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Planktonic crustacean populations in a Missouri River Oxbow Lake.

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PLANKTONIC CRUSTACEAN POPULATIONS IN A MISSOURI RIVER OXBOW LAKE

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THESIS ACCEPTANCE

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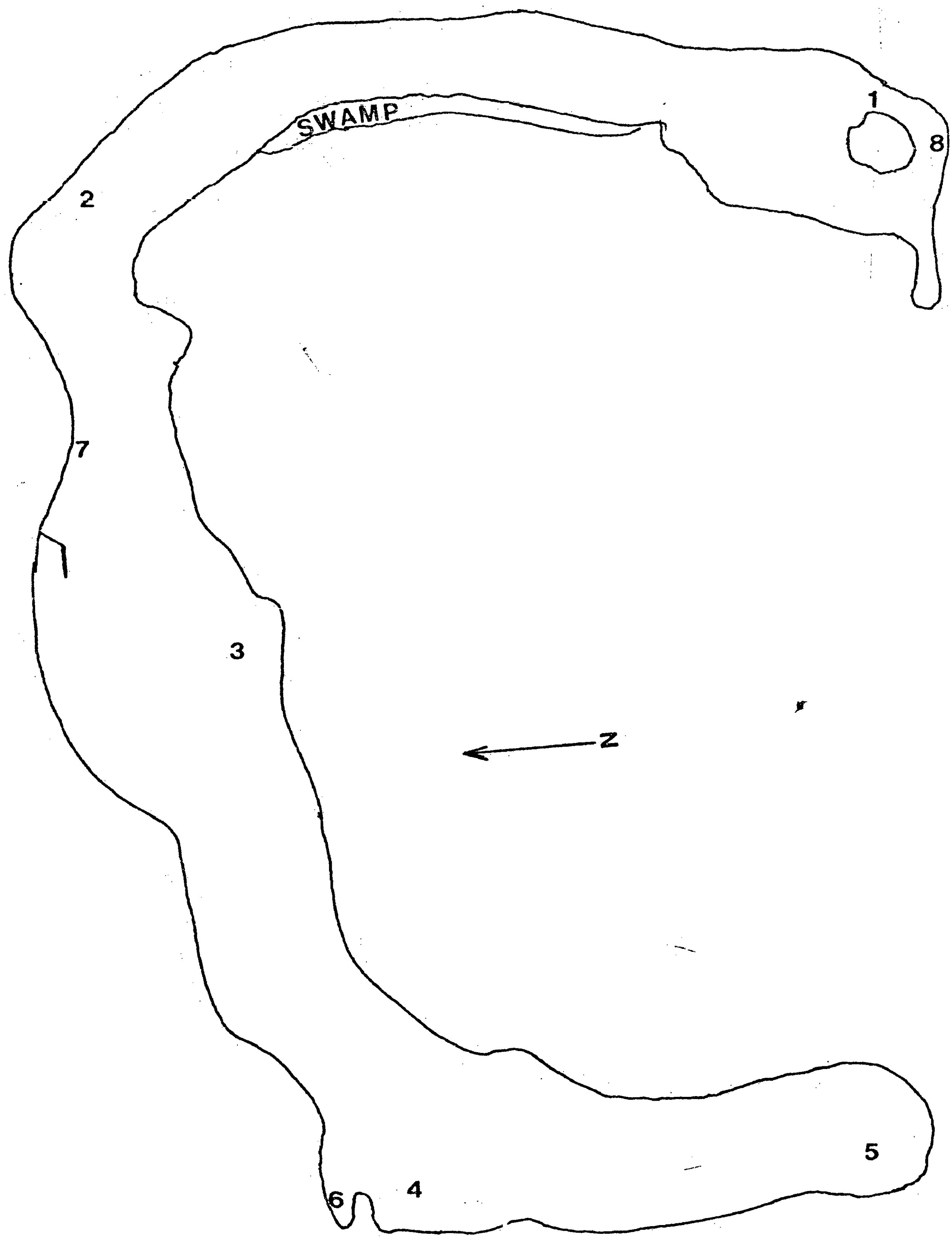

Fig. 1. A map of Carter Lake showing numbered collecting stations.

PLANKTONIC CRUSTACEAN POPULATIONS IN A MISSOURI RIVER OXBOW LAKE

INTRODUCTION

Oxbow lakes and their biota are important in the ecology of the Missouri River basin. The only completed study of these lakes has been Welker's (1965) study of the fish of five oxbows. Descriptions of oxbow fauna and their ecology are generally lacking in the literature. This study is designed to partially fill that void.

Small crustaceans have been studied by many workers. Most have dealt with environmental forces acting on one species. Coker (1933) found that the size of *Cyclops vernalis* varied inversely with the temperature at which the animals were reared. Coker and Addlestone (1938), Kiang (1942), Pratt (1943), and Brooks (1946) studied the effect cf temperature on *Daphnia*. They agreed that temperature had no effect on cyclomorphosis in *Daphnia*.

Birge (1898) suggested that the total number of Entomostraca in Lake Mendota was correlated with temperature; Ward (1940), Pratt (1943), and Comita and Anderson (1959) support this view. Schacht (1897) found that *Diaptomus siciloides* carried more eggs in summer in the Illinois River than in Lake Tulare, California. He suspected that higher temperature and more abundant food supply were responsible. Birge (1898) noted that clutch size of Diaptomus oregonensis in Lake Mendota showed a seasonal trend with 20-30 eggs carried in spring and 9-15 in summer. Comita and Anderson (1959) however, found greatest egg production of Diaptomus ashlandi in Lake Washington occurring from mid-January through mid-March. Hutchinson (1967) points out the conflict in these findings. Genetic influence may be a factor, therefore the problem has not been resolved.

On the effect of food supply, Pennak (1946, 1949) saw no correlation between algal and zooplankton populations. Cheatum et al (1942), and Anderson et al (1955) showed that correlation may exist. Comita and Anderson (1959) found highly significant correlation between chlorophyll concentration and Diaptomus egg production. Borecky (1956) decided that cladoceran densities were primarily dictated by food supply. He was able to show significant correlation between the density and chemical and physical factors related to food production. Hutchinson (1967) related that Czeczuga (1960) was able to show an interesting relationship between trophic stage of a lake and the number of eggs per clutch of Diaptomus gracilis and D. graciloides.

Various aspects of competition have been studied. Frank (1952) found that Daphnia pulicaria would eliminate

Simocephalus vetulus when reared in the same medium. Daphnia has also been shown to limit Eucyclops agilis (Parker, 1961) and S. vetulus suppresses Cyclops viridis in culture (Parker, 1960). Slobodkin and Richman (1956) removed fixed percentages of newborn Daphnia from culture and decided that the increased birth rates resulted from increased food supply.

Paine (1966, 1969) showed that the effect of dominant predator on dominant prey organism reduced competition among prey species and increased population diversity. He termed the dominant predator the "keystone species." Hall et al (1970) observed community response to regulated predation and nutrient supply. They observed the keystone effect of bluegill predation and found that either high nutrient concentration or heavy predation restructured both plant and animal communities.

Cushing (1951) and Hutchinson (1967) have reviewed the literature on the widely studied phenomenon of vertical migration. Healey (1967) established a new aspect of the accepted diurnal pattern when he found that juvenile and adult Diaptomus leptopus showed opposite diurnal migration patterns. During the night when adults were most abundant near the surface, juveniles were most concentrated below 5 meters. During the day, adults were concentrated below 5 meters and juveniles were clustered near the surface.

Many workers (Hutchinson, 1967) have reported that small and large animals of the same species are often found at widely separated depths. However, none of the investigators have attempted to show statistically the extent of such a size difference, if difference actually exists.

Composition of a Diaptomus ashlandi population has been studied by Comita and Anderson (1959). They assayed densities of each juvenile instar as well as that of adult males, females, and gravid females.

Few studies have dealt with entire natural communities. Hazelwood and Parker (1961) studied the response of a natural population of Daphnia schodleri and Diaptomus leptopus to the environmental factors of temperature, possible food supply, light extinction, dissolved oxygen, and photoperiod. They found the number of Daphnia was correlated with possible food supply, water temperature, dissolved oxygen, and the number of Diaptomus present. The number of Diaptomus per liter correlated with photoperiod, possible food, light extinction, dissolved oxygen, total alkalinity, and to a lesser extent with the number of Daphnia present. Total depletion of dissolved oxygen during the study would seem to have influenced their findings.

The limnology of Missouri River oxbows and their plankton have received little attention. This study was conducted to establish some of the physical and chemical characteristics of one of these lakes. Constituent species of the planktonic Crustacea and their densities were determined. Composition of the diaptomid population in terms of percentages of juveniles, adult males and females, gravid females, and their vertical distribution were considered. *Daphnia pulex* was studied to determine if correlation exists between body length and the depth of collection.

STUDY AREA

Carter Lake (Fig. 1) is situated on the Missouri River floodplain at the northeastern edge of Omaha, Nebraska. At this point the floodplain is about 980 feet above sea level. The lake was formed July 8, 1877, when the channel cut a large meander off from the river. The lake remained as a backwater until siltation isolated it from the river about 1890. River floodwaters have entered the lake periodically as late as 1952 (Anon., 1960).

The lake has no natural outlets. Storm drains enter at several points and contribute substantially to the water level. As protection to the adjacent airport, drain pipes have been installed to prevent waters from rising above 975 feet above sea level. Water did not leave the lake by this route during the study.

The lake covers 320 acres (Anon., 1960) to an average depth of 6 feet. The length is 15,400 feet and maximum effective length (Welch, 1948) 7,240 feet. The average width is 860 feet. Shoreline development is 2.69. Most of the shoreline consists of a bank rising sharply from the waters to an average height of 4 feet. A half mile of swampy area exists on the west side of the east arm. The bottom contours are regular. An impervious clay silt covers the bottom in a layer 3 to 19.5 feet thick (Anon., 1960), overlying a previous siltation sand.

A hornwort (*Ceratophyllum sp.*) was the dominant submerged aquatic plant. Heavy stands occurred in all shallow areas, interrupted in isolated areas by a green alga, *Chara sp.* A bed of *Nymphea tuberosa* occurred west of the small island in the east arm. A *Cladophora sp.* was the dominant alga; thick tufts were attached to sticks, stones, and bits of concrete along the shoreline. *Spirogyra sp.*, *Ulothrix sp.*, *Zygnema sp.*, and *Oedogonium sp.* were less common. A few of the desmids *Cosmarium sp.*, *Closterium sp.*, and *Micrasterias Sp.* occurred. A *Gonium sp.* was present but rare. The Cyanophytes *Anabena sp.* and *Phormidium sp.* were present throughout the study. Globose colonies of *Rivularia sp.* were commonly attached to *Ceratophyllum*.

Fish were abundant. The following is a list of those collected by Wiley (unpublished).

Family Centrarchidae

Pomoxis annularis	White crappie
Pomoxis nigromaculatus	Black crappie
Lepomis macrochirus	Bluegill
Lepomis cyanellus	Green sunfish
Lepomis humilis	Orange spotted sunfish
Micropterus salmoides	Largemouth bass

Family Ictaluridae	
Ictalurus punctatus	Channel catfish
Ictalurus melas	Black bullhead
Ictalurus natalis	Yellow bullhead
Noturus gyrinus	Tadpole madtom
Family Cyprinidae	
Notropis lutrensis	Red shiner
Notemigonus crysoleucas	Golden shiner
Cyprinus carpio	European carp
Family Percidae	
Perca flavescens	Yellow perch
Etheostoma exile	Iowa darter
Family Catastomidae	
Ictiobius sp.	Buffalo
Family Sciaenidae	
Aplodinotus grunniens	Freshwater drum
Family Percichthyidae	
Morone chrysops	White bass
Family Clupeidae	
Dorosoma cepedianum	Gizzard shad

White crappie and bluegill were abundant to the point of being stunted.

METHODS AND MATERIALS

The Corps of Engineers, U. S. Army supplied a map dated May, 1959. A facsimile is shown in Fig. 1. The soundings for most areas were accurate; however, a deep dredge hole in the east arm shown as 40 feet had silted in to 29 feet. Collection stations were established with consideration of depth and prevailing winds (Ruttner, 1963). Five limnetic stations were established, one near the south end of each arm, and 3 approximately transecting the north body. One littoral station was established at the southeast corner and 2 along the north shore. Limnetic stations varied in depth from 5 to 29 feet; littoral stations were all 2 feet deep. The stations are described below.

Station number	Depth	Location
1	29 feet	Between small island and east shore at south end of east arm.
2	5 feet	Near storm drain entrance at northeast corner.
3	11 feet	600 feet from south shore in widest part of north body.
4	11 feet	Near boathouse at northwest corner.
5	8 feet	South end of west arm.
6	2 feet	In cove at northwest corner.

7	2 feet	600 feet east of boat dock on north shore.
8	2 feet	South end of east arm.

A coding system was designed to preclude sample confusion. Collections and stations were numbered. Depths were designated, A (near surface), B (mid-depth), and C (near bottom). A collection labeled 3-4B would represent collection number 3 from station 4 at mid-depth.

Eight field collections were taken at approximate two week intervals from July 19 to November 7, 1972. Collecting was begun shortly after sun up and concluded near 1100. Biological samples were taken with a Juday plankton trip (Tressler, 1939 and Welch, 1948). Samples from limnetic stations were collected from near the surface, at mid-depth, and near the bottom. Samples were washed from the trap and stored in 50 ml. vials in a solution of 5% glycerin in 70% alcohol.

Efforts to obtain quantitative samples from littoral areas were largely unsuccessful. Thick stands of Ceratophyllum sp. prevented proper closing of the trap. Supplementary samples were taken with a Kemmerer sampler and a hand plankton net. The presence of early naupliar stages in all samples verified effective collection of smaller organisms.

Water samples for chemical and seston determinations were removed from immediately below the surface with a

Kemmerer sampler. Dissolved oxygen, free CO_2, pH, and hardness determinations were made at the site with a Hach Chemical Company water test kit.

Secchi readings were taken at each limnetic station. Temperatures were taken near the surface and bottom. Isothermic conditions existed except at the deep hole in the east arm where a thermocline became established in late July and persisted until mid-September. The small hypolimnion created was devoid of dissolved oxygen.

Water samples for seston were returned to the laboratory in one gallon plastic jars and refrigerated overnight. Determinations were made by the filtration method (Welch, 1948, and Andrews, 1972).

Before assaying, biological samples were adjusted to 25 ml. volume by adding or removing fluid. One ml, aliquots were removed by pipette and placed in a Sedgwick-Rafter counting cell. Organisms were placed in a depression slide and identified using a 20-60X dissecting microscope. Note was made of identification, sex, developmental stage, and whether gravid or barren. Five aliquots from each sample were treated as described above. Male diaptomids were identified by viewing the 5th pair of legs from the ventral aspect with a dissecting scope. Female diaptomids are more difficult to identify. The female Diaptomus siciloides has sharply pointed lobes on the genital segment and asymmetrical metasomal wings. These characteristics were unique among this population, and facilitated easy identification of this species. Identification of other female *Diaptomus* required dissection of 5th legs and examination at 400X with a compound microscope. Cladocerans were identified with a dissecting scope; occasional checks were made with a compound microscope to verify species identification.

Cladocerans and cyclopoids were identified by using keys found in Pennak (1953). M. S. Wilson's (1959) key was used for diaptomids, and that of C. B. Wilson (1915) for *Ergasilus*.

After aliquots had been examined, the entire sample was placed in a petri dish and examined to detect taxa which might have been missed by sampling. Finally, samples were returned to the container with a note listing those removed.

Number per liter of each group being studied was determined by the formula ($25n/8x = N$) where

n = total number of each group counted

N = number per liter

x = number of aliquots

25 = number of ml. in total sample

Graphs were constructed to show the population of each of the groups investigated over the study period.

Tables were prepared to show the *Diaptomus* population composition for each collection and at each depth.

To determine if an apparent size-depth correlation in *Daphnia pulex* was real, samples of the animal from each depth were measured with an ocular micrometer, and the sizes compared statistically.

RESULTS

The lake was turbid, isothermal, and well oxygenated. Secchi readings ranged from 16 to 22 inches (Table 1). The turbidity was lowest after a rainless period of two weeks, when temperature of the waters was maximum.

Total suspended solids, or seston, was high, ranging from 20.5 mg/liter to 33.6 mg/liter. Organic portions ranged from 8.2 to 12.8 mg/liter (Table 2).

Hydrogen ion concentration was low; pH values ranged from 8.0 to 9.5. Values were 8.5 on all collections except the two where the high and low were encountered (Table 1). The free CO_2 values found resulted from pH conditions (Reid, 1961). Low concentrations of hydrogen ion promote formation of carbonates, causing CO_2 to be found in the bound or half bound form as carbonates or bicarbonates. The equipment used for CO_2 determinations in Table 1 gave indications in increments of 5 ppm. A reading of zero therefore, does not imply total absence of free CO_2.

Dissolved oxygen levels were consistently high, both in ppm and as percentage of saturation. Oxygen should not be considered ecologically limiting in this lake (Hynes, 1970). Determinations were made shortly after sunrise. By 1100, oxygen usually increased by 2 ppm; other parameters remained constant. The values shown in Table 1 are

Table 1. Chemical and Physical Data

Date	Secchi inches	pH	Free CO_2 ppm	Hardness ppm	Dissolved Oxygen ppm	Dissolved Oxygen % Saturation	Temperature C.
July 19	18	8.5	0	222.3	7	82	23.5
August 2	16	8.5	10	205.2	7	85	25.0
August 16	22	8.0	0	256.5	8	105	26.0
September 2	16	9.5	0	188.1	8	95	24.0
September 14	16	8.5	0	205.2	7	94	20.0
September 27	18	8.5	0	205.2	9	78	15.0
October 18	19	8.5	5	205.2	8	75	12.5
November 7	18	8.5	10	307.8	10	85	9.0

Table 2. Seston (mg/liter)

Collection date	Total suspended solids	Organic	Inorganic
July 19	28.1	9.6	18.4
August 2	30.5	8.6	21.9
August 16	20.5	10.1	10.4
September 2	25.4	8.9	16.5
September 16	33.6	9.9	23.4
September 27	24.4	12.8	11.6
October 18	23.6	8.2	15.3
November 7	26.3	8.4	17.9

the early morning readings. Chemical and physical determinations for August 16 are significant. The rainless two weeks preceding this date would seem to have ameliorated conditions in the lake. The Secchi reading was high, pH low, hardness low, and oxygen level high.

The following crustaceans were collected:

Order Eucopepoda

Suborder Calanoida

Family Diaptomidae

Diaptomus siciloides Lilljeborg 1889

D. pallidus Herrick 1879

D. pygmaeus Pearse 1906

D. sicilis Forbes 1882

Suborder Cyclopoida

Family Cyclopidae

Cyclops vernalis Fischer 1853

Eucyclops agilis (Koch) 1838

Macrocyclops albidus (Jurine) 1820

Family Ergasilidae

Ergasilus chatauquensis Fellows 1888

Suborder Harpaticoida

Family Canthocamptidae

Canthocamptus staphylinoides Pearse 1905

Order Cladocera

Suborder Calyptomera

Family Sididae

Diaphanasoma brachyurum (Lieven)

Family Daphnidae

Daphnia pulex (DeGeer)

Simocephalus vetulus (Muller)

Ceriodaphnia quadrangula (Muller)

Family Chydoridae

Chydorus sphaericus (Muller)

Camptocercus oklahomensis (Mackin)

Pleuroxus denticulatus Birge

Kurzia latissima Kurz

Leydigia quadrangularis Leydig

Family Macrothricidae

Ilyocryptus sordidus

Family Bosminidae

Bosmina longirostris (Muller)

Suborder Gymnomera

Family Leptodoroidae

Leptodora kindtii (Focke)

Order Amphipoda

Family Talitridae

Hyalella azteca (Saussure)

Order Ostracoda

Diaptomus siciloides was the dominant plankter and composed about 98% of the diaptomid population. Fig. 2 shows the diaptomid population range of 37 to 56/liter. Population was highest July 19, and declined through

August 16. A fall maximum of 50/liter occurred in late September. At the completion of the study the population had declined to 37/liter.

Diaptomus pallidus and D. pygmaeus occurred in about equal numbers in association with D. siciloides. Approximately equal numbers of male and female D. pallidus occurred. Only female D. pygmaeus were collected during the study. Males of the species were collected during a preliminary study conducted in June, but not found during the study period. A gravid female D. pygmaeus was collected on September 27, indicating that males were present, probably in greatly reduced numbers. Only two female specimens of Diaptomus sicilis were identified. All of the adult diaptomids were identified to species but the genus was considered as a whole for population tabulations.

Cyclopoid copepods were abundant with Cyclops vernalis appearing most often of the three genera identified. Members of Cyclopidae were also treated together in population data. The population was 7/liter when the study began. The numbers increased gradually through early September, and remained near 25/liter, as shown in Fig. 3.

Ergasilus chatauquensis was common. This copepod is seldom mentioned in the literature. Dorris (1958), who found it in Illinois River floodplain lakes, reported it as previously collected only from Lake Champlain and Lake

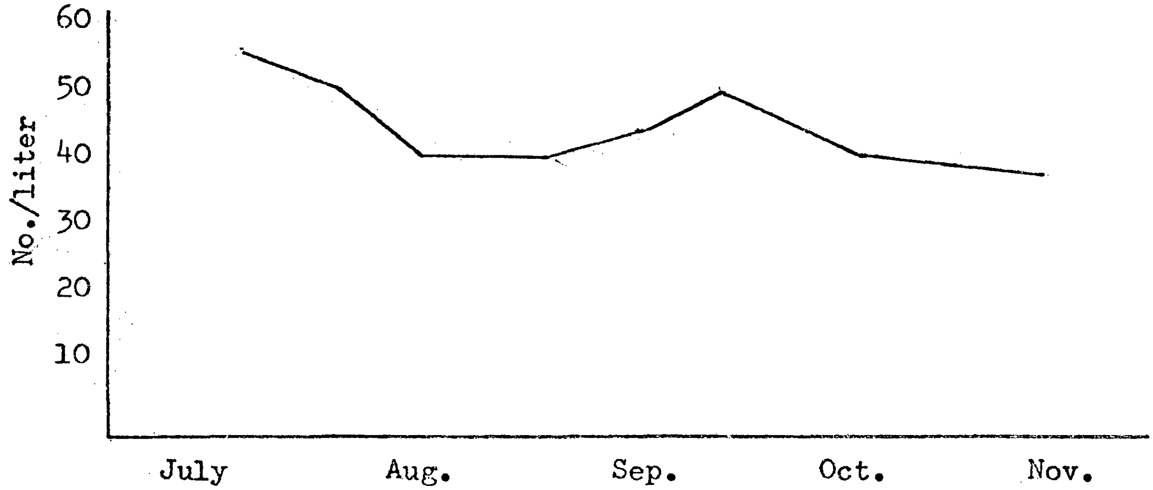

Fig. 2. Number of Diaptomus / liter in Carter Lake.

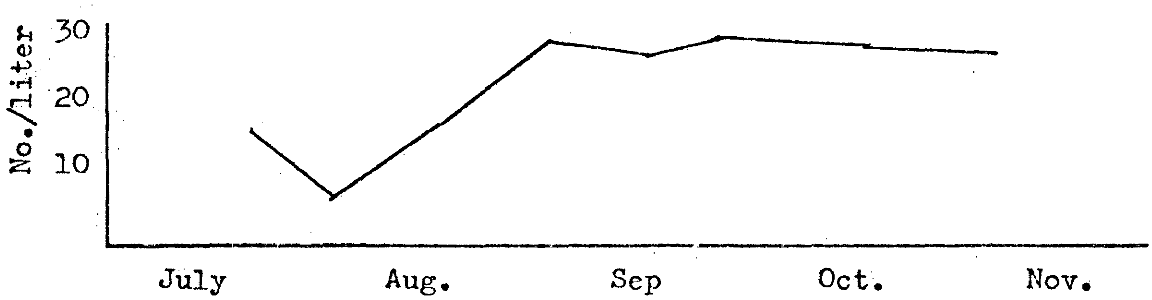

Fig. 3. Number of cyclopoids / liter in Carter Lake.

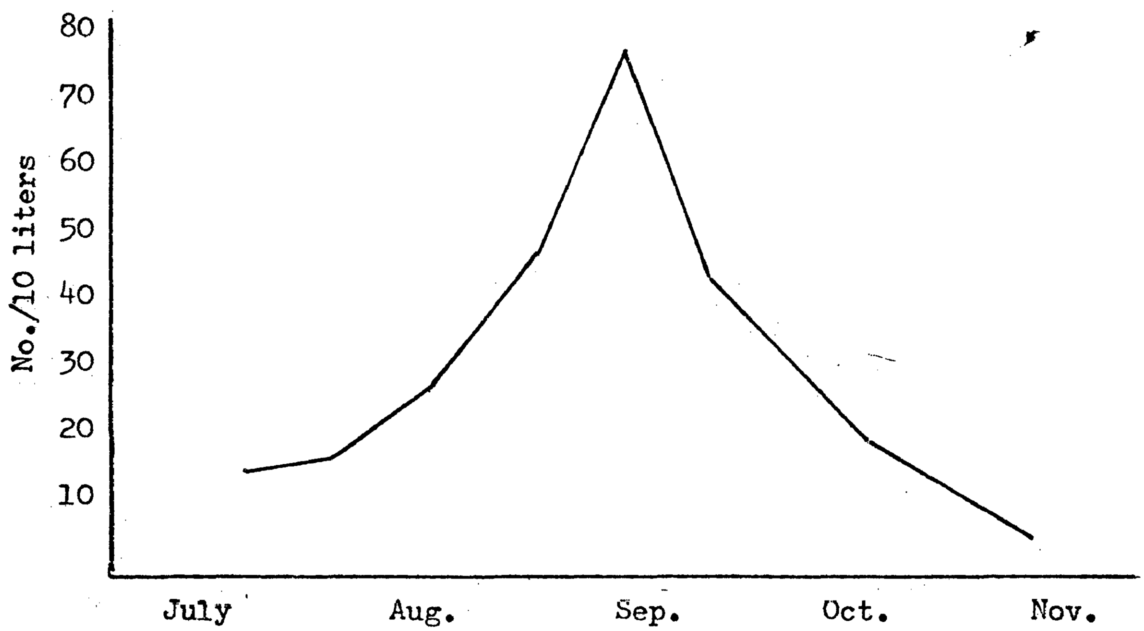

Fig. 4. Number of Ergasilus / liter in Carter Lake.

Mendota. Smith (1949) reported it from Lake Champlain, Lake Mendota, and also from Fairport, Iowa. Wilson (1959) reports it from Cross Lake, Louisiana. They increased from 1.4/liter to a definite peak of 7.5/liter in mid-September. They then declined to less than 1/liter at conclusion of the study (Fig. 4).

Diaphanasoma brachyurum was the dominant cladoceran. Their numbers increased rapidly from 22/liter on July 19 to the apparent annual high of 52/liter on August 2. They then declined steadily to less than 1/liter (Fig. 5) by early November.

Daphnia pulex was the only other common limnetic cladoceran. They were most common July 19, but apparently were already on the decline. By mid-August they had gone from 21/liter to less than 1/liter. Their numbers remained low until late September (Fig. 6) when they began increasing to the 10.5/liter at end of study.

The number and diversity of specimens was greatest in littoral zone samples. Average number of species was 5 in the limnetic samples and 12 in the littoral samples. Thick hornwort (*Ceratophyllum sp.*) in the littoral zone complicated quantitative collecting; relative dominance was based on subjective judgement. The relatively large *Hyalella azteca* appears to be the dominant crustacean of the littoral zone. *Chydorus sphaericus* was abundant, followed closely by the larger *Camptocercus oklahomensis*.

Ostracods were periodically abundant. *Daphnia pulex* and *Diaphanasoma brachyurum* were common there, as well as in the limnetic collections. *Simocephalus vetulus* was common and grew large in size. The average size of cladocerans taken in the littoral zone was greater than that of the same species from the limnetic zone.

Quade (1960) demonstrated that cladoceran species showed preference for certain aquatic plants. The characteristic appeared in Cladocera of Carter Lake, and appeared to exist in other orders as well. Station 6 was in a protected cove where the predominant flora was filamentous green algae. *Chydorus sphaericus* was most abundant in this habitat, with many ostracods and few cyclopoids or diaptomids. Station 7 was a windswept shoreline where *Ceratophyllum sp*. was the dominant plant. This area was favored by diaptomids and cyclopoids. *Daphnia pulex* or *Diaphanasoma brachyurum* were common, according to season. *Camptocercus oklahomensis* were abundant, and *Chydorus* less noticeable. *Simocephalus vetulus* and *Hyalella azteca* were common to both areas.

Leptodora kindtii is unusual in eastern Nebraska, and was not collected in the area previous to 1970 (Brooks, M. E., personal conversation). Fordyce (1901) sampled 58 sites across Nebraska and was unable to find this genus. *Leptodora* is definitely a summer form in

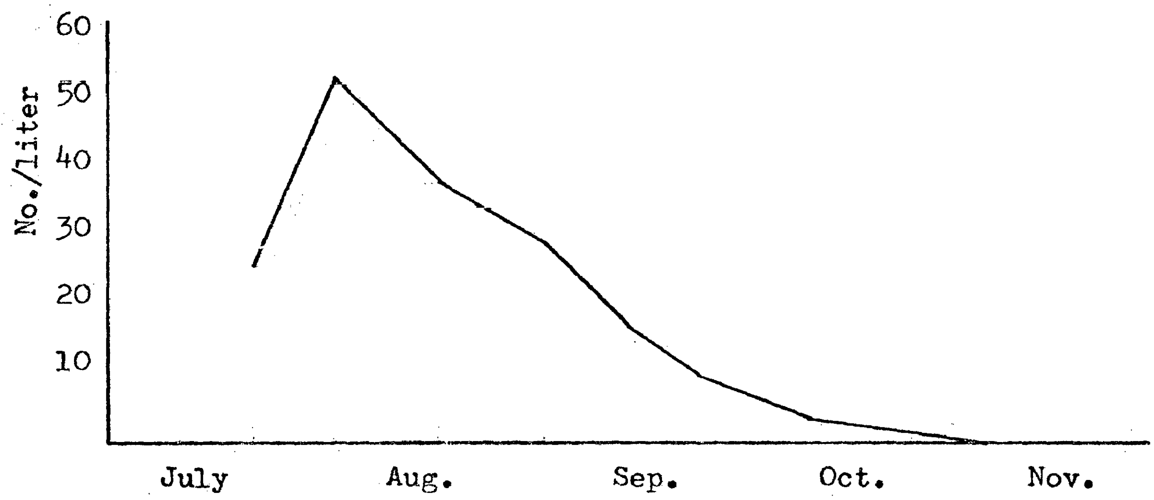

Fig. 5. Number of Diaphanasoma / liter in Carter Lake

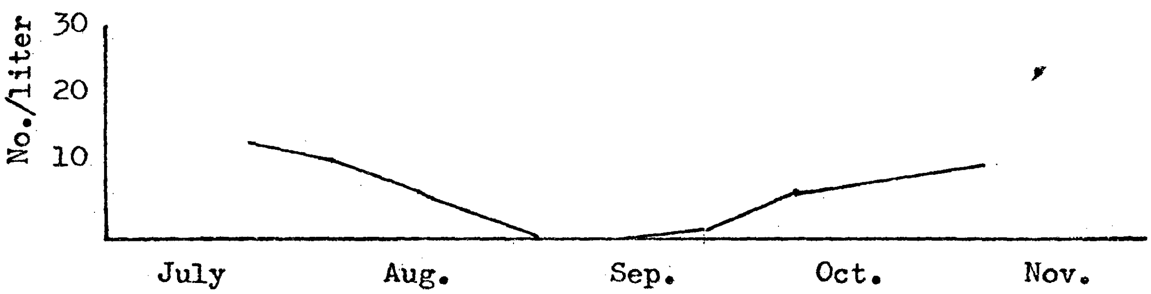

Fig. 6. Number of Daphnia pulex / liter in Carter Lake.

northern lakes (Andrews, 1948). He reported them in Lake Erie from May through October, and Kofoid found them in Winnebago Lake from May through September. They were present in Carter Lake in July, and persisted through late September. Water temperature was 15° at its last appearance. The density of the animal never exceeded 3/liter. Andrews (1948) compared catches between the Juday trap and a tow net; he decided they were able to avoid the Juday trap to some extent.

Only two specimens of *Bosmina longirostris* were found in all of the collections. *Leydigia quadrangularis*, *Kurzia latissima*, and *Ilyocryptus sordidus* each appeared as only a single specimen.

The composition of the *Diaptomus* population was studied. Diaptomids were divided into the following groups: total population, adult males, all adult females, gravid females, and juveniles.

Adults composed from 21% to 42% of the population, averaging 34% over the study as shown in Table 3. They occurred in lowest percentages during the late summer population dip, increasing to 42% during the fall maximum in late September.

Nine to 19% of the population were adult males. These occurred in lowest percentages during the mid-summer minimum and increased to 19.3% shortly after fall maximum. They averaged 14.5% of the population.

Table 3. _Diaptomus_ population composition

Collection	Total population	Adult Males %	All Adult Females %	Gravid Females %	Juveniles %
July 19	56/liter	12.6	19.2	5.0	68.2
August 2	50/liter	13.8	23.6	13.9	63.5
August 16	39.5/liter	9.0	12.2	3.7	78.8
September 2	40/liter	13.1	15.7	7.6	70.1
September 14	43.5/liter	14.5	21.3	10.4	69.0
September 27	50/liter	19.0	21.2	10.7	59.8
October 18	40.5/liter	19.3	18.8	8.1	62.1
November 7	37.5/liter	17.7	16.6	3.0	65.7

The all female category was slightly larger than the all male, averaging 18.4% of the population. They too occurred in low percentages during periods of low overall population.

Gravid females were present during the entire study and in highest percentages on August 16, when they totalled 13% of the population. Note in Fig. 2 that total population was decreasing on this date and continued to do so for some time. During periods when large numbers of females were present, high percentages were gravid.

Juveniles of copepodite stage V or earlier occurred as the largest percentage of the population during periods when overall numbers were low. These data are summarized in Table 3.

Many workers have noted that juveniles and adults of a species occur at different depths (Hutchinson, 1967). Healey (1967) studied the phenomenon in Corbett Lake, B. C., and the subject was pursued in the current investigation. Station 2 was shallow and collections were not made at depth B; accordingly its data are not included in Table 4.

Twenty per cent of total collections, or 6556 diaptomids were examined. As expected, populations were most dense at depths B and C. Concentration of animals was greatest at depth B (Table 4). Adults showed the most affinity for depth B, and males were the most concentrated there of all categories. Adult females were quite evenly distributed between depths B and C, but the gravid females congregated slightly more at depth B than did the barren. Juveniles were more evenly distributed than the adults.

Table 4. Diaptomus clumping

	Depth					
	A		B		C	
Category	number	%	number	%	number	%
Total population	1956	29.8	2409	36.7	2191	33.4
Adults	631	27.1	888	38.1	812	34.8
Adult males	246	29.7	436	42.0	355	34.2
Adult females including gravid	385	29.7	452	34.9	457	35.3
Gravid females	145	28.4	188	36.8	178	32.6
Juveniles	1325	31.4	1521	36.0	1379	32.6

Comita and Anderson (1959) found that gravid females in the hypolimnion carried a greater mean number of eggs than those in the epilimnion. They speculated that the weight of additional eggs might force the animals downward. Clutch size was not studied, but in this investigation the gravid females showed no greater tendency than the barren to sink to the depths. It should be noted that a significant hypolimnion did not exist in this lake.

Healey (1967) showed that juveniles were found at different depth than the adults. Such was not the case in this study.

Oxygen was absent at station 1C during much of the study. Concomitant shunning of the area tended to skew results somewhat by increasing relative percentages present at depths A and B.

A possible correlation between <u>Daphnia</u> <u>pulex</u> size, and depth of collection was investigated. Animals from each depth of one collection, at a station selected at random (Station 4), were placed in a petri dish and swirled. All <u>Daphnia</u> from 4 fields of a dissecting microscope were removed and measured from crest of helmet to base of caudal spine. The mean size for those at each depth was determined. The possibility of gravid animals congregating at one depth and distorting results was eliminated by considering both the entire group, and only those without eggs. The 2 classes created by this measure could then be compared separately.

Size difference was found to be significant only between depths A and C when the entire group was considered. Barren animals from samples at each depth were then considered; differences were found to be not significant in these cases. In both classes, animals from deep collections showed mean sizes 10% to 15% larger than those from collections near the surface (Table 5).

Table 5. *Daphnia pulex* variation in length (mm.) at different depths

Depth	A		B		C	
Class	All	Barren only	All	Barren only	All	Barren only
N	36	33	41	31	40	34
Range	0.38-0.90	0.38-0.86	0.38-1.03	0.38-0.85	0.39-1.07	0.39-0.97
Mean	0.599	0.577	0.659	0.573	0.693	0.643
Standard error	0.026	0.024	0.031	0.025	0.025	0.029
Comparison	A-B all	A-C all	B-C all	A-B barren only	A-C barren only	B-C barren only
"t" value	1.463	2.392	0.807	0.125	1.846	1.960
degrees freedom	75	74	79	62	65	63
Significant	No	Yes	No	No	No	No

Variation in size of *Diaphanasoma* from different depths was also observed. The size of the samples was inadequate for statistical treatment, but the trend of large animals from deep collections was apparent. This aspect of cladoceran ecology would appear to be worthy of further study.

DISCUSSION

Secchi readings from a few centimeters in turbid lakes, to 40 meters in Crater Lake (Hasler, 1938) have been reported. Hutchinson (1957) reports that Secchi transparency for small Wisconsin drainage lakes ranged from 1.0 to 1.4 meters. He found transparency inversely related to seston content and was unable to separate effects of dissolved and particulate matter. Kikuchi (1937) and Yoshimura (1938) have determined that the Secchi disk disappears at the level of from 5% to 12% of solar radiation. Secchi readings in Table 2 indicate that little light penetrates below 2 feet. This was substantiated during a dive to recover a lost sampler. Complete darkness was encountered almost immediately after leaving the surface.

Total seston of 20.5 to 33.6 mg/liter, shown in Table 2 was high. Brinker (1967) found total seston of 8.6 to 10.9 mg/liter in a Nebraska farm pond. Organic portions ranged from 2.1 to 4.1 mg/liter. Thomas (1961) found total seston values of 0.77 to 7.72 mg/liter in selected farm ponds. He did not determine organic content.

Seston and Secchi readings in this lake are quite compatible. High organic seston reflects high productivity. The high inorganic content reflects high amounts of suspended silt and dissolved materials.

Nebraska waters tend to be basic. Thomas (1961) and Brinker (1967) found values ranging from pH 8.0 to pH 9.0. Crustaceans are adapted to a wide range of hydrogen ion concentrations; values between pH 6.0 and 8.5 are not usually of ecological significance (Hutchinson, 1967). Brooks (1956), however, found a rapid drop in the number of cladoceran species present in waters with pH 8.0 or above. The values for Carter Lake (Table 1) were generally 8.5. The high of 9.5 is somewhat extreme; persistence at this level could be limiting to fish as well as crustaceans and other invertebrates. The Hach method which was used, allows pH determinations in increments of 0.5. This accuracy was deemed adequate for this study.

Levels of CO_2 were consistently low, as one would expect in a hard water lake (Reid, 1961). In aqueous systems, CO_2 combines with H_2O to form H_2CO_3. Depending on conditions of pH and availability of cations, the H_2CO_3 may dissociate into $H^+ + HCO_3^-$. In waters where pH is low and calcium plentiful, conditions promote formation of $CaCO_3$, and CO_2 is found in this bound form. Low levels of free CO_2 are not limiting to crustaceans (Brooks, 1956, and Hutchinson, 1967).

Hardness (Table 1) indicates $CaCO_3$ and $Ca(HCO_3)_2$ in ppm. The term "hardness" is often used to express the total alkaline earth content (Hutchinson, 1957). The high readings found place the lake in the hardwater category, according to parameters established by Welch (1935), Reid (1961), and Ruttner (1963).

Dissolved oxygen was plentiful, in terms of both absolute and percentage of saturation (Table 1). Hutchinson (1957-1967), Reid (1961), and Ruttner (1963) thoroughly discuss the relationship between organisms and oxygen. The different families of crustaceans vary in oxygen requirements, but generally find 2 ppm adequate. In general, copepods are more tolerant of oxygen deficiency than cladocerans. _Cyclops_ and _Canthocamptus_ have often been collected from areas with complete oxygen deficiency (Pennak, 1953).

Maximum temperature occurred on August 16. The 26° which occurred may be considered moderate. Many of the groups encountered may be found in shallow ponds and ditches where temperatures approach 40° (Ratzlaff, 1952 and Brooks, 1956). Temperature must, however, be considered important in the composition and size of the crustaceans found in the waters (Aycock, 1942 and Hutchinson, 1967).

A "typical" planktonic population in temperate latitudes is often at its lowest abundance in early spring (Hutchinson, 1967). As temperature increases the population increases, usually reaching peak numbers by June. Numbers often decline through midsummer, then show a less rapid increase through autumn before dropping to low winter numbers.

The reasons for such cycles have been sought by many workers. Effect of temperature was examined by Birge (1898), Ward (1940), Pratt (1943), Comita and Anderson (1959) and Hall (1962). An explanation in food supply was sought by Cheatum et al (1942), Pennak (1946-1949), Anderson et al (1955), Borecky (1956), Comita and Anderson (1959), and Hall (1962). Others looked for a chemical answer (Borecky 1956; Hazelwood and Parker 1961; Hall et al 1970). Effects of competition in the cycles were examined by Pratt (1943), Frank (1952), Slobodkin and Richman (1956) Parker (1960-1961), Paine (1966-1969), and Hall et al (1970).

Hall's (1962) study of Daphnia mendotae has done much to clarify effects of temperature and food supply on cycles. He found that a population existing at moderately low temperature on moderate food supply could be made to increase rapidly by increasing either factor. Raising the temperature increased the frequency of molting. Since a brood was released at each molt, the frequency of brood release was increased. When Hall increased the food supply, broods became larger.

Pratt (1943) found the death rate of Daphnia magna strongly density dependent, and egg production inversely related to density. Slobodkin (1954) fed Daphnia obtusa standard amounts of Chlamydomonas, and found the animal linearly dependent on food supply.

Considering all the above, Hutchinson (1967) has postulated the chain of events which occurs in a population cycle. As temperature increases in the spring, food supply in the form of algal growth becomes abundant. Increased temperature increases frequency of brood release, and the abundant food supply increases the number of eggs produced in each brood. As a result of these factors, the population increases logarithmically. Swarms of young begin to decimate the food supply and development slows, and as starvation occurs, numbers decline slowly. Reduced numbers gradually allow egg production to increase, and with the increased nutrients available at the lower population level, numbers again begin to increase.

Diaptomid population cycles vary greatly. In arctic or alpine lakes, the population may develop from resting eggs, and the entire population may be approximately the same instar, with the female/male ratio being variable. In temperate lakes, reproduction may occur all year, usually showing pulses. Nauplii and copepodites may be present throughout the year, or absent part of the time. Males also, may be absent part of the time, but during the breeding season they usually outnumber the females (Hutchinson, 1967).

Comita and Anderson (1959), working with _Diaptomus ashlandi_ in Lake Washington, found that females made up from 25% to 100% of the adult population. In Corbett Lake, British Columbia, Healey (1967) found females present as 28% to 70% of the population. These workers found juveniles absent much of the time, but present at other times in numbers several times greater than adults.

Females in Carter Lake ranged from 49% to 63% of the adult population. Gravid females were most numerous on August 2, when they made up 13.9% of adults. At the same time the percentage of females reached its high of 63%. The population, minus nauplii which were not counted, was declining then. The decline continued until early September, when nauplii, resulting from reproductive activity in August, began reaching copepodite stage.

The lowest percentage of gravid females (3%) coincides with the low percentage of females in the adult population on November 7. The scarcity of gravid females in the last collection showed a rapid decrease in reproductive activity. A sample taken after the study period on March 10, 1973, lacked instars between nauplius III and copepodite IV.

Time spent as each instar is temperature dependent (Hutchinson, 1967). Data developed by Comita and Anderson (1959) and others (Hutchinson, 1967), however, indicates that the missing instars would take 80 to 100 days to have developed. One must assume that reproductive activity was greatly curtailed for this length of time.

Males were present during the entire study. Proportions ranged from 38% to 51% of the adult population, outnumbering females only in the last collection. The female/male ratio here was more constant than in studies of Comita and Anderson (1959) and others (Hutchinson, 1967).

The reason for the size difference of Daphnia pulex between surface and bottom poses an interesting problem. The characteristic is difficult to separate from, and in fact may be, another aspect of diurnal migration. Cushing (1951) related the two subjects. He showed a typical population concentrating near the surface during hours of darkness. About 0600, concentrations began moving deeper, and sank steadily until near 1500, when the trend was reversed. Density centers then moved upward, and arrived near the surface about 2100. This idealized picture is the result of thorough study and is widely accepted.

Cushing (1951) found migration modified by four factors: weather, sunlight, temperature, and phytoplankton density. He acknowledged that intraspecific differences are found, and responses may differ between sex, age, and broods of the same species.

Birge (1898) found young Crustacea nearer the surface than the old. Juday (1904) found in cases where young and old both migrate, young appeared at the surface earlier and left later than adults. Steuer (1901) showed experimentally that young Cyclops showed more affinity for the surface than did the mature animals. Pennak (1944) also found this in Diaptomus shoshone. Ruttner (1914) found no vertical difference in adult and juvenile Cyclops strenuus. Southern and Gartner (1932) and Worthington (1931) found small Daphnia longispina near the surface, and the large animals lying deep in the water. Worthington (1931) found the same habit in Diaptomus gracilis and Bosmina longirostris.

Cushing concluded that animals which customarily live in waters near the bottom have young which live near the surface. If the adults live near the surface, the young will live deep in the waters.

Eyden (1923) measured sinking rates of Daphnia pulex and found variation, both diurnally and seasonally. Large specimens (2.0-3.0 mm) sank at 0.80 cm/sec to 0.98 cm/sec, and small (1.5-2.0 mm) specimens sank at rates of 0.43 cm/sec to 0.61 cm/sec. Hutchinson (1967) in his literature review quotes studies (Lowndes, 1938-1942; Hamilton, 1958) which place the specific gravity of Daphnia pulex at 1.017 at 7°C. Size of the specimens measured is not mentioned. Hutchinson continued to explore the effect of expansion with temperature change on specific gravity of the animal. He related the factors with changing density and viscosity of the water and concluded that they sink faster in cold water.

Consideration of the many variables suggest possible reasons for differences in size at various depths when it does occur. *Daphnia* are filter feeders, utilizing small diatoms, bacteria, and detritus particles. The size of the particle which the animal can ingest is a factor of the animals size (Pennak, 1953). High productivity in the euphotic zone and natural wind caused turbulence combine to keep a rich supply of these small food particles near the surface (Hutchinson, 1957). The turbulence also acts effectively on small *Daphnia*, and little effort is required on their part to stay in this food rich area. The result is an adaptation which effectively avoids competition between small and large *Daphnia* (Cushing, 1951).

SUMMARY

Carter Lake, Nebraska, a Missouri River oxbow, was sampled at two week intervals from July 19 to November 7, 1972. Samples were analyzed for dissolved oxygen, free CO_2, pH, seston, transparency and numbers of crustaceans per liter. The waters were turbid, isothermal, well oxygenated, and hard. Hydrogen ion concentration was low and seston content high.

Twenty two species from 11 families of crustaceans were observed. Diaptomus siciloides, occurring congenerically with two other species, appeared mostly in the limnetic zone, and was the dominant crustacean. Daphnia pulex, Diaphanasoma brachyurum, and three species of Cyclops were also abundant in the limnetic zone. In the littoral zone, Hyalella azteca was dominant over Chydorus sphaericus, Camptocercus oklahomensis and ostracods.

Diaptomus populations ranged from 37.5 to 56/liter. The population averaged 67% juveniles, 18% adult females, and 15% adult males. Gravid females were present during the entire period. They averaged 7.7% of the population and were most abundant when adult females were numerous. Low numbers of gravid females in the last collection

indicates that reproductive activity is curtailed during the winter months. *Daphnia pulex* from samples near the bottom were significantly larger than those taken near the surface.

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