The Ecology of the Zooplankton Community of a Small Quarry Pond with Special Reference to the Rotifers

Leo J. Curro

The College at Brockport

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The Ecology of the Zooplankton Community of a Small Quarry Pond with Special Reference to the Rotifers

by

Leo J. Curro

B.S., Heidelberg College, 1964

Submitted to the Faculty of the Department of Biological Sciences in partial fulfillment for the degree of Master of Science in Zoology

State University of New York College at Brockport

1972
The author wishes to express his indebtedness to Dr. Robert R. Costa, for his support and direction throughout this investigation and the writing of the thesis.

Gratitude is also extended to the other members of the committee, Dr. Delmont C. Smith and Dr. Harold V. Kibby, for their advice and suggestions.

This thesis is dedicated to my wife, Kathy, without whose patience and encouragement it would not have been possible.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Foreword</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>A. The Study Area</td>
<td>2</td>
</tr>
<tr>
<td>B. Literature Review</td>
<td>3</td>
</tr>
<tr>
<td>1. Abiotic Factors</td>
<td>5</td>
</tr>
<tr>
<td>2. Biotic Factors</td>
<td>8</td>
</tr>
<tr>
<td>II. METHODS AND MATERIALS</td>
<td>14</td>
</tr>
<tr>
<td>Zooplankton Methods</td>
<td>14</td>
</tr>
<tr>
<td>1. Sampling Procedures</td>
<td>14</td>
</tr>
<tr>
<td>2. Counting Procedures</td>
<td>15</td>
</tr>
<tr>
<td>Identification</td>
<td>16</td>
</tr>
<tr>
<td>B. Physical and Chemical Methods</td>
<td>16</td>
</tr>
<tr>
<td>III. Results</td>
<td>18</td>
</tr>
<tr>
<td>A. Physical and Chemical Data</td>
<td>18</td>
</tr>
<tr>
<td>1. Temperature</td>
<td>18</td>
</tr>
<tr>
<td>2. Dissolved Oxygen</td>
<td>19</td>
</tr>
<tr>
<td>Other Parameters</td>
<td>20</td>
</tr>
<tr>
<td>4. Diurnals</td>
<td>22</td>
</tr>
<tr>
<td>B. Zooplankton Data</td>
<td>24</td>
</tr>
<tr>
<td>1. Rotifers</td>
<td>24</td>
</tr>
<tr>
<td>2. Crustaceans</td>
<td>26</td>
</tr>
<tr>
<td>IV. DISCUSSION</td>
<td>29</td>
</tr>
<tr>
<td>V. SUMMARY</td>
<td>41</td>
</tr>
</tbody>
</table>
APPENDIX A (TABLES) .............................. 45
APPENDIX B (FIGURES) ................................. 108
LITERATURE CITED ........................................... 121
I. INTRODUCTION

The pond habitat is a dynamic system with constant fluctuations in its abiotic and biotic components. These fluctuations are often intensified by the small volume of water usually characteristic of ponds. This often produces a greater instability in pond communities as compared to lakes (Elgmark, 1964).

A detailed study of populations may provide considerable information regarding factors affecting the ecology of pond biota. In this investigation, individual zooplankton populations in a quarry pond were studied from April 6, 1971 to November 17, 1971. Special emphasis was directed toward the rotifer community.

The immediate objective of this investigation was to study the ecological factors that operate within a pond environment and to attempt to ascertain how they affect the biota. This was done by recording the seasonal patterns of each zooplankton population; documenting vertical distribution patterns within the zooplankton community; and by gathering quantitative data on seasonal physical and chemical changes of the pond. It is hoped that information resulting from this investigation may provide a better insight into the responses of populations
to environmental conditions which often produce physiological stress.

A. The Study Area

The study site was a small, limestone quarry pond, 2.6 miles west of Holley, New York on Route 31 in Orleans County. Limestone extraction in the early part of this century had created the quarry, which had since been abandoned.

The quarry measured approximately 46 meters (east to west) by 44 meters (north to south) and had a surface area that covered 0.20 acres (Fig. 1). The pond was shallow with depths ranging between 2.30 meters in the spring and 1.28 meters in the fall.

The steep sides of the pond and its relatively flat, rock-bottom substrate provided little opportunity for rooted vegetation. The littoral zone, prevalent in most ponds, was almost non-existent. However, in the late summer, the water receded enough to expose a small shelf in the south-eastern corner of the pond, where some rooted vegetation appeared.

Welch (1935) defined a pond as a small, shallow body of standing water, with extensive growth of higher aquatic plants. The quarry pond differed from Welch's definition in that it had very little rooted aquatic vegetation; instead, there was a relatively large open-
water area. Thus the quarry had the major characteristics of a small pond, except for the higher aquatic plants. A relatively large open-water zone existed and provided an excellent opportunity for the study of zooplankton.

B. Literature Review

In the early part of this century, Scott (1910), Allee (1912), Kreker (1919) investigated the zooplankton communities of ponds in central United States. Scott (1910) and Allee (1912) investigated most of the invertebrate community for occurrences of population maxima. Kreker (1919) compared population differences, both quantitatively and qualitatively, in quarries of different ages. List (1915) investigated pond zooplankton in Germany and noticed the irregular patterns of occurrence exhibited by many zooplankters. Nordquist (1921), working in Swedish ponds, concentrated on zooplankton exclusively. Included in his investigations were population changes in several species of rotifers.

In 1926, Peterson attempted to find seasonal patterns for the commonly-occurring invertebrates in a Chara-cat-tail pond. Samples were taken in both the littoral and the small open-water zone of a pond near the southern end of Lake Michigan.

Two limestone quarry ponds in Wisconsin were exam-
ined by Wimmer (1929). He noted variations in the zoo-
plankton and phytoplankton communities. Several abiotic
components of the pond community were also studied.

In Denmark, Wesenberg-Lund (1930), in his monumen-
tal investigation of the sexual period in rotifers, also
investigated the qualitative and quantitative differences
between rotifer species of lakes and those of small ponds.

Kreutner (1934) mentioned in his studies of pond zoo-
plankton in Germany that fluctuations in population den-
sities were influenced by temperature.

Investigations into the relationships of small pond
organisms and their abiotic environment were undertaken
by Griffiths (1936) in England, and by Ward (1940) in the
United States. Griffiths (1936) observed the periodicity
and distribution of the numerically dominant zooplankton
species in a shallow field pond. Ward (1940) concen-
trated on the crustacean population fluctuations of three
closely situated ponds in Ohio.

Hasler and Jones (1949) working with experimental
ponds studied the effect of vascular plants on the occur-
rence and abundance of zooplankton and phytoplankton.

More recently, Smyly (1957) studied the seasonal abun-
dance of crustaceans in moorland ponds in England. A com-
parison was made between the numbers and kinds of species
of the littoral and limnetic zones.

Pejler (1957) made comparisons of rotifers living
in ponds and lakes in Swedish Lapland. Included in this study were observations of diversity and number of rotifers in alpine and subalpine ponds.

An intensive investigation of zooplankton dynamics in four ponds in close proximity was completed by Elgmork (1964) in Norway. The relationships between population fluctuations for both crustaceans and rotifers were observed. Elgmork (1964) also compared organisms found in the ponds with those found in nearby rivers and lakes.

1. Abiotic Factors

Fluctuations in the physical and chemical conditions in small ponds are extensive, and can occur within short periods of time. Water temperatures often vary considerably over a one-year period. Ranges of 25°C are not uncommon (Peterson, 1926; Wimmer, 1929; Wesenberg-Lund, 1930; Ward, 1940). In India, where atmospheric temperature ranged between 6°C and 40°C, Seenayya (1971) recorded a water temperature range of 31°C.

Griffiths (1936) sampled two levels of a small English pond that was three meters deep, to determine the effect of wind velocity on temperature uniformity. He found that complete uniformity of temperature was rapidly brought about by mixing, even in light breezes. When differences in temperature between the surface and bottom
levels did appear, the changes were gradual, and no strati-
fication was evident. However, in summer a slight ten-
dency toward stratification did occur.

All pond investigators who recorded both air and
water temperatures, reported a close parallel between them. Ward (1940) noted that of all the abiotic factors moni-
tored within three ponds of close proximity, water tem-
perature was the most variable. Weekly temperature dif-
ferences of 6° C. were not uncommon in the spring months.

The amount of dissolved oxygen in pond waters can
be related to both abiotic and biotic factors. However,
Griffiths (1936), Ward (1940) and Whitney (1942) contended
that in small ponds the biotic influences usually play
the major role in oxygen changes. Ward (1940) detected
dissolved oxygen values from 1.68 to 25.0 parts per mil-
lion. The latter value was recorded when the pond was
a "dull grass green" color due to a bloom of the flagel-
late Cryptoglena.

Quantities of dissolved oxygen ranging from super-
saturation to almost complete depletion were also recorded
by Griffiths (1936). Large increases in dissolved oxygen
coincided with algal blooms in the summer. Oxygen deple-
tion was thought to be caused by the decomposition of
organic substances in the mud substrate, and "the great
preponderance of zooplankton over phytoplankton." (Griffiths,
1936).
Whitney (1942) determined oxygen fluctuations over a twenty-four hour period. Conclusions drawn from this study indicated that "absorption" of oxygen from the air was a minor factor in the amount of dissolved oxygen in the pond. It was contended that the diurnal oxygen pulse was probably dependent on the intensity and penetration of light, water temperature, and the extent of oxygen consuming factors such as decomposition and respiration.

Whitney (1942) also noted the close parallel between oxygen and pH changes in the pond. He contended that photosynthetic activity increased the oxygen content and diminished the carbon dioxide, which in turn altered the pH values.

Seenayya (1971) completed an extensive investigation of buffer systems in ponds in India. It was found that fluctuations of pH were identical to those of the carbonate content, and varied inversely with fluctuations of the bicarbonates. An unusually high pH value (9.4) was recorded in one of the ponds during algal blooms. Seenayya (1971) mentioned that the algae probably withdrew CO₂ from HCO₃⁻, releasing OH⁻ ions into the water.

Jard (1940) noticed that fluctuations in pH over a early period were irregular and often extensive. In one pond, values ranged from 5.5 to 9.6, and six observations were above "available indicators". However, in
another pond the pH values were "remarkably constant" and varied no more than 0.5 units over several months.

2. Biotic Factors

Research on the diversity of pond zooplankton communities has been undertaken by several investigators. Pejler (1957) sampled alpine and subalpine lakes and ponds in the Swedish Lapland. A comparison of large and small bodies of water located at similar altitudes revealed that lakes had a greater number of species than ponds. As the size of the ponds decreased, the kinds and numbers of species also decreased.

In Denmark, however, Wesenberg-Lund (1930) found that pond zooplankton communities were more diverse than those of lakes. Elgmork (1964) also reported great diversity in Norwegian ponds. However, Elgmork (1964) noted that seasonal distributions in small ponds were characterized by a relatively large abundance of only a few species.

Yearly comparisons of pond and lake zooplankton populations reveal lake populations to be more stable. Lakes show more uniformity both quantitatively and qualitatively from year to year (Wesenberg-Lund, 1930; Pejler, 1957; Elgmork, 1964). It was also noted by Pejler (1957) and Wesenberg-Lund (1930) that yearly stability varied directly with the size of the body of water.

Compared with the wealth of information gathered on
lakes, relatively little information has been gathered concerning zooplankton seasonality in small ponds. Several different trends in the seasonal occurrences of zooplankters have been reported. Tendencies toward maximal populations in spring and fall with minimal populations in the summer were observed in ponds studied by Scott (1910), Peterson (1926), Kreutner (1934), and Elgmork (1964). A general reduction of zooplankton organisms in the fall with maximal populations occurring in late spring and early summer was detected by Nordquist (1921). Summer abundances of pond zooplankton have also been recorded. Griffiths (1936) found all plankton more abundant in summer, and Allee (1912) observed the greatest number of species in mid-summer.

After studying the occurrence of zooplankters in Ohio ponds, Ward (1940) categorized the organisms into four groups, according to their occurrence during the year. The four groups were: forms of constant occurrence, forms not constantly present but occurring without pronounced reference to season, forms with a tendency toward one or two periods of abundance but not limited to those seasons, and forms with rather sharply limited seasonal distribution.

Differing patterns of seasonal occurrence for the Copepoda, Cladocera and Rotifera have been observed by several pond investigators. Copepods were observed by Elgmork (1964) to be the most abundant zooplankters in
four ponds which he investigated. Of these, *Cyclops* populations were numerically dominant. *Cyclops* were more numerous in the cooler seasons, showing "extreme dominance" in spring and fall (Elgmork, 1964). Wimmer (1929) observed the maximal population of *Cyclops* in the fall. Ward (1940) found most *Cyclops* species were present throughout the year. In the investigation of an English pond, Griffiths (1936) detected very few copepods at any time during the year.

The Cladocera and Rotifera were the most abundant groups of zooplankters found by Griffiths (1936). Large numbers of Cladocera were also reported by Elgmork (1964). Their numbers were exceeded only by the Copepoda.

Most Cladocera genera were found in the cooler parts of the year, although some genera were found in the summer months. Ward (1940) and Nordquist (1921) noted high numbers in spring, while Wimmer (1929) and Scott (1910) reported largest numbers in the fall. *Daphnia* and *Bosmina* were the most frequently encountered cladocern genera in ponds studied by Elgmork (1964), Ward (1940), Griffiths (1936) and Nordquist (1921).

Elgmork (1964) and Nordquist (1921) found *Bosmina* to be more numerous in spring and early summer. Ward (1940) reported *Bosmina* occurrences intermittently throughout the year, with no preference for a particular season.

*Daphnia* occurred in such abundance during the summer
months in the pond investigated by Griffiths (1936) that "extensive clouds" were formed in the waters. Ward (1940) noted that Daphnia pulex was present throughout the year but that Daphnia longispina occurred only in the spring and fall.

Fewer investigations have been done on pond rotifer populations than have been done on crustacean populations. Many planktonic pond rotifers were found by Elgmork (1964) and Nordquist (1921) to occur in greatest numbers in the spring and fall, although a few species were abundant in the summer. The seasonal distribution of Synchaeta spp. reported by Elgmork (1964) was characterized by a sharp division between the cooler and warmer months. Spring and fall maxima occurred, but the genus was "totally absent" during the summer months.

Griffiths (1936) commented that rotifer populations, notably Keratella quadrata and Polyarthra spp., occurred in such great numbers in summer as to color the water. Nordquist (1921), Wesenberg-Lund (1930), Peijler (1957), and Elgmork (1964) found that Keratella cochlearis and Polyarthra spp. were the most frequently encountered rotifers both large and small ponds.

Temperature seems to play an important role in population fluctuations of pond communities. Peterson (1926), Ward (1940), and Elgmork (1964) noted that temperature probably the most important abiotic influence on the
dynamics of zooplankton communities. Elgmork (1964) mentioned the possible negative influence of high temperature as the cause of summer minimums in zooplankton populations. Peterson (1926) proposed that seasonal succession of animals was caused by temperature and water level conditions, while pH and dissolved oxygen were "accompanying rather than causal factors." Edmondson (1965), after an extensive study of the reproductive rates of three species of rotifers in the English Lake District, concluded that reproductive rates of all three rotifer species he studied "related strongly" to temperature.

Large numbers of planktonic crustacea were observed by Ward (1940) to live under very low dissolved oxygen conditions. Populations of Daphnia and Cyclops were found to live in ponds in which dissolved oxygen values were as low as 0.68 parts per million. These environments apparently never showed an oxygen content low enough to limit their existence. Ward (1940) therefore felt that oxygen was not a causal factor in their quantitative or qualitative distribution. Hazelwood and Parker (1960) observed that the minimum dissolved oxygen needed for the "survival" of Daphnia scudelari was approximately 1.0 milligram per liter. Pejler (1957) recorded that some species of rotifers were living in oxygen-deficient waters under the ice.

Biotic relationships between planktonic organisms have been reported in various pond studies. Elgmork (1954)
noticed that cladocerans and rotifers never occurred together in large numbers in the fall. Pejler (1957) never found two closely related species of rotifers living "side by side in waters which were extreme in some respect". He also found that the crustacean plankton populations "... on the whole has a better possibility of establishing itself than rotifer populations in extreme habitats." Ward (1940) observed an inverse relationship between density changes in Scaphaleberis and Daphnia populations.

Except for some observations by Wimmer (1929) vertical distribution of zooplankton in ponds has been virtually unstudied. Wimmer (1929) found that nauplii were most abundant at the surface, while Diaptomus and adult Cyclops most common at the 1.0 meter level. Daphnia was generally encountered at lower depths than Cyclops or Diaptomus.
II. METHODS AND MATERIALS

A. Zooplankton Methods

1. Sampling Procedures

Plankton samples were collected from April 6 to November 17 in order to obtain detailed information about the seasonal changes of the zooplankton community in the quarry pond. A number 20 mesh net with a mouth diameter of 23.5 cm. was towed along a permanently marked transect (Fig. 1). The net was bolted to a pole which was attached to the side of a small boat. The boat was then pulled along the rope which marked the permanent sampling area. The first series of tows were 18 meters long. These were extended to 27 meters on June 2, 1971 and became the standard for the remainder of the study.

Upon the completion of a tow, the net was lifted out of the water and the organisms were concentrated into a 30 ml. vial. The concentrated sample was then poured into a bottle and 20 ml. of filtered pond water was added to bring the total volume to 50 ml.

Throughout the study period, the sampling interval was held as closely as possible to three times a week, usually Mondays, Wednesdays and Fridays. Sixty-two percent of the samples were taken at two-day intervals.
Between April 6, 1971 and November 17, 1971 there were 86 sampling days. The surface, 0.5 meter, and 1.5 meter depths were sampled. For each depth duplicate tows were taken. 52 per cent of the sampling days. Ninety-one per cent of the samples were taken between 1:30 p.m. and 4:00 p.m.

2 Counting Procedures

Immediately after sampling the field samples were taken from the quarry to the Rancher Campus Laboratory, a trip taken approximately three minutes. All rotifers were counted live because of the difficulty of identifying some species after preservation. The crustaceans were preserved and counted at a later date.

The live count procedure was begun by carefully mixing the contents of a concentrated sample. This distributed the organisms so that they could be drawn off with a calibrated dropper (10 drops = 0.5 ml.). The first few drops of the subsample were squeezed back into the bottle. Then one drop was placed into a well of a pot plate. This procedure was followed until each of ten wells contained one drop of the concentrated sample.

An A O Spencer Binocular Microscope with variable magnification ranging from 20 X to 60 X was employed in counting and identifying the organisms in each well.
Upon the completion of the live counts, one to two milliliters of Congo Red stain and 95 per cent alcohol were added to the bottle, bringing each preserved sample to 100 ml. The Congo Red stain provided more reliable counting of preserved organisms. At a later date these preserved samples were counted in the same manner described above.

Throughout the year, six species of rotifers were frequently encountered. These were: Brachionus calyciflorus, Brachionus havanaensis, Euchlanis tricuetra, Rotaria neptunia, Synchaeta pectinata and Testudinella patina. Their identification was based upon the use of taxonomic keys of: Hudson and Gosse (1886), Rousselet (1902), Meyers (1930; 1941), Alhstrom (1940; 1943), and Edmondson (1959). Thirteen infrequently encountered rotifers, designated as "Other Rotifers" were also detected (Table 1). Their identifications were based upon keys of: Harring (1916), Harring and Meyers (1926), Alhstrom (1940; 1943), and Edmondson (1959). Crustaceans were identified using Pennak (1953) and Edmondson (1959).

Physical and Chemical Methods

During each visit to the quarry pond, physical and chemical data were collected near the center of the open-
water zone, immediately after sampling for zooplankton. Air temperature, water temperature, dissolved oxygen, dissolved solids, total alkalinity, pH, dissolved carbon dioxide, and water transparency were determined on each sampling date. Wind speed and direction, precipitation and cloud cover were also noted.

A one-liter Van Dorn Bottle was used to collect water at three depths (surface, 0.5 meter, and 1.5 meter) for chemical determinations. Standard titrametric methods for dissolved oxygen and alkalinity determinations were performed according to procedures of the American Public Health Association (1960). The azide modification of the Winkler method was used for dissolved oxygen determinations. An Amstro pH Meter, type G K A was used to determine pH values. Dissolved solids concentrations were obtained with a Myron D. S. Meter, model 512 T 5.

Temperature and light patterns were documented during each sampling period. Temperature was taken with an Applied Research F T 3 Marine Hydrographic Thermometer. Water transparency was determined with a 20 cm. diameter Secchi disc attached to a calibrated line.
A. Physical and Chemical Data

1. Temperature

Water temperature patterns at the surface, 0.5 and 1.5 meter depths usually followed air temperature closely (Fig. 2). The mean difference between air temperature and water surface temperature over the entire sampling period was 3.0° C. On June 30 and September 6, a maximum air temperature of 32.0° C. was recorded. The maximum water temperature of 27.0° C. was recorded on September 6 (Tables 2,3,4). Temperature differences on any sampling day never exceeded 5.5° C. between the surface and 0.5 meter depth, and 7.5°C. between the surface and 1.5 meter depth.

Increases in temperature occurred at all depths between April 6 and June 4 (Fig. 3). During this period temperatures ranged from 1.5° C. to 19.5° C. at the surface (Table 2); 3.0° C. to 18.0° C. at the 0.5 meter depth (Table 3); and 1.5° C. to 15.5° C. at the 1.5 meter depth (Table 4). Mean temperature differences of 1.5° C., 0.7° C., and 0.8° C. occurred between the surface and 1.5 meter depth, surface and 0.5 meter depth, and 0.5 and 1.5 meter depth, respectively.

Between June 7 and September 22, temperature fluctua-
tions were not as great. Water surface temperatures ranged between 18.0° C. and 27.0° C. (Table 2). Those at the 0.5 meter depth varied between 17.5° C. and 24.5° C. (Table 3). Those at the 1.5 meter depth ranged between 15.0° C. and 23.0° C. (Table 4).

Temperature differences between the depths were more pronounced during this period than during the spring period. (Fig. 3). Between the surface and 1.5 meter depth, the mean difference was 2.8 degrees, a value almost twice that of the preceding period (April 6 to June 4).

In late September, temperatures at all three depths began to decrease (Fig. 3). Thereafter, fluctuations in temperature were greater than during the summer months. Within a span of two months, September 22 through November 17, there was a range of 20.5° C. at the surface. At the 0.5 meter depth a range of 20.5° C. was also recorded. At the 1.5 meter depth a range of 14.5° C. was detected (Fig. 3).

In November the water level decreased to 1.28 meters and tows were taken at the surface and 0.5 meter depth only. The mean difference between the surface and 0.5 meter depth was 1.1° C.

Dissolved Oxygen

Dissolved oxygen content varied considerably throughout the sampling period (Fig. 4). Recorded dissolved oxygen values ranged from 1.0 to 14.0 parts per million at
the surface (Table 2); 0.4 to 11.0 parts per million at the 0.5 meter depth (Table 3); and 0.1 to 14.0 parts per million at the 1.5 meter depth (Table 4). Maximum values were detected in September and minimum values in July. For the entire sampling period a greater mean difference occurred between the 0.5 and 1.5 meter depth (1.2 parts per million), than the surface and 1.5 meter depth (0.6 parts per million), (Fig. 4). A mean difference of 1.8 parts per million occurred between the surface and 1.5 meter depth (Fig. 4). On any one sampling day the largest recorded differences in dissolved oxygen content between depths were: 4.6 parts per million between the surface and 0.5 meter depth (September 17); 5.4 parts per million between the 0.5 and 1.5 meter depths (September 8); and 7.4 parts per million (September 8) between the surface and 1.5 meter depths (Tables 2,3,4).

3. Other Parameters

Total alkalinity values ranged between 148 and 324 parts per million throughout the sampling season (Tables 2,3,4). After May, the concentrations were more uniform and the majority of the readings ranged between 250 and 300 parts per million.

Secchi disc values decreased steadily from 2.00 meters in April, to 0.60 meters at the beginning of July. Throughout the next four months ninety-three per cent of
the values recorded were between 0.30 and 0.60 meters (Table 5).

Throughout most of the sampling period an inverse relationship existed between Secchi disc readings and dissolved solids values. Dissolved solids concentration increased from 200 parts per million in April to 400 parts per million in September. Secchi disc readings generally decreased during this same period (Table 5).

An inverse relationship also existed between the seasonal patterns of dissolved solids and fluctuation in water levels (Fig. 5). This was especially noticeable after the stream which flowed into the quarry, dried up during the week of August 30. Within a period of two and one-half months following the cessation of the stream flow, dissolved solids increased from 400 to 600 parts per million, while the depth decreased from 1.85 meters to 1.28 meters (Table 5).

Precipitation was below average in April, May, September, October and November (Table 6). This had a direct effect on the pond, causing an almost continuous decrease in depth throughout the sampling period.

The seasonal range of pH values was between 6.8 and 8.6. Before September 11, approximately 95 per cent of the values were below 8.0. Thereafter, approximately 95 per cent of the values were above 8.0.
4. Diurnals

On June 30 and August 23, studies were undertaken to obtain information on the abiotic and biotic diurnal changes over an 18-hour period. During the June 30 study, air temperatures varied by $9^\circ$ C., reaching a high of $32.0^\circ$ C. at noon and a low of $23.0^\circ$ C. at midnight (Table 7).

Water temperatures at all depths increased approximately $4.0^\circ$ C. from 6:00 a.m. through 6:00 p.m. At 6:00 p.m., maximum water temperatures were recorded at all depths. Maximum recorded temperatures were $25.0^\circ$ C. for the surface and 0.5 meter depth, and $24.0^\circ$ C. for the 1.5 meter depth (Table 7). The mean difference between air and water temperatures for the entire period was $4.4^\circ$ C. At noon the largest difference, $8.5^\circ$ C., was recorded. Differences between water depths were smaller, never exceeding $2.5^\circ$ C. (Table 7).

Dissolved oxygen values were low. The maximum value was 2.2 parts per million recorded at the surface at 6:00 p.m. (Table 7). At 6:00 a.m., the dissolved oxygen values at all three depths were 1.2 parts per million. Dissolved oxygen values for the surface and 0.5 meter depth followed similar patterns, increasing through 6:00 p.m., then decreasing. At the 1.5 meter depth the dissolved oxygen values did not follow this pattern. A decrease at noon
was followed by increasing values recorded at 6:00 p.m. and midnight (Table 7).

Differences in dissolved oxygen values never exceeded 1.0 part per million between the depths. The mean values for each depth over the entire 18-hour period were 1.8, 1.4, and 1.2 parts per million for the surface, 0.5 and 1.5 meter depths respectively.

Air temperatures during the August 23 diurnal ranged from 7.0° C. at 1:30 a.m. to 19.5° C. at 1:00 p.m. (Table 7). Water column temperatures fluctuated much less, ranging between 19.0° C. and 21.5° C. Differences between the depths were small, never exceeding 0.5° C. The mean difference between the air and water surface temperature was much larger (6.2° C.). Temperature fluctuations for the three depths followed similar patterns throughout the 18-hour period. Temperatures rose between 0.5 and 1.0° C. after 8:00 a.m., until 1:00 p.m., then decreased to a recorded low of 19° C. at 1:30 a.m. (Table 7).

Dissolved oxygen values ranged between 1.4 and 5.4 parts per million (Table 7). A comparison of dissolved oxygen for each depth showed the mean value to be greater at the 0.5 meter depth (4.5 ppm.) than at the surface. 1.1 ppm.) or 1.5 meter depth (3.2 ppm.).

At 7:30 p.m. more dissolved oxygen was detected at the 1.5 meter depth than at the surface (Table 7). This
was rarely encountered during the seasonal sampling period. The greatest difference in dissolved oxygen content, 3.4 parts per million, was recorded at 1:00 p.m. between the 0.5 and 1.5 meter depths (Table 7). Dissolved oxygen patterns for the surface and 1.5 meter depth were similar. From 8: a.m. through 1:00 p.m. the values dropped, then increased to recorded highs of 4.4 and 4.8 parts per million at 7:30 p.m. Between 7:30 p.m. and 1:30 a.m. the values decreased.

Dissolved oxygen at the 0.5 meter depth followed a different pattern. Recorded values increased from 4.0 parts per million at 8:00 a.m. to 5.4 parts per million at 7:30 p.m., decreasing thereafter (Table 7).

B. Zooplankton Data

1. Rotifers

During the spring months of April, May and early June, rotifers comprised approximately 70-80 per cent of the total zooplankton community (Fig. 6). Approximately 50 per cent of the Total Rotifer community consisted of Rotaria neutunia (Table 8). Synchaeta pectinata plus the other infrequently occurring species (Table 1), comprised the remaining 50 per cent. By mid-June, Euchlanis tricueta, Brachionus calyciflorus and Testudinella patina appeared (Table 8). A seasonal peak
of 9.68 per liter occurred for the Total Rotifers on June 16. S. nectinata were dominant, comprising approximately two-thirds of the Total Rotifer community (Table 3). By late June, the S. pectinata population had crashed.

Four commonly occurring species: E. tricueria, B. calyciflorus, T. patina and R. neptunia remained. These populations and the "Other Rotifers" continued through July. At that time Total Rotifers comprised only 18 per cent of the total zooplankton population (Fig. 6).

The Total Rotifer population declined in August (Fig. 7). E. tricueria, B. calyciflorus, and T. patina, however, increased again in the fall, but never attained their earlier peaks (Table 8). S. pectinata and R. neptunia were not detected again after their spring occurrence. The species, Brachionus havanaensis, occurred exclusively in the fall (Table 8).

The seasonal maxima of each commonly occurring species of rotifers were never detected on the same day, although the recorded peaks of E. tricueria and B. calyciflorus were detected only two days apart (Table 8). During the first three weeks in June, four species R. neptunia, E. tricueria, B. calyciflorus, S. pectinata, attained seasonal population maxima. In the first week value of 1.36 per liter was recorded for R. neptunia. During the second week, 0.73 per liter was recorded for
_E. triquetra_ and 0.86 per liter for _B. calyciflorus_. In the third week 6.26 per liter was detected for _S. sec- tinata_. The next population maximum did not occur until the second week in July, when 0.75 rotifers per liter were recorded for _T. patina_. After July 9, no rotifer population peaks were detected until the fall. A value of 0.92 rotifers per liter was recorded on October 8 for _Brachionus havanaensis_. (Table 8).

Some rotifer species were infrequently encountered and/or usually occurred in very small quantities or remained in the pond only for short periods of time. These are the species listed in Table 1. This group accounted for 50 per cent of the total rotifers 16 of 65 sampling days when 0.50 rotifers per liter were counted.

2. Crustaceans

In July and early August, _Bosmina_ numerically dominated the zooplankton community (Table 9). Between the end of June and beginning of August, the _Bosmina_ population increased from 2.28 per liter to a maximum of 246.50 per liter (Table 9). This represented a change from three to fifty-five per cent of the zooplankton community (Fig. 6). By late August, the _Bosmina_ population had crashed and no _Bosmina_ were detected after August 25.
Another commonly occurring cladoceran was *Chydorus*. It first appeared in small numbers (0.22 per liter) for about a week in mid-July, then was not encountered until two months later (Table 9). From comprising only 6 per cent of the zooplankton community in September, the population rose to 61 per cent in October and 68 per cent in November (Fig. 6). The *Chydorus* population increased 35-fold from 0.79 organisms per liter on September 9, to a recorded peak of 31.29 per liter on October 27.

A third cladoceran, *Daphnia*, was encountered from July 16 through November 17 (Table 9). *Daphnia* populations never comprised more than 10 per cent of the zooplankton community (Fig. 6). Two population peaks were observed about a month apart (Fig. 8). The first was on August 23 (2.51 per liter) and the second on September 29 (3.27 per liter).

Cyclopoida populations first appeared in mid-June, comprising only 1.0 per cent of the zooplankters (Fig. 6). The population then increased until September 17, when a maximum of 14.64 organisms per liter was recorded (Table 9). In September, the cyclopoids comprised 59 per cent of the zooplankton population, then decreased to only eight per cent in October (Fig. 6).

Naupliar stages of the cyclopoids were found throughout the entire sampling period. A comparison of the nau-
piar standing crop values with adult values shows that preceeding the adult population peak of 14.64 per liter, there was a two-month period (July 16 through September '15) during which nauplii standing crop values averaged 4.25 organisms per liter (Fig. 9). The interval between the naupliar maximum population (8.41 per liter) and the adult maximum was approximately three weeks (Table 9).
IV. DISCUSSION

Open-water zones in small shallow ponds are often marked by biotic and abiotic changes that may occur in relatively short periods of time. This provides an excellent opportunity to study the effects of rapidly changing environmental factors upon zooplankton populations.

The complexity of the inter-relationships that exist between physical and biological factors makes it difficult to isolate the specific effects of any single factor. However, some factors, like temperature, affect the dynamics of the zooplankton community more than others (Edmondson, 1965; and others).

In this study an attempt was made to relate the role of temperature to the development of the zooplankton community. This was done by a comparison between zooplankton abundance and mean temperature values within designated time-blocks. The time-blocks were based upon periods of similarity in temperature (Fig. 10). Approximately 95 percent of the temperature values assigned to each block did not vary more than 6 degrees. Block I (May 17 to June values ranged between 12.0 and 18.0° C. and had a mean of 14.3° C. (Fig. 10). Block II (June 7 to September 22) values ranged from 17.0 to 23.0° C. and had a mean of 21.8° C.
(Fig. 10). Block III (September 24 to November 5) values ranged between 11.0 and 14.0°C and had a mean of 15.2°C. (Fig. 10). Peak numbers of zooplankton were encountered during the period of Block II. (Fig. 10). Within this block the cladocerans were most numerous (14.35 per liter). The cyclopoids had the next largest density (6.58 per liter). The rotifers had a density of 1.83 per liter. The mean temperature of this time-block was 6 degrees greater than the other two blocks (Fig. 10).

Time-Blocks I and III had similar mean quantities of rotifers and cyclopoids (Fig. 10). It was interesting to note that mean temperatures in Blocks I and III were virtually the same, although separated in time by approximately 3 months. The cladocerans were not detected during the time period of Block I.

The greatest recorded increase in temperature between two consecutive sampling days occurred between June 4 and June 7. Temperatures increased 10.0°C at the surface (Table 2), 7.0°C at the 0.5 meter depth (Table 3); and 6.0°C at the 1.5 meter depth (Table 4).

During this time and immediately following it, marked changes in populations of several organisms were recorded. The standing crop of the rotifer *Euchlanis triouetra* more than tripled between June 7 and June 9. This was its greatest recorded increase in density throughout the sampling
period (Table 8). Prior to June 9, *Brachionus calyciflorus* had only been detected on two occasions and in very small quantities (Table 8). Within a period of 5 days the density increased more than 30-fold. From June 7 to June 9 the *Synchaeta pectinata* density quadrupled, increasing from 0.62 per liter to 2.49 per liter (Table 8). Cope- pod nauplii increased 4-fold between June 4 and June 9 (Table 9).

An observable increase in phytoplankton was detected during this period of rapid temperature increase. Although no quantitative data were obtained, large algal blooms were noted. An increase in the branched colony *Dinobryon* was noticed on June 9 and seemed to reach a maximum density about June 16.

These patterns of density changes associated with the warmer periods appear to provide evidence that water temperature was a major influence, both directly and indirectly, on the abundance of plankton inhabiting the quarry pond. Elgmork (1964) noted that variations in zooplankton abundance corresponded directly to temperature fluctuations. A "steep rise" in temperature was often followed by a rapid increase in zooplankton populations.

The effect of low dissolved oxygen concentration upon plankton populations has been studied for some organisms. Herbert (1954), Hazelwood and Parker (1960), and others. particular interest during this investigation was a
6-week period from the middle of June to early August. Dissolved oxygen values above 4.0 parts per million were not detected (Fig. 4). During the 9-day period between June 30 and July 9, values never exceeded 2.0 parts per million. On July 7, dissolved oxygen concentrations at the 1.5 meter depth dropped to 0.1 part per million, the lowest value detected during the year for the entire water column (Table 4).

During this 6-week period, total rotifers decreased steadily (Fig. 7). Total Rotifers comprised 73 per cent of the zooplankton community in June, then decreased to 18 per cent in July (Fig. 6). On August 4, only Rotaria neptunia and "Other Rotifers" were left, and these were present in extremely low (0.02 per liter) densities (Table 8).

As the Total Rotifer population decreased during this period of low oxygen, the Bosmina population increased rapidly. Bosmina rose from 3.0 per cent of the zooplankton community in June, to 55 per cent in July, an 18-fold increase (Fig. 6). The population increased to a maximum density of 246.50 per liter on August 2 (Table 9). Following this, the Total Rotifer population had almost disappeared.

Low dissolved oxygen content did not seem to affect the crustacean community in general. However, during the brief period following the extremely low dissolved oxygen values (0.1 part per million), Bosmina and the cyclopoid
populations declined sharply. Decreases of over 50 per cent were recorded for both on July 12, approximately 4 days after the minimum oxygen value was recorded (Table 9). However, recovery seemed rapid, and both increased in density within 2 or 3 days after the decline (Table 9).

A comparison between dissolved oxygen values and quantities of planktonic organisms suggested a direct relationship between the occurrence of large algal blooms and oxygen. In the middle of September, a thick cover of *Anabaena* extended over approximately 20 per cent of the quarry pond. Dissolved oxygen readings during this time were the highest of the year, ranging from 10.0 to 14.0 parts per million (Fig. 4). Calculated saturation values were as high as 140 per cent.

It was of interest to note that the maximal standing crop recorded for adult cyclopoids corresponded closely to increases in dissolved oxygen. During a 7-day period (September 17 to September 24), no density value less than 10.0 per liter was recorded for the cyclopoids (Table 9). At this time the algal cover was thickest and the concentration of dissolved oxygen highest.

Throughout the sampling period certain characteristics of the pond community became apparent. Each population of the zooplankton community had a maximum density peak separated by time. Intervals of approximately six weeks
occurred between the maxima of rotifer, cladoceran, and cyclopid standing crops (Fig. 7). The seasonal density peak for Total Rotifers occurred in June (Fig. 7). The Cladocera had two major maxima, one occurring in August, and the other in October. The maximum peak for Cyclopoidea occurred in September (Fig. 7).

Peaks of the standing crops for the various Cladocera species were detected approximately one month apart (Fig. 8). The maximum density for Bosmina was detected in early August, while the Daphnia maximum occurred in late September. The Chydorus maximum was recorded in late October. Comparisons of the monthly mean percent showed that in July, when Bosmina was numerically dominant, the other cladocerans present comprised less than one percent of the total zooplankton community (Fig. 6). Similarly, when Chydorus was dominant in October and November, the other Cladocera comprised only 2 percent of the total zooplankton community (Fig. 6).

Maximum density peaks for most rotifer species occurred more than five days apart (Table 8). However, a 2-day interval was observed between B. calyciflorus and E. triquetra (Table 8). Maximum densities for the two most abundant rotifer species, S. pectinata and R. neptunia occurred approximately two weeks apart. Maxima of all commonly occurring rotifers, with the exception
of *B. havanaensis*, were observed in the spring. Its maximum was recorded approximately four months later in October (Table 8).

Another characteristic of the pond community was that relatively few species attained large abundance throughout the sampling period. Only *Bosmina*, *Chydorus*, the cyclopoids, and *S. pectinata* ever reached densities above 4.0 organisms per liter (Fig. 11).

*Bosmina*, by far the most abundant zooplankter, had a maximum density of 246.50 per liter (Fig. 11). *Chydorus*, the next most abundant, had a maximum of 31.29 per liter. The cyclopoids had a recorded peak of 14.64 per liter (Table 9). *Synchaeta pectinata*, which had a peak population of 6.26 per liter, was the only rotifer that had a population maximum of over 2.0 per liter (Table 8).

One of the major features of the quarry pond zooplankton community was the large difference in abundance between the rotifers and the crustaceans. *Bosmina*, *Chydorus* and the *Cyclopoida*, each attained population densities over 10.00 organisms per liter (Fig. 11). By contrast, the Total Rotifers never attained a density greater than 10.00 organisms per liter (Table 8). *S. pectinata* had the greatest recorded rotifer peak of 6.26 per liter, a relatively low value when compared to the crustaceans (Fig. 11). A particularly striking example
of the difference in abundance between crustaceans and rotifers was the 40-fold difference between the density maximum of *Bosmina* (246.50 per liter) and that of *S. pectinata* (6.26 per liter).

These characteristics of the rotifer and crustacean populations appear to be mechanisms which reduce species competition. Apparently, this is also achieved spatially, via vertical distribution and migration. Partitioning of the zooplankton populations due to vertical distribution was observed in a design which sampled three depths. Differences in the individual population densities of rotifers at the surface (Table 10), 0.5 meter depth (Table 11), and 1.5 meter depth (Table 12), were recorded. Similar differences were also noted for the crustaceans at these three levels (Tables 13, 14, and 15). These differences were subjected to an analysis of variance test (Table 16). When a significant difference \( p < 0.05 \) was found between depths, the Least Significant Difference Test was then employed. Significant differences were found for the rotifers: *Euchlanis triquetra*, *Brachionus havanaensis*, *Testudinella patina*, *Synchaeta pectinata*, and *Rotaria neptunia*. Significant differences were also found for the crustaceans *Chydorus*, *Daphnia* and the Cyclopoida. From this procedure it appeared that *Euchlanis triquetra* and *Brachionus havanaensis* favored the upper one-third of
the quarry pond. *Testudinella patina*, *Synchaeta pectinata* and *Chydorus* more often frequented the middle third. Only *Rotaria neptunia* seemed to frequent the lower third. The cyclopoids and "Other Rotifers" seemed to favor the upper two-thirds, while *Daphnia* most often inhabited the lower two-thirds (Fig. 12).

On two separate occasions (June 30 and August 23) the diurnal vertical movements of the zooplankton were investigated. A two-way analysis of variance showed significant \((p < .05)\) interaction between time and depth over the two 18-hour periods. This indicated that vertical migration had occurred. During the June diurnal, three species of rotifers, *Brachionus calyciflorus*, *Testudinella patina*, and *Rotaria neptunia* were detected in the pond. Of these three, only *Rotaria neptunia* showed no significant \((p < .05)\) interaction between time and depth (Table 17). A significant \((p < .05)\) interaction was found for adult and immature cyclopoids and *Bosmina*, the only crustaceans present at the sampling time (Table 17).

During the August diurnal only one rotifer, *Testudinella patina*, occurred in quantities large enough to test. This species showed significant interaction between time and depth (Table 18). The cyclopoids and *Daphnia* were detected in the pond at this time. *Daphnia* showed a significant interaction (Table 18). It is interesting
to note that the cyclooids showed significant interaction between time and depth during both the June and the August diurnal.

Throughout the diurnals, changes in oxygen and temperature values were small. During the June diurnal the greatest temperature change was 4.0° C and the greatest dissolved oxygen change was 1.0 part per million. During the August diurnal, 2.0° C was the greatest recorded change in temperature and 3.4 parts per million was the greatest change in dissolved oxygen. Differences in dissolved oxygen and temperature values between the depths were also small. For either diurnal, the temperature differences were not greater than 2.5° C and the dissolved oxygen did not differ more than 3.4 parts per million (Table 7). These small changes probably did not play an important role in the vertical migration patterns of zooplankters.

Throughout much of the seasonal sampling period, light penetration failed to reach the lower half of the quarry pond (Table 5). This is unlike many shallow ponds where light penetrates to the bottom for much of the year. Reaction to light probably varied with each kind of organism; and it is not unreasonable to assume that light played an important role in both vertical partitioning and migration. Costa and Cummins (1969) examined the
role of light, temperature and oxygen in the diurnal migration pattern of the cladoceran Leptodora kindtii (Focke) in a shallow body of water approximately three meters deep. Of the three factors evaluated, light appeared to play the dominant role.

In addition to data collected on the organisms, the two diurnals provided information which was needed to properly evaluate the routine sampling procedure. Since vertical migration patterns were evident, the need to sample three depths was substantiated.

By comparing original and replicate samples taken throughout the year, the sampling consistency could be evaluated through the use of the Student's t-test. When this was applied to replicate samples of the water column, it was found that no significant difference ($p < .05$) existed for any of the organisms tested (Table 19).

From this investigation it appears that separation in time between maxima of populations of different organisms; the large abundance of relatively few kinds of organisms; the large difference in abundance between rotifers and crustaceans; and the vertical partitioning and migration of zooplankton in a quarry pond are important to the population dynamics of pond communities. These patterns caused by combinations of biotic and abiotic factors, no doubt produce these separations in time and
space, even in so shallow a body of water as the quarry pond. These may very well be the important mechanisms whereby competition between species is avoided.
V. SUMMARY

The zooplankton community of a small, shallow limestone quarry pond was investigated from April through November, 1971. Both rotifers and crustaceans were encountered in this investigation. The commonly occurring rotifers were: *Euchlanis triquetra*, *Brachionus calyciflorus*, *Brachionus havanaensis*, *Testudinella patina*, *Synchaeta pectinata*, and *Rotaria neptunia*. The crustaceans encountered were *Bosmina*, *Chydorus*, *Daphnia* and the adult and naupliar cyclopoids.

Plankton samples were collected with a number 20 mesh net towed along a fixed transect. Tows were made at the surface, 0.5 meter and 1.5 meter depths. The sampling consistency of the tows was examined by comparing the original and replicate samples with the Student's *t*-test. Each major organism was evaluated using the samples of the water column gathered throughout the year. The results showed no significant differences (*p* < .05). Physical and chemical data were also gathered to determine the influence of abiotic changes on the zooplankton populations.

A relationship between temperature and the abundance of zooplankton was found when blocks of time were desig-
nated on the basis of similarity in temperature values. The temperature-time blocks corresponded roughly with spring, summer, and fall. The greatest number of organisms occurred in summer, when the mean temperature was above 20.0° C. This value was 6.0° C. greater than the means of the other two blocks.

A relationship was also noted between dissolved oxygen concentrations and planktonic organisms. During a 6-week period (middle of June to early August), when dissolved oxygen values were as low as 0.1 part per million, the rotifer populations steadily declined. On August 4, only two species of rotifers remained, in very small quantities. As the rotifers decreased during this period of low oxygen, Bosmina reached its population maximum of 246.50 per liter. Crustaceans, in general, did not seem to be affected by low concentrations of dissolved oxygen, but during a brief period of extremely low values, Bosmina and cyclopoid populations did decrease. However, recovery was rapid.

Separations in time of population peaks were noted to be more than 6 weeks between the maxima of rotifer, cladoceran, and cyclopoid standing crops. Intervals between population peaks of the cladoceran genera were approximately one month. Most intervals between population peaks of rotifer species were more than 5 days.
The pond community was characterized by a large abundance of relatively few kinds of organisms. Bosmina, the most numerous organism, attained a maxima of 246.50 per liter. Only Bosmina and Chydomorpha were detected in quantities exceeding 20 organisms per liter, and Synchaeta pectinata was the only rotifer detected in quantities over 5.0 per liter. Crustaceans were by far the most numerous group of organisms in the zooplankton community.

Significant differences (p < .05) were found for zooplankton populations at different depths. Vertical partitioning occurred for the rotifers: Euchlanis triquetra, Brachionus havanaensis, Testudinella patina, Synchaeta pectinata, and Rotaria neptunia, and for the crustaceans Chydomorpha, Daphnia, and the Cyclopoidea. Least Significant Differences Tests showed that E. triquetra and B. havanaensis favored the upper third of the pond, T. patina, S. pectinata and Chydomorpha favored the middle third. Only R. neptunia seemed to favor the lower third. Crustaceans seemed to be less limited to one level of the pond. Daphnia was most frequently found in the lower two-thirds while the cyclopoids favored the upper two-thirds. Only Chydomorpha appeared to favor one level, the middle third.

Significant (p < .05) interactions between time and depth were found for zooplankton organisms during 2 diurnal investigations. Vertical migration appeared to
occur for the rotifers *B. calyciflorus* and *T. patina*, and adults and immature cyclopoids. *Rotaria neptunia* and *Daphnia* showed no significant \( p < 0.05 \) interaction between time and depth.

A combination of abiotic and biotic factors appeared to play an important role in influencing and regulating zooplankton populations. This may have been achieved primarily through mechanisms which separated populations in time and space. This was particularly noticeable through separation in time between the maximal densities of different organisms; the large abundance of relatively few species; the pronounced difference in crustacean and rotifer standing crops; and the separation in space through vertical distribution and migration. All of these interactions no doubt lessened competition in so shallow a body of water as the quarry pond.
APPENDIX A (TABLES)
<p>| A. | Filinia longista                |
| B. | Hexarthra sp.                  |
| C. | Keratella cochlearis           |
| D. | Keratella quadrata             |
| E. | Leptodella sp.                 |
| F. | Monostyla sp.                  |
| G. | Philodina sp.                  |
| H. | Platynias patulus              |
| I. | Polyarthra sp.                 |
| J. | Trichocera sp.                 |
| K. | Ascomorpha sp.                 |
| L. | Pompomphylx sp.                |
| M. | Conochilus sp.                 |</p>
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Table 2: (cont.). Air temperature, water temperature, dissolved oxygen, pH and total alkalinity values at the surface, 1971.

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Table 4. Water temperature, dissolved oxygen, pH and total alkalinity values at the 1.5 meter depth, 1971.

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Table 5. Dissolved solids, Secchi disc and depth values, 1971.

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Table 5 (cont.). Dissolved solids, Secchi disc and depth values, 1971.

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Table 6. Monthly precipitation values for the Rochester area; April through November, 1971.

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* Note: Data obtained from:
  U. S. Department of Commerce
  National Oceanic and Atmospheric Administration
  Environmental Data Service
  (Rochester Weather Bureau
  Local Climatological Data)
Table 7. Diurnal temperature and dissolved oxygen changes.

**June 30, 1971**

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**August 23, 1971**

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<td>B. calyciflorus</td>
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<td>-------------</td>
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Table 8 (cont.). Standing crop of total rotifer populations, 1971.

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Table 12 (cont.). Standing crop of rotifers at the 1.5 meter depth, 1971.

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Table 15. Standing crop of crustaceans at the 1.5 meter depth, 1971.

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Table 15 (cont.). Standing crop of crustaceans at the 1.5 meter depth, 1971.

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Table 16. Analysis of variance for differences between the zooplankton densities at three depths during the sampling season, 1971.

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NS - Not Significant
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**E. triquetra**

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<tr>
<td>Depth</td>
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<td>87.39</td>
<td>43.69</td>
<td>14.96**</td>
</tr>
<tr>
<td>Days</td>
<td>17</td>
<td>151.78</td>
<td>8.92</td>
<td>3.06</td>
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* p<.05
*p<.01
** Not Significant
Table 16 (cont.). Analysis of variance for differences between the zooplankton densities at three depths during the sampling season, 1971.

**B. calyciflorus**

<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>2</td>
<td>32.76</td>
<td>16.38</td>
<td>3.07 NS</td>
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<tr>
<td>Days</td>
<td>26</td>
<td>566.51</td>
<td>27.78</td>
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**B. havanaensis**

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</thead>
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<td>70.01</td>
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<tr>
<td>Days</td>
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<td>274.34</td>
<td>14.43</td>
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<td>243.28</td>
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**T. patina**

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* p < .05
** p < .01

NS = Not Significant
Table 16 (cont.) Analysis of variance for differences between the zooplankton densities at three depths during the sampling season, 1971.

### S. pectinata

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<th>F</th>
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</thead>
<tbody>
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<td>Depth</td>
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<td>946.01</td>
<td>473.01</td>
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<tr>
<td>Days</td>
<td>10</td>
<td>10622.98</td>
<td>1062.30</td>
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<tr>
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<td>37.78</td>
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### R. neptunia

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<th>MS</th>
<th>F</th>
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<td>194.66</td>
<td>97.33</td>
<td>7.43**</td>
</tr>
<tr>
<td>Days</td>
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<td>711.00</td>
<td>29.62</td>
<td>2.26</td>
</tr>
<tr>
<td>Error</td>
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"Other Rotifers"

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<th>MS</th>
<th>F</th>
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<td>404.20</td>
<td>202.10</td>
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<td>Days</td>
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<td>127.13</td>
<td>10.75</td>
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<td>Error</td>
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<td>1607.82</td>
<td>11.82</td>
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* p<.05
** p<.01

S. - Not Significant
Table 17. Analysis of variance for time and depth interaction over an 18-hour period, June 30, 1971.

<table>
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<tr>
<th>Sources of variation</th>
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<th>SS</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclopoida</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subgroups</td>
<td>11</td>
<td>755.3425</td>
<td>68.6672</td>
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</tr>
<tr>
<td>Time (A)</td>
<td>3</td>
<td>255.2434</td>
<td>85.0000</td>
<td>24.2857**</td>
</tr>
<tr>
<td>Depth (B)</td>
<td>2</td>
<td>3.0917</td>
<td>1.5450</td>
<td>0.4414 NS</td>
</tr>
<tr>
<td>Interaction (A x B)</td>
<td>6</td>
<td>497.2532</td>
<td>82.8750</td>
<td>23.6771**</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td>42.1165</td>
<td>3.5000</td>
<td></td>
</tr>
</tbody>
</table>

| Nauplii              |    |        |        |          |
| Subgroups            | 11 | 341.5000 | 31.0454 |          |
| Time (A)             | 3  | 179.1662 | 59.7224 | 24.7132**|
| Depth (B)            | 2  | 76.7575  | 38.3755 | 15.8797**|
| Interaction (A x B)  | 6  | 86.5840  | 14.4306 | 5.9714** |
| Error                | 12 | 29.0000  | 2.4166 |          |

* p < .05
** p < .01
NS = Not Significant
The table represents the sources of variance in Bosmina and B. calyciflorus over a 15-hour period, June 30, 1971.

### Bosmina

<table>
<thead>
<tr>
<th>Sources of Variance</th>
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<th>SS</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subgroups</td>
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<td>408.4584</td>
<td>37.1325</td>
<td></td>
</tr>
<tr>
<td>Time (A)</td>
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<td>95.4584</td>
<td>31.8194</td>
<td>10.7559**</td>
</tr>
<tr>
<td>Depth (B)</td>
<td>2</td>
<td>258.0834</td>
<td>129.0417</td>
<td>43.6202**</td>
</tr>
<tr>
<td>Interaction (A x B)</td>
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<td>54.9166</td>
<td>9.1527</td>
<td>3.0939**</td>
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<tr>
<td>Error</td>
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<td>2.9583</td>
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### B. calyciflorus

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<th>F</th>
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<td>4.6785</td>
<td></td>
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<tr>
<td>Time (A)</td>
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<td>18.7917</td>
<td>6.2636</td>
<td>4.3494*</td>
</tr>
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<td>5.5834</td>
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<td>2.1614 NS</td>
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<td>6</td>
<td>27.0833</td>
<td>4.5138</td>
<td>3.4947*</td>
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<td>Error</td>
<td>12</td>
<td>15.5000</td>
<td>1.2916</td>
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</tr>
</tbody>
</table>

* *p < .05
** *p < .01
NS = Not Significant
Table 17 (cont.). Analysis of variance for time and depth interaction over an 18-hour period, June 30, 1971.

**T. patina**

<table>
<thead>
<tr>
<th>Sources of variance</th>
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<th>MS</th>
<th>F</th>
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</thead>
<tbody>
<tr>
<td>Subgroups</td>
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</tr>
<tr>
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<td>7.1667</td>
<td>2.3889</td>
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<td>16.3334</td>
<td>8.1667</td>
<td>7.5387**</td>
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<tr>
<td>Interaction (A x B)</td>
<td>6</td>
<td>41.3333</td>
<td>6.8888</td>
<td>6.3590**</td>
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<td>Error</td>
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<td>13.0000</td>
<td>1.0833</td>
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**R. neptunia**

<table>
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<th>MS</th>
<th>F</th>
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</thead>
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<td>25.4860</td>
<td>32.1955**</td>
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<td>2.6250</td>
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<td>2.4037 NS</td>
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<td>0.7916</td>
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*p < .05
**p < .01
NS - Not Significant
Table 7. (cont.). Analysis of variance for time and depth interaction over an 18-hour period, June 30, 1971.

"Other Rotifers"

<table>
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<td>12.0000</td>
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<td>82.7525</td>
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* p < .05  
** p < .01

NS - Not Significant
Table 18. Analysis of variance for time and depth interaction over an 18-hour period, August 23, 1971.

<table>
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<tr>
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<td>421.5555</td>
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<td>455.2917</td>
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* p < .05  
** p < .01  
NS = Not Significant
Analysis of variance for time and depth interaction over an 18-hour period, August 23, 1971.

### Daphnia

<table>
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<tr>
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<th>F</th>
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<tbody>
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<td>346.5555</td>
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### T. patina

<table>
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<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
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<td>23.3340</td>
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</tr>
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<td>5.6675*</td>
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<td>3.2921</td>
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</tr>
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<td>1.8471</td>
<td>5.5418**</td>
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<tr>
<td>Error</td>
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<td>4.0000</td>
<td>0.3333</td>
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</tr>
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</table>

* p < .05
** p < .01
NS - Not Significant
Table 18 (cont.). Analysis of variance for time and depth interaction over an 18-hour period, August 23, 1971.

"Other Rotifers"

<table>
<thead>
<tr>
<th>Sources of variance</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
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<td>35.9962</td>
<td>1.9113 NS</td>
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<td>100.3542</td>
<td>5.3285**</td>
</tr>
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<td>216.2916</td>
<td>36.0486</td>
<td>1.9140 NS</td>
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</table>

* p < .05
** p < .01
NS - Not Significant
Table 19. Student's t-test between original and replicate samples.

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<th>T_{calc.}</th>
<th>Significance(p &lt; .05)</th>
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<td>0.95</td>
<td>N. S.</td>
</tr>
<tr>
<td>nauplii</td>
<td>44</td>
<td>0.20</td>
<td>N. S.</td>
</tr>
<tr>
<td>Bosmina</td>
<td>20</td>
<td>1.32</td>
<td>N. S.</td>
</tr>
<tr>
<td>Chydorus</td>
<td>14</td>
<td>0.80</td>
<td>N. S.</td>
</tr>
<tr>
<td>Daphnia</td>
<td>25</td>
<td>0.16</td>
<td>N. S.</td>
</tr>
<tr>
<td><em>E. tricuetra</em></td>
<td>15</td>
<td>-2.00</td>
<td>N. S.</td>
</tr>
<tr>
<td><em>calyciflorus</em></td>
<td>15</td>
<td>-1.25</td>
<td>N. S.</td>
</tr>
<tr>
<td><em>B. havanaensis</em></td>
<td>13</td>
<td>-0.60</td>
<td>N. S.</td>
</tr>
<tr>
<td><em>patina</em></td>
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<td>N. S.</td>
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<td>0.22</td>
<td>N. S.</td>
</tr>
<tr>
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<td>17</td>
<td>-2.00</td>
<td>N. S.</td>
</tr>
<tr>
<td>&quot;Other Rotifers&quot;</td>
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<td>-2.00</td>
<td>N. S.</td>
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N. S. - Not Significant
APPENDIX B (FIGURES)
Fig. 1. The quarry pond study area

Scale: 1 cm. = 3.3 m.
Fig. 2. Seasonal changes in the weekly means of air and water surface temperature, 1971.
Fig. 3. Seasonal changes in the weekly means of water temperature at the surface, 0.5 m. and 1.5 m. depths, 1971.
Fig. 4. Seasonal changes in the weekly means of dissolved oxygen at the surface, 0.5 m, and 1.5 m depths, 1971.
Fig. 5. Seasonal changes in the weekly means of dissolved solids and fluctuations in water level, 1971.
Fig. 6. Seasonal variations in the monthly means of per cent composition of zooplankton, 1971.
Fig. 7. Seasonal changes in the weekly means of zooplankton standing crop, 1971.
Fig. 8. Seasonal change in the weekly means of Cladocera standing crop, 1971.
Fig. 9. Seasonal change in the weekly means of adult cyclooids and nauplii standing crop, 1971.
Fig. 10. Zooplankton densities and temperature blocks.
Fig. 11. Maximum standing crop of zooplankton, 1971.
Fig. 12. Pictorial representation of partitioning of zooplankton.


