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# Population Dynamics of *Chaoborus* and Zooplankton in a Small Lake Before and After the Introduction of Fish

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# POPULATION DYNAMICS OF CHAOBORUS AND ZOOPLANKTON IN A SMALL LAKE BEFORE AND AFTER THE INTRODUCTION OF FISH [1]

By Merle G. Galbraith, Jr.

## Abstract

Two lakes adjacent to one another, which contained no fish were studied from 1973 through 1975 to determine seasonal and yearly changes in abundance of zooplankton. Rainbow trout (Salmo gairdneri) were stocked in one lake in 1976 and 1977, while the other lake served as the control. The study continued during, and for 2 years after, the stocking of trout to determine the impact of fish on the unexploited zooplankton population and the response of zooplankton to the cessation of stocking.

Before the introduction of trout Diaptomus leptopus, Holopedium gibberum, Diaphanosoma brachyurum, a rotifer, and two species of Chaoborus were abundant in both lakes. Daphnia pulex, the only species of Daphnia present, was rarely found in either lake. After the introduction of trout there was an immediate decrease in the Chaoborus population in the lake with trout, accompanied by a nearly 37-fold increase in the number of large ($\gtrapprox$ 1.35 mm) daphnids. There was no such change in the control lake. The copepod D. leptopus, the most abundant zooplankter present in both lakes, was not affected by trout. However, this species declined in both lakes during the last 2 years of the study. After cessation of stocking, the density of Chaoborus increased to about one-half of its former pre-trout level. Water clarity was highest while fish were present and daphnids were abundant.

The most important food items in the gut of rainbow trout during the first year of stocking were Daphnia, Anisoptera, Tendipedidae, Amphipoda, and Chaoborus. During the second year, the most important food items were Daphnia followed in significance by Trichoptera, Tendipedidae, Zygoptera, Hemiptera, and Hirudinea. The absence of Chaoborus, Amphipoda, and Anisoptera in the second year indicated that predation on these items was severe. The growth of the trout the first year was exceptional with an average increase in length of 16.6 cm from May through October. The trout planted in 1977 grew at about the same rate but their condition appeared to decline. The stocking rate of 101 trout per hectare matched the potential production of the lake the first year but it appeared to be too high a rate for the lake on a sustained basis.

Many studies have shown that the introduction of planktivores can have a deleterious impact on the Chaoborus population, but few studies have

[1] Contribution from Federal Aid in Fish Restoration Project F-35-R, Michigan.

documented tremendous increases in large daphnids following an introduction of planktivores. Apparently the near elimination of Chaoborus by trout in this study lake was responsible for the large increase in daphnids. After most trout disappeared from the lake the number of large daphnids declined but in contrast to the pre-trout years they still comprised a significant part of the zooplankton population.

Other studies have shown that Chaoborus prey heavily on copepods. If this had occurred in this study lake, the near elimination of Chaoborus should have permitted the copepods to increase. However the abundance of copepods remained at about the same level and did not change until after trout had disappeared. The expected replacement of large planktonic crustacean species by smaller forms following fish introduction did not occur.

## Introduction

Until recently very little was known about seasonal and annual fluctuations of zooplankton in lakes without fish. During the last decade, however, there have been many studies published which compare the differences in species composition of zooplankton between lakes with and without fish (Nilsson and Pejler 1973; Northcote and Clarotto 1975; O'Brien 1975; Sprules 1975). Most studies of fishless lakes have been surveys of short duration. Some investigators have studied the dynamics of zooplankton in absence of fish following treatments with rotenone. However, these invertebrate communities become temporarily unstable and cannot be expected to help us understand fully the natural dynamics of zooplankton populations. Very few studies have dealt with the dynamics of natural zooplankton populations in fishless lakes over extended periods of time. Anderson (1972), and Northcote et al. (1978) have made intensive studies of the zooplankton in lakes without fish, both before and after the introduction of fish. The objectives of this study were to ascertain: (1) the impact of introduced rainbow trout on an unexploited zooplankton population, and (2) the response of zooplankton after permitting the lake to revert to a fishless state.

Two small lakes, Sid and Deer, were selected for study because they contained no fish. In May 1973, I started collecting plankton samples from both lakes at monthly intervals and continued sampling through 1980. In 1976 and 1977, Sid Lake was stocked with rainbow trout (*Salmo gairdneri*) and Deer Lake, the control lake, remained virtually fishless.

## Description and Methods

The two study lakes are located in the eastern half of the upper peninsula of Michigan, 5 miles south of Lake Superior, in Luce County. These lakes are situated in an infertile sand plain which is covered by a thin mantle of organic matter. The vegetative cover surrounding the lakes is mainly red and white pine with hemlock and maple interspersed. Both lakes are inaccessible by road and may be reached only by hiking, which may explain why they contained no fish. Sid and Deer lakes are approximately 3.2 and 8.0 hectares in size, respectively, and Deer Lake is slightly deeper--13.7 vs. 12.2 m maximum depth. Both are dimictic and stratify thermally. Dissolved oxygen, measured by the Winkler method, is usually present at the bottom in both lakes. Only during August and September of some years was there no oxygen at the bottom. There is always adequate oxygen in both lakes for invertebrates down to 9.8 m. The water in both lakes was acidic (pH 4.5-5.9), poorly buffered (total alkalinity of 1-9 mg/liter) and thus relatively infertile. Values of pH were determined in the field using a battery operated Model 47 mini-pH-meter and rechecked in the laboratory with an Orion Model 407A electric pH meter.

Plankton was collected with a Wisconsin-type plankton net 80 cm long with a mouth diameter of 11.75 cm. The mesh size of the Nytex net was 160$\mu$ and the filtration ratio was 8.9 to 1. Water clarity was determined with the plankton net because its diameter is nearly as large as a secchi disk and it was convenient to carry. The deep basin in each lake was divided into four quadrants and four samples were collected each month, one from each quadrant. The general location of each collecting station was the same each month, but the exact position in each quadrant was varied to assure a minimum oxygen content of 0.1 ppm at the bottom. The sampler was lowered to the bottom at each station and retrieved vertically at the rate of approximately $1\frac{1}{4}$ m per second. Immediately prior to each chemical analysis all water samples were visually inspected for live zooplankton and their number and genera recorded. Rarely were any zooplankters present in the strata containing less than 0.1 ppm of oxygen.

Plankton samples were preserved in the field with 5% formalin. They were sorted in the laboratory by filtering them through a series of three wire screens of 30-, 50-, and 100-mesh per inch, and preserving the organisms retained on each screen separately. Lengths of the _Daphnia_ and copepods were measured from the anterior portion of their head to the base of the spine or to the end of the caudal ramus using an ocular micrometer in a binocular microscope. Large size zooplankton were considered to be $\gtrsim$1.35 mm. Most large zooplankters were removed by the 30-mesh screen and by hand selecting those marginally large individuals which were forced through the 30-mesh screen in the washing process. _Daphnia pulex_, _Diaptomus leptopus_, _Holopedium gibberum_, _Chaoborus americanus_, _C. punctipennis_ and _C. flavicans_, were the large organisms present. The large zooplankters were counted using a binocular microscope and their volumes were measured in a graduated centrifuge tube following a standard procedure of centrifuging. The number of plankters is presented in the tables as the mean number per net haul. To convert these figures to mean number per square meter it is necessary to multiply by 91.73 and to convert them to numbers per liter. Sid Lake values must be divided by 116 and Deer Lake values by 126.

Arbitrary levels of abundance were assigned to the medium- and small-sized species according to whether they were most abundant, many, quite-a-few, some, few, or rare. These groups were ranked 0-6 with 0 equal to none observed and 6 the most numerous.

Yearling rainbow trout, averaging 14.9 cm in total length, were stocked in Sid Lake during May of 1976 and 1977 at a density of 322 (12.7 kg) and 300 (12.2 kg) trout per year, respectively. The public was not advised of these plantings and apparently no one fished for them during the first 2 years. No fishermen were ever seen at the lake, however signs of someone having fished from shore were found in October of 1977. Hence, during the first 2 years I considered that fish mortality was due either to natural causes or to netting.

Two 38-m experimental gill nets, and hook-and-line, were used to collect fish samples. Except for September 1976, nets were set every month during June through October 1976 and 1977. Fish sampling ceased after June 1978 because no fish were being caught. Stomachs were removed from the fish caught, flushed out immediately, and their contents preserved for later identification in the laboratory. Stomach contents were sorted by the major taxons and the individual organisms were counted. Total net weight for each taxon was determined by weighing them on a Mettler electro-balance to the nearest 0.01 g.

## Results

Before the introduction of rainbow trout in Sid Lake, the clarity of both lakes was similar. Clarity ranged from 6.7 m in early summer to 4.1 m in late summer (Table 1). After trout were stocked, however, the transparency in Sid Lake increased considerably. From July 1976 to October 1977 the clarity ranged between 6.7 m and 9.5 m. In 1978, after the trout population had diminished, the clarity dropped to pre-stocking levels.

Although the amount of dissolved oxygen was generally higher in Sid than in Deer Lake, part of the difference was probably due to the slightly deeper water sampled at Deer Lake. Fluctuations in dissolved oxygen during the summer were extreme at Sid Lake compared to Deer Lake. These fluctuations were undoubtedly due to periodic algal blooms and to an earlier fall turnover in Sid Lake.

It is noteworthy that when these two lakes were first checked for pH (1973) both were 5.9. However, 7 years later the pH of Sid Lake had dropped to 4.5 from surface to bottom whereas at Deer Lake it remained the same.

Four organisms dominated the zooplankton in both lakes before the introduction of trout--*Diaptomus leptopus*, *Holopedium gibberum*, *Diaphanosoma brachyurum*, and a rotifer. Two species of *Chaoborus*--*americanus* and *flavicans* were also abundant. *Daphnia pulex*, the only species of *Daphnia* present, was about equally abundant but rare in both lakes. Other rarely occurring plankters were the small cladocerans: *Alona* sp., *Bosmina coregoni*, *Chydorus sphaericus*, and *Polyphemus pediculus*. The former three species were always present at Deer Lake, but none of these were present in Sid Lake until after the introduction of trout--then *E. sphaericus* and *P. pediculus* were observed only rarely. The potentially large plankters, *D. leptopus*, *H. gibberum*, and *Chaoborus*, dominated the plankton in both lakes throughout this study, but in Sid Lake they shared their dominance with *D. pulex* after trout were introduced. Many more very large copepods were observed in Sid Lake during the 3 years before trout were introduced. In both lakes the large *D. leptopus* which were collected in late summer and early fall had colorful bright orange bodies with dark purple antennae. These colorful copepods were observed late in the season most years at Deer Lake, but bright colored individuals disappeared in Sid Lake after trout were planted. They did not reappear until the fall of 1978 after most trout were gone.

Tables 2 and 3 contain monthly averages per net haul of the numbers of large plankters, and the total net-plankton volume, arranged by study periods: pre-trout (1973-75), trout present (1976-77), and post-trout (1978-80).

Daphnids were very rare in both lakes prior to 1976, and the small differences which existed between lakes were not significant ($\alpha = 0.05$). However, during the 2-year period when trout were stocked in Sid Lake, the number of daphnids exploded, whereas in Deer Lake (control) there was no significant change. In 1978-80, following the decline of the fish population in Sid Lake, the number of daphnids also declined, but their density remained significantly much greater than in Deer Lake both on a monthly and an annual basis. During the periods of greatest abundance in Sid Lake, daphnids were most numerous during September and October 1976-77 and during August 1978-80.

The change in density of large daphnids before, during, and after fish introduction was highly significant ($\alpha = 0.05$). The average number of daphnids increased from $5.2 \pm 8.9$ for the 1973-1975 period to an average of $182.9 \pm 8.9$ during 1976-77. After the trout population declined in 1978, the density of daphnids also decreased to an average of $8.1 \pm 8.9$ during the

1978-1980 period. Collections during 1980, the final year, however, indicated that daphnids were beginning to increase.

The volumetric index per net haul was calculated for large Daphnia (Table 4), as this is indicative of their mean size (Galbraith 1975). This index can be used to detect a change in the mean size of the large daphnids due to size-selective predation by fish (Galbraith 1967). A value between 0.30 and 0.60 indicates that the majority of large daphnids are not much larger than 1.34 mm. When they are smaller than this size rainbow trout usually cease feeding on them. In Sid Lake there was never a reduction in the mean size of large Daphnia after trout were introduced.

Daphnia, both large and small, were rare in Deer Lake throughout the three study periods. There was an increase in large daphnids during 1978-80, but the difference was very small--6.6 ± 1.2 individuals compared to 4.1 ± 1.2 in 1976-1977, and to 1.8 ± 1.2 in 1973-1975. Thus in the control lake the daphnid population remained stable and sparse throughout this study.

The copepod Diaptomus leptopus was the most abundant plankton organism present in both lakes when all of its instars were included. Before trout were introduced the average number of large copepods differed significantly between lakes (93.2 ± 7.1 individuals in Sid Lake vs. 63.2 ± 4.4 in Deer Lake). But during the 1976-1977 period copepods in Deer Lake increased sufficiently to equal the number in Sid Lake. There was no difference in abundance during 1978-80 when there was an equivalent decline in density in both lakes.

The density of copepods in Sid Lake was the same both before and during the presence of trout but afterwards declined significantly, from 91.9 ± 7.1 to 22.6 ± 7.1. In the control lake the number of copepods increased during 1976-77 from an average of 63.2 ± 4.4 individuals to 94.0 ± 4.4, but then like Sid Lake they abruptly declined during 1978-80 to 22.7 ± 4.4. Monthly fluctuations in the density of large copepods in both lakes were too great to show significant seasonal differences in abundance.

The average number of Chaoborus present in the pelagic zone was the same in both lakes during 1973-75. Thereafter, however, there were more Chaoborus in Deer Lake than in Sid Lake especially during 1976-77 (26.7 ± 2.3 vs. 2.5 ± 0.4) when trout were present in Sid. Differences between lakes for the 1979-80 period were barely significant because of the resurgence of Chaoborus in Sid Lake. Chaoborus population in Deer Lake remained very stable throughout this study. In contrast, there was a 14-fold decrease in the Chaoborus population at Sid Lake after trout were introduced. By August of 1976, almost no Chaoborus were collected in the samples. They remained rare throughout 1977 and did not show any sign of recovering until July 1978, when C. punctipennis first appeared. Subsequently Chaoborus increased to about one-half their abundance during the pre-trout period (17.6 ± 0.4 vs. 29.8 ± 0.4). Because species of Chaoborus differ in time of recruitment (von Ende 1978) peak densities may have been missed in some years by starting the sampling too late in the season. However, during the years fish were absent, Chaoborus spp. were most abundant in both lakes during June, July, and August.

The volume of plankton samples was determined in order to detect any significant changes that occurred among the minor zooplankters which might remain undetected as a result of considering only the major zooplankters. Chaoborus were excluded from the total plankton volume measurements. There was no significant difference in the amount of net plankton between Sid and Deer lakes during the beginning period of this study. However, when trout were present (1976-77) the volume of plankton in Sid Lake increased to a level significantly greater than in Deer Lake. This increase was due to both the large increase of daphnids in Sid Lake and to the simultaneous decrease in plankton at Deer Lake. The changes in plankton abundance during this period indicate considerable differences between the two lakes. After 1977, no changes occurred in the total volume of plankton in Deer Lake, but in Sid Lake the total volume decreased. The decline in Sid Lake after 1977 was due to the significant decline in large daphnids and copepods. As might be expected, the seasonal abundance of net plankton was generally highest during the early part of the season in both lakes.

Monthly rankings of abundance of each taxon for the medium- and small-sized zooplankton were determined each year, and a yearly average determined for each of the three study periods (Tables 5 and 6). The number of medium-sized D. pulex in Sid Lake increased during and after fish introduction. There was no change in the number of medium-sized copepods in Sid Lake during the first two periods but after most of the trout were gone they declined. The relative abundance of medium-sized copepods in Deer Lake, however, increased throughout the study. The abundance of rotifers and Diaphanosoma declined in Sid Lake after trout were introduced but the rotifers increased after trout were depleted. In contrast, in Deer Lake, rotifers declined abruptly during the same period but then remained sparse.

Diaphanosoma did not decline and remained quite stable throughout the entire study. Filamentous algae apparently decreased in Sid Lake after trout were introduced and again increased as the trout were depleted. This observation is corroborated by the increased clarity observed while fish were present. This temporary increase in clarity in Sid Lake can probably be attributed to the increased grazing on the phytoplankton by the large population of Daphnia.

Traditional methods used to show the relative importance of various food items consumed by fish are adversely affected by such factors as differences in size and volume, and to differential rates of digestion of the food organisms. I have chosen to use an index of relative importance (IRI) adapted from the version by Pinkas et al. (1971).

$$IRI = \sqrt{(NP + VP) \times F_o}$$

where:

NP = the numerical percentage

VP = the volumetric percentage

$F_o$ = the frequency of occurrence percentage of the major organisms in the gut

The square root of IRI has been used here to reduce the number of digits in the index. The data are presented in Table 7 in descending order or importance. The most important food items in the gut of rainbow trout during their first year in Sid Lake were Daphnia, Anisoptera, Tendipedidae, Amphipoda, and Chaoborus. Dragonfly larvae (Anisoptera) and amphipods were most important during the first month and daphnids, tendiped larvae, dragonfly larvae, and Chaoborus comprised the bulk of their diet during the remaining months. Daphnids had not yet become abundant by June, otherwise they probably would have been consumed in greater quantity that month.

Surface activity by feeding trout and number of trout taken in the nets each month indicated that survival during 1976 was exceptional. During July when the trout were most active in the pelagic zone, and feeding mostly on daphnids, one of the trout stomachs contained 20 rotifers. Judging from observations of rainbow trout stomach contents from many Michigan lakes, and from the published literature, the presence in stomachs of rotifers is extremely rare.

In 1977 the most important food items in trout stomachs were Daphnia followed in significance by Trichoptera, Tendipedidae, Zygoptera, Hemiptera, and Hirudinea. Predation on Chaoborus, amphipods, and Anisoptera larvae during 1976 was apparently the cause of the decline in their abundance in the 1977 stomach and plankton samples. During 1977 surface activity of the trout decreased considerably as the season progressed and trout were much harder to catch. By the spring of 1978 it was difficult to catch any trout and in the ensuing months and years there were very few signs of trout present. Thus, for the purpose of this study, Sid Lake was considered to be nearly void of fish after the winter of 1977-78.

The growth of trout during 1976 and 1977 was very rapid and as is often the case, was especially rapid during their first year in the lake (Table 8). They were planted in mid-May at an average size of 14.9 cm and a month later had grown 7.5 cm. By October they had attained an average length of 31.5 cm. Survival over winter was good and by October 1977, some fish had attained lengths of 40.9 cm.

The trout stocked in 1977 grew at about the same rate but their condition factor was not as good, their flesh was not as pink, and fat deposits in the body cavity were rare. Apparently the stocking rate of only 101 trout per hectare was not out of line with the potential lake productivity the first year. Sampling during 1976 alone removed 4.1 kg per hectare of fish biomass. Projecting this and assuming a conservative 60% survival the first year, the annual biomass of fish produced in Sid Lake (weight removed - weight planted) amounted to 17.7 kg/hectare. Based on the apparent decline in the invertebrates consumed by the trout in 1976 as well as the apparent decrease in their condition it is doubtful that this much biomass could be produced on a sustained basis.

## Discussion

The average annual abundance of the large planktonic invertebrates in Sid and Deer lakes is presented in Fig. 1. For a comparison of the averages for other organisms refer to Tables 5, 6, and 7. The most dramatic impact the introduction of fish had on the zooplankton was the abrupt decline in the density of Chaoborus, and the immediate increase (nearly 37-fold) in the population of large ($\gtrless$ 1.35 mm) D. pulex. An abrupt decline in a Chaoborus population after fish are introduced is a common occurrence (Stabl 1966; Pope et al. 1973; von Ende 1979). Trout stocked in Sid Lake in May 1976 must have fed intensely on Chaoborus. By mid-June Chaoborus were already rare and by August they were almost absent in plankton samples. They were not rare in Deer Lake and they were not rare in either lake during June in previous years. Thus the decline was not seasonal in nature. Northcote et al. (1978), also found that Chaoborus declined abruptly in two study lakes after trout stocking and they attributed this decline to fish predation.

Seldom has such a rapid increase of large daphnids, especially in the presence of planktivores, been documented in the literature. Pastorok (1980), citing Neil (unpublished) stated that in the absence of Chaoborus, Daphnia rosea populations may double their abundance within a month. Northcote et al. (1978) also detected an increase in the daphnid population in Eunice and Katherine lakes after trout were introduced but it was not nearly as dramatic as the increase in this study. Because of the high fecundity and short generation time of Daphnia such a response might be expected if predation by Chaoborus was controlling the population (Anderson and Raasveldt 1974).

I attribute the large increase in daphnids in Sid Lake to the near elimination of Chaoborus. There is much evidence which indicates that Chaoborus prefers Diaptomus copepods over daphnids especially when the former are abundant (Sprules 1972; Swüste et al. 1973; Anderson and Raasveldt 1974; Fedorenko 1975a and 1975b). From this evidence it seems that the Diaptomus population in Sid Lake should have responded to the depletion of Chaoborus, unless the newly introduced trout were also preying heavily on diaptomids. But, based on the stomach analysis trout in 1976 were not eating very many copepods. They were feeding on Daphnia, Anisoptera larvae, amphipods, and Hemiptera larvae. Hence, contrary to the results of other investigators, Chaoborus in Sid Lake apparently preferred daphnids over copepods because after Chaoborus were nearly eliminated the population of copepods remained at the same level of abundance and the daphnids increased. If D. leptopus had also been a controlling influence on the daphnid population, the effect was not very apparent. The daphnids increased dramatically even though the average density of the copepods did not change. Similarly, in Deer Lake during 1978-80, there was a significant decline in the average number of D. leptopus but there was barely an increase in the number of large daphnids.

I did not measure individual daphnids in order to determine whether their average size decreased due to size-selective predation by rainbow trout. However, the volumetric index (Table 4) indicated there was no appreciable change in their size during the periods of high or low fish predation. Using methods similar to those Northcote et al. (1978) used to explain fish predation alone was not the major factor directly responsible for changes in body size of daphnids, I calculated the direct effect that fish predation in Sid Lake would have on the population of large daphnids. If each trout was consuming an average of 4,000 large daphnids per day, fish predation alone would have accounted for no more than 2% of the standing crop of large daphnids per day from July through October 1976 and 1977. This low level of predation would allow the daphnid population to rapidly multiply and maintain its dominant position in the zooplankton community.

The usual replacement of large planktonic crustacean species by smaller forms following fish introductions (Brooks and Dodson 1965; Galbraith 1967) did not occur in Sid Lake during this study period. Given more time this normal turn of events probably would have occurred. Anderson (1972) found in his study of subalpine lakes that it sometimes took up to 6 years after the introduction of fish for the large crustaceans to be eliminated. If trout stocking had continued, many of the interactions or changes that occurred in the invertebrate community after 1977 would probably have occurred more rapidly and the end result would have been different.

The study raises many questions concerning the long- and short-term effects of the temporary perturbation by trout. For example, will the daphnid population continue to dominate in face of the increasing population of *Chaoborus*? Will the *Chaoborus* population return to its former density and what species will it comprise? The latter question is especially interesting since the larger *C. americanus* was replaced by the smaller *C. punctipennis*. *C. americanus* is seldom found in lakes with fish (von Ende 1979) and now that it has been replaced by another species will it reestablish itself in the currently fish-free community? If not, will *C. punctipennis* together with *C. flavicans*, have the same suppressing influence on daphnids that *C. americanus* had?

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Table 1.--Water clarity and the amount of dissolved oxygen at 11 m in Sid Lake, and at 12 m in Deer Lake, 1973-1980.

| Year, month and day | Sid Lake | | Deer Lake | |
|---|---|---|---|---|
| | Oxygen (ppm) | Clarity (m) | Oxygen (ppm) | Clarity (m) |
| 1973 | | | | |
| 6-4 | 0.85 | 6.7 | 8.8 | 6.1 |
| 6-26 | 0.35 | 5.6 | 5.6 | 6.1 |
| 7-24 | 0.00 | 6.1 | 3.3 | 6.1 |
| 8-21 | 0.00 | 4.7 | 1.2 | 6.1 |
| 9-18 | 0.00 | 6.3 | 0.75 | 6.4 |
| 10-23 | 9.40 | 4.6 | 8.4 | 5.3 |
| 1974 | | | | |
| 5-30 | 3.2 | 5.5 | 1.4 | 5.3 |
| 6-26 | 9.7 | 5.8 | 1.2 | 6.1 |
| 7-24 | 3.7 | 6.7 | 1.4 | 5.5 |
| 9-25 | 8.5 | 4.1 | 0.9 | 4.0 |
| 10-31 | - | 5.2 | - | 4.0 |
| 1975 | | | | |
| 6-3 | 0.75 | 5.8 | - | - |
| 8-18 | 6.1 [a] | 6.3 | 2.4 | 5.9 |
| 1976 | | | | |
| 6-22 | 4.2 | 4.6 | 1.0 | 6.7 |
| 7-20 | 1.6 | 7.6 | 1.8 | 4.6 |
| 8-17 | 0.4 | 8.4 | 0.4 | 6.1 |
| 9-21 | 2.2 | 6.7 | 0.3 | 4.6 |
| 10-19 | 10.0 | 8.2 | 10.0 | 3.0 |
| 1977 | | | | |
| 6-14 | 6.2 | 6.7 | 0.9 | 4.9 |
| 7-20 | 6.7 | 7.0 | 0.8 | 5.2 |
| 8-23 | 1.7 | 9.1 | 0.7 | 3.8 |
| 9-21 | 8.4 | 9.5 | 0.0 | 4.6 |
| 10-26 | 11.3 | 8.2 | 9.5 | 3.7 |
| 1978 | | | | |
| 6-20 | 8.2 | 4.6 | 1.0 | 4.4 |
| 7-19 | 7.6 | 5.8 | 1.0 | 5.5 |
| 8-15 | 10.1 | 8.4 | 1.0 | 5.3 |
| 9-20 | 7.2 | 7.0 | 0.6 | 6.1 |
| 10-24 | 10.4 | 6.7 | 9.8 | 4.3 |
| 1979 | | | | |
| 7-17 | 1.6 | 3.0 | 1.4 | 4.9 |
| 8-22 | 0.0 | 5.5 | 0.5 | 5.2 |
| 9-19 | 9.2 | 5.6 | 1.6 | 5.8 |
| 10-24 | 7.1 | 4.6 | - | - |
| 1980 | | | | |
| 7-15 | 0.0 | 5.5 | 0.0 | 4.3 |
| 8-14 | 0.0 | 6.1 | 0.0 | 4.9 |

[a] Collected at 10 m.

Table 2.--The monthly mean number of Daphnia pulex, Diaptomus leptopus, and Chaoborus sp. per net haul collected in 1973-75 before trout introduction, in 1976-77 when trout were present, and in 1978-80 when few trout remained. The 95% confidence limit is shown in parentheses.

| Years and lake | June | July | Aug | Sep | Oct | Season |
|---|---|---|---|---|---|---|
| | | | Mean number of large Daphnia pulex | | | |
| 1973-75 | | | | | | |
| Deer | 0.00 (±1.4) | 3.8 (±1.4) | 5.1 (±1.4) | 0.0 (±1.4) | 0.0 (±1.4) | 1.8 (±1.2) |
| Sid | 2.2 (±9.7) | 15.2 (±10.4) | 8.2 (±10.4) | 1.6 (±10.4) | 0.5 (±10.4) | 5.2 (±8.9) |
| 1976-77 | | | | | | |
| Deer | 4.8 (±1.4) | 13.9 (±1.4) | 1.1 (±1.4) | 0.1 (±1.4) | 0.8 (±1.4) | 4.1 (±1.2) |
| Sid | 34.5 (±10.4) | 165.8 (±10.4) | 180.4 (±10.4) | 221.4 (±10.4) | 312.5 (±10.4) | 182.9 (±8.9) |
| 1978-80 | | | | | | |
| Deer | 0.0 (±1.2) | 10.7 (±1.3) | 11.0 (±1.3) | 0.6 (±1.4) | 0.0 (±1.9) | 6.6 (±1.2) |
| Sid | 30.0 (±14.0) | 67.2 (±9.7) | 131.2 (±9.7) | 68.1 (±10.4) | 65.1 (±10.4) | 81.1 (±8.9) |
| | | | Mean number of Diaptomus leptopus | | | |
| 1973-75 | | | | | | |
| Deer | 53.9 (±5.1) | 65.2 (±5.1) | 111.0 (±5.1) | 62.9 (±5.1) | 23.0 (±5.1) | 63.2 (±4.4) |
| Sid | 118.5 (±7.7) | 52.8 (±8.2) | 181.1 (±8.2) | 59.2 (±8.2) | 41.5 (±8.2) | 93.2 (±7.1) |
| 1976-77 | | | | | | |
| Deer | 116.8 (±5.1) | 108.6 (±5.1) | 94.1 (±5.1) | 73.6 (±5.1) | 76.6 (±5.1) | 94.0 (±4.4) |
| Sid | 163.6 (±8.2) | 68.8 (±8.2) | 141.1 (±8.2) | 65.0 (±8.2) | 20.9 (±8.2) | 91.9 (±7.1) |
| 1978-80 | | | | | | |
| Deer | 58.2 (±6.8) | 15.4 (±4.7) | 17.8 (±4.7) | 15.4 (±5.1) | 38.0 (±6.8) | 22.7 (±4.4) |
| Sid | 3.0 (±11.1) | 19.3 (±7.7) | 35.0 (±7.7) | 9.1 (±8.2) | 32.0 (±8.2) | 22.6 (±7.1) |

(continued, next page)

Table 2.--continued.

| Years and lake | June | July | Aug | Sep | Oct | Season |
|---|---|---|---|---|---|---|
| | Mean number of *Chaoborus* sp. | | | | | |
| 1973-75 | | | | | | |
| Deer | 38.7 (±2.7) | 54.1 (±2.7) | 35.2 (±2.7) | 23.9 (±2.7) | 7.4 (±2.7) | 31.8 (±2.3) |
| Sid | 35.0 (±0.5) | 39.2 (±0.5) | 38.2 (±0.5) | 20.2 (±0.5) | 13.5 (±0.5) | 29.8 (±0.4) |
| 1976-77 | | | | | | |
| Deer | 41.4 (±2.7) | 40.0 (±2.7) | 22.9 (±2.7) | 16.8 (±2.7) | 12.6 (±2.7) | 26.7 (±2.3) |
| Sid | 3.4 (±0.5) | 6.8 (±0.5) | 1.1 (±0.5) | 1.0 (±0.5) | 0.1 (±0.5) | 2.5 (±0.4) |
| 1978-80 | | | | | | |
| Deer | 32.5 (±3.6) | 20.9 (±2.5) | 25.7 (±2.5) | 20.0 (±2.7) | 23.2 (±3.6) | 23.6 (±2.3) |
| Sid | 0.0 (±0.7) | 23.8 (±0.5) | 36.6 (±0.5) | 10.1 (±0.5) | 1.2 (±0.5) | 17.6 (±0.4) |

Table 3.--The monthly mean volume of net plankton per net haul in Sid and Deer lakes collected in 1973-75 before trout introduction, in 1976-77 when trout were present, and in 1978-80 when few trout remained. The 95% confidence limit is shown in parentheses.

| Years and lake | Mean volume (ml) of net plankton | | | | | |
|---|---|---|---|---|---|---|
| | June | July | Aug | Sep | Oct | Season |
| 1973-75 | | | | | | |
| Deer | 1.2 (±0.1) | 1.3 (±0.1) | 0.2 (±0.1) | 0.3 (±0.1) | 0.2 (±0.1) | 0.6 (±0.1) |
| Sid | 0.9 (±0.1) | 0.8 (±0.1) | 0.4 (±0.1) | 0.2 (±0.1) | 0.1 (±0.1) | 0.5 (±0.1) |
| 1976-77 | | | | | | |
| Deer | 0.6 (±0.1) | 0.4 (±0.1) | 0.2 (±0.1) | 0.2 (±0.1) | 0.2 (±0.1) | 0.3 (±0.1) |
| Sid | 1.0 (±0.1) | 1.0 (±0.1) | 0.7 (±0.1) | 0.8 (±0.1) | 0.6 (±0.1) | 0.8 (±0.1) |
| 1978-80 | | | | | | |
| Deer | 0.4 (±0.2) | 0.6 (±0.1) | 0.2 (±0.1) | 0.2 (±0.1) | 0.4 (±0.2) | 0.4 (±0.1) |
| Sid | 1.5 (±0.1) | 0.6 (±0.1) | 0.6 (±0.1) | 0.3 (±0.1) | 0.2 (±0.1) | 0.6 (±0.1) |

Table 4.--Volumetric index [a] for large Daphnia collected at deep-water stations in Sid and Deer lakes, 1973-1980.

| Lake, and year | Month of collection | | | | | | |
|---|---|---|---|---|---|---|---|
| | April | May | June | July | Aug | Sep | Oct |
| Sid Lake | | | | | | | |
| 1973 | -- [b] | 0.00 [c] | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1974 | -- | 0.00 | 0.00 | 1.20 | -- | 0.00 | 0.00 |
| 1975 | -- | -- | 0.00 | -- | 1.11 | -- | -- |
| 1976 | -- | -- | 1.00 | 1.17 | 0.85 | 0.91 | 0.61 |
| 1977 | -- | -- | 1.00 | 1.18 | 1.08 | 1.11 | 0.95 |
| 1978 | -- | -- | 1.00 | 1.28 | 0.96 | 1.11 | 0.94 |
| 1979 | -- | -- | -- | 1.11 | 0.94 | 1.30 | 0.83 |
| 1980 | -- | -- | -- | 1.30 | 1.09 | -- | -- |
| Deer Lake | | | | | | | |
| 1973 | -- | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1974 | -- | 0.00 | 0.00 | 0.83 | -- | 0.00 | 0.00 |
| 1975 | -- | -- | -- | -- | 0.50 | -- | -- |
| 1976 | -- | -- | 0.00 | 0.67 | 0.00 | 0.00 | 0.00 |
| 1977 | -- | -- | 0.00 | 0.59 | 0.00 | 0.00 | 0.00 |
| 1978 | -- | -- | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1979 | -- | -- | -- | -- | -- | -- | -- |
| 1980 | -- | -- | -- | 1.11 | 0.67 | -- | -- |

[a] Volumetric index = average volume (ml) per average number times 1,000.

[b] A blank space = no sample collected.

[c] 0.00 denotes only a few or no large Daphnia.

Table 5.--Average relative abundance of the medium- and small-sized zooplankters in Deer Lake in 1973-75 before trout were introduced into Sid Lake, 1976-77 when trout were present in Sid Lake, and 1979-80 when few trout remained. Abundance was ranked from 0-6 with 6 the most abundant.

| Organism | Medium-size | | | Small-size | | |
|---|---|---|---|---|---|---|
| | 1973-1975 | 1976-1977 | 1978-1980 | 1973-1975 | 1976-1977 | 1978-1980 |
| *Daphnia pulex* | 2[a] | 2 | 1 | 2 | 1 | 1 |
| *Diaptomus leptopus* | 3 | 4 | 5 | 6 | 6 | 6 |
| *Diaphanosoma* | 3 | 2 | 3 | 3 | 3 | 2 |
| *Holopedium* | 3 | 4 | 4 | 1 | 1 | 2 |
| Rotifers | 2 | 1 | 0 | 4 | 1 | 1 |
| *Bosmina* | 1 | 0 | 2 | 1 | 1 | 2 |
| *Alona* | 1 | 0 | 0 | 1 | 0 | 0 |
| *Chydorus* | 0 | 0 | 0 | 0 | 1 | 0 |
| *Polyphemus* | 0 | 0 | 0 | 0 | 0 | 0 |
| Filamentous algae | 1 | 1 | 2 | 1 | 1 | 2 |

[a] Believed to be somewhat elevated because only one month was sampled in 1975.

Table 6.--Average relative abundance of the medium- and small-sized zooplankters in Sid Lake in 1973-75 before trout introduction, 1976-77 when trout were present, and 1979-80 when few trout remained. Abundance was ranked from 0-6 with 6 the most abundant.

| Organism | Medium-size | | | Small-size | | |
|---|---|---|---|---|---|---|
| | 1973-1975 | 1976-1977 | 1978-1980 | 1973-1975 | 1976-1977 | 1978-1980 |
| *Daphnia pulex* | 2 | 4 | 5 | 1 | 1 | 1 |
| *Diaptomus leptopus* | 5 | 5 | 3 | 6 | 6 | 6 |
| *Diaphanosoma* | 3 | 0 | 1 | 3 | 1 | 1 |
| *Holopedium* | 3 | 4 | 4 | 1 | 1 | 1 |
| Rotifers | 1 | 1 | 0 | 3 | 1 | 3 |
| *Bosmina* | 0 | 0 | 0 | 1 | 0 | 0 |
| *Alona* | 0 | 0 | 0 | 1 | 0 | 0 |
| *Chydorus* | 0 | 0 | 0 | 0 | 1 | 0 |
| *Polyphemus* | 0 | 1 | 1 | 0 | 0 | 0 |
| Filamentous algae | 2 | 1 | 1 | 3 | 1 | 3 |

Table 7.--Rankings of the major organisms in the gut of rainbow trout in Sid Lake as determined by the index of relative importance (IRI).

| Year, and food item | Index of relative importance of gut contents | | | | |
|---|---|---|---|---|---|
| | June | July | Aug | Sep | Oct |
| 1976 | | | | | |
| *Daphnia* | 5 | 107 | 47 | -- | 85 |
| Anisoptera | 78 | 36 | 21 | -- | 29 |
| Tendipedidae | 17 | 54 | 61 | -- | tr |
| Amphipoda | 41 | 0 | 9 | -- | 81 |
| *Chaoborus* | 33 | 11 | 39 | -- | 0 |
| Trichoptera | 12 | tr[a] | tr | -- | 42 |
| Hemiptera | 23 | 4 | 12 | -- | 13 |
| Zygoptera | 0 | 0 | 24 | -- | 12 |
| Copepoda | 5 | tr | 15 | -- | tr |
| Coleoptera | 7 | 8 | 0 | -- | tr |
| Other diptera | 5 | 0 | tr | -- | 0 |
| Hydracarina | 0 | 6 | tr | -- | 0 |
| Hirudinea | 0 | tr | 5 | -- | tr |
| Stomachs examined | 4 | 5 | 4 | | 7 |
| 1977 | | | | | |
| *Daphnia* | 21 | 80 | 79 | 95 | 32 |
| Trichoptera | 33 | 58 | 27 | 39 | 100 |
| Tendipedidae | 94 | 42 | 54 | 18 | 0 |
| Zygoptera | 22 | 0 | 16 | 39 | 20 |
| Hemiptera | 13 | 5 | 42 | tr | 21 |
| Hirudinea | 7 | 16 | 0 | 27 | 29 |
| Amphipoda | 3 | 0 | 5 | 11 | 19 |
| Anisoptera | 6 | tr | 8 | 4 | 9 |
| Coleoptera | 20 | tr | 3 | 0 | 0 |
| Copepoda | 4 | 5 | 6 | tr | 0 |
| Other diptera | 6 | 0 | 0 | 5 | tr |
| Hydracarina | 11 | tr | tr | tr | 0 |
| *Chaoborus* | 3 | 4 | tr | tr | 0 |
| Stomachs examined | 12 | 12 | 9 | 9 | 4 |

[a] tr = trace.

Table 8.--Average size of rainbow trout collected in Sid Lake, 1976 and 1977.

| Year stocked | Year of collection | June | | July | | Aug | | Sep | | Oct | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total length (cm) | Weight (g) | Total length (cm) | Weight (g) | Total length (cm) | Weight (g) | Total length (cm) | Weight (g) | Total length (cm) | Weight (g) |
| 1976 | 1976 | 22.4 | 120 | 25.4 | 197 | 27.4 | 342 | -- | - | 31.5 | 347 |
| | 1977 | 35.3 | 478 | 37.6 | 533 | 36.3 | 440 | 37.6 | 524 | 39.1 | 570 |
| 1977 | 1977 | 22.4 | 118 | 25.7 | 189 | 28.4 | 227 | 29.7 | 272 | 31.8 | 319 |

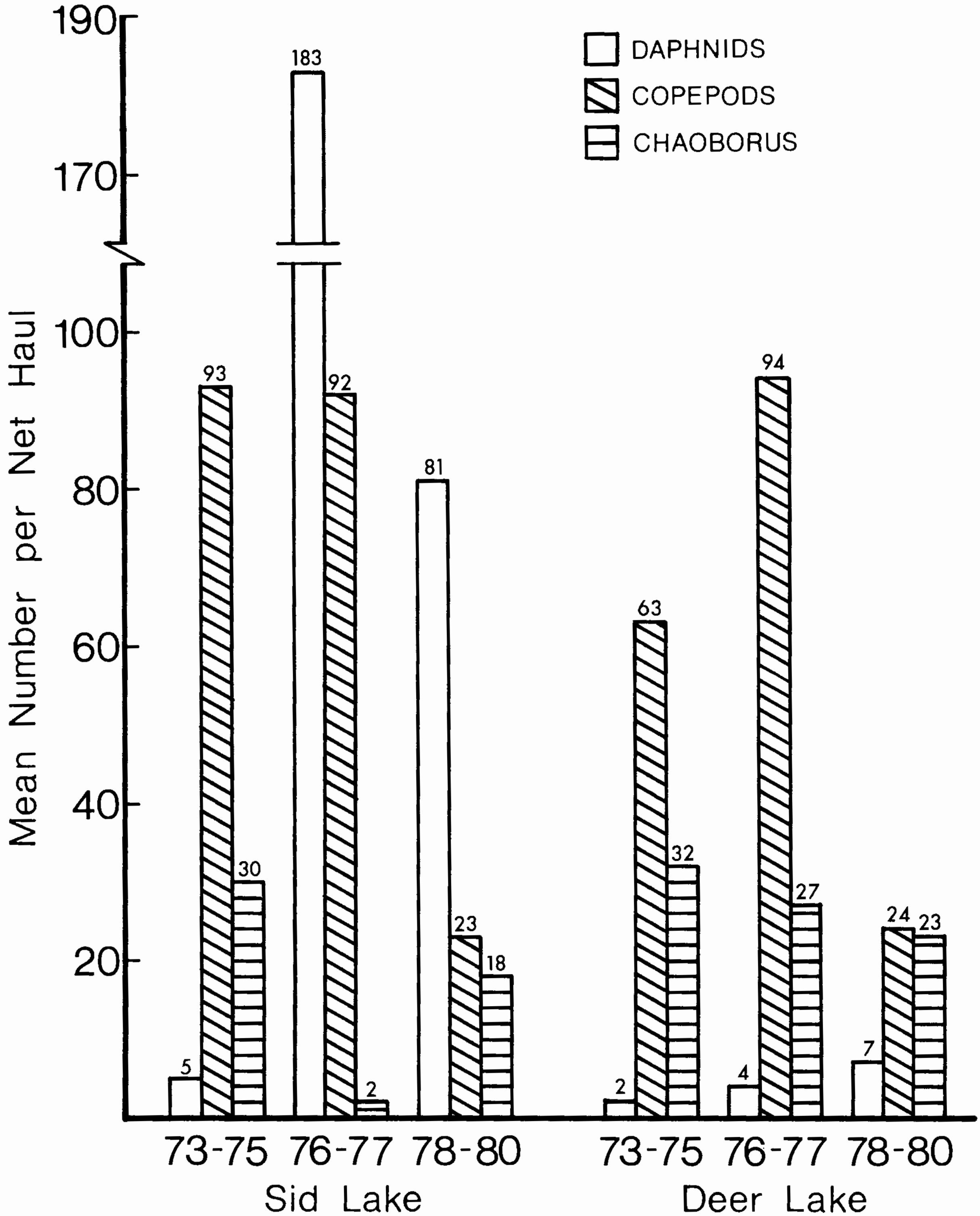


Figure 1.--Yearly mean number of large daphnids, large copepods and Chaoborus collected in Deer Lake (the control lake) and in Sid Lake in 1973-75 before trout introduction, in 1976-77 when trout were present, and in 1978-80 when few trout remained.

## Literature cited

Anderson, R. S. 1972. Zooplankton composition and change in an alpine lake. Verh. Internat. Verein Limnol. 18:264-258.

Anderson, R. S., and L. G. Raasveldt. 1974. Gammarus predation and the possible effects of Gammarus and Chaoborus feeding on the zooplankton composition in some small lakes and ponds in western Canada. Can. Wildl. Serv. Occ. Pap. 18:1-23.

Brooks, J. L., and S. I. Dodson. 1965. Predation, body size and composition of plankton. Science 150:28-35.

Fedorenko, A. Y. 1975a. Instar and species diets in two species of Chaoborus. Limnol. Oceanogr. 20:238-249.

Fedorenko, A. Y. 1975b. Feeding characteristics and predation impact of Chaoborus (Diptera, Chaoboridae) larvae in a small lake. Limnol. Oceanogr. 20:250-258.

Galbraith, M. G., Jr. 1967. Size-selective predation on Daphnia by rainbow trout and yellow perch. Trans. Am. Fish. Soc. 96:1-10.

Galbraith, M. G., Jr. 1975. The use of large Daphnia as indices of fishing quality for rainbow trout in small lakes. Verh. Internat. Verein Limnol. 19:2485-2492.

Nilsson, N-A., and B. Pejler. 1973. On the relation between fish fauna and zooplankton composition in north Swedish lakes. Rep. Inst. Freshw. Res. Drottningholm 53:51-77.

Northcote, T. G., and R. Clarotto. 1975. Limnetic macrozooplankton and fish predation in some coastal British Columbia lakes. Verh. Internat. Verein Limnol. 19:2378-2393.

Northcote, T. G., C. J. Walters, and J. M. B. Hume. 1978. Initial impacts of experimental fish introductions on the macrozooplankton of small oligotrophic lakes. Verh. Internat. Verein Limnol. 20:2003-2012.

O'Brien, W. J. 1975. Ponds and lakes of Noatak drainage basin. Verh. Internat. Verein Limnol. 19:472-479.

Pastorok, Robert A. 1980. Selection of prey by Chaoborus larvae: A review and new evidence for behavioral flexibility. Pages 538-554 in Evolution and ecology of zooplankton communities. University Press of New England Special Symposium 3.

Pinkas, Leo, Malcolm S. Oliphant, and Ingrid L. K. Iverson. 1971. Food habits of albacore, bluefin tuna, and bonito in California waters. California Fish Game Fish. Bull. 152:1-105.

Pope, G. F., J. C. H. Carter, and G. Power. 1973. The influence of fish on the distribution of Chaoborus spp. (Diptera) and density of larvae in the Matamek River system, Quebec. Trans. Am. Fish. Soc. 102:707-714.

Sprules, W. G. 1972. Effects of size-selective predation and food competition on high altitude zooplankton communities. Ecology 53:375-386.

Sprules, W. G. 1975. Factors affecting the structure of limnetic crustacean zooplankton communities in central Ontario lakes. Verh. Internat. Verein Limnol. 19:635-643.

Stabl, J. B. 1966. The ecology of Chaoborus in Myers Lake, Indiana. Limnol. Oceanogr. 11:177-183.

Swüste, H. F. S., R. Cremer, and S. Parma. 1973. Selective predation by larvae Chaoborus flavicans (Diptera; Chaoboridae). Verh. Internat. Verein Limnol. 18:1159-1563.

von Ende, Carl N. 1978. Regional coexistence of four Chaoborus species. Verh. Internat. Verein Limnol. 20:2630-2633.

von Ende, Carl N. 1979. Fish predation, interspecific predation, and the distribution of two Chaoborus species. Ecology 60:119-128.

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