Effects of destratification and aeration of a lake on the distribution of planktonic crustacea, yellow perch, and trout. No. 99 1977

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EFFECTS OF DESTRATIFICATION AND AERATION OF A LAKE ON THE DISTRIBUTION OF PLANKTONIC CRUSTACEA, YELLOW PERCH, AND TROUT

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ABSTRACT

To improve living conditions and expand the living zone for fish and their prey, dissolved-oxygen-poor Mirror Lake (5.3 ha, maximum depth 13 m) in central Wisconsin was artificially aerated during 1972-74.

After destratification (total aeration) of Mirror Lake in September 1973, trout and yellow perch and their primary prey, the *Daphnia*, occupied the entire lake. Before destratification of Mirror Lake, they were limited mainly to the upper half of the lake because of low dissolved oxygen levels in the lower half.

Although *Daphnia* occupied the entire lake in September 1973, they did not show an increase in average number per liter. *D. pulicaria* doubled in average number per liter but *D. galeata* decreased by two-thirds, leaving the total number of daphnids essentially static. In September 1974, however, *Daphnia* showed an increase of four-fold in average number per liter after total aeration. Unlike 1973, however, *D. pulicaria* decreased by one-half and *D. galeata* and *D. retrocurva* were the daphnids that increased, the latter over 10-fold.

The density of calanoid and cyclopoid copepods increased during both 1973 and 1974 after total aeration, but there was no significant change in the density of the relatively small cladocerans, *Bosmina longirostris* and *Diaphanosoma leuchtenbergianum*, after aeration.

Only a small number of calanoid and cyclopoid copepods were found in the stomachs of yellow perch, while none were found in the stomachs of brook, brown, and rainbow trout from Mirror Lake even though there were as many large copepods (1 mm and larger) as there were large daphnids. Stomachs of age 1 domesticated brown and rainbow trout stocked in Mirror and Larson Lake, respectively, did not contain daphnids or copepods one week to one month after they were stocked in these lakes. Their diets were comprised mainly of terrestrial insects that were dominated in early autumn by winged ants.

EFFECTS OF DESTRATIFICATION AND AERATION OF A LAKE ON THE DISTRIBUTION OF PLANKTONIC CRUSTACEA, YELLOW PERCH, AND TROUT

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INTRODUCTION

The Inland Lakes Demonstration Project, a joint venture of the Wisconsin Department of Natural Resources and the University of Wisconsin, installed and monitored aeration equipment in Mirror and Larson lakes in 1972 and 1973, respectively. These lakes typified many of the problems associated with lake eutrophication in the upper midwestern United States. From these aeration studies came needed information on the effects of aeration on the biological, chemical and physical regime of lakes (Smith et al. 1975).

In Mirror Lake, our major contribution to the team study was to observe what effects the September 1973-74 vertical mixing had on the depth distribution of yellow perch and trout and their planktonic crustacean prey, with emphasis on *Daphnia*. Studies at Larson Lake were limited to observations on the distribution of planktonic Crustacea during hypolimnetic aeration and assessment of the food of perch and trout after a natural destratification, the fall overturn. Movement and distribution of rainbow trout, after hypolimnetic aeration in Larson Lake, was reported by Serns (1976).

DESCRIPTION OF STUDY AREAS

Mirror Lake (5.3 ha, maximum depth 13 m) is located within the city limits of Waupaca, Wisconsin. Larson Lake (4.8 ha, maximum depth 12 m) is a bog lake in Lincoln County, Wisconsin. Detailed chemical and physical aspects of these lakes are described by Smith et al. (1975). They reported that Mirror Lake's spring and fall overturns were incomplete in 1971-72 but Larson Lake mixed normally each fall and spring during the investigation.

Mirror and Larson lakes are managed for trout and panfish. However, due to low dissolved oxygen levels in the winter of 1971-72 it was questionable whether fish in Mirror Lake survived (Smith et al. 1975). For example, their records show that on 24 February 1972, dissolved oxygen directly under the ice was 1.0 mg/l and only 0.3 mg/l at 1 meter below the ice; while none was present at and below the 2-meter level.

METHODS

PLANKTONIC CRUSTACEA

Density Determination

Planktonic Crustacea were collected over the deepest area of the lakes. At each sampling period (10:00-11:30 a.m.), 12 liters of water were collected with a 3-liter Kemmerer sampler at every 2-meter depth interval in Mirror Lake during 1973 and in Larson Lake during 1974. During most of 1974 and all of 1975, water samples from Mirror Lake were taken at every 1-meter depth interval in both lakes. The composite of the four 3-liter water samples were strained through a number 10 plankton net to remove the crustaceans for preservation. In the laboratory, the crustaceans were counted on a circular 3-ml counting cell. Methods were similar to those of Priegel (1970) and Brynildson and Kempinger (1970 and 1973). By counting the contents of 3 cells, we examined a total of 9 ml of the original sample which had been diluted up to 1,000 ml depending upon the density of the Crustacea in a given sample. Lengths of individual Crustacea, excluding antennae and spines, were measured to the nearest 0.2 mm with an ocular micrometer.

Identification

Identification of the *Daphnia* was based on the *Systematics of North American Daphnia* (Brooks 1957). Byron Torke of Ball State University at Muncie, Indiana, identified *Daphnia pulicaria* Forbes, and most of the calenoids and cyclopoids. Crustacea collected from Mirror Lake in the number 10 net included: *Bosmina longirostris* (O. F. Muller), *Ceriodaphnia quadrangula* (O. F. Muller), *Chydorus sphaericus* (O. F. Muller), *Daphnia ambigua* Scourfield, *Daphnia galeata mendotae* Birge, *Daphnia pulicaria* Forbes, *Daphnia retrocurva* Forbes, *Diaphanosoma leuchtenbergianum* Fischer, *Diacyclops thomasi* Forbes, *Epischura lacustris* Forbes, *Eubosmina coregoni* (Baird), *Leptodora kindti* (Focke), and *Skistodiaptomus pallidus.* Crustacea collected from Larson Lake included: *Acanthocyclops vernalis* (Fischer), *Bosmina longirostris* (O. F. Muller), *Ceriodaphnia quadrangula* (O. F. Muller), *Daphnia galeata mendotae* Birge, *Daphnia parvula* Fordyce, *Daphnia pulicaria* Forbes, *Diaphanosoma leuchtenbergianum* Fischer, *Orthocyclops modestus* (Herrick), *Skistodiaptomus oregonensis* Lilljeborg, and *Tropocyclops prasinus* Fischer.

TROUT AND YELLOW PERCH

Stocking

Mirror Lake received 1,000 age I domesticated brook trout, *Salvelinus fontinalis* (Mitchill), and 1,000 domesticated rainbow trout, *Salmo gairdneri* Richardson, each April during 1972-75. On 5 September 1974, one week before total aeration of Mirror Lake began, 2,500 age 0 brown trout, *Salmo trutta* Linneaus, were released into Mirror Lake. Larson Lake received 1,000 age 0 domesticated rainbow trout on 6 September 1974. Yellow perch, *Perca flavescens* (Mitchill), were wild residents of Mirror and Larson lakes.

Distribution Determination

Four vertical gill nets were run from the surface to the bottom of Mirror Lake during 21-23 June 1974 and 10-11 September 1974, before destratification, and 25-26 September 1974, after destratification. Two of the nets were 19 mm stretch and two 25 mm. The nets were set at 8:00 a.m. and pulled at 8:00 p.m.

Stomach Analyses

In Mirror Lake, stomachs were obtained both from trout taken by anglers and captured in vertical gill nets, while stomachs of trout from Larson Lake and stomachs of perch from both lakes were obtained only from fish captured in vertical gill nets. Each stomach was examined for the presence of various food items. Whenever a stomach contained over one hundred small food items, such as *Daphnia*, the contents were subsampled. Contents of the stomachs were examined and counted under a wide-field binocular microscope with an ocular micrometer to measure the size of the Crustacea in the stomachs.

RESULTS

PLANKTONIC CRUSTACEA DISTRIBUTION AND DENSITY

During a typical year, the living zone of planktonic Crustacea is limited mainly to the upper half of Mirror Lake during summer and winter. The lake usually fails to mix completely after the winter ice melts and enters spring and summer with low levels of dissolved oxygen in the bottom waters. Rapid solar heating of the surface water and lack of prevailing winds through the sheltered basin of Mirror Lake impedes holomixis. A typical year was 1975 when Mirror Lake was not aerated artificially (Fig. 8, Append.).

Daphnia and other planktonic crustacean numbers are closely related to dissolved oxygen concentrations in Mirror Lake when water temperatures are optimum. These crustaceans can tolerate low levels (< 1mg/liter) of dissolved oxygen, at least for short periods, when water temperatures are as low as they are in the hypolimnion throughout the year (Fig. 8, Append.).

The large zooplankton predators, *Epischura* and *Leptodora*, were present in plankton collections from Mirror Lake on 25 September 1974, but were too sparse to be found in the subsamples counted. However, a yellow perch stomach (5.2 percent of the stomachs examined — Table 2) contained 50 *Epischura* while 4 other yellow perch stomachs averaged 2 *Leptodora*. Selection of the largest species of planktonic Crustacea is well documented. For example, young walleyes selected *Epischura* (Hovde 1967) and young sauger and stocked rainbow trout selected scarce *Leptodora* (Priegel 1969 and Brynildson 1958, respectively). Because these large forms lik *Epischura* are selectively eaten by planktivores, they can easily become overgrazed, (Byron Torke, Ball State University, Muncie, Indiana, pers. comm.).

Daphnia did not increase in average number after Mirror Lake was destratified on 21 September 1973. The average number of *Daphnia* (27/liter) was the same on 12 September, when total aeration began, as on 21 September (Fig. 1). *D. pulicaria* nearly doubled in average number per liter but *D. galeata* decreased by two thirds, leaving the total *Daphnia* population static. Redistribution of *Daphnia* did occur, however, after destratification. Densities of both *D. galeata* and *D. pulicaria* increased during daylight (10:00-11:30 a.m.) near the surface of the lake but decreased at the 5-m level where they reached their highest density 12 September (Fig. 1). Moreover, both daphnids were collected near the bottom at 13 m after destratification. *D. pulicaria* was not found in that near-anoxic zone before destratification (Fig. 1).

Total aeration of Mirror Lake was repeated on 12 September 1974, and the lake was destratified by 20 September. The *Daphnia* population increased fourfold from 10 September to 25 September (Fig. 3). Unlike 1973, however, *D. pulicaria* decreased in number by one-half in 1974 while both *D. galeata* (which decreased in 1973) and *D. retrocurva* increased, the latter over 10-fold. *D. retrocurva* was collected from Mirror Lake in 1972 but was not found in the collections of 1973. This daphnid first appeared in the 1974 collections on 16 August (Fig. 3) in small numbers (< 1/liter).

The standing crops of *Daphnia* in Mirror Lake decreased by 25 percent from immediately after destratification in September to mid-October in 1973 and 1974 (Figs. 1 and 3). The 1973 drop was caused by the decline in *D. galeata*, while in 1974 the decline was caused primarily by *D. pulicaria* which nearly disappeared by October (Fig. 3).

Other cladocerans, such as *Diaphanosoma leuchtenbergianum*, had a mean density of 1 and 3 per liter, respectively, on 12 and 21 September 1973 before and after destratification, but there was no change in the mean density of this cladoceran in 1974 after destratification (Fig. 4). *Bosmina longirostris* maintained its low mean density of 1 per liter after destratification in 1973, but increased from 11 to 60 per liter after destratification in 1974 (Fig. 4). Both cladocerans occupied the entire lake after destratification during both years (Fig. 4).

The density of calanoid and cyclopoid copepods increased during both years after destratification of Mirror Lake; when sampled on 25 September 1974, cyclopoids were concentrated near the bottom of the lake while the calanoids were more numerous near the surface (Fig. 4).

After Mirror Lake was initially

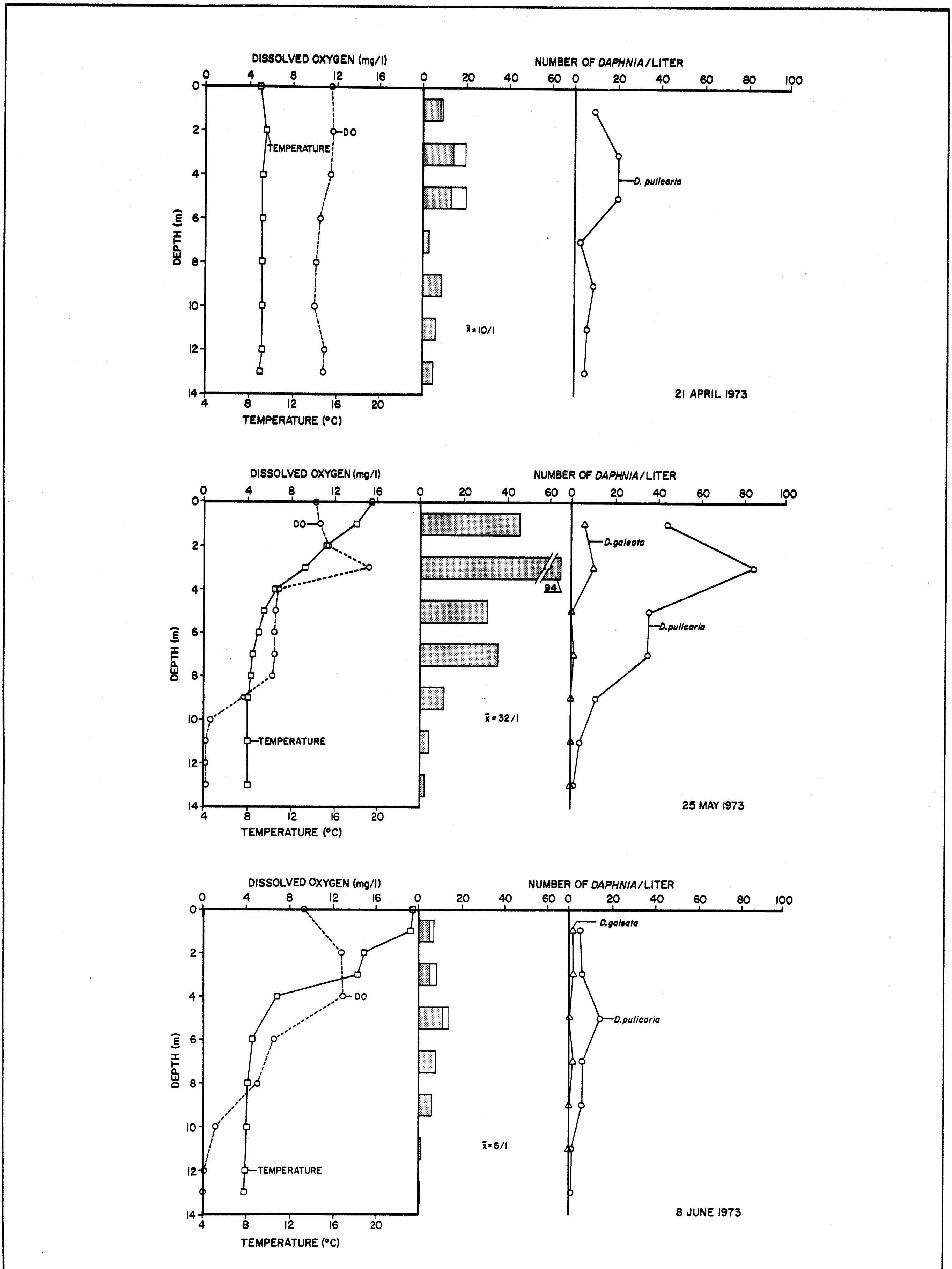


FIGURE 1. Density of *Daphnia*, water temperatures, and the levels of dissolved oxygen at various depths in Mirror Lake on given dates during 1973. Shaded areas of the histograms denote the number of *Daphnia* 1 mm and larger.

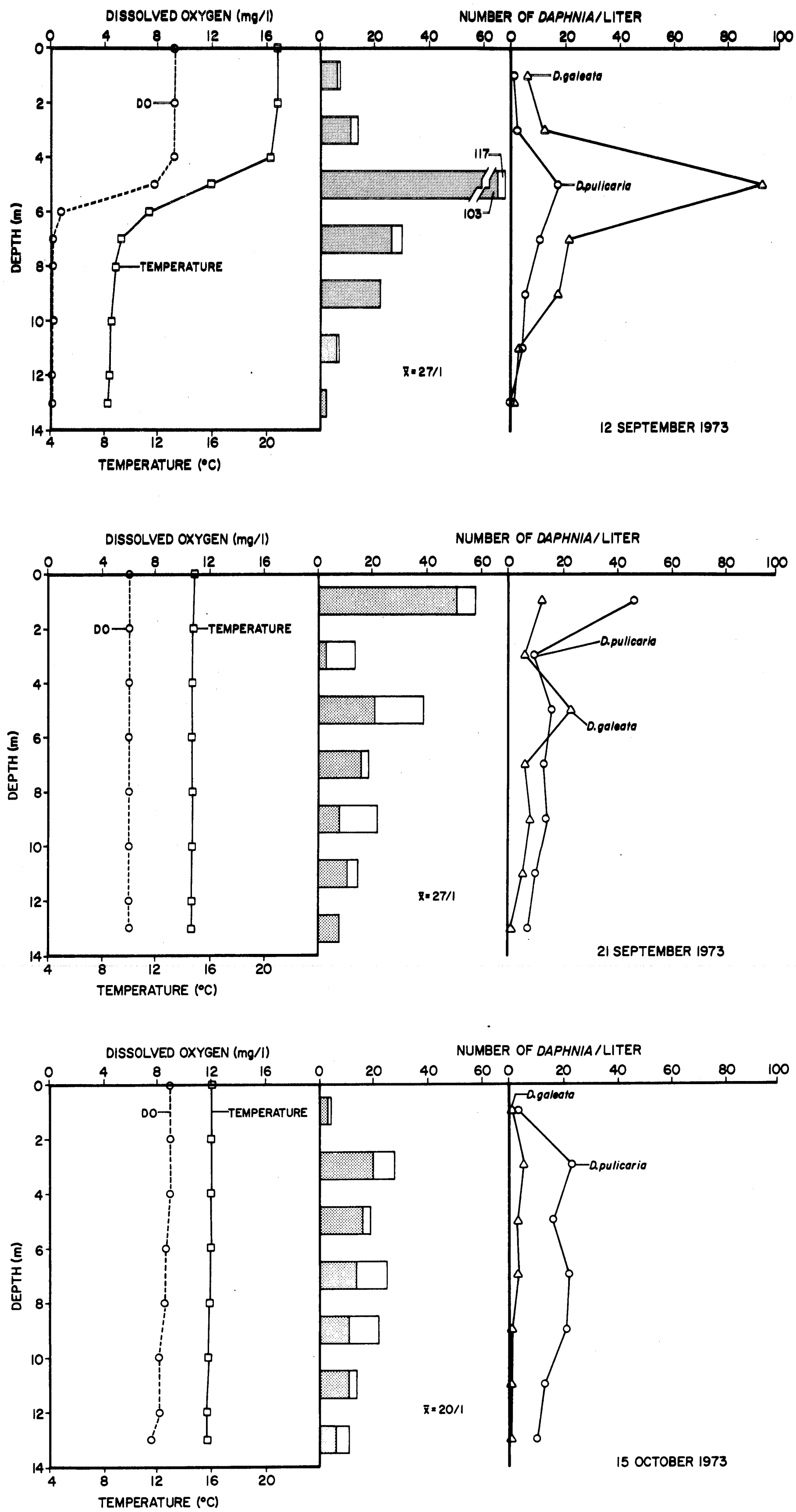


FIGURE 1. Continued.

destratified on 21 September 1973 and 20 September 1974, total aeration continued to 6 November 1973 and 4 December 1974. As a result, higher dissolved oxygen levels were maintained through February 1974-75. With the prevailing water temperatures found under ice-cover, there was adequate dissolved oxygen for *Daphnia* to a depth of 12 m and for trout and yellow perch to 10 m, up to mid-February in 1974 and 1975, (Fig. 10, Append).

TROUT AND YELLOW PERCH DISTRIBUTION AND FOOD

Water temperatures in Mirror Lake were within the range of trout and yellow perch in June and September 1974, and probably did not restrict their depth distribution as did low dissolved oxygen levels, which confined them to the upper half of the lake (Figs. 2, 3, and 5). After destratification of Mirror Lake in September 1974, nearly 6 mg/l of dissolved oxygen and uniform water temperatures extended to the bottom of the lake. Trout and yellow perch now moved to deeper areas of the lake. During 24-25 September 1974 in Mirror Lake, yellow perch were caught in the vertical gill nets at depths of 4-13 m and trout from the surface to 12 m (Fig. 5). In comparison, bluegills (*Lepomis macrochirus*) and black bullheads (*Ictalurus melas*) were caught from the surface down to 7 m before destratification, while after destratification these fishes were caught down to 12 and 11 m, respectively.

The percentage of trout and yellow perch stomachs containing a listed food item and the percentage of that item in the stomach contents are presented in Tables 1-4, Append. During May and June, *Daphnia* (larger than 1 mm) was the dominant food of trout and yellow perch (Table 1, Append.).

Stomachs from 18 age I brook and 18 age I rainbow trout (TL 23-27 cm), caught by angling during May-June 1973 and 1974, averaged 772 and 1,198 *Daphnia*, respectively, while stomachs of three age II rainbow trout (36-38 cm) averaged 1,984 *Daphnia*. Trout caught in vertical gill nets contained less identifiable *Daphnia* in their stomachs than those caught by angling, indicating that many *Daphnia* eaten by trout and yellow perch were digested during the 12-hour interval when nets were pulled and the trout and yellow perch collected.

Daphnia continued to be dominant in the diet of yellow perch during 10-11 September 1974, before destratification and 25-26 September after destratification (Table 2, Append.). Of the 11 yellow perch exceeding 20 cm in total length, however, 82 and 36 percent of their stomachs contained chironomid larvae-pupae and *Daphnia*, respectively.

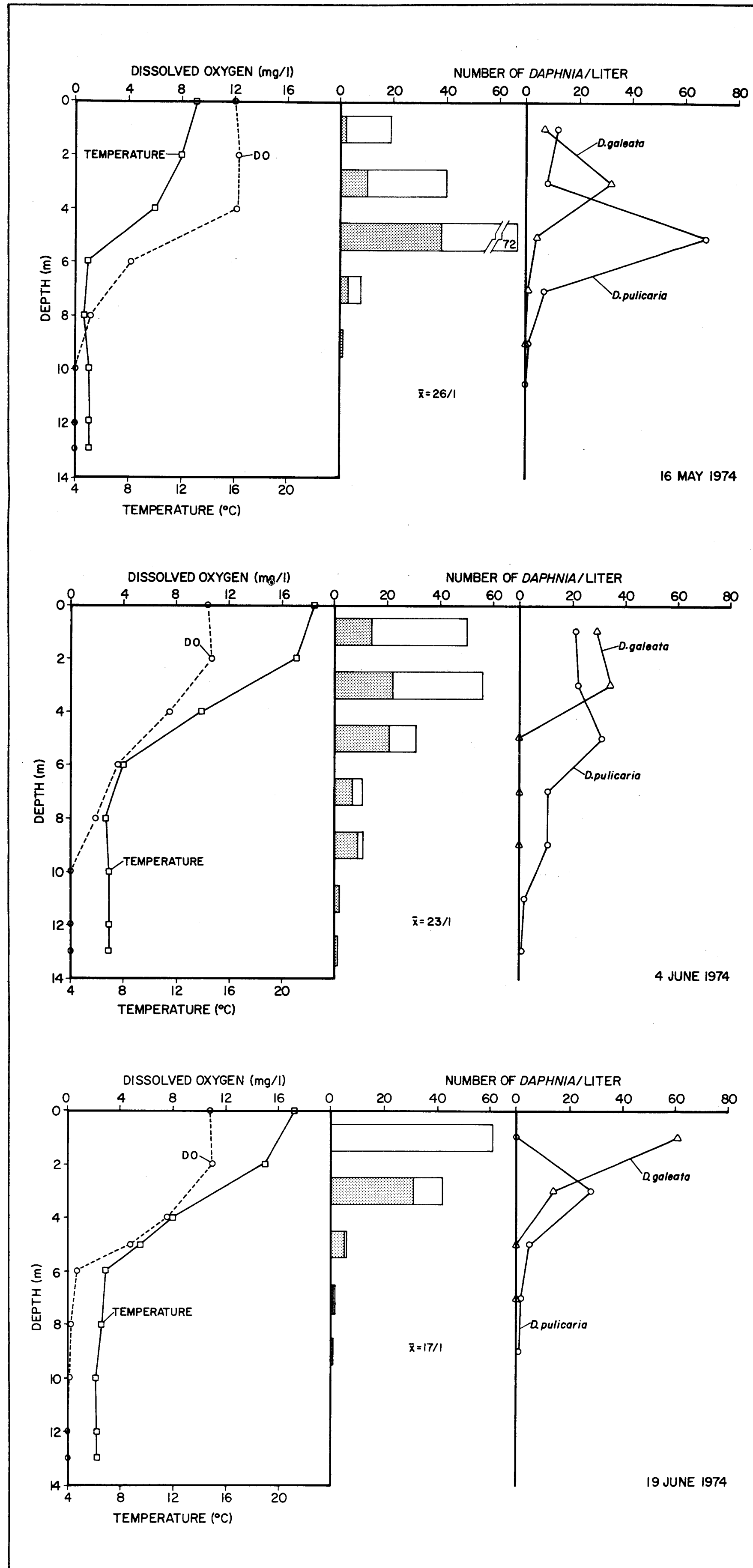


FIGURE 2. Density of *Daphnia*, water temperatures, and the levels of dissolved oxygen at various depths in Mirror Lake on given dates during 1974. Shaded areas of the histograms denote the number of *Daphnia* 1mm and larger.

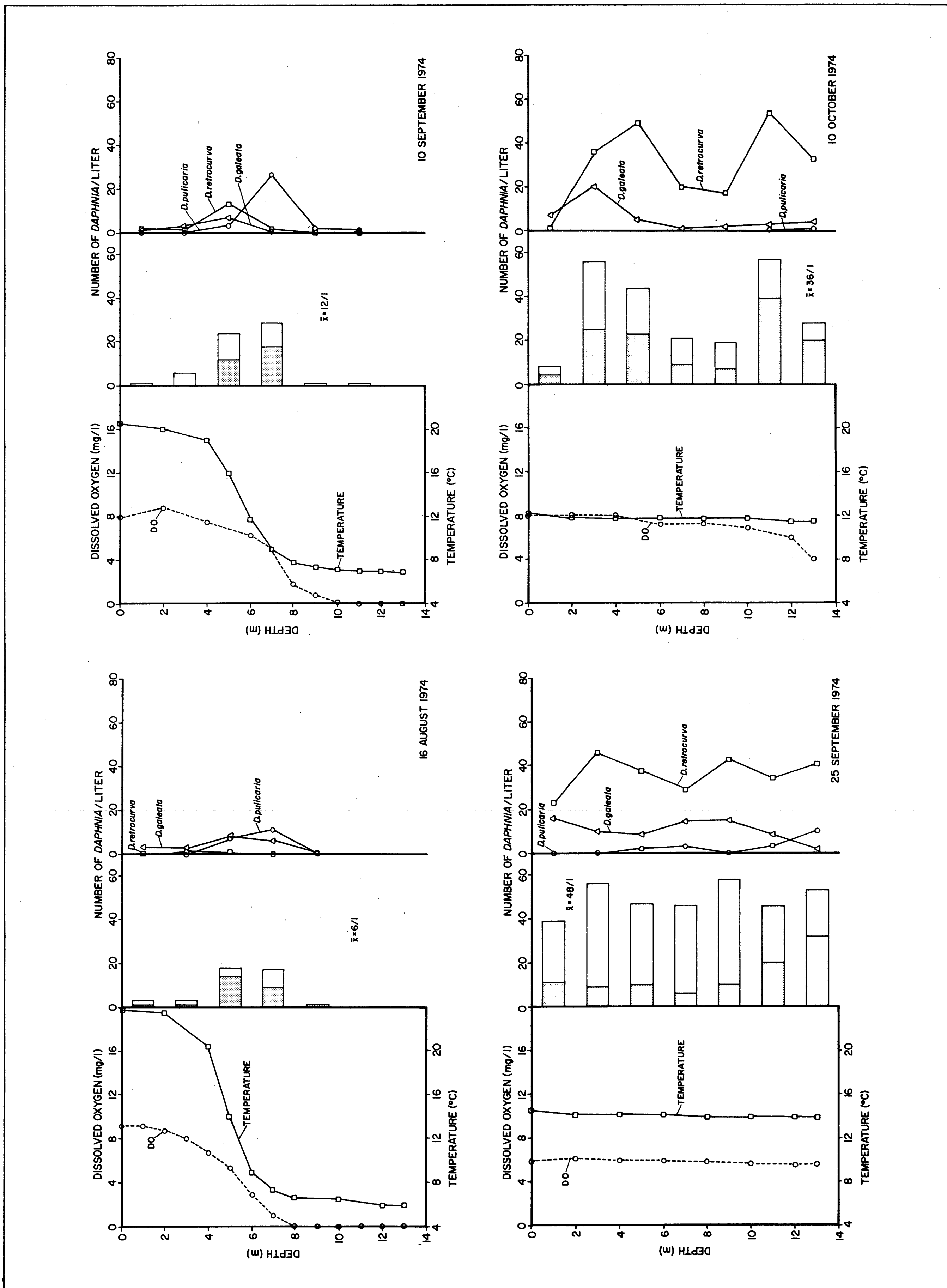


FIGURE 3. Density of *Daphnia*, water temperatures, and the levels of dissolved oxygen at various depths in Mirror Lake on given dates during 1974. Shaded areas of the histograms denote the number of *Daphnia* 1 mm and larger.

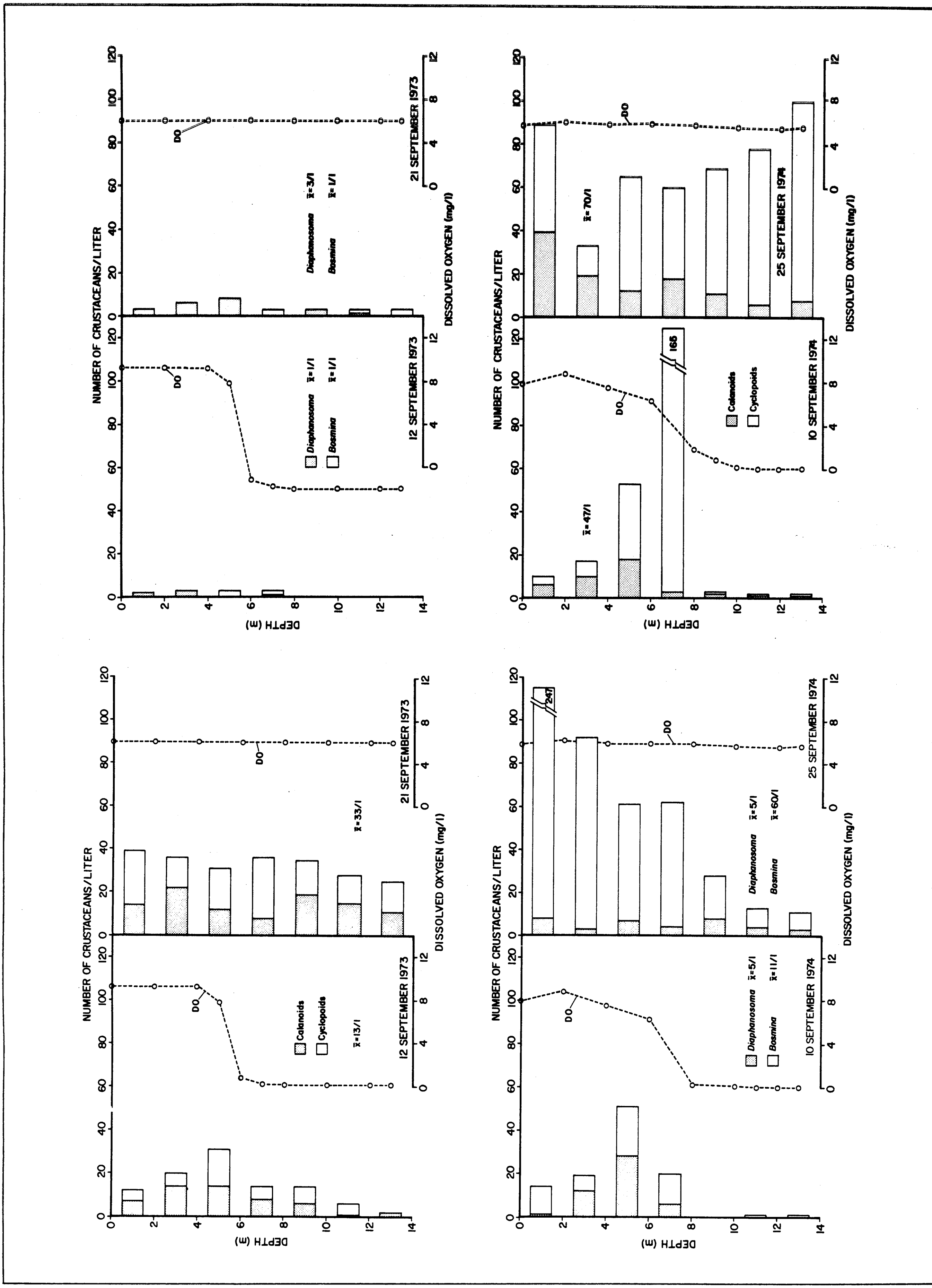


FIGURE 4. Density of four planktonic crustaceans and the levels of dissolved oxygen at various depths in Mirror Lake before and after destratification during early and late September, in 1973 and 1974, respectively.

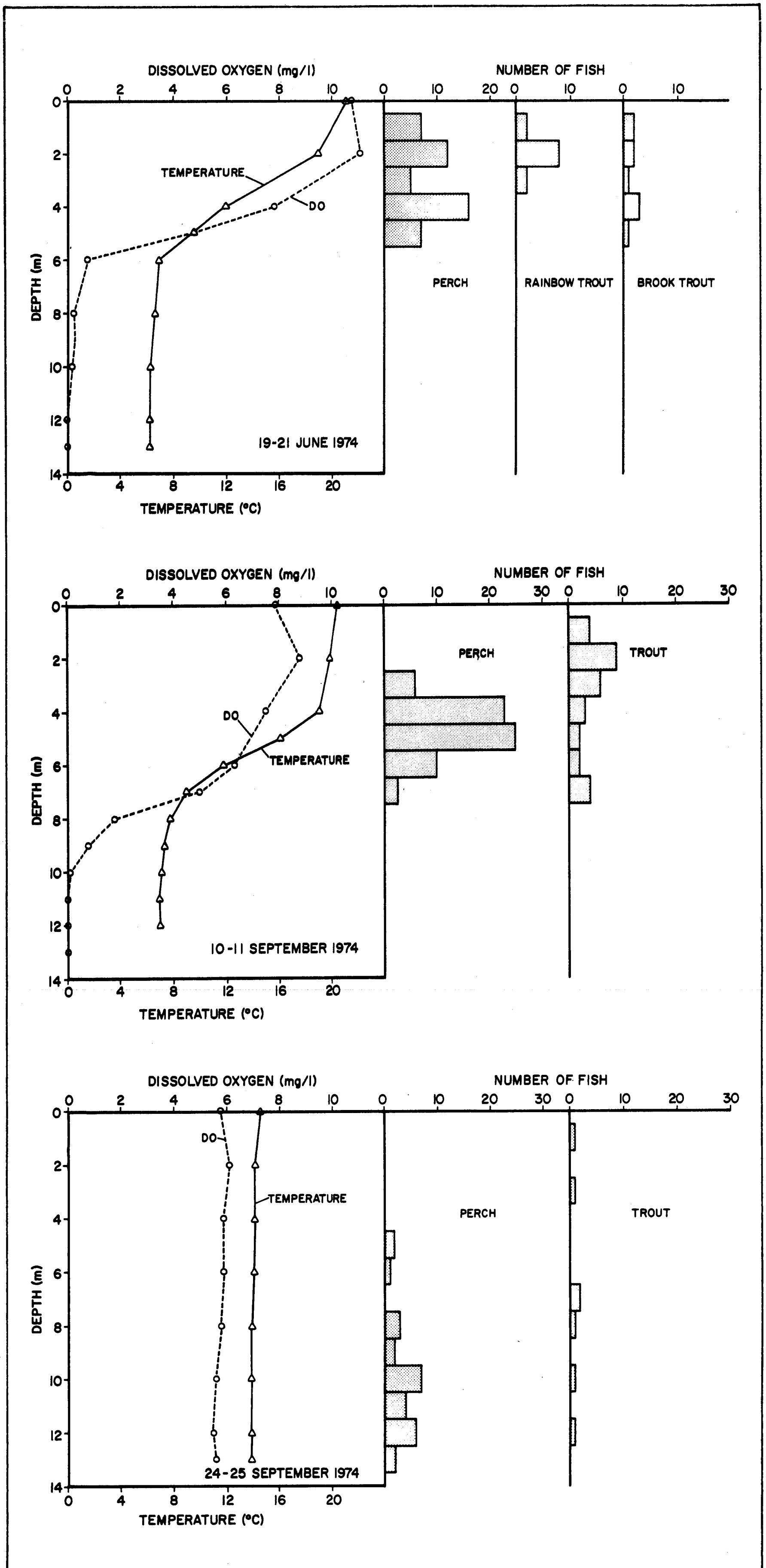


FIGURE 5. Water temperatures, dissolved oxygen, and the distribution of yellow perch and trout in Mirror Lake on given dates during 1974.

In contrast, the stomachs from the 29 yellow perch less than 20 cm in total length contained 28 percent chironomid larvae-pupae and 83 percent *Daphnia*. Only a small number of copepods (all 1 mm and larger) were found in the stomachs of yellow perch from Mirror Lake (Tables 1-2, Append.), while none were found in the stomachs of trout even though there were as many large (1 mm and larger) copepods as there were large *Daphnia* during May-June and September 1974 (Fig. 6, Append.). In Larson Lake, where the yellow perch caught in gill nets did not exceed 15 cm in total length, half the yellow perch had fed on *Daphnia parvula*, cyclopoids, and ostracods (Table 4, Append.). *D. parvula*, a small daphnid, was the only significant daphnid found in Larson Lake* and only a small number of those were 1 mm and larger (Fig. 11, Append.). The length range of the *D. parvula*, cyclopoids, and ostracods in the yellow perch stomachs was 0.8-1.0 mm, 0.8-1.2 mm, and 1.4-1.5 mm, respectively. The yellow perch caught in Mirror Lake were larger and consumed larger crustaceans than those in Larson Lake.

The 25 stomachs from domesticated brown trout (TL 14-18 cm) stocked on 5 September 1974 in Mirror Lake did not contain *Daphnia* before or after destratification. The stomachs contained mostly terrestrial insects that were dominated in early autumn by winged ants (Table 3, Append.). Stomachs from domesticated rainbow trout (TL 15-18 cm) stocked in Larson Lake on 6 September 1974, indicated that these fish, like the brown trout in Mirror Lake, had fed mostly on terrestrial insects such as ants, beetles, and adult dipterans, but not on *Daphnia* during 8-10 October, a month after release into Larson Lake (Table 4, Append.).

*One specimen each of *D. galeata* and *D. pulicaria* was found in the plankton samples taken on 9 October 1974 and one *D. galeata* was found in the samples taken on 22 January 1975.

PLANKTONIC CRUSTACEA

Hypolimnetic aeration (Smith et al. 1975) during the summer of 1973 increased the living state of planktonic Crustacea in Mirror Lake because by 12 September 1973 they were distributed throughout the lake. They were present, however, at relatively low densities at 13 m near the bottom (Figs. 1 and 4). Dissolved oxygen, although at low levels of only 0.2 mg/l at 13 m, was adequate to maintain the crustaceans because the summer hypolimnetic aeration had not increased the water temperatures in the hypolimnion above 9° C. In Larson Lake, where hypolimnetic aeration continued through 1974 and into 1975, the planktonic Crustacea were distributed from the surface to the bottom of the lake, including the dissolved oxygen-poor metalimnion of 23 July and 4 September 1974 (Fig. 11, Append.).

Daphnia and other cladocerans were lower in number, while the number of copepods was not significantly changed nor was the depth distribution of the zooplankton generally affected after destratification of Parvin Lake, Colorado (Lakey 1973). Fast (1971) reported that total zooplankton (including rotifers, ostracods and copepod nauplii) doubled in number and shifted their vertical distribution from 0-10 m to 10-24 m after destratification. By lumping the number of cladocerans and copepods collected in Mirror Lake, we find that these crustaceans increased by 60 and 156 percent after destratification in September 1973 and 1974, respectively.

The reason for the gain and loss in the numbers of *D. pulicaria* after total aeration of Mirror Lake in 1973 and 1974, respectively, is unknown. *D. pulicaria* is the largest of the four *Daphnia* collected in Mirror Lake. Because a high percentage of the individuals exceed 1 mm in length, they are, when available, the dominant *Daphnia* prey of yellow perch and trout.

TROUT AND YELLOW PERCH

Before hypolimnetic aeration reduced thermal stratification in Hemlock Lake, Michigan, rainbow trout were limited to a depth of 6 m and fed mostly on *Chaoborus*. After destratification, the trout ranged down to the bottom of the lake (18 m) and *D. pulex* became the dominant food (Fast 1973a). *D. pulicaria* was the dominant daphnid in Mirror Lake and in the yellow perch and trout stomachs during May and June (Fig. 1 and Table 1, Append.). Noble (1975) determined that the occurrence of the larger *Daphnia pulex* in the stomachs of yellow perch was approximately equal to that of the smaller *D. galeata*, although the density of *D. pulex* was only one-third that of *D. galeata* in the plankton of Oneida Lake, New York.

Results of other studies strongly indicate the importance of large (1 mm and larger) *Daphnia* in the diet of yellow perch (Galbraith 1967), European perch and roach, (Stenson 1972), brook trout (Carline et al. 1976), brown trout (Brynildson and Kempinger 1973; Nilsson and Pejler 1973), rainbow trout (Brynildson 1958; Galbraith 1967 and 1974; Brynildson and Kempinger 1970), European char (Nilsson and Pejler 1973), alewife (Brooks and Dodson 1965; Wells 1970; Hutchinson 1971; Warshaw 1972), goldfish (Archbald 1975), and whitefish (Nilsson and Pejler 1973; Seghers 1974).

Destratification of Mirror Lake in September 1974 was not only followed by an upsurge in the number of *Daphnia* per liter but also by an increase in the number that were 1 mm and larger (Fig. 3). There was no evidence of overgrazing of the *Daphnia* by planktivores during the open-water months in Mirror Lake in spite of the restricted living space (due to low dissolved oxygen levels) during the periods without artificial aeration, for example, in 1975 (Fig. 8, Append.). During the warm months, the number of *Daphnia* and copepods (that as adults equal or exceed 1 mm in length) appear to be in balance with smaller (<1 mm) and younger individuals of their species (Figs. 1-3 and 8, Append.). However, selective grazing on the adults of the larger species of *Daphnia* during the cold months could be the main cause of their rapid decline from November 1974 through January-February and up to, at least, 2 May 1975 (Fig. 7, Append.).

The first to decline in number were the *Daphnia* that do not reproduce parthenogenetically during the cold months — *D. pulicaria* and *D. retrocurva*. *D. pulicaria* was missing from the plankton collections from October 1974 to late May 1975. *D. retrocurva* declined from its late September and early October dominance (Fig. 3) to a low density on 19 November 1974 and was absent from plankton collections until 27 May 1975 (Figs. 7 and 9, Append.). *D. galeata* was absent from the 2 May 1975 plankton samples (Figs. 7 and 9, Append.). Although this daphnid was reproducing parthenogenetically on 18 November 1974, on 6 January 1975 and 18 February 1975, the egg-bearing females perhaps were grazed too severely to sustain the *D. galeata* population through the winter. The only daphnid in the plankton samples on 2 May 1975 was the small (mostly < 1 mm) and sporadically occurring *D. ambigua*. However, all daphnids except *D. pulicaria* recovered strongly by 27 May 1975 (Figs. 7 and 9, Append.) after their ephippial eggs (lying dormant in the lake during the cold months) hatched, thus producing females to begin anew the parthenogenetic generations that dominate during open water.

Hatching of the ephippial eggs apparently occurs earlier when adequate oxygen is available to the eggs in the spring. For example, total aeration of Mirror Lake began 23 March 1973 and ended 23 April 1973 (Smith et al. 1975). By 21 April, aeration had increased dissolved oxygen to at least 10 mg/l throughout the lake (Fig. 1), thus extending the living zone for fish and zooplankton. That year *D. pulicaria* was well on its spring population pulse on 21 April (Fig. 1), and the adult population was at its peak on 25 May 1973 when all the *D. pulicaria* were 1 mm or larger (Fig. 1). In contrast, no artificial aeration was initiated in Mirror Lake during the spring of 1975. That spring, as in most years, the lake failed to turn over, hence, dissolved oxygen below 5 m was not replenished, and by 2 May 1975 (Fig. 7, Append.) the lake was stratified. Without adequate oxygen, the ephippial eggs lying on the muds below 5 m probably failed to hatch, thus delaying the initial surge of the *Daphnia* spring population pulse. As a consequence, the larger *Daphnia* such as *D. galeata*, *D. pulicaria*, and *D. retrocurva* had not as yet reappeared in the lake or at least in adequate numbers to be collected in the plankton samples on 2 May 1975 (Fig. 7, Append.). Trout which are stocked in Mirror Lake each April, cannot depend on *Daphnia* for food until late May unless Mirror Lake is totally mixed by artificial aeration as in April 1973.

Fast (1973b) reported that the dissolved oxygen reserve during the winter in Hemlock Lake, Michigan, was sustained by summer hypolimnetic aeration that reduced the BOD. Halsey (1968) prevented the winterkill of trout in Corbett Lake, British Columbia, by total circulation just prior to ice-cover.

The total aeration of Mirror Lake in late fall 1972 and the winter hypolimnetic aeration in 1973 (Smith et al. 1975) helped maintain the winter supply of dissolved oxygen. Total aeration from early fall to 6 November 1973 was sufficient to maintain dissolved oxygen levels adequate for trout under ice-cover to at least 18 February 1974 (Fig. 10, Append.). That the trout survived the late winters of 1973-74 in Mirror Lake was evidenced by the relatively high catch of "carry-over" rainbow trout by anglers during May-June 1973-74. As stated under Methods, 1,000 age I rainbow trout were included in the stock of trout released into Mirror Lake each April. During May-June 1973-74, the ratio in the angler's catch was 4 recently stocked age I rainbow trout to 1 carry-over age II rainbow trout, which by May had grown to 36-41 cm in total length and still were feeding primarily on *Daphnia*.

SUMMARY AND MANAGEMENT IMPLICATIONS

After destratification of Mirror Lake in late September 1974, trout and yellow perch and their primary prey, *Daphnia*, occupied the entire lake. Before destratification, they were limited mainly to the upper half of the lake because of low dissolved oxygen levels in the hypolimnion.

The *Daphnia* did not increase in number after destratification in September 1973; however, they increased four-fold in number after destratification in September 1974. The density of calanoid and cyclopoid copepods increased during both years after destratification. There was no significant change in the density of the cladocerans, *Bosmina* and *Diaphanosoma*, after destratification during either year.

Total aeration of Mirror Lake during the spring hastened the *Daphnia pulicaria* spring population pulse and increased their living space and the living space of their primary predators, the trout and yellow perch. Total aeration into late fall of 1973-74 helped to maintain higher levels of dissolved oxygen through February, the critical month for winterkill of fish in Mirror Lake. During both years, trout carried-over the winter and anglers were able to catch lake-grown trout as well as recently stocked smaller trout.

Total aeration of Mirror Lake in the spring and fall (when water density is nearly equal throughout the lake) is the most efficient and rapid method to expand the dissolved oxygen content of its water, and hence, the living space for trout and yellow perch and their aquatic food. Although holomixis is evident in Larson Lake in spring and fall, the duration of turnover in the spring is short and stratification occurs early due to rapid warming of the brown-stained surface waters, thus oxygen demand outstrips dissolved oxygen input. By midsummer the dissolved oxygen-rich, but shallow, epilimnion is too warm for the larger limnetic *Daphnia* found in Wisconsin, while the cooler, shallow metalimnion and the cold deep hypolimnion are dissolved oxygen-poor or anoxic.

Prolonged total aeration in the spring augmented by intermittent hypolimnetic aeration during the summer may be needed for dark-stained bog lakes such as Larson Lake to maintain the larger species of *Daphnia* utilized by trout and yellow perch for food.

TABLE 1. *Contents of stomachs from trout and yellow perch captured in Mirror Lake, May-June 1973-74.*

Food Items	**Brook Trout** (TL 23-27 cm) 24 Stomachs - 17,416 Food Items		**Rainbow Trout** (TL 23-41 cm) 30 Stomachs - 30,032 Food Items		**Yellow Perch** (TL 15-18 cm)* 12 Stomachs - 23,352 Food Items	
	Percentage of Stomachs Containing Food Item	Percentage of Total Food Items in Stomachs	Percentage of Stomachs Containing Food Item	Percentage of Total Food Items in Stomachs	Percentage of Stomachs Containing Food Item	Percentage of Total Food Items in Stomachs
Daphnia	100.00**	99.8	96.7**	99.7	100.0	99.8
Calanoid copepods	0.0	–	0.0	–	33.3	0.2
Cyclopoid copepods	0.0	–	0.0	–	8.3	X
Chaoborus larvae	16.7	X	10.0	X	50.0	X
Chironomid larvae	25.0	0.1	36.7	0.2	0.0	–
Mayfly nymphs	0.0	–	0.0	–	10.0	X
Terrestrial insects	12.5	0.1	20.0	0.1	0.0	–
Snails	0.0	–	10.0	X	0.0	–

*Yellow perch were all captured in vertical gill nets in June, 1974; while trout were captured by hook and line (72%) and vertical gill nets.
**Both *D. galeata mendotae* and *D. pulicaria*, but mostly large (1.0-2.0 mm) *D. pulicaria.*
X Indicates trace of food item in stomachs.

TABLE 2. *Contents of stomachs from yellow perch* captured in vertical gill nets set in Mirror Lake 10-11 September 1974, before destratification, and 25-26 September 1974, after destratification.*

Food Items	**Before Destratification** 19 Stomachs - 20,795 Food Items		**After Destratification** 21 Stomachs - 2,180 Food Items	
	Percentage of Stomachs Containing Food Item	Percentage of Total Food Items in Stomachs	Percentage of Stomachs Containing Food Item	Percentage of Total Food Items in Stomachs
*Daphnia***	89.5	98.0	52.4	93.6
Leptodora kindtii	0.0	–	23.8	0.3
Epischura lacustris	0.0	–	5.2	2.3
Other calanoids	0.0	–	9.5	1.4
Cyclopoids	0.0	–	19.0	1.1
Chaoborus larvae-pupae	15.7	X	4.8	X
Chironomus larvae-pupae***	31.6	2.0	61.9	1.3

*Total length range 15-26 cm.
***D. galeata mendotae, D. pulicaria,* and *D. retrocurva.*
****C. plumosus* and *C. attenuatus*, but *C. plumosus* was dominant.

TABLE 3. *Contents of stomachs from brown and rainbow trout* captured in vertical gill nets set in Mirror Lake 10-11 September 1974, before destratification, and 25-26 September 1974, after destratification.*

	Before Destratification 21 Brown and 2 Rainbow Trout - 481 Food Items		**After Destratification** 4 Brown and 2 Rainbow Trout - 322 Food Items	
Food Items	Percentage of Stomachs Containing Food Item	Percentage of Total Food Items in Stomachs	Percentage of Stomachs Containing Food Item	Percentage of Total Food Items in Stomachs
*Daphnia pulicaria***	8.7	26.0	0.0	–
Chaoborus larvae-pupae**	17.4	3.1	16.7	49.7
Chironomus larvae-pupae	17.4	1.7	66.7	35.7
Corixidae	4.3	0.2	33.3	1.6
Notonecta undulata	8.7	0.5	0.0	–
Terrestrial insects**	91.3	68.4	50.0	12.7
Fish	0.0	–	16.7	0.3

*Total length ranges of brown and rainbow trout were 14-18 cm and 32-33 cm, respectively.
**Only brown trout stomachs contained terrestrial insects; while *Daphnia* and *Chaoborus* were found only in the rainbow trout stomachs.

TABLE 4. *Contents of stomachs from yellow perch and rainbow trout captured in vertical gill nets set in Larson Lake 8-10 October 1974.*

	Yellow Perch (TL 13-15 cm) 16 Stomachs - 192 Food Items		**Rainbow Trout** (TL 15-18 cm) 16 Stomachs - 174 Food Items	
Food Items	Percentage of Stomachs Containing Food Item	Percentage of Total Food Items in Stomachs	Percentage of Stomachs Containing Food Item	Percentage of Total Food Items in Stomachs
Daphnia parvula	31.2	9.9	0.0	–
Cyclopoids	18.8	1.6	0.0	–
Ostracods	12.5	2.6	0.0	–
Chaoborus larvae-pupae	56.2	78.6	6.2	0.6
Chironomid larvae-pupae	37.5	6.8	43.8	9.8
Chironomid adults	0.0	0.0	18.8	8.6
Notonecta undulata	0.0	0.0	12.5	1.7
Corixidae	6.2	0.5	0.0	–
Terrestrial insects	0.0	–	68.8	79.3

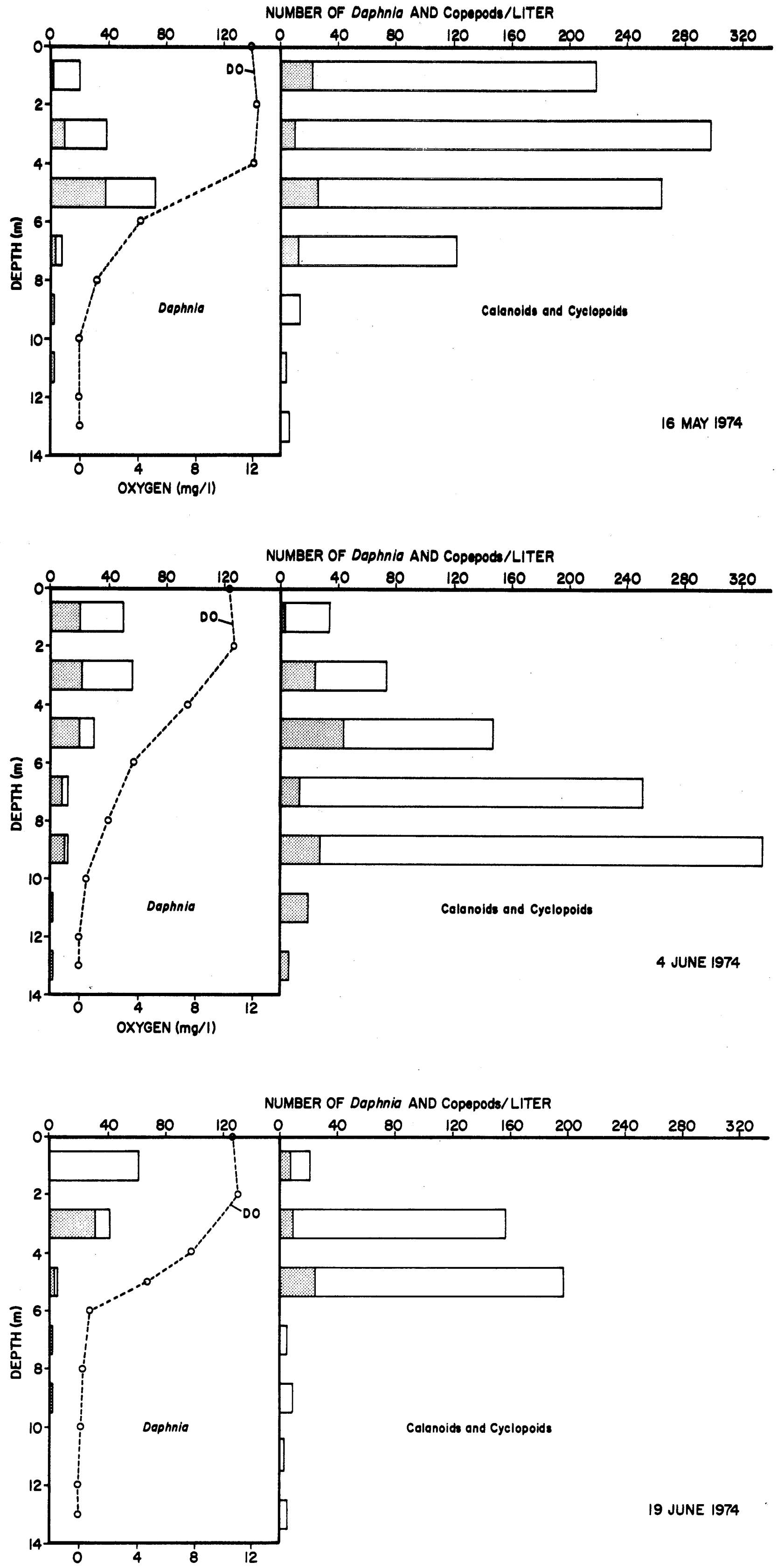
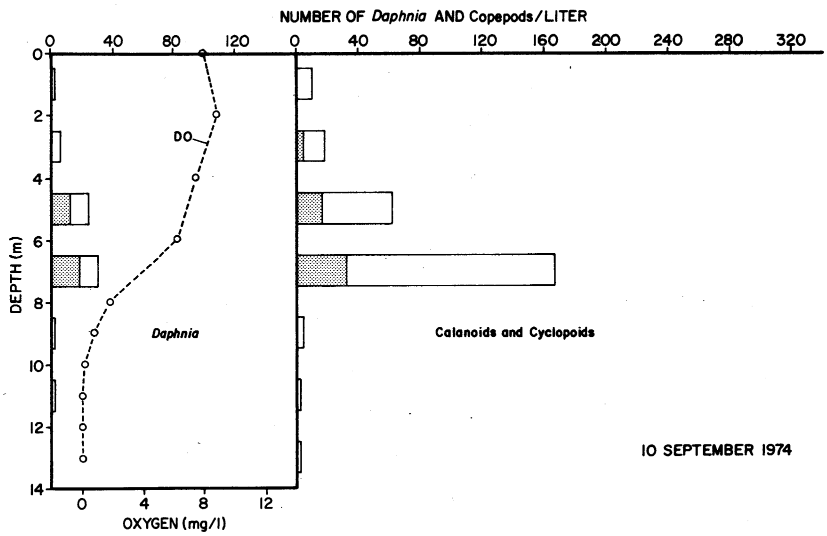


FIGURE 6. Dissolved oxygen and the distribution and density of *Daphnia* and copepods in Mirror Lake on given dates during 1974. Shaded areas of the histograms denote the number of *Daphnia* and copepods 1 mm and larger.



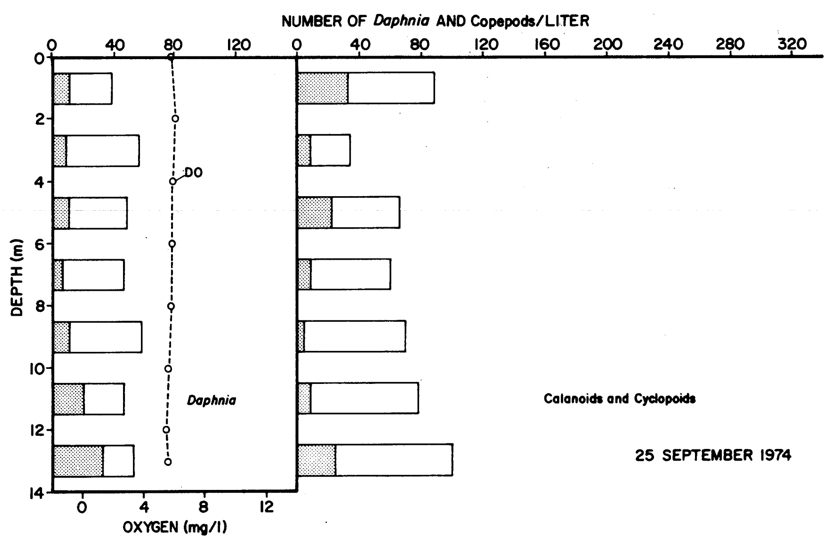


FIGURE 6. Continued.

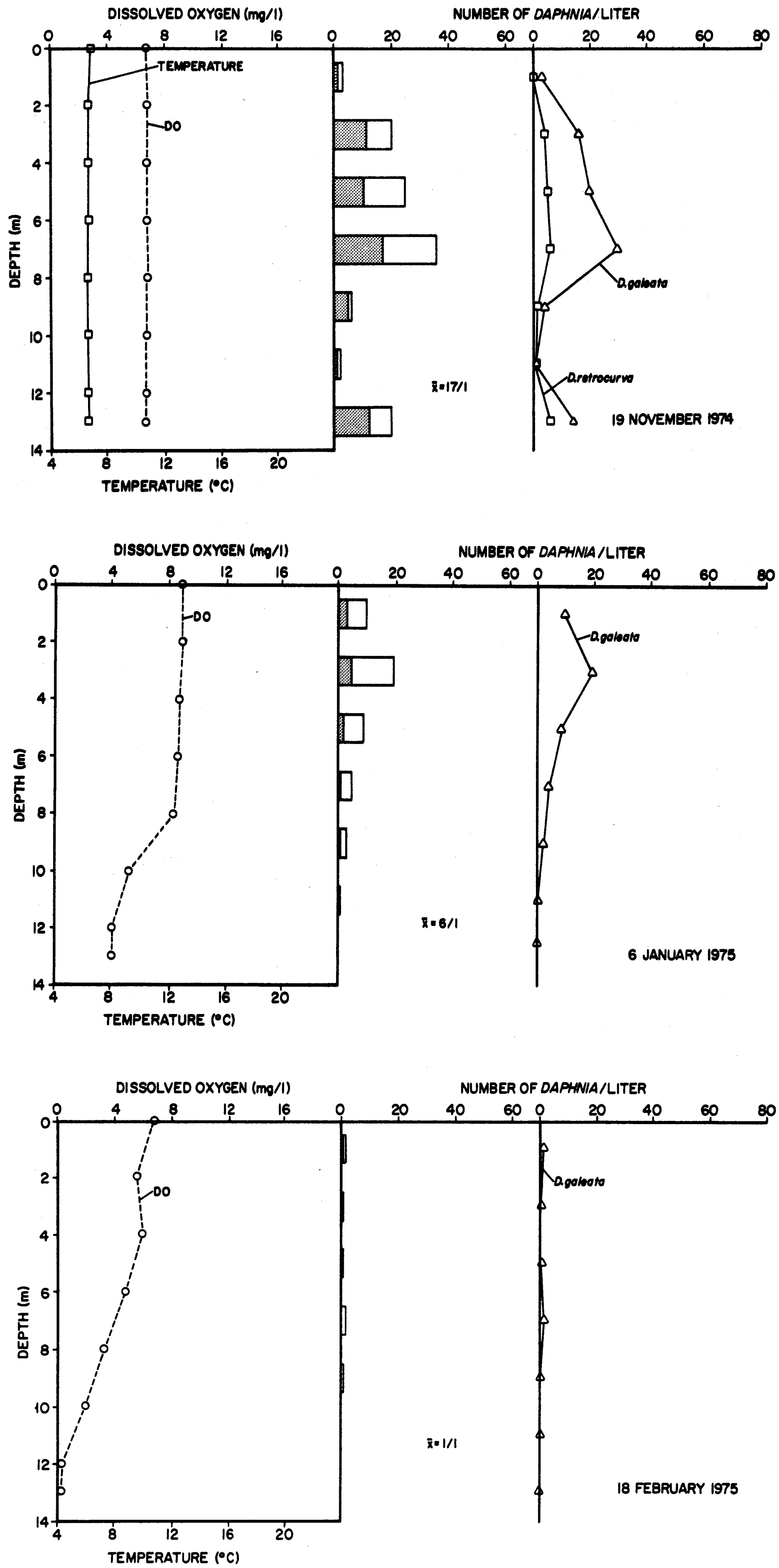


FIGURE 7. Density of *Daphnia*, water temperatures, and the levels of dissolved oxygen at various depths in Mirror Lake on given dates during 1974-75. Shaded areas of the histograms denote the number of *Daphnia* 1 mm and larger.

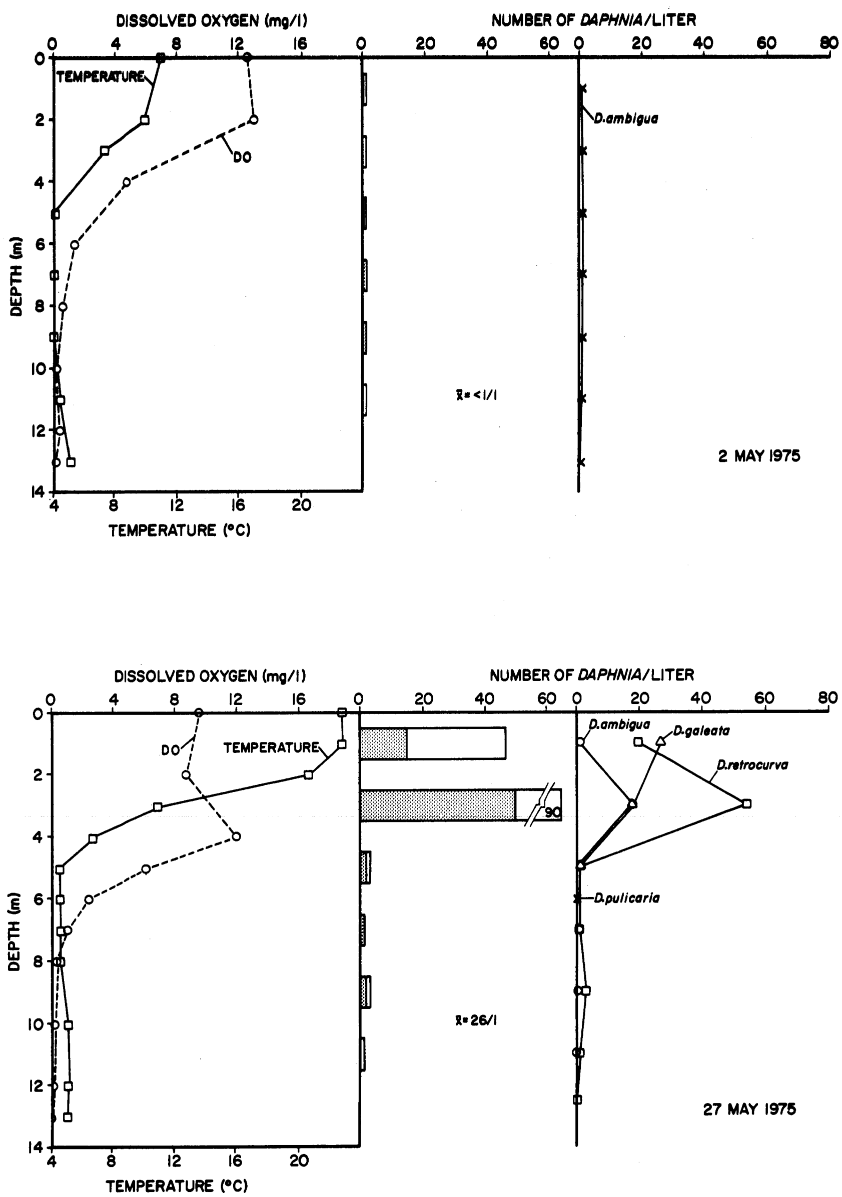


FIGURE 7. Continued.

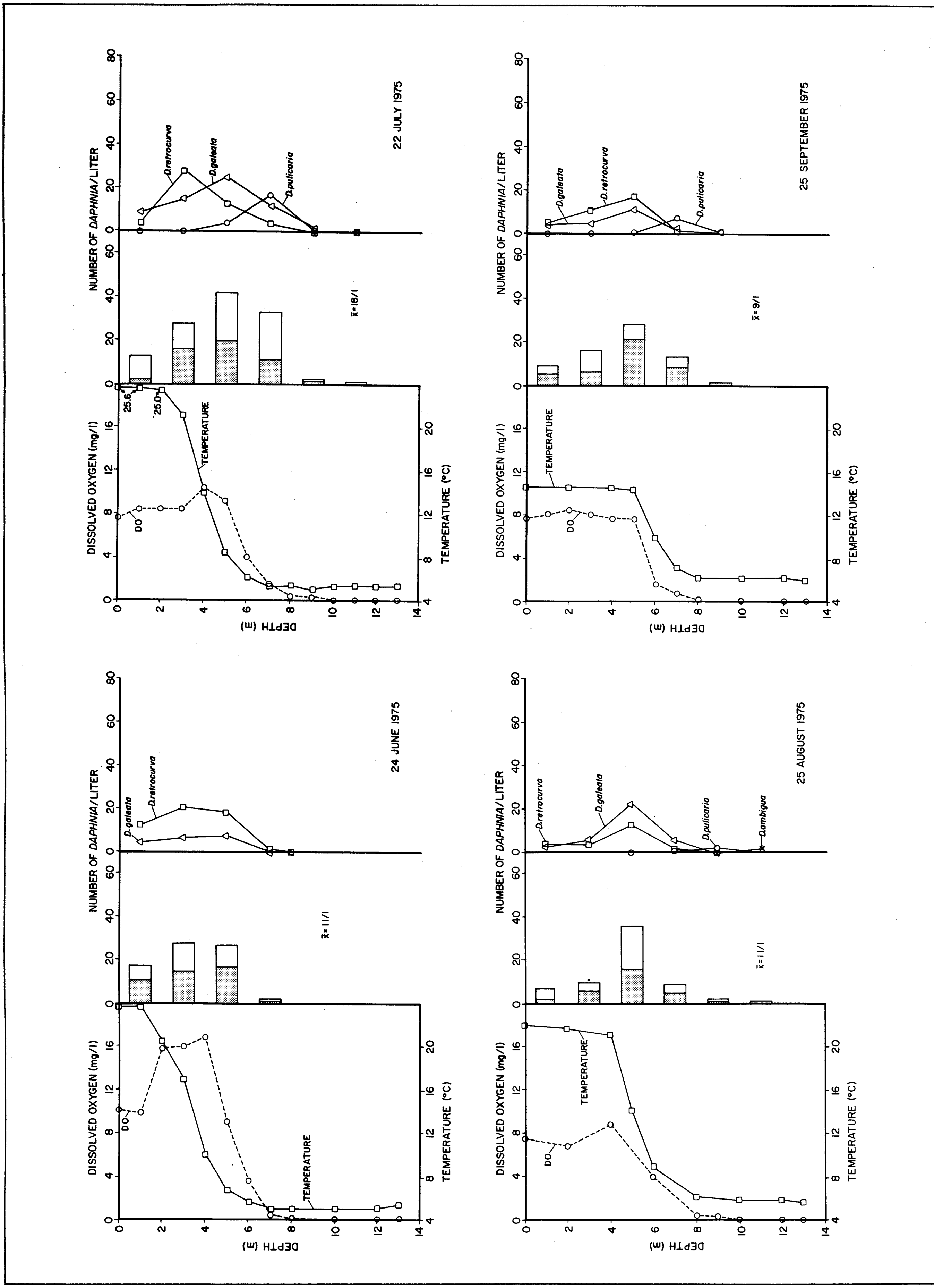


FIGURE 8. Density of *Daphnia*, water temperatures, and dissolved oxygen at various depths in Mirror Lake on given dates during 1975. Shaded areas of the histograms denote the number of *Daphnia* 1 mm and larger.

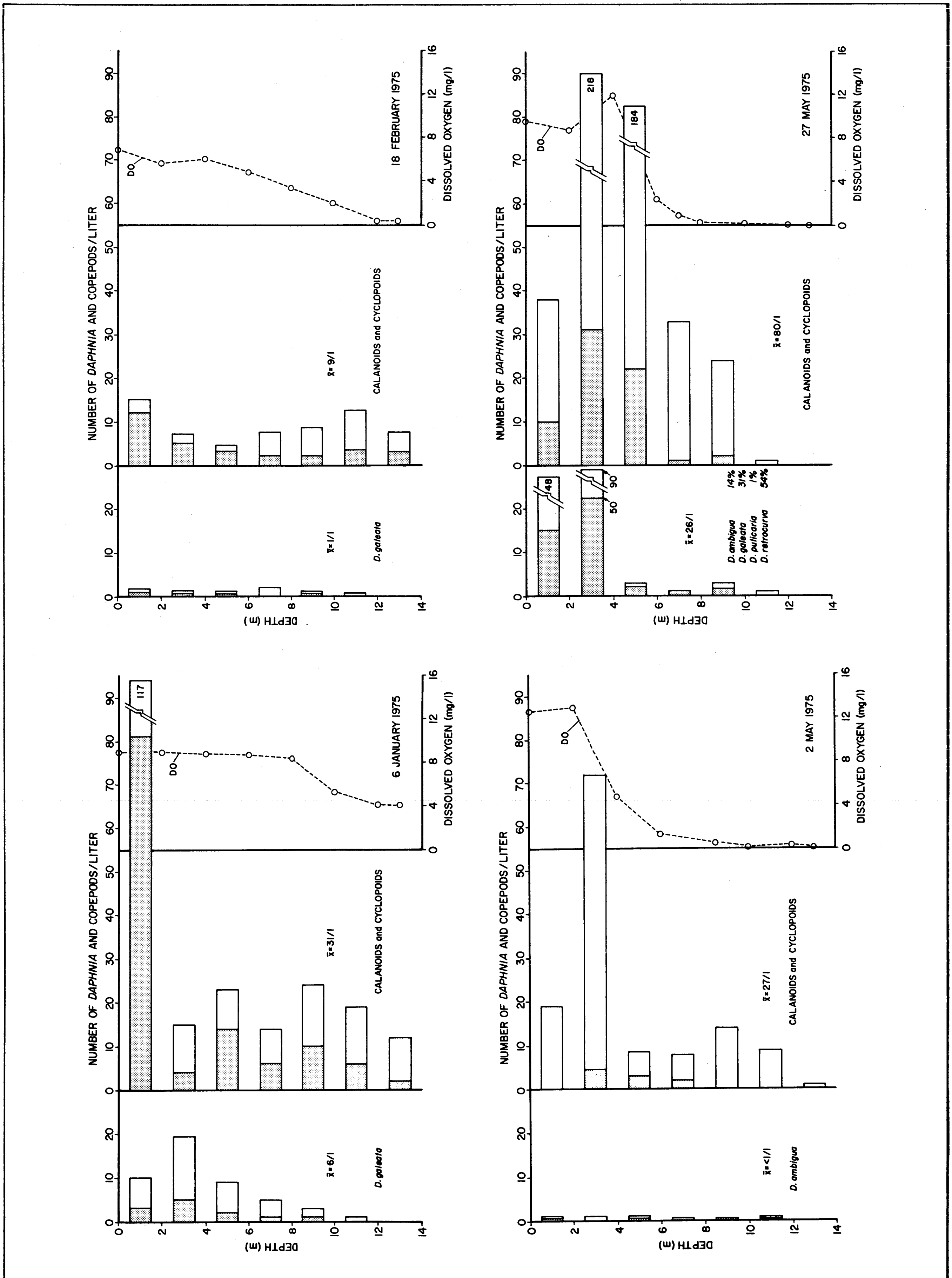


FIGURE 9. Dissolved oxygen and the distribution and density of *Daphnia* and copepods in Mirror Lake on given dates during 1975. Shaded areas of the histograms denote the number of *Daphnia* 1 mm and larger.

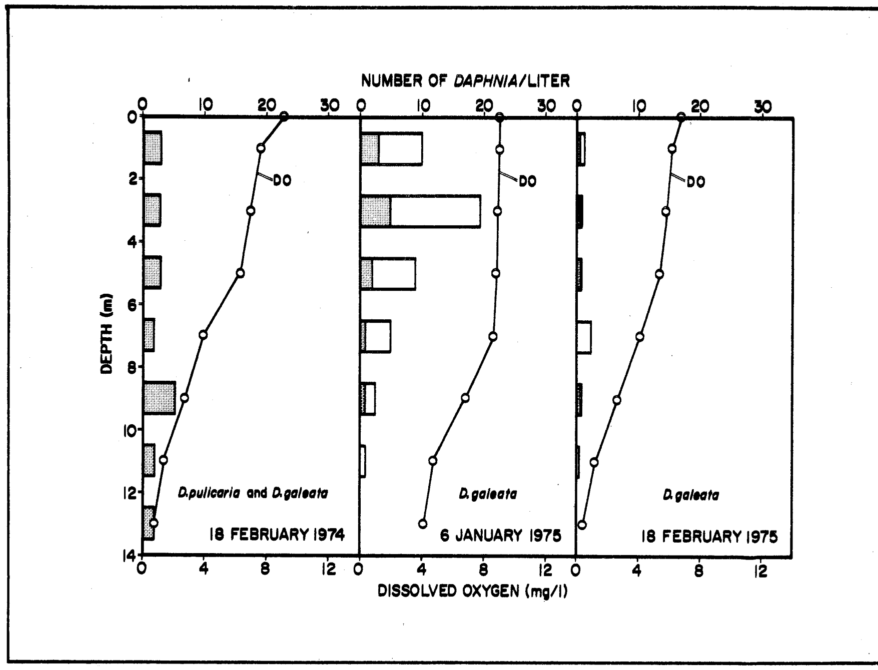


FIGURE 10. Dissolved oxygen and the distribution and density of *Daphnia* in Mirror Lake during ice-cover in January and February in 1974 and 1975. Shaded areas of the histograms denote the number of *Daphnia* 1 mm and larger.

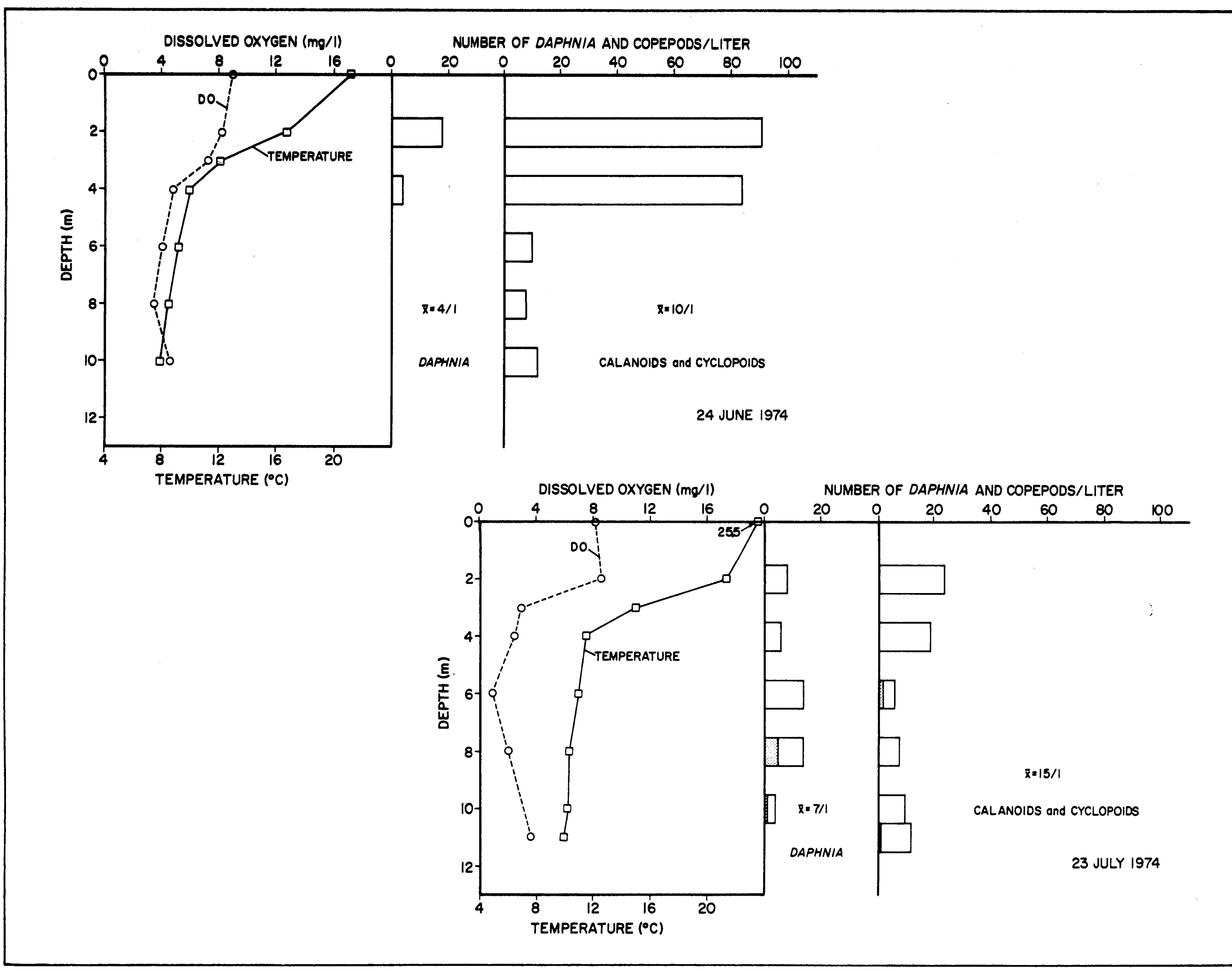


FIGURE 11. Dissolved oxygen, water temperatures, and the density and distribution of *Daphnia* and copepods in Larson Lake on given dates during 1974-75. Shaded areas of the histograms denote the number of *Daphnia* and copepods 1 mm and larger.

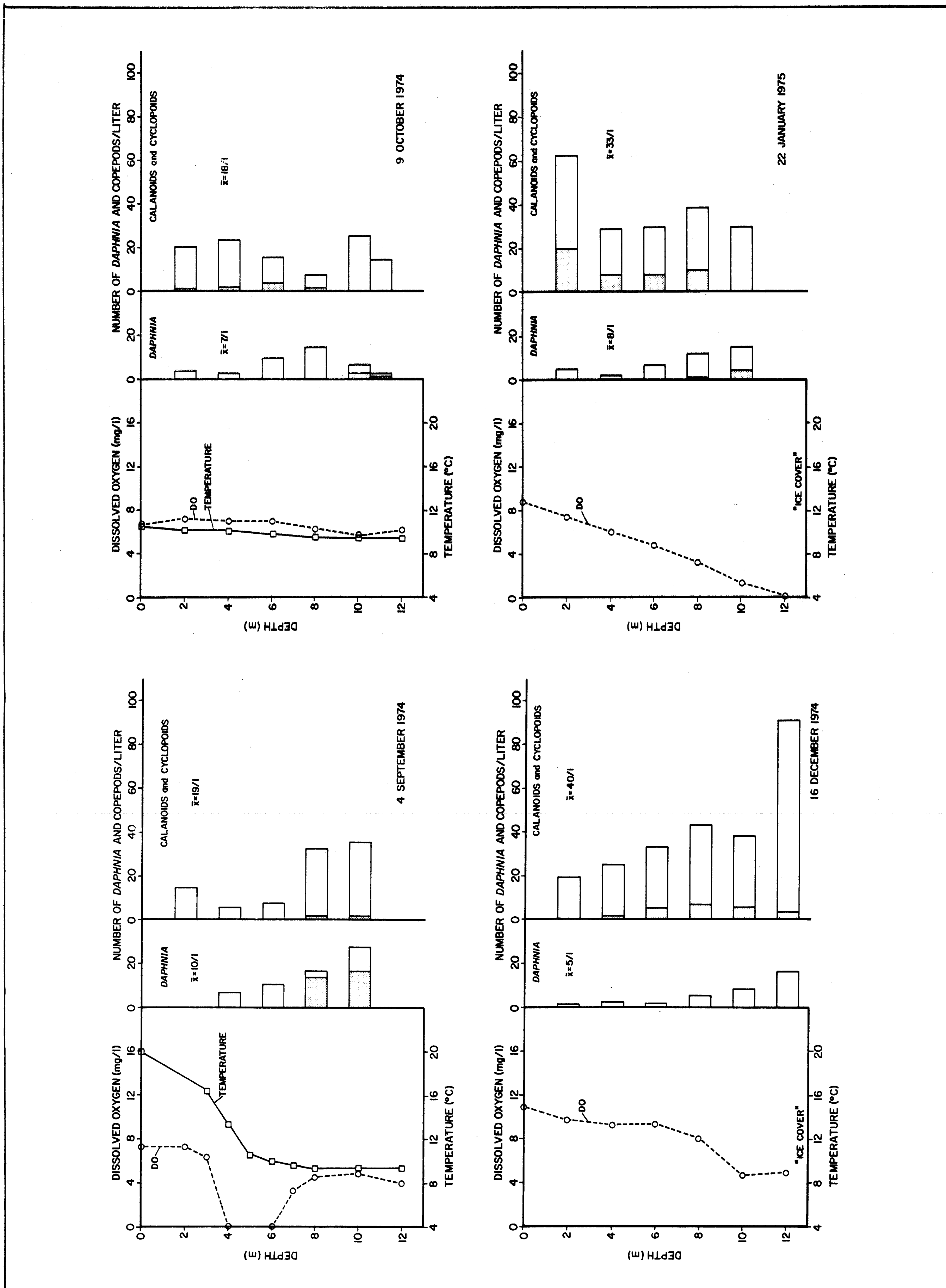


FIGURE 11. Continued.

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