-316.

_____and Robertson, D., 1869, Notes on a week's dredgings in the west of Iceland: Annual Magazine of Natural History, ser. 4, v. 3, p. 353-374.

_____and Norman, A. M., 1889, A Monograph of the marine and fresh water Ostracoda of the North Atlantic and of Northwestern Europe: Royal Dublin Society of Science Transactions 4, pt. 2, ser. 2, p. 63-270.

Brillouin, L., 1962, Science and Information Theory (2d ed.): New York, Academic Press, 474 p.

Bronstein, Z. S., 1930, Beitrage zur Kenntris der Ostracoden Fauna des Baikal Sees: Trau. Comm. e'tude Lac. Bajkal, v. 3, p. 117-157.

_____1947, Fauna de l'urss Crustaces, ostracodes des eaux douce: Institute Zoology Academy of Science URSS 2, v. 1, p. 1-339.

Brown, S. R., 1956, A piston sampler for surface sediments of lake deposits: Ecology, v. 37, p. 611.

Callender, E., 1968, The postglacial sedimentology of Devils Lake, North Dakota: University of North Dakota unpublished Ph. D. dissertation, 312 p.

_____and Armstrong, R., 1966, A preliminary study of some calcium mineral equilibria in the water-sediment system of Devils Lake, North Dakota: North Dakota Academy of Science Proceedings, v. 20, p. 157-158.

Clayton, L., Moran, S. R., and Bluemle, J. P., 1980, Explanatory text to accompany the Geologic Map of North Dakota: North Dakota Geological Survey Report of Investigations No. 69, 93 p.

_____Moran, S. R., Bluemle, J. P., and Carlson, C. G., 1980, Geologic Map of North Dakota: North Dakota Geological Survey.

Cole, G. A., 1949, A new cytherid ostracode from Minnesota: American Microscopical Society Transactions, v. 68, p. 350-354.

Colinvaux, P. A., 1964, Sampling stiff sediments of an ice covered lake: Limnology and Oceanography, v. 9, p. 262-264.

Daday, J., 1900, A Magyarorszagi Kagylosrakok Maganrajza, Ostracoda Hungariae: Budapest Magyar Tudomanyos Akas, p. 1-320.

Delorme, L. D., 1967a, Freshwater ostracode synonyms: Journal of Paleontology, v. 41, p. 792-794.

_____1967b, New freshwater ostracoda from Saskatchewan, Canada: Canadian Journal of Zoology, v. 45, p. 357-363.

_____1969, Ostracodes as paleoecological indicators: Canadian Journal of Earth Sciences, v. 6, p. 1471-1476.

_____1970a, Freshwater ostracodes of Canada, Part I. Subfamily Cypridinae: Canadian Journal of Zoology, v. 48, p. 153-168.

_____1970b, Freshwater ostracodes of Canada, Part II. Subfamily Cypridopsinane and Herpetocypridinae and Family Cyclocypridae: Canadian Journal of Zoology, v. 48, p. 253-266.

_____1970c, Freshwater ostracodes of Canada, Part III. Family Candonidae: Canadian Journal of Zoology, v. 1099-1129.

_____1970d, Freshwater ostracodes of Canada, Part IV. Families Ilycyprididae, Notodromadidae, Darwinulidae, Cytherideidae, and Entocytheridae: Canadian Journal of Zoology, v. 48, p. 1251-1259.

_____1971a, Freshwater ostracodes of Canada, Part V. Families Limnocytheridae, Loxoconchidae: Canadian Journal of Zoology, v. 49, p. 43-64.

_____1971b, Paleoecological determinations using Pleistocene freshwater ostracodes: Bull Centre Rech Pau, p. 314-347.

_____1971c, Paleoecology of Holocene sediments from Manitoba using freshwater ostracodes: Geological Association of Canada Special Paper 9, p. 301-304.

Ferguson, E., 1959, A synopsis of the ostracoda (Crustacea) genus Cypridopsis with the description of a new species: Biological Society of Washington Proceedings, v. 72, p. 39-68.

Furtos, N. C., 1933, The Ostracoda of Ohio: Ohio Biological Survey Bulletin 29, v. 5, p. 413-524.

Green, R. H., 1969, Population dynamics and environmental variability: American Zoology, v. 9, p. 393-398.

Gutentag, E. D., and Benson, R. H., 1962, Neogene (Plio-Pleistocene) freshwater ostracodes from the Central High Plains: State Geological Survey of Kansas, Bulletin, v. 157, p. 1-64.

Hoff, C. C., 1942, The ostracods of Illinois, their biology and taxonomy: Illinois Biological Monographs, v. 19, p. 1-196.

Jaccard, P., 1908, Nouvelles recherches sur ia distribution florale: Bulletin Society Vaud Science and Nature, v. 44, p. 223-270.

Jurine, L., 1820, Histoire des Monocles, que se Trouvent aux Environs de Geneve: 206 p.

Kaufmann, A., 1900a, Cypriden und Darwinuliden der Schweiz: Review Suisse Zoologie, v. 8, p. 209-423.

_____1900b, Neue ostracoden aus der Schweiz: Zoologie Anz. v, 23, 131-133.

_____1900c, Zur Systematik der Cypriden: Naturf. Gesell. Bern. Mitt, no., 1476, p. 103-109.

Klassen, R. W., Delorme, L. D., and Mott, R., 1967, Geology and paleontology of Pleistocene deposits in southwestern Manitoba: Canadian Journal of Earth Science, v. 4, p. 433-447.

Koch, C. L., 1837b, Deutschlands Crustacean, Myriapoden und Arachniden. Ein Beitrag zur deutschen fauna: Regensburg, Pustet, Heft 12, Species 1-5.

_____1838, Deutschlands Crustacean Myriapoden und Arachniden. Ein Beitrag zur deutschen fauna: Regensburg, Pustet, Heft 12, species 12-24.

_____1841, Deutschlands Crustacean, Myripoden und Arachniden. Ein Beitrag zur deutschen fauna: Regensburg, Pustet, Heft 36, Species 17-19.

Kontrovitz, M., 1967, An investigation of ostracode preservation: Quarterly of the Florida Academy of Science Journal, v. 29, p. 171-177.

Kullenberg, B., 1947, The piston core sampler: Svensk Hydrografisk Biologiska Komm. Skr. ser. 3, Hydrografi v. 1, no. 2.

Larson, D. W., 1968, The occurrence of neotenic salamanders Ambystoma-tigrinum Diaboli in Devila Lake, North Dakota USA: Copeia, v. 928, p. 620-621.

_____1972, Size and coloration characteristics of neotenic salamanders in Devils Lake, North Dakota USA: Prairie Naturalist, v. 4, p. 77-80.

Lichtwardt, R. W., 1952, A new light-weight shaft for peat samplers: Paleobotanist, v. 1, p. 317-318.

Liljeborg, W., 1853, De Crustaceis en ordinibus tribus Cladocera, Ostracoda et Copepoda in Scania occurrentibus, Lund, Berlingske: Boktryck, p. 1-223.

Lister, K. H., 1974, Paleoecology of Ostracoda from Quaternary sediments of the Great Salt Lake Basin, Utah: University of Kansas unpublished Ph.D. dissertation, 380 p.

_____1975, Quaternary freshwater ostracoda from the Great Salt Lake Basin, Utah: Kansas Paleontological Contributions, Paper 78, p. 1-39.

Livingston, D. A., 1955, A lightweight piston sampler for lake deposits: Ecology, v. 36, p. 137.

MacArthur, R. H., 1955, Fluctuations of animal populations as a measure of community stability: Ecology, v. 35, p. 533-536.

Margalef, R., 1958, Information theory in ecology: General Systems. v. 3, p. 36-71.

_____1963, On certain unifying principles in ecology: American Naturalist, v. 92, p. 357-374.

Mercil, S. B., Conway, C. M., and Shubert, L. E., 1980, Phosphorus stability in a hypereutrophic lake: In Hypereutrophic Ecosystems (Mur, L.) ed. Dr. W. Junk b.v. Publishers, The Hague, The Netherlands.

Metcalf, F. P., 1931, Wild duck foods of North Dakota lakes: U.S. Department of Agriculture Technical Bulletin, v. 221, p. 1-72.

Müller, G. W., 1900, Deutschlands Susswasser-ostracoden: Zoologica, 12, Heft 30, p. 1-112.

_____1912, Ostracoda In das Tierreicn: Edited by F. E. Schultz, Berlin, Frielander un Sohn, Lief 31, p. 1-434.

Müller, O. F., 1776, Zoologiae danicae prodramus, sev animalium, daniae et norvegiae inoigenarum characteres, nomina et Sinonyma imprimis popularium Lipsiae et Hauniae. 228 p.

_____1785, Entomostraca sev Insecta Testacea, quae inaquis Daniae et Norvegiae reperit, descripsit et inconibus illustrauit: Hauniae, Typis Thiele p. 48-67.

Neel, J. K., Vennes, J. W., Anderson, D. W., Knauss, J. D., and Buchli, G. L., 1970, The Limnobiochemistry of Devils Lake, North Dakota: U. S. Government Research Development Report, v. 70, no. 8.

Nerhus, P. T., 1920, A study of the solubility relations of the salts in Devils Lake water: University of North Dakota unpublished M.S. thesis, 44 p.

Nicollet, J. N., 1843, Report intended to illustrate a map of the hydrographical basin of the Upper Mississippi River: U. S. 26th Congress 2d Session, Senate Document, v. 237, p. 42-53.

Owen, J. B., Anderson, R., Armstrong, P., and Callender, E., 1973, The Biogeochemistry of Devils Lake, North Dakota: Water Resources Research Institute Technical Completion report, 93 p.

Paulson, Q. F., and Akin, P. D., 1964, Groundwater resources of the Devils Lake area, Benson, Ramsey and Eddy Counties, North Dakota: North Dakota Groundwater Studies 56, 211 p.

Pianka, E. R., 1966, Latitudinal gradients in species diversity; A review of concepts: American Naturalist, v. 100, p. 33-46.

Pope, T. E., 1909, Devils Lake, North Dakota, a study of the physical and biological conditions with a view to acclimitization of fish: U.S. Bureau of Fisheries Document 634.

Raup, D. M. and Crick, R. E., 1979, Measurement of faunal similarity in paleontology: Journal of Paleontology, v. 53, p. 1213, 1227.

Rowley, J. R., and Dahl, O. H., 1956, Modifications in design and use of the Livingston piston sampler: Ecology, v. 37, p. 849.

Sars, G. O., 1863, Beretning om en isommeren 1862 foretagen zooligisk reise i Christianias or Trondhjems stifter: Nyt. Mag. Natur., v. 12, p. 218-223, 249, 252.

Scott, T., 1906, A catalogue of land, freshwater, and marine Crustacea found in the basin of the River Forth and its estuary, Part 2. The Ostracoda, Copepoda, and Cirripedia: Royal Physics Society of Edinburg Proceedings, v. 16, p. 267-382.

Scott, W. H., 1961, The Treatise on Invertebrate Paleontology, Part Q, Arthropoda Volume 3, Ostracoda. R. C. Moore ed., The Geological Society of America and the University of Kansas Press, 422 p.

Shaak, G. D., 1975, Diversity and community structure of the Brush Creek Marine Interval (Conemough Group, Upper Pennsylvanian), in the Appalachian Basin of Western Pennsylvania: Florida State Museum of Biological Science Bulletin, v. 19, p. 69-133.

_____and Franz, R., 1977, Faunal succession and environments of deposition of Pleistocene Lake Buffalo, Northwestern Oklahoma: Oklahoma Geology Notes, p. 175-190.

Sharpe, R. W., 1903, Report of the freshwater ostracoda of the United States National Museum, including a revision of the Subfamilies and Genera of the Family Cyprididae: U. S. National Museum Proceedings, v. 26, p. 969-1001.

Shubert, L. E., 1976, Investigations of the algal growth potential of Devils Lake, North Dakota: U.S. Department of Interior Bureau of Reclamation Report, 150 p.

_____1978, The algal growth potential of an inland saline and eutrophic lake: Mitt International Verein Limnology, v. 21, p. 555-574.

Simpson, E. H., 1949, Measurement of Diversity: Nature, v. 163, p. 688.

Simpson, G. G., 1943, Mammals and the nature of continents: American Journal of Science, v. 241, p. 1-31.

Simpson, H. E., 1912, Physiography of the Devils-Stump Lake region: North Dakota Geological Survey, 6th Biennial Report, p. 101-157.

_____1929, Geology and groundwater resources of North Dakota: U. S. Geological Survey Water-supply Paper 598, 312 p.

Sokal, R. P., and Sneath, P. H. A., 1963, Principles of numerical taxonomy: Freeman, San Fransisco, 359 p.

Staplin, F. L., 1963a, Pleistocene Ostracoda of Illinois, Part I. Subfamilies Candoninae, Cyprinae, General Ecology, Morphology: Journal of Paleontology, v. 37, p. 758-797.

_____1963b, Pleistocene Ostracoda of Illinois, Part II. Subfamilies Cyclocyprinae, Cypridopinae, Ilyocyprinae, Families Darwinulidae, and Cytheridae. Stratigraphic ranges and assemblage patterns: Journal of Paleontology, v. 37, p. 1164-1203.

Stinemeyer, E. H., 1965, Microfossil vacuum-needle segregating pick: in Kummel, B. and Raup, D., eds. Handbook of Paleontological Techniques: W. H. Freeman and Co., San Fransisco, 852 p.

Stoermer, E. F., Taylor, S. M., and Callender, E., 1971, Paleoecological interpretations of the Holocene diatom succession in Devils Lake, North Dakota: Transactions of the American Microscopical Society, v. 90, p. 195-206.

Swain, F. M., 1947, Tertiary nonmarine Ostracoda from the Salt Lake Formation, Northern Utah: Journal of Paleontology, v. 21, p. 518-528.

_____1961, Ostracoda from the Pleistocene Gubik Formation, Arctic coastal plain, Alaska: in Geology of the Arctic. Volume 1, Raasch, G. O., ed., University of Toronto Press, Toronto, p. 600-606.

Swenson, H. A., and Colby, B. R., 1955, Chemical quality of surface waters in Devils Lake Basin, North Dakota: U. S. Geological Survey Water-supply Paper 1295, 82 p.

Tressler, W. K., 1957, The Ostracoda of Great Slave Lake: Washington Academy of Science Journal, v. 47, p. 415-423.

_____1959, Ostracoda: In. Fresh-water Biology. Edmonston, E. T., ed. John Wiley and Sons, New York, p. 657-734.

Upham, W., 1895, The glacial Lake Agassiz: U. S. Geological Survey Monograph 25, 658 p.

Valentine, J. W., 1973, Evolutionary paleoecology of the marine biosphere: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 498 p.

Vallentyne, J. R., 1955, A modification of the Livingston piston sampler for lake deposits: Ecology, v. 36, p. 139.

VanMorkhoven, F. P. C. M., 1963, Post-Paleozoic Ostracoda, Volumes I and II: Elsevier Publishing Company, 270 p.

Vavra, W., 1891b, Monographie der Ostracoda Bohmens: Archiv naturw. Landesduren forschung Bohmen, v. 8, p. 1-118.