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EVALUATION OF LIMNOLOGICAL PARAMETERS AS RELATED TO THE SUCCESS OF MYSIS RELICTA INTRODUCTIONS

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ABSTRACT

A comparative investigation monitoring biological, chemical, and physical parameters of three subalpine lakes in Wyoming was undertaken during 1981 to determine the impact of introduced *Mysis relicta* (opossum shrimp) on these lakes' ecosystems. General life history characteristics of the introduced mysid populations were analyzed in relation with the limnological data. The introduced shrimp populations were found to be strongly influenced by ambient water quality and lake productivity. Applying the results of this study and other information from the scientific literature, a fisheries management tool utilizing decision criteria was developed to aid in predicting the success of *Mysis relicta* introductions.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CONTENTS OF APPENDICES

APPENDIX A: CHEMICAL LIMNOLOGY DATA

CONTENTS OF APPENDICES

APPENDIX B: NET PLANKTON DATA

CONTENTS OF APPENDICES

APPENDIX C: MYSIS RELICTA DATA

I. LITERATURE REVIEW

INTRODUCTION

Mysis relicta, commonly known as the opossum shrimp, is a freshwater form of the genus Mysis, which is considered to be a glacial relict (Table 1). It is theorized that this glacial relict reached its freshwater niche during pleistocene glaciation. The mysids were pushed ahead of the glaciers into lakes along the ice margins (Ricker, 1959).

The natural distribution of Mysis relicta in the northern hemisphere follows the southern periphery of pleistocene glaciation (Gregg, 1976). This mysid generally inhabits cold, deep, oligotrophic lakes across the northern United States, Canada, and northern Europe. Mysis relicta has also been reported to naturally inhabit a few temperate eutrophic lakes (Sayre and Stout, 1965; Lasenby and Langford, 1972).

Table 1. Taxonomic classification of Mysis relicta Loven

Phylum Arthropoda
Class Crustacea
Subclass Malacostraca
Superorder Peracarida
Order Mysidacea
Family Mysidae
Genus Mysis Latreilla
Mysis relicta Loven

Source: Barnes (1974)

In the past thirty years, the region of distribution for *Mysis relicta* has been greatly enlarged through introductions of this specie into many lakes around the world. Fürst (1965) reported that *Mysis relicta* was planted into several lakes in Sweden to enhance declining food supplies for fish. By 1963, mysid introductions had become an integral part of coldwater fishery management programs in North America. This was an attempt to increase fish production through the provision of an additional food source for fish such as lake trout (*Salvelinus namaycush*) and kokanee (*Onychorynchus nerka*) (Linn and Frantz, 1965; Northcote, 1972a; Gregg, 1976; Morgan et al., 1978).

Results of mysid introductions have been variable and unpredictable (Lasenby et al., 1981). *Mysis* introduction into Kootenay Lake, British Columbia, represented one of the initial successful stocking of mysids (Gosho, 1975). Successful transplants of *Mysis relicta* have occurred in other lakes such as Twin Lakes, Colorado (Gregg, 1976), Grindstone Lake, Minnesota (Schumacher, 1966) and Lake Tahoe, California-Nevada (Morgan, 1980). However, Gosho (1975) also reported failures of attempted introductions into two Swedish lakes and several North American Lakes. Reported reasons for the failures of these mysid introductions varied from low pH levels to problems of acclimatization to changes in environmental conditions for the introduced mysids. Although the stocking of *Mysis relicta* has become a common fisheries management tool to increase fish production, questions still remain regarding the overall impact of mysids on these lakes.

In order to successfully evaluate the role and feasibility of *Mysis relicta* in fishery management programs, it is critical to answer the following questions:

1. What are the general life history patterns of *Mysis relicta*?
2. What are the feeding habits of *Mysis relicta*?
3. What effect does the daily behavior of *Mysis relicta* have on the lake ecosystem?
4. What water quality is required for survival of *Mysis relicta*?

These questions and problems regarding mysids and their introduction into freshwater lakes will be addressed in this literature review of previous research.

LIFE HISTORY AND GROWTH PATTERNS

The life cycles and growth patterns of *Mysis relicta* populations can generally vary in recruitment, growth rate, and breeding seasons. These variations are reported to be a result of such factors as lake morphometry and chemistry, plankton species composition and overall lake productivity (Morgan, 1980).

Fürst (1972a) reported three variations of mysid life cycles in Swedish lakes. These three types were winter breeders exhibiting a one-year life-cycle, winter breeders exhibiting a two-year life-cycle, and summer breeders exhibiting a one-year life-cycle. Morgan (1980) studied the life history characteristics of introduced mysid populations in Lake Tahoe and found considerable variations. A four-year life-cycle was described for *Mysis relicta* in the main basin of Lake Tahoe, while only a two-year life-cycle was reported for mysids in Emerald Bay, a semi-isolated basin of the lake. Other variations in life history of mysids are also described by Lasenby and Langford (1972). In this study it was found that in Char Lake, an arctic lake in the Northwest Territories, Mysis populations took two years to reach maturity, while in Stoney Lake, an eutrophic lake in southern Ontario, Mysis populations required only one year before reproducing. In the Laurentian Great Lakes, the time to first reproduction of Mysis relicta varies from one to two years depending on the lake (McWilliam, 1970; Carpenter et al., 1974; Morgan and Beeton, 1978).

These variations in the Mysis life cycle are attributed to the environmental conditions to which the animal is exposed. Morgan (1980) suggests these differences in life cycles are a phenotypic response to the variability in trophic conditions among lakes. Table 2 supports this theory by showing that the life cycle is dependent upon the trophic level of the lake. Mysid populations in oligotrophic lakes are subjected to cooler temperatures and are limited by scarce food supplies, while in more temperate eutrophic lakes, which have greater nutrient enrichment, mysids experience warmer water temperatures and thus greater overall lake productivity and food availability (Gosho, 1975).

Another variation in the life history among populations is the reproductive season. Some mysid populations have been reported to limit reproduction to winter, while other populations have been found to reproduce continuously (Lasenby and Langford, 1972; Morgan, 1980). "Continuous reproduction does not mean that any given individual reproduces continuously, just that at any point in time some individuals in the population are reproducing" (Morgan, 1980).

Table 2. Comparison of lake trophic status and years to maturity of *Mysis relicta*.

Lake	Trophic Status	Number of Years to First Reproduction
Lake Tahoe, California-Nevada	Oligotrophic	4
Emerald Bay (Lake Tahoe)	Oligotrophic	1-2
*Donner Lake, California	Oligotrophic	2
*Fallen Leaf Lake, California	Oligotrophic	2
Great Slave Lake, N.W.T.	Oligotrophic	2
Char Lake, N.W.T.	Oligotrophic	2
**Twin Lakes, Colorado	Oligotrophic	2
Lake Superior, USA-Canada	Oligotrophic	1.5
Lake Huron, USA-Canada	Oligotrophic	2
Lake Ontario, USA-Canada	Mesotrophic	1.5
Lake Michigan, USA (Southern Basin)	Mesotrophic	1
Cayuga Lake, New York	Mesotrophic	1
Green Lake, Wisconsin	Mesotrophic	1
Stoney Lake, Ontario	Eutrophic	1

Source: Morgan (1980)

*Source: Morgan (1981)

**Source: Gregg (1976)

Generally in most cold oligotrophic lakes, Mysis will breed in the late fall with juveniles being released in the spring. This is exemplified in Twin Lakes, Colorado where the mysid populations are reported by Gregg (1976) to have fall breeding, winter brooding of embryos by females, and recruitment during the spring months. Similar reproductive cycles are reported for Great Slave and Char Lakes of the Northwest Territories (Larkin, 1948; Lasenby and Langford, 1972).

Lasenby (1971) believed that temperature and dissolved oxygen (D.O.) content of the water, along with food availability, determined the time of reproduction of Mysis relicta. Breeding usually initiates when water temperatures drop to 7°C during the fall overturn and is most active at 3 to 4°C (Gosho, 1975). At this time, D.O. is replenished throughout the water column and would be sufficiently high throughout the fall and winter for breeding. In oligotrophic lakes, these conditions of low temperatures and high D.O. levels may occur year-round and therefore extend the reproductive period. However, again in most lakes of this type, the limiting factor for growth and reproduction is the scarcity of adequate food.

After mating takes place in the fall, most of the mature male mysids die off within a few months. The embryos are carried by the females throughout the winter months in their brood chamber. The juvenile mysids are released in the spring at a length of 3 to 4 millimeters (mm) (Gosho, 1975). Tattersall and Tattersall (1951) reported that the number of eggs produced by females ranged from about 10 to 40, with larger females producing more eggs. Fürst (1972b) also reported in three Swedish lakes that there was a direct relation between fecundity and increased length of the females.

Once the juveniles are released, they grow at an average rate of about one mm per month and become sexually differentiable at 8 to 11 mm (Gregg, 1976). Females usually grow at a faster rate than males and attain a greater length. Maximum size of a male will be about 16 to 18 mm in length, while females have been reported to reach lengths up to 30 mm (Gosho, 1975).

FEEDING HABITS

When assessing the impact of introduced mysid populations, it is important to examine the effect of *Mysis* predation on natural zooplankton and phytoplankton assemblages in the aquatic ecosystem. In many of the lakes in which *Mysis relicta* has been introduced, some zooplankton populations such as the cladocerans were virtually eliminated (Zyblut, 1970; Goldman et al., 1979; Nelson and Finnell, 1981). However, *Mysis* have been reported to feed on a variety of different items such as phytoplankton, zooplankton, detrital matter, and inorganic particles (Lasenby and Langford, 1973).

Beeton (1960) described the food preferences of *Mysis* to be mainly detritus material during the day and plankton during their diel vertical migrations. Lasenby and Langford (1973) found that the diet of mysids varied from lake to lake. Differences in the diet are attributed to relative availability and abundance of various food types. Large pennate diatoms are the main food stuff for *Mysis relicta* in Lake Michigan

(Bowers and Grossnickle, 1978), while copepods are the majority of the diet of Lake Tahoe mysids due to the lack of diatoms and cladocerans in that lake (Cooper and Goldman, 1980).

Lasenby and Langford (1973) reported that in Stoney Lake, Ontario mysids less than 6 mm in length fed only on algae and detritus, while larger mysids (greater than 7 mm in length) are detritivores by day and carnivores by night preying on *Daphnia* sp.. Mysis are described by Cooper and Goldman (1980) to have "selectivity for specific prey sizes and types." The larger mysids prefer larger prey, while the juvenile mysids feed on the smallest available prey. *Mysis relicta* in Lake Michigan were found to have no size selection during fall or winter when food is relatively scarce, but showed a strong preference for larger prey in the summer (Grossnickle, 1981). Cooper and Goldman (1980) have shown in their predation study that, when available, *Daphnia* sp. was the consistent prey preference over cyclopoid copepods, which had a greater preference over calanoid copepods. Grossnickle (1981) also found the same food preferences of mysids: *Daphnia* sp. > *Cyclops* sp. > *Diaptomus* sp. In general, the prey selectivity patterns of *Mysis* are basically related to prey availability, prey size, and prey ability to escape mysid predation (Cooper and Goldman, 1980).

VERTICAL AND HORIZONTAL DISTRIBUTION

The introduction of *Mysis relicta* into lakes can add a new source of food for fish, but at the same time can cause dramatic changes in the trophic structure of these lakes through shifts in plankton species abundance and composition (Northcote, 1972a). The extent to which the trophic structure is affected is directly related to the mysids' behavioral mechanism of diel vertical migrations. During daylight hours the mysids feed on bottom detritus matter and these migrations have the effect of bringing the mysids in contact with pelagic zooplankton and phytoplankton populations (Gregg, 1976). Nocturnal upward migrations of Mysis transport nutrients and energy back into the upper regions of the lake from the sediment-water interface that otherwise would have been lost or unavailable to the rest of the lake system (Beeton, 1960; Teraguchi, 1969; Morgan and Beeton, 1978).

Beeton (1959) reported that Mysis relicta had a varying phototactic response to light intensity in the lab. If the mysids were subjected to total darkness for more than ten hours they were negatively phototactic. Beeton (1960) concluded that "light is the major environmental factor which triggers and controls these migrations, while thermal conditions interact and modify the influence of light." The evening ascent is initiated by the decreasing light intensity on the lake. Juvenile mysids, being less sensitive to light and temperature changes, ascend before the adults and descend back to the lower regions after the adults during the pre-dawn hours. The length and extent of the migrations can be greatly modified by moonlight illumination on the lake and could actually restrict the mysids from reaching the upper water column, and thus from feeding on plankton (Beeton and Bowers, 1981).

Thermal gradients in the metalimnion can also influence mysid migrations. Beeton (1960) reported that if temperature gradients of 1.67 to 2.0°C per meter existed in the metalimnion, then the mysids would not migrate through this layer. Brownell (1970) and Lasenby (1971) found that the thermocline was only temporarily penetrated by immature mysids when sharp gradients existed.

It is still uncertain why mysids will migrate these great distances every night. In some lakes, such as Lake Tahoe, the mysids will migrate more than 300 meters to near the surface in one night (Rybock, 1978). Beeton and Bowers (1981) described three hypotheses for *Mysis* migrations:

1. To feed on preferred items such as large diatoms and zooplanktors.
2. To maintain their metabolic balance.
3. To avoid predators such as lake trout.

It is the consensus of literature that migrations are probably due to a combination of these hypotheses.

The horizontal distribution of *Mysis* throughout the lake is mainly affected by depth and seasonal changes. *Mysis* are limited to the deepest areas of the lake where water temperature and D.O. levels are adequate for survival (Gregg, 1976). Tattersall and Tattersall (1951) reported that in most lakes *Mysis* migrated to deeper waters during the summer and returned to shallower water in the winter to breed. Reynolds and Degraeve (1972) suggested a similar breeding migration of adults in Lake Michigan. Morgan and Threlkeld (1981) report that adult mysids release their young in cold, deep water and then the young migrate to shallow water. As these juveniles grow they return back to deep water, usually by the end of the summer. This behavior is explained by the fact that juveniles, being less sensitive to light and warmer temperatures than adult mysids, migrate to the generally more productive shallower areas of the lake. Thus, horizontal migrations seem to be the result of the same basic factors that trigger vertical migrations.

WATER QUALITY REQUIREMENTS

Pennak (1953) reported that *Mysis relicta* exhibit a preference for cold water with 14°C believed to be the maximum temperature that could be tolerated for an extended amount of time. However, Juday and Birge (1927) found that mysids could tolerate 20 to 21°C water during their diurnal vertical migrations in Trout Lake, Wisconsin. Smith (1970) reports that the lethal temperature for mysids is dependent upon acclimation temperatures. Mysids acclimitized at 5 to 7°C had an upper thermal limit between 18 and 20°C, while mysids acclimatized at 9 to 14°C were found to have an increased thermal tolerance of 22°C (Ricker, 1959).

Brownell (1970) has shown that the lethal D.O. concentration for mysids is directly dependent on the ambient water temperature. Before this study, reported D.O. lower limits varied considerably, but Ricker (1959) found that the usual lower limit for mysid survival was 40 to 50% oxygen saturation. Brownell (1970) reported that mysids could survive at 2 mg/l D.O. at 7°C, but as water temperature increased, the required D.O. for survival also increased.

Mysis relicta also seems to exhibit a preference for certain pH ranges. They are commonly found in slightly basic lakes, but are also reported in lakes with pH values less than 7 (Table 3). Nero and Schindler (1981), studying the effects of low pH on mysids, found that the lethal pH was between values of 5.9 and 5.6. Mysids seem to have

Table 3. The pH of lakes containing populations of *Mysis relicta*.

Lake and Location	pH	Date and Depth of Measurement	Mysis relicta	Source
Kappebosjön, Sweden	6.0-6.7	September and October 1953, 21.5-4.8 m	abundant	Holmquist (1959)
Teåkersjön, Sweden	6.6	September 1953, 19.8 m	moderate	Holmquist (1959)
Ivösjön, Sweden	7.2-7.4	June and September 1955	abundant	Holmquist (1959)
Furesö, Denmark	7.2-8.2	July and September 1954	moderate	Holmquist (1959)
Cayuga Lake, New York, USA	7.5-8.6 7.6-8.1	Entire lake hypolimnion	abundant	Brownell (1970)
Blåsjön, Sweden	7.60	--	now abundant	Fürst (1965)
Jansjön, Sweden	7.75	--	abundant	Fürst (1965)
Waterton Lake, Montana, USA and Alberta, Canada	7.8	--	abundant	Sayre and Stout (1965)
Lough Derg, Ireland	8.0-8.4	Surface	abundant	Holmquist (1959)
Kootenay Lake, British Columbia, Canada	8.16-8.42	Surface 1964	now abundant	Zyblut (1970)
Lough Neagh, Ireland	8.3-8.4	Surface water near shore	abundant	Holmquist (1959)

Source: Gosho (1975).

extremely low tolerance to these pH levels when not acclimatized. A similar effect is also shown for changes in specific conductance in a lake. *Mysis relicta* appears to be very sensitive to changes in the electrolyte content of lake water, especially when being transplanted from one lake to another (Gosho, 1975).

IMPACT OF INTRODUCTIONS

The economic value of *Mysis relicta* introductions is of great importance. In many vacation areas, the majority of the economy is based on local sport fisheries that attract many fishermen each year. Mysid introductions have become a common tool for fishery managers in an attempt to increase trout production in lakes with heavy fishing pressure. *Mysis* provide a potential food source for sport fish, especially lake trout. Studies have indicated that in some cases, *Mysis* have actually increased growth rates of lake trout, but have also had a significant impact on the trophic structure of the aquatic ecosystem (Morgan et al., 1978).

In many of the lakes in which mysids have been stocked, shifts in relative abundance of zooplankton species has occurred with possible economic effects (Northcote, 1972a & b). Threlkeld (1981) and Goldman et al. (1979) have reported that *Mysis* are largely responsible for the disappearance of three species of cladocerans in Lake Tahoe: *Daphnia pulicaria*, *Daphnia rosea*, and *Bosmina longirostris*. Nelson and Finnell (1981) describe similar findings in their studies of the impact of *Mysis* relicta introductions in Colorado lakes and reservoirs, where the

Daphnia and Bosmina population have been eliminated since the establishment of Mysis relicta populations. "The establishment of Mysis may have influenced cladoceran populations through competition for shared resources or through predation by Mysis" (Goldman et al., 1979).

Galbraith (1967) reports that decreases in cladoceran populations may have adverse effects on the growth rate of rainbow trout (Salmo gairdneri). Due to their specific prey-size preferences, rainbow trout usually will not feed on the smaller more available zooplankton. This may result in competition between the rainbow trout and mysids, unless the rainbow trout prey heavily upon the Mysis (Lasenby, 1971). Lasenby et al. (1981) and Northcote (1972b) report that in many lakes there is no evidence that rainbow trout or other intermediate-sized trout are feeding on Mysis. They also reported that in some Swedish lakes the pelagic char is decreasing in size and number, and have attributed this trend to competition since the char are not feeding on the Mysis.

Studies in Kootenay Lake, British Columbia have indicated that the kokanee are utilizing Mysis to a great extent. It was also shown that there has been a significant increase in growth rate, model length, and length-weight relationships in kokanee (Northcote, 1972a & b, 1973). Grimas et al. (1972a & b) report in Swedish lakes, fish that feed readily on mysids have increased growth rates and have a reddish coloration of their tissue.

Morgan et al. (1978) found that lake trout in Lake Tahoe shifted their feeding preferences from benthic and pelagic fish to Mysis after the establishment of the mysid population. "Thus it appears Mysis has been successfully added to the lake trout diet, but only at the expense of other food sources, and that the shift to *Mysis* has been beneficial only when *Mysis* are abundant." Fürst (1972a) also showed that predation on *Mysis* by fish did not begin until populations were dense. The delay factor is approximately ten years in establishing mysid populations after introductions (Gosho, 1975).

It appears that the impact and success of *Mysis relicta* introductions is directly related to lake productivity and morphometry (Morgan et al., 1978). Complete elimination of cladoceran populations has not occurred in relatively shallow and productive lakes (Young and Oglesby, 1972; Gosho, 1975). In lakes such as Lake Tahoe that are extremely deep and unproductive, it appears that the cladoceran population cannot withstand the additional predation pressure by *Mysis* and the lack of predation pressure on *Mysis* by higher predators (Morgan et al., 1978). Thus in ultra-oligotrophic systems, lake productivity is not great enough to establish and maintain both fish and *Mysis* populations (Lasenby et al., 1981).

STUDY OBJECTIVES

Even though previous research has dealt with problems of mysid introductions, no definite answers have been attained to the questions directed in the introduction of this text. Some general trends have been identified in the literature, but it has also illustrated differences in mysid introductions among lakes that appear to be similar in many respects. The main differences from lake to lake regarding these introductions include the amount of success achieved in establishing a

Mysis relicta population and the extent to which the introduced mysids influence the lake trophic structure.

In this study, it was attempted to gain a better understanding of these differences through a comparative investigation of three subalpine lakes located in the same immediate geographic area of Wyoming in which the three lakes appear to be analogous in chemical, biological, and physical characteristics. The primary objective of this study is to develop a predictive tool for fishery managers to aid in determining whether *Mysis relicta* should be introduced in similar montane lakes to increase lake trout production.

Of the three lakes in concern--Halfmoon, Willow, and Fremont Lakes--only Halfmoon and Willow Lakes were stocked with *Mysis relicta*. Two separate plants were made in each lake during June and October of 1971 with 14,000 and 50,000 mysids, respectively. Verification of established mysid populations in these two lakes was reported during 1976 and 1977 (Wyoming Game and Fish Department, Personal Communication, 1980). Fremont Lake was not stocked with *Mysis relicta* in 1971 and the proposed introduction of this specie into Fremont Lake is pending the outcome of this investigation.

Fremont Lake was used as a control in this study to analyze any changes in the aquatic ecosystem of Halfmoon and Willow Lakes attributed to the mysid introduction. The impact on the ecosystem was evaluated through the assessment of general lake productivity, water quality, and plankton species composition and abundance. Also, general life history characteristics of mysid populations in Halfmoon and Willow Lakes was correlated with the limnological data in developing this management tool to assist in determining the feasibility of mysid introduction in similar subalpine lakes.

II. DESCRIPTION OF STUDY AREA

EXPERIMENTAL METHODS AND MATERIALS

DESCRIPTION OF STUDY AREA

Fremont, Willow, and Halfmoon Lakes are located in Sublette County, Wyoming, near the town of Pinedale (Figure 1). The lakes lie almost entirely within the Bridger National Forest on the western slope of the Wind River Mountain Range. Elevations of the three lakes are between 2,179 and 2,346 meters (m) above sea level with their respective watersheds feeding each lake with streams originating on or below Fremont Peak on the Continental Divide at an altitude of 4,200 m. The drainage areas are mainly composed of highly insoluble Precambrian crystalline rock to which the dilute and oligotrophic nature of these lakes can be attributed (Rickert and Leopold, 1972).

These lakes are considered to be "piedmont" lakes due to their altitude along with their morphometric characteristics of deep, elongated and glacially scoured depressions (Hutchinson, 1957). Fremont, Willow, and Halfmoon Lakes along with many other smaller lakes in the Wind River Range were formed by glacial excavation during the Late Pleistocene period. During this glaciation, Fremont, Willow, and Halfmoon Lake basins were scoured and dammed with the formation of moraines which now compose the lakes' boundaries.

Fremont Lake, one of the deepest lakes in the United States, has a maximum depth of 185 m in its southern basin with a mean depth of approximately 83 m (Figure 2). Surface area of Fremont Lake is 20.6

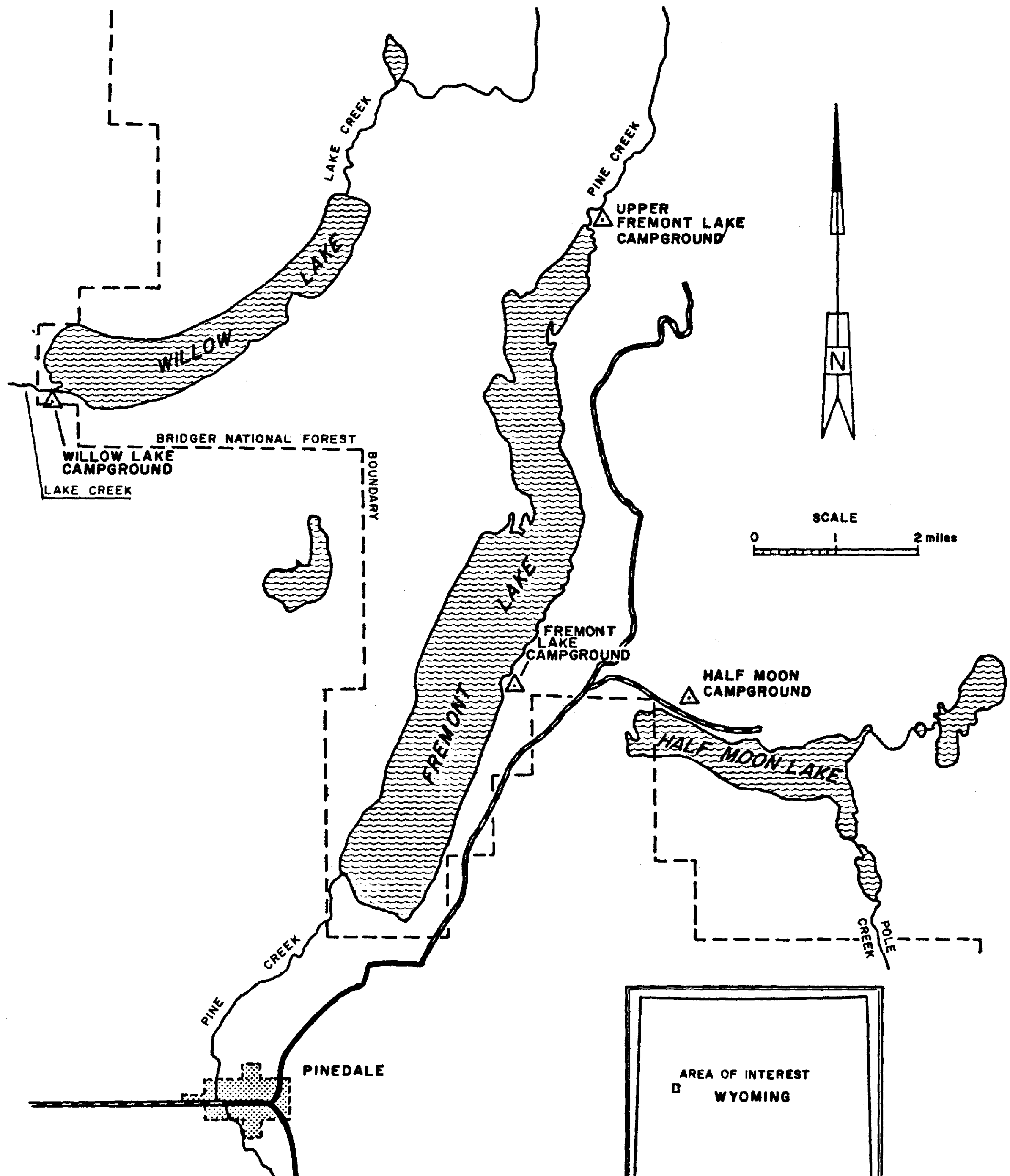

Figure 1. Map of study area.

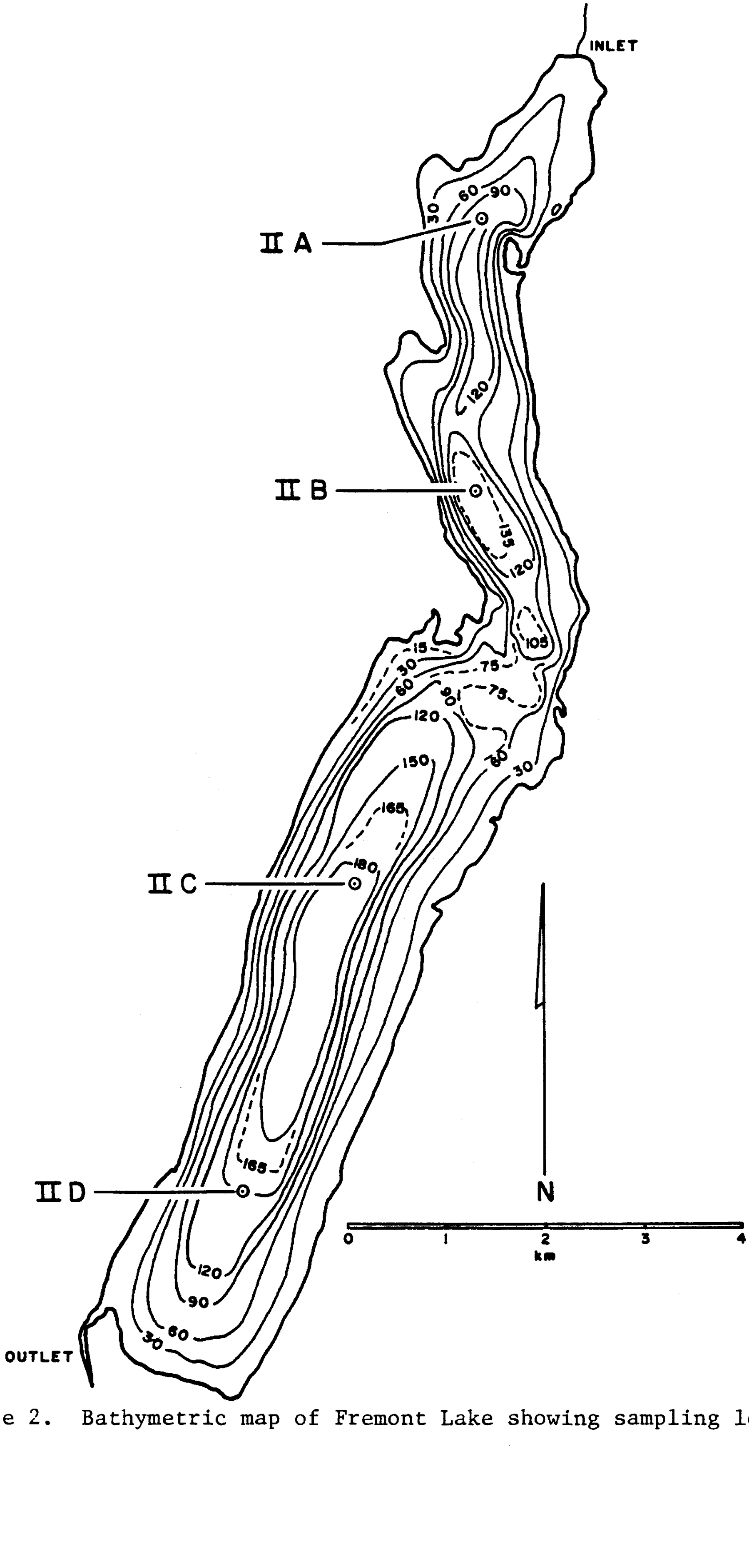

Figure 2. Bathymetric map of Fremont Lake showing sampling locations.

square kilometers (km^2) with a maximum length of 14.6 km and a maximum breadth of 2.1 km. See Table 4 for summary of morphometric data.

Fremont Lake is elongated in a north-south direction and is divided into two separate basins by a rock outcrop forming a constriction near the midpoint of the lake. Steep moraines and rocky cliffs rising from the water's edge border the lake on both shores and are sparsely vegetated with aspen and mixed conifers. Pine Creek, the only perennial tributary feeding Fremont Lake, has an average annual flow of 5.0 m^3/sec with the annual peak discharge usually occurring in June as reported in the U.S. Geological Survey Water Data Report WY-79-2. The discharge at the lower end of Fremont Lake is controlled by an overflow dam which has four feet of storage.

Access to Fremont Lake is easily attained through the two public boat ramps on the south and east shores. The access on the east shore

Table 4. Summary of lake morphometry data

	Fremont Lake	Willow Lake	Halfmoon Lake
Elevation, m	2,179	2,346	2,316
Surface area, km^2	20.6	7.3	4.1
Lake volume, km^3	1.7	0.3	0.1
Maximum depth, m	185	70-85	86
Mean depth, m	83	31	28
Maximum length, km	14.6	7.0	5.1
Maximum width, km	2.1	2.0	1.7

Sources: Wyoming Game and Fish Department; Rickert and Leopold, 1972.

is located at a developed Bridger National Forest campground. A second campground is located at the upper end of Fremont Lake near the major inlet, but is undeveloped and only accessible by boat or hiking in from the Bridger Wilderness Area of the National Forest. A lodge with marina is located on the extreme south shore. Also, a summer home development is located on the east shore of the lake.

Four sampling stations were set up on Fremont Lake to sample plankton and water chemistry throughout the lake. Two stations were located in each basin (Figure 2). The Pine Creek inlet was also to be sampled for water chemistry parameters.

Willow Lake, located about 20 km north of Pinedale, has the least recreational use of the three lakes due to difficult accessibility through an unimproved gravel road. Access to the lake is gained through an undeveloped Bridger National Forest campground located on the southwest shore. One summer dwelling is located on the north side of the lake with a private access.

Willow Lake has a surface area of 7.3 km^2 with a maximum depth of 70 m according to Wyoming Game and Fish records and 85 m as reported in Leopold's (1980) study. Mean depth is approximately 31 meters. Maximum length and width is 7.0 km and 2.0 km, respectively (Table 4). Willow Lake is oriented in a southwest-northeast manner with two points of land extending out from the south shore partially separating the lake into three basins. The lake is bounded by lateral moraines along the entire length of shoreline. South facing slopes along the shoreline are mostly barren with areas of sagebrush, while north facing slopes and the area near the inlet are mainly conifers with dispersed stands of aspen. The west end of the lake is completely open and unprotected from the prevailing westerly winds due to lack of high ridges or vegetation. Ridges are much steeper and higher toward the east end of Willow Lake near the inlet.

The lake's main tributary is Lake Creek which enters on the northeast end and discharges on the southwest end of the lake. No record of discharge from Lake Creek is available. Willow Lake is also dammed at the outlet with a gate structure to increase water storage for irrigation purposes during the summer months. The water control structure caused fluctuations in water levels up to 4 m as observed in the summer of 1981.

A monitoring station was set up for sampling at the deepest section of each of the three basins of Willow Lake to give representative conditions of the total lake (Figure 3). The inlet was also sampled for chemical parameters.

Halfmoon Lake is the smallest of the three lakes of concern and has a surface area of 4.1 km^2. It is 5.1 km and 1.7 km at the extreme length and width, respectively. Maximum depth of Halfmoon Lake is 86 m with its mean depth approximately 28 m (Table 4). The lake is stretched in an east-west orientation with steeply sloping glacial moraines comprising the entire shoreline. The immediate watershed of Halfmoon Lake is heavily vegetated mostly with conifers mixed with stands of aspen.

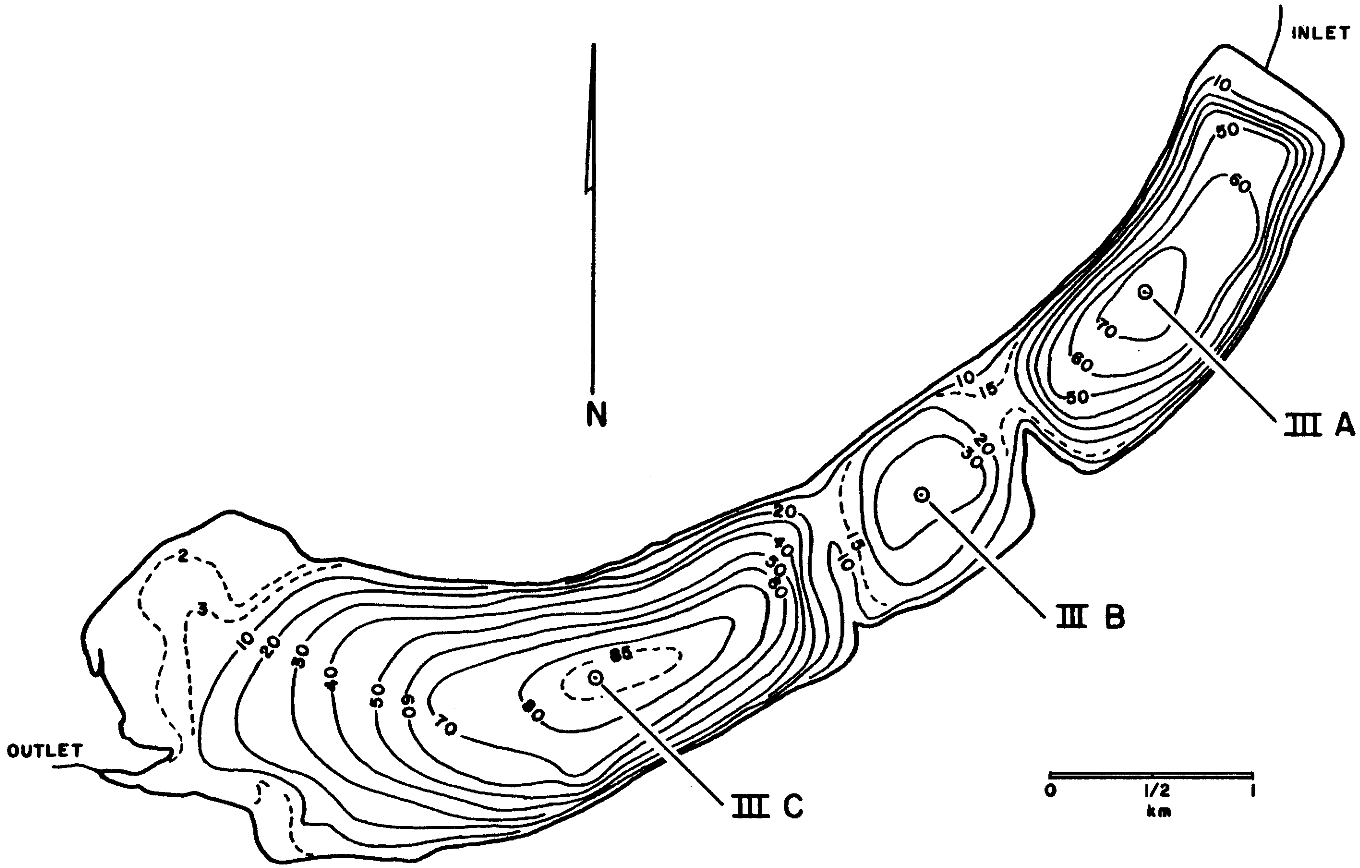

Figure 3. Bathymetric map of Willow Lake showing sampling locations.

The major inlet and outlet are both located on the east end of the lake with another minor tributary entering on the northwest end of the lake. No estimates of inlet or outlet flows are available.

Access to the lake can be attained through a public ramp located at the Halfmoon campground of the Bridger National Forest on the north shore. Also, one private home is located on the north shore adjacent to the campground.

Three sampling locations along the length of Halfmoon Lake were utilized to sample biological and chemical parameters (Figure 3). The major inlet was also sampled to determine chemical quality of influent water.

METHODS AND MATERIALS

Chemical Limnology

Water quality data were obtained during April, June, and August, 1981, for Halfmoon and Fremont Lakes. Adverse weather conditions during the April sampling trip prevented collection of any data on Willow Lake so only two sets of data were obtained for Willow Lake during this study.

Temperature, dissolved oxygen, pH, and specific conductivity were measured in the field with a Hydrolab System 8000 water quality monitoring instrument manufactured by the Hydrolab Corporation of Austin, Texas. This system monitors the parameters with a data transmitter, which contains sensor and analog circuits, that is attached to a 200 meter electrical cable. The transmitter unit, carried and protected by a clear plastic cylinder, contains a motor-driven

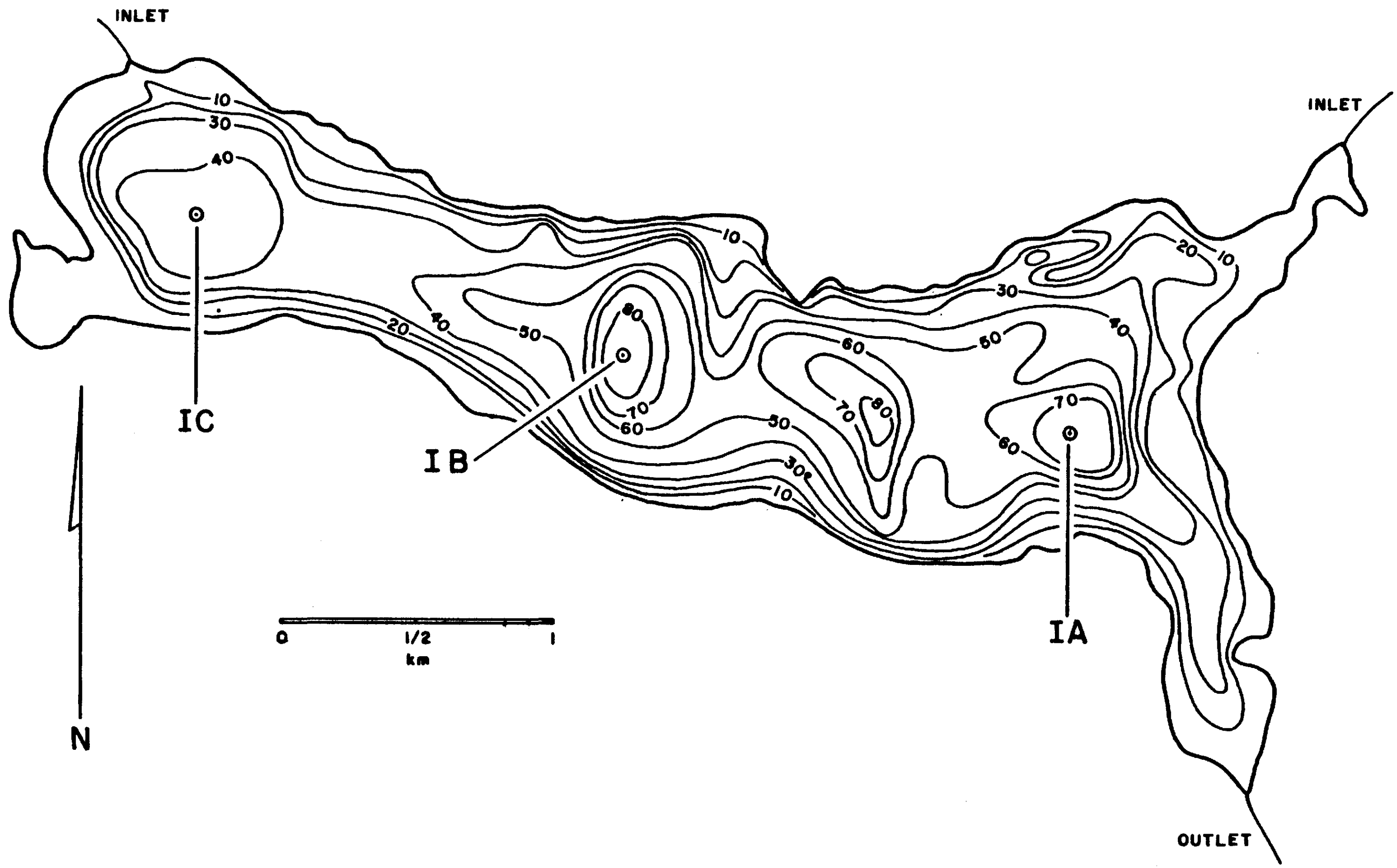

Figure 4. Bathymetric map of Halfmoon Lake showing sampling locations.

impeller to provide proper circulation of water through the sensor chamber. Parameter values are read to the nearest 0.1 of a unit from the digital display on the control unit. Power is provided for the entire system with a 12 volt rechargeable battery pack.

The depth sensor of the instrument was calibrated in the field to adjust for local changes in atmospheric pressure and altitude. A calibration check on all other parameters monitored by the instrument was completed daily before each use at the Pinedale Game and Fish Office. Two of the parameters measured in the field by the Hydrolab had to be converted from field values read off the control unit to actual values due to calibration sensitivity problems with the instrument.

The unit would only read 0.8 of the actual depth. Field measurements for depth were divided by 0.8 to obtain actual depth. The specific conductivity sensor was not as sensitive at lower conductivity ranges as the manufacturer specifications indicated and the instrument would not calibrate properly in the lower ranges. This sensor was then precisely calibrated in higher range with a standard KCl solution of 1,370 μmhos/cm at 25°C. Four other standard KCl solutions of 120 μmhos/cm or less were used to attempt to calibrate this sensor. A linear relationship was found to occur between the standard solutions and the value reading off the meter: $y = 0.86x - 18.16$, where x is the conductivity reading off meter in μmhos/cm and y is the actual value of conductivity that should be displayed on the meter. This unit automatically compensates conductivity readings to 25°C.

Estimation of the percent saturation of dissolved oxygen, compensating for high altitude, was determined with an Oxygen Saturation Nomograph (Wetzel, 1975). Water transparency was measured with a standard 20 centimeter (cm) secchi disk. Samples for all other water analyses were taken with a 1.2 liter (1) Kemmerer sampler at the surface, 15, and 30 m of depth.

Field determinations of total alkalinity (mg/1 as $CaCO_3$) were made immediately after collection of samples. Total alkalinity was measured by a potentiometric titration with standardized 0.02N sulfuric acid using a 10 milliliter (ml) microburet as described in "EPA Methods for Chemical Analysis of Water and Wastes" (1979).

Water samples for nutrient analyses were stored in acid rinsed polyethylene bottles. Bottles to be used for dissolved silica were not acid rinsed. Dissolved silica samples were filtered in the field with 0.45 μm millipore filters. Phosphorus and nitrogen nutrient samples were preserved with mercuric chloride according to U.S. Geological Survey standard methods (1979). All samples were then packed in coolers with ice and shipped Special Delivery from Pinedale to the U.S.G.S. National Water Quality Laboratory in Denver, Colorado, for analysis. Time of transport was less than 24 hours. Analysis was conducted by U.S.G.S. within a week of receiving the samples.

Plankton

Plankton were sampled on all three lakes in June and August of 1981. Samples were collected with a no. 20 Clark-Bumpus closing plankton sampler. Four depth-integrated net hauls were taken at each station. The sampling integrations were set up on the basis of temperature stratification zones of the lake. This amount of sampling did not allow time for replicate sampling of plankton. All samples were fixed with Lugol's solution and stored in coolers until lab analysis.

The preserved plankton were counted using the Sedgewick Rafter method with 1 ml aliquots according to "U.S.G.S. Aquatic Biological Methods" (1979). Phytoplankton were enumerated in the counting cell at a magnification of 200x using a minimum of ten random fields depending on the quantity of phytoplankton. All zooplankton in the 1 ml volume counting cell were counted at a magnification of 100x. Three 1 ml subsamples were taken from each sample and the results were converted to number of organisms/liter and then averaged (U.S.G.S. Aquatic Biological Methods, 1977). All plankton counted were identified to genus.

Mysis relicta

Mysis relicta were sampled from Halfmoon and Willow Lake in June and August of 1981 using nighttime vertical net tows. Samples were collected with the use of 0.5 m diameter, 500 μm nylon mesh plankton net towed from the lake bottom to the surface. The net was lowered to the bottom and raised by hand at an approximate towing speed of 0.33 to 0.50 m/sec. In June, three replicate samples were taken at each station on each of the two nights of sampling. During the August sampling trip, a total of only three samples could be collected at each station due to successive nights of thunderstorms and rough water. Mysids were scheduled to be sampled for two nights on each trip in order to avoid a possible sampling bias caused by moonlight or weather conditions. These factors might affect the accuracy of mysid collection on the basis that certain conditions may exist which will influence the vertical migration of *Mysis* and hence distribution of mysids throughout the water column and the ability to sample all sizes and sexes of the population accurately. Also, vertical tows were taken from the lower limits of the thermocline to the surface to determine the composition of the migrating population. All specimens were preserved in 95% ethyl alcohol.

A possible problem with sampling accuracy was encountered. The bottom of the plankton net was not weighted and the cable was quite heavy, so the net descended mouth open at a speed of about 0.33 m/sec. In actuality, the water column was being sampled twice on each net haul or at least some factor between 1 and 2. This situation can be represented by the following relationship: k x (# of mysids collected) = Actual # in water column, where k is a constant between 0.5 and 1.0. For purposes of this study k is assumed to have a value of 0.5 in order to correct for this sampling error. This problem is not considered to be crucial to the study because it is assumed that each water column was sampled identically for each net haul and results of mysid densities will only be compared within each lake and between the two lakes of concern.

All mysids in a sample were counted and then the total number in each sample was multiplied by the correction coefficient of 0.5 and converted to density estimates of mysids per square meter of lake bottom (mysids · m^{-2}). Then all replicate samples at each station were pooled for length-frequency analysis and sex determination. If necessary, subsampling was done to reduce a pooled sample to a workable size of 100 to 200 individuals.

Total length of a Mysis individual was measured from the tip of the rostrum to the tip of the telson under a dissecting scope at 40x magnification. Mysid size was recorded in the standard length-frequency manner (Gregg, 1976).

Mysids were classified into five classes according to sex characteristics: juvenile, immature male, immature female, mature male, and mature female. Individuals that were sexually undifferentiable were classified as juveniles. Males were identified by the presence of enlarged fourth pleopods and were considered mature if there was complete development of the fourth pleopod with a visible endopod and exopod. Females were identified by the presence of a brood pouch and were considered mature if the brood pouches were fully developed (Morgan and Beeton, 1978).

III. CHEMICAL LIMNOLOGY

CHEMICAL LIMNOLOGY

Fremont Lake

Fremont Lake is dimictic, undergoing a complete mix, surface to bottom, in both fall and spring during most years according to recent and previously collected thermal profile data (Rickert and Leopold, 1972; Leopold, 1980; Wyoming Game and Fish Department, personal communication, 1980). While complete turnover occurs most years, Rickert and Leopold (1972) report incomplete mixing took place in the spring of 1971. Vernal mixing occurred only to a depth of about 60 m due to rapid warming of the upper strata producing premature stratification and hence the lack of full circulation throughout the entire water column. According to Wyoming Game and Fish Department, Fremont Lake freezes over in mid-January and opens in mid-May. In 1981, the lake did not have full ice cover until late winter and was ice free the last week of April.

The initial sampling of Fremont Lake occurred on May 1, 1981, only a few days after ice break-up. Thermal profiles indicated the water column to be nearly isothermal with surface temperatures ranging from 4.7 to 5.5°C. The lowest surface temperatures were measured in the south basin at stations IIC and IID, furthest from the warmer influent waters of Pine Creek. The inlet water temperature was 9°C as measured by a hand thermometer.

Lower regions of the lake on May 1 exhibited temperatures less than 5°C. Depths below 100 m at the monitoring stations had water temperatures near 3.8°C, a lower temperature of maximum water density due to increased hydrostatic pressure at those depths (Strom, 1945).

By June 28, moderate temperature stratification had taken place with depths below 30 m exhibiting temperatures less than 5°C. Surface temperatures were between 13 and 14°C. Thermal profiles taken on August 21 show Fremont Lake to be well stratified with very distinct layers present. Mixing occurred down to about 8 to 10 m in depth. Epilimnion temperatures were approximately 17°C. The thermocline was set up between 10 and 25 m with an approximate gradient of 0.7°C per meter in depth. Bottom strata temperatures remained consistent at less than 5°C from May through the August sampling. All depth profile data for Fremont Lake are presented in Tables A-1 through A-3.

These thermal profiles of Fremont Lake throughout the summer months were typical of other temperature data collected during previous limnology studies of high mountain lakes (Gaufin et al., 1976; Larson, 1973; Rawson, 1953). Refer to Figure 5 for representative thermal profiles of Fremont Lake. Results of this study were also similar to Rickert and Leopold (1972) findings of an earlier limnological survey of Fremont Lake.

Secchi disk measurements were taken at all four stations during each sampling trip (Table A-12). In May, the transparencies were identical throughout the entire lake at approximately 14.3 m. Readings on June 21 ranged from 9.4 m in south basin to 9.8 m at the

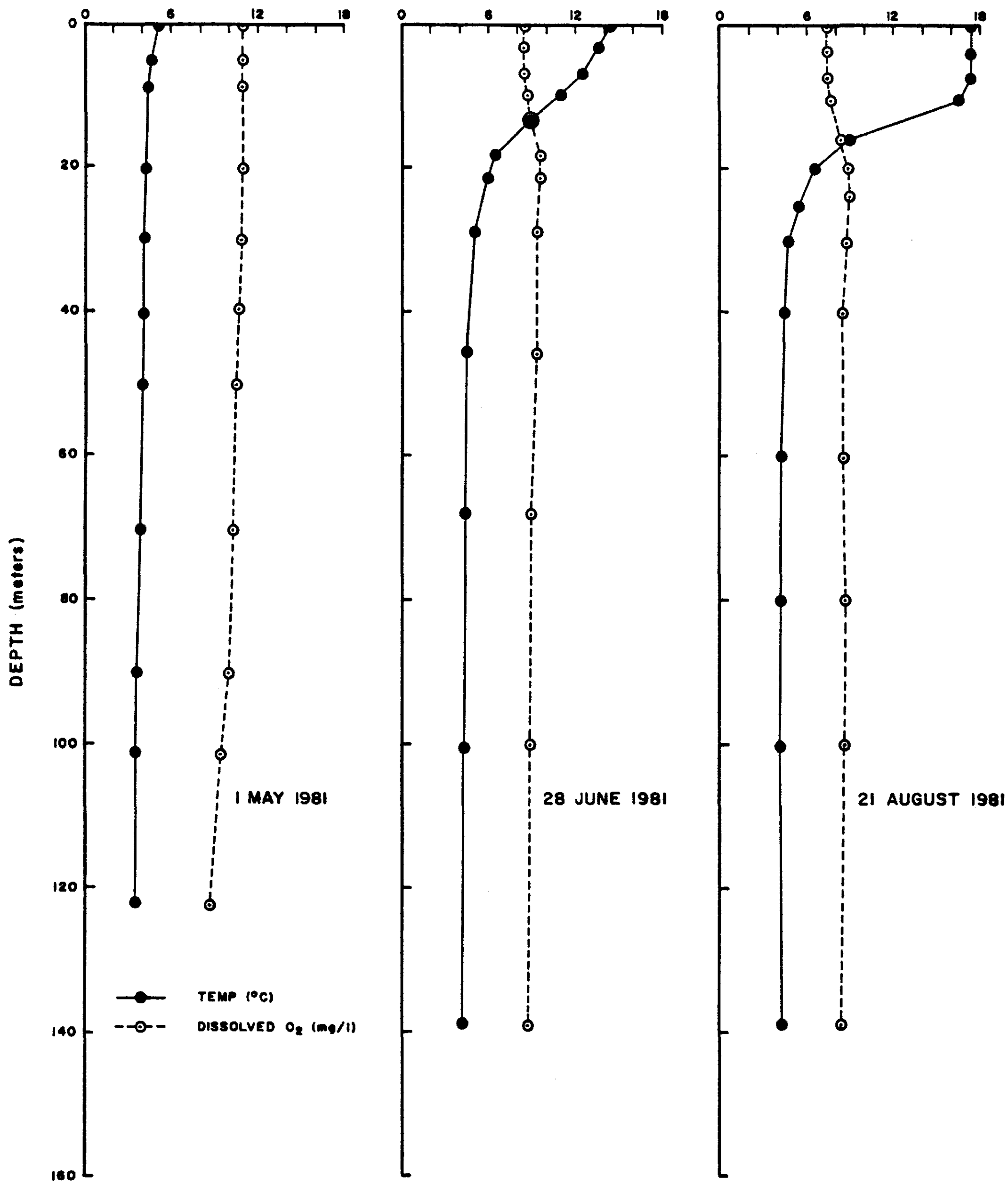

Figure 5. Temperature and DO profiles, Fremont Lake - Station IIB.

north end of the lake. The difference may be due to slightly more productive waters in south end of the lake, which is also more open to sunlight than the north end. The same type of phenomena was also observed in August where a slightly greater secchi disk depth was measured at stations IIA and IIB in the north basin. Water transparencies at station IIA and IIB were 12.4 and 12.6 m, respectively. Secchi disk depths at stations IIC and IID were 12.0 m.

Fremont Lake exhibits a vertical dissolved oxygen (DO) profile that is characteristic of the unproductive nature of an oligotrophic lake (Wetzel, 1975). The oxygen profiles throughout the sampling period were found to be orthograde showing a trend toward a positive heterograde curve during summer thermal stratification (Figure 5). The primary influence on DO content in Fremont Lake appears to be physical in nature through complete circulation in autumn and spring and low water temperatures. Metalimnetic oxygen increases during stratification are attributable to extreme water clarity influencing photosynthetic activity of phytoplankton at depths isolated from wind-induced mixing.

Dissolved oxygen levels at the surface on May 1, 1981, were at or near 11 milligrams per liter (mg/l). Complete saturation or supersaturation in the water column occurred to a depth of about 100 m. A slight hypolimnetic deficit below 100 m was observed, but saturation remained 87 percent or greater. High saturation values at these great depths are indicative of complete spring turnover and good oxygen transfer at the surface.

A positive heterograde DO profile with a metalimnetic maximum between 20 and 25 m was measured during the June 21 sampling. Surface DO concentrations ranged between 8.2 and 8.4 mg/l, which were the lowest values found in the water column. These lower DO levels are related to the higher water temperatures found in the upper strata. Hypolimnion concentrations remained at the same levels measured in early May.

By the August sampling, the oxygen content in Fremont Lake began to deplete throughout the water column. This minimal depletion is caused by the greater temperature stratification in the lake which prevents mixing to take place below a depth of 10 m as well as higher water temperatures. The August profiles were similar to those measured in June, except the metalimnetic peak occurred at shallower depths between 15 and 20 m at all monitoring stations. Dissolved oxygen concentrations in the lower regions of the lake ranged down to 8 mg/l, which were slightly lower concentrations than the previous months. The decrease in DO levels are possibly due to oxidation of a small amount of organic matter that has settled out from the euphotic zone of the lake.

Specific conductance, an indicator of the amount of ions in solution, was measured in the field throughout the entire water column at all four monitoring stations (see Tables A-1 through A-3). Fremont Lake was found to be extremely dilute with conductance values just slightly greater than that of distilled water. The ionic composition of the lake, as determined by Rickert and Leopold (1972), is classified as calcium bicarbonate type.

Conductance values measured in May and June varied only about 4 µmhos/cm between surface and bottom. Maximum values measured were 16.2 µmhos/cm at 25°C in the south basin. There were no observed temporal or spatial differences in conductance measurements during May and June. In August, during summer stratification, the specific conductance remained constant down to a depth of 10 m, the approximate boundary between the epilimnion and thermocline. The maximum observed conductance was found in the thermocline at a value of 13.7 µmhos/cm at 25°C. Values in the lower regions of the lake ranged down to less than 9 µmhos/cm at 25°C.

Vertical ph profiles were also measured in the field throughout the study. The pH values of Fremont Lake would be considered relatively low, but are still within the range for unproductive subalpine lakes (Table 5). There was a small decrease in pH from surface to bottom observed during the three separate samplings, except for station IIC on May 1. Surface values in May ranged from 6.12 to 6.25 standard units, while values at the bottom were 5.93 to 6.39 units. An increase in pH throughout the water column was observed in June and August. The maximum pH values, ranging up to a value of 7.0 units, were found in the thermocline, which coincides with the metalimnetic dissolved oxygen peak. This relation of pH and DO suggests that these parameters are influenced by algal photosynthesis in the euphotic zone.

Table 5. Water chemistry comparison of selected oligotrophic lakes.

Lake	Total Phosphorus (µg/l)	Total Nitrogen (µg/l)	Specific Conductance (µmhos/cm at 25°C)	pH (Standard Units)	Total Alkalinity (mg/l $CaCO_3$)	Source
Harding, Alaska	6-20	70-300	48-96	6.8-8.2	12-42	LaPierriere et al. (1978)
Mowich, Washington	2-4	15-135	11-16	6.9-7.2	5-10	Larson (1973)
Superior, USA-Canada	9	*	79	7.4	23	Minn. P.C.A. (1970)
Tahoe, Calif.-Nevada	2-20	100-150	86	7.2-8.0	36-46	Goldman (1974 Lake Tahoe Area Council (1971)
Experimental Lakes, Ontario	3-20	110-300	19	5.6-6.7	0-8	Armstrong and Schindler (1971)
Fremont, Wyoming	1-13	300-900	9-17	5.9-7.0	8-13	Present study
Willow, Wyoming	2-19	200-1000	18-25	5.5-7.1	14-33	Present study
Halfmoon, Wyoming	2-15	300-800	10-18	5.8-7.0	8-14	Present study

*No data available.

Total alkalinity was measured in June and August at the surface, 15 and 30 m (Table A-9). No definite trends in relation with depth or monitoring stations were observed. Alkalinity values ranged between 7.5 and 13.4 mg/l as $CaCO_3$. This extremely low bicarbonate alkalinity content provides only minimal buffering capacity. This poor buffering system may cause Fremont Lake to be subject to large pH fluctuations caused by algal productivity during the summer or from influx of acidic runoff from precipitation.

An overview of the nutrient status of Fremont Lake was obtained through analysis of total phosphorus, total nitrogen, and dissolved silica. Due to the small amount of sampling, a complete analysis of the nutrient cycles cannot be accomplished. Individual species of nitrogen were analyzed and then summed to determine total nitrogen. The only specie of phosphorus measured was total phosphorus (PO_4-P), because the expected concentrations for extremely dilute lakes are near the analytical detection limit.

Samples were collected for nutrient analysis on all three sampling trips. Nutrient samples from the April-May sampling were attempted to be analyzed by the Wyoming Game and Fish Water Quality Laboratory in Lander, Wyoming, but concentrations were below their detection limits and values were not reliable. Phosphorus and nitrogen samples collected during June and August were analyzed by the U.S. Geological Survey Water Quality Laboratory in Denver, Colorado, which is capable of accurately measuring low nutrient levels. Silica analysis was done by the U.S. Geological Survey Lab on all three occasions.

Total phosphorus values in June and August ranged between 1 and 5 micrograms per liter (μg/l), except for a single value of 13 μg/l at station IIC in June. No spatial or temporal trends in phosphorus concentrations were identified. Refer to Table A-9 for nutrient chemistry data of Fremont Lake.

Total nitrogen content in Fremont Lake varied from a low of about 0.3 mg/l (300 μg/l) to greater than 0.9 mg/l. An average total nitrogen concentration was approximately 0.5 mg/l in both June and August. Nitrate exhibited a range of concentrations from 0 to 14 μg/l. In August, ammonia nitrogen (NH_3-N) was measured. Organic nitrogen was then determined as the difference of total Kjeldahl nitrogen (TKN) and ammonia nitrogen. It was found that organic nitrogen accounted for a majority of the total nitrogen. According to Hutchinson (1957), this relationship of high percent of organic nitrogen is what is normally found in lakes, regardless of lake trophic status. In general, total nutrient status of Fremont Lake is in the range of other oligotrophic lakes (Table 5).

Dissolved silica (SiO_2) is of major importance in cycles of diatom algae, the dominant phytoplankton of oligotrophic lakes (Wetzel, 1975). Dissolved silica concentrations on May 1, 1981, were all less than 0.1 mg/l. These low values are related to the assimilation rate of silica by diatom algae for utilization in the synthesis of their silica frustules (Parker et al., 1977a). By June, the silica levels increased to 1.1 mg/l, which varied little throughout the water column. An average concentration of 1.2 mg/l SiO_2 was measured in August. With silica levels decreasing to less than 0.1 mg/l during spring turnover, and then increasing to above 1.0 mg/l, silica could be a limiting nutrient for diatom growth during the spring.

Willow Lake

Sampling of Willow Lake did not begin until June 23, 1981, due to adverse weather conditions during the late April sampling trip. No recent or adequate water quality data are available for Willow Lake to observe any trends or changes over time or to help support data collected in this study. Profile data collected for Willow Lake are presented in Tables A-4 and A-5.

Thermal profiles taken only during June and August do not constitute sufficient data to determine the annual thermal regime of the lake. Willow Lake, analogous to Fremont and Halfmoon Lakes in many respects, would be expected to be dimictic in nature undergoing complete spring and fall turnovers.

Willow Lake was found to be moderately stratified on June 23 with mixing occurring in the upper 7 m. The thermal gradient of the metalimnion was approximately 0.5°C/m (Figure 6). Surface temperatures ranged from 13.0°C at station IIIA, nearest sampling location to the inlet, to 11.7°C at station IIIC. Inlet temperature was 16°C on this date. Bottom temperatures at stations IIIA and IIIC

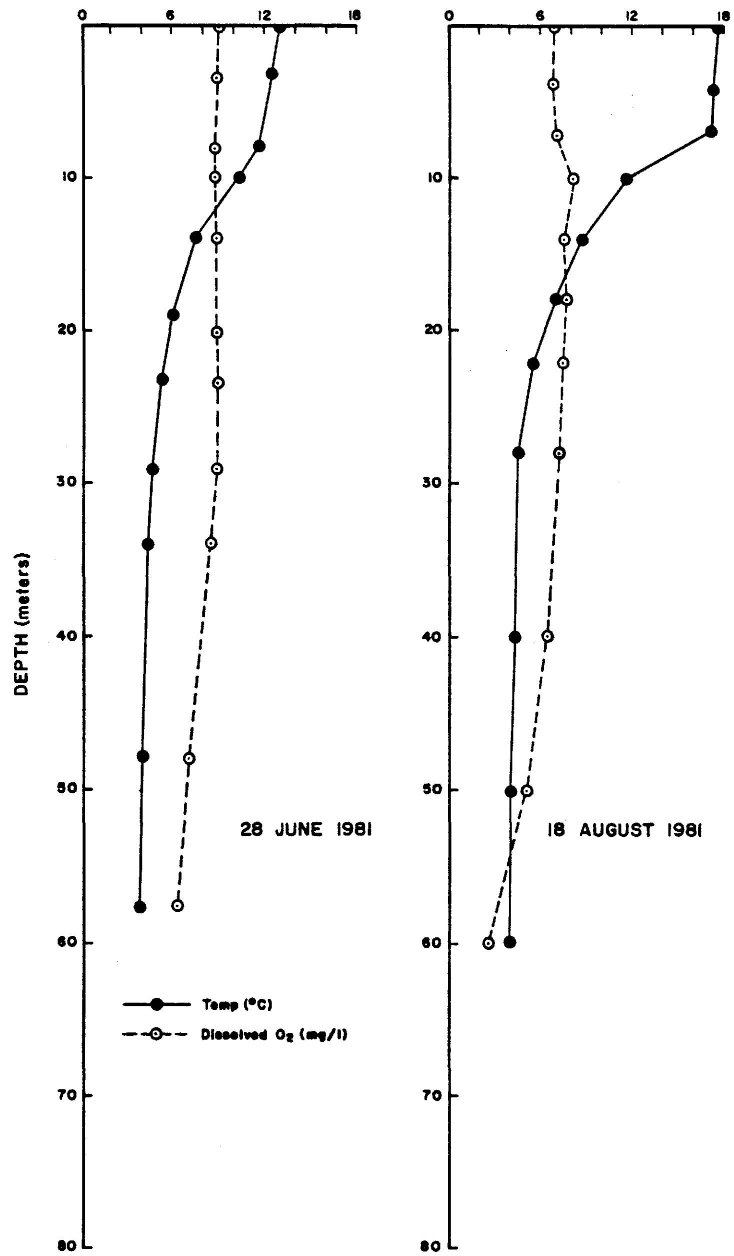

Figure 6. Temperature and DO profiles, Willow Lake - Station IIIA.

were near 4.0°C. Station IIIB, only about 26 m deep, had higher bottom temperatures of greater than 5°C.

Relatively strong thermal stratification was observed on August 18. The thermocline was set up between 7 and 22 m with an approximate thermal gradient of 1.0°C/m. Surface temperatures had increased to 17.8°C or greater. Bottom temperatures at stations IIIA and IIIC remained the same as measured in June. Station IIIB exhibited warmer water temperatures than IIIA or IIIC due to much shallower depths at IIIB.

Secchi disk depths in June were greatest at station IIIA (6.7 m). Stations IIIB and IIIC recorded secchi disk depths of 5.8 m. In August, water transparencies varied between 7.6 and 9.1 m with the maximum secchi disk reading being observed at station IIIC. Secchi disk measurements in relation to lake productivity will be discussed in a following section. See Table A-12 for secchi disk values.

Dissolved oxygen profiles of Willow Lake in June revealed an orthograde curve, which had a hypolimmetic oxygen decline (Figure 6). At stations IIIA and IIIB, the water column was supersaturated to a depth of 14 m. Oxygen saturation occurred to a depth of 44 m at station IIIC, which is presumably due to strong wind and wave action at the open west end of the lake. The lowest DO level of 6.2 mg/1 was measured at station IIIA.

A much pronounced DO deficit was found in the hypolimnion during the August sampling at station IIIA. Saturation decreased to a minimum of 32 percent. Dissolved oxygen concentrations in the lower regions ranged from 5.6 mg/l at station IIIC to 3.1 mg/l at station IIIA. The oxygen content reductions are caused by bacterial respiration during decomposition of organic matter in the benthic region. This condition of low oxygen levels can be stressful, if not fatal, to most forms of aquatic life, particularly cold water game fish such as Lake trout. A DO concentration of 6.0 mg/l is believed to be the lower limit for survival of a coldwater fishery (Everhart and Youngs, 1981).

Profiles of pH levels in Willow Lake, June 23, 1981, display slightly acidic conditions throughout most of the water column (Table A-4). Station IIIC exhibits alkaline pH values up to a 7.09 unit maximum in the upper 10 m. The higher pH levels are caused by the higher algal production at station IIIC, also shown by lower secchi disk readings and higher DO concentrations. The higher primary productivity at station IIIC may be due to a greater amount of direct sunlight reaching the water surface than at the other stations. Stations IIIA and IIIB may be sunlight limited during several hours of the day by high ridges along the east end of the lake.

Hydrogen ion profiles in August show a decrease in bottom pH levels to less than 5.5 at station IIIA. There was also a small decrease in epilimnion and metalimnion pH values. This may be the result of the time of day the profiles were taken. Measurements were taken between 0800 and 1000 hours. These observed pH levels may be reflecting diurnal fluctuations in pH and oxygen due to the rate of algal photosynthesis and respiration at different times of the day.

Total alkalinity values show Willow to have a small amount of buffering capacity (Table A-10). An average alkalinity value of about 18 mg/1 as $CaCO_3$ was measured June 23. The concentrations on this date ranged from 13.5 to 32.5 mg/1 as $CaCO_3$. A decrease of approximately 2 mg/1 occurred in average total alkalinity values from June to August. No other trends in alkalinity values were identified.

Specific conductance measurements taken in June ranged from 20.5 to 24.8 µmhos/cm at 25°C. Conductance measurements taken in August show a range of values from 18.0 to 20.5 µmhos/cm at 25°C. These values indicate Willow Lake to have relatively low concentrations of dissolved solids (Table 5).

Total phosphorus levels in Willow Lake during June and August were found to be wide-ranging with values up to 19 µg/1. Concentrations in June averaged about 6 µg/1, while the mean concentration of the August sampling was 8 µg/1. These values are within the range of total phosphorus values found for other oligotrophic lakes (Table 5). Station IIIC recorded the maximum phosphorus values on each sampling date. See Table A-10 for nutrient chemistry data for Willow Lake.

Total nitrogen varied between 0.2 and 1.0 mg/1 during the sampling period, with an average value of about 0.5 mg/1. In June, nitrate measurements were consistently less than 8 µg/1. August nitrate concentrations ranged from nondetectable levels (<1 µg/1) to 12 µg/1. Using the difference between TKN and ammonia nitrogen to determine organic nitrogen, it was found that organic nitrogen comprised more than 90 percent of the total nitrogen content. This is the situation most commonly found in freshwater lakes (Allen and Kramer, 1972).

Dissolved silica levels showed very little variation between monitoring stations or with depth. Silica levels in June were between 2.9 and 3.2 mg/l, well above the expected limiting concentration (Kilham, 1975). The inlet concentration was only 2.5 mg/l, suggesting that a portion of silica is provided by dissolution of diatom frustules and recycling of that silica during fall and spring lake circulation (Ferrante and Parker, 1978). Silica concentrations in August were between 3.3 and 3.6 mg/l, with 3.4 mg/l being the most typical value. The slight increase in silica may be due to phytoplankton succession where less diatom production is occurring in August and hence less uptake of silica. It appears from the nutrient chemistry analysis with total phosphorus concentrations being low and total nitrogen and dissolved silica being comparatively high, that the limiting nutrient for primary production in Willow Lake is phosphorus.

Halfmoon Lake

Halfmoon Lake was initially sampled on April 30, 1981. Ice break-up on Halfmoon Lake occurred April 27. Due to the surrounding topography of the lake, it would be expected in a normal year for Halfmoon Lake to freeze earlier in the winter than Fremont Lake. A minimal amount of background information regarding physical and chemical characteristics of Halfmoon Lake is available to allow comparison of previous and recent data. See Tables A-6 through A-8 for depth profile data collected on Halfmoon Lake during this present study.

Halfmoon Lake, with a mean depth of 28 m, is shallow enough to expect the lake to be dimictic, circulating freely after ice break-up in the spring and prior to ice formation in late fall or early winter. Thermal profile data collected on April 30, 1981, support the theory that the lake completely circulates after ice-off in the spring. Temperatures throughout the water column were nearly isothermal with a 5°C maximum at the surface and 4.0°C at the bottom. The warmest surface temperature of 5.0°C was measured at station IA, nearest the main inlet. The inlet water temperature on April 30 was 9°C.

Weak thermal stratification began to appear by the June 26 sampling. Partial mixing of the water column was still occurring in the upper 20 m, probably during windy days. Surface temperatures had risen to a maximum of 14.5°C at station IB. Also, bottom temperatures had warmed to 5.4°C at all stations.

Thermal profiles taken August 19 were typical of cool temperate lakes that stratify during summer months. The epilimnion extended down to about 8 m with temperatures in this upper strata about 16°C or greater. The thermocline was set up between 8 and 20 m and had a mean thermal gradient of about 0.8°C/m. Hypolimnion temperatures had only slightly increased from June to a maximum of 5.7°C (Figure 7).

Water transparency, as measured with a secchi disk, was consistent throughout the lake at a depth of 11.3 meters on April 30. See Table A-12 for secchi disk depths. Secchi disk readings on

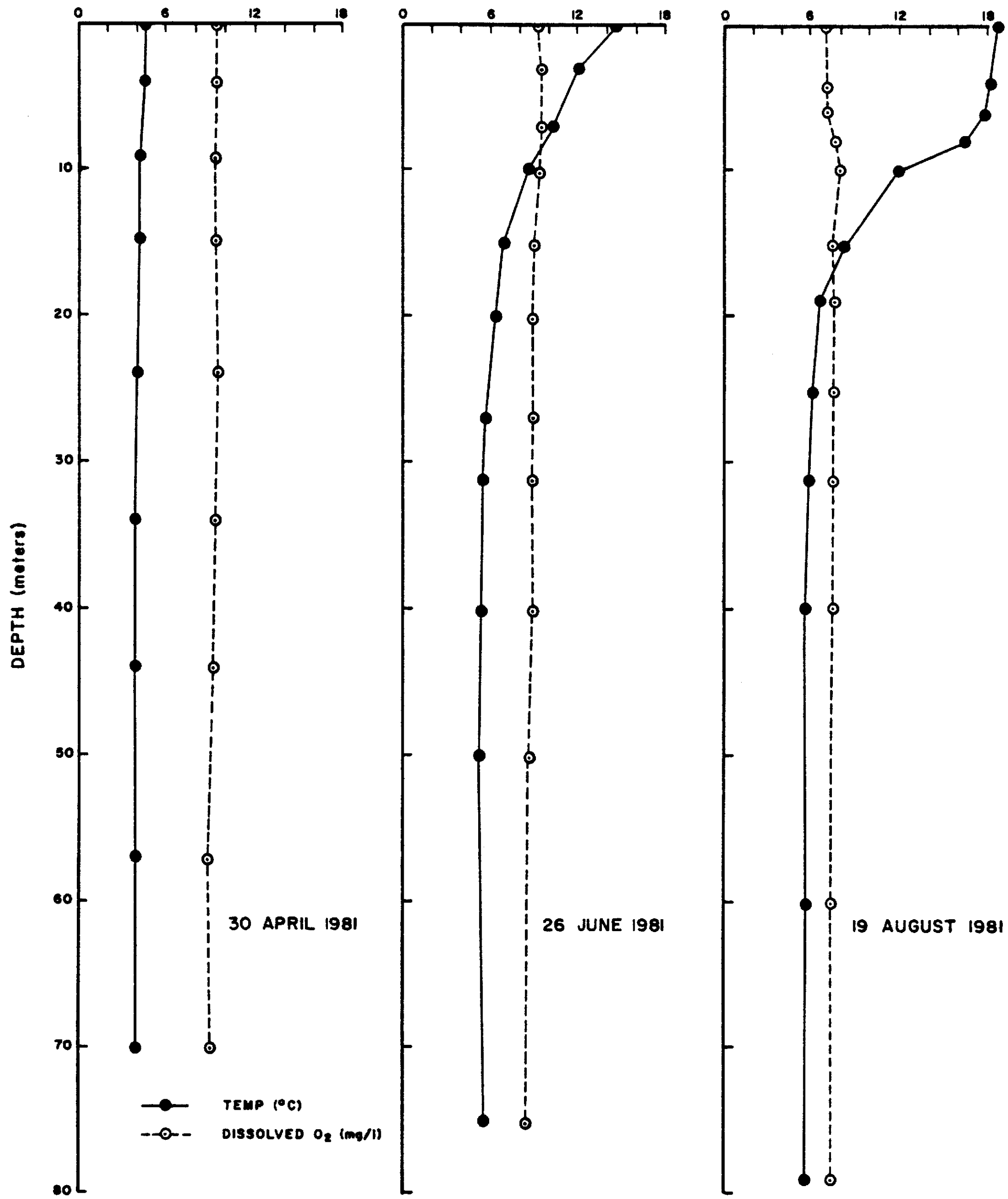

Figure 7. Temperature and DO profiles, Halfmoon Lake - Station IB.

June 26 showed a spatial difference. The lowest measurement, 5.2 m, was at station IC. Stations IA and IB had secchi disk measurements of 6.0 and 5.8 m, respectively. This difference in transparencies at the monitoring stations could possibly be due to spatial differences in nutrient concentrations and phytoplankton densities, which will be discussed in following sections of this text. Also, these secchi disk readings taken in June may not be representative of the general lake productivity, since there was uniform surface layer approximately 15 cm thick consisting of fine suspended matter causing shallower readings than expected. The suspended matter was not any type of algal growth, but upon analysis it appeared to be pollen grains which might have blown onto the water surface from the surrounding area.

In August, the secchi disk measurements showed the same trend in relation to monitoring stations. Station IC had a reading of 7.7 m, while stations IA and IB were 8.5 and 8.4 m, respectively. No suspended matter was present in the surface layer during the August sampling.

Dissolved oxygen profiles taken during April and June exhibited an orthograde curve. Refer to Figure 6 for representative DO profiles. Concentrations in April were all greater than 9 mg/l. Oxygen saturation was just above or below 100 percent, adding evidence to full lake circulation in May. June measurements showed DO saturation still above 90 percent in the lower regions with actual concentrations 8.7 mg/l or greater. Supersaturation occurred in the upper 15 m of the lake due to wind-induced mixing or algal production or a combination of the two factors.

Oxygen profiles taken August 19 produced an orthograde curve with a metalimnetic oxygen peak at 10 m of depth (Figure 7). Also, a small hypolimnetic oxygen deficit was observed with DO saturation ranging down to 76 percent, which is quite adequate for the support of aquatic life.

Hydrogen ion profiles in April indicated Halfmoon Lake to be acidic, which may be due to an influx of humic acid runoff from the wooded watershed. The pH levels were less than 6.0 standard units at stations IB and IC, while the maximum recorded pH of 6.06 units was found at station IA. Bottom pH's were found to range down to 5.85 units. Latest available data concerning pH levels in Halfmoon Lake collected in 1959 show pH's between 7.0 and 5.5 (Wyoming Game and Fish Department Records). This would indicate that no dramatic increase in hydrogen ion content has occurred over the past 20 years.

An increase in pH was observed in the upper water strata in June and August. Values were slightly less than 7.0 near the surface, but values were still at or less than 6 units below 30 m. These increases in pH appear to be strongly influenced by biological utilization of carbon dioxide in photosynthetic processes in the euphotic zone (Wetzel, 1975).

These low pH levels in Halfmoon Lake may be of extreme consequence to the aquatic fauna. Nero and Schindler (1981) report that the critical pH for Mysis relicta is between 5.9 and 5.6. Beamish (1976) states that Lake trout stop reproduction at pH levels near 5.5; however, the reproductive success is dramatically reduced in most fish species below about 6.0 units.

Alkalinity measurements taken throughout the study reveal Halfmoon Lake to be very poorly buffered (Table A-11). Total alkalinity values ranged down to less than 8 mg/l as $CaCO_3$. The carbonate buffering system of Halfmoon Lake does not have the capacity to neutralize any influx of acidic waters.

Conductivity values in Halfmoon Lake varied less than 2 μmhos/cm throughout the water column on each sampling date. Dissolved ion content decreased from April to August, possibly related to less runoff of snowmelt from watershed causing smaller amounts of dissolved materials to enter the lake. Specific conductance values were at a maximum in April with 18.0 μmhos/cm at 25°C. By August, maximum value had decreased to 14.5 μmhos/cm at 25°C. These conductance values are comparable to other oligotrophic lakes and would indicate Halfmoon Lake to be extremely dilute (Table 5).

Nutrient chemistry of Halfmoon Lake exhibited some definite trends in differences of concentrations between monitoring stations and sampling dates (Table A-11). Measurements taken in June displayed total phosphorus concentrations the highest at station IC with an average concentration of greater than 8 μg/l. Average total phosphorus concentrations at stations IA and IB were 3 to 4 μg/l less than at station IC. Total nitrogen levels in June did not vary much between stations, although the highest nitrogen species concentrations were all found at station IC.

An overall decrease in total nitrogen and nitrate concentrations was observed from June to August, which may be attributed to phytoplankton succession and therefore greater demand of nitrogen species, especially nitrate, by green and blue-green algae (Wetzel, 1975). Again, higher total phosphorus concentrations were found at station IC, which were also slightly greater concentrations than measured in June. Nitrogen species concentrations were also greatest at stations IB and IC. The differences in nutrient concentrations between stations may result from cultural activities. A Bridger National Forest campground is located at the west end of the lake near station IC. The campground was heavily utilized and was completely filled with campers throughout most of the summer. It is possible that the campground waste disposal system may be the source of the nutrient enrichment.

Dissolved silica concentrations in April were all less than 0.1 mg/l, including the major inlet. A sample taken from a minor inlet at the northwest end of the lake showed silica levels to be approximately 5 mg/l. Due to access problems to the stream with monitoring equipment, no other water quality measurements could be taken except for water temperature.

The dissolved silica that enters the lake from the inlet is usually only of minor importance compared to autochthonous silica sources. Silica that has gone into solution from sedimentary fractured diatom frustules is returned to the overlying waters during spring turnover (Ferrante and Parker, 1978; Parker et al., 1977b). This silica is immediately taken up by diatom algae, which causes the depletion of silica in the upper water column as shown by the low concentrations in Halfmoon Lake on April 30. Thus, during the spring diatom bloom, silica appears to be the limiting nutrient since concentrations have dropped well below 0.5 mg/l, which is believed to be the limiting concentration (Lund et al., 1963; Kilham, 1975). Dissolved silica levels returned to nonlimiting concentrations of greater than 2 mg/l in June and August.

IV. PLANKTON

PLANKTON

Net plankton were collected on only two dates for each of the three lakes during this study. Due to a lack of availability of equipment, a no. 20 mesh-size net was used, which is most suitable for capturing larger forms of phytoplankton and zooplankton. Because of the forementioned reasons, the results obtained in this study should only be used as a comparative index among these three lakes. Refer to Appendix B, Tables B-1 through B-12 for plankton density data.

Fremont Lake

The phytoplankton of Fremont Lake were found to be characteristic of nutrient-poor oligotrophic conditions (Table 6). The dominant algal group in June and August were the diatoms, which composed 95 and 87 percent of the total algae populations, respectively (see Figure 8). Diatoms consisted only of pennate form, no centric forms were collected. Asterionella sp. was the most abundant genus on both sampling dates. Other associated diatom genera collected were Tabellaria sp. and Fragilaria sp. Synedra sp. was found only in samples collected on August 21.

Golden-brown algae, specifically Dinobryon sp., made up approximately 4 percent of the total phytoplankton in both June and August. Only one genus of blue-green algae, Nostoc sp., was collected in Fremont Lake, and that was in August at the time of relatively warm water temperatures. Green algae was predominantly the desmid,

Table 6. List of net plankton in Fremont Lake.

I. Phytoplankton

A. Bacillariophyceae (Diatoms)

Asterionella sp.
Tabellaria sp.
Fragilaria sp.
Synedra sp.

B. Chrysophyceae (Golden-Browns)

Dinobryon sp.

C. Chlorophyceae (Greens)

Staurastrum sp.
Unidentified filaments

D. Cyanophyta (Blue-Greens)

Nostoc sp.

II. Zooplankton

A. Cladocera

Daphnia sp.
Bosmina sp.

B. Copepoda

Cyclops sp.
Diaptomus sp.

C. Rotifera

Keratella sp.
Kellicottia sp.

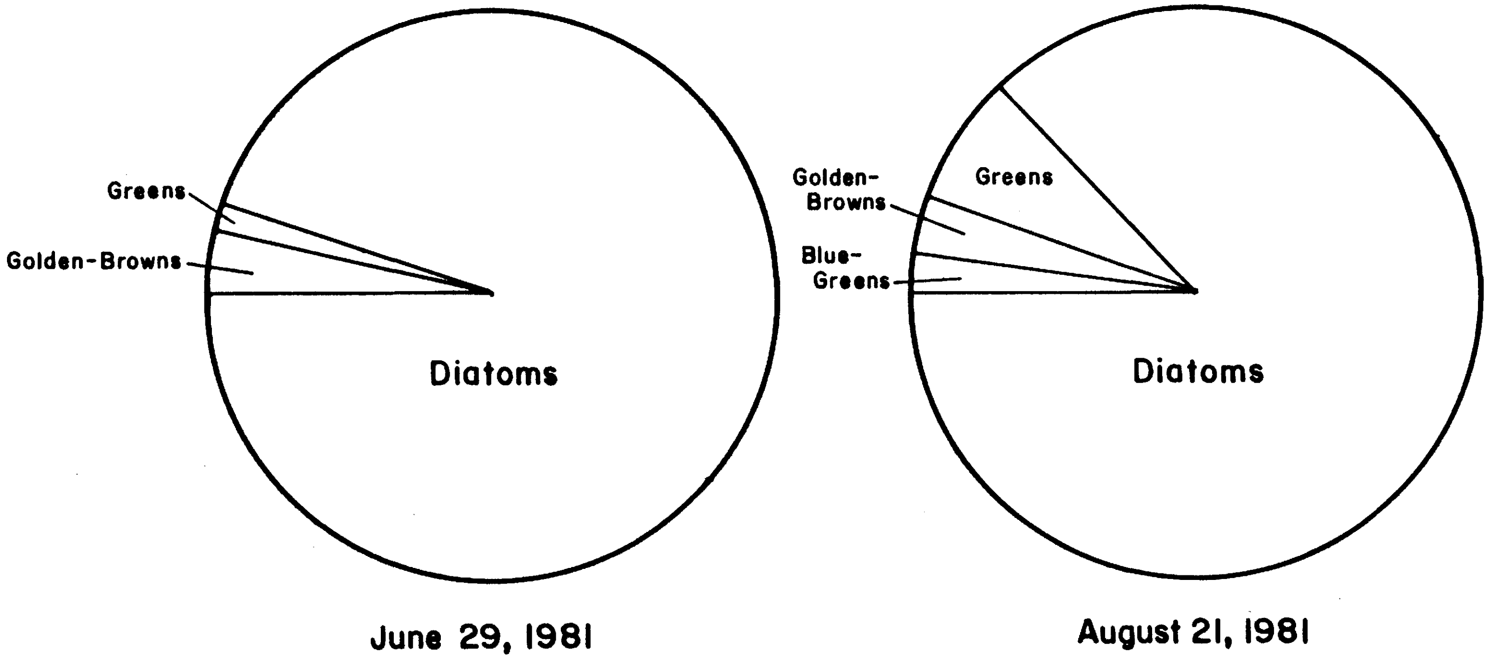

Figure 8. Relative composition of phytoplankton populations in Fremont Lake.

Staurastrum sp., but filamentous greens were more common in the August plankton tows.

The relative phytoplankton densities in June were greatest at stations IIC and IID (Tables B-1 and B-2). This lesser amount of primary production at stations IIA and IIB may be due to these stations being located in the north basin of the lake surrounded by high cliffs and not receiving as much direct sunlight as stations IIC and IID. Lower total algal densities were found in the August samples and densities were more variable among stations.

Zooplankton populations sampled in Fremont Lake consisted of six genera of three different orders. The types of zooplankton found in Fremont Lake compose a community similar to that described in other studies of the zooplankton fauna in oligotrophic lakes (Larson, 1973; Gaufin et al., 1976; Pennak, 1949). Table 6 gives a list of plankton captured in Fremont Lake.

Copepods composed approximately two-thirds of the total zooplankton population in June and August (Figure 9). Diaptomus was the predominant genera of the two copepods and was also generally the most abundant zooplanktor throughout the sampling period.

Cladocerans, Daphnia and Bosmina, were present in all but one plankton tow on the two sampling dates. These two genera comprised about 9 percent of the zooplankton on June 29. In the period between June 29 and August 21, the cladocerans increased in percent and abundance. It appears from this overall increase of these two genera, that any planting of Rainbow trout fingerlings by the Wyoming Game and

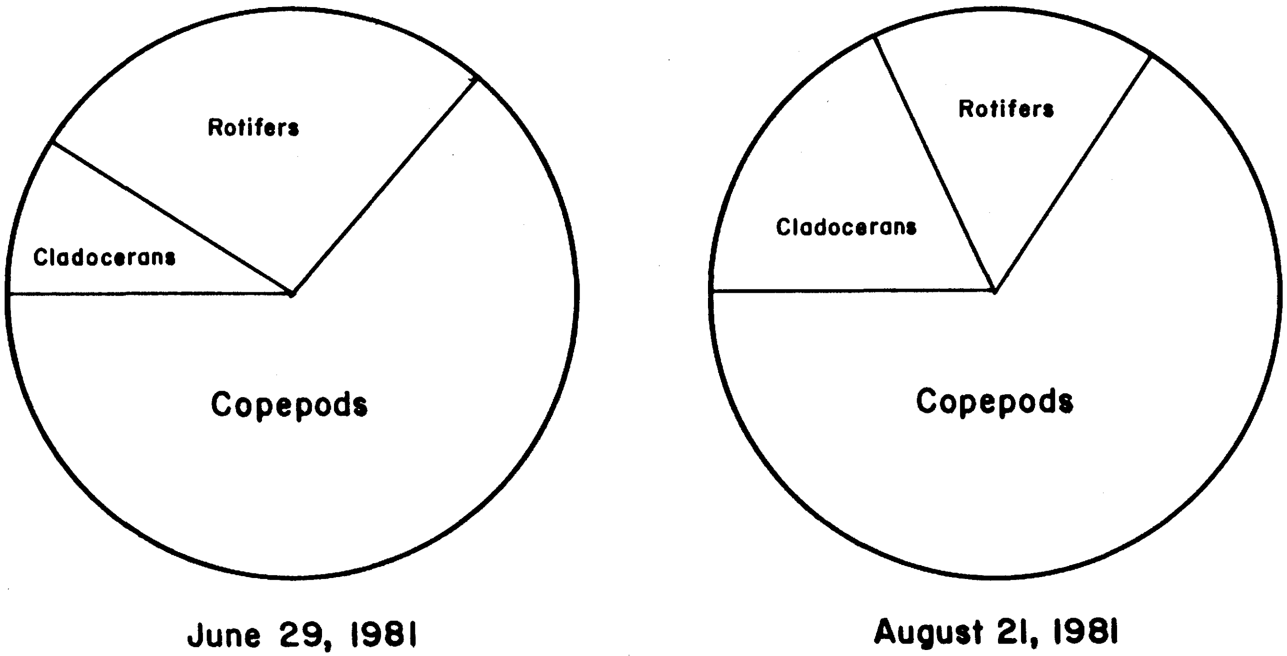

Figure 9. Relative composition of zooplankton populations in Fremont Lake.

Fish Department after the June 29 plankton collections did not have any severe impact on the cladoceran populations in Fremont Lake.

Keratella sp. and *Kellicottia* sp. were found in about equal proportions to each other. These rotifers comprised 27 percent of the zooplankton fauna of Fremont Lake during the June sampling. In August, these rotifers comprised only 16 percent of the total population. These two types of rotifers are considered to be dicyclic in nature having spring and autumn maxima (Pennak, 1953). It appears that the August sampling occurred on the lower portion of this cycle.

All forms of zooplankton found on Fremont Lake occurred commonly throughout the lake, but some temporal and spatial differences in abundances were observed. Refer to Tables B-3 and B-4 for zooplankton densities according to depth interval and station. Total zooplankton abundance decreased from June to August by about 25 to 45 percent. In June, the majority of zooplankton resided in the thermocline, but in August, the zooplankton were more dense below the thermocline. This would suggest that they may be limited by location of their food supply and possibly by water temperature.

Willow Lake

The phytoplankton population of Willow Lake was found to be different in composition than Fremont or Halfmoon Lakes. Table 7 gives a listing of plankton collected in Willow Lake. The dominant algal class in June was the green algae (Figure 10). Sampling took place during the period of an algal bloom of *Pandorina* sp., which made up a high percentage of the entire green algae. The only diatom

Table 7. List of net plankton in Willow Lake.

I. Phytoplankton

A. Bacillariophyceae (Diatoms)

Asterionella sp.
Tabellaria sp.

B. Chrysophyceae (Golden-Browns)

Dinobryon sp.

C. Dinophyceae (Dinoflagellates)

Ceratium sp.

D. Chlorophyceae (Greens)

Staurastrum sp.
Selenastrum sp.
Eudorina sp.
Pandorina sp.
Unidentified filaments

E. Cyanophyta (Blue-Greens)

Nostoc sp.

II. Zooplankton

A. Cladocera

Daphnia sp.

B. Copepoda

Cyclops sp.
Diaptomus sp.

C. Rotifera

Keratella sp.
Kellicottia sp.

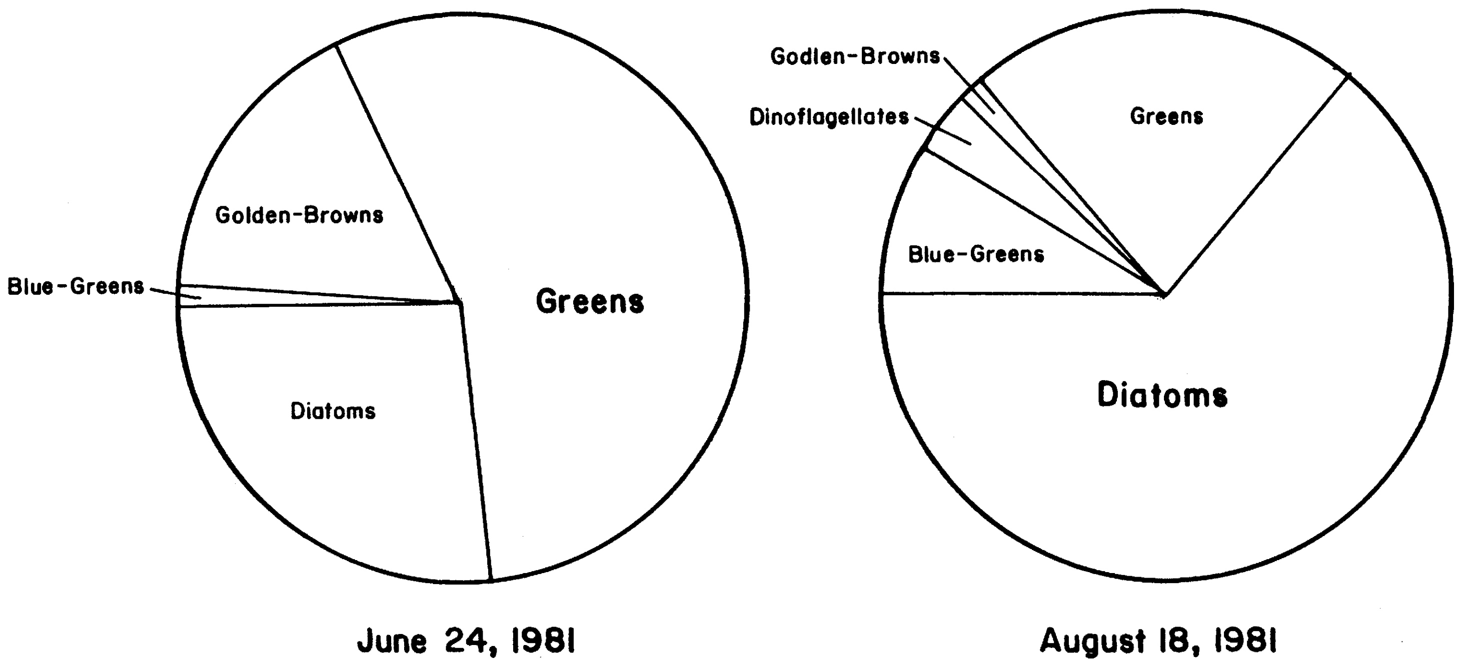

Figure 10. Relative composition of phytoplankton populations in Willow Lake.

present in the samples collected in June was Asterionella sp. Also, the blue-green Nostoc sp. was present in June plankton samples.

By the August sampling, the diatoms had become the dominant phytoplankton group, comprising about 64 percent of the total algae population. Tabellaria sp. was the only other diatom present in August samples, besides the abundant Asterionella sp. On the average, there were a greater number of diatoms per liter in June than in August, but due to the Pandorina sp. bloom in June, the percentage of green algae was out of proportion with the diatoms.

In the August samples, Dinobryon sp. had all but disappeared while the dinoflagellates were present in every plankton tow throughout the lake. The only dinoflagellate found in Willow Lake was Ceratium sp. Also, with the relatively warm water temperatures in August, the blue-greens had increased in abundance to comprise about 9 percent of the total population.

Station IIIC had the greatest relative densities throughout the study (Tables B-5 and B-6). These greater algal densities were reflected in the June secchi disk measurements, but it was not the case in August. Station IIIA recorded the shallowest secchi disk depth on August 18. This could have been related to an increase of inorganic sediments in the water column rather than to algae growth. Pole Creek may have been carrying a greater amount of sediment at this time due to frequent heavy thunderstorms. The materials carried in the stream would then be pushed out into the lake in the vicinity of station IIIA decreasing the water transparency.

The zooplankton community of Willow Lake consisted of five genera from three orders. Refer to Table 7 for a listing of zooplankton found in Willow Lake. This community was found to be somewhat less diverse than Fremont Lake, suggesting there may be an additional influence on zooplankton, such as opossum shrimp (*Mysis relicta*).

Only one cladoceran genus, *Daphnia*, was collected in June and August plankton samples. A decrease of *Daphnia* occurred during the summer months from 3 percent down to 1 percent of the zooplankton population (Figure 11). This decrease may have been related to either the impact of Rainbow trout plantings or the impact of increased number of mysids reaching the age when they begin to feed on zooplankton. The latter reason is believed to be what the decrease in cladoceran population is attributed to, because the cladocerans in Fremont Lake did not decline in number after stocking of Rainbow trout during the summer months.

Copepods and rotifers remained relatively constant in proportion to total zooplankton throughout the sampling period. *Diaptomus* sp. and *Keratella* sp. were the co-dominant zooplankton in both June and August. *Kellicottia* sp. was only present in two depth intervals in June, and was not present in any samples collected in August. The rotifers did not drastically decline by the August sampling as was observed in Fremont and Halfmoon Lakes. Pennak (1953) reported that rotifer population cycles are highly variable from lake to lake. In some lakes, rotifers were found to be perennial, exhibiting no substantial fluctuations in abundances.

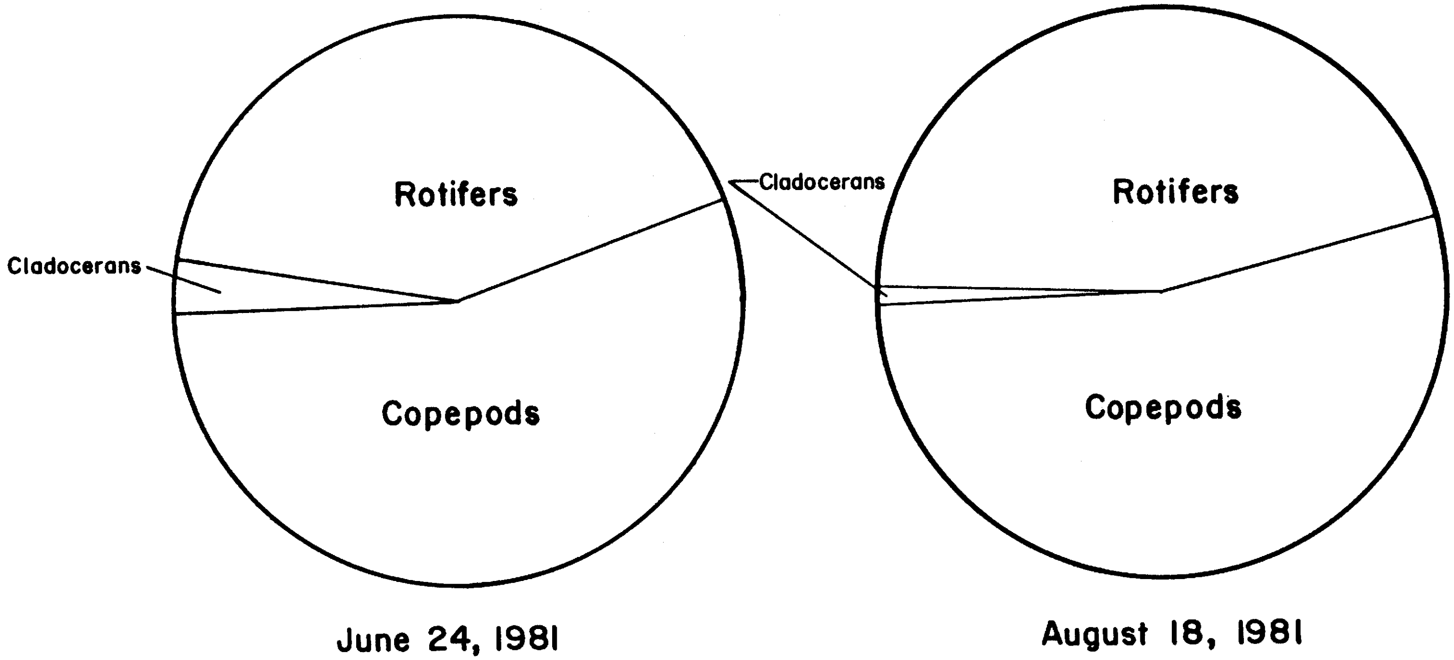

Figure 11. Relative composition of zooplankton populations in Willow Lake.

Generally, the zooplankton were mostly concentrated in the upper 7 m of the water column (Tables B-7 and B-8). This also corresponds to the phytoplankton maxima occurring in the upper portions of the thermocline or in the epilimnion. Total numbers were found to decrease from June to August, as would be expected from the decline in phytoplankton densities.

Halfmoon Lake

Halfmoon Lake exhibited an algal flora that is also characteristic of most oligotrophic lakes (Table 8). Diatoms were dominant in both June and August, comprising over 60 percent of the total algal population. *Dinobryon* sp. made up about 23 percent of the phytoplankton in June, while green algae only comprised 13 percent. Greens increased to 28 percent in August, while the blue-green, *Nostoc* sp., made up 1 percent of the algae. Figure 12 shows the relative proportion of phytoplankton in Halfmoon Lake on June 27 and August 20, 1981.

Of the diatoms, *Asterionella* was the most numerous genus. *Tabellaria* sp. and *Fragilaria* sp. were significantly less dense than *Asterionella* sp. in June and August. *Synedra* sp. was observed only in plankton tows collected August 20. The dinoflagellate, *Ceratium* sp., the green, *Pandorina* sp., and the blue-green, *Nostoc* sp. were also only found in August samples. *Eudorina* sp. and the desmids, *Staurastrum* sp. and *Selenastrum* sp., were the dominant green algae in June and August.

Table 8. List of net plankton in Halfmoon Lake.

I. Phytoplankton

A. Bacillariophyceae (Diatoms

Asterionella sp.
Tabellaria sp.
Fragilaria sp.
Synedra sp.

B. Chrysophyceae (Golden-Growns)

Dinobryon sp.

C. Dinophyceae (Dinoflagellates)

Ceratium sp.

D. Chlorophyceae (Greens)

Staurastrum sp.
Selenastrum sp.
Eudorina sp.
Pandorina sp.
Unidentified filaments

E. Cyanophyta (Blue-Greens)

Nostoc sp.

II. Zooplankton

A. Copepoda

Cyclops sp.
Diaptomus sp.

B. Rotifera

Keratella sp.
Kellicottia sp.

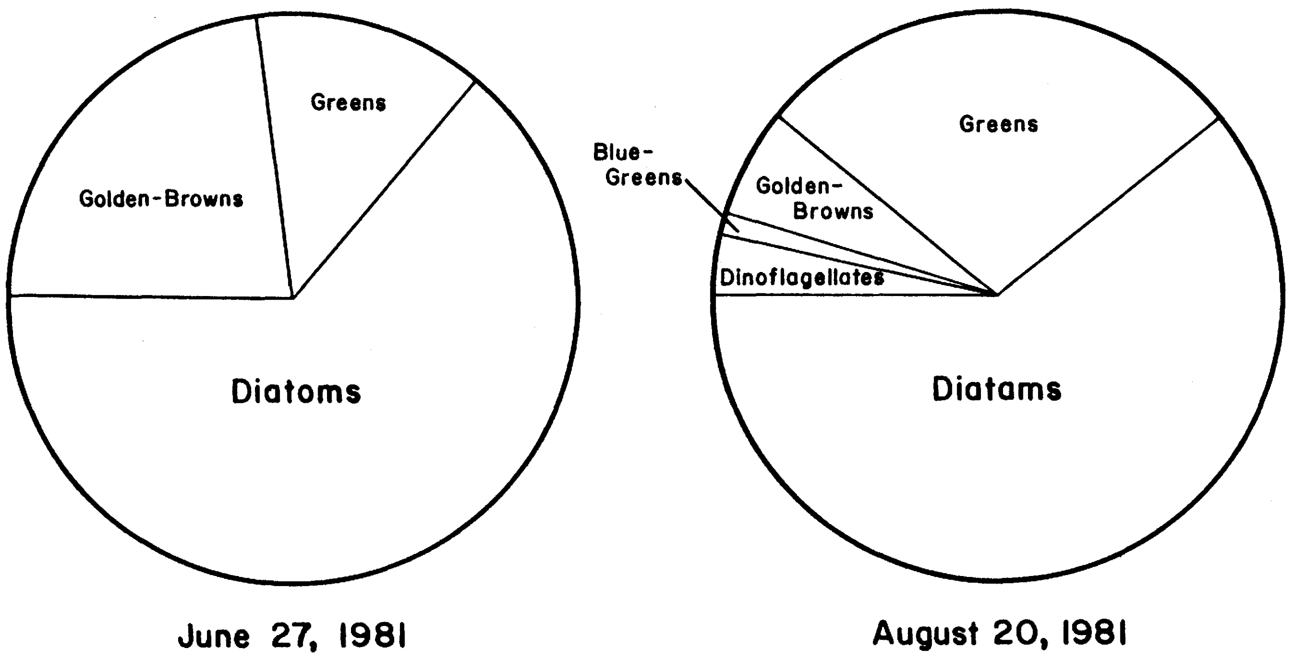

Figure 12. Relative composition of phytoplankton populations in Halfmoon Lake.

Station IC was the most productive of the three monitoring sites on Halfmoon Lake. This was also indicated by secchi disk readings on both summer sampling dates. Refer to Appendix B, Tables B-9 and B-10 for relative phytoplankton densities in Halfmoon Lake. Green algae were found to be most numerous at station IC throughout the sampling period. This greater algal production and abundance of green algae is attributed to higher nutrient concentrations measured at station IC. See previous chapter of this text for nutrient chemistry analysis.

The zooplankton community of Halfmoon Lake was found to be less diverse than Fremont Lake (Table 8). Cladocerans, _Daphnia_ sp. and _Bosmina_ sp., were not present in samples collected during this study. Since stocking of fish took place after the June sampling, it would appear that cladocerans have been eliminated from the zooplankton fauna of Halfmoon Lake by a cause other than fish predation. This absence of cladocerans will be discussed in relation to _Mysis relicta_ predation in the following chapter.

Copepods, _Diaptomus_ sp. and _Cyclops_ sp., were found to comprise about 55 percent of the total zooplankton populations in June and about 86 percent in August (Figure 13). _Diaptomus_ sp. was up to three or four times more abundant than _Cyclops_ sp. on both sampling dates. This extreme difference in abundance between the two genera may be related to selective prey preferences for larger food items by fish and mysids.

As was seen in Fremont Lake, the rotifer population in Halfmoon Lake declined significantly between June 27 and August 20. This is

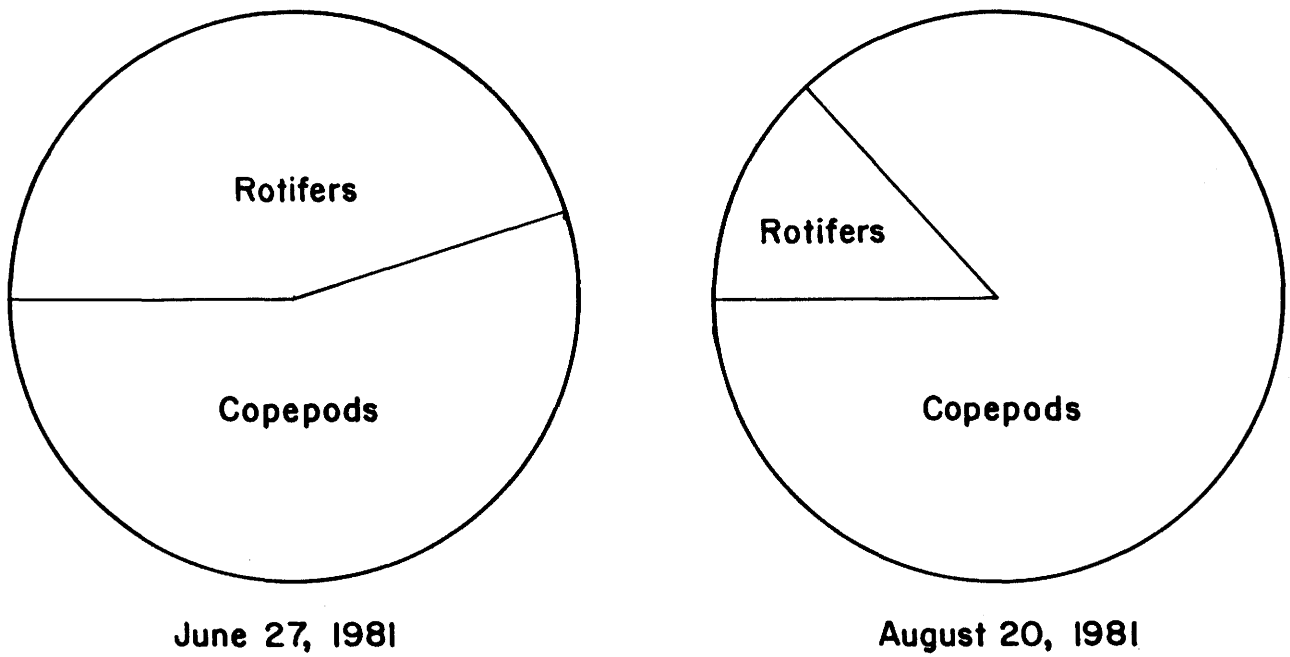

Figure 13. Relative composition of zooplankton populations in Halfmoon Lake.

related to the population cycles of rotifers. *Keratella* sp. was the most abundant of the two rotifers.

The majority of rotifers inhabited the epilimnion, which accounts for the large percentage of zooplankton in the upper 7 m. Relative zooplankton densities for Halfmoon Lake are presented in Appendix B, Tables B-11 and B-12. Copepods resided in the lower half of the thermocline, except for station IC, where the copepod maximum density was in the upper half of the thermocline. This spatial difference is related to the depth at which the phytoplankton maximum was found. Station IC had the greatest algal densities in the 7 to 15 m depth interval, which corresponds to the greatest zooplankton densities in the upper metalimnion. Overall secondary production decreased sharply in number between June and August as was also observed in Fremont Lake.

V. *MYSIS RELICTA* (OPOSSUM SHRIMP)

MYSIS RELICTA (OPOSSUM SHRIMP)

Willow Lake

Mysis relicta was found to be established in Willow Lake according to results obtained from vertical tows in June and August, 1981. Mean *Mysis* densities according to station are presented in Table 9. Mysids were more abundant at stations IIIA and IIIC than at station IIIB. An analysis of spatial and temporal variations in the population distribution was made to determine any effects of environmental conditions on mysid densities. The mean densities at each station were compared using the two sample t-test (unpaired t-test) at the 0.05 alpha level. This statistical test was used to test the null hypothesis that there were no significant differences in the sample means between sampling stations. The unpaired t-test

Table 9. Mean density estimates of *Mysis* · $M^{-2} \pm$ 95% confidence limits (n)* at each station on Willow Lake.

Station	June 1981	August 1981
IIIA	359 ± 54 (6)	659 ± 756 (3)
IIIB	24 ± 14 (6)	0 ± 0 (6)
IIIC	341 ± 49 (6)	1166 ± 232 (3)

*(n) denotes the number of samples.

requires the assumption that population variances are equal. The F-test tests the validity of this assumption. A check for homogeneous population variances at the 0.05 significance level was made prior to each mean density comparison.

Comparison of June sampling variances and mean densities between stations IIIA and IIIC, where depths are 60 m or greater, indicated homogeneous variances and no statistically significant difference in mean densities. At this time of the summer, there was little variation in ambient water temperatures and DO content between these two stations. All five sex classes of mysids were represented in samples at these stations and the class frequency distributions were nearly identical to each other. See Figure 14 for class frequency distributions according to station.

From inspection, it is apparent that the mean *Mysis* density in June is comparatively less abundant at station IIIB than the other two stations. Juvenile was the only age class represented in samples collected at station IIIB (Figure 14). With the low density value and only juveniles present at station IIIB, this suggests that mysid population in this relatively shallow area (26 m) is being influenced by light penetration rather than by water temperature, DO content, or plankton abundance, since these latter three factors are relatively similar in value at all three monitoring stations.

The variances of the August mysid samples were much larger than in June. This is attributed to only collecting a total of three samples at each station in August, F-tests run on comparison of mean

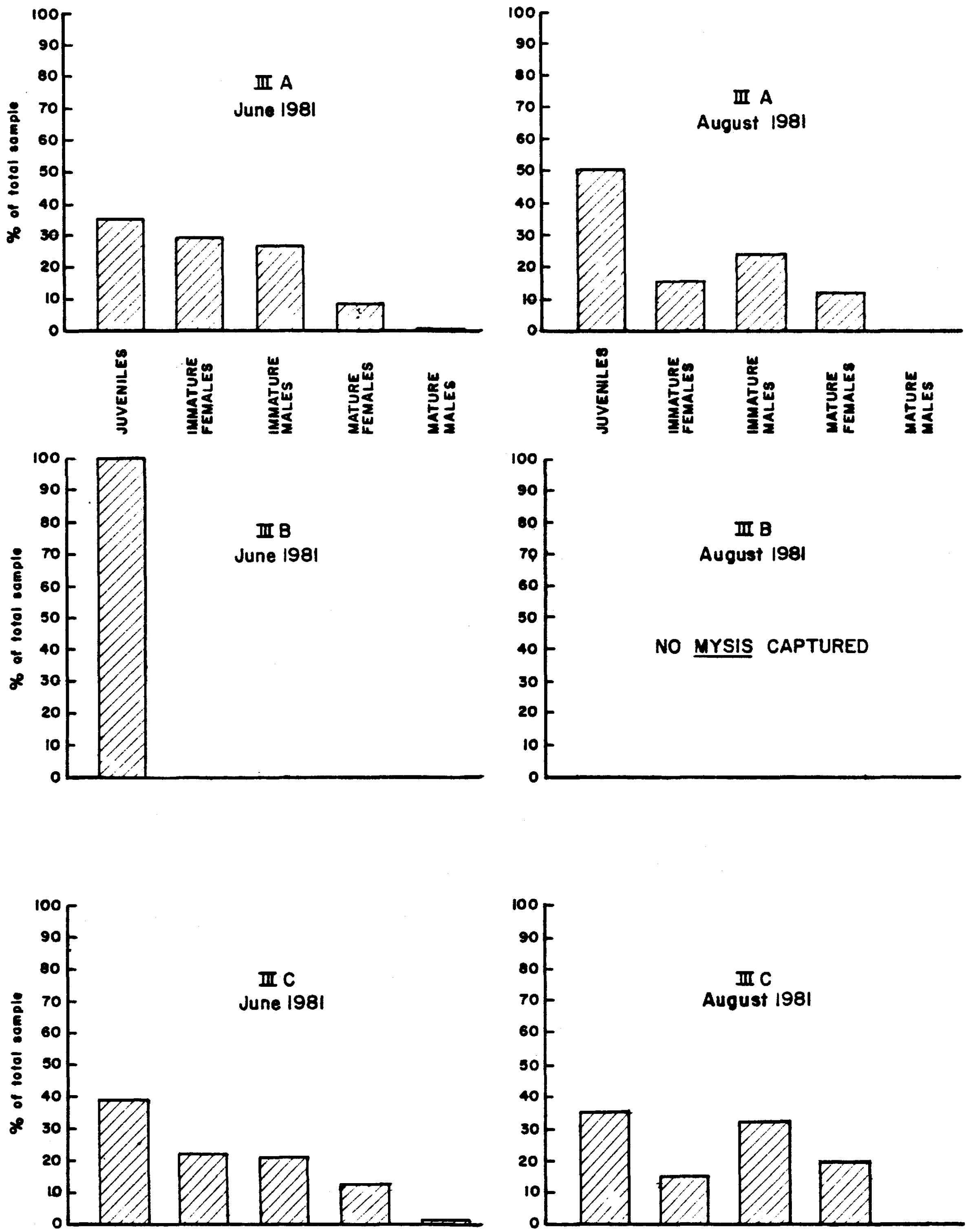

Figure 14. Class frequency distributions of Mysis relicta according to station in Willow Lake.

density data from August indicated homogeneous variances, but population variances of station IIIA in June and August were not equal and thus t-tests could not be used to compare mean densities of station IIIA between the two dates.

Unpaired t-tests indicated mean densities of stations IIIA and IIIC in August to be significantly different only at the 90% confidence levels. It appears from the data that if a greater number of samples could have been collected the population means would have also been significantly different at the 95% confidence level.

The difference in mean densities between the two stations in August is attributed to DO content in the lower hypolimnion. The dissolved oxygen saturation in the lower regions at station IIIA was about 32 percent (temperature = 4.0°C and DO = 3.1 mg/l). This DO saturation value is near the lower limit for mysid survival according to previous studies. Station IIIC exhibited more favorable conditions having a DO saturation greater than 55 percent in the hypolimnion. The juvenile age class composed 50 percent of the total *Mysis* population at station IIIA, while immature and mature *Mysis* made up the majority of the population at station IIIC (Figure 14). This variation in class frequency distribution with older mysids being more abundant at station IIIC, is related to older mysids not being able to adapt to less favorable environmental conditions as well as juveniles.

No mysids were collected at station IIIB in August. This is apparently due to the shallower depths at station IIIB and light penetrating the entire water column.

From this analysis of mysid abundances and class frequency distributions, it appears that *Mysis* will migrate across depth contours to areas of the lake where physical conditions are more suitable for survival. Factors that can trigger the horizontal migrations appear to be water temperature, DO content, light penetration, and possibly pH. In August, pH values were the lowest at station IIIA, where lower mysid densities than station IIIC were found.

In both June and August, vertical net tows were taken from the bottom of the thermocline to the surface to determine the composition of the migrating population. Vertical migrations of *Mysis* began immediately following sundown. The initial samples of the water column above the hypolimnion consisted only of juveniles, but as the evening progressed, all sex classes were represented. *Mysis* counts of these tows showed the vertical migrations in June to involve a majority of the total population. Since the vertical migrations of *Mysis* are known to take place over an entire nighttime, and sampling at a particular site lasted only one hour, the exact intensity of the nightly migrations is not known.

During the nightly sampling in June, both juvenile and mature mysids were observed near the surface at 2230 hours. Larger mysids were vigorously feeding on copepods. Upon shining direct light on a mysid, the mysid would dart quickly downward. The shrimp would then return rapidly to the surface once the light was turned off.

No mysids were observed at the surface during the August sampling period. All age classes were represented in the vertical tows above the hypolimnion, but the total number of migrating mysids was much less than the values from June. The majority of the migrating population were juveniles with only a few mature females being captured. Approximately 75 to 80 percent of the total mysid population in August remained below the thermocline during the time of sampling, compared with only 15 to 20 percent in June. With mysids being sensitive to warm water temperatures of about 20°C, as was measured at the surface in August, it is evident that the mysids prefer to remain in the cool dark hypolimnetic waters as long as sufficient quantities of food items are available below the thermocline.

Length frequency analysis of *Mysis relicta* in Willow Lake during the summer of 1981 suggests that the population exhibits a two-year life cycle. Size frequency histograms are depicted in Figure 15. The mean length of each cohort (i.e., peak at 5 mm and 15 mm in June, 7 mm and 16 mm in August) were plotted on growth curves of *Mysis relicta* populations in Twin Lakes and Emerald Bay, where mysids exhibit a two-year life cycle (Figure 16). This plot was constructed in order to estimate the growth rate and length of life cycle of *Mysis* in Willow Lake. This would otherwise require monthly sampling and size frequency analysis for a period of at least two years. Since the points plotted on the graph for Willow Lake are from two distinct cohorts, this analysis requires the assumption that the growth

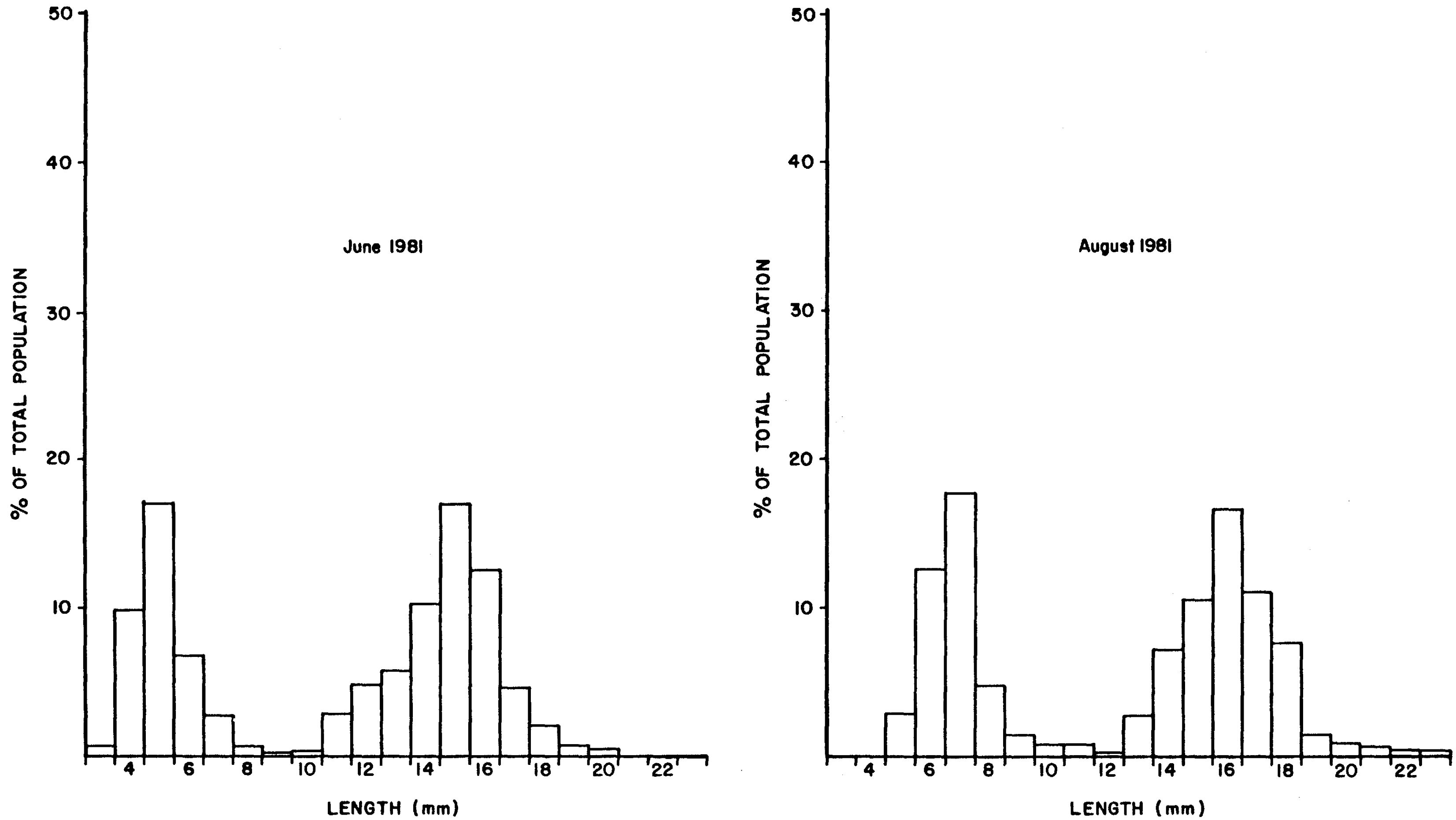

Figure 15. Length frequency distributions of Mysis relicta in Willow Lake.

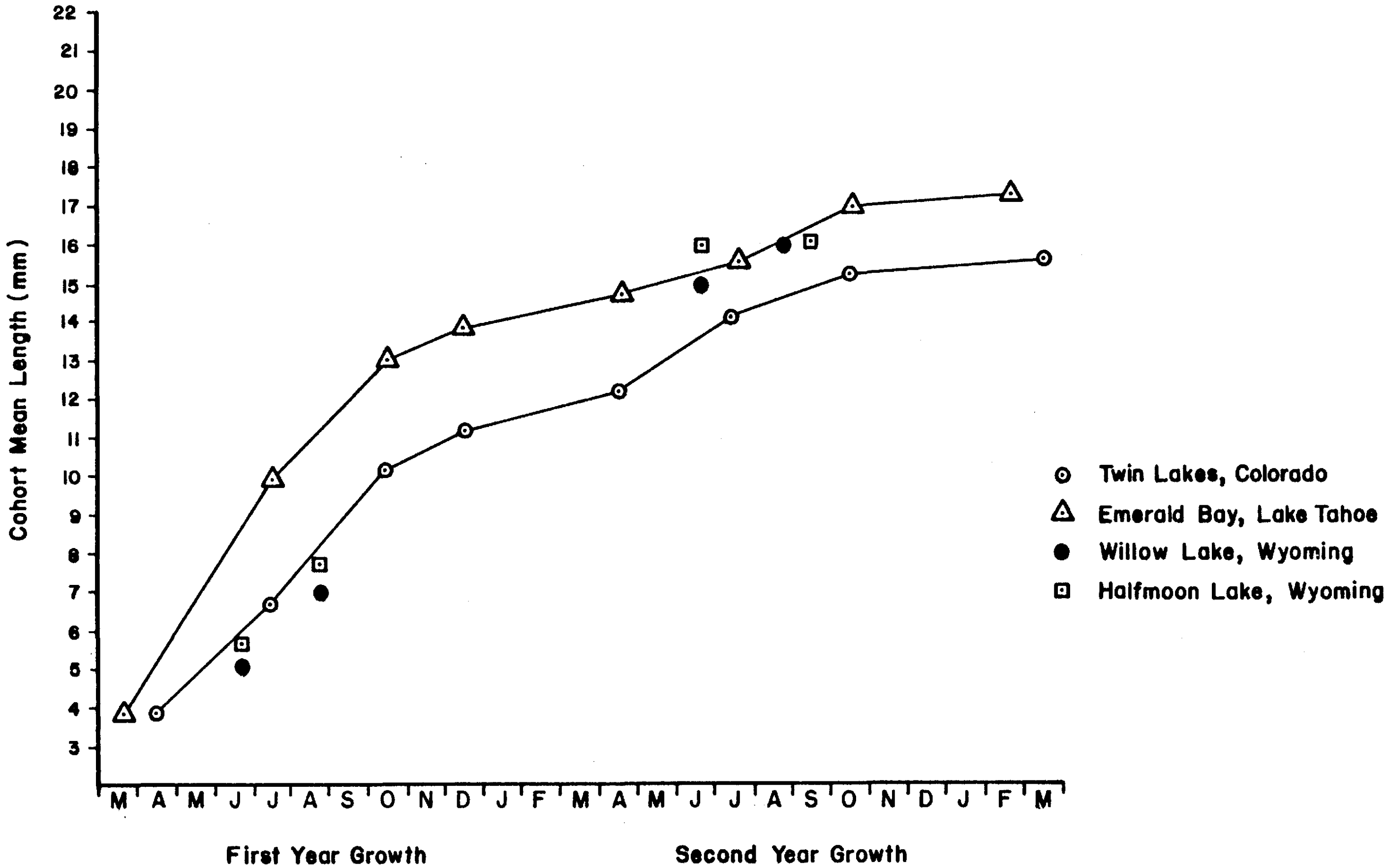

Figure 16. Growth curves of *Mysis relicta* in Twin Lakes, Colorado, and Emerald Bay of Lake Tahoe, which exhibit a two-year life cycle. Mean cohort lengths of Willow and Halfmoon Lakes are also plotted to show comparison of life cycles.

patterns of successive cohorts are similar. Morgan (1981) provides extensive data to support the assumption. Thus, life history data previously collected in other lakes can be used to model *Mysis relicta* populations of Willow and Halfmoon Lakes.

From the growth curves found in Figure 16, it can be seen that the data points fall along the other curves that represent a two-year life cycle. This two-year life cycle for *Mysis* is what would be expected from the oligotrophic conditions of Willow Lake (Table 2). See Figure 17 for a typical life cycle for a *Mysis* cohort in Willow and Halfmoon Lakes.

The length frequency histograms and growth curves show the juvenile mysids to be released at a length of 3 mm. Growth rate of the young-of-the-year is 1.0 to 1.5 mm per month throughout the summer. The recruitment period appears to begin in February and continues through until June, with the peak release period occurring in April. The young-of-the-year peak can be followed from June to August, reaching a length of 7 mm in August (Figure 15). The mysids of Willow Lake become sexually differentiable at 10 mm in length. During late fall and winter, the first year mysids appear to grow at a rate of about 0.5 mm per month or less.

Applying the previously stated assumption of similar growth patterns of successive cohorts, the 1981 juveniles would attain a length of 15 mm by June 1982. This is shown by the peak at 15 mm on

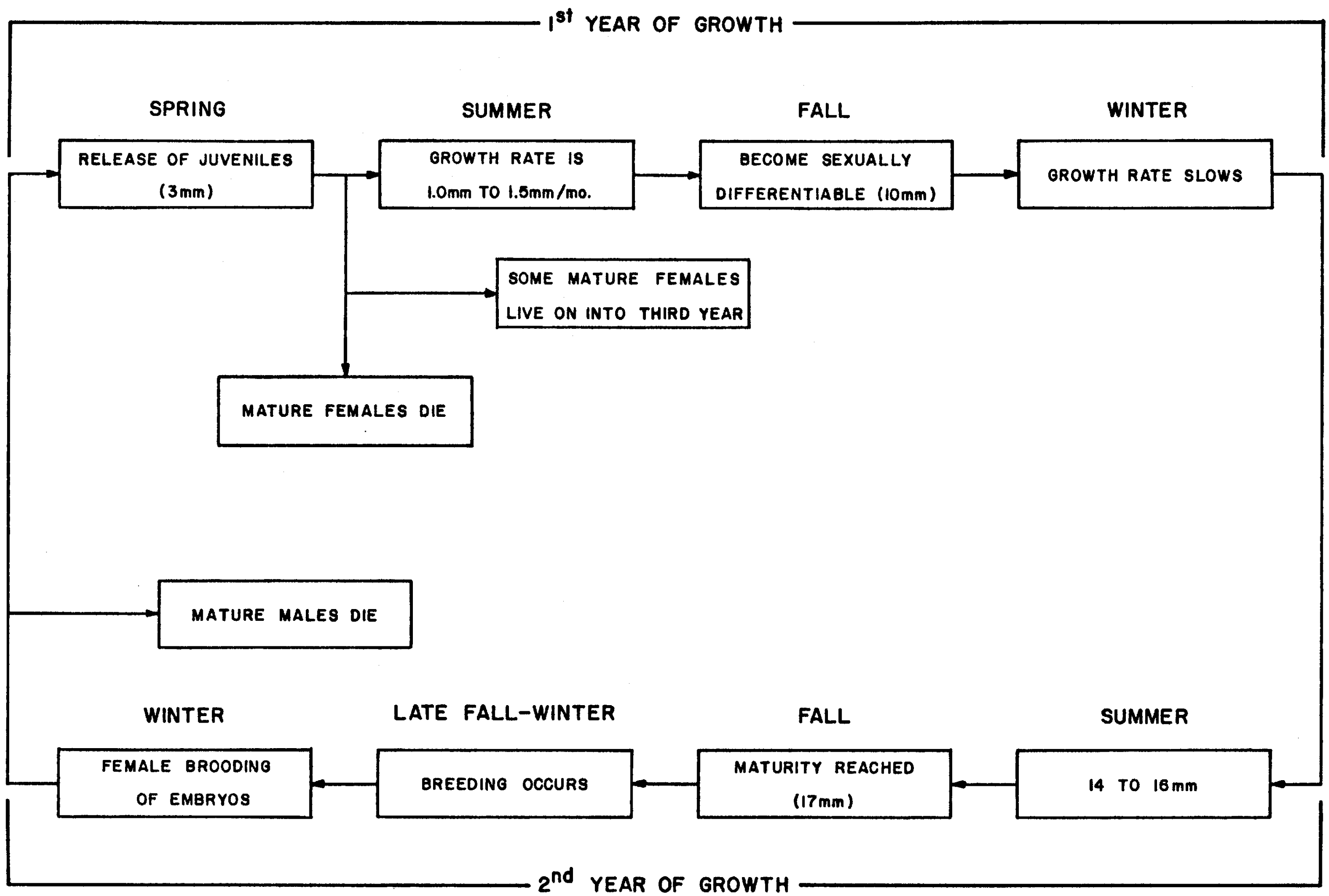

Figure 17. Typical life cycle of a *Mysis relicta* cohort in Willow or Halfmoon Lake.

the June 1981 length frequency diagrams of Figure 15. Average growth rate in the first year of life is about 0.8 mm per month.

Growth rates in the second year begin to decrease. From June to August, the second year *Mysis* only increased 1 mm in length. This is approximately one-half of the first year summer growth rate. The slower growth rate in the second year is said to be due to a shift of energy from growth to reproduction (Morgan, 1981).

Beginning in the fall of the second year of growth, the mysids mate and the breeding continues into the winter months. Males attain sexual maturity at a length of 17 mm, while the length at which females become sexually mature varies between 15 and 17 mm. After mating, the mature males die about three months later. Only an extremely small percentage of mature males were found in the June samples and no mature males were collected in August (Figure 18).

Some females, after releasing their young in the spring, apparently live on into their third year and mate a second season. Figure 15 shows a third year cohort to be present, consisting only of females of 19 mm or longer. Mature males were found only to reach a maximum length of 18 mm and females grew up to lengths of 23 mm. This third year cohort of mature females comprises less than 4 percent of the total mysid population. All mysid data concerning class and length frequency distributions are presented in Appendix C, Tables C-1 through C-5.

In order to successfully evaluate the impact of the introduced *Mysis* population on the aquatic ecosystem, the effects of mysid

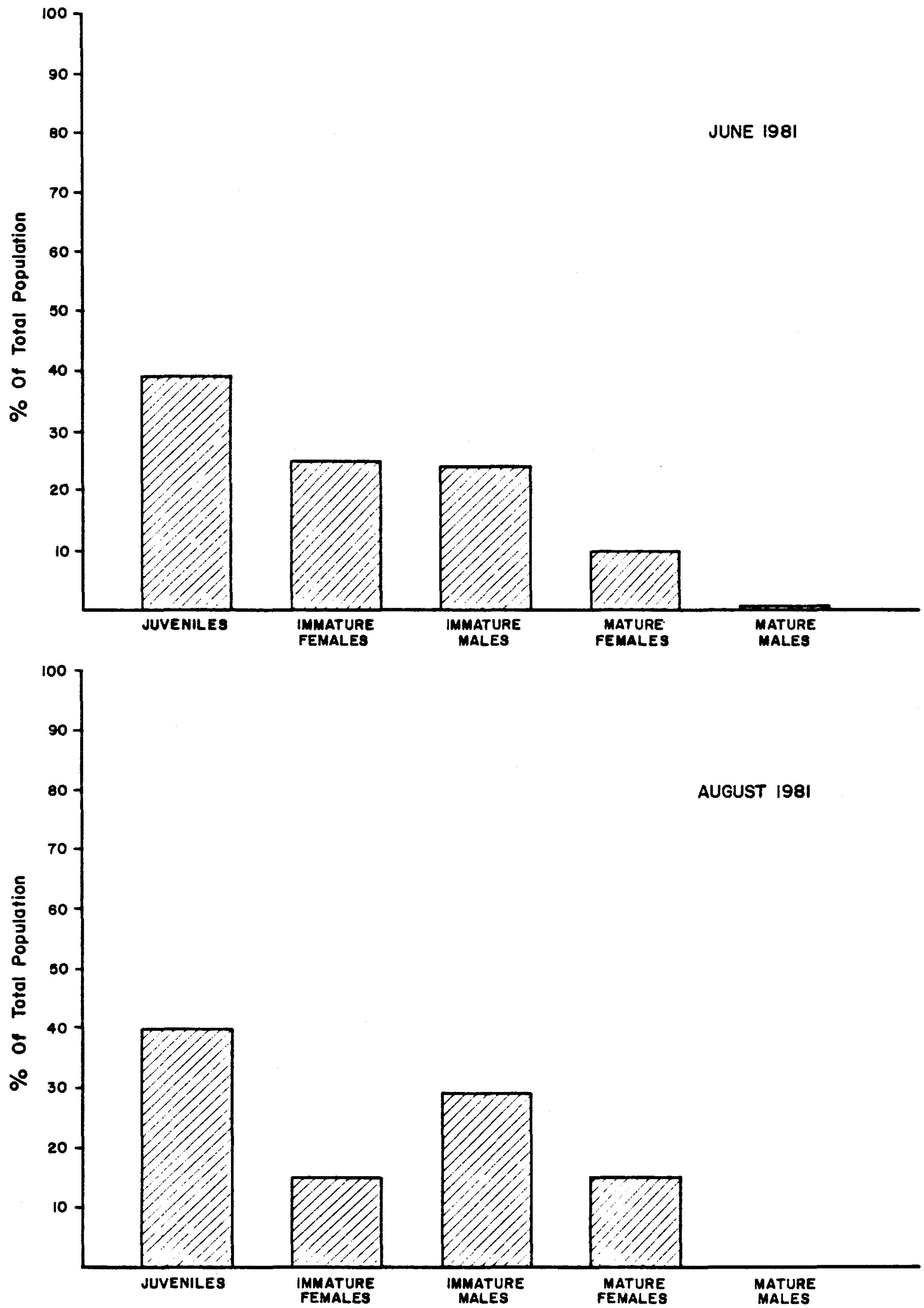

Figure 18. Lake-wide class frequency distributions of *Mysis relicta* in Halfmoon Lake.

predation on plankton in Willow Lake must be evaluated. Qualitative analyses of mysid gut contents were made on a number of captured individuals throughout the study. These analyses indicate that mysids began to readily feed on zooplankton at 8 mm in length. Smaller mysids mainly had fractured diatom frustules and detrital matter in their gut at the time of analysis.

Larger mysids primarily fed on copepods, particularly *Diaptomus*. *Daphnia*, *Cyclops* and also a few rotifers were found in the stomachs of larger mysids. The reason for heavy predation on *Diaptomus* is probably related to prey availability. Even though *Daphnia* and *Cyclops* are a more preferred food item, *Diaptomus* was easily preyed upon due to its greater relative densities.

Halfmoon Lake

Mysis relicta in Halfmoon Lake were found to be very abundant relative to Willow Lake *Mysis* densities (Table 10). This difference in lake-wide population densities is due to the large numbers of juveniles collected in Halfmoon Lake. Juveniles comprised 95 percent of the total Halfmoon mysid population at the time of sampling in June (Figure 19). August class frequency distributions also showed juvenile mysids to be in much greater number than immature and mature mysids combined. Even though the mysid population is apparently established in number, this prevalent situation of an extreme disproportionate amount of juveniles in relation to older individuals suggests an unstable population.

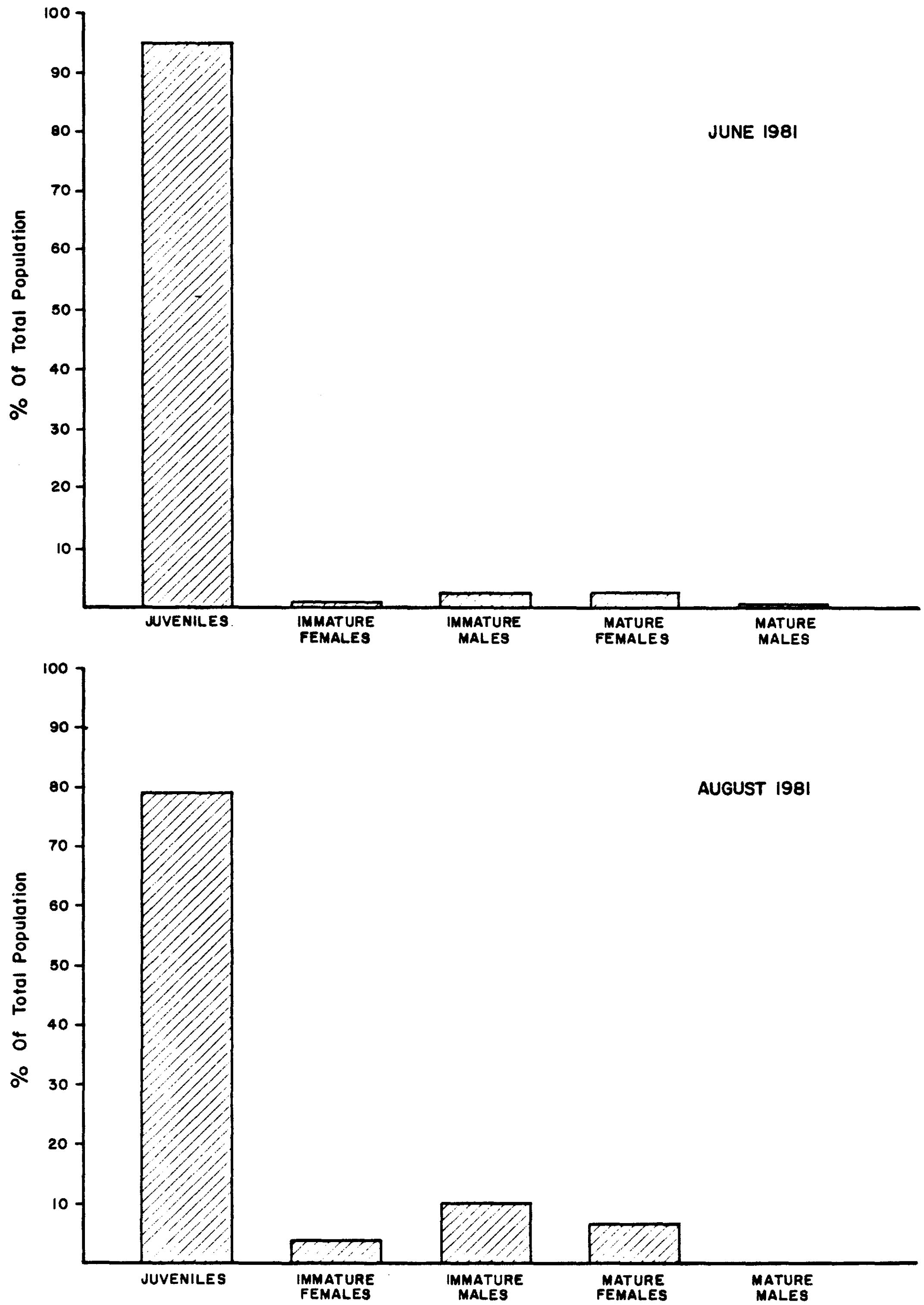

Figure 19. Lake-wide class frequency distributions of *Mysis relicta* in Halfmoon Lake.

Table 10. Mean density estimates of _Mysis_ $\cdot$ M^{-2} $\pm$ 95% Confidence Limits (n)* at each station on Halfmoon Lake.

Station	June 1981	August 1981
IA	214 $\pm$ 126 (6)	1502 $\pm$ 383 (3)
IB	535 $\pm$ 126 (6)	600 $\pm$ 440 (3)
IC	1286 $\pm$ 353 (6)	583 $\pm$ 329 (3)

*(n) denotes the number of samples collected.

There are three possible explanations to account for the extreme abundance of juvenile mysids in Halfmoon Lake. The first explanation is a possibility of a sampling bias selecting in favor of juveniles or against older individuals. This appears to be highly unlikely due to the amount of sampling done on four separate days throughout the summer with the same trend resulting from each sampling. The sampling bias was therefore ruled out because the class frequency of juveniles remained fairly consistent from station to station throughout the sampling duration. Also, the sampling methodology was identical in both Halfmoon and Willow Lakes, and this type of a class frequency did not result from sampling in Willow Lake.

A second explanation for this present situation may be the result of a pH fluctuation in Halfmoon Lake during the spring. Spring runoff, possibly containing humic acids picked up from the surrounding wooded watershed, empties into this poorly buffered lake system decreasing the pH into the critical range for mysid. Since the older mysids are more sensitive to environmental changes, a large percentage of these individuals may be dying as a direct result of the increased acidic conditions. Nero and Schindler (1981) report mysids subjected to pH values less than 5.9 had significantly reduced growth rates and the causative mechanism of mysid elimination at low pH was the impairment of the shrimp's molting ability. Reduced growth of mysids was not observed in Halfmoon Lake, which suggests that pH levels are not having a chronic effect on the *Mysis* populations. The *Mysis* of Halfmoon Lake may not be affected by pH values less than 5.9 due to the fact that they are more acclimated to year-round acidic conditions (Nero, personal communication, 1981). No data are available concerning direct toxic effects on mysids resulting from mobilization of heavy metals at these pH values.

The most feasible explanation to account for the distorted class distribution is extremely high reproductive success of mysids in this particular year. In June, there was a relatively high number of mature females and nearly half of these females were in their third year of growth. Fürst (1972b) reported increased egg production with greater female length. So it is evident that the large amount of juveniles in Halfmoon Lake is related to the high percentage of third year females of 19 mm or longer.

Mean densities of *Mysis* at each station in June were all significantly different from each other using unpaired t-tests ($\alpha = 0.05$). Initial F-tests indicated homogeneity of variances. Station IC had the greatest density and also had a class distribution that was comprised totally of juvenile mysids (Figure 20). The juveniles have apparently migrated to this area of the lake where primary production was the greatest, particularly diatom production. Water temperatures, DO content, pH, and conductivity were comparatively similar throughout the lake suggesting the juvenile portion of the mysid population is most influenced by lake productivity when environmental conditions are adequate.

By August, the highest percentage of juveniles was at station IA and the density at station IC was reduced to half of its June value (Figure 20). This type of a situation suggests that once the juveniles reach the age at which they begin to feed on zooplankton (7 to 8 mm in length), they will migrate out of the more productive shallower waters to areas where environmental conditions, especially light, are more conducive to survival.

The migrating population in Halfmoon Lake was mainly composed of younger mysids, although there were a few older individuals collected in the vertical tows above the hypolimnion. During June, a smaller percentage of the Halfmoon mysid population migrated into or above the thermocline than what was observed during the June sampling of Willow Lake. Only about 10 to 25 percent of the population was collected above the hypolimnion on the two nights of sampling on Halfmoon Lake. This may not be a true indicator of the extent and intensity of vertical migrations. A noticeable difference in moonlight illumination was observed between the nights of mysid sampling at Halfmoon and Willow Lakes. The moon was not in the sky during the

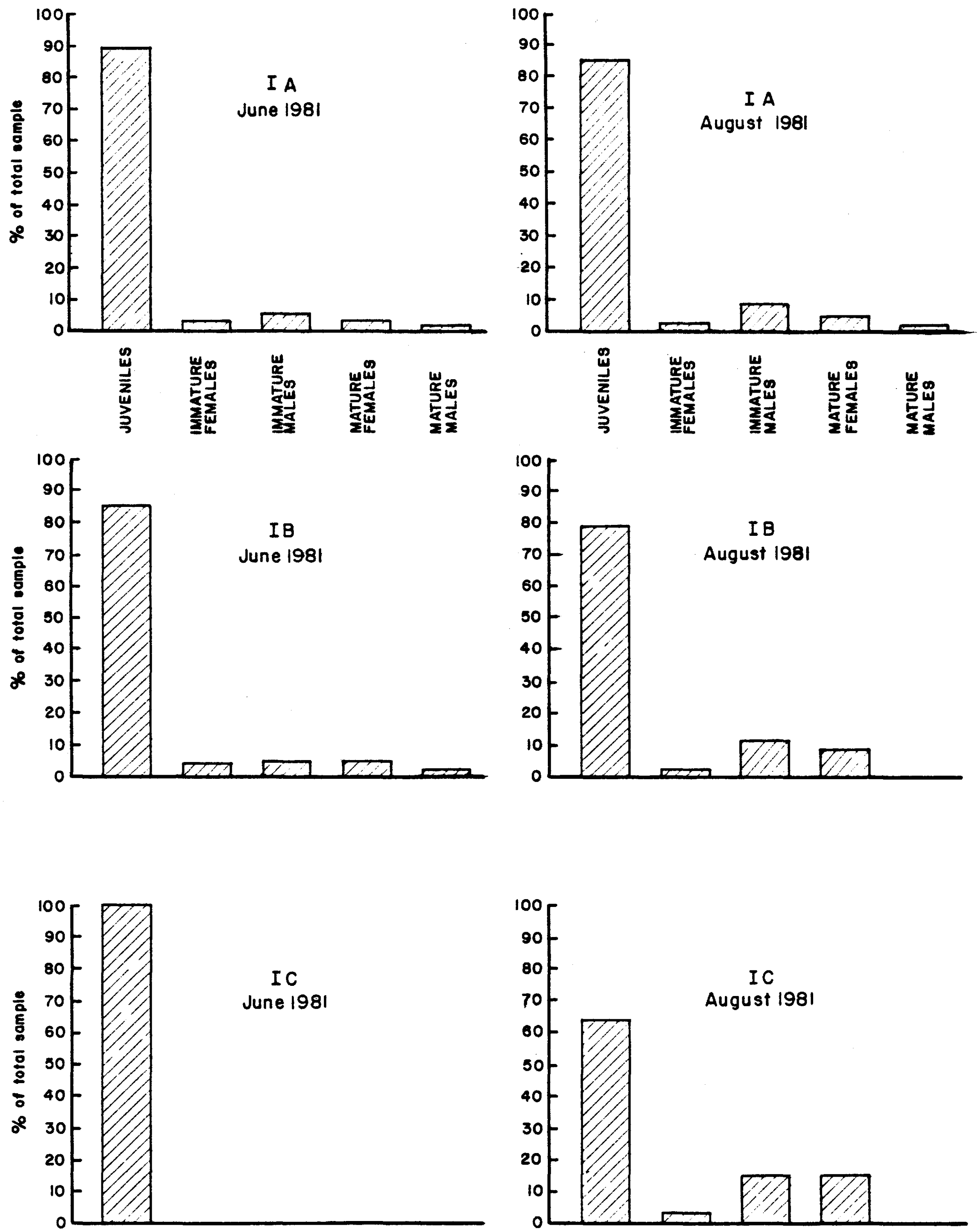

Figure 20. Class frequency distributions of Mysis relicta according to station in Halfmoon Lake.

time of sampling at Willow Lake, but was present toward the end of sampling each night on Halfmoon Lake. It is likely the moonlight illumination on Halfmoon Lake modified the vertical migration of mysids on these two nights in June by either delaying the migration until the moonlight illumination on the lake surface was less bright, or totally restricting the mysids from moving into the upper water column. Thermal gradients of metalimnion in June were not sharp enough to have any adverse effect on migrating mysids.

In general, August samples showed the extent of vertical migration to be extremely variable. *Mysis* sampling took place on nights in which the weather may have been an added influence on vertical migrations. Sampling was done between intermittent thunderstorms on two nights and weather conditions were variable with respect to wind and rain intensity. Samples revealed the intensity of the migration to range from 15 to about 75 percent of the total population. Older mysids made up about 25 percent of the migrating population. This is approximately the same proportion of older mysids to juveniles in total lake-wide *Mysis relicta* population.

The life history of *Mysis relicta* populations in Halfmoon Lake appears to be identical in nearly every aspect to that of the Willow Lake population. The life cycle is basically summarized in the Willow Lake *Mysis* section and is also diagrammed in Figure 17. Again, using the growth curves of Twin Lakes and Emerald Bay to model populations of other lakes (Figure 16), *Mysis relicta* are indicated to have a two-year life cycle in Halfmoon Lake. These findings of a two-year life cycle for mysids in Halfmoon Lake remain consistent with the duration of life cycles in other oligotrophic lakes (Table 2).

Analysis of length frequency histograms depicted in Figure 21 and Tables C-8 through C-10 show the *Mysis* of Halfmoon Lake to only be slightly different from Willow Lake mysid populations in two respects. Juveniles in Halfmoon Lake become sexually differentiable at a length of about 11 mm. Also, the second year cohort in June 1981 had a slightly greater mean length due to a large number of mature mysids at that time. All other aspects of the life cycle such as growth rates, recruitment period, and maximum attainable lengths of *Mysis* were similar, if not identical in both lakes.

An evaluation of mysid predation in Halfmoon Lake through gut analyses revealed juveniles to become omnivorous at a length of 7 mm and totally carnivorous at about 11 mm. Juveniles less than 7 mm fed exclusively on diatom algae. Older individuals were found to prey on both copepods and rotifers. All four genera of zooplankton collected in Halfmoon Lake were represented in gut contents. Rotifers were found more frequently in gut contents in June at the time of higher relative densities of rotifers. *Kellicottia* sp. and *Keratella* sp. were apparently preyed upon more by smaller immature mysids than larger individuals. *Diaptomus* sp. and *Cyclops* sp. were the most common zooplankton in the guts of mature and larger immature mysids.

These findings of *Mysis* predation in Halfmoon Lake is consistent with the results of Cooper and Goldman (1980). Their study revealed *Mysis relicta* to have both specific prey sizes and types. Smaller

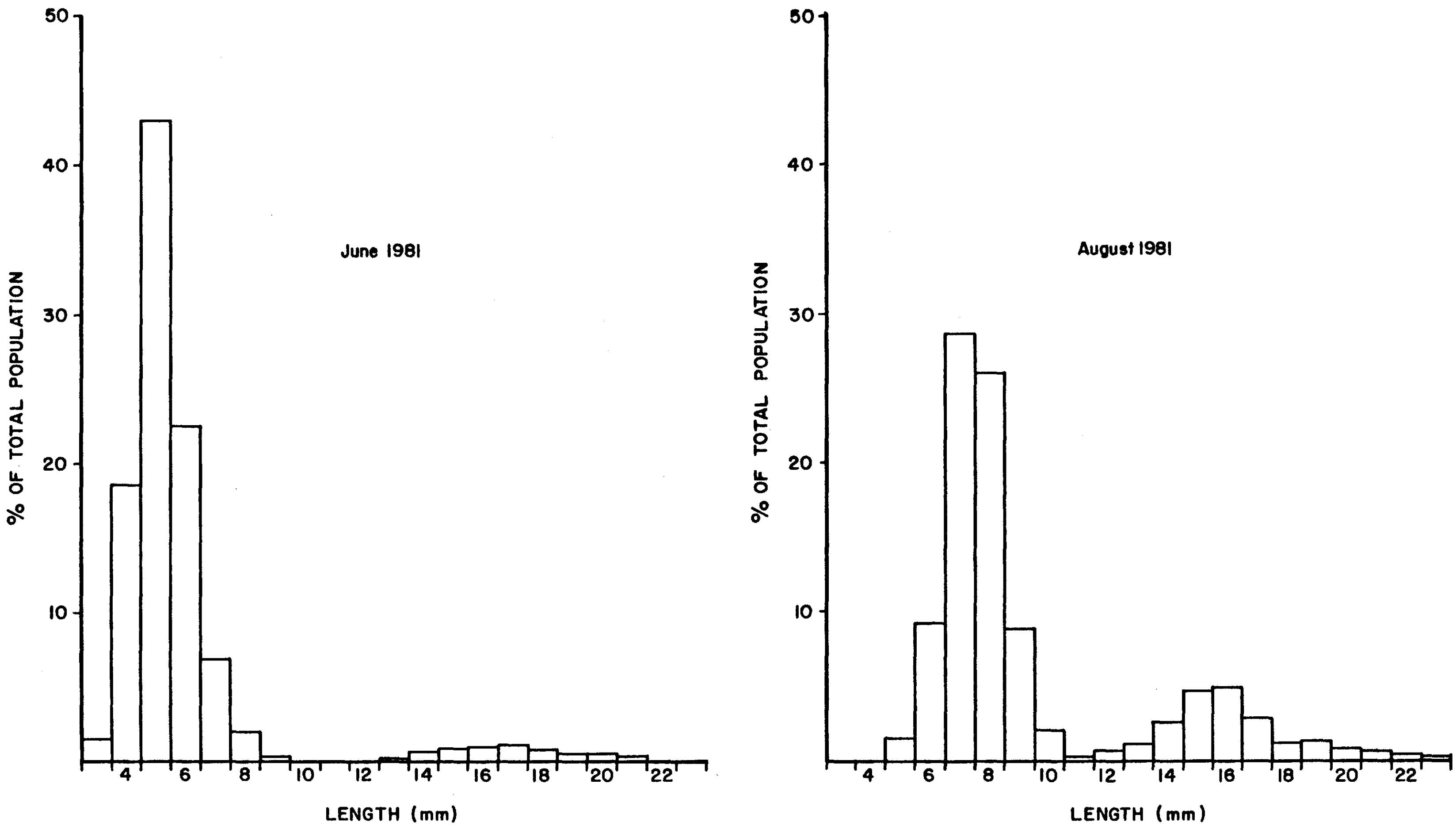

Figure 21. Length frequency distributions of Mysis relicta in Halfmoon Lake.

individuals less than 9 mm prefer small prey while larger mysids shown an increasing preference for larger prey. Also, they have shown *Mysis* to have a consistent preference of *Daphnia* over cyclopoid copepods (*Cyclops* sp.) and calanoid copepods (*Diaptomus* sp.).

No cladocerans were found in gut contents or in plankton tows suggesting that this portion of the zooplankton population has been completely eliminated in Halfmoon Lake, probably through mysid predation. So it is apparent that the present heavy predation on copepods is reflecting the fact that *Diaptomus* sp. and *Cyclops* sp. are the only appropriately sized food items available to larger mysids. Consequently, the observed prey preferences of *Mysis relicta* in Halfmoon Lake are a function of both prey availability and prey size.

VI. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The introduction of *Mysis relicta* into Willow Lake appears to be a great success. The mysid population is both stable and reproducing. Mysids were also found to be quite dense in the deeper portions of the lake. A two-year life cycle is exhibited, which is typical for oligotrophic lake conditions.

Although Willow Lake would be considered oligotrophic, overall lake productivity is greater than in Fremont or Halfmoon Lakes. Relatively higher nutrient concentrations measured in Willow Lake lends itself to greater primary and secondary production. Cattle grazing is very extensive along the west end of the lake. This factor coupled with widely fluctuating lake levels may be washing nutrients into the lake and contributing to the higher lake productivity.

It appears that lake productivity is the major influence determining the success of mysid introductions. To have a successful introduction of *Mysis relicta*, this species must be added to the lake trophic structure without eliminating any essential link in the food chain, such as the cladoceran population. Planktivorous fish rely on the cladocerans for a major part of their diet, and cladocerans are also the preferred food item for *Mysis*. If secondary productivity is not great enough to withstand the added predation pressure by mysids, the result will be elimination of the cladocerans. This will mean that fish feeding on the cladocerans will be in direct competition with mysids for food. Since mysids are able to change their prey preference, while the pelagic fish are highly size selective and will not usually prey on other organisms, the planktivorous fish will begin to show a decline in growth rate. Hence, the entire food chain of that aquatic ecosystem is disrupted, even at the highest levels where predators depend on these smaller fish for food.

This situation described above was found not to be the case in Willow Lake. General lake productivity was great enough that the cladoceran population was not totally eliminated. *Daphnia* was collected in both June and August plankton tows. Also, there has been noted improvement in the lake trout fishery in the past few years with the lake trout being reported as having pinkish flesh coloration (Wyoming Game and Fish Department, personal communication, 1981). This type of flesh coloration may indicate utilization of *Mysis* by lake trout (Grimes et al., 1972a, 1972b; Threinen, 1962). Sufficient fisheries data are not available at this time to confirm the extent of predation on *Mysis* in Willow Lake.

A totally different situation is occurring in Halfmoon Lake. Even though the Halfmoon mysid population is established in number and exhibits a two-year life cycle identical to that of Willow mysid population, the introduction of this exotic species has appeared to have a detrimental effect on the aquatic ecosystem by completely eliminating the cladoceran population. Cladocerans were assumed to be present before the *Mysis relicta* introduction into Halfmoon Lake.

This is supported by the fact that Halfmoon Lake and the control lake, Fremont Lake, are similar in plankton composition and abundance, except that Fremont Lake presently contains both *Daphnia* and *Bosmina*.

The fishery of Halfmoon Lake is reported to be in poor condition. Growth rates have declined along with angler catch rates (Wyoming Game and Fish Department, personal communication, 1981). This may be related to several different factors or a combination of them. First, the poor condition of the fishery could be related to the elimination of the cladoceran population as was previously described in this chapter. In addition to the elimination of cladocerans, the target fish of this introduction, juvenile lake trout and rainbow trout, may not be feeding extensively on the mysids to compensate for the loss of the other food source which would account for the poor growth.

Gosho (1975) states that the average period for establishing *Mysis* populations from the time of introduction is approximately ten years. Morgan et al. (1978) report that lake trout predation on mysids does not begin until the mysids are very abundant. The introduction of *Mysis relicta* into Halfmoon Lake occurred in 1971, ten years prior to the initiation of this study. The shrimp population of Halfmoon Lake may have now just become relatively dense and a stable population may be seen in the near future. If this is the case, the target fish may have now just begun preying on the mysids and an improvement in the fishery may be noted in a few years if the shift from cladocerans to mysids and copepods is an adequate food substitution.

It should be noted that the lag time of establishing an abundant Mysis relicta population in Willow Lake apparently did not require as long a period of time as the population in Halfmoon Lake. This was evident by the noted improvement in lake trout condition in recent years. This difference in lag time can be attributed to the relative difference in lake productivity.

A third factor may also enter in relation to the condition of the Halfmoon fishery. Low pH values of less than 6.0 units were measured throughout the water column during the time of spring turnover. Some species of fish have been found to decline in numbers as the pH fell below 6.0 (Alabaster and Lloyd, 1980; Beamish, 1976). If the pH of the water is 6.0 or lower at the time of spawning in the fall, lower reproductive success and inhibited growth rates of fish may be encountered (Schofield, 1976).

Ambient water quality appears to have the greatest influence on the lake-wide distribution of mysids. Water temperature, DO content, and light penetration were noted to trigger migrations of mysids in Willow Lake to areas of the lake where these environmental conditions are all adequate for survival. Low pH values may also provide an additional influence on factors controlling the distribution of mysids within a lake. It is vital to the maintenance of a healthy Mysis population that a lake contain areas where these constituents are at suitable concentrations.

It is evident from data collected on Halfmoon Lake that if all environmental conditions are adequate, the juvenile mysids will migrate in the spring to more shallow and productive areas of the lake. This phenomenon was also observed by Morgan and Threlkeld (1981). As water temperatures increase in the shallower areas and the young-of-the-year mysids become more sensitive to light, they seek refuge in deeper regions of the lake.

Using the results of this study and other pertinent information from the scientific literature, a cold-water fisheries management tool was developed to aid in predicting the outcome of a proposed *Mysis relicta* introduction into a particular lake. This tool consists of nine parameters that should be measured or considered in relation to one another by a fisheries manager before introducing *Mysis relicta* into a lake system. The nine constituents are listed below and each one will be discussed thereafter.

1. Lake trophic status
2. Plankton abundance and composition
3. Resident fish species
4. Lake bathymetry
5. Water temperatures
6. Thermal gradient of metalimnion
7. Dissolved oxygen content
8. Acidity levels
9. Dissolved ion content

1. Lake Trophic Status

The trophic state of a lake proposed for a mysid introduction should not be ultra-oligotrophic, due to the fact that highly unproductive lakes have low carrying capacities which makes an extremely dilute lake a more unstable environment. Goldman et al. (1978) observed zooplankton assemblages near starvation during certain times of the year in Lake Tahoe. "Small shifts in overall production may be proportionately more important than similar shifts in more productive lakes" (Morgan, 1980). A mesotrophic lake would be the most ideal type of lake to introduce *Mysis relicta*. The introduced mysids would probably exhibit a one-year life cycle (Figure 2) and would thus have a relatively rapid growth rate and a greater caloric content than mysids of an oligotrophic lake (Gosho, 1975). Carlson (1977) developed a model for determining the trophic state of a particular lake using a secchi disk, total phosphorus or chlorophyll A concentrations. This model may be used to aid in the use of this fisheries management tool.

2. Plankton Composition and Abundance

The lake in concern should contain a significant amount of diatoms, especially in spring and early summer when juvenile mysids feed primarily on diatoms. In relation to this, nutrient levels, particularly silica, should not be severely limiting. If year-round silica values are less than 0.5 mg/l, the concentration at which silica is thought to be limiting (Kilham, 1975), it would be advised not to stock mysids into this lake since diatom growth would be inhibited. Also, total phosphorus and nitrogen concentration should at least be in the upper range of nutrient values for oligotrophic lakes (Figure 5) in order to ensure greater primary production and hence greater secondary production.

The resident zooplankton population should be stable and also abundant to withstand greater predation and competition from introduced mysids. This holds particularly for cladoceran populations since they are the preferred food item for mysids and fish such as rainbow trout.

3. Resident Fish Species

A *Mysis* introduction should only be used as a means to increase lake trout production. No other species of game fish should be the target for this type of introduction. The forage fish for the lake trout should be species that will feed readily on mysids. The lake trout in this type situation will benefit both directly and indirectly from the *Mysis*, since lake trout up to about 30 cm in length will primarily feed on *Mysis* (Young and Oglesby, 1972; Brownell, 1970; Hacker, 1956). The forage fish should not be rainbow trout or kokanee. These two species of fish, especially rainbow trout, are highly prey size-selective and will compete directly with the mysids since these salmonids will not feed heavily on them.

A forage fish that has been proven to both utilize *Mysis* to a great extent and also be preyed upon by lake trout is the cisco (*Coregonus artedii*). Scott and Crossman (1973), Schumacher (1966), Grimas et al. (1972a), and Dryer et al. (1965) report ciscoes to be the preferred natural food item of adult lake trout where ciscoes are present. Ciscoes are a cold water species which can inhabit waters deeper than 50 m. It is also known to be a plankton feeder, but it is not highly selective in its prey preference and will probably not compete with *Mysis*. The ciscoes will prey on the *Mysis* and in turn keep the *Mysis* population in check, possibly aiding in the prevention of complete cladoceran elimination.

4. Lake Bathymetry

Mysis relicta definitely require a refuge from strong light levels. In this present study, only a few juveniles were collected at a sampling site on Willow Lake that was approximately 25 m deep. In most oligotrophic lakes, some light would penetrate to those depths. Therefore it is necessary for an oligotrophic lake to have a maximum depth greater than 25 m if a *Mysis* introduction is to be successful. A maximum depth of less than about 90 m would also be preferred. Robertson et al. (1968) observed mysids off the bottom in Lake Michigan at depths greater than about 85 m. It is a preferable situation to have the mysids feeding on the bottom detritus matter in order to provide an additional food and energy source. In lakes which have an extremely large mean depth, mysids will have a relatively greater length to migrate every night; this will cause the mysids to allocate a more significant portion of their total energy budget to vertical migrations resulting in slower growth rates.

5. Water Temperatures

Mysis relicta require low water temperatures, especially in the hypolimnion where they reside. *Mysis* in Halfmoon and Willow Lakes were subjected to bottom water temperatures less than 6°C. Temperatures less than 6°C appear to be adequate for survival. Smith (1970) reports Mysis relicta to tolerate maximum epilimnion temperatures of about 18 to 20°C during their nightly vertical migrations. This present study pointed out that most mysids did not migrate into the upper water column. This suggests they prefer the cooler hypolimnetic waters as long as food is not extremely limiting below the thermocline.

6. Thermal Gradient of the Metalimnion

According to Beeton (1960), mysids will not migrate through a thermal gradient of greater than 1.67°C/m. A strong gradient of this nature would prevent mysids from reaching the upper water column and would prevent planktivorous fish from feeding on the mysids. Mysis relicta in Halfmoon and Willow Lakes appeared to be unaffected by thermal gradients (<1°C/m) since all age classes were represented in vertical tows above the hypolimnion. Therefore it would be advised that a lake proposed for Mysis relicta stocking not have a sharp thermal stratification.

7. Dissolved Oxygen Content

In order to establish a stable lake trout fishery as well as a stable mysid population, the dissolved oxygen content should be at least 5 to 6 mg/l in some of the lower regions of the lake. Mysids are probably less sensitive to lower DO levels than lake trout. Mysids were collected in Willow Lake where oxygen concentrations were just slightly greater than 3 mg/l, but significantly lower mysid densities were found there than at other stations that had DO levels greater than 5 mg/l. As long as water temperatures are near 4°C, it would be expected that mysids could survive in water with less than 3 mg/l dissolved oxygen.

8. Acidity

Some effects of acidity on mysids and lake trout have been discussed previously in this text. It would appear that lakes exhibiting pH levels greater than 6.0 units would be the best for *Mysis relicta* introductions. Holmquist (1959) noted mysids to be abundant in lakes where the pH was greater than 6.0. Also, Walton et al. (1981) have reported that low pH values will simplify zooplankton communities which may have a direct or indirect effect on mysid populations. Lakes where pH levels are greater than or equal to 5.5, the mysids and salmonids will probably survive if there is a lack of high heavy metal concentrations. Also, waters that have extremely low concentrations of sodium, chloride, and calcium (<1 mg/l) tend to add to the acid stress of both fish and invertebrates (Wright and Snekvik, 1978; Almer et al., 1974). Low pH values and low ionic strength of waters cause osmoregulatory problems and ionic imbalances in the organisms (Alabaster and Lloyd, 1980).

9. Dissolved Ion Content

Mysis relicta have been noted to be extremely sensitive to relative differences in dissolved ion content of water when transplanted from one lake to another. Gosho (1975) states that the two lakes involved in the transplanting of *Mysis relicta* should be nearly identical in conductivity to avoid large numbers of mysids dying while acclimating to their new environment. Fürst (1965) showed the percent die-off of mysids to increase as the difference in dissolved ion content of water between the lakes of concern increased. Proper acclimatization procedures during transplantation must be undertaken to ensure a high survival rate of *Mysis*. Refer to Gosho (1975) for proper transplant procedures. Also, lakes that will contain mysids should not have any internal dissolved ion content fluctuations throughout the year that may have a detrimental effect on an introduced *Mysis relicta* population.

The introduction of *Mysis relicta* should only occur when deemed necessary, because the action is usually irreversible. All nine criteria previously discussed, as well as any other pertinent or unique information regarding the particular lake to receive the mysids should be considered before any introduction occurs. Also, every attempt should be made to prevent dispersal of mysids downstream into other lakes where mysid introductions were not intended.

Specific Recommendations

1. Utilizing collected water quality and lake productivity data, along with morphometric characteristics of Fremont Lake and applying the data to this management tool, it is advised that Fremont Lake not be stocked with *Mysis relicta* on the basis that ambient lake conditions are not adequate to support the impact that this introduced

species would have on that aquatic ecosystem. The trophic status of Fremont Lake is considered to be ultra-oligotrophic and very similar in nature to other unproductive lakes such as Lake Tahoe. Even though diatoms compose nearly the entire phytoplankton population, total primary production is not nearly great enough to establish an abundant zooplankton population that could withstand an added predator such as *Mysis relicta*. Also, rainbow trout are being stocked heavily into Fremont Lake and this species of fish would not be compatible with mysid populations in this type of nonproductive environment. Fremont Lake also is extremely deep at a 185 m maximum as well as having a mean depth of 83 m.

2. There is a need for an evaluation of the present fish stocking program for Halfmoon and Willow Lakes. Rainbow trout should not be stocked in any number into these two lakes while trying to establish and maintain a *Mysis relicta* population in an attempt to increase lake trout production. Every year the current stocking programs call for 300,000 and 200,000 advanced fingerling rainbow trout (10 cm) to be stocked in Willow and Halfmoon Lakes, respectively (Wyoming Game and Fish Department, personal communication, 1982). Stocking of another type of forage fish for lake trout, such as the cisco (*Coregonus artedii*) or the lake whitefish (*Coregonus clupeaformis*) should be considered.

3. A regular monitoring program should be set up for all three lakes. Chemical constituents should be measured at least quarterly. The four critical periods when the lake should be monitored is during

(1) spring turnover immediately after ice-off, (2) late summer at the time of strongest thermal stratification, (3) fall turnover prior to ice formation, and (4) mid-winter when ice is sufficiently thick to make measurements through the ice. Indicator water quality parameters such as temperature, DO, pH, and conductivity should be measured throughout the entire water column during the four monitoring periods.

Since an unstable fishery and mysid population currently exists in Halfmoon Lake, it is recommended that pH be measured more often than the other constituents. It is also advised that a complete water chemistry analysis be made measuring all ionic species and heavy metals. This may give additional information toward solving the present fishery problem in Halfmoon Lake.

Plankton samples should be collected and analyzed on an annual basis and more frequent if possible, especially throughout the summer months. Both qualitative and quantitative analyses of phytoplankton and zooplankton should be made. *Mysis relicta* collections should be made quarterly in Willow and Halfmoon Lakes. This will enable the fisheries manager to have a continued working knowledge of the life history and ecology of the introduced mysids. It is also deemed necessary to establish a program in Willow and Halfmoon Lakes to analyze fish stomach contents. This will determine the extent of lake trout and forage fish predation on mysids.

VII. REFERENCES AND BIBLIOGRAPHY

REFERENCES

Alabaster, J. S., and R. Lloyd. 1980. Water Quality Criteria for Freshwater Fish. Butterworths Inc., Boston, Massachusetts, 297 pp.

Allen, H. E., and J. R. Kramer. 1972. Nutrients in Natural Waters. John Wiley and Sons, New York, New York, 457 pp.

Almer, B., W. Dickson, C. Ekstrom, E. Hornstrom, and U. Miller. 1974. Effects of acidification on Swedish lakes. Ambio 3:3-36.

Armstrong, F. A., and D. W. Schindler. 1971. Preliminary chemical characteristics of waters in the Experimental Lakes area, northwestern Ontario. J. Fish. Res. Bd. Canada 28:171-187.

Barnes, R. D. 1974. Invertebrate Zoology. W. B. Saunders Co., Philadelphia, Pennsylvania, 870 pp.

Beamish, R. J. 1976. Acification of lakes in Canada by acid precipitation and the resulting effects on fishes. Water, Air, and Soil Poll. 6:501-514.

Beeton, A. M. 1959. Photoreception in the opossum shrimp, *Mysis relicta*. Biol. Bull. 116:204-216.

_____. 1960. The vertical migration of *Mysis relicta* in Lakes Huron and Michigan. J. Fish. Res. Bd. Canada 17:517-539.

_____, and J. A. Bowers. 1981. Vertical migration of *Mysis relicta* Loven. Am. Soc. Limnol. Oceanogr. 44th Annual Conference, Milwaukee, Wisconsin.

Bowers, J. A., and N. E. Grossnickle. 1978. The herbivorous habits of *Mysis relicta* in Lake Michigan. Limnol. Oceanogr. 23:767-776.

Brownell, W. 1970. Studies on the ecology of *Mysis relicta* in Cayuga Lake. Thesis. Cornell University, Ithaca, New York, 76 pp.

Carlson, R. E. 1977. A trophic state index for lakes. Limnol. Oceanogr. 22:361-369.

Carpenter, G. F., E. L. Mansey, and N. H. Watson. 1974. Abundance and live history of *Mysis relicta* in the St. Lawrence Great Lakes. J. Fish. Res. Bd. Canada 31:319-325.

Cooper, S. D., and C. R. Goldman. 1980. Opossum shrimp (*Mysis relicta*) predation on zooplankton. Can. J. Fish. Aquat. Sci. 37:909-919.

Dryer, W. R., L. F. Erkkila, and C. L. Tetzloff. 1965. Food of the lake trout in Lake Superior. Trans. Am. Fish. Soc. 94:169-176.

Everhart, W. H., and W. D. Youngs. 1981. Principles of Fishery Science, 2nd Ed. Cornell Press University, Ithaca, New York, 349 pp.

Ferrante, J. F., and J. I. Parker. 1978. The influence of planktonic and benthic crustaceans on silicon cycling in Lake Michigan. Verh. Int. Verein. Limnol. 20:324.

Fürst, M. 1965. Experiments on the transplantation of *Mysis relicta* into Swedish lakes. Rept. Inst. Freshwater Res., Drottningholm 46:79-89.

_____. 1972a. On the biology of the opossum shrimp *Mysis relicta* Loven and its introduction in impounded lakes in Scandinavia. Abstracts of Uppsala dissertations from the Faculty of Science, No. 207, University of Uppsala, Sweden, 9 pp.

_____. 1972b. Life cycles, growth rate, and reproduction in *Mysis relicta* Loven. Information från Sötvattens-Laboriet, Drottningholm, No. 11, 41 pp. (English summary)

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

Gaufin, A. R., G. W. Prescott, and J. F. Tibbs. 1976. Limnological studies of Flathead Lake, Montana: A status report. EPA-600/3-76-039, 85 pp.

Goldman, C. R. 1974. Eutrophication of Lake Tahoe emphasizing water quality. EPA-660/3-74-034, 408 pp.

_____, M. D. Morgan, S. T. Threlkeld, and N. Angeli. 1979. A population dynamics analysis of cladoceran disappearance from Lake Taho, California-Nevada. Limnol. Oceanogr. 24:289-297.

Gosho, M. E. 1975. The introduction of *Mysis relicta* into fresh-water lakes. Circular number 75-2. College of Fisheries, University of Washington, Seattle, Washington, 66 pp.

Gregg, R. E. 1976. Ecology of *Mysis relicta* in Twin Lakes, Colorado. Report REC-ERC-76-14. Division of General Research, Bureau of Reclamation, Denver, Colorado, 70 pp.

Grimas, U., N-A. Nilsson, and C. Wendt. 1972a. Lake Vättern: Effects of exploitation, eutrophication, and introductions on the salmonid community. J. Fish. Res. Bd. Canada 29:807-817.

_____, N-A. Nilsson, J. Toivonen, and C. Wendt. 1972b. The future of salmonid communities in Fennoscandian lakes. J. Fish. Res. Bd. Canada 29:937-940.

Grossnickle, N. E. 1981. Feeding habits of Mysis relicta - an overview. Am. Soc. Limnol. Oceanogr. 44th Annual Conference, Milwaukee, Wisconsin.

Hacker, V. A. 1956. Biology and management of Lake trout in Green Lake, Wisconsin. Trans. Am. Fish. Soc. 86:71-83.

Holmquist, C. 1959. Problems on marine-glacial relicts on account of investigations on the genus Mysis. Berlingska Boktrycheriet, Lund, Sweden, 270 pp.

Hutchinson, G. E. 1957. A Treatise on Limnology. Vol. 1. John Wiley and Sons, New York, New York, 1015 pp.

Juday, C., and E. A. Birge. 1927. Pontoporeia and Mysis in Wisconsin lakes. Ecology 8:445-452.

Kilham, S. S. 1975. Kinetics of silicon limited growth in the freshwater diatom Asterionella formosa. J. of Phycol. 11:396-399.

Lake Tahoe Area Council. 1971. Eutrophication of Surface Waters - Lake Tahoe. EPA 16010DWS, 155 pp.

LaPierriere, J. D., T. Tilsworth, and L. A. Casper. 1978. Nutrient Chemistry of a Large, Deep Lake in Subarctic Alaska. EPA-600/3-78-088, 128 pp.

Larkin, P. A. 1948. Pontoporeia and Mysis in Athebaska, Great Bear, and Great Slave Lakes. Bull. Fish. Res. Bd. Canada 78:1-33.

Larson, G. L. 1973. A limnology study of a high mountain lake in Mountain Rainier National Park, Washington State. Arch. Hydrobiol. 72:10-48.

Lasenby, D. C. 1971. The ecology of Mysis relicta in an arctic and temperate lake. Dissertation. University of Toronto, Toronto, Ontario, 119 pp.

_____, and R. R. Langford. 1972. Growth, life history, and respiration of Mysis relicta in an arctic and temperate lake. J. Fish. Res. Bd. Canada 29:1701-1708.

_____, and R. R. Langford. 1973. Feeding and assimilation of Mysis relicta. Limnol. Oceanogr. 18:280-285.

_____, T. G. Northcote, and M. Fürst. 1981. The theory and practice of Mysis relicta introductions into North American and Scandinavian lakes. Am. Soc. Limnol. Oceanogr. 44th Annual Conference, Milwaukee, Wisconsin.

Leopold, L. B. 1980. Bathymetry and temperature of some glacial lakes in Wyoming. Proc. Natl. Acad. Sci. USA 77:1754-1758.

Linn, J. D., and T. C. Frantz. 1965. Introductions of the opossum shrimp (Mysis relicta) into California and Nevada. Calif. Dept. Fish Game, 51:48-51.

Lund, J. W. G., F. J. H. Mackereth, and C. H. Mortimer. 1963. Changes in depth and time of certain chemical and physical conditions and of the standing crop of Asterionella formosa in the north basin of Windermere in 1947. Phil. Trans. Roy. Soc. London 246:255-290.

McWilliam, P. S. 1970. Seasonal changes in abundance and reproduction in the opossum shrimp, Mysis relicta Loven, in Lake Michigan. Thesis. University of Sydney, Sydney, Australia, 94 pp.

Minnesota Pollution Control Agency. 1970. Proceedings of Conference in the Matter of Pollution of Lake Superior and Its Tributary Basins - Minnesota, Wisconsin, Michigan. Vol. 2. 473-499.

Morgan, M. D. 1981. Abundance, life history, and growth of introduced populations of the opossum shrimp (Mysis relicta) in subalpine California lakes. Can. J. Fish. Aquat. Sci. 38:939-993.

_____. 1980. Life history characteristics of two introduced populations of Mysis relicta. Ecology 61:551-561.

_____, and A. M. Beeton. 1978. Life history and abundance of Mysis relicta in Lake Michigan. J. Fish. Res. Bd. Canada 35:1165-1170.

_____, and S. T. Threlkeld. 1981. Size dependent horizontal migration by Mysis relicta. Am. Soc. Limnol. Oceanogr. 44th Annual Conference, Milwaukee, Wisconsin.

_____, S. T. Threlkeld, and C. R. Goldman. 1978. Impact of the introduction of kokanee (Onycochynchus nerka) and opossum shrimp (Mysis relicta) on a subalpine lake. J. Fish. Res. Bd. Canada 35:1572-1579.

Nelson, W. C., and J. M. Finnell. 1981. Impact of Mysis introduction on Daphnia populations in some Colorado lakes and reservoirs. Am. Soc. Limnol. Oceanogr. 44th Annual Conference, Milwaukee, Wisconsin.

Nero, R. W. 1981. Personal communication.

_____, and D. W. Schindler. 1981. The decline of Mysis relicta in response to experimental whole lake acidification. Am. Soc. Limnol. Oceanogr. 44th Annual Conference, Milwaukee, Wisconsin.

Northcote, T. G. 1972a. Some effects of mysid introduction and nutrient enrichment on a large oligotrophic lake and its salmonids. Verh. Int. Verein. Limnol. 18:1096-1106.

_____. 1972b. Kootenay Lake: Man's effects on the salmonid community. J. Fish. Res. Bd. Canada 29:861-865.

_____. 1973. Some impacts of man on Kootenay Lake and its salmonids. Great Lakes Fish Comm. Tech. Rep. 25:46.

Parker, J. I., H. L. Conway, and E. M. Yaguchi. 1977a. Seasonal periodicity of diatoms and silicon limitations in off-shore Lake Michigan. J. Fish. Res. Bd. Canada 34:552-558.

_____, H. L. Conway, and E. M. Yaguchi. 1977b. Dissolution of diatom frustules and recycling of amorphous silicon in Lake Michigan. J. Fish. Res. Bd. Canada 34:545-551.

Pennak, R. W. 1949. Annual limnological cycles in some Colorado reservoir lakes. Ecol. Monogr. 19:233-267.

_____. 1953. Freshwater Invertebrates of the United States. Ronald Press Co., New York, New York, 769 pp.

Rawson, D. S. 1953. The limnology of Amethyst Lake, a high alpine lake near Jasper, Alberta. Can. J. Zool. 31:193-210.

Reynolds, J. G., and G. M. Degraeve. 1972. Seasonal population characteristics of the opossum shrimp, Mysis relicta, in southeastern Lake Michigan. Proceedings of the 15th Conference of Great Lakes Research, Ann Arbor, Michigan, 117-131.

Ricker, K. E. 1959. The origin of two glacial relict crustaceans in North America as related to pleistocene glaciation. Can. J. Zool. 37:871-893.

Rickert, D. A., and L. B. Leopold. 1972. Fremont Lake, Wyoming - Preliminary survey of a large mountain lake. U.S.G.S. Prof. Paper 800D:173-188.

Robertson, A., C. F. Powers, and R. F. Anderson. 1968. Direct observations of Mysis relicta from a submarine. Limnol. Oceanogr. 13:700-702.

Rybock, J. T. 1978. Mysis relicta Loven in Lake Tahoe: Vertical distribution and nocturnal precation. Dissertation. University of California-Davis, Davis, California, 116 pp.

Sayre, R. C., and W. H. Stout. 1965. Opossum shrimp collection. Oregon State Game Commission, Habitat Improvement Project No. 16.

Schofield, C. L. 1976. Acid precipitation: Effects on fish. Ambio 5:228-230.

Schumacher, R. E. 1966. Successful introduction of Mysis relicta into a Minnesota lake. Trans. Am. Fish. Soc. 95:216.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Bulletin 184. Fish. Res. Bd. Canada, Ottawa, 966 pp.

Smith, W. E. 1970. Tolerance of Mysis relicta to thermal shock and light. Trans. Am. Fish. Soc. 99:418-422.

Strom, K. M. 1945. The temperature of maximum density in fresh waters. Geofysiske Publikasjoner 16(8), 14 pp.

Tattersall, W. M., and O. S. Tattersall. 1951. The British Mysidacea. Bartholomew Press, London, 460 pp.

Teraguchi, M. 1969. Diel vertical migration of Mysis relicta Loven in Green Lake, Wisconsin. Dissertation. University of Wisconsin, Madison, Wisconsin, 91 pp.

Threinen, C. W. 1962. What's new in fish management? Wisconsin Conserv. Bull. 27:14.

Threlkeld, S. T. 1981. The recolonization of Lake Tahoe by Bosmina longirostris: Evaluating the importance of reduced Mysis relicta populations. Limnol. Oceanogr. 26:433-444.

United States Environmental Protection Agency. 1979. Methods for Chemical Analysis of Water and Wastes. EPA-600/4-79-020, 460 pp.

United States Geological Survey. 1977. Methods for Collection and Analysis of Aquatic Biological and Microbiological Samples. Book 5, Chapter A4, 92 pp.

_____. 1979. Methods for Determination of Inorganic Substances in Water and Fluvial Sediments. Book 5, Chapter A1, 626 pp.

_____. 1980. Water Resources Data for Wyoming, Water Year 1979. Vol. 2. USGS-WDR-WY-79-2.

Walton, W. E., S. Compton, and S. D. Allan. 1981. Effects of acid stress on Daphnia pulex. Am. Soc. Limnol. Oceanogr. 44th Annual Conference, Milwaukee, Wisconsin.

Wetzel, R. G. 1975. Limnology. W. B. Saunders Co., Philadelphia, Pennsylvania, 743 pp.

Wright, R. F., and E. Snekvik. 1978. Chemistry and fish populations in 700 lakes in southernmost Norway. Verh. Int. Verein. Limnol. 20:765-775.

Wyoming Game and Fish Department. 1980. Personal communication, Bob Wiley, Supervisor of Fishery Research.

_____. 1981. Personal communication, Glen Dunning, Pinedale Area Fisheries Manager.

_____. 1982. Personal communication, John Baughman, Coordinator of Fisheries Management.

Young, W. D., and R. T. Oglesby. 1972. Cayuga Lake: Effects of exploitation and introductions on the salmonid community. J. Fish. Res. Bd. Canada 29:787-794.

Zyblut, E. R. 1970. Long-term changes in the limnology and macrozooplankton of a large British Columbia lake. J. Fish. Res. Bd. Canada 27:1239-1250.

BIBLIOGRAPHY

Anderson, R. S. 1971. Crustacean plankton of 146 alpine and subalpine lakes and ponds in western Canada. J. Fish. Res. Bd. Canada 28:311-321.

Bennett, G. W. 1970. Management of Lakes and Ponds. VanNostrand Reinhold Co., New York, New York, 375 pp.

Berrill, M. 1969. The embryonic behavior of the mysid shrimp, Mysis relicta. Can. J. Zool. 47:1217-1221.

Conway, H. L., J. I. Parker, E. M. Yaguchi, and D. L. Mellinger. 1977. Biological utilization and regeneration of silicon in Lake Michigan. J. Fish. Res. Bd. Canada 34:537-544.

Eddy, S., and J. C. Underhill. 1976. Northern Fishes. University of Minnesota Press, Minneapolis, Minnesota, 414 pp.

Edmondson, W. T., and G. G. Winberg. 1971. A Manual on Methods for the Assessment of Secondary Productivity in Fresnwaters. IBP Handboon No. 17. Blackwell Scientific Publications, Oxford, England.

Grossnickle, N. E., and M. D. Morgan. 1979. Density estimates of Mysis relicta in Lake Michigan. J. Fish. Res. Bd. Canada 36:694-698.

Gruendling, G. K., and J. L. Malanchuk. 1974. Seasonal and spatial distribution of phosphates, nitrates, and silicates in Lake Champlain, USA. Hydrobiolgia 45:405-421.

Hanson, J. A. 1966. The final introduction of the opossum chrimp into California and Nevada. Calif. Dept. Fish. Game 52:220.

Hem, J. D. 1970. Study and Interpretation of the Chemical Characteristics of Natural Water. 2nd Ed. U.S.G.S. Water-Supply Paper 1473.

Hutchinson, G. E. 1967. A Treatise on Limmology. Vol. II. John Wiley and Sons, New York, New York, 1116 pp.

Lande, A. 1973. Primary production and other limnological features in an oligotrophic Norwegian lake. Hydrobiologia 42:335-344.

Lind, O. T. 1974. Handbook of Common Methods in Limnology. C. V. Mosby Co., St. Louis, Missouri, 154 pp.

Lund, J. W. G. 1950. Studies on Asterionella formosa - Nutrient depletion and the spring maximum. J. Ecol. 38:1-35.

Miller, I., and J. E. Fruend. 1977. Probability and Statistics for Engineers. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 529 pp.

Prescott, G. W. 1968. The Algae: A Review. Houghton Mifflin Co., Boston, Massachusetts, 436 pp.

Rawson, D. S. 1960. A limnological comparison of twelve large lakes in northern Saskatchewan. Limnol. Oceanogr. 5:195-211.

Sparrow, R. A., P. A. Larkin, and R. A. Rutherglen. 1964. Successful introduction of Mysis relicta Loven into Kootenay Lake, British Columbia. J. Fish. Res. Bd. Canada 21:1325-1327.

Teraguchi, M., T. E. Wissing, and A. D. Hasler. 1972. Change in caloric content of adult males of Mysis relicta during a diel migratory cycle. Am. Midland Nat. 88:235-239.

Vollenweider, R. A. 1974. A Manual on Methods for Measuring Primary Production in Aquatic Environments. 2nd Ed. Blackwell Scientific Publications, Oxford, England.

APPENDIX A: CHEMICAL LIMNOLOGY DATA

Table A-1: Depth profile data, Fremont Lake - May 1, 1981.

Station	Depth (m)	Temp. (°C)	D.O. (mg/l)	D.O. Saturation (%)	pH (units)	Conductivity (μmhos/cm) 25°C
IIA	0	5.5	10.6	111	6.13	14.5
	2.1	5.4	10.6	112	6.12	15.4
	4.0	4.7	10.6	109	6.14	15.4
	7.8	4.3	10.6	109	6.16	15.4
	9.9	4.2	10.7	109	6.17	16.5
	19.5	4.0	10.7	109	6.16	15.4
	29.6	4.0	10.4	105	6.13	15.4
	38.6	3.9	10.3	104	6.12	15.4
	48.5	3.9	10.1	101	6.10	15.4
	69.3	3.9	9.8	100	6.08	15.4
	79.8	3.9	9.8	100	6.06	15.4
	92.6	3.9	8.7	87	5.95	14.5
IIB	0	5.1	11.0	115	6.25	14.5
	2.5	4.8	10.8	112	6.25	14.5
	4.4	4.6	10.9	113	6.24	14.5
	8.4	4.4	11.0	114	6.24	14.5
	10.4	4.4	10.9	111	6.24	14.5
	20.0	4.3	10.8	111	6.22	14.5
	29.8	4.2	10.7	108	6.20	14.5
	40.3	4.1	10.7	107	6.18	14.5
	50.4	4.0	10.6	107	6.16	14.5
	70.8	3.9	10.3	104	6.13	14.5
	91.3	3.9	10.0	101	6.10	14.5
	101.3	3.8	9.7	97	6.06	14.5
	122.4	3.8	9.1	91	5.93	13.7

Table A-1 (continued)

Station	Depth (m)	Temp. (°C)	D.O. (mg/l)	D.O. Saturation (%)	pH (units)	Conductivity (μmhos/cm) 25°C
IIC	0	5.5	10.5	110	6.16	16.2
	4.1	4.9	11.0	114	6.15	16.2
	8.0	4.7	11.5	116	6.15	16.2
	10.0	4.5	11.6	118	6.17	16.2
	19.6	4.3	12.2	124	6.15	16.2
	29.6	4.2	12.5	128	6.15	16.2
	39.5	4.1	10.6	107	6.14	16.2
	50.0	4.1	10.3	104	6.14	15.4
	80.0	4.0	9.8	99	6.14	14.5
	100.0	3.9	9.9	100	6.21	13.7
	131.3	3.8	9.6	97	6.29	11.9
	151.5	3.8	9.5	96	6.34	11.9
	153.8	3.8	9.2	92	6.39	11.9
IID	0	4.7	11.2	115	6.12	16.2
	2.4	4.6	11.1	115	6.12	16.2
	4.4	4.6	11.0	114	6.12	16.2
	8.4	4.5	11.0	114	6.12	17.1
	10.5	4.5	11.0	114	6.13	17.1
	15.5	4.5	10.9	112	6.12	17.1
	20.6	4.5	10.9	112	6.13	16.2
	30.6	4.3	10.8	110	6.12	16.2
	50.1	4.2	10.6	108	6.11	16.2
	71.1	4.2	10.6	108	6.11	15.4
	98.9	3.9	9.9	100	6.04	13.7

Table A-2: Depth profile data, Fremont Lake - June 28, 1981.

Station	Depth (m)	Temp. (°C)	D.O. (mg/l)	D.O. Saturation (%)	pH (units)	Conductivity (μmhos/cm) 25°C
IIA	0	14.1	8.4	109	6.54	11.9
	3.5	13.8	8.3	108	6.57	11.9
	5.4	13.2	8.4	108	6.56	11.9
	7.4	12.9	8.4	108	6.56	11.1
	10.0	10.7	8.9	108	6.49	10.2
	14.6	8.2	9.4	106	6.55	11.9
	19.3	6.0	9.6	102	6.52	13.7
	25.3	5.1	9.4	97	6.48	14.5
	30.0	4.8	9.4	96	6.41	14.5
	34.4	4.6	9.3	95	6.34	14.5
	40.0	4.4	9.3	95	6.28	14.5
	50.0	4.3	9.3	94	6.22	13.7
	62.8	4.3	9.3	94	6.19	13.7
	75.0	42	9.1	93	6.16	13.7
IIB	0	14.1	8.2	106	6.45	11.9
	2.6	13.7	8.1	102	6.44	11.9
	6.4	12.5	8.4	104	6.43	11.9
	8.9	11.0	8.7	104	6.47	11.1
	12.8	9.0	9.0	104	6.53	11.9
	17.4	6.7	9.5	101	6.56	13.7
	20.9	6.0	9.6	101	6.59	13.7
	28.5	5.0	9.4	98	6.51	13.7
	45.8	4.5	9.4	96	6.34	13.7
	59.0	4.3	9.4	95	6.27	13.7
	68.3	4.2	9.0	92	6.24	13.7
	81.0	4.2	8.9	91	6.18	13.7
	100.0	4.1	8.9	90	6.16	12.8
	125.5	4.1	8.9	90	6.14	12.8
	138.0	4.1	8.7	88	6.15	11.9

Table A-2 (continued)

Station	Depth (m)	Temp. (°C)	D.O. (mg/l)	D.O. Saturation (%)	pH (units)	Conductivity (μmhos/cm) 25°C
IIC	0	13.9	8.4	108	6.46	13.7
	4.0	13.6	8.7	111	6.47	14.5
	6.3	11.8	9.1	112	6.46	14.5
	8.5	10.3	9.6	113	6.59	14.5
	10.0	9.9	9.9	116	6.64	14.5
	13.9	8.4	10.4	117	6.68	14.5
	20.0	6.2	11.1	118	6.75	15.4
	28.4	5.1	11.5	120	6.66	15.4
	40.0	4.4	11.6	118	6.51	15.4
	50.0	4.3	11.8	120	6.41	14.5
	71.3	4.1	11.7	116	6.29	13.7
	100.0	4.0	10.5	106	6.21	12.8
	125.0	3.9	9.8	100	6.21	11.9
	146.6	3.9	9.5	97	6.20	11.1
	163.0	3.9	9.2	93	6.18	10.2
IID	0	13.6	8.4	107	6.39	16.2
	1.8	13.5	8.4	106	6.39	16.2
	5.1	12.4	8.7	107	6.39	16.2
	8.9	9.8	9.1	107	6.56	16.2
	12.0	9.0	9.5	109	6.65	15.4
	17.4	7.4	9.9	109	6.70	15.4
	20.8	5.9	9.9	104	6.67	15.4
	24.6	5.2	9.9	103	6.63	14.5
	39.3	4.4	9.7	98	6.48	14.5
	53.5	4.3	9.7	98	6.39	13.7
	77.0	4.1	9.6	96	6.32	13.7
	97.1	4.0	9.6	95	6.25	12.8

Table A-3: Depth profile data, Fremont Lake - August 21, 1981.

Station	Depth (m)	Temp. (°C)	D.O. (mg/l)	D.O. Saturation (%)	pH (units)	Conductivity (µmhos/cm) 25°C
IIA	0	17.5	7.1	99	6.58	9.4
	4.0	17.1	7.1	98	6.58	9.4
	7.0	16.9	7.1	97	6.60	9.4
	10.0	14.9	7.9	101	6.76	9.4
	15.0	10.3	8.9	105	6.90	11.1
	20.0	7.3	9.0	99	6.81	11.9
	25.0	5.7	8.8	92	6.69	11.9
	30.0	5.1	8.7	90	6.55	11.9
	40.0	4.7	8.6	88	6.38	11.9
	50.0	4.5	8.6	87	6.24	11.9
	60.0	4.4	8.6	86	6.15	11.9
IIB	0	17.2	7.2	100	6.50	9.4
	4.0	17.1	7.2	100	6.52	9.4
	7.0	17.1	7.1	99	6.54	9.4
	10.0	16.2	7.5	101	6.63	9.4
	15.0	8.9	8.8	100	6.83	11.1
	20.0	6.4	9.0	97	6.80	11.1
	25.0	5.3	9.0	94	6.60	11.1
	30.0	4.9	8.9	92	6.45	11.1
	40.0	4.6	8.9	91	6.31	11.1
	50.0	4.4	8.9	90	6.20	11.1
	60.0	4.3	8.8	88	6.12	11.1
	70.0	4.2	8.8	87	6.08	11.1
	80.0	4.2	8.8	87	6.03	11.1
	90.0	4.2	8.8	87	6.00	11.1
	100.0	4.2	8.8	87	5.98	11.1
	123.6	4.1	8.7	86	5.95	10.2
	137.5	4.1	8.5	85	5.94	9.4

Table A-3 (continued)

Station	Depth (m)	Temp. (°C)	D.O. (mg/l)	D.O. Saturation (%)	pH (units)	Conductivity (μmhos/cm) 25°C
IIC	0	17.6	6.7	93	6.45	9.4
	4.0	17.4	7.0	96	6.47	9.4
	7.0	17.3	6.9	96	6.50	10.2
	10.0	17.2	6.1	85	6.51	10.2
	15.0	11.6	7.9	96	7.00	11.9
	18.9	7.9	8.6	95	6.98	11.9
	25.0	5.5	8.2	87	6.76	12.8
	30.0	4.8	8.5	87	6.52	11.9
	40.0	4.5	8.8	88	6.36	11.9
	50.0	4.4	8.6	86	6.23	11.9
	60.0	4.4	8.1	83	6.14	11.9
	70.0	4.3	8.3	83	6.06	11.9
	80.0	4.3	8.2	82	6.04	11.1
	90.0	4.2	8.3	82	6.02	11.1
	100.0	4.2	8.1	81	6.01	11.1
	120.0	4.0	8.0	80	6.00	10.2
	156.3	3.9	8.0	80	5.99	8.5
	175.0	3.9	8.0	80	5.96	8.5
IID	0	17.3	7.1	99	6.26	11.9
	4.0	17.3	7.2	100	6.29	11.9
	7.0	17.3	7.6	104	6.33	11.9
	10.0	17.3	7.6	104	6.36	11.9
	15.0	11.2	9.5	115	6.80	13.7
	18.9	8.1	10.2	116	6.80	13.7
	25.0	5.8	10.5	111	6.70	12.8
	30.0	5.1	10.5	110	6.52	12.8
	40.0	4.6	10.7	109	6.33	12.8
	50.0	4.3	10.8	109	6.22	11.9
	60.0	4.2	10.9	109	6.12	11.9
	70.0	4.2	9.4	95	5.99	11.1
	80.0	4.1	9.1	92	5.96	11.1
	90.0	4.1	9.0	91	5.95	11.1
	100.0	4.1	8.9	89	5.98	10.2
	120.0	4.0	8.9	89	5.96	9.4
	141.4	3.9	8.5	84	5.91	11.1

Table A-4: Depth profile data, Willow Lake - June 23, 1981.

Station	Depth (m)	Temp. (°C)	D.O. (mg/l)	D.O. Saturation (%)	pH (units)	Conductivity (μmhos/cm) 25°C
IIIA	0	13.0	8.9	113	6.82	22.3
	3.3	12.6	8.8	110	6.80	23.1
	7.6	11.8	8.8	108	6.75	23.1
	9.8	10.4	8.8	105	6.73	24.0
	13.8	7.6	8.9	100	6.51	24.8
	19.1	6.0	8.9	97	6.42	24.0
	23.3	5.6	8.9	96	6.35	24.0
	28.5	4.8	8.8	92	6.25	24.0
	33.6	4.4	8.5	88	6.15	24.0
	48.0	4.0	7.4	76	5.96	24.0
	57.3	4.0	6.2	64	5.81	23.1
IIIB	0	12.6	8.9	112	6.87	22.3
	2.0	12.6	8.9	112	6.86	22.3
	4.5	12.0	8.9	110	6.86	23.1
	6.8	10.6	9.0	108	6.85	23.1
	8.3	10.1	9.1	105	6.83	23.1
	10.3	9.1	9.1	105	6.75	23.1
	14.1	7.4	9.0	100	6.59	23.1
	20.0	5.9	8.7	94	6.42	23.1
	25.0	5.4	8.1	86	6.13	23.1
	26.5	5.3	7.9	84	6.06	23.1
IIIC	0	11.7	9.4	116	7.08	22.3
	2.0	11.7	9.4	116	7.09	22.3
	3.9	11.6	9.4	115	7.09	22.3
	7.4	11.3	9.4	114	7.06	22.3
	8.9	10.8	9.4	113	7.04	22.3
	12.6	9.5	9.6	113	6.91	22.3
	17.1	6.5	9.6	104	6.72	22.3
	21.0	5.7	9.6	102	6.60	22.3
	25.4	5.2	9.7	102	6.48	21.4
	30.3	5.0	9.8	102	6.41	21.4
	34.8	4.7	9.8	101	6.36	21.4
	43.9	4.4	9.7	100	6.29	21.4
	55.5	4.2	9.5	96	6.22	21.4
	66.6	4.1	8.8	90	6.10	20.5
	71.1	4.1	7.2	74	5.87	20.5

Table A-5: Depth profile data, Willow Lake - August 18, 1981.

Station	Depth (m)	Temp. (°C)	D.O. (mg/l)	D.O. Saturation (%)	pH (units)	Conductivity (µmhos/cm) 25°C
IIIA	0	17.8	6.9	99	6.60	18.8
	4.3	17.3	6.9	97	6.60	18.8
	6.5	17.1	6.9	96	6.62	18.8
	10.0	11.9	8.0	98	6.58	19.7
	13.9	8.4	7.4	85	6.36	20.5
	17.5	7.1	7.4	82	6.22	19.7
	19.4	6.7	7.3	80	6.15	19.7
	22.1	5.3	7.5	79	6.06	19.7
	25.0	4.8	7.5	78	6.02	19.7
	28.1	4.5	7.4	77	5.95	19.7
	34.1	4.2	7.2	74	5.90	19.7
	40.0	4.1	6.5	67	5.81	19.7
	50.0	4.0	5.1	52	5.65	19.7
	60.0	4.0	3.1	32	5.47	20.5
IIIB	0	18.1	7.2	102	6.72	18.0
	2.5	17.5	7.0	98	6.77	18.0
	7.6	15.6	7.5	100	6.66	18.8
	10.0	10.6	8.0	96	6.57	19.7
	14.4	8.2	7.6	87	6.42	19.7
	18.0	7.0	6.4	71	6.11	19.7
	22.3	6.3	5.4	58	5.81	19.7
	23.8	6.0	4.6	49	5.69	19.7
IIIC	0	17.9	7.0	99	6.64	19.7
	4.0	17.3	6.8	95	6.67	19.7
	7.4	16.7	7.0	96	6.70	19.7
	10.0	14.9	7.4	98	6.72	19.7
	14.8	9.7	7.8	92	6.64	19.7
	18.0	7.6	7.6	85	6.52	19.7
	22.4	6.3	7.8	85	6.30	18.8
	24.9	5.8	7.8	84	6.25	18.8
	32.1	5.0	8.1	85	6.15	18.8
	40.0	4.6	7.9	82	6.05	18.8
	50.0	4.2	8.1	83	6.03	18.8
	60.1	4.2	6.9	72	5.90	18.8
	70.3	4.1	5.6	57	5.70	18.0

Table A-6: Depth profile data, Halfmoon Lake - April 30, 1981.

Station	Depth (m)	Temp. (°C)	D.O. (mg/l)	D.O. Saturation (%)	pH (units)	Conductivity (μmhos/cm) 25°C
IA	0	5.0	9.6	101	6.06	18.0
	2.1	4.8	9.6	100	6.03	18.0
	4.0	4.7	9.5	99	6.00	18.0
	7.8	4.5	9.4	97	5.99	18.0
	9.8	4.4	9.4	98	5.98	18.0
	14.4	4.4	9.4	98	5.96	18.0
	22.3	4.2	9.4	97	5.94	18.0
	31.8	4.1	9.3	95	5.94	18.0
	46.6	4.1	9.2	94	5.92	17.1
	65.9	4.1	9.1	93	5.91	17.1
IB	0	4.7	9.8	102	5.99	18.0
	3.5	4.6	9.7	101	5.96	18.0
	8.5	4.2	9.6	99	5.95	18.0
	14.9	4.1	9.5	97	5.93	18.0
	23.6	4.1	9.4	96	5.90	18.0
	34.0	4.0	9.4	96	5.90	18.0
	44.0	4.0	9.3	95	5.88	17.1
	46.3	4.0	9.1	93	5.87	18.0
	56.5	4.0	9.1	93	5.87	18.0
	70.1	4.0	9.1	93	5.86	17.1
IC	0	4.5	10.4	107	5.87	17.1
	2.0	4.4	10.1	104	5.83	17.1
	4.0	4.4	10.1	104	5.84	17.1
	6.0	4.3	10.1	104	5.86	17.1
	7.9	4.3	10.0	103	5.86	17.1
	9.8	4.3	9.9	102	5.87	17.1
	14.6	4.3	9.9	102	5.87	17.1
	19.8	4.3	9.8	101	5.86	17.1
	24.5	4.3	9.8	101	5.86	17.1
	29.6	4.3	9.7	100	5.86	16.2
	34.5	4.2	9.6	99	5.86	16.2
	38.9	4.2	9.6	98	5.85	16.2

Table A-7: Depth profile data, Halfmoon Lake - June 26, 1981.

Station	Depth (m)	Temp. (°C)	D.O. (mg/l)	D.O. Saturation (%)	pH (units)	Conductivity (μmhos/cm) 25°C
IA	0	13.7	9.1	115	6.71	13.7
	2.4	12.4	9.4	118	6.75	12.8
	4.6	10.8	9.4	114	6.68	12.8
	7.3	10.1	9.3	110	6.61	12.8
	9.0	9.5	9.3	108	6.54	13.7
	10.0	9.2	9.4	108	6.48	13.7
	15.9	7.7	9.4	105	6.34	14.5
	20.9	6.4	9.1	99	6.21	14.5
	31.0	5.6	9.0	96	6.01	14.5
	40.0	5.4	8.9	95	5.98	14.5
	50.0	5.4	8.9	93	5.95	14.5
IB	0	14.5	9.1	119	6.69	13.7
	2.9	12.0	9.3	115	7.03	14.5
	6.9	10.1	9.4	112	6.90	14.5
	9.8	8.8	9.2	105	6.75	15.4
	12.6	7.8	9.1	102	6.63	15.4
	15.4	7.1	9.0	99	6.51	15.4
	18.9	6.5	9.0	97	6.40	15.4
	21.1	6.3	9.0	97	6.31	15.4
	26.9	5.9	9.0	96	6.24	15.4
	30.6	5.8	8.9	95	6.19	15.4
	40.0	5.5	8.9	94	6.11	15.4
	50.5	5.4	8.8	92	6.06	14.5
	70.3	5.4	8.8	92	6.02	14.5
	75.0	5.4	8.7	91	5.99	13.7
IC	0	13.4	9.1	116	6.77	14.5
	2.0	13.1	9.1	115	6.97	14.5
	4.5	11.2	9.2	112	6.93	14.5
	6.6	10.5	9.3	111	6.90	14.5
	10.0	9.1	9.1	105	6.75	15.4
	13.6	8.1	9.0	102	6.59	15.4
	18.4	6.8	8.9	97	6.42	15.4
	20.0	6.7	8.9	97	6.36	15.4
	22.5	6.5	8.9	95	6.29	15.4
	25.6	6.1	8.8	94	6.22	15.4
	30.0	5.8	8.8	93	6.16	15.4
	42.4	5.4	8.8	92	6.05	15.4

Table A-8: Depth profile data, Halfmoon Lake - August 19, 1981.

Station	Depth (m)	Temp. (°C)	D.O. (mg/1)	D.O. Saturation (%)	pH (units)	Conductivity (μmhos/cm) 25°C
IA	0	18.4	6.8	97	6.83	11.9
	4.0	17.9	7.0	99	6.86	11.9
	6.0	17.2	7.0	98	6.79	12.8
	8.0	15.8	7.3	99	6.71	12.8
	10.0	12.6	8.0	101	6.65	12.8
	15.0	8.2	7.5	86	6.38	13.7
	18.9	6.8	7.4	82	6.26	13.7
	22.3	6.5	7.4	81	6.18	13.7
	25.6	6.2	7.5	82	6.11	13.7
	31.3	5.9	7.5	80	6.05	13.7
	40.0	5.8	7.7	82	5.99	12.8
	50.0	5.7	7.6	81	5.96	12.8
	60.0	5.6	7.6	81	5.93	12.8
	70.0	5.5	7.2	76	5.90	12.8
IB	0	18.7	7.0	100	6.83	11.1
	4.0	18.1	7.2	101	6.90	11.1
	6.0	17.8	7.2	100	6.89	11.1
	8.0	16.1	7.7	102	6.71	11.9
	10.0	11.7	8.0	99	6.61	13.7
	15.0	8.1	7.8	88	6.43	14.5
	19.0	6.6	7.6	82	6.24	14.5
	21.8	6.4	7.6	84	6.15	13.7
	25.0	6.2	7.7	82	6.04	13.7
	31.3	6.0	7.8	81	5.98	13.7
	40.0	5.8	7.8	80	5.95	13.7
	50.0	5.7	7.6	79	5.94	13.7
	60.0	5.7	7.5	79	5.90	12.8
	70.0	5.6	7.5	79	5.89	12.8
	79.1	5.6	7.3	77	5.88	11.9
IC	0	18.3	7.3	104	6.81	10.2
	4.0	17.8	7.5	105	6.92	10.2
	8.0	17.3	8.0	111	6.67	11.1
	10.0	11.3	8.3	101	6.50	12.8
	13.8	7.9	8.0	90	6.32	13.7
	18.9	6.6	7.9	87	6.19	13.7
	21.5	6.3	7.9	86	6.07	13.7
	25.0	6.0	7.8	83	6.02	13.7
	36.4	5.7	7.6	81	5.89	13.7
	40.0	5.7	7.5	80	5.86	13.7

Table A-9: Nutrient chemistry, Fremont Lake (all data in mg/l except as noted).

Date	Station	Depth (m)	PO_4-P	NH_4-N	NO_3-N	T.K.N.	Total N	Dissolved SiO_2	Total Alkalinity*
28 June 1981	IIA	0	0.001	--	0.012	0.51	0.522	1.3	12.7
		15	0.002	--	0.016	0.63	0.646	1.2	9.7
		30	0.001	--	0.006	0.38	0.386	1.3	9.0
	IIB	0	0.002	--	0.011	0.41	0.421	1.2	13.4
		15	0.005	--	0.005	0.56	0.565	1.2	7.5
		30	0.003	--	0.009	0.54	0.549	1.2	11.1
	IIC	0	0.003	--	0.006	0.75	0.756	1.2	9.7
		15	0.003	--	0.009	0.93	0.939	1.2	11.2
		30	0.013	--	0.008	0.38	0.388	1.2	8.2
	IID	0	0.002	--	0.004	0.30	0.304	1.2	9.7
		15	0.003	--	0.010	0.45	0.460	1.2	9.7
		30	0.002	--	0.008	0.51	0.518	1.2	11.2
	Inlet	0	--	--	--	--	--	--	--

Table A-9 (continued)

Date	Station	Depth (m)	PO_4-P	NH_4-N	NO_3-N	T.K.N.	Total N	Dissolved SiO_2	Total Alkalinity*
21 August 1981	IIA	0	0.004	0.062	0.0	0.88	0.880	1.1	9.7
		15	0.005	0.035	0.0	0.40	0.400	1.0	9.0
		30	0.006	0.0	0.001	0.42	0.421	1.0	9.7
	IIB	0	0.007	0.039	0.001	0.66	0.661	1.1	8.6
		15	0.009	0.067	0.0	0.46	0.460	1.0	9.3
		30	0.003	0.034	0.005	0.34	0.345	1.1	11.2
	IIC	0	0.004	0.019	0.014	0.31	0.324	1.1	9.0
		15	0.006	0.043	0.0	0.50	0.500	1.1	9.3
		30	0.003	0.127	0.006	0.50	0.506	1.1	9.3
	IID	0	0.006	0.052	0.0	0.38	0.380	1.1	8.6
		15	0.006	0.033	0.003	0.40	0.403	0.9	8.6
		30	0.007	0.007	0.0	0.67	0.670	1.1	10.4
	Inlet	0	--	--	--	--	--	--	--

*mg/l as $CaCO_3$.

Table A-10: Nutrient chemistry, Willow Lake (all data in mg/l except as noted).

Date	Station	Depth (m)	PO_4-P	NH_4-N	NO_3-N	T.K.N.	Total N	Dissolved SiO_2	Total Alkalinity*
25 June 1981	IIIA	0	0.006	--	0.004	0.56	0.564	2.9	18.9
		15	0.006	--	0.004	0.66	0.664	3.1	15.0
		30	0.007	--	0.008	0.62	0.628	3.2	17.2
	IIIB	0	0.003	--	0.005	0.60	0.605	3.1	15.7
		15	0.004	--	0.003	0.73	0.733	3.2	--
		30	0.006	--	0.006	0.99	0.996	3.2	--
	IIIC	0	0.012	--	0.002	0.73	0.732	3.1	13.5
		15	0.002	--	0.005	0.56	0.565	3.1	15.0
		30	0.005	--	0.006	0.69	0.696	3.2	32.5
	Inlet	0	0.006	--	0.007	0.61	0.617	2.5	11.3

Table A-10 (continued)

Date	Station	Depth (m)	PO_4-P	NH_4-N	NO_3-N	T.K.N.	Total N	Dissolved SiO_2	Total Alkalinity*
18 August 1981	IIIA	0	0.006	0.0	0.004	0.53	0.534	3.4	15.7
		15	0.010	0.078	0.006	0.20	0.206	3.6	16.4
		30	0.007	0.066	0.0	0.37	0.370	3.3	16.0
	IIIB	0	0.006	0.004	0.006	0.45	0.456	3.4	17.5
		15	0.004	0.007	0.0	0.47	0.470	3.4	16.4
		30	0.009	0.056	0.010	0.54	0.550	3.4	16.8
	IIIC	0	0.004	0.039	0.0	0.42	0.420	3.5	16.4
		15	0.019	0.048	0.012	0.49	0.502	3.4	15.3
		30	0.004	0.042	0.001	0.92	0.921	3.4	17.1
	Inlet	0	0.009	0.057	0.001	0.66	0.661	3.4	--

*mg/l as $CaCO_3$.

Table A-11: Nutrient chemistry, Halfmoon Lake (all data in mg/l except as noted).

Date	Station	Depth (m)	PO_4-P	NH_4-N	NO_3-N	T.K.N.	Total N	Dissolved SiO_2	Total Alkalinity*
26 June 1981	IA	0	0.004	--	0.014	0.70	0.714	2.2	11.2
		15	0.005	--	0.025	0.50	0.525	2.4	9.0
		30	0.005	--	0.034	0.69	0.724	2.4	7.5
	IB	0	0.002	--	0.008	0.66	0.668	2.3	9.0
		15	0.005	--	0.005	0.65	0.655	2.3	11.2
		30	0.009	--	0.034	0.65	0.684	2.4	12.9
	IC	0	0.003	--	0.009	0.57	0.579	2.3	11.2
		15	0.009	--	0.006	0.80	0.806	2.2	12.9
		30	0.014	--	0.035	0.56	0.595	2.4	14.2
	Inlet	0	0.004	--	0.009	0.50	0.509	1.8	--

Table A-11 (continued)

Date	Station	Depth (m)	PO_4-P	NH_4-N	NO_3-N	T.K.N.	Total N	Dissolved SiO_2	Total Alkalinity*
20 August 1981	IA	0	0.005	0.074	0.001	0.43	0.431	2.2	8.2
		15	0.004	0.024	0.006	0.36	0.366	2.2	10.1
		30	0.004	0.016	0.006	0.29	0.296	2.2	9.2
	IB	0	0.005	0.031	0.0	0.46	0.460	2.1	9.3
		15	0.009	0.030	0.008	0.59	0.598	2.1	10.1
		30	0.004	0.119	0.022	0.41	0.432	2.3	8.6
	IC	0	0.015	0.045	0.013	0.49	0.503	2.2	9.3
		15	0.007	0.001	0.002	0.38	0.382	2.1	10.1
		30	0.009	0.075	0.023	0.61	0.633	2.3	10.4
	Inlet	0	0.006	0.093	0.0	0.76	0.760	0.4	6.7

*mg/l as $CaCO_3$.

Table A-12: Secchi disk values (meters).

Station	May 1	June 28	August 21
		FREMONT LAKE	
IIA	14.3	9.7	12.4
IIB	14.3	9.8	12.6
IIC	14.3	9.4	12.0
IID	14.3	9.4	12.0
		WILLOW LAKE	
	April	June 23	August 18
IIIA	*	6.7	7.6
IIIB	*	5.8	8.0
IIIC	*	5.8	9.1
		HALFMOON LAKE	
	April 30	June 26	August 19
IA	11.3	6.0	8.5
IB	11.3	5.8	8.4
IC	11.3	5.2	7.7

*No data available.

APPENDIX B: NET PLANKTON DATA

Table B-1: Relative phytoplankton densities (10^3 cells/liter), Fremont Lake - June 29, 1981.

	Depth Interval (m)			
	0-8	8-15	15-22	22-30
Station IIA				
Diatoms	10.0	8.6	7.9	4.1
Golden-browns	0	0.2	0.2	0.2
Greens	0	0	0.1	0
Blue-greens	0	0	0	0
	10.0	8.8	8.2	4.3
Station IIB				
Diatoms	6.2	11.6	6.8	4.9
Golden-browns	0.1	0	0.6	0.8
Greens	0.1	0	0	0.1
Blue-greens	0	0	0	0
	6.4	11.6	7.4	5.8
Station IIC				
Diatoms	6.7	6.5	13.2	10.0
Golden-browns	0.2	0.2	0.2	0.6
Greens	0.1	0	0.2	0
Blue-greens	0	0	0	0
	7.0	6.7	13.6	10.6
Station IID				
Diatoms	5.7	10.3	11.3	8.0
Golden-browns	0.1	0.6	1.2	0.2
Greens	0.1	0.1	0.4	0
Blue-greens	0	0	0	0
	5.9	11.0	12.9	8.2

Table B-2: Relative phytoplankton densities (10^3 cells/liter), Fremont Lake - August 21, 1981.

	Depth Interval (m)			
	0-10	10-17	17-25	25-30
Station IIA				
Diatoms	4.1	5.8	6.7	3.5
Golden-browns	0.1	0.1	0.2	0.6
Greens	0.1	0.3	0.2	0
Blue-greens	0	0	0	0
	4.3	6.2	7.2	4.1
Station IIB				
Diatoms	9.5	6.5	6.4	2.9
Golden-browns	0.3	0.1	0.2	0.1
Greens	1.2	1.8	0.6	0
Blue-greens	0.8	0.3	0	0
	11.8	8.7	7.2	3.0
Station IIC				
Diatoms	8.3	6.3	6.4	5.1
Golden-browns	0.1	0.4	0.2	0.2
Greens	0.3	1.3	0.1	0
Blue-greens	0	0	0	0
	8.7	8.0	6.8	5.3
Station IID				
Diatoms	7.1	8.2	3.5	2.4
Golden-browns	0.3	0.1	0.3	0.1
Greens	1.1	1.2	0.8	0.3
Blue-greens	0.1	0.1	0.3	0
	8.6	9.6	4.9	2.8

Table B-3: Relative zooplankton densities (10^3 organisms/m^3), Fremont Lake - June 29, 1981.

	Depth Interval (m)			
	0-8	8-15	15-22	22-30
Station IIA				
Cladocerans	1.9	2.6	1.1	0
Copepods	7.0	11.0	5.8	2.8
Rotifers	2.8	9.0	3.6	2.8
	11.7	22.6	10.5	5.6
Station IIB				
Cladocerans	2.8	3.7	0.5	0.9
Copepods	19.5	21.2	6.8	12.0
Rotifers	7.9	8.4	11.1	6.0
	30.2	33.3	18.4	18.9
Station IIC				
Cladocerans	4.2	4.2	1.1	1.4
Copepods	12.5	15.9	21.2	17.7
Rotifers	1.9	10.0	8.5	4.2
	18.6	30.1	30.8	23.3
Station IID				
Cladocerans	2.9	1.6	2.1	0.6
Copepods	26.0	14.6	23.9	9.2
Rotifers	1.7	6.3	11.0	1.4
	30.6	22.5	37.0	11.2

Table B-4: Relative zooplankton densities (10^3 organisms/m^3), Fremont Lake - August 21, 1981.

	Depth Interval (m)			
	0-10	10-17	17-25	25-30
Station IIA				
Cladocerans	1.9	1.6	0.4	3.7
Copepods	7.0	3.7	3.3	6.5
Rotifers	0.4	4.2	0.5	4.5
	9.3	9.5	4.2	14.7
Station IIB				
Cladocerans	2.0	7.3	3.7	2.9
Copepods	11.5	13.7	5.0	5.8
Rotifers	0.3	1.1	3.1	6.7
	13.8	22.1	11.8	15.4
Station IIC				
Cladocerans	1.1	1.6	1.4	3.8
Copepods	16.2	7.5	5.9	17.0
Rotifers	0	0	3.7	4.5
	17.3	9.1	11.0	25.3
Station IID				
Cladocerans	1.5	1.7	1.3	3.7
Copepods	7.8	5.2	11.6	18.5
Rotifers	1.1	0	1.0	3.0
	10.4	6.9	13.9	25.2

Table B-5: Relative phytoplankton densities (10^3 cells/liter), Willow Lake - June 24, 1981.

	Depth Interval (m)			
	0-7	7-15	15-22	22-30
Station IIIA				
Diatoms	20.4	14.7	14.6	8.9
Golden-browns	14.7	13.8	9.1	2.4
Greens	28.1	37.8	21.0	4.0
Blue-greens	0	0	0	0
	63.2	66.3	44.7	15.3
Station IIIB				
Diatoms	21.5	17.3	8.3	--
Golden-browns	13.5	7.4	1.2	--
Greens	61.1	43.2	23.1	--
Blue-greens	0.1	0	0	--
	96.2	67.9	32.6	
Station IIIC				
Diatoms	23.7	21.9	11.2	3.7
Golden-browns	16.7	20.1	4.2	1.7
Greens	39.1	49.3	30.0	4.9
Blue-greens	0	0	0	0
	79.5	91.3	45.4	10.3

Table B-6: Relative phytoplankton densities (10^3 cells/liter), Willow Lake - August 18, 1981.

	Depth Interval (m)			
	0-7	7-15	15-22	22-30
Station IIIA				
Diatoms	8.8	10.9	6.1	1.2
Golden-browns	0.2	0	0	0.1
Dinoflagellates	0.6	0.3	0.9	0.2
Greens	2.9	3.7	5.8	0.9
Blue-greens	1.2	2.1	1.0	0.4
	13.7	17.0	13.8	2.8
Station IIIB				
Diatoms	10.4	6.2	6.5	--
Golden-browns	0.2	0	0	--
Dinoflagellates	0.4	0.3	0.4	--
Greens	4.1	3.9	4.2	--
Blue-greens	2.1	0.9	1.3	--
	17.2	11.3	12.4	
Station IIIC				
Diatoms	11.0	25.0	4.2	2.1
Golden-browns	0	0.1	0	0
Dinoflagellates	0.4	0.3	0.4	0.1
Greens	1.2	3.6	3.0	0.8
Blue-greens	--	0.9	2.0	0.4
	12.6	29.9	9.6	3.4

Table B-7: Relative zooplankton densities (10^3 organisms/m^3), Willow Lake - June 24, 1981.

	Depth Interval (m)			
	0-7	7-15	15-22	22-30
Station IIIA				
Cladocerans	0.4	0.5	0	1.0
Copepods	9.6	11.2	11.1	6.1
Rotifers	15.9	9.7	4.2	4.3
	25.9	21.4	15.3	11.4
Station IIIB				
Cladocerans	0.5	1.9	0	--
Copepods	5.2	18.1	12.3	--
Rotifers	9.0	6.0	6.9	--
	14.7	26.0	19.2	
Station IIIC				
Cladocerans	1.1	0.5	0.6	0
Copepods	17.4	16.7	7.1	9.5
Rotifers	23.8	6.0	7.0	4.2
	42.3	23.2	14.7	13.7

Table B-8: Relative zooplankton densities (10^3 organisms/m^3), Willow Lake - August 18, 1981.

	Depth Interval (m)			
	0-7	7-15	15-22	22-30
Station IIIA				
Cladocerans	0	0.5	0	0
Copepods	15.9	6.9	4.8	5.0
Rotifers	17.5	7.4	4.2	4.1
	33.4	14.8	9.0	9.1
Station IIIB				
Cladocerans	0	0	0.6	--
Copepods	11.1	17.2	3.1	--
Rotifers	21.2	3.2	3.2	--
	32.3	20.4	6.9	
Station IIIC				
Cladocerans	0.5	0.9	0	0
Copepods	18.0	13.0	6.4	4.5
Rotifers	14.3	4.6	7.9	0.8
	32.8	18.5	14.3	5.3

Table B-9: Relative phytoplankton densities (10^3 cells/liter), Halfmoon Lake - June 27, 1981.

	Depth Interval (m)			
	0-7	7-15	15-22	22-30
Station IA				
Diatoms	16.8	24.3	21.0	9.8
Golden-browns	3.2	8.1	12.0	6.2
Greens	3.6	1.0	0.1	0.3
Blue-greens	0	0	0	0
	23.6	33.4	33.1	16.3
Station IB				
Diatoms	17.1	18.3	24.0	13.0
Golden-browns	8.0	6.2	14.1	7.2
Greens	6.0	2.1	2.0	0.5
Blue-greens	0	0	0	0
	31.1	26.6	40.1	20.7
Station IC				
Diatoms	21.4	30.1	26.3	13.0
Golden-browns	7.9	7.6	13.0	8.0
Greens	6.1	4.0	2.2	0
Blue-greens	0	0	0	0
	35.4	41.7	41.5	21.0

Table B-10: Relative phytoplankton densities (10^3 cells/liter), Halfmoon Lake - August 20, 1981.

	Depth Interval (m)			
	0-8	8-14	14-20	20-30
Station IA				
Diatoms	4.4	3.6	1.7	2.1
Golden-browns	0	0.6	0.9	1.0
Dinoflagellates	0	0.2	0	0.8
Greens	1.0	2.1	1.1	0.6
Blue-greens	0	0.1	0	0
	5.4	6.6	3.7	4.5
Station IB				
Diatoms	2.8	5.6	3.9	2.9
Golden-browns	0.2	0.3	0.7	1.2
Dinoflagellates	0	0.6	0.7	0
Greens	4.1	2.8	1.3	0
Blue-greens	0.2	0	0.1	0
	7.3	9.3	6.7	4.1
Station IC				
Diatoms	4.4	7.8	7.8	3.1
Golden-browns	0	0.1	0.2	0.6
Dinoflagellates	0	0	0	0.3
Greens	0.3	3.2	4.1	2.0
Blue-greens	0.1	0	0.2	0.3
	4.8	11.1	12.3	6.3

Table B-11: Relative zooplankton densities (10^3 organisms/m^3), Halfmoon Lake - June 27, 1981.

	Depth Interval (m)			
	0-7	7-15	15-22	22-30
Station IA				
Cladocerans	0	0	0	0
Copepods	11.2	17.2	50.9	15.4
Rotifers	24.9	7.9	5.3	0.9
	36.1	25.1	56.2	16.3
Station IB				
Cladocerans	0	0	0	0
Copepods	9.1	10.3	17.0	8.3
Rotifers	65.2	4.6	4.8	5.1
	74.3	14.9	21.8	13.4
Station IC				
Cladocerans	0	0	0	0
Copepods	23.3	47.0	32.3	5.8
Rotifers	59.9	6.9	16.9	0.5
	83.2	53.9	49.2	6.3

Table B-12: Relative zooplankton densities (10^3 organisms/m^3), Halfmoon Lake - August 20, 1981.

	Depth Interval (m)			
	0-8	8-14	14-20	20-30
Station IA				
Cladocerans	0	0	0	0
Copepods	10.2	7.1	11.8	2.9
Rotifers	2.4	1.9	1.9	0.7
	12.6	9.0	13.7	3.6
Station IB				
Cladocerans	0	0	0	0
Copepods	11.1	6.8	23.5	6.2
Rotifers	3.7	1.2	1.2	0.4
	14.8	8.0	24.7	6.6
Station IC				
Cladocerans	0	0	0	0
Copepods	7.0	17.9	9.3	8.9
Rotifers	1.9	0.6	1.9	1.5
	8.9	18.5	11.2	10.4

APPENDIX C: *MYSIS RELICTA* (OPOSSUM SHRIMP) DATA

Table C-1: Relative abundances of *Mysis relicta* in Willow Lake ($Mysis \cdot m^{-2}$).

	Station IIIA		Station IIIB		Station IIIC	
	6-23-81	6-29-81	6-23-81	6-29-81	6-23-81	6-29-81
Rep. #1	360	375	41	38	296	372
Rep. #2	436	278	13	13	332	278
Rep. #3	337	365	28	13	388	380
Daily $\bar{X}$	378	339	27	21	339	343
Daily S^2	2,684	2,846	196	208	2,149	3,217
Station $\bar{X}$	359		24		341	
Station S^2	2,653		173		2,153	
	8-18 and 22-81		8-18-81	8-22-81	8-18 and 22-81	
Rep. #1	582		0	0	1,255	
Rep. #2	995		0	0	1,069	
Rep. #3	401		0	0	1,173	
Daily $\bar{X}$	--	--	0	0	--	--
Daily S^2	--	--	0	0	--	--
Station $\bar{X}$	659		0		1,166	
Station S^2	92,694		0		8,689	

Table C-2: Class frequency data for *Mysis relicta* in Willow Lake.

Sex Class	Station IIIA No.	Station IIIA %	Station IIIB No.	Station IIIB %	Station IIIC No.	Station IIIC %	Lake Total No.	Lake Total %
June, 1981:								
Juveniles	300	35.6	57	100	304	38.0	661	38.9
Immature Females	245	29.1	0	0	185	23.1	430	25.3
Immature Males	230	27.3	0	0	181	22.6	411	24.2
Mature Females	67	7.9	0	0	117	14.6	184	10.8
Mature Males	1	0.1	0	0	14	1.7	15	0.9
	843		57		801		1,701	
August, 1981:								
Juveniles	389	50.2	0	0	480	35.0	869	40.5
Immature Females	117	15.1	0	0	212	15.5	329	15.3
Immature Males	178	23.0	0	0	436	31.8	614	28.6
Mature Females	91	11.7	0	0	243	17.7	334	15.6
Mature Males	0	0	0	0	0	0	0	0
	775		0		1,371		2,146	

Table C-3: Length frequency data for *Mysis relicta* in Willow Lake - June 1981.

	Station IIIA		Station IIIB		Station IIIC		Lake Total	
Length (mm)	No.	%	No.	%	No.	%	No.	%
3.0	9	1.1	4	7.0	3	0.4	16	0.9
4.0	72	8.5	23	43	74	92	169	9.9
5.0	159	18.9	24	42	105	13.1	288	16.9
6.0	39	4.6	5	8.8	74	9.2	118	6.9
7.0	10	1.2	1	1.8	43	5.4	54	3.2
8.0	7	0.8	0	0	5	0.6	12	0.7
9.0	4	0.5	0	0	0	0	4	0.2
10.0	5	0.6	0	0	0	0	5	0.3
11.0	51	6.0	0	0	0	0	51	3.0
12.0	66	7.8	0	0	14	1.7	80	4.7
13.0	65	7.7	0	0	33	4.1	98	5.8
14.0	95	11.3	0	0	78	9.7	173	10.2
15.0	154	18.3	0	0	134	16.7	288	16.9
16.0	67	7.9	0	0	142	17.5	209	12.3
17.0	21	2.5	0	0	56	7.0	77	4.5
18.0	10	1.2	0	0	26	3.2	36	2.1
19.0	5	0.6	0	0	8	1.0	13	0.8
20.0	4	0.5	0	0	6	0.8	10	0.6
21.0	0	0	0	0	0	0	0	0
22.0	0	0	0	0	0	0	0	0
23.0	0	0	0	0	0	0	0	0
	843		57		801		1,701	

Table C-4: Length frequency data for Mysis relicta in Willow Lake - August 1981.

	Station IIIA		Station IIIB		Station IIIC		Lake Total	
Length (mm)	No.	%	No.	%	No.	%	No.	%
3.0	0	0	0	0	0	0	0	0
4.0	0	0	0	0	0	0	0	0
5.0	14	1.8	0	0	52	3.8	66	3.1
6.0	123	15.9	0	0	144	10.5	267	12.4
7.0	181	23.4	0	0	200	14.6	381	17.8
8.0	39	5.0	0	0	65	4.7	104	4.8
9.0	18	2.3	0	0	17	1.2	35	1.6
10.0	14	1.8	0	0	2	0.1	16	0.7
11.0	10	1.3	0	0	4	0.3	14	0.7
12.0	0	0	0	0	5	0.4	5	0.2
13.0	44	5.7	0	0	14	1.0	58	2.7
14.0	48	6.2	0	0	109	8.0	157	7.3
15.0	71	9.2	0	0	150	10.9	221	10.3
16.0	113	14.6	0	0	238	17.4	351	16.4
17.0	47	6.1	0	0	193	14.1	240	11.2
18.0	37	4.8	0	0	123	9.0	160	7.6
19.0	10	1.3	0	0	22	1.6	32	1.5
20.0	5	0.6	0	0	13	0.9	18	0.8
21.0	1	0.1	0	0	9	0.7	10	0.5
22.0	0	0	0	0	7	0.5	7	0.3
23.0	0	0	0	0	4	0.3	4	0.2
	775		0		1,371		2,146	

Table C-5: Length frequency data for *Mysis relicta* in Willow Lake according to sex.

	June 1981		August 1981	
Length (mm)	No.	%*	No.	%*
Females:				
10.0	3	0.5	0	0
11.0	37	6.0	2	0.3
12.0	48	8.0	1	0.2
13.0	51	8.3	24	3.6
14.0	87	14.1	56	8.4
15.0	133	21.6	63	9.5
16.0	139	22.6	120	18.1
17.0	62	10.1	166	25.0
18.0	31	5.0	160	24.1
19.0	13	2.1	32	4.8
20.0	10	1.6	18	2.7
21.0	0	0	10	1.5
22.0	0	0	7	1.1
23.0	0	0	4	0.6
	614		663	
Males:				
10.0	2	0.5	0	0
11.0	14	3.3	12	2.0
12.0	32	7.3	4	0.7
13.0	47	11.1	34	5.5
14.0	86	20.2	101	16.4
15.0	155	36.5	158	25.7
16.0	70	16.5	231	37.6
17.0	15	3.5	74	12.1
18.0	5	1.2	0	0
	426		614	

*Percent of total female or total male population.

Table C-6: Relative abundances of *Mysis relicta* in Halfmoon Lake (Mysis · m^{-2}).

	Station IA		Station IB		Station IC	
	6-26-81	6-27-81	6-26-81	6-27-81	6-26-81	6-27-81
Rep. #1	219	133	526	620	1,190	1,071
Rep. #2	434	140	395	398	1,740	1,679
Rep. #3	245	112	689	584	957	1,079
Daily $\bar{X}$	229	128	537	534	1,296	1,276
Daily S^2	13,770	212	21,694	14,196	161,541	121,621
Station $\bar{X}$	214		535		1,286	
Station S^2	14,365		14,358		113,381	
	8-19 and 22-81		8-19 and 22-81		8-19 and 22-81	
Rep. #1	1,602		801		648	
Rep. #2	1,324		467		671	
Rep. #3	1,579		531		431	
Daily $\bar{X}$	--	--	--	--	--	--
Daily S^2	--	--	--	--	--	--
Station $\bar{X}$	1,502		600		583	
Station S^2	23,806		31,425		17,536	

Table C-7: Class frequency data for Mysis relicta in Halfmoon Lake.

	Station IA		Station IB		Station IC		Lake Total	
Sex Class	No.	%	No.	%	No.	%	No.	%
June, 1981:								
Juveniles	446	88.7	1,083	86.0	3,025	100.0	4,554	95.1
Immature Females	6	1.2	33	2.6	0	0	39	0.8
Immature Males	26	5.2	65	5.2	0	0	9.	1.9
Mature Females	21	4.2	63	5.1	0	0	84	1.8
Mature Males	4	0.8	15	1.2	0	0	19	0.4
	503		1,259		3,025		4,787	
August, 1981:								
Juveniles	1,504	85.2	543	77.0	440	64.1	2,487	78.8
Immature Females	55	3.1	24	3.4	30	4.4	109	3.5
Immature Males	131	7.4	87	12.3	108	15.7	326	10.3
Mature Females	75	4.2	51	7.2	108	15.7	234	7.4
Mature Males	1	0.1	0	0	0	0	1	0.1
	1,766		705		686		3,157	

Table C-8: Length frequency data for *Mysis relicta* in Halfmoon Lake - June 1981.

	Station IA		Station IB		Station IC		Lake Total	
Length (mm)	No.	%	No.	%	No.	%	No.	%
3.0	9	1.8	14	1.1	55	1.8	18	1.6
4.0	99	19.7	235	18.7	556	18.3	890	18.6
5.0	194	38.6	483	38.4	1,379	45.6	2,056	42.9
6.0	103	20.5	233	18.5	727	24.0	1,063	22.2
7.0	33	6.6	87	6.9	247	8.2	367	7.7
8.0	7	1.4	27	2.1	58	1.9	92	1.9
9.0	1	0.2	4	0.3	3	0.1	8	0.2
10.0	0	0	0	0	0	0	0	0
11.0	0	0	0	0	0	0	0	0
12.0	0	0	0	0	0	0	0	0
13.0	0	0	3	0.2	0	0	3	0.1
14.0	8	1.6	22	1.7	0	0	30	0.6
15.0	6	1.2	21	1.7	0	0	27	0.6
16.0	10	2.0	33	2.6	0	0	43	0.9
17.0	24	4.8	32	2.5	0	0	56	1.2
18.0	5	1.0	30	2.4	0	0	55	0.7
19.0	3	0.6	18	1.4	0	0	21	0.4
20.0	1	0.2	13	1.0	0	0	14	0.3
21.0	0	0	3	0.2	0	0	3	0.1
22.0	0	0	1	0.1	0	0	1	0
23.0	0	0	0	0	0	0	0	0
	503		1,259		3,025		4,787	

Table C-9: Length frequency data for Mysis relicta in Halfmoon Lake - August 1981.

	Station IA		Station IB		Station IC		Lake Total	
Length (mm)	No.	%	No.	%	No.	%	No.	%
3.0	0	0	0	0	0	0	0	0
4.0	0	0	0	0	0	0	0	0
5.0	32	1.8	7	1.0	12	1.7	51	1.6
6.0	204	12.5	41	5.8	48	7.0	293	9.3
7.0	572	32.3	186	26.4	152	22.2	910	28.8
8.0	448	25.3	211	29.9	159	23.2	818	25.9
9.0	213	12.0	77	10.9	58	8.5	348	11.0
10.0	35	1.9	21	3.0	11	1.6	67	2.1
11.0	4	0.2	1	0.1	1	0.1	6	0.2
12.0	12	0.6	1	0.1	6	0.9	19	0.6
13.0	22	1.2	9	1.3	8	1.2	39	1.2
14.0	33	1.8	15	2.1	27	3.9	75	2.4
15.0	58	3.3	41	5.8	40	5.8	139	4.4
16.0	59	3.3	37	5.2	59	8.6	155	4.9
17.0	29	1.5	26	3.7	35	5.1	90	2.9
18.0	17	1.0	8	1.1	18	2.6	43	1.4
19.0	13	0.7	7	1.0	27	3.9	47	1.5
20.0	6	0.3	7	1.0	10	1.5	23	0.7
21.0	3	0.1	7	1.0	9	1.3	19	0.6
22.0	5	0.3	3	0.4	6	0.9	14	0.4
23.0	1	0.1	0	0.0	0	0.0	1	0.1
	1,766		705		686		3,157	

Table C-10: Length frequency data for *Mysis relicta* in Halfmoon Lake according to sex.

	June 1981		August 1981	
Length (mm)	No.	%*	No.	%*
Females:				
10.0	0	0	0	0
11.0	0	0	1	0.3
12.0	0	0	7	2.0
13.0	0	0	21	6.1
14.0	18	13.5	22	6.4
15.0	15	11.3	36	10.5
16.0	23	17.3	55	16.1
17.0	22	16.5	55	16.1
18.0	20	15.0	42	12.2
19.0	17	12.8	47	13.7
20.0	14	10.5	23	6.7
21.0	3	2.3	19	5.5
22.0	1	0.8	14	4.1
23.0	0	0	1	0.3
	133		343	
Males:				
10.0	0	0	0	0
11.0	0	0	5	1.5
12.0	0	0	12	3.7
13.0	3	3.1	18	5.5
14.0	12	12.5	53	16.2
15.0	12	12.5	103	31.5
16.0	20	20.8	100	30.6
17.0	34	35.4	35	10.7
18.0	15	15.6	1	0.3
	96		327	

*Percent of total female or total male population.