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UNIVERSITY OF ALBERTA

RESPONSE OF PELAGIC ZOOPLANKTON TO HYPOLIMNETIC OXYGENATION IN AMISK LAKE, ALBERTA

BY

KELLY FIELD ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

DEPARTMENT OF ZOOLOGY

Edmonton, Alberta
SPRING 1993

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ISBN 0-315-82139-6

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduates Studies and Research for acceptance, a thesis entitled RESPONSE OF PELAGIC ZOOPLANKTON TO HYPOLIMNETIC OXYGENATION IN AMISK LAKE, ALBERTA submitted by KELLY FIELD in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

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Date 22 Mar 93

Abstract

In June 1988, hypolimnetic oxygenation began in the north basin of naturally eutrophic Amisk Lake, while the south basin was untreated and served as a reference system. To examine the effect of hypolimnetic oxygenation on the pelagic zooplankton, I sampled zooplankton in treatment and reference basins with a Plexiglas trap, and with plankton nets. From May to September 1989, dissolved oxygen (DO) concentrations were > 1 mg/L in the hypolimnion of the treatment basin, but DO concentrations fell to < 1 mg/L in the reference basin in early July, as they had historically in the treatment basin. In summer 1989, three zooplankton species were primarily epilimnetic (*Daphnia galeata mendotae*, *Diaptomus oregonensis*, *Acanthocyclops vernalis*) and two species were primarily hypolimnetic (*Daphnia longiremis*, *Bosmina longirostris*). In addition, *Daphnia pulex* and *Diacyclops bicuspidatus thomasi* had bimodal distributions from July to September; I examined the epi- and hypolimnetic populations of these two species separately. There were no apparent treatment effects on distribution, abundance or biomass of zooplankton in the epilimnion (0 to 10 m). However, from July to September 1989, the four zooplankton species in the hypolimnion were generally found at significantly greater depths (as median depth) ($P < 0.001$) at the Treatment than at the Reference site. In addition, during this period, the median depths of hypolimnetic zooplankton tracked species-specific DO concentrations of between 1.5 and 2.5 mg/L. Coincident with enhanced DO concentrations in the treatment basin in August, *D. longiremis* exhibited vertical diel migration at the Treatment site (median depth day versus night, $P < 0.001$, median migration 4 m), but not at the Reference site ($P > 0.9$, median migration 0 m). In summer 1989, abundances of two of four zooplankton species (*D. longiremis* and *D. pulex*) were significantly higher ($P = 0.02$, 0.03, respectively) in the hypolimnion at the Treatment site than at the Reference site. Abundances of hypolimnetic *D. longiremis* and *D. pulex* were also substantially higher at the Treatment site in summer 1989 than at this site in summer 1984 (four years before oxygenation). In summary, hypolimnetic oxygenation enhanced DO concentrations in the deep hypolimnion of the treatment basin, and of the four dominant hypolimnetic zooplankton species: (1) four species moved down to the deep hypolimnion, (2) one species expanded its amplitude of diel vertical migration, and (3) two species increased in abundance.

Acknowledgements

I am grateful for the support, insight, and encouragement provided to me by Dr. E.E. Prepas during this thesis program. I also thank Dr. Prepas for permission to use unpublished data.

I would like to thank everyone who augered, hauled, rowed or otherwise made fieldwork much easier: K. Bowers, J. Burke, P. Dinsmore, S. Hagen, K. Rimney, C.L.K Robinson, N.C. Robinson, M. Seridiak, and D. Webb. Thanks also go to G. Hutchinson for assistance in the lab and for helping me find "long-lost" sampling equipment and supplies. J. Burke, K. Gibson, and R. Madro helped with the drafting of figures. Thanks to C. Walker, who had all the answers to my questions about Departmental policy and photocopy machines!

Research facilities were provided at the University of Alberta's Meanook Biological Research Station, and I would like to thank the station manager, K. Keglovitch, for running a tight ship!

My thesis committee, Dr. W.M. Tonn, Dr. W.G. Evans and Dr. D.W. Schindler offered helpful advice during the study. I also appreciate the critical reviews of parts of this thesis provided by P. Aku, J.M. Hanson, H. Hop, and D. Webb.

Finally, I give thanks to Janice, who was always there with an encouraging word.

Financial support for this study was provided by Alberta Environment, Alberta Fish and Wildlife (Bucks for Wildlife Fund), the Boreal Institute for Northern Studies (Boreal Alberta Research Grant to the author), Limnofix, the National Hydrology Research Institute, the National Water Research Institute, the Natural Sciences and Engineering Research Council of Canada (Operating and University Industry Grants to Dr. E.E. Prepas), and Praxair.

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I. General Introduction

Oxygen and temperature may well be the most important of all limnological parameters; oxygen is utilized in the metabolism of all aerobic organisms, and temperature is an important regulator of most physiochemical processes, and therefore of the productivity of aquatic systems (Wetzel 1983). Not surprisingly, considerable research has thus been conducted on the influences of these variables on an enormous number of marine and freshwater organisms, including zooplankton. Zooplankton play an important role in aquatic systems, as they transfer energy from the primary producers to higher trophic levels, such as many species of commercially important fishes (McCleod 1971, Makarewicz 1985). Natural or induced variations in dissolved oxygen (DO) concentration and/or temperature may have substantial effects on the distribution and abundance of zooplankton through the modification of individual behavior and physiology. The initiation of a hypolimnetic oxygen injection project at Amisk Lake in June, 1988, provided an opportunity to examine the effects of enhanced hypolimnetic DO concentrations and water temperatures on the pelagic zooplankton community.

A. Effects of Oxygen Stress on Zooplankton

The effect of DO concentration on the respiration of many zooplankton taxa (especially *Daphnia*) is well studied. There is always a specific DO concentration below which respiration rates decline rapidly (Peters 1987). This critical point appears to vary among species, within a species among habitats, and even among clones of a species from a single habitat. Generally, pond zooplankton appear to be more tolerant of low DO concentrations than their lake counterparts (Herbert 1954); the higher hemoglobin content in pond morphs likely gives them this added tolerance (Peters 1987). *Daphnia galeata mendotae*, for example, is very sensitive to low DO concentrations; the respiration rate is approximately linearly dependent on ambient oxygen conditions (Heisey and Porter 1977). The threshold DO concentration for *D. magna* is given as 3 mg /L by Heisey and Porter (1977), but Kobayashi and Hoshi (1984) list the critical value of this species as 0.5 to 0.9 mg/L, depending upon the hemoglobin content of the individual. Conflicting results such as these may be due to differing experimental methodologies, such as the temperature at which animals were cultured, and/or the length of time the animals spent in acclimation to near-anoxic conditions prior to the experimental run (Peters 1987). However, these discrepancies in specific tolerances to low DO concentrations may also reflect actual genetically determined physiological differences among clonal genotypes For example, three clones of *D. pulex* from a eutrophic farm pond differed in their relative abilities to produce hemoglobin, and thus, to regulate rates of respiration The higher hemoglobin content of two clones, coupled with long experimental acclimation times, resulted in significantly lower lethal DO concentrations (i.e the DO concentration at which 50% of the animals died) of 0.17 and 0.19 mg/L, respectively, compared with a lethal DO concentration of 0.34 mg/L for a third clone (Weider and Lampert 1985) Hemoglobin does appear to offer individuals an advantage in survivorship and reproduction, but only below some threshold DO concentration, or one should observe high hemoglobin concentrations in all *Daphnia* (Fox et al. 1950).

Low ambient DO concentrations will also limit zooplankton grazing rates During summer stratification, grazing of cladoceran and copepod species may be restricted to strata where the DO concentration is greater than 1 mg/L (Haney 1973). When the ambient DO concentration was decreased in a laboratory experiment, the filtering rate of *D. pulex* initially decreased rapidly below a threshold of 3 mg/L. However, with acclimation at low DO concentrations and subsequent hemoglobin production over 15 days, the filtering rate remained constant down to 0.8 mg/L (Kring and O'Brien 1976).

Abundance and biomass may be impacted by variation in DO concentration. The biomass of crustacean zooplankton declined substantially after experimental fertilization of a northern Ontario lake, likely due to a combination of high epilimnetic pH (occasionally > 10) and anoxia in the metalimnion and hypolimnion (Malley et al. 1988).

In addition to modifying zooplankton physiology, vertical oxygen gradients can have a substantial effect on the vertical distribution and migration of marine and freshwater zooplankton. In a laboratory experiment on the effects of DO concentration on zooplankton distribution, Langford (1938) observed that most of the individuals of populations of *Daphnia magna* and *Cyclops bicuspidatus* (i.e *Diacyclops bicuspidatus thomasi*) "moved from regions of low to high dissolved oxygen content." In Bear Lake, Colorado, more than 85% of the population of *Daphnia longispina* was located above approximately the 1 mg/L dissolved oxygen isopleth, whereas *D. longispina* distributed much deeper and showed more pronounced diel vertical migration, in the well-oxygenated hypolimnetic waters of nearby Big and Grand lakes (Pennak 1944). In eutrophic Drowned Bog Lake, Ontario, *Daphnia*, *Diaptomus* and *Cyclops* were restricted to the upper 3 m by hypolimnetic anoxia, but in nearby oligotrophic Hall's Lake, these taxa were distributed throughout the well-oxygenated 50-m water column (Haney 1973). In Crystal Lake, Ontario, the peak density of *Mysis relicta* was generally located at a depth just above the 1 mg/L dissolved oxygen isopleth, and subsequent laboratory experiments confirmed a 16-h LC_{50} value of 1 mg/L dissolved oxygen (Sherman et al. 1987).

Some marine zooplankton populations may be less sensitive to low DO concentrations than their freshwater relatives. In the northern Arabian Sea, small populations of the calanoid copepods *Eucalanus bungii* and *Rhincalanus nasutus* were noted at a DO concentration of 0.15 mg/L (Vinogradov 1968). Several of the species observed in the oxygen minimum of the eastern Pacific Ocean undergo diel migrations whereby they encompass DO concentrations from 0.2 to 5.0 mg/L, and the peak abundance of populations of *Calanus helgolandicus* at all thirteen sampling stations was recorded at depths where the DO concentration was between 0.2 and 1.0 mg/L (Longhurst 1967). Longhurst (1967) suggested that these populations are either resting stocks that remain in the oxygen minimum for a long time period, or actively migrating stocks that spend only their daytimes at this greater depth. In the eastern Pacific Ocean off the coast of Peru, zooplankton aggregated a few meters above the 0.1 mg/L dissolved oxygen isopleth, and at least one species, *Eucalanus inermis*, concentrated within anoxic waters for at least four hours before migrating up to oxygenated water (Judkins 1980).

B. Effects of Water Temperature on Zooplankton

Considerable attention also has been given to the influence of water temperature on the physiology of zooplankton. *Daphnia* are essentially eurythermal animals (Peters 1987). For example, *D. pulex* and *D. magna* can be cultured successfully at all temperatures between 5 and 35°C (Goss and Bunting 1983). In the laboratory, *D. pulex* and *D. longispina* may be active indefinitely in 1°C water, and the lower temperature limit also appears to be between 0 and 1°C for many other northern and cold adapted species (Brown 1929). There also appear to be species-specific upper limits at temperatures above 35°C (Goss and Bunting 1983). Coker (1934) found that at a critical high temperature, *Cyclops vernalis* (i.e. *Acanthocyclops vernalis*) entered a state of dormancy; the temperature at which this species entered dormancy was lower for animals raised at lower temperatures, and acclimation at a new temperature after development did not change this result.

Most studies on the effect of water temperature on filtering rates (i.e. rates of food ingestion) have generated curves with optimum temperatures, often with peaks at temperatures between 15 and 20°C (Kibby 1971; Kersting 1978). However, the slopes of the curves, and the optimum temperatures, have varied among species (Lampert 1987). In one study, filtering rates of *D. pulex* and *D. schødleri* peaked at 20°C, whereas those of *D. galeata mendotae* and *D. magna* increased through the experimental range (15 to 25° C) (Burns 1969). McMahon (1965) also found that filtering rates for *D. magna* began to decrease after a peak at 24°C, and then dropped off sharply at 33°C. The optimum may be altered by acclimation, at least in some species. The optimum temperature for *D. rosea* was 20°C after culture at this temperature (Burns and Rigler 1967), but filtering rates peaked at 14°C after culture at 12°C for two months (Kibby 1971). Filtering rates of *D. middendorffiana* from cold-water field populations peaked at 12°C (Chisholm et al. 1975).

The respiration rates of *Daphnia* increase over most of the viable range of temperatures (Kobayashi 1974; Goss and Bunting 1980), thus at higher water temperatures *Daphnia* require a greater ambient DO concentration (Hoshi et al. 1978).

Development rates are generally positive functions of temperature for *Daphnia* and *Cyclops* (McClaren 1963; Bottrell et al. 1976; Hebert 1978). Development rate in *Daphnia pulex*, for example, increases proportionally with temperature (Goss and Bunting 1983). However, *Daphnia magna* may have a growth peak between 15 to 25°C (Kersting 1978).

Generally, sizes at maturity of *Daphnia* and *Cyclops* are negatively correlated with temperature, although there is much scatter in the relationships (McLaren 1963). The size of *Cyclops vernalis* (i.e. *Acanthocyclops vernalis*) may be related to the temperature at which the animals mature. Animals cultured at 9°C were larger than those raised at 19°C, which were, in turn, larger than those reared at 29°C, and there was almost no overlap in size-frequency distributions among the three groups (Coker 1934).

There appear to be species-specific optimum temperatures for fecundity among zooplankton. The number of eggs per individual peaked at between 15 and 20°C in *Daphnia pulex* and *D. magna* (Lei and Armitage 1980), and at 21°C in *Cyclops vernalis* (i.e. *Acanthocyclops vernalis*) (Hunt and Robertson 1977).

Collectively, the above physiological characteristics should express themselves as variation in zooplanktonic abundance and/or biomass. Although summer peaks in zooplankton abundance are generally attributed to higher water temperatures, the actual mechanisms behind summer population maxima have not been isolated. Besides temperature, there are usually many other seasonally variable parameters, such as amount and type of food resources and relative predation pressures, which also may be important determinants of population size (Threlkeld 1987). Laboratory evidence, at least, suggests that when other variables are held constant, *Daphnia* cultures grow best at water temperatures between 15 and 25°C (Goss and Bunting 1983). This range of temperatures is found in the epilimnion during the mid-summer zooplankton population maximum, at least in temperate zone lakes.

For many zooplankton species, vertical distribution and diel movements are not well correlated with water temperature (Pennak 1944). The thermocline in three mountain lakes in Colorado did not present a barrier to diel movements of several species of Cladocera and Copepoda (Pennak 1944). Off the coast of Peru, vertical distributions of zooplankton were not related to water temperature (Judkins 1980). Additionally, sudden changes of 15°C did not adversely affect individuals of *Daphnia pulex* and *D. magna* (Goss and Bunting 1976), indicating that in nature, they would be able to tolerate all temperatures encountered in migration throughout the water column of a thermally stratified lake.

However, there is evidence that the rate of diel movement is related to water temperature. In five Colorado lakes, the greatest vertical movements occurred in Summit Lake, where the difference in temperature between the top and bottom of the water column was the smallest (13.1 and 9.5°C, respectively) (Pennak 1944). In Lake Mendota, Wisconsin, the rates of diel movement of *Daphnia galeata mendotae* and *D. schødleri* were proportional to water temperature, at least in instances where changes in light intensity were constant (McNaught and Hasler 1964).

C. Lake Aeration and Effects on Zooplankton

In recent years, much research has been focused on methods for the reversal of eutrophication (Cowell et al. 1987), especially in systems altered primarily by human activity (Dunst et al. 1974). Lake aeration was pioneered as a lake restoration technique over 40 yr ago in Switzerland (Mercier and Perret 1949). Since then, hypolimnetic aeration (with air) and destratification aeration have been employed extensively throughout Europe, and in several eutrophic lakes in North America (McQueen and Lean 1986). Experimentation with hypolimnetic oxygenation (hypolimnetic aeration with pure oxygen) commenced in the seventies (Fast et al. 1975; Bianucci and Bianucci 1979; Whipple et al. 1979). The primary goals of all forms of aeration were to eliminate fish kills due to oxygen deficits, and/or to control algal blooms and improve water clarity by the reduction of internal phosphorus loading (Cowell et al. 1987).

Hypolimnetic aeration, destratification aeration, and hypolimnetic oxygenation have had variable effects on the DO concentrations and water temperatures in treated lakes. In a survey of 16 study lakes in Europe and North America, McQueen and Lean (1986) noted that hypolimnetic aeration increased the DO concentration to an average of 3 to 4 mg/L in the treatment basin. For example, in Black Lake, British Columbia, hypolimnetic aeration increased the mean summer DO concentration at 9 m (lake bottom) from 0.2 to 2.7 mg/L (Ashley 1983). Summer hypolimnetic temperatures were between 1 and 2°C warmer on the aerated side of Black Lake, but thermal stratification was maintained (Ashley 1983). Unfortunately, in most of the long-term projects, the mean hypolimnetic DO concentration dropped below 2 mg/L at some point in late summer, likely due to insufficient aerator capacity and/or aeration-induced biological oxygen demand (McQueen and Lean 1986). Additionally, hypolimnetic aeration may induce vertical mixing, which, in turn, may cause hypolimnetic warming and even thermal destratification, especially in lakes < 15 m deep (McQueen and Lean 1986). Destratification aeration eliminates thermal stratification, and hypolimnetic DO concentrations and temperatures are increased substantially by the resultant vertical mixing (Fast 1971; Cowell et al. 1987). Because pure oxygen has a greater gas transfer efficiency than air (which is 21% oxygen), hypolimnetic oxygenation has the potential to increase hypolimnetic DO concentrations more effectively than hypolimnetic aeration (Whipple et al. 1979), without causing the high hypolimnetic temperatures associated with destratification aeration. For example, in Ottoville Quarry, Ohio, hypolimnetic oxygenation (by side stream pumping) increased DO concentrations from less than 0.5 to 8.0 mg/L, while hypolimnetic temperatures increased by < 0.5°C (Fast et al. 1975).

The responses of pelagic zooplankton to hypolimnetic aeration have been highly variable. After hypolimnetic aeration has increased hypolimnetic DO concentrations, one might expect that distribution and/or abundance of hypolimnetic zooplankton would increase. However, a review of the five hypolimnetic aeration studies that had collected zooplankton data concluded that the abundance, biomass and vertical distribution of zooplankton were largely unaffected by the treatment (McQueen and Lean 1986). For example, zooplankton distribution, species composition and successional patterns were unaffected by hypolimnetic aeration in enclosure experiments in Lake St. George, Ontario (McQueen and Story 1986). Also, in Black Lake, British Columbia, the vertical distributions of *Daphnia pulex* were similar on aerated and unaerated sides of the lake (Ashley 1982). However, there are documented cases of impacts of hypolimnetic aeration on zooplankton. Abundances of *Cyclops bicuspidatus* (i.e. *Diacyclops bicuspidatus thomasi*) and *Diaptomus leptopus* were slightly higher on the aerated side of Black Lake, British Columbia (Ashley 1982). Additionally, in Tory Lake, Ontario, hypolimnetic aeration resulted in the establishment of a toxic (H_2S-rich) and anoxic metalimnion, which restricted most zooplankton to the epilimnion. As a result, selective predation by fathead minnows (*Pimephales promelas*) decimated populations of large-bodied zooplankton taxa. A small population of *Daphnia pulex* that was trapped in the hypolimnion then collapsed when DO concentrations fell below 2 mg/L (Taggart 1984).

Zooplankton have also responded to destratification aeration in a variable fashion. Zooplankton were distributed deeper after destratification aeration in a California reservoir. Two days before treatment, the hypolimnion had a maximum DO concentration of 0.5 mg/L below 10 m, and only 15% (relative abundance) of the zooplankton community was found in this habitat. After aeration had destratified the lake, the DO concentration increased to 1.7 mg/L below 10 m, and 85% of the zooplankton community was found below this depth (Fast 1971). After destratification aeration in a eutrophic Ontario lake, zooplankton moved from epilimnetic waters (0 to 2 m) to invade depths > 5 m, but densities of zooplankton were reduced after treatment (Ellis and Tait 1981). In hypereutrophic Lake Brooker, Florida, densities of Cladocera and Copepoda decreased by 92% with the onset of destratification aeration. This result was attributed tentatively to changes in phytoplankton size structure and/or rapid column mixing which caused animals to become trapped in the surface film. Also, *Daphnia ambigua* and other large-bodied zooplankton were replaced by smaller taxa, such as *Bosmina longirostris* (Cowell et al. 1987). Conversely, destratification aeration has also resulted in the establishment of populations of large-bodied zooplankton, possibly by providing a deep-water refugium from sight-feeding planktivores. For instance, the small cladocerans *Daphnia parvula* and *Diaphanosoma brachyurum* were present in Heart Lake, Ontario in the two years prior to destratification aeration (Haney 1970). However, a population of the larger cladoceran, *Daphnia pulex*, became established after destratification aeration, while *D. parvula* was rare and *D. brachyurum* disappeared (Strus 1976).

Research associated with hypolimnetic oxygenation has generally focused on the improvement of water quality (e.g. Bianucci and Bianucci 1979) or the establishment and maintenance of populations of cold-water sport fishes (e.g. Overholtz et al. 1977). As a result, few data exist on the response of zooplankton to hypolimnetic oxygenation. For example, live zooplankton were "observed" in the oxygenated hypolimnion of Ottoville Quarry, Ohio, but no quantitative data were presented on the abundance, biomass, or depth distribution of the zooplankton (Fast et al. 1975). The response of an aquatic system to a perturbation, such as hypolimnetic oxygenation, would be better understood if zooplankton and other trophic levels (e.g. phytoplankton, planktivorous fishes, piscivorous fishes) were examined in concert.

D. Hypolimnetic Oxygenation of Amisk Lake

Amisk, like many Alberta lakes, is a naturally eutrophic lake that has historically suffered hypolimnetic anoxia (Prepas and Trew 1983). Data from 1980 to 1982 and from 1984 to 1985 show that pelagic zooplankton were restricted to the epilimnion and upper portion of the hypolimnion by anoxic conditions in late summer (Prepas and Vickery 1984; E.E. Prepas and A. Trimbee, Univ. Alberta, unpubl. data). In June 1988, hypolimnetic oxygenation commenced in the north basin of Amisk Lake. The south basin was not treated and served as a reference basin. The main goals of the oxygen treatment were: (1) to enhance habitat for the sport fishes of the lake; and (2) to improve water clarity through the reduction of internal phosphorus cycling.

In the summers 1988 and 1989, and in the winters of 1989 and 1990, I collected data to determine how enhanced hypolimnetic DO concentrations and/or water temperatures affected the vertical distribution, diel migration, and abundance (or biomass) of the pelagic zooplankton. The following effects were expected: (1) increased DO concentrations in the hypolimnion of the treated basin would allow zooplankton to re-distribute to greater depths, (2) oxygenation would reduce or remove restrictions of movement in the treated basin, which would result in an increase in the amplitude of diel migration of hypolimnetic zooplankton, and (3) increased DO concentrations and/or water temperatures in the treated basin would result in a greater abundance and/or biomass of zooplankton.

In addition to this study, three other graduate research projects on aquatic ecology have commenced at Amisk Lake since 1988. Debbie Webb (Univ. Alberta, unpubl. data) surveyed patterns of spatial and temporal heterogeneity in the phytoplankton community in 1988 and 1989. The effects of hypolimnetic oxygenation on the benthic macroinvertebrate community were investigated from 1988 to 1992 (Dinsmore and Prepas 1992, In Press; Dinsmore unpubl.). Aku et al. (In Press) examined the effects of hypolimnetic oxygenation on the pelagic fish community from 1989 to 1992.

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II. Increased Depth Distribution and Abundance of Pelagic Zooplankton During Hypolimnetic Oxygenation of a Eutrophic Alberta Lake[1]

A. Introduction

Variation in dissolved oxygen (DO) concentrations may significantly influence zooplankton distribution and physiology in both marine and freshwater systems. The lower limit of vertical distribution of freshwater zooplankton is often determined by a species-specific critical DO concentration, usually between 0.5 and 1.0 mg/L (Pennak 1944; Fast 1971). However, some marine species (e.g. *Eucalanus inermis*) may tolerate DO concentrations as low as 0.1 to 0.2 mg/L (Vinogradov 1968; Judkins 1980), and undergo diel migrations through DO concentrations that range from 0.2 to 5.0 mg/L (Longhurst 1967). Below species-specific critical DO concentrations, respiration rates (Heisey and Porter 1977; Weider and Lampert 1985) and grazing rates (Haney 1973; Kring and O'Brien 1976) decline. Zooplankton biomass declined after experimental fertilization in an Ontario lake, likely due to a combination of anoxia and high pH (> 10) (Malley et al. 1988).

Water temperature does not appear to be as critical as DO concentration in determining vertical distribution of zooplankton, but it plays an important role in their physiology. Zooplankton are generally eurythermal (Peters 1987) and many cold-water species tolerate water temperatures < 1°C (Brown 1929). Vertical distribution of zooplankton is therefore not well correlated with temperature (Pennak 1944; Judkins 1980). The rate of movement during diel migration, however, is reportedly proportional to water temperature (McNaught and Hasler 1964), as are respiration rates, at least in *Daphnia* spp. (Kobayashi 1974; Goss and Bunting 1980). Maximum grazing rates have been experimentally observed at species-specific optima between 15 and 25°C (Burns 1969; Kibby 1971; Kersting 1978), but grazing rates may peak at lower temperatures in cold-water or cold-acclimated populations (Kibby 1971; Chisholm et al. 1975). Peaks in zooplankton abundance are usually associated with the higher water temperatures of summer, but it is not known whether temperature is a significant causal agent, or whether biological factors (e.g. the balance between food availability and predation) are more important in the determination of zooplankton abundance (Threlkeld 1987).

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[1] A version of this chapter has been submitted to the *Canadian Journal of Fisheries and Aquatic Sciences* for publication.

Aeration has been utilized extensively as a restoration technique in eutrophic lakes in Europe and North America since its inception over 40 yr ago in Switzerland (Mercier and Perret 1949; McQueen and Lean 1986). The primary goal of aeration projects has been to increase hypolimnetic DO concentrations, which would then: (1) eliminate fish kills caused by hypolimnetic oxygen deficits, and (2) improve poor water quality caused by the release of phosphorus from anoxic sediments into the overlying water (Cowell et al. 1987). Destratification aeration and hypolimnetic aeration (using air) have been the most frequently used forms of this restoration technique; relatively few lakes have been treated by the more recently developed technique of hypolimnetic oxygenation (Fast et al. 1975, Bürgi and Stadelmann 1991). Destratification aeration removes thermal stratification, and the resulting vertical mixing significantly increases hypolimnetic DO concentrations and water temperatures (Fast 1971; Cowell et al. 1987). Hypolimnetic aeration, which infuses the hypolimnion with air, has generally been unable to maintain hypolimnetic DO concentrations > 2 mg/L for the entire period of summer stratification, and hypolimnetic water temperatures > 10°C have been noted in shallow (i.e. < 15 m depth) lakes where the aerator has induced vertical mixing (McQueen and Lean 1986). Because pure oxygen has a greater gas transfer efficiency than air (Whipple et al. 1979), a well-designed hypolimnetic oxygenation system has the potential to increase hypolimnetic DO concentrations more effectively than hypolimnetic aeration, without causing the high hypolimnetic temperatures associated with destratification aeration (e.g. Fast et al 1975).

The effects of aeration-induced increases in hypolimnetic DO concentrations and/or water temperatures on pelagic zooplankton have been variable. After destratification aeration, zooplankton have generally moved to deeper water (Fast 1971; Ellis and Tait 1981). Destratification aeration has also resulted in decreases in zooplankton abundance (Ellis and Tait 1981; Cowell et al. 1987) or altered the size-structure of the zooplankton community (Strus 1976). A review of five studies of hypolimnetic aeration (McQueen and Lean 1986) concluded that treatment had little effect on zooplankton distribution and abundance (e.g. Ashley 1982; McQueen and Story 1986). Yet, abundances of two zooplankton species were slightly higher in the hypolimnion of the aerated side of Black Lake, British Columbia (Ashley 1982), and Taggart (1984) noted that zooplankton abundance declined substantially during hypolimnetic aeration in Tory Lake, Ontario. Most hypolimnetic oxygenation projects have been concerned only with water quality (e.g. Bianucci and Bianucci 1979) or the survival of cold-water sport fishes (e.g. Overholtz et al. 1977). Few data therefore exist on the effects of hypolimnetic oxygenation on pelagic zooplankton.

In June 1988, hypolimnetic oxygenation commenced in the north basin of Amisk Lake. This was the first whole-lake basin in North America to be oxygenated. The primary goals of oxygenation were to enhance sport fish habitat, and to improve water clarity through the reduction of internal phosphorus cycling (Prepas 1990). However, this treatment also provided an opportunity to examine the effects of increased hypolimnetic DO concentrations, and possible warming of hypolimnetic waters, on the pelagic zooplankton community. The south basin was not oxygenated and served as a reference system. The following three treatment effects were expected in the north basin of Amisk Lake: (1) zooplankton would move to deeper water in the hypolimnion, (2) the increase in vertical habitat would permit an increase in the amplitude of diel vertical migration, (3) the increase in vertical habitat would result in greater zooplankton abundance and/or biomass.

B. Methods

Study Lake

Amisk Lake is located at the southern edge of the western Boreal forest, in central Alberta (Fig. 1). The following information is excerpted from Prepas (1990), unless otherwise noted. Amisk is a 5.15-km^2 naturally eutrophic lake (mean chlorophyll a = 17.5 Og/L, May to August 1987, n = 13) with two deep basins (z_{max} = 34 and 60 m in north and south basins, respectively) separated by a 350-m wide, 13-m deep channel (Fig. 1). Average water residence time is 8 yr. The majority of the shoreline of Amisk Lake is undeveloped, although two cottage subdivisions and one trailer park are situated on the west shore of the north basin. About 4% of the drainage basin is developed for agriculture, and about 88% of the drainage basin is forested; dominant tree species are trembling aspen, balsam poplar and jack pine. Fishing, boating and swimming are popular at Amisk; the sport fishery includes yellow perch (*Perca flavescens*), northern pike (*Esox lucius*) and yellow walleye (*Stizostedion vitreum vitreum*). In addition, cisco (*Coregonus artedi*), lake whitefish (*Coregonus clupeaformis*), white sucker (*Catostomus commersoni*), burbot (*Lota lota*), and several smaller prey fishes are found in Amisk Lake. The benthic macroinvertebrate community is dominated by midge larvae (Chironomidae), aquatic earthworms (Oligochaeta), fingernail clams (Sphaeridae) and scuds (Amphipoda). Crayfish (Orconectes virilis) are also present. Amisk Lake is home to several species of waterfowl, including common loons, red-necked grebes and mallards. Osprey and bald eagles have also been observed to nest along the shoreline.

Pre-treatment data on hypolimnetic DO concentrations and water temperatures were available for Amisk Lake for the open-water seasons of 1980, 1981, 1982, 1987 (north and south basins) and 1984, 1985 (north basin), and for the winter in 1983 (north and south basins) and 1986 (north basin) (E.E. Prepas, Univ. Alberta, unpubl. data). Historically, the hypolimnia of both basins have had high oxygen demand, and have undergone incomplete turnover during spring and fall mixing periods (Prepas 1990). As a result, more than 50% (north basin) and 75% (south basin) of the water volume may become anoxic during periods of thermal stratification in winter and summer (Prepas 1990). Many fish species are considered to be oxygen-stressed at DO concentrations below 2 to 5 mg/L, and in pre-treatment years, DO concentrations fell below 2 mg/L at 13 to 18 m in March, and at 5 to 9 m in August. It was estimated that hypolimnetic oxygenation would be able to increase fish habitat by maintaining DO concentrations > 2 mg/L throughout the water column during the stratified periods. Additionally, by mid-summer in 1980, 1981, 1982 (Prepas and Vickery 1984) and 1984 (E.E. Prepas and A.M. Trimbee, Univ. Alberta, unpubl. data) zooplankton were concentrated in the upper 10 to 15 m of the water column, and may have been limited in depth distribution by hypoxic conditions in deeper waters.

Dissolved Oxygen and Water Temperature

I measured DO concentrations and water temperatures every two weeks from May to October in 1988 and 1989, and monthly from January to March in 1989 and 1990. I collected water for DO analyses at one to three sites per basin (Fig. 1) at approximately 3-m intervals from the water surface to within 3 m of the bottom sediments. Water samples were fixed in the field and analysed within 24 h by Carpenter's (1965) modification of the Winkler dissolved oxygen method. I measured temperature at the same sites, at 1-m intervals from the water surface to within 1 m of the bottom sediments, with a Montedoro-Whitney model TC-5C thermister.

Zooplankton Composition, Distribution, and Abundance

I collected zooplankton samples every two weeks from May to November 1988, and once each in January and March 1989, with a 40-L modified Schindler-Patalas trap (Schindler 1969) fitted with a 243-µm mesh plankton bucket. I took samples at depths of 1, 3, 6 and 10 m, and at 5-m intervals from 10 m to within 1 m of the bottom sediments. I adjusted the rope so that the middle of the trap would be at the sampled depth; since the trap was approximately 0.6 m in height, a sample taken at 1-m depth was actually a composite of depths from 0.70 to 1.3 m. In summer 1988, I collected samples (and pooled them for each depth within each basin) at Treatment sites 1, 2 and 3 (N1, N2, N3 in Fig. 1), and at Reference sites 1, 2 and 3 (S1, S2, S3 in Fig. 1). In winter 1989, I collected samples (and pooled them for each depth within each basin) at Treatment sites 2 and 3, and at Reference sites 1 and 3.

I collected zooplankton samples every two weeks from May to October 1989, and monthly from January to March 1990, also with the modified Schindler-Patalas trap. However, I fitted the trap with a plankton bucket with 64-µm mesh, because a lab test revealed that a substantial proportion of copepods and *Bosmina longirostris* > 243 µm in length (20 and 70%, respectively) passed through the 243-µm mesh. In both summer 1989 and winter 1990, I took zooplankton samples at 2-m intervals from the lake surface to within 1 m of the bottom sediments. I sampled at Treatment sites 1 and 2 and Reference sites 1 and 2; samples were not pooled. All samples were preserved immediately in a chilled sugar-formalin solution (Prepas 1978).

To determine the abundance and species composition of zooplankton, I transferred preserved samples to distilled water, and diluted them until subsamples of 10 mL contained between 30 and 40 individuals. The volumes of diluted samples were generally 300, 500 (500-mL beaker), or 1500 mL (2000 mL beaker), depending upon the density of zooplankton in the sample. I took at least two 10-mL subsamples with a spring-loaded subsampler while the sample was being mixed with a Tekpro model Tekstir-20 magnetic stirrer. To test the accuracy and precision of this subsampling method, I prepared a "test" sample of 1155 zooplankton individuals in 200 mL of distilled water (in a 300-mL beaker). I then took five replicate test subsamples of 10 mL each by the above method. Each of these subsamples was enumerated and placed back in the test sample before the next replicate subsample was taken. I used a paired *t*-test (5 replicate subsamples = 5 pairs) to examine the mean difference between the number of individuals in a test subsample and the expected number of animals in a 10-mL subsample (1155 x 10 / 200 = 57.75). The observed number of individuals (based on the subsampling method) did not differ from the expected number of individuals ($P > 0.50$), so this method was deemed accurate. Based on this test, the subsampling method also gave relatively precise estimates of zooplankton abundance (C.V. of 5 test subsamples = 0.13).

I identified zooplankton with the keys of Pennak (1978), Torke (1974), Brooks (1957), and Wilson and Yeatman (1918). I was able to positively identify all pelagic species by examination of common identifying structures at low magnification (25 to 50 x), with the exception of *Diacyclops bicuspidatus thomasi* and *Acanthocyclops vernalis* (Copepoda, Cyclopoida) which required dissection to reveal the detail of the fifth leg (Torke 1974). To estimate the relative abundance of these two species in the hypolimnion in summer 1989, the species were positively identified in samples taken at 21 m (the middle of the hypolimnion), at the Treatment 2 and Reference 1 sites, on 11 July and 11 August 1989. Among the Copepoda, adults and copepodites were grouped together; nauplii and egg sacs were not counted. Among the Cladocera, adults and juveniles were grouped together; eggs were not counted. Rotifers were not examined.

Data from summer 1989 and winter 1990 were better suited for the estimation of treatment effects on vertical distribution and abundance, than those of summer 1988, and winter 1989. This was so because in summer 1989 and winter 1990: (1) oxygenation more effectively increased hypolimnetic DO concentrations in the treatment basin, (2) the plankton bucket with 64-μm mesh captured a more representative sample of the zooplankton community, (3) I sampled a greater number of hypolimnetic depths, and therefore obtained finer resolution of trends in vertical distribution and abundance, (4) further modifications made to the plankton trap in summer 1989 helped it to function more reliably than the modified trap used in summer 1988, and (5) I did not pool samples from sites within each basin in 1989, thus I could examine variation in abundance from site to site. Data from summer 1988 and winter 1989 were examined to see whether they reflected the trends in vertical distribution of zooplankton that were suggested by data from summer 1989 and winter 1990.

Treatment site 2 was in the deepest part of the north basin (31 m) and Reference site 1 was the same depth (31 m) in the untreated south basin. These were the main sites sampled in summer 1989 and winter 1990, for comparison of vertical distribution and abundance of zooplankton. Therefore, Treatment site 2 and Reference site 1 will be referred to as the Treatment and Reference sites, respectively, unless otherwise noted.

I examined data from summer 1989 and winter 1990, to get a general picture of seasonal patterns in whole-lake areal abundance of zooplankton. I inspected variation in abundance between sites in each basin in summer 1989. On a given date, I calculated the population abundance at a given site by multiplying the mean density (animals/m^3) in the stratum (i.e. epilimnion, hypolimnion, or entire water column) by the depth of the stratum (m) to yield areal abundance as animals/m^2. For each date sampled, I estimated the whole-lake abundance of a taxon by computing the mean of the population abundances in the entire water column at the four lake sites; I assumed that each of the four sites represented one quarter of the total lake area and depth strata were not volume weighted. I estimated monthly whole-lake abundances by calculating the mean of whole-lake abundances for all dates sampled during that month (e.g. in July 1989, the whole-lake abundance of each taxon was calculated as a mean of three sampling dates).

I defined the thermocline on each date, as the stratum in which the temperature decreased by > 1°C per m of depth (Wetzel 1983). I classified zooplankton taxa that resided primarily below the thermocline as "hypolimnetic taxa," whereas those found primarily within and above the thermocline were considered "epilimnetic taxa." Zooplankton taxa that exhibited bimodal vertical distributions (i.e. density peaks in both the upper epilimnion and lower hypolimnion, with fewer individuals at depths in between) were divided into epilimnetic and hypolimnetic "populations" on each date. I then analysed epi- and hypolimnetic populations as distinct entities.

Diel Migration of Hypolimnetic Zooplankton

In 1989, I measured patterns of diel migration of pelagic zooplankton on 3 and 4 June (at 1200 and 0000 h, respectively), and on 11 and 12 August (at 1200 and 0000 h, respectively). I collected samples at 1200 and 0000 h because zooplankton would likely be near maximum and minimum depths, respectively (Cruz-Pizarro 1978). Zooplankton were sampled with the modified Schindler-Patalas trap fitted with a 64-µm mesh bucket. I took samples at the Treatment and Reference sites at 2-m intervals from the water surface to within 1 m of the bottom sediments. The "night" samples at the Reference site were collected only to a depth of 25 m on 4 June, due to equipment failure. Samples were preserved and sorted as described previously.

Biomass of Epilimnetic Plankton and Zooplankton

I sampled every two weeks from May to September 1988, and from May to October 1989, with two conical nets (64- and 243-µm mesh-size), 90-cm long, with a 29-cm aperture. Each net was fitted with a plankton bucket of like size mesh. I towed each net from 6 m to the water surface; the 243-µm net was also towed from 12 m to the water surface in 1988, and from 10 m to the water surface in 1989. I made pooled samples (in duplicate) from tows at three or four sites in each basin, for each of the three depth-mesh combinations. Samples were chilled, then analysed within 48 h.

To determine dry weight, I diluted samples to between 200 and 500 mL. While stirring the sample in a figure-eight pattern with a glass rod, I removed subsamples of between 2 and 10 mL with a calibrated Pasteur pipette; I took smaller subsamples from samples with greater plankton density, and vice-versa. I filtered subsamples onto pre-weighed 2-cm Whatman GF/C filters, dried them for 24 h at 60°C, and re-weighed them on a Cahn model-29 electrobalance. Three subsamples were analysed from each sample. After the subsamples were withdrawn for total plankton in 1989, I bubbled CO_2 gently through the samples to narcotize zooplankton. Zooplankton sank to the bottom of the jar, whereas the phytoplankton floated to the surface. The phytoplankton were carefully decanted, leaving only zooplankton in the jar. Zooplankton biomass was determined as described above.

Statistical Analyses

I chose median depth, rather than mean depth, as the descriptor of central tendency for vertical distribution of summer 1989 and winter 1990 populations, because the distribution of animals with depth tended to be non-normal, and transformation did not normalize the data successfully (Snedecor and Cochran 1980). I tested differences in vertical distribution between populations with a median test (Zar 1974). This test is only about 64% as powerful as the 2-sample *t*-test when applied to data where the latter is applicable (Mood 1954), but its result is more reliable than the *t*-test when a comparison is made between non-normal distributions (Snedecor and Cochran 1980), such as those in Amisk Lake. I also used the median test to determine whether the amplitude of diel migration was significant (i.e. did the median depth change significantly between day and night?). I did not calculate a median depth for any population whose mean density was < 1 animal/L, nor for any population in summer 1988 or winter 1989, because I sampled too few hypolimnetic depths to get a reliable estimate of the median depth of a population.

For each taxon, I compared the Median DO concentration (MDO) and the Median temperature (MT) between treatment and reference populations (the MDO and MT are defined as the mean of the DO concentrations, and the mean of the temperatures, respectively, that were associated with the median depths of the population) with the standard two-sample *t*-test when variances were homogeneous, and with a modified t-test when samples had heterogeneous variances (Prepas 1984). I also compared pre- and post-treatment mean summer hypolimnetic DO concentrations and water temperatures with this test.

I used the standard paired *t*-test to compare areal abundances at Treatment and Reference sites during summer 1989. A paired test was chosen to eliminate seasonal variation in zooplankton abundance.

C. Results

Dissolved Oxygen and Water Temperature

Data on DO concentrations and water temperatures from pre-treatment years (1980 to 1987) were taken from Prepas et al. (ms submitted), and compared with data on DO concentration and water temperature collected in this study in summer 1988 and 1989. Hypolimnetic oxygenation increased summer DO concentrations in the hypolimnion of the treatment basin. The mean summer (June to August) hypolimnetic DO concentration in the treatment basin was significantly higher ($P < 0.01$) during oxygenation (1988 and 1989 mean = 2.8 mg/L) than in pre-treatment years (1980 to 1987 mean = 1.0 mg/L). Hypolimnetic oxygenation also caused slight hypolimnetic warming in the treatment basin. The mean (June to August) hypolimnetic temperature in the treatment basin was significantly higher ($P < 0.02$) during oxygenation (1988 and 1989 mean = 8.1°C) than in pre-treatment years (1980 to 1987 mean = 7.0°C). Although the north and south basins of Amisk Lake are joined by a 13-m deep channel, little dissolved oxygen diffused from the treatment to the reference basin in 1988 and 1989, and thus hypolimnetic DO concentrations in the reference basin were not significantly affected by oxygenation in these first two treatment years; water temperatures in the reference basin were also not significantly affected by the oxygenation (Prepas et al., ms submitted). Vertical profiles of DO concentration and water temperature were similar from site to site within basins in pretreatment (Prepas et al., ms submitted) and treatment years.

Amisk Lake Zooplankton Community

The pelagic zooplankton community from May 1988 to March 1990 consisted primarily of the cladocerans *Daphnia longiremis*, *D. pulex*, *D. galeata mendotae* and *Bosmina longirostris*, the calanoid copepod *Diaptomus oregonensis*, and the cyclopoid copepods *Diacyclops bicuspidatus thomasi* and *Acanthocyclops vernalis*. These seven species of zooplankton were numerically dominant. In summer 1989, *D. longiremis*, *D. pulex* and *Diacyclops bicuspidatus thomasi* were the most abundant species in the hypolimnion, while *D. galeata mendotae* and *Diaptomus oregonensis* were relatively abundant in the epilimnion. Total whole-lake areal abundance of the seven dominant zooplankton species peaked in July (Fig. 2). The February 1990 peak in abundance of cyclopoid copepods (i.e. *Diacyclops bicuspidatus thomasi* + *Acanthocyclops vernalis*) indicates that total zooplankton abundance may be as high in winter as it is in spring and late summer. However, the winter zooplankton community was generally less diverse than the summer community.

On occasion, samples contained small numbers of *Mesocyclops edax*, *Tropocyclops prasinius mexicanus*, *Leptodora kindtii*, *Chaoborus*, Chironomidae, and water mites (Acari). Additionally, in August and September of 1988 and 1989, mean water column densities of the cladoceran *Diaphanosoma leuchtenbergianum* varied from 1 to 6 animals/L in the epilimnion. However, this species was not important for most of the spring and summer in 1988 and 1989, and not present in the winters of 1989 and 1990 Densities of these seven zooplankton taxa were relatively low; I therefore grouped them into the category "other" (Fig. 2), and I will not discuss them further.

Vertical Distribution of Zooplankton

In May 1989, pelagic zooplankton were found primarily in the epilimnion (above 6 m) at all sites. Most *D. galeata mendotae* and *Diaptomus oregonensis* remained in the epilimnion (above 6 to 10 m) throughout the summer, while most *D. longiremis*, *D. pulex*, *Diacyclops bicuspidatus thomasi* and *B. longirostris* had moved into the hypolimnion by July (Fig. 3). From July to September 1989, the vertical distributions of *D. pulex* and cyclopoid copepods showed distinct epi- and hypolimnetic population modes, especially at the Treatment site (e.g. 11 July, Fig. 4). During this period, the epilimnetic cyclopoid populations at both sites were dominated by approximately equal proportions of *Diacyclops bicuspidatus thomasi* and *Acanthocyclops vernalis*, and I will refer to these epilimnetic populations as "cyclopoid copepods". However, in zooplankton samples taken at 21 m (the middle of the hypolimnion) on 11 July and 11 August, at both Treatment and Reference sites, no *Acanthocyclops vernalis* were found, while *Diacyclops bicuspidatus thomasi* was abundant. I assumed from these results, that *Diacyclops bicuspidatus thomasi* dominated hypolimnetic populations of cyclopoid copepods from July to September 1989. Thus, I will refer to hypolimnetic populations of cyclopoid copepods as "*Diacyclops bicuspidatus thomasi*" during this period.

Data from summer 1989 support our prediction that hypolimnetic oxygenation would allow zooplankton to distribute deeper in the treatment basin. By July 1989, most individuals of the species *D. longiremis*, *D. pulex*, *Diacyclops bicuspidatus thomasi*, and *B. longirostris* had moved into the hypolimnion at the Treatment and Reference sites (Fig. 3). After this descent, and for the duration of the summer, hypolimnetic populations of each of these species were found at significantly greater depths (as median depth) at the Treatment than at the Reference site (Fig. 3) (results of statistical comparisons are given in Table 1). For example, on 11 July 1989, DO concentrations were > 1.5 mg/L throughout the hypolimnion at the Treatment site, while the lower hypolimnion at the Reference site was becoming oxygen-deficient (Fig. 4). As a result, hypolimnetic populations of *D. longiremis*, *D. pulex*, *Diacyclops bicuspidatus thomasi* and *B. longirostris* were found significantly deeper at the Treatment than at the Reference site ($P < 0.001$, 0.001, 0.05, 0.001, respectively). Hypolimnetic oxygenation allowed zooplankton to move freely within the hypolimnion at the Treatment site, while zooplankton generally avoided the oxygen-poor lower hypolimnion at the Reference site.

The vertical distributions of the epilimnetic zooplankton taxa were largely unaffected by the oxygen treatment in summer 1989. Median depths of epilimnetic populations of *D. galeata mendotae*, *Diaptomus oregonensis*, *D. pulex* and cyclopoid copepods generally did not differ between Treatment and Reference sites (Fig. 3). For example, on 11 July 1989, the median depths of Treatment and Reference site populations of these taxa were not significantly different ($P > 0.5$, 0.1, 0.5, 0.9, respectively) (Fig. 4). An exception to this trend was the median depth of the epilimnetic species *D. galeata mendotae*, which by August, was approximately 5 m deeper at the Reference than at the Treatment site ($P < 0.05$, Fig. 3). However, small densities (usually < 5 animals/L) of *D. galeata mendotae* were found at most depths in the hypolimnion at both Treatment and Reference sites throughout summer 1989. At the Reference site in August, epilimnetic densities of *D. galeata mendotae* had declined to < 10 animals/L, thus the overall median depth of the population was skewed down by small numbers of *D. galeata mendotae* in the hypolimnion. I also observed statistical differences in median depth between the Treatment and Reference populations of epilimnetic *D. pulex*, cyclopoid copepods, and *Diaptomus oregonensis* on one date each (Fig. 3). However, these differences were likely not biologically significant, as median depths differed between the Treatment and Reference sites by only 1.4, 1.2 and 0.7 m, respectively.

Relationships between DO concentration and vertical distribution of zooplankton are not as obvious in the data from summer 1988, because I sampled only four hypolimnetic depths. However, these data generally support the trends suggested by the data from summer 1989. For example, on 7 August 1988, peak densities of the two dominant hypolimnetic taxa, *D. longiremis* and cyclopoid copepods, were found deeper in the treatment basin (at 25 m), than in the reference basin (at 10 m) (Fig. 5). The DO concentrations associated with these peaks were 1.0 mg/L at 25 m in the treatment basin, and 1.3 mg/L at 10 m in the reference basin. Densities of *D. pulex*, *B. longirostris*, *D. galeata mendotae* and *Diaptomus oregonensis* were too low to determine trends in vertical distribution on this date.

Data from winter 1990 provided an opportunity to examine vertical distributions of zooplankton when DO concentrations and water temperatures were relatively constant with depth. On 16 and 17 January 1990, the minimum DO concentration at either site (5 mg/L) did not limit the vertical distribution of any zooplankton taxon (Fig. 6). The vertical distributions of *D. pulex*, cyclopoid copepods and *Diaptomus oregonensis* also were not affected by the observed range of water temperatures (1 to 3°C), since each taxon was fairly evenly dispersed throughout the water column at Treatment and Reference sites. Median depths of populations at Treatment and Reference sites did not differ significantly for each of these taxa ($P > 0.1$, 0.5, 0.5, respectively). *B. longirostris* was absent from the top 4 and 10 m of the water column at Treatment and Reference sites, respectively; in these depth strata, water temperatures were between 1 and 2°C. I did not make statistical comparisons of median depths between Treatment and Reference sites for *B. longirostris*, *D. longiremis* or *D. galeata mendotae*, because the mean densities of these species were too low (< 1 animal/L) at one or both sites. However, the vertical distributions of these three species appeared to be similar at Treatment and Reference sites. Results on 29 February 1990 were similar; low water temperatures (Appendix B, Table 4) did not appear to affect vertical distributions of zooplankton (Appendix A, Table 4).

Vertical distribution of hypolimnetic zooplankton appeared to be strongly influenced by a species-specific DO concentration for much of summer 1989. *D. longiremis*, *D. pulex*, *Diacyclops bicuspidatus thomasi* and *B. longirostris* resided primarily in the hypolimnion at both the Treatment and Reference sites from July to September 1989. During this time, the median depths (at mid-day) of each species varied considerably among sampling dates, and between sites (Fig. 7). However, the DO concentrations that were associated with the median depths of a population (i.e. the median DO concentration = MDO) varied only slightly (Fig. 7). The MDO's of *D. longiremis*, *Diacyclops bicuspidatus thomasi* and *B. longirostris* did not differ significantly between populations of the Treatment and Reference sites for the period July to August 1989 ($P = 0.30$, 0.14, 0.20, respectively). Thus, I computed a species MDO for each of *D. longiremis*, *Diacyclops bicuspidatus thomasi* and *B. longirostris* by taking the mean of MDO's of Treatment and Reference populations. The resulting mean (± 95% C.I.) species MDO's were 1.7 mg/L ± 0.4, 1.5 mg/L ± 0.3, and 2.3 mg/L ± 1.0, respectively. The MDO of hypolimnetic *D. pulex* at the Treatment site (1.5 mg/L ± 0.2) was significantly lower ($P = 0.02$) and much less variable than at the Reference site (2.6 mg/L ± 2.0). However, at the Reference site, the hypolimnetic population of *D. pulex* was relatively small, and a portion of the epilimnetic population extended into the upper hypolimnion (e.g. Fig. 4). Thus, I may have overestimated the true MDO of the hypolimnetic *D. pulex* population at the Reference site by inadvertently including epilimnetic *D. pulex* in our calculations. Generally, the median depths of hypolimnetic zooplankton species at both sites were associated with MDO's of between 1.5 and 2.3 mg/L, but I usually observed a few individuals of each hypolimnetic species at depths with DO concentrations approaching zero (e.g. Fig. 4).

In addition to DO concentration, water temperature may have limited depth distribution of hypolimnetic zooplankton in summer 1989. The median depths (mid-day) of each hypolimnetic zooplankton species appeared to be associated with a relatively constant "median" water temperature (MT) from July to September 1989 (Fig. 7). MT's of *D. longiremis*, *D. pulex*, *Diacyclops bicuspidatus thomasi* and *B. longirostris* did not differ significantly between Treatment and Reference populations ($P > 0.05$, 0.10, 0.05, 0.90, respectively). Thus, I computed a species MT for each of *D. longiremis*, *Diacyclops bicuspidatus thomasi* and *B. longirostris* by taking the mean of MT's of Treatment and Reference populations. The resulting mean (± 95% C.I.) species MT's were 7.6°C ± 0.8, 7.8°C ± 0.9, 7.5°C ± 1.0, and 7.6°C ± 1.1, respectively. The median depths of hypolimnetic zooplankton were associated with species-specific water temperatures of between 7.5 and 7.8°C from July to September 1989. These temperatures are 4 to 6 °C higher than winter 1990 temperatures (Fig. 6), which had no apparent effect on the vertical distributions of these four species.

Diel Migration of Hypolimnetic Zooplankton

Diel vertical migration was first surveyed on 3 and 4 June 1989, before DO concentrations became severely limiting in the hypolimnion of the reference basin. Minimum DO concentrations were 5.2 and 3.1 mg/L, and mean hypolimnetic temperatures were 6.9 and 6.2°C, at the Treatment and Reference sites, respectively (Fig. 8). The dominant hypolimnetic taxa, cyclopoid copepods, underwent significant upward migration (median depth day versus night) at night at the Treatment site ($P < 0.001$, median amplitude 6.5 m), but not at the Reference site ($P > 0.05$, median amplitude = 2.5 m). On this date, *D. longiremis* was primarily epilimnetic, and migrated down at night at the Treatment and Reference sites ($P < 0.001$ both sites). *D. longiremis* appeared to migrate further at the Treatment site (median amplitude 6.7 m) than at the Reference site (median amplitude 2.7 m). Densities of *D. pulex* were too low on this date to examine statistically, but the distributions suggest that *D. pulex* did not move substantially between day and night.

On 11 and 12 August 1989, hypolimnetic DO concentrations were potentially limiting at the Reference site (< 2.0 mg/L at 13 m and below), but not at the Treatment site (> 2.0 mg/L to a depth of 21 m) (Fig. 9). Mean hypolimnetic temperatures were 9.2 and 7.0°C at the Treatment and Reference sites, respectively. On this date, the dominant hypolimnetic species, *D. longiremis*, underwent significant upward migration at night at the Treatment site ($P < 0.001$, median amplitude 4.0 m), but no significant movement was detected at the Reference site ($P > 0.9$, median amplitude 0.0 m). *D. longiremis* appeared to avoid the bottom 10 m of the hypolimnion at the Reference site, where DO concentrations were < 1.0 mg/L. Hypolimnetic *D. pulex* and *Diacyclops bicuspidatus thomasi* appeared to move upward slightly at night at the Treatment site (median amplitudes 1.7 and 1.3 m, respectively), but these movements were non-significant ($P > 0.1$, 0.5, respectively). Hypolimnetic populations of these two species were relatively small at the Reference site, and thus no obvious diel movements were apparent. The data show that in mid-August, one hypolimnetic species, *D. longiremis*, migrated further at the Treatment than at the Reference site.

Biomass of Epilimnetic Plankton and Zooplankton

Plankton biomass of both size fractions (> 64 µm, > 243 µm) and depth strata (0 to 6 m, 0 to 10 m) did not appear to differ between treatment and reference basins during summer 1988 or 1989 (Fig. 10). In addition, plankton biomass > 243 µm of both depth strata (0 to 6 m, 0 to 10 m) did not differ between the open-water seasons of 1988 and 1989. However, plankton biomass > 64-µm (0 to 6 m) appeared to be much higher for the period June to August in 1988 than in 1989 (Fig. 10). When phytoplankton were removed from plankton samples in 1989, epilimnetic zooplankton biomass did not appear to differ between the treatment and reference basins in either of the two size fractions or depth strata (Fig. 10). Overall, the most noticeable feature of epilimnetic plankton biomass was the large decrease in the 64-µm fraction from summer 1988 to summer 1989.

Abundance of Hypolimnetic Zooplankton

There was considerable horizontal variation in hypolimnetic zooplankton abundance within each of the treatment and reference basins in summer 1989. *D. longiremis*, *D. pulex*, *Diacyclops bicuspidatus thomasi* and *B. longirostris* were found in great abundance in the hypolimnion at Treatment site 2, but abundances of these species were always substantially lower at the shallower (21 m) Treatment site 1 (Fig. 11). In the reference basin, abundances of *D. longiremis* and hypolimnetic *Diacyclops bicuspidatus thomasi* were notably lower at the deeper (49 m) Reference site 2 than at Reference site 1 for much of the summer. Since hypolimnetic zooplankton abundance appeared to vary with lake depth, I primarily compared abundance between Treatment 2 and Reference 1 sites, which were each 31 m deep.

Data from summer 1989 in part support the prediction that oxygenation would result in increased hypolimnetic zooplankton abundance. From May to August 1989, *D. longiremis* and hypolimnetic *D. pulex* were found in significantly higher numbers ($P = 0.02$, 0.03, respectively) at Treatment site 2 than at Reference site 1 (Fig. 11). In addition, hypolimnetic abundances of these two species were substantially higher at Treatment site 2 in summer 1989 than at this site in summer 1984 (four years prior to oxygenation) (Fig. 12). Abundances of hypolimnetic *Diacyclops bicuspidatus thomasi* and *B. longirostris*, however, were similar at Treatment site 2 and Reference site 1 in summer 1989 ($P = 0.17$, 0.48, respectively) (Fig. 11). Also, the abundance of hypolimnetic *Diacyclops bicuspidatus thomasi* at Treatment site 2 in summer 1989 was similar to that of hypolimnetic cyclopoid copepods (i.e. *Diacyclops bicuspidatus thomasi* + *Acanthocyclops vernalis*) at this site in summer 1984 (Fig. 12). *B. longirostris* appeared to be less abundant at Treatment site 2 in mid-summer in 1989 than in 1984 (Fig. 12). However, when the four hypolimnetic species were considered together, Treatment site 2 supported a greater total abundance of hypolimnetic zooplankton during oxygenation in summer 1989 than either Reference site 1 in summer 1989, or Treatment site 2 in summer 1984 (Fig. 13). In sum, abundances of two of four hypolimnetic species (*D. longiremis* and *D. pulex*) appear to have increased substantially during hypolimnetic oxygenation.

D. Discussion

Vertical Distribution of Zooplankton

The results of our study support the prediction that as a result of hypolimnetic oxygen injection, zooplankton would distribute deeper in the treatment basin. During the open-water seasons of 1980, 1981 and 1982, zooplankton were concentrated in the top 10 to 15 m of the water column in Amisk Lake (Prepas and Vickery 1984). This suggests that the hypolimnion was uninhabitable, possibly due to low DO concentrations (< 2.0 mg/L below a depth of 15 m after early June in 1980, 1981 and 1982) (E.E. Prepas, Univ. Alberta, unpubl. data). In summer 1989, hypolimnetic oxygenation expanded suitable zooplankton habitat (i.e. for the "median" individual = DO concentrations > 2.0 mg/L) in the treatment basin by 6 m in July, and by 10 m in August, and hypolimnetic zooplankton populations moved into this new habitat.

These results are similar to those found in studies of destratification aeration and zooplankton depth distribution. The zooplankton community of El Capitan Reservoir, California consisted almost entirely of copepods (zooplankton were identified to major groups only), and they moved from an average pre-treatment depth of 7.4 m to an average depth of 15.5 m after destratification (Fast 1971). After commencement of destratification aeration of a 9-m deep eutrophic kettle lake in Ontario, zooplankton moved from a median depth of 1.1 m to median depths of 5.0 and 3.8 m, respectively, in two successive treatment years (Ellis and Tait 1981). Unlike destratification aeration, however, hypolimnetic oxygenation did not substantially alter water temperatures or DO concentrations in the epilimnion (Prepas et al. ms submitted). Thus hypolimnetic oxygenation in Amisk Lake allowed hypolimnetic zooplankton at the Treatment site to expand their vertical distributions into the previously unavailable habitat of the deep hypolimnion, while vertical distributions of epilimnetic zooplankton were generally unaffected by the treatment.

In contrast to the present study, and to previous studies of destratification aeration, a controlled enclosure aeration experiment (McQueen and Story 1986), and a hypolimnetic aeration study (Ashley 1982) reported no treatment effects on vertical distribution of zooplankton. The hypolimnetic population of *Diacyclops bicuspidatus thomasi* moved to the deep hypolimnion during oxygenation of Amisk Lake, but hypolimnetic aeration of a 15-m-deep enclosure in Lake St. George did not significantly affect the distribution of this species (McQueen and Story 1986). However, it may not be appropriate to compare our results with those of McQueen and Story (1986). In August 1989 in Amisk Lake, DO concentrations were < 1.5 mg/L (our estimate of the MDO of hypolimnetic *Diacyclops bicuspidatus thomasi*) between 15 and 31 m at the Reference site, resulting in a "treatment-effect-zone" 16 m deep. I collected zooplankton at 2-m intervals in this zone, and therefore had good resolution of changes in density with depth. In August 1981 in Lake St. George, DO concentrations were < 1.5 mg/L between 7 and 15 m in the unaerated enclosure, resulting in a "treatment-effect-zone" 8 m deep (McQueen and Story 1986). Zooplankton were sampled at 8 and 12 m in the "treatment-effect-zone" of the unaerated enclosure, and these two depths were pooled (McQueen and Story 1986). Zooplankton captured at 8 m may have been making regular forays between hypoxic water at 8 m and suitable habitat at 7 m. Therefore, treatment effects that may have existed at 12 m may have been obscured when the 8- and 12-m samples were pooled. It is also possible that treatment effects would have been observed if the enclosures had extended deeper into hypoxic waters in McQueen and Story's (1986) study. In summer 1978 in Black Lake, British Columbia, the vertical distribution of *D. pulex* was unaffected by hypolimnetic aeration (Ashley 1982). Ashley (1982) postulated that DO concentrations were not low enough in the hypolimnion of the unaerated side of Black Lake, to restrict distribution of *D. pulex* significantly, as this population was believed to be adapted to low DO concentrations. Thus, no effect on vertical distribution was observed after hypolimnetic aeration, because "the aerated and unaerated sides of the lake were similar as far as *D. pulex* was concerned" (Ashley 1982). Like *D. pulex* in Black Lake (Ashley 1982), the vertical distribution of epilimnetic *D. pulex* in Amisk Lake was unaffected by oxygenation. However, hypolimnetic *D. pulex* in Amisk Lake were found between 7 and 1[illegible] m deeper in the hypolimnion at the Treatment than at the Reference site. The apparently conflicting responses of epi- and hypolimnetic *D. pulex* to oxygenation in

Amisk Lake may be resolved if they were comprised of different clonal genotypes. Co-existing clonal populations of *D. pulex* may be more common that previously thought (Hebert and Crease 1980), and clones of this species may have significantly different hemoglobin production capabilities, and thus differing tolerances to hypoxic conditions (Weider and Lampert 1985). In the Black Lake study (Ashley 1982), the *D. pulex* population may have consisted of a clonal genotype with a very high tolerance for hypoxic conditions. In summer 1989 in Amisk Lake, a clonal population with a low tolerance for hypoxic conditions (epilimnetic *D. pulex*), and a clonal population with a high tolerance for hypoxic conditions (hypolimnetic *D. pulex*) may have functioned as behaviorally distinct "species." The bimodal distributions of *Diacyclops bicuspidatus thomasi* and *D. pulex* in Amisk Lake in summer 1989 demonstrate that each zooplankton species should be examined independently during studies of aeration or oxygenation, as treatment effects on vertical distribution may vary substantially among species, and among two populations of a single species.

The two most common indices for reporting the "limiting" DO concentration for a species or population are: (1) the DO concentration below which few individuals are found (e.g. Langford 1938; Pennak 1944; Fast 1971; Judkins 1980), and (2) the DO concentration that is associated with the modal density (e.g. Longhurst 1967; Sherman et al. 1987). The first index makes the limiting DO concentration difficult to estimate, because there is often no obvious DO concentration below which "few individuals" are found. Most hypolimnetic zooplankton populations in Amisk Lake in summer 1989 contained a few evidently healthy individuals that appeared indifferent to ambient DO concentrations and thus were found several meters below the oxic-anoxic interface. On the other hand, an index based on the modal density may be biased in favor of a small portion of the total population, especially in populations whose distributions are extremely skewed. As a result, this index may be less meaningful than one which adequately reflects the preferences of the "median" individual. In this study, I have defined the MDO ("median" DO concentration) of a population or species as the DO concentration that is, on average, associated with the median depth of the population or species. This index describes the mean DO concentration that limits vertical distribution for 50% of the individuals of a population or species. Mean summer MDO's were calculated for the four dominant zooplankton species that resided in the hypolimnion of Amisk Lake in summer 1989. From July to September 1989, the MDO of each of these species was a relatively constant index of the influence of DO concentration on their vertical distribution.

These results support previous reports that DO concentration is important in the determination of the lower limit of vertical distribution of hypolimnetic zooplankton populations. For example, in Amisk Lake, the mean MDO (± 95% C.I.) for *Diacyclops bicuspidatus thomasi* from July to September 1989 was 1.5 ± 0.3 mg/L. This compares well with pre-aeration zooplankton data in El Capitan Reservoir (Fast 1971). Prior to destratification, approximately 70% of the zooplankton (mostly copepods) in El Capitan Reservoir were found above 8 m, below which, DO concentrations were < 1.3 mg/L (Fast 1971). However, after destratification, DO concentrations were above 1.5 mg/L down to a depth of 24 m, but the median depth of the copepod population was 15 m (Fast 1971). This seeming inconsistency may have resulted from Fast's (1971) grouping of two or more species of copepods; each may have had a different specific MDO. Alternatively, unknown chemical or biological variables may have acted in concert with DO concentration to limit zooplankton depth distribution. Peak (modal) densities of several deep water marine copepods (e.g. *Calanus helgolandicus*) occur at DO concentrations between 0.2 and 1.0 mg/L off the coast of California (Longhurst 1967), and in the eastern Pacific off Peru, 25% of a population of *Eucalanus inermis* was found below the 0.1 mg/L isopleth (Judkins 1980). In Amisk Lake, by comparison, modal densities of *Diacyclops bicuspidatus thomasi* were found at DO concentrations as low as 0.4 mg/L, and there were always a few individuals below the 0.1 mg/L isopleth at the Reference site. However, the MDO, as estimated from median depth, gave the most consistent estimate of the limiting DO concentration for each hypolimnetic species in Amisk Lake in summer 1989.

In previous studies, water temperature and vertical distribution of zooplankton have generally been poorly correlated. Vertical distributions of marine zooplankton were not linked to water temperatures off the coast of Peru (Judkins 1980). In three alpine lakes in Colorado, temperature differences between the epilimnion (20°C) and the hypolimnion (8°C) had no appreciable effect on vertical distribution of zooplankton (Pennak 1944). However, some species of *Daphnia* are clearly cold-water forms (e.g. *D. longiremis*) (Hutchinson 1967). In Amisk Lake, although the median depth of each hypolimnetic zooplankton species varied substantially among sites and sampling dates from July to September 1989, median depths were associated with a relatively constant species-specific MT (median water temperature) (e.g. *D. longiremis*: median depth ranged from 16.4 to 26.0 m, MT = 7.6 ± 0.8°C). For many hypolimnetic zooplankton, low DO concentrations may have determined the lower limit of distribution, while high water temperatures may have imposed an upper limit on their vertical distribution. For example, on 3 June 1989, the median depth of *D. longiremis* was 4.5 m, where the temperature was 9.7°C. By 3 July, the temperature at 4.5 m had increased to 16°C, and *D. longiremis* had moved down to a median depth of 21.6 m, where the temperature was 7.4°C. Thus, *D. longiremis* likely moved to the lower hypolimnion to avoid warmer surface waters, since no *D. longiremis* were found at depths with temperatures > 10°C during the period 3 July to 6 September. *D. pulex*, *Diacyclops bicuspidatus thomasi* and *B. longirostris* also migrated to the cooler waters of the lower hypolimnion when epilimnetic waters began to warm in June. For the balance of the open-water season, the four hypolimnetic zooplankton species appeared to remain as deep as ambient DO concentrations would allow.

Although hypolimnetic zooplankton in Amisk Lake in summer 1989 appeared to have a species-specific MT, the biological significance of the observed relationship between water temperature and vertical distribution is less clear. It is possible that the hypolimnetic zooplankton benefited from residence in the deep hypolimnion, which had much lower water temperatures than surface waters. Individuals in cooler waters may gain an energy bonus, through a reduction in basal metabolism, which can be channeled into growth and reproduction (McLaren 1963). However, this "energy bonus" would have to offset decreased growth rates (Kersting 1978) and fecundity (Goss and Bunting 1983) that result from residence in cooler waters. There would also have to be enough locally available food to effect this energy bonus, or the population would have to migrate up to a food resource for part of the day. Data from Amisk Lake in May and August 1984, and in May 1985 (E.E. Prepas and A.M. Trimbee, Univ. Alberta, unpubl. data) show that bacterial densities were approximately constant with depth, and densities of between 17 and $32 \cdot 10^5$ cells/mL were found at 25 m at the "main deep" (i.e. Treatment) site in the north basin. Since many species of *Daphnia* are non-selective feeders with respect to taste, they are better classified as detritivores rather than herbivores (Kerfoot and Kirk 1991), and bacteria can also be an important part of the diet of cladocerans (Wylie and Currie 1991). Lampert (1987) also suggests that one or more of phytoplankton, bacteria, protozoa, and detritus may contribute significantly to the diet of *Daphnia*. It is thus possible that hypolimnetic bacterial populations, along with phytoplankton and detritus falling from surface waters, may have served as a major food resource for hypolimnetic cladoceran zooplankton populations in Amisk Lake in summer 1989. The carnivorous species *Diacyclops bicuspidatus thomasi* can feed selectively on soft-bodied rotifers, while avoiding cladocerans (Stemberger 1985). It is possible that an adequate population of suitable rotifer prey supported the large *Diacyclops bicuspidatus thomasi* population in the hypolimnion of each basin of Amisk Lake during summer 1989, although no data were collected on rotifer population density.

I believe that in summer 1989 in Amisk Lake, the lower limits of vertical distribution of *D. longiremis*, *B. longirostris*, and of hypolimnetic populations of *D. pulex* and *Diacyclops bicuspidatus thomasi*, were strongly influenced by a species-specific MDO. In order to remain at their MDO, hypolimnetic populations were forced to inhabit increasingly shallower waters at the Reference site as the summer progressed. However, oxygenation allowed hypolimnetic populations to distribute significantly deeper at the Treatment than at the Reference site, while still residing at their MDO. The upper limit of distribution of these hypolimnetic species was probably influenced by water temperature, as each species had a relatively constant MT. However, it appeared that ambient DO concentrations had a greater effect on vertical distribution of hypolimnetic zooplankton than water temperatures, since zooplankton would move up into warmer water in order to reside at their MDO. It is possible that below the thermocline, temperatures were not warm enough to limit the vertical distribution of hypolimnetic zooplankton. Thus, these species would have been able to exploit food resources (e.g. bacteria, detritus) at all depths within the hypolimnion where DO concentration was not limiting.

Diel Migration of Hypolimnetic Zooplankton

I predicted that hypolimnetic oxygenation would result in an increase in the amplitudes of diel migration of hypolimnetic zooplankton in the treatment basin of Amisk Lake. Our results indicate that this prediction was supported for one of four hypolimnetic species, but only the August 1989 survey. On 3 and 4 June 1989, cyclopoid copepods migrated further at the Treatment than at the Reference site. However, the minimum hypolimnetic DO concentration at both sites was > 1.5 mg/L (the MDO of *Diacyclops bicuspidatus thomasi*), and thus variation in DO concentration was not likely responsible for the greater amplitude of migration at the Treatment site. The rate of vertical movement of *Daphnia* varies proportionally with temperature (McNaught and Hasler 1964), and oxygenation increased the mean hypolimnetic temperature by 1°C at the Treatment relative to the Reference site. However, even if rates of vertical movement of cyclopoid copepods in Amisk Lake were proportional to temperature, a difference of 1°C is likely too small to have caused significantly different rates of diel movement between the cyclopoid copepods populations at the Treatment and Reference sites (McNaught and Hasler 1964). *D. longiremis* populations were found primarily within the epilimnion at the Treatment and Reference sites during this survey, and there were no significant differences in DO concentration or temperature between the epilimnia of these two sites. Observed differences in amplitudes of vertical migration between the Treatment and Reference site populations of cyclopoid copepods and *D. longiremis* were the result of unknown variables, and not hypolimnetic oxygenation.

The data from 11 and 12 August 1989 show that oxygenation may have enhanced diel vertical migration, but only for *D. longiremis*. At the Treatment site, *D. longiremis* distributed deepest (median depth 26.0 m) during the day, and moved up 4 m (median amplitude) at night. The oxygenation maintained DO concentrations > 1.7 mg/L (species estimated MDO) at all depths above 24 m at this site, and between 1.0 and 1.7 mg/L from 25 to 31 m. Most *D. longiremis* were therefore not limited in distribution by low DO concentrations, and were able to migrate freely to any depth at the Treatment site. In contrast, no diel vertical movement was detected for *D. longiremis* at the Reference site (median depth 16.4 m day and night). At this site, DO concentrations were < 1.7 mg/L (species estimated MDO) below 15 m, and < 1.0 mg/L below 17 m. Thus, probably due to oxygen limitation, most *D. longiremis* at the Reference site were found at shallower depths, and appeared to migrate less, than those at the Treatment site. The mean hypolimnetic temperature was 1°C warmer at the Treatment than at the Reference site. This difference was probably too small to contribute significantly to differences in amplitude of vertical migration of *D. longiremis* at Treatment and Reference sites (McNaught and Hasler 1964). Diel migrations of hypolimnetic *D. pulex* and *Diacyclops bicuspidatus thomasi* were probably not limited by ambient DO concentrations at the Treatment site, but diel movements were insignificant. At the Treatment site, the unknown selective force(s) that caused the diel movements of *D. longiremis* did not affect *D. pulex* and *Diacyclops bicuspidatus thomasi* to the same degree. Populations of hypolimnetic *D. pulex* and *Diacyclops bicuspidatus thomasi* had nearly collapsed at the Reference site, possibly as a result of hypoxic conditions in the lower hypolimnion, and thus it was not possible to estimate amplitudes of diel migration.

Biomass of Epilimnetic Plankton and Zooplankton

During the summers of 1988 and 1989, hypolimnetic oxygenation apparently had no significant impact on epilimnetic (0 to 6 m; 0 to 10 m) plankton or zooplankton biomass of the > 243-µm fraction, since biomasses in treatment and reference basins were similar. It is possible that treatment effects were undetectable due to inter-basin exchange of water. The two basins are connected by a 13-m deep (z_{max}) by 350-m wide (mean width) channel, and zooplankton may have been entrained in epilimnetic currents and transferred between basins, thus masking any differences in epilimnetic zooplankton biomass between treatment and reference basins. However, the similarity in epilimnetic zooplankton biomass between basins is not an unexpected result, as hypolimnetic oxygenation did not significantly alter epilimnetic temperatures or DO concentrations.

Oxygenation was probably responsible for the decrease in both basins in plankton biomass > 64-µm from summer 1988 to summer 1989. Oxygenation of Amisk Lake during the winter of 1988-89 may have been responsible for the delay in the onset of the cyanobacterial bloom in summer 1989. As a result, in June to August 1989, the biovolume of cyanobacteria at a depth of 3 m was four to eight times lower than during the same period in 1988 (D. Webb, Univ. Alberta, unpubl. data). In summer 1989, almost 50% of the biomass of plankton > 64 µm consisted of phytoplankton. If this condition were true for the 1988 plankton > 64 µm, the large decrease in plankton biomass of this size fraction in 1989 may have been due partially to the decrease in cyanobacteria, of which some taxa were large colonial masses (e.g. *Gomphosphaeria* spp.) that might have easily been sampled with a mesh net of 64-µm size (D. Webb, Univ. Alberta, pers. commun.). In addition, total phosphorus and chlorophyll a concentrations, which are correlates of phytoplankton biomass, have decreased from historic values (Prepas et al. ms submitted). While hypolimnetic oxygenation had no apparent effect on epilimnetic plankton and zooplankton biomass > 243 µm in the summers of 1988 or 1989, the treatment was likely responsible for the decrease in plankton biomass > 64 µm from summer 1988 to summer 1989.

Abundance of Hypolimnetic Zooplankton

Abundances of two of the four hypolimnetic zooplankton species may have increased in the treatment basin as a result of oxygenation, but only at the deepest site. Generally, hypolimnetic oxygenation did not appear to affect abundances of *Diacyclops bicuspidatus thomasi* and *B. longirostris*. However, *D. longiremis* and *D. pulex* were substantially more abundant at Treatment site 2 than at Reference site 1 in summer 1989, and several times more abundant at Treatment site 2 in summer 1989 than at this site in the pre-treatment summer of 1984. In addition, the seasonal population collapses of *D. longiremis* and *D. pulex* were delayed at Treatment site 2 relative to the other three lake sites. The variation in abundance between Treatment sites 1 and 2 in summer 1[illegible] was likely due to differences in site-depth. After oxygenation increased the availability of suitable habitat in the deep hypolimnion of the treatment basin, zooplankton populations may have moved from shallower areas, such as Treatment site 1, to aggregate in deeper areas of the basin, such as the 31-m deep Treatment site 2. It is not known how localized this event was, but hypolimnetic zooplankton species apparently preferred to move below 21 m, the maximum depth of Treatment site 1. Apparently, hypolimnetic oxygenation and adequate depth permitted Treatment site 2 to maintain much denser aggregates of zooplankton than the hypoxic Reference sites and the shallow Treatment site.

Our data provide evidence that oxygenated lakes may sustain greater densities of hypolimnetic zooplankton, and for a greater portion of the open-water season than lakes with untreated, hypoxic hypolimnia. Further work is needed to establish the impact of hypolimnetic oxygenation on horizontal variation in total biomass, abundance and production of pelagic zooplankton. However, if results in the treatment basin are indicative of an increase in production of zooplankton, then hypolimnetic oxygenation may provide a greater food resource for deep-water planktivorous fishes, such as cisco (*Coregonus artedi*).

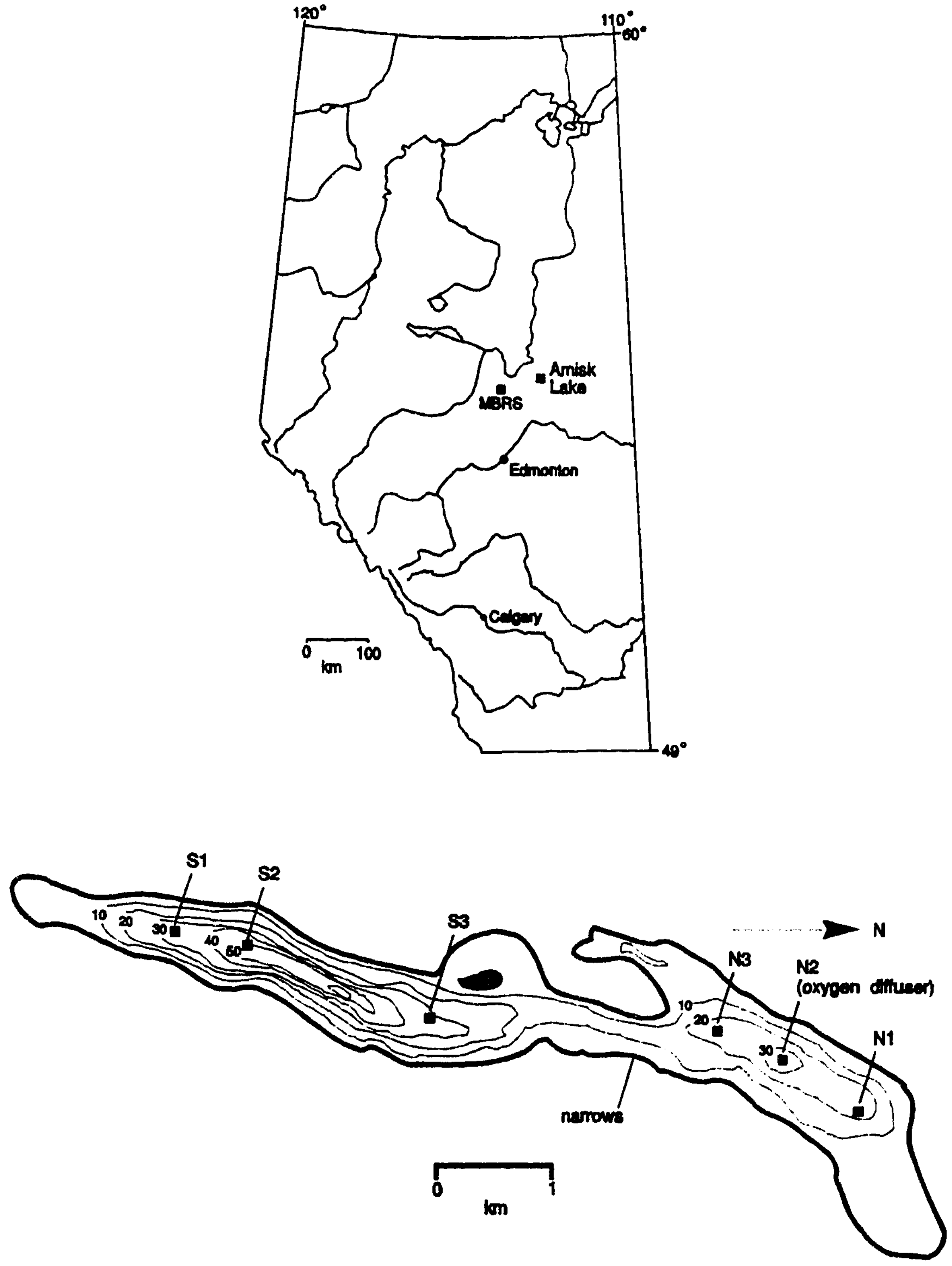

FIG. 1. Geographical location and contour map of Amisk Lake, Alberta. Research facilities were provided at Meanook Biological Research Station (MBRS). Squares on contour map indicate sampling sites in north and south basins of the lake. The oxygen diffuser was located at a depth of 34 m at site N2.

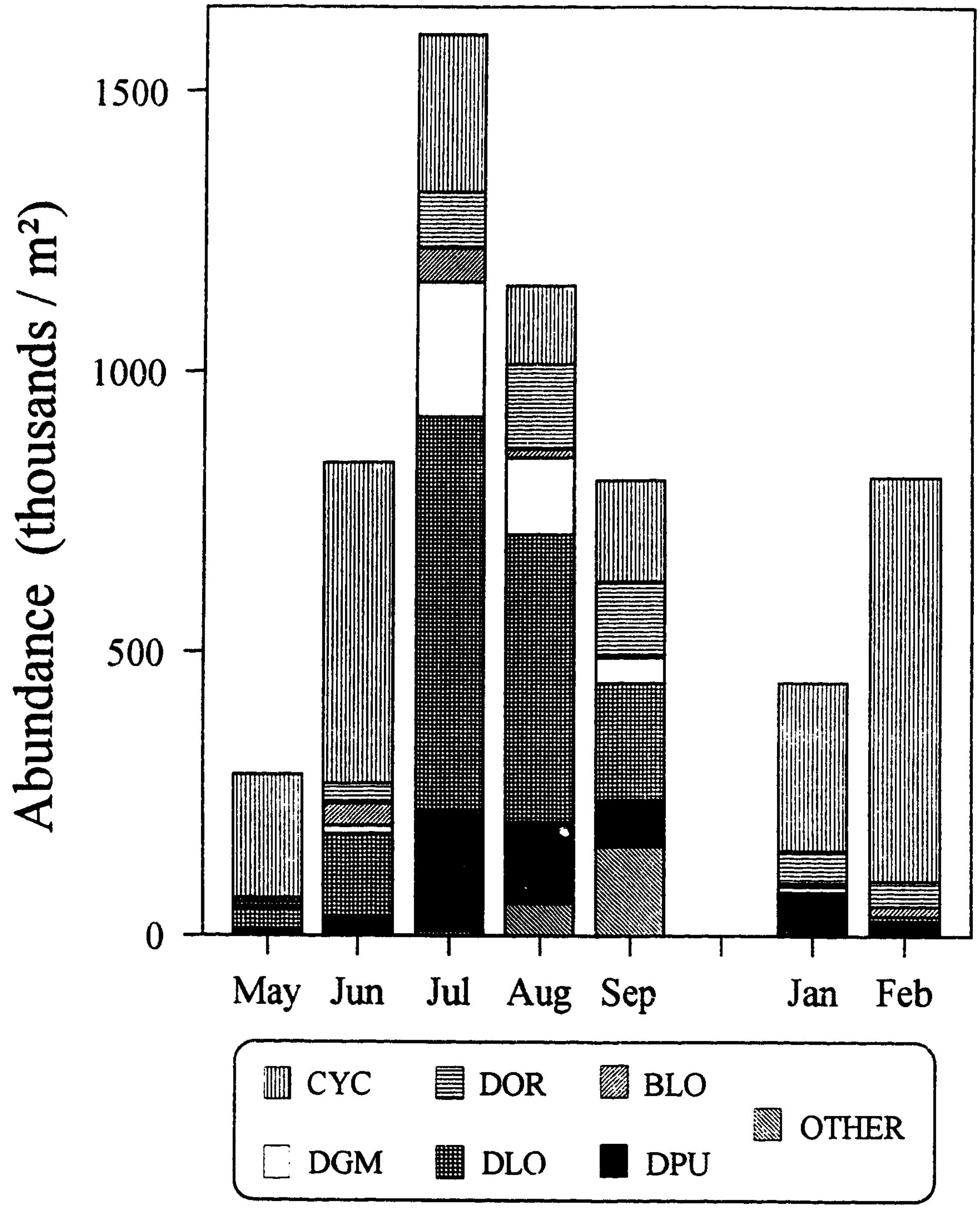

FIG. 2 Mean areal abundance (whole water column) of pelagic zooplankton in summer 1989 and winter 1990 in Amisk Lake. Data were collected on one date in each month, except in July (bar is mean of 3, 11, 25 July). BLO = *Bosmina longirostris*; CYC = *Diacyclops bicuspidatus thomasi* + *Acanthocyclops vernalis*; DGM = *Daphnia galeata mendotae*; DLO = *Daphnia longiremis*; DOR = *Diaptomus oregonensis*; DPU = *Daphnia pulex*; OTHER = All other taxa in samples - see text for description.

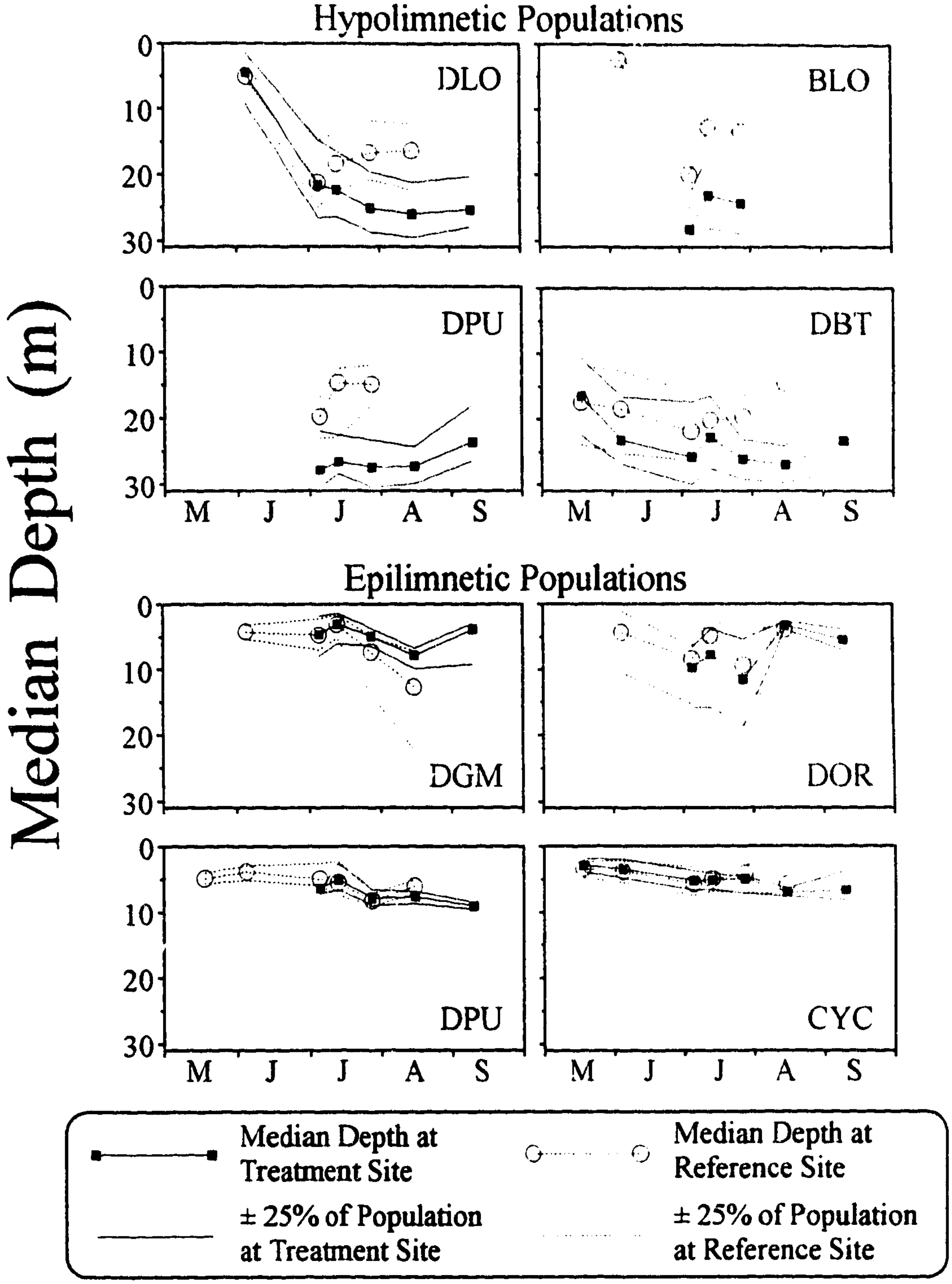

FIG. 3. Vertical distribution of the dominant zooplankton taxa during summer 1989 in Amisk Lake. Frames show median vertical depths (± 25% of population) for zooplankton at the Treatment and Reference sites. Median depths were not calculated for populations with mean water column densities < 1.0 animal/L. DBT = hypolimnetic *Diacyclops bicuspidatus thomasi*; other taxa labels as in FIG.2.

TABLE 1. Statistical comparison of median depths (median test, Zar 1974) of populations of pelagic zooplankton at the Treatment 2 and Reference 1 sites in Amisk Lake, during the period June to August 1989. ns = median depths of populations were similar; T = Treatment population was significantly deeper; R = Reference population was significantly deeper; *P* = statistical probability; numerical value in meters (m) on last line of cell indicates absolute difference in median depth between Treatment site 2 and Reference site 1 populations.

Taxon	Jun 03	Jul 03	Jul 11	Jul 25	Aug 11
Daphnia longiremis	ns $P > 0.5$ 0.6 m	ns $P > 0.9$ 0.3 m	T $P < 0.001$ 4.0 m	T $P < 0.001$ 8.4 m	T $P < 0.001$ 9.6 m
Bosmina longirostris	-	T $P < 0.001$ 8.3 m	T $P < 0.001$ 10.4 m	ns $P > 0.1$ 11.0 m	-
hypolimnetic *Daphnia pulex*	-	T $P < 0.001$ 8.0 m	T $P < 0.001$ 11.9 m	T $P < 0.001$ 12.5 m	-
hypolimnetic cyclopoid copepods	T $P < 0.001$ 4.7 m	T $P < 0.001$ 3.9 m	T $P < 0.05$ 2.6 m	T $P < 0.001$ 6.4 m	T $P < 0.01$ 12.4 m
Daphnia galeata mendotae	-	ns $P > 0.5$ 0.1 m	ns $P > 0.5$ 0.1 m	R $P < 0.01$ 2.4 m	R $P < 0.05$ 5.5 m
Diaptomus oregonensis	-	ns $P > 0.5$ 1.3 m	ns $P > 0.1$ 2.9 m	ns $P > 0.1$ 2.2 m	R $P < 0.01$ 0.7 m
epilimnetic *Daphnia pulex*	-	T $P < 0.05$ 1.4 m	ns $P > 0.5$ 0.5 m	ns $P > 0.5$ 0.4 m	ns $P > 0.1$ 1.6 m
epilimnetic cyclopoid copepods	ns $P > 0.5$ 0.3 m	ns $P > 0.5$ 0.5 m	ns $P > 0.9$ 0.1 m	ns $P > 0.5$ 0.8 m	T $P < 0.05$ 1.2 m

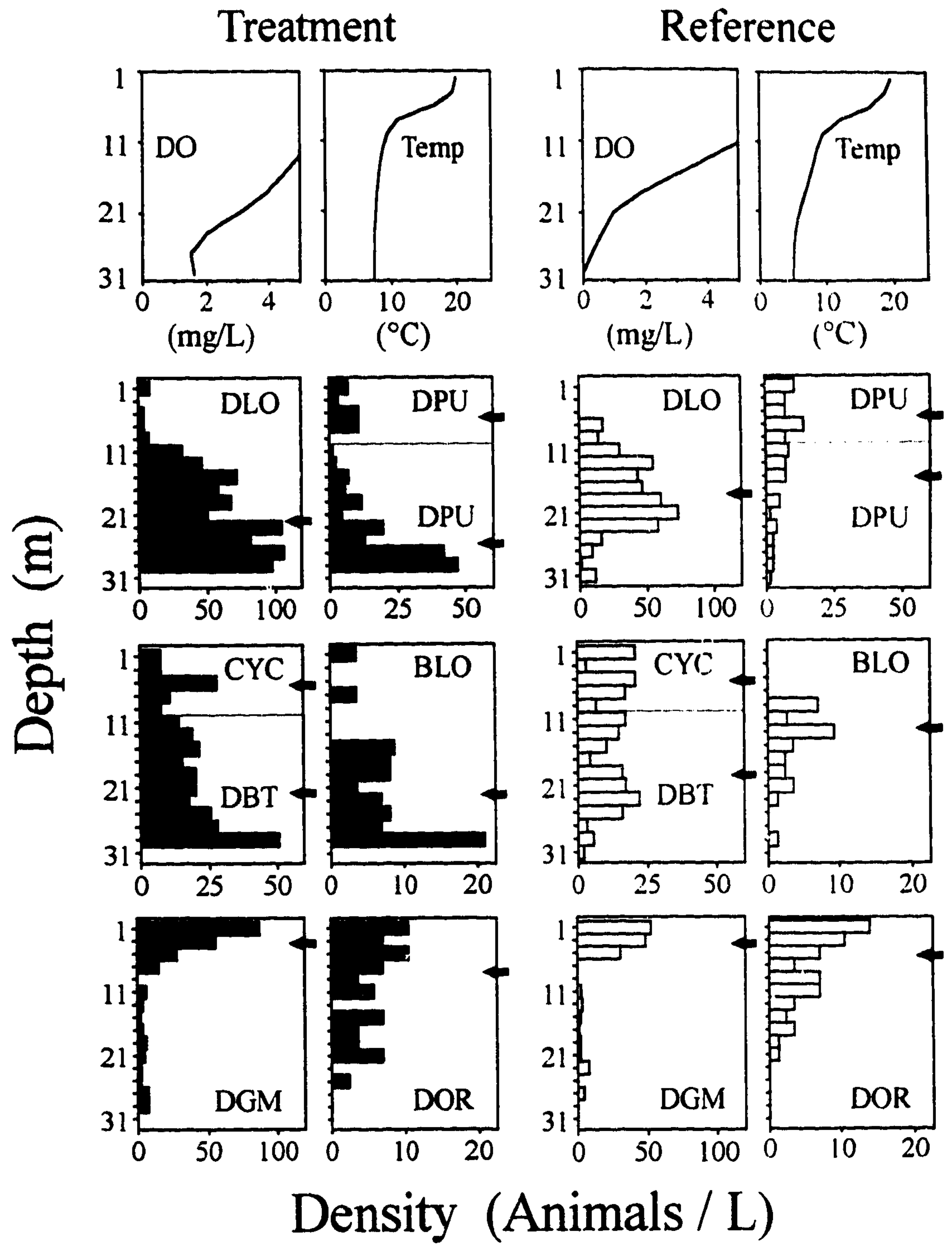

FIG. 4. Vertical profiles of dissolved oxygen (DO), temperature (Temp), and the dominant pelagic zooplankton on 11 July 1989 at the Treatment and Reference sites of Amisk Lake. Note that the density axis varies from a maximum of 20 to 100 animals/L. Arrows on right side of each frame indicate median depth of population. Where two arrows are present on one graph, the upper is the median of the epilimnetic population, the lower is the median of the hypolimnetic population, and the horizontal line indicates the top of the hypolimnion. Taxa labels as in FIG. 3.

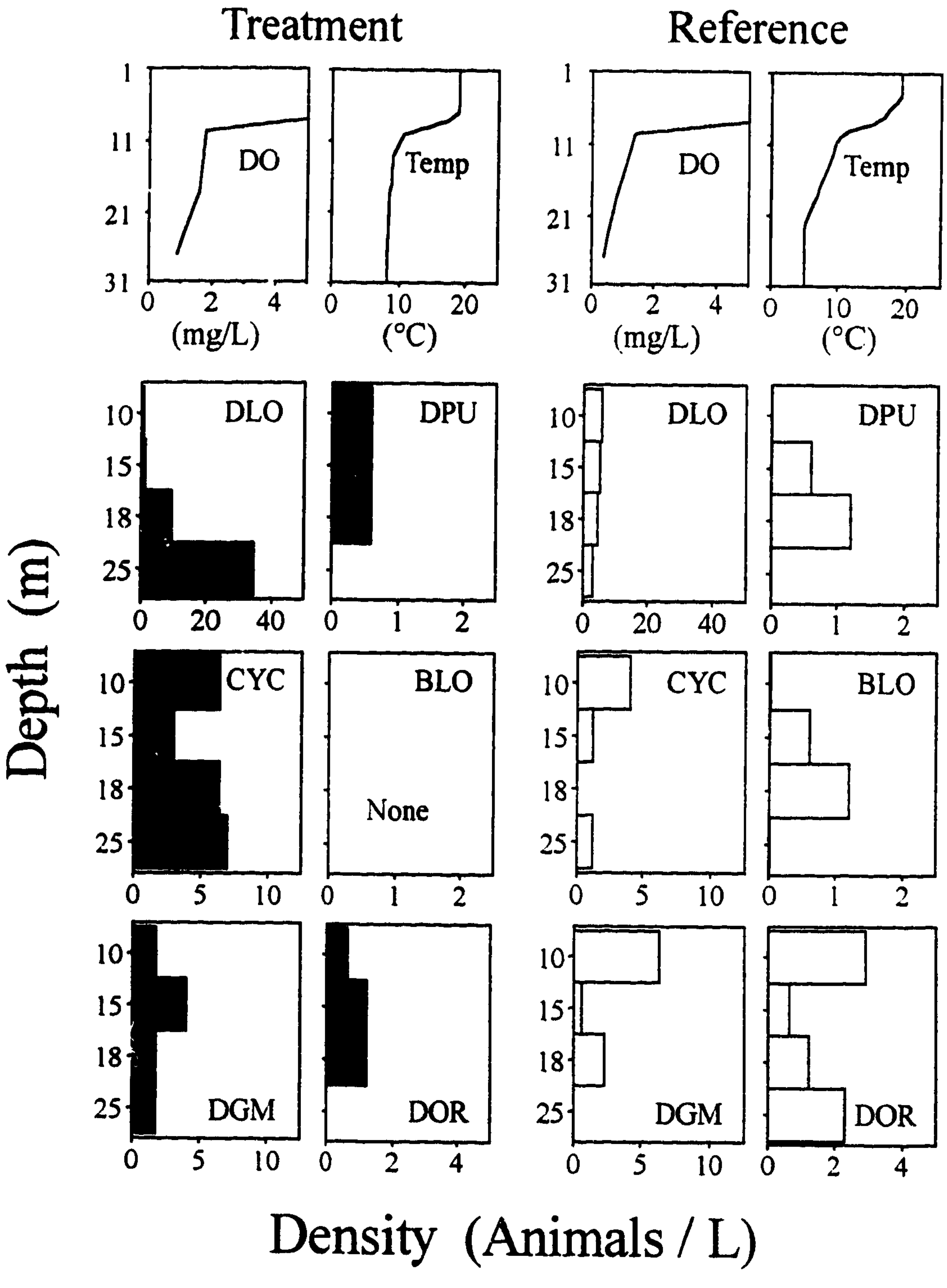

FIG. 5. Vertical profiles of dissolved oxygen (DO), temperature (Temp), and the dominant pelagic zooplankton on 7 August 1988 in the treatment and reference basins of Amisk Lake. Each bar represents a pooled mean from three sites per basin. Note that the density axis varies from a maximum of 2 to 40 animals/L. Dissolved oxygen and temperature profiles are from Treatment 2 and Reference 1 sites. Taxa labels as in FIG. 2.

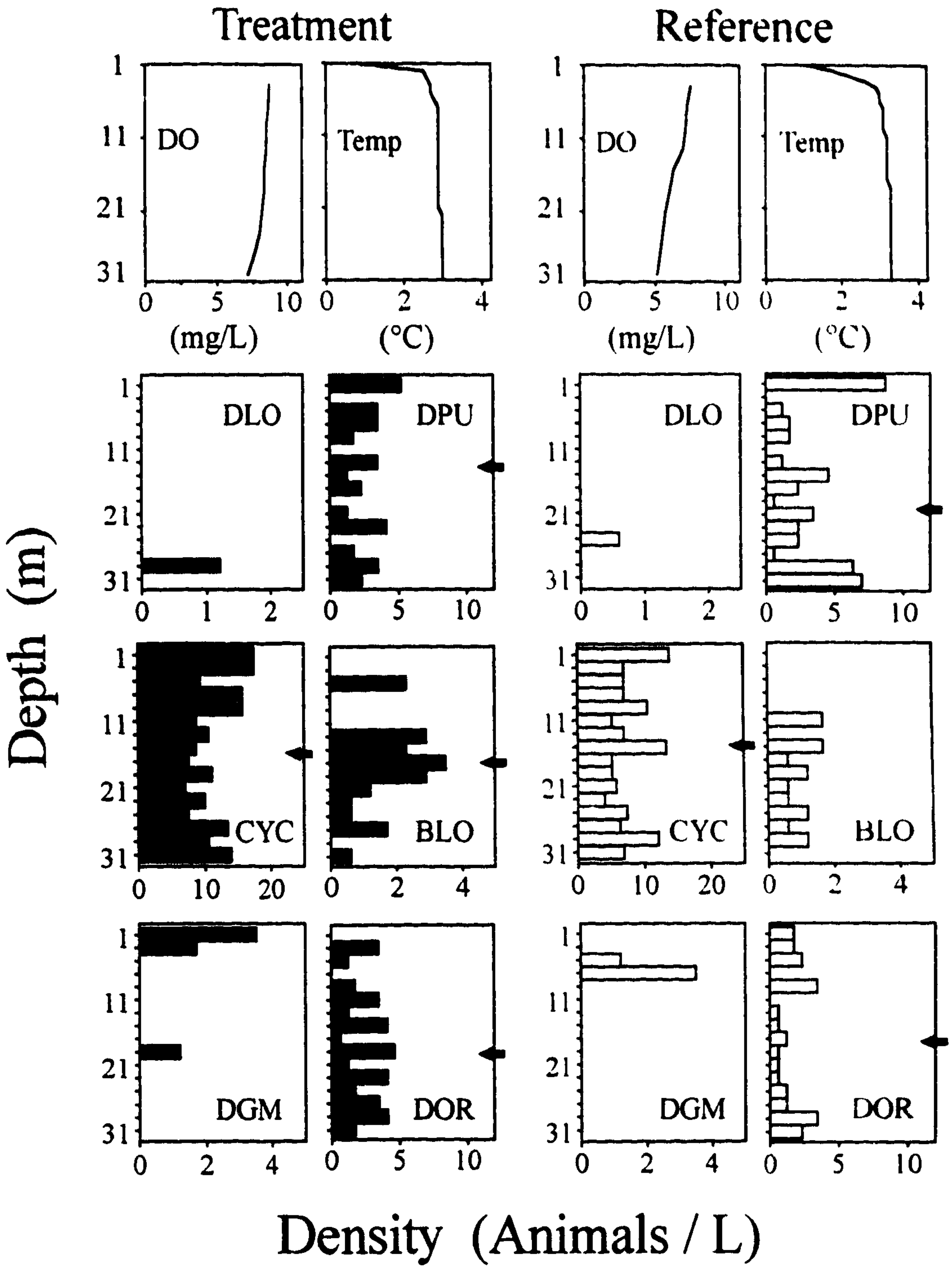

FIG. 6. Vertical profiles of dissolved oxygen (DO), temperature (Temp), and the dominant pelagic zooplankton on 17 January 1990 at the Treatment site and on 16 January 1990 at the Reference site, in Amisk Lake. Note that the density axis varies from a maximum of 2 to 20 animals/L. Arrows on right side of frame indicate median depth of population. No arrows are given for populations whose mean density was < 1 animal/L. Taxa labels as in FIG. 2.

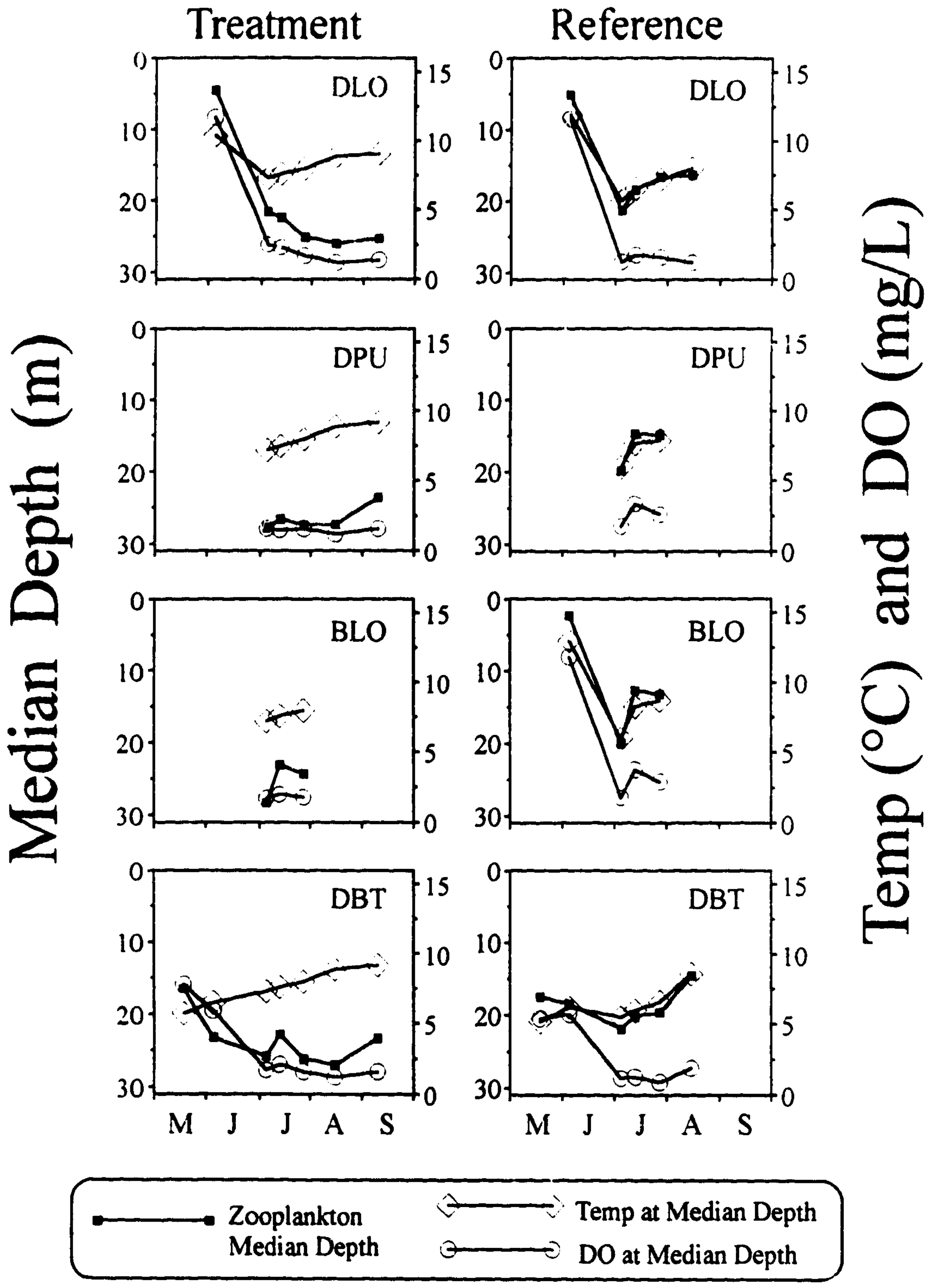

FIG. 7. Median vertical depths (left vertical axis) for the four dominant hypolimnetic zooplankton populations at the Treatment and Reference sites in Amisk Lake during summer 1989, and temperatures (Temp) and dissolved oxygen concentrations (DO) associated with these median depths (right vertical axis). Taxa labels as in FIG. 3.

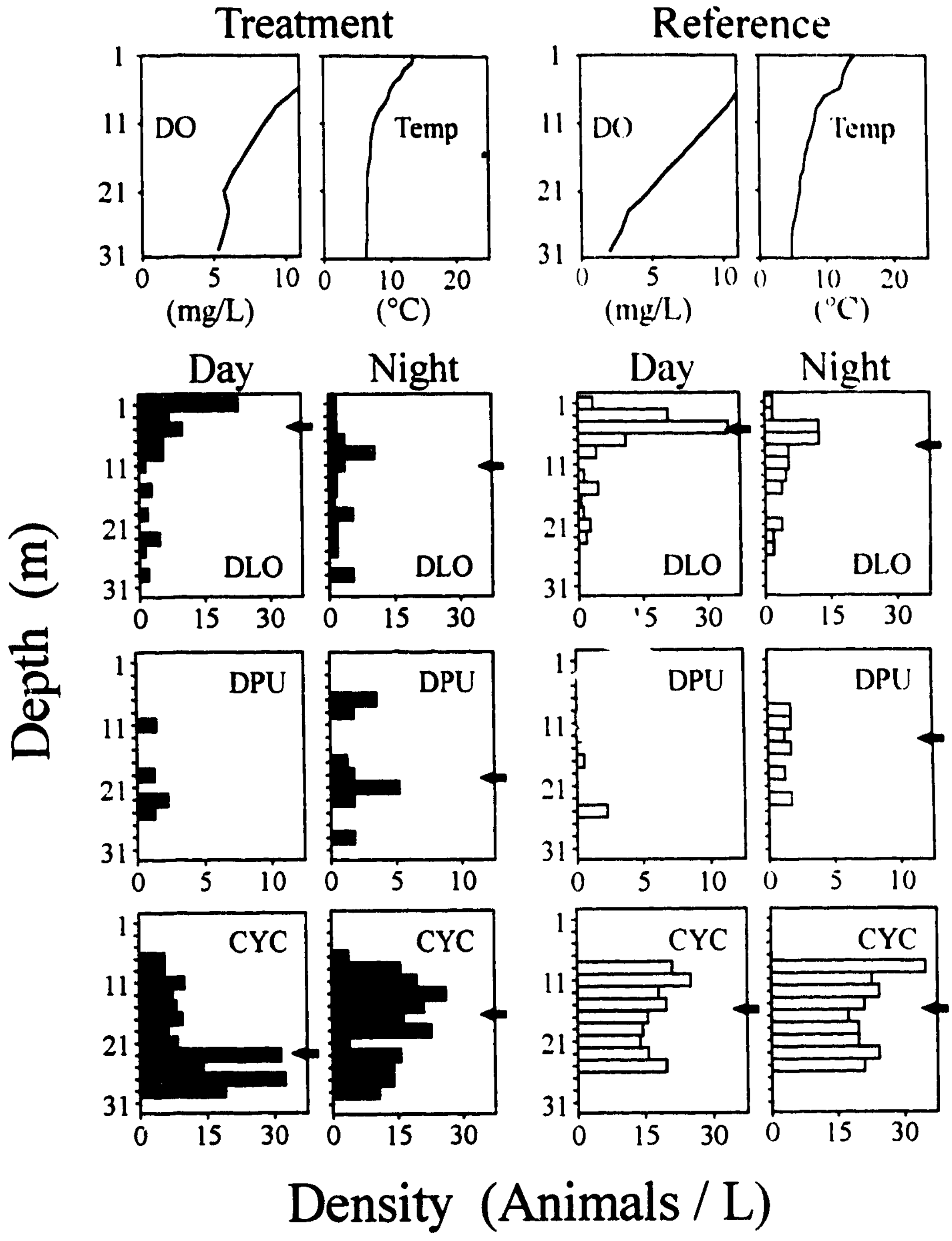

FIG. 8. Diel vertical profiles of dissolved oxygen (DO), temperature (Temp), and zooplankton on 3 and 4 June 1989 at the Treatment and Reference sites in Amisk Lake. Profiles of zooplankton were taken at 1200 h on 3 June (Day) and at 0000 h on 4 June (Night). Dissolved oxygen and temperature profiles are from 3 June (Day). Note that the density axis varies from a maximum of 10 to 30 animals/L. Arrows on right hand side of frame indicate median depths of populations. Taxa labels as in FIG. 2.

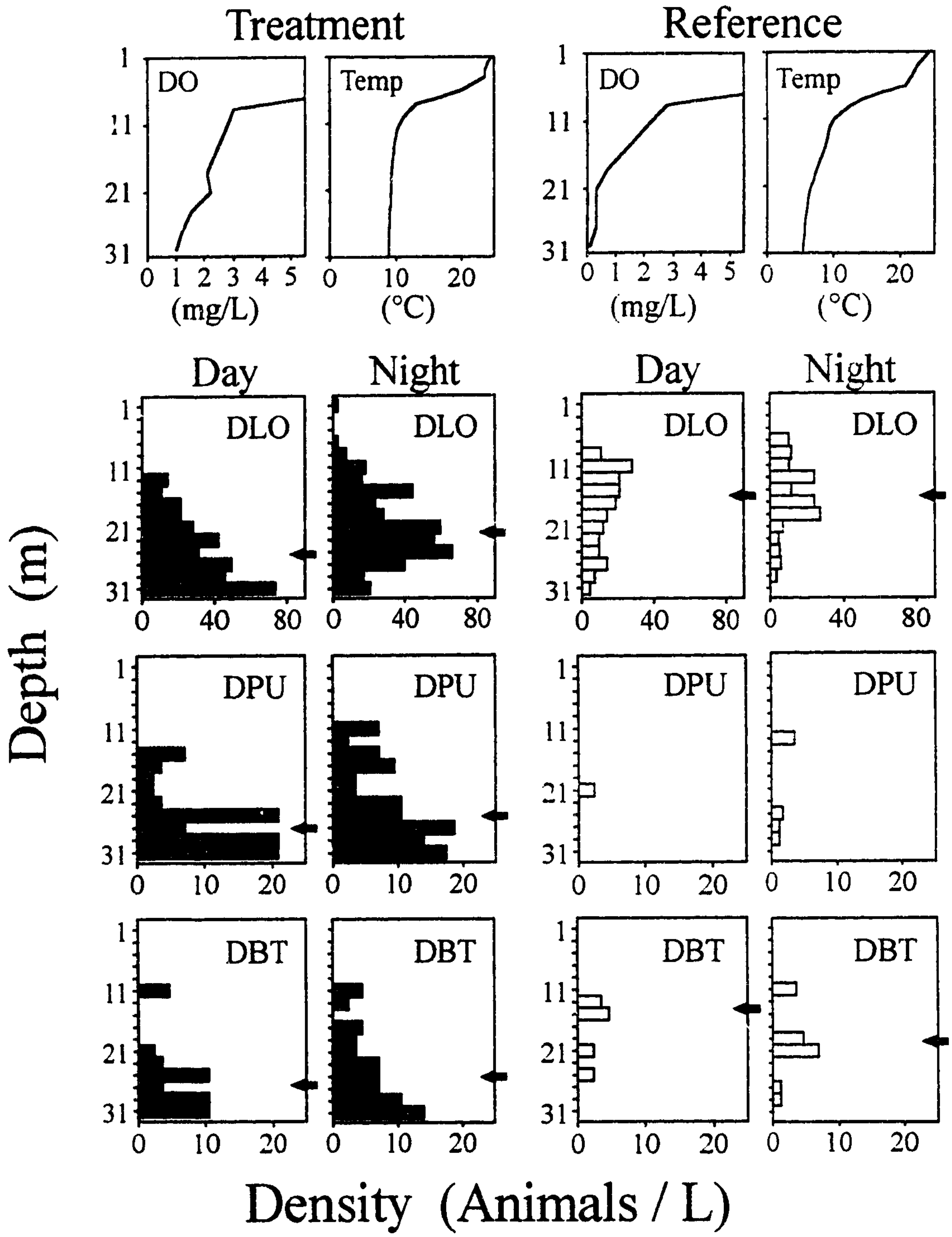

FIG. 9. Diel vertical profiles of dissolved oxygen (DO), temperature (Temp), and zooplankton on 11 and 12 August 1989 at the Treatment and Reference sites in Amisk Lake. Profiles of zooplankton were taken at 1200 h on 11 August (Day) and at 0000 h on 12 August (Night). Dissolved oxygen and temperature profiles are from 11 August (Day). Note that the density axis varies from a maximum of 20 to 80 animals/L. Arrows on right hand side of frame indicate median depths of populations. Taxa labels as in FIG. 3.

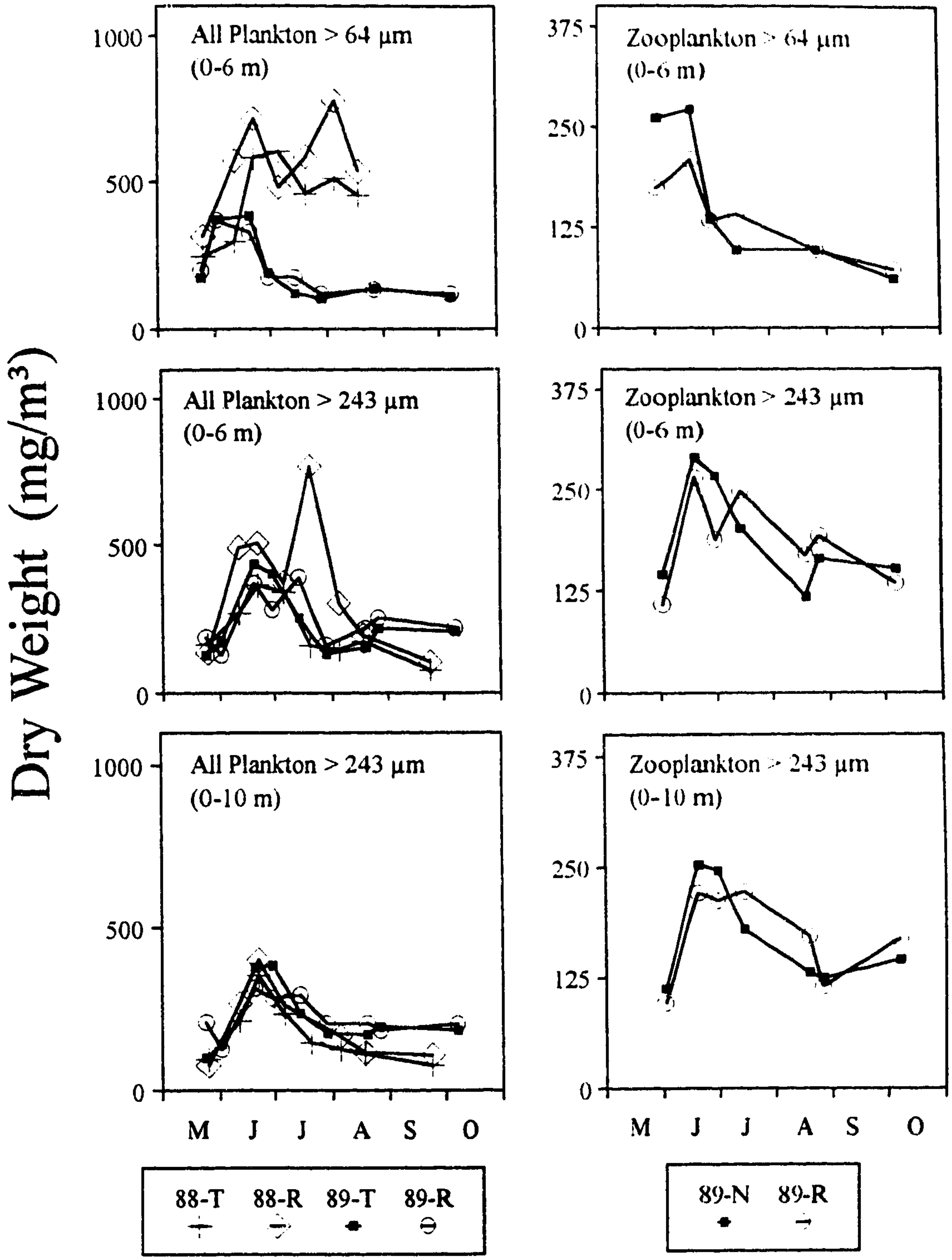

FIG. 10. Epilimnetic plankton biomass in summer 1988 (88) and 1989 (89) in the treatment (T) and reference (R) basins of Amisk Lake. Data are pooled means from two to three sites per basin on each date. All Plankton = zooplankton + phytoplankton; Zooplankton = zooplankton only (1989 only).

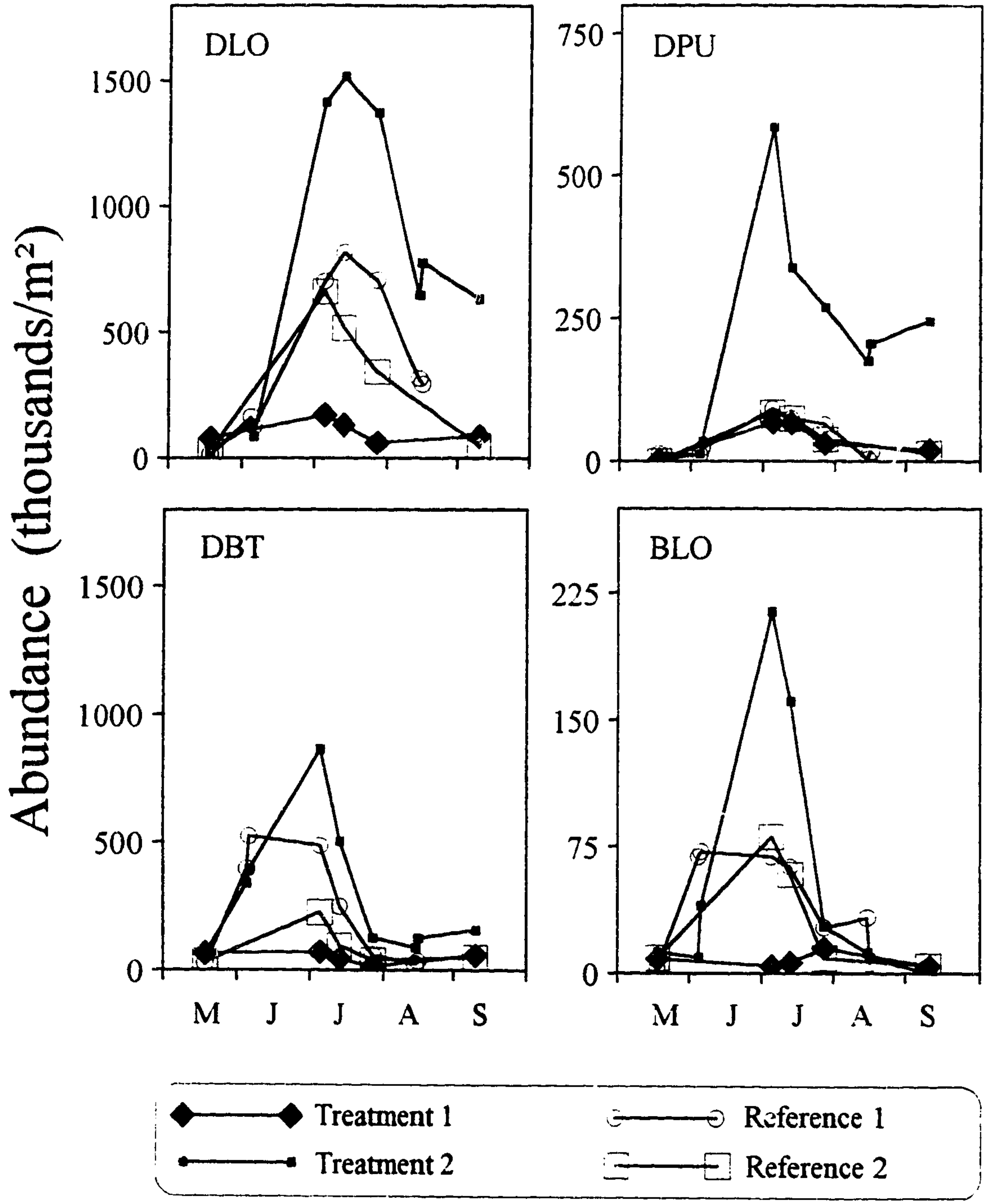

FIG. 11. Areal abundance of the dominant hypolimnetic zooplankton in summer 1989 at Treatment sites 1 (21 m deep) and 2 (31 m deep) and at Reference sites 1 (31 m deep) and 2 (49 m deep) in Amisk Lake. Note that maximum abundance varies among taxa from 225 to 1500 · 10^3 animals/m². Taxa labels as in FIG. 3

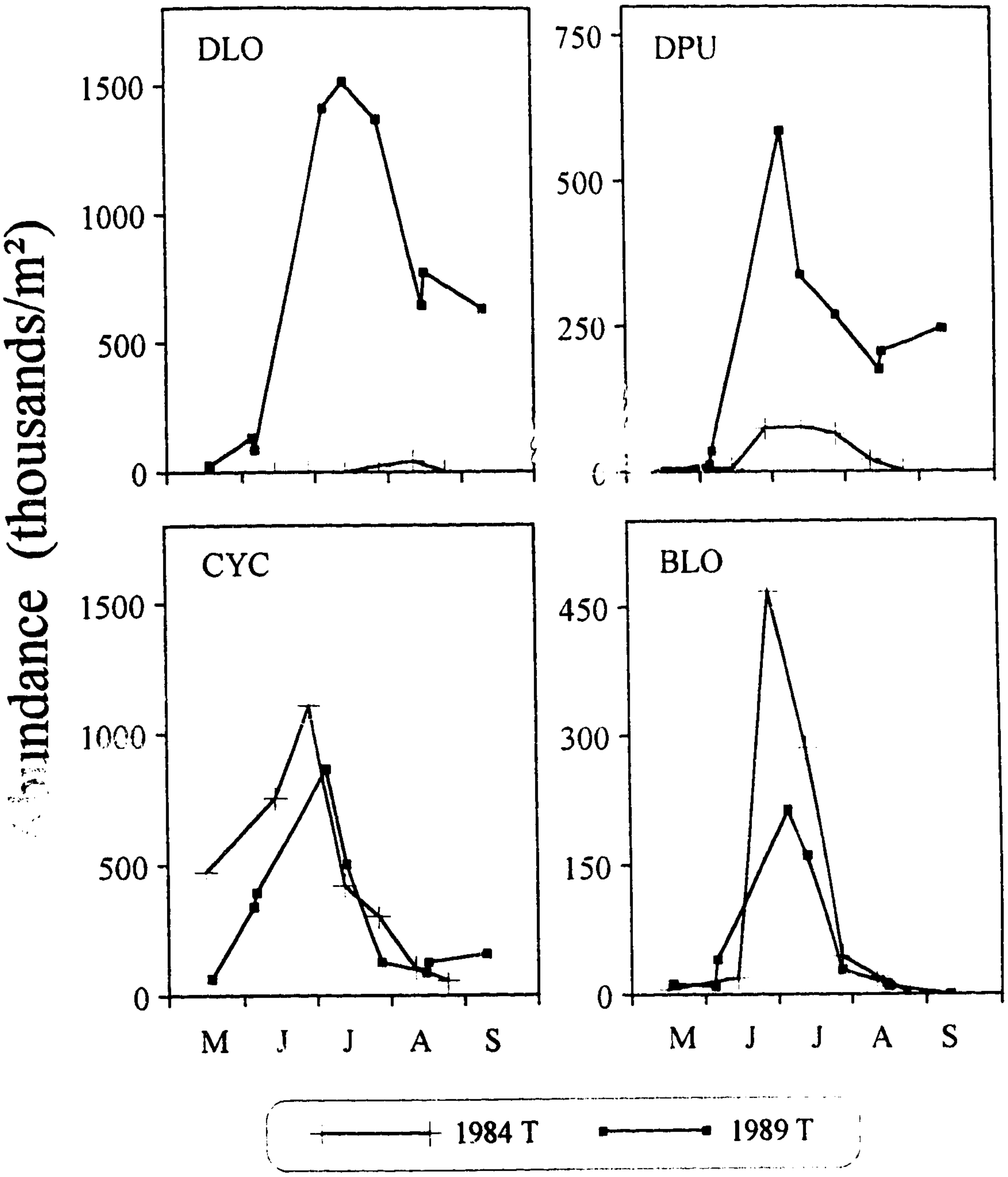

FIG. 12. Areal abundance (hypolimnetic) of the dominant four hypolimnetic zooplankton taxa in Amisk Lake at Treatment site 2, in summer 1984 (four years before treatment) and summer 1989 (second year of oxygenation). Note that maximum abundance varies among taxa from 450 to 1500 · 10^3 animals/m². (Data from 1984 E.E. Prepas, Univ. Alberta, unpubl.). Taxa labels as in FIG. 2.

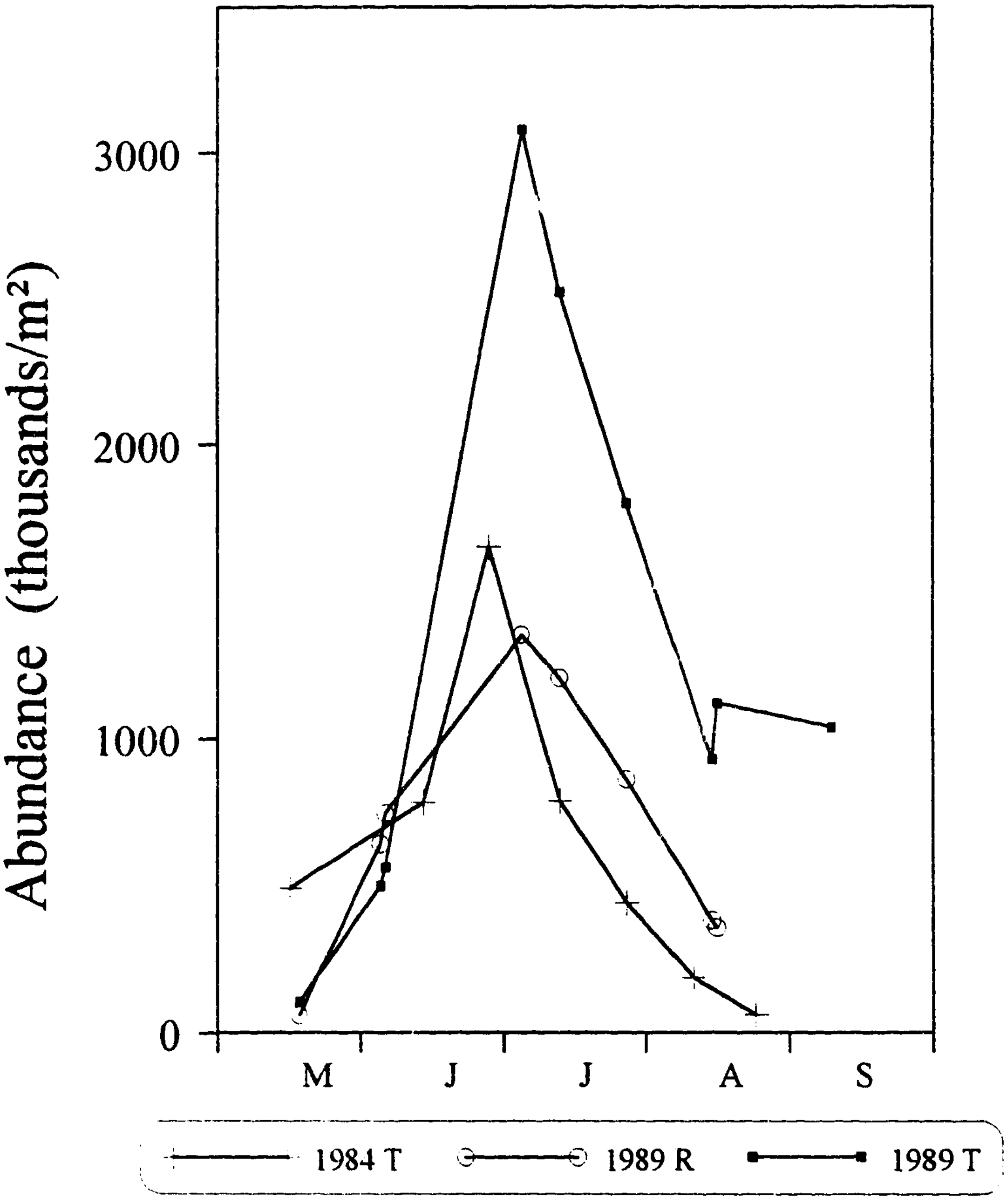

FIG. 13. Combined areal abundances (hypolimnetic) of the dominant four hypolimnetic zooplankton taxa at Treatment site 2 (T) in summer 1984 (four years before treatment), and at Reference site 1 (R) and Treatment site 2 (T) in summer 1989 (second year of oxygenation). (Data from 1984 E.E. Prepas, Univ. Alberta, unpubl.).

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III. General Discussion and Conclusions

(1) Vertical Distribution of Zooplankton

In Amisk Lake, hypolimnetic oxygenation did not significantly affect vertical distribution of epilimnetic zooplankton in summer 1989. However, from July to September 1989, hypolimnetic populations of *Daphnia longiremis*, *Daphnia pulex*, *Diacyclops bicuspidatus thomasi* and *Bosmina longirostris* were found between 5 and 10 m deeper (median depths) at the Treatment than at the Reference site. During this period in the reference basin, hypolimnetic zooplankton were excluded from depths below 20 m (median depth) by DO concentrations of between 0.0 and 1.3 mg/L. However, hypolimnetic oxygenation in the treatment basin maintained DO concentrations between 1.0 and 3.0 mg/L in the 21 to 30 m depth stratum until late August, and thus hypolimnetic zooplankton were able to move into this deepwater habitat. Thus, for each hypolimnetic zooplankton species, differences in median depth between Treatment and Reference populations were explained by differences in ambient hypolimnetic DO concentration at the Treatment and Reference sites.

In addition, hypolimnetic populations of *D. longiremis*, *D. pulex*, *Diacyclops bicuspidatus thomasi* and *B. longirostris* had specific "median" DO concentrations (MDO's) during the period July to September 1989. For hypolimnetic populations of each of these species, the median depths varied considerably between sites and among sampling dates, but the DO concentrations associated with the median depths of populations were relatively constant. At both the Treatment and Reference sites, populations moved up or down in the water column in order to track their MDO. Thus, in summer 1989 in Amisk Lake, the vertical distribution of each species of hypolimnetic zooplankton appeared to be strongly influenced by a specific MDO.

In previous studies of hypolimnetic aeration, vertical distributions of pelagic zooplankton have generally been unaffected by treatment (McQueen and Lean 1986). However, I believe that treatment effects will be more apparent if the experimental system meets several criteria. First, the DO concentration should be approaching zero in the lower 5 to 10 m of the reference hypolimnion, while remaining above 2.0 mg/L throughout most of the treatment hypolimnion. If DO concentrations are too high in the reference hypolimnion, vertical distributions of zooplankton may not be limited; if DO concentrations are near zero in both treatment and reference hypolimnia, zooplankton may be excluded from both systems. For example, DO concentrations on the unaerated side of Black Lake, British Columbia, were not low enough to limit distribution of *D.*

pulex, and as a result, distributions of this species were similar on aerated and unaerated sides of the lake (Ashley 1982). Second, treatment and reference systems should have hypolimnia that are at least 5 to 10 m deep. In the reference hypolimnion, the anoxic stratum must be deep enough to allow the observer to differentiate between resident zooplankton, and zooplankton that are just making a quick foray down into anoxic waters. For example, in an anoxic hypolimnion 3 m deep, are zooplankton caught in this stratum resident, or have they just come down from the epilimnion for a moment? In contrast, healthy zooplankton found several meters into hypoxic waters are likely residents of this area. Third, each zooplankton species should be examined separately in each of the epi- and hypolimnion of the experimental system. This was necessary in Amisk Lake, where the response to oxygenation varied substantially among species, and between the epi- and hypolimnetic populations of two species (*D. pulex* and *Diacyclops bicuspidatus thomasi*). Fourth, zooplankton samples should be collected at a small depth interval throughout the water column, and all depths should be examined separately. The depth interval will depend upon available resources, and upon the depth of the lake, but I estimate that a depth interval of 3 m may have been adequate to assess treatment effects on vertical distribution of zooplankton in Amisk Lake (depth of Treatment and Reference sites = 31 m; depth of hypolimnion = 20 m). In shallower lakes, the depth interval should be correspondingly smaller. I believe that when the above criteria are met in a system undergoing hypolimnetic oxygenation, one may observe that hypolimnetic zooplankton extend their vertical distributions into the previously unavailable habitat of the deep hypolimnion.

(2) MDO as an Index of the Limiting DO Concentration

The limiting DO concentration for zooplankton has generally been defined as the DO concentration below which few individuals are found (e.g. Pennak 1944; Vinogradov 1968; Fast 1971; Judkins 1980), or the DO concentration associated with the peak density of the population (Longhurst 1967; Sherman et al. 1987). I defined the limiting DO concentration for a hypolimnetic zooplankton population or species in Amisk Lake as the mean DO concentration that was associated with the median depth of the population or species. This index, which I termed the "median DO concentration" (MDO), describes the DO concentration which limits vertical distribution for 50% of the population or species. For hypolimnetic zooplankton in Amisk Lake, the MDO was a relatively constant index, both between sites and among sampling dates, during the period July to September 1989. Thus, I believe that the MDO may be a good indicator of the limiting DO concentration for hypolimnetic zooplankton.

(3) Diel Migration of Hypolimnetic Zooplankton

In August 1989, hypolimnetic oxygenation appeared to enhance diel migration of *D. longiremis* at the Treatment site, by maintaining DO concentrations at or near the MDO of this species throughout the water column. However, diel movements of other epi- and hypolimnetic zooplankton were unaffected by oxygenation. If selective forces are present to drive diel migration of some zooplankton species, then hypolimnetic oxygenation may result in an increase in the amplitude of diel movement of these migratory species. Further research is necessary to determine what these selective forces are in Amisk Lake, and why they effected diel migration in only one of four hypolimnetic zooplankton species.

(4) Biomass of Epilimnetic Plankton and Zooplankton

Although biomass of the phytoplankton portion of plankton > 64-µm may have been reduced by hypolimnetic oxygenation, epilimnetic zooplankton biomass was apparently unaffected. The latter result is not unexpected, since hypolimnetic oxygenation did not alter conditions (e.g. DO concentration, temperature) in the epilimnion. However, I may have been unable to detect treatment effects on epilimnetic zooplankton biomass because the two basins were connected to a depth of 13 m by a 350-m wide (mean width) channel through which epilimnetic water currents may have transferred epilimnetic zooplankton between basins. Thus, more research (e.g. on a curtained lake) is needed to determine whether hypolimnetic oxygenation may indirectly effect epilimnetic zooplankton biomass.

(5) Abundance of Zooplankton

During hypolimnetic oxygenation in Amisk Lake, abundances of *D. longiremis* and *D. pulex* appeared to increase in the treatment basin. whereas abundances of *Diacyclops bicuspidatus thomasi*, *B. longirostris*, and all epilimnetic zooplankton were generally unaffected by the treatment. The increase in abundances of *D. longiremis* and *D. pulex* in the treatment basin was observed at the 31-m deep site, but not at the 21-m deep site. I believe that abundances were low at the 21-m site because it was too shallow, since at the 31-m site, the median depths of *D. longiremis* and *D. pulex* were generally well below 21 m. I have evidence that lakes undergoing hypolimnetic oxygenation may sustain greater densities of zooplankton than lakes with hypoxic hypolimnia. However, more research is necessary to determine the impact of lake depth on horizontal variation in abundance of hypolimnetic zooplankton.

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IV. Appendix A: Amisk Lake Zooplankton Counts

Table 1. Abundance (animals/L) of major zooplankton taxa in the hypolimnion at Treatment sites 1, 2 and 3 (N1, N2, N3) and Reference sites 1, 2 and 3 (S1, S2, S3) in Amisk Lake, during summer 1988. Data are pooled means for the three sites in each basin; exceptions are indicated with an asterisk. Samples were collected near mid-day. Mean hypolimnetic densities (Mean Den) are listed for the populations of each basin on each date.

a) Daphnia longiremis

Treatment Basin (*=N2 only)					Reference Basin (*=S1, S2 only)				
Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20	Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20
10	0.0	0.6	0.6	0.0	10	0.0	0.0	5.7	0.6
15	2.9	12.2	1.2	1.2	15	7.0	*4.3	5.2	0.6
18	11.3	1.7	9.2	5.2	18	4.1	*5.2	4.6	*2.6
25	*3.5	*0.0	*34.4	*3.5	25	6.4	*6.0	2.9	*0.9
Mean Den	**3.6**	**3.6**	**2.8**	**1.6**	**Mean Den**	**4.4**	**0.0**	**4.6**	**0.3**

(Table 1 continued)

b) Daphnia pulex

Treatment Basin (*=N2 only)

Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20
10	0.0	0.0	0.6	0.0
15	0.0	0.0	0.6	0.6
18	0.0	0.0	0.6	0.0
25	*0.0	*0.0	*0.0	*0.0
Mean Den	**0.0**	**0.0**	**0.5**	**0.2**

Reference Basin (*=S1, S2 only)

Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20
10	0.0	0.0	[illegible]	0.6
15	0.6	*0.0	0.6	0.0
18	0.0	*0.0	1.2	*0.9
25	0.0	*0.0	0.0	*0.0
Mean Den	**0.2**	**0.0**	**0.5**	**0.2**

c) Daphnia galeata mendotae

Treatment Basin (*=N2 only)

Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20
10	58.8	8.7	1.7	15.7
15	11.0	15.1	4.0	5.8
18	20.9	9.3	1.7	5.8
25	*15.7	*19.2	*1.7	*1.7
Mean Den	**22.7**	**8.3**	**1.9**	**6.8**

Reference Basin (*=S1, S2 only)

Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20
10	18.6	4.3	6.3	17.4
15	14.5	*0.0	0.6	7.0
18	8.7	*5.2	2.3	*4.4
25	9.3	*0.9	0.0	*15.7
Mean Den	**12.8**	**1.1**	**2.3**	**6.1**

(Table 1 continued)

d) Bosmina longirostris

Treatment Basin (*=N2 only)

Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20
10	1.2	0.0	0.0	0.0
15	0.0	1.7	0.0	0.0
18	0.9	0.0	0.0	0.0
25	*0.0	*0.0	*0.0	*0.0
Mean Den	**0.5**	**0.4**	**0.0**	**0.0**

Reference Basin (*=S1, S2 only)

Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20
10	0.0	0.0	0.0	0.0
15	0.0	*0.9	0.6	0.0
18	0.6	*0.9	1.2	*0.0
25	0.6	*1.7	0.0	*0.0
Mean Den	**0.3**	**0.0**	**0.5**	**0.0**

e) Diaphanosoma leuchtenbergianum

Treatment Basin (*=N2 only)

Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20
10	0.0	0.0	1.7	0.6
15	0.0	1.2	5.2	0.6
18	0.0	0.0	0.6	1.2
25	*0.0	*0.0	*0.0	*0.0
Mean Den	**0.0**	**0.3**	**1.9**	**0.6**

Reference Basin (*=S1, S2 only)

Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20
10	0.0	0.9	3.4	1.7
15	0.0	*0.0	0.6	1.2
18	0.0	*0.0	0.0	*0.0
25	0.0	*0.0	0.6	*0.9
Mean Den	**0.0**	**0.2**	**1.2**	**1.0**

(Table 1 continued)

f) cyclopoid copepods

Treatment Basin (*=N2 only)					Reference Basin (*=S1, S2 only)				
Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20	Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20
10	3.1	2.3	6.3	5.8	10	1.7	3.4	4.0	7.0
15	1.7	7.0	2.9	1.7	15	2.3	*0.9	1.2	1.7
18	5.2	2.3	6.3	0.0	18	1.7	*1.7	0.0	*7.8
25	*1.7	*7.0	*6.9	*0.0	25	5.2	*3.4	1.2	*8.7
Mean Den	**2.9**	**4.7**	**5.6**	**1.9**	**Mean Den**	**2.7**	**0.9**	**1.6**	**2.2**

g) Diaptomus oregonensis

Treatment Basin (*=N2 only)					South Basin (*=S1, S2 only)				
Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20	Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20
10	2.7	5.2	0.6	2.9	10	1.2	4.3	2.9	2.9
15	0.0	9.9	1.2	1.7	15	1.2	*0.9	0.6	2.3
18	0.9	4.6	1.2	1.2	18	0.6	*0.0	1.2	*0.0
25	*0.0	*10.5	*0.0	*0.0	25	1.2	*0.0	2.3	*3.5
Mean Den	**0.9**	**7.6**	**0.8**	**1.5**	**Mean Den**	**1.1**	**1.1**	**1.8**	**1.3**

Table 2. Abundance (animals/L) of major zooplankton taxa at Treatment sites 1-3 (N1, N2, N3) and Reference sites 1 and 2 (S1, S2) in Amisk Lake during winter 1989. Samples were collected near mid-day. Mean densities for the whole water column (Mean Den) are listed for the populations at all sites on each date.

a) Daphnia longiremis

Treatment Sites 3 (N3; Jan 10)
and 1 (N1; Mar 06)

Depth (m)	Jan 10	Depth (m)	Mar 06
1	2.9	1	1.2
3	1.2	3	0.6
-		5	0.6
6	1.2	7	1.2
-		9	0.0
10	1.2	11	0.6
-		12	1.7
15	0.0	15	0.6
18	5.2		
Mean Den	**1.7**		**0.8**

Treatment Site 2 (N2)

Depth (m)	Jan 10	Depth (m)	Mar 06
1	2.9	1	0.0
3	2.3	3	0.6
-		5	1.2
6	1.7	7	0.0
-		9	2.3
10	1.2	11	0.6
-		12	2.3
15	4.1	15	2.3
18	2.9	20	0.0
25	0.6	25	2.3
Mean Den	**2.0**		**1.2**

(Table 2 continued)

a) Daphnia longiremis (continued)

Reference Site 1 (S1)

Depth (m)	Jan 11	Depth (m)	Mar 07
1	2.3	1	0.0
3	1.7	3	0.6
-		5	0.0
6	1.7	7	0.6
-		9	1.2
10	0.6	11	0.6
-		12	0.0
15	0.6	15	0.6
18	0.0	-	
25	0.0	-	
Mean Den	**0.7**		**0.5**

Reference Site 2 (S2)

Depth (m)	Jan 11	Depth (m)	Mar 07
1	0.0	1	1.2
3	2.9	3	0.0
-		5	0.6
6	0.6	7	0.4
-		9	0.0
10	0.0	11	0.0
-		12	0.6
15	0.6	15	0.6
18	0.6	20	1.2
25	0.0	25	0.0
Mean Den	**0.5**		**0.5**

(Table 2 continued)

b) Daphnia pulex

Treatment Sites 3 (N3; Jan 10)
and 1 (N1; Mar 06)

Depth (m)	Jan 10	Depth (m)	Mar 06
1	2.9	1	1.2
3	2.9	3	1.2
-		5	0.6
6	1.7	7	0.6
-		9	0.0
10	2.3	11	0.0
-		12	0.0
15	0.6	15	0.0
18	1.7		
Mean Den	**1.9**		**0.5**

Treatment Site 2 (N2)

Depth (m)	Jan 10	Depth (m)	Mar 06
1	0.6	1	0.0
3	7.5	3	1.7
-		5	0.6
6	1.7	7	0.0
-		9	0.0
10	0.6	11	0.6
-		12	0.0
15	2.3	15	1.2
18	2.3	20	0.6
25	6.4	25	1.2
Mean Den	**3.3**		**0.7**

(Table 2 continued)

b) Daphnia pulex (continued)

Reference Site 1 (S1)

Depth (m)	Jan 11	Depth (m)	Mar 07
1	0.6	1	1.2
3	0.6	3	1.7
-		5	0.0
6	0.0	7	0.6
-		9	0.0
10	0.0	11	0.6
-		12	0.6
15	1.7	15	1.2
18	0.6	-	
25	0.6	-	
Mean Den	**0.6**		**0.7**

Reference Site 2 (S2)

Depth (m)	Jan 11	Depth (m)	Mar 07
1	2.3	1	0.0
3	4.1	3	0.0
-		5	0.6
6	4.1	7	0.4
-		9	0.6
10	3.5	11	0.0
-		12	0.0
15	1.7	15	0.0
18	0.6	20	0.0
25	2.3	25	1.2
Mean Den	**2.5**		**0.3**

(Table 2 continued)

c) Daphnia galeata mendotae

Treatment Sites 3 (N3; Jan 10)
and 1 (N1; Mar 06)

Depth (m)	Jan 10	Depth (m)	Mar 06
1	0.0	1	0.0
3	0.0	3	0.0
-		5	0.0
6	0.0	7	0.0
-		9	0.0
10	0.0	11	0.0
-		12	0.0
15	0.0	15	0.0
18			
Mean Den	**0.0**		**0.0**

Treatment Site 2 (N2)

Depth (m)	Jan 10	Depth (m)	Mar 06
1	1.7	1	0.0
3	0.0	3	0.0
-		5	0.0
6	1.7	7	0.0
-		9	0.0
10	2.3	11	0.0
-		12	0.0
15	0.0	15	0.0
18	0.0	20	0.0
25	1.2	25	0.0
Mean Den	**1.0**		**0.0**

(Table 2 continued)

c) Daphnia galeata mendotae (continued)

Reference Site 1 (S1)

Depth (m)	Jan 11	Depth (m)	Mar 07
1	0.6	1	0.0
3	0.0	3	0.0
-		5	0.0
6	0.6	7	0.0
-		9	0.0
10	0.6	11	0.0
-		12	0.0
15	0.0	15	0.0
18	0.0	-	
25	0.0	-	
Mean Den	**0.2**		**0.0**

Reference Site 2 (S2)

Depth (m)	Jan 11	Depth (m)	Mar 07
1	0.0	1	0.0
3	0.0	3	0.0
-	0.0	5	0.0
6	0.0	7	0.0
-	0.0	9	0.0
10	0.0	11	0.0
-	0.0	12	0.0
15	0.0	15	0.0
18	0.0	20	0.0
25	0.0	25	0.0
Mean Den	**0.0**		**0.0**

(Table 2 continued)

d) Bosmina longirostris

Treatment Sites 3 (N3; Jan 10)
and 1 (N1; Mar 06)

Depth (m)	Jan 10	Depth (m)	Mar 06
1	0.0	1	0.0
3	0.0	3	0.0
-		5	0.0
6	0.0	7	0.0
-		9	0.0
10	0.6	11	0.0
-		12	0.0
15	0.6	15	0.6
18	1.5		
Mean Den	**0.5**		**0.1**

Treatment Site 2 (N2)

Depth (m)	Jan 10	Depth (m)	Mar 06
1	0.0	1	0.0
3	0.0	3	0.0
-		5	0.6
6	0.0	7	0.0
-		9	0.0
10	0.6	11	0.0
-		12	0.0
15	0.6	15	1.2
18	1.2	20	0.6
25	1.2	25	2.9
Mean Den	**0.7**		**0.8**

(Table 2 continued)

d) Bosmina longirostris (continued)

Reference Site 1 (S1)				Reference Site 2 (S2)			
Depth (m)	Jan 11	Depth (m)	Mar 07	Depth (m)	Jan 11	Depth (m)	Mar 07
1	0.0	1	0.0	1	0.0	1	0.0
3	0.0	3	0.0	3	0.0	3	0.0
-		5	0.0	-		5	0.0
6	0.0	7	0.0	6	0.0	7	0.4
-		9	0.0	-		9	0.0
10	1.7	11	0.6	10	0.6	11	0.0
-		12	0.6	-		12	0.6
15	1.2	15	0.0	15	0.0	15	0.0
18	2.3	-		18	1.7	20	0.0
25	0.6	-		25	1.7	25	0.6
Mean Den	**1.0**		**0.2**	**Mean Den**	**0.8**		**0.2**

(Table 2 continued)

e) Diaphanosoma leuchtenbergianum

Treatment Sites 3 (N3; Jan 10)
and 1 (N1; Mar 06)

Depth (m)	Jan 10	Depth (m)	Mar 06
1	0.0	1	0.0
3	0.0	3	0.0
-		5	0.0
6	0.0	7	0.0
-		9	0.0
10	0.0	11	0.0
-		12	
15	0.0	15	0.0
18			
Mean Den	**0.0**		**0.0**

Treatment Site 2 (N2)

Depth (m)	Jan 10	Depth (m)	Mar 06
1	0.0	1	0.0
3	0.0	3	0.0
-		5	0.0
6	0.0	7	0.0
-		9	0.0
10	0.0	11	0.0
-		12	0.0
15	0.0	15	0.0
18	0.0	20	0.0
25		25	
Mean Den	**0.0**		**0.0**

(Table 2 continued)

e) Diaphanosoma leuchtenbergianum (continued)

Reference Site 1 (S1)

Depth (m)	Jan 11	Depth (m)	Mar 07
1	0.0	1	0.0
3	0.0	3	0.0
-	0.0	5	0.0
6	0.0	7	0.0
-	0.0	9	0.0
10	0.0	11	0.0
-	0.0	12	0.0
15	0.0	15	0.0
18	0.0	-	
25	0.0	-	
Mean Den	**0.0**		**0.0**

Reference Site 2 (S2)

Depth (m)	Jan 11	Depth (m)	Mar 07
1	0.0	1	0.0
3	0.0	3	0.0
-	0.0	5	0.0
6	0.0	7	0.0
-	0.0	9	0.0
10	0.0	11	0.0
-	0.0	12	0.0
15	0.0	15	0.0
18	0.0	20	0.0
25	0.0	25	0.0
Mean Den	**0.0**		**0.0**

(Table 2 continued)

f) cyclopoid copepods

Treatment Sites 3 (N3; Jan 10)
and 1 (N1; Mar 06)

Depth (m)	Jan 10	Depth (m)	Mar 06
1	10.5	1	3.5
3	4.6	3	3.5
-		5	4.6
6	3.5	7	8.1
-		9	2.3
10	4.1	11	2.3
-		12	4.1
15	2.9	15	2.3
18	3.2		
Mean Den	**4.3**		**3.8**

Treatment Site 2 (N2)

Depth (m)	Jan 10	Depth (m)	Mar 06
1	3.5	1	1.7
3	5.2	3	7.0
-		5	4.6
6	2.9	7	6.4
-		9	4.6
10	4.6	11	10.5
-		12	8.7
15	4.6	15	9.9
18	6.4	20	5.2
25	5.8	25	1.7
Mean Den	**5.0**		**5.5**

(Ta tinued)

f) c copepods (continued)

Reference Site 1 (S1)

Depth (m)	Jan 11	Depth (m)	Mar 07
1	5.2	1	2.3
3	3.5	3	13.4
-		5	9.9
6	4.6	7	8.1
-		9	4.6
10	2.3	11	8.7
-		12	11.0
15	1.7	15	9.9
18	0.6	-	
25	2.9	-	
Mean Den	**2.7**		**8.5**

Reference Site 2 (S2)

Depth (m)	Jan 11	Depth (m)	Mar 07
1	2.3	1	3.5
3	1.7	3	4.1
-		5	4.6
6	0.6	7	7.7
-		9	8.1
10	2.3	11	3.5
-		12	11.0
15	1.7	15	5.8
18	1.7	20	3.5
25	2.9	25	14.5
Mean Den	**2.0**		**7.1**

(Table 2 continued)

g) Diaptomus oregonensis

Treatment Sites 3 (N3; Jan 10)
and 1 (N1; Mar 06)

Depth (m)	Jan 10	Depth (m)	Mar 06
1	6.4	1	1.2
3	3.5	3	0.6
-		5	1.7
6	5.8	7	1.7
-		9	4.1
10	1.7	11	1.2
-		12	1.2
15	1.2	15	0.0
18	2.0		
Mean Den	**3.1**		**1.5**

Treatment Site 2 (N2)

Depth (m)	Jan 10	Depth (m)	Mar 06
1	1.7	1	0.6
3	5.2	3	4.1
-		5	1.7
6	1.2	7	0.6
-		9	0.0
10	2.9	11	2.9
-		12	1.2
15	2.3	15	2.3
18	2.3	20	0.6
25	0.6	25	0.6
Mean Den	**2.1**		**1.3**

(Table 2 continued)

g) Diaptomus oregonensis (continued)

Reference Site 1 (S1)

Depth (m)	Jan 11	Depth (m)	Mar 07
1	4.6	1	0.6
3	3.5	3	0.6
-		5	1.2
6	3.5	7	0.0
-		9	1.7
10	0.6	11	2.9
-		12	1.2
15	0.0	15	1.2
18	0.6	-	
25	0.6	-	
Mean Den	**1.4**		**1.2**

Reference Site 2 (S2)

Depth (m)	Jan 11	Depth (m)	Mar 07
1	1.7	1	1.7
3	1.2	3	1.2
-		5	0.6
6	0.6	7	0.4
-		9	1.2
10	0.6	11	0.6
-		12	0.6
15	0.0	15	0.0
18	0.0	20	0.0
25	0.6	25	0.0
Mean Den	**0.5**		**0.5**

Table 3. Abundance (animals/L) of major zooplankton taxa at Treatment sites 1 and 2 (N1, N2) and Reference sites 1 and 2 (S1, S2) in Amisk Lake during summer 1989. Samples were collected near mid-day, except as indicated. Mean densities for the whole water column (Mean Den) are listed for the populations at all sites on each date. Median depths (Median Z) of populations are given for sites N2 and S1 only; an asterisk (*) indicates that mean density was too low (i.e. < 1 animal/L) for calculation of median depth. For D. pulex and cyclopoid copepods, median depths are listed for each of epilimnetic (Epi Med Z) and hypolimnetic (Hyp Med Z) populations; solid line through the vertical profile for N2 and S1 indicates the top of the hypolimnion on each date.

a) Daphnia longiremis

Treatment Site 1 (N1)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	25.5	0.0	0.0	0.0	1.2
3	4.6	0.0	0.0	0.0	0.0
5	2.3		0.0	0.0	0.0
7	1.4	0.0	1.2	0.0	0.0
9	0.7	5.8	9.3	0.6	1.2
11	0.7	8.7	4.6	1.2	1.7
13	0.3	13.9	3.5	5.8	1.7
15	0.7	20.9	7.5	4.6	0.6
17	-	22.6	10.5	5.8	2.3
19	0.3	10.5	26.7	10.5	10.5
21	-	-	-	-	26.7
Mean Den	**3.7**	**8.2**	**6.3**	**2.9**	**4.2**

(Table 3 continued)

a) Daphnia longiremis (continued)

Treatment Site 2 (N2)

Depth (m)	May 17	Jun 03	Jun 04 01:30	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 06
1	1.7	22.6	1.7	7.0	7.0	0.0	0.0	2.3	0.0
3	2.3	7.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0
5	2.3	9.8	1.7	0.0	3.5	0.0	0.0	0.0	0.0
7	0.3	5.6	3.5	0.0	3.5	0.0	0.0	2.3	0.0
9	0.3	5.6	10.5	36.6	7.0	3.5	0.0	7.0	3.5
11	0.0	1.4	3.5	62.7	31.4	18.0	0.0	18.5	3.5
13	0.2	0.0	1.7	45.3	45.3	25.5	13.9	16.3	[illegible]
15	0.0	2.7	1.7	76.6	71.4	30.2	10.5	44.1	[illegible]
17	-	0.0	1.2	48.8	58.1	58.1	20.9	23.2	[illegible]
19	-	1.7	5.2	45.3	67.3	52.3	20.9	27.9	[illegible]
21	1.7	0.0	1.7	52.3	49.9	[illegible]	27.9	59.2	[illegible]
23	-	4.6	1.7	87.1	104.5	[illegible]	41.8	55.7	17.4
25	0.0	1.2	1.7	61.0	81.3	[illegible]	31.4	66.2	40.1
27	-	0.0	0	78.4	106.2	[illegible]	48.8	39.5	65.0
29	-	1.9	5.2	63.9	97.5	[illegible]	45.3	17.4	73.2
31	0.6	-	-	63.9	-	[illegible]	73.2	20.9	-
Mean Den	**0.8**	**4.3**	**2.8**	**45.6**	**48.9**	**44.2**	**20.9**	**25.0**	**20.4**
Median Z	*****	**4.5**	**11.2**	**21.6**	**22.4**	**25.1**	**26.0**	**22.0**	**25.3**

(Table 3 continued)

a) Daphnia longiremis (continued)

Reference Site 1 (S1)

Depth (m)	May 17	Jun 03	Jun 04 01:30	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 06
1	0.0	3.5	1.7	3.5	0.0	0.0	0.0	0.0	-
3	2.3	20.9	1.7	3.5	0.0	0.0	0.0	0.0	-
5	2.3	34.8	12.2	3.5	0.0	1.2	0.0	0.0	-
7	0.3	11.1	12.2	13.9	17.4	17.4	0.0	10.5	-
9	0.0	4.2	5.2	15.7	13.9	25.5	10.5	11.6	-
11	0.3	0.0	5.2	19.2	30.2	49.9	27.9	10.5	-
13	0.0	1.4	4.6	15.7	54.6	35.6	20.9	24.4	-
15	0.0	4.6	3.5	27.9	43.0	30.2	20.9	11.6	-
17	-	0.6	0	19.2	46.4	46.4	18.6	24.4	-
19	-	1.2	0	22.6	60.4	35.6	13.9	27.9	-
21	0.6	2.8	3.5	45.3	73.2	66.9	11.6	7.0	-
23	-	1.9	1.7	52.3	58.1	20.4	9.3	4.6	-
25	0.0	0.0	1.7	41.8	16.3	9.1	9.3	5.2	-
27	-	0.0	-	59.2	9.3	8.7	13.9	5.8	-
29	-	0.0	-	7.0	1.2	5.8	7.0	3.5	-
31	-	0.0	-	-	11.6	-	4.6	-	-
Mean Den	**0.5**	**5.4**	**4.1**	**23.4**	**27.2**	**23.5**	**10.5**	**9.8**	**-**
Median Z	*****	**5.2**	**7.8**	**21.3**	**18.4**	**16.7**	**16.4**	**16.4**	**-**

a) Daphnia longiremis (continued)

Reference Site 2 (S2)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	1.2	0.0	0.0	0.0	0.0
3	2.3	0.0	0.0	0.6	0.0
5	5.8	3.5	0.0	0.6	0.0
7	1.7	13.9	4.6	5.8	0.0
9	0.3	13.9	24.4	17.4	1.2
11	0.	17.4	20.3	15.7	3.5
13	0.3	15.7	21.5	13.4	7.0
15	0.3	15.1	22.1	16.8	6.4
17	-	15.7	19.7	15.7	2.3
19	-	15.7	26.1	10.5	1.2
21	0.0	19.2	34.8	18.0	0.0
23	-	20.9	20.9	10.8	0.0
25	0.0	24.4	27.3	5.2	1.2
27	-	31.4	5.2	4.2	0.0
29	-	41.8	5.2	7.3	0.6
31	0.2	34.8	1.2	7.0	0.6
33	-	24.4	4.1	4.8	0.6
35	0.7	15.7	2.3	4.1	0.0
37	-	13.9	4.6	3.7	0.0
39	-	9.3	6.4	3.2	0.0
41	0.0	4.1	8.7	1.4	0.0
43	-	6.4	5.8	3.5	0.0
45	0.2	7.0	5.2	4.5	0.6
47	-	1.7	6.4	-	0.6
49		1.7	-	-	-
Mean Den	**0.7**	**14.7**	**11.5**	**7.6**	**1.1**

(Table 3 continued)

b) Daphnia pulex

Treatment Site 1 (N1)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	0.0	0.0	0.0	0.0	0.0
3	0.0	7.0	0.0	0.0	1.2
5	0.0	7.0	1.2	0.0	0.0
7	0.7	3.5	7.0	4.6	1.2
9	0.0	13.9	11.6	5.2	3.5
11	0.0	5.2	8.7	2.3	3.5
13	0.3	3.5	2.9	4.1	1.2
15	0.3	5.2	2.9	3.1	5.2
17	-	1.7	1.7	0.6	1.2
19	0.0	0.0	11.6	2.9	2.3
21	-	-	-	-	1.7
Mean Den	**0.1**	**4.7**	**4.8**	**2.3**	**1.9**

(Table 3 continued)

b) Daphnia pulex (continued)

Treatment Site 2 (N2)

Depth (m)	May 17	Jun 03	Jun 04 (01:30)	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 (01:30)	Sep 06
1	0.0	0.0	3.5	7.0	7.0	0.0	0.0	0.0	0.0
3	0.0	0.0	3.5	0.0	3.5	0.0	0.0	0.0	0.0
5	1.2	2.8	5.2	10.5	10.5	2.3	0.0	7.0	0.0
7	0.7	0.0	3.5	24.4	10.5	5.8	17.4	7.0	0.0
9	0.3	0.0	1.7	17.4	0.0	7.0	10.5	20.9	10.5
11	0.0	1.4	0.0	0.0	1.2	5.8	0.0	7.0	5.2
13	0.0	0.0	0.0	7.0	2.3	3.1	0.0	2.3	5.2
15	0.0	0.0	0.0	10.5	7.0	4.6	7.0	7.0	8.7
17	-	0.0	1.2	13.9	5.8	3.5	3.5	9.3	8.7
19	-	1.2	1.7	7.0	11.6	3.5	2.3	3.5	10.5
21	0.0	0.0	5.2	24.4	4.6	5.8	2.3	3.5	3.5
23	-	2.3	1.7	7.0	19.7	11.6	3.5	10.5	17.4
25	0.0	1.2	0.0	43.5	12.8	13.9	20.9	10.5	19.2
27	-	0.0	0.0	17.4	41.8	23.2	7.0	18.6	23.2
29	-	0.0	1.7	46.4	47.0	16.3	20.9	13.9	10.5
31	0.0	-	-	98.7	-	44.1	20.9	17.4	-
Mean Den	**0.1**	**0.6**	**1.9**	**20.9**	**12.4**	**9.4**	**7.3**	**8.7**	**8.2**
Epi Med Z	*	*	**3.5**	**6.3**	**5.0**	**7.8**	**7.6**	**8.3**	**9.0**
Hyp Med Z	*	*	**20.1**	**27.8**	**26.6**	**27.4**	**27.3**	**25.6**	**23.6**

(Table 3 continued)

b) Daphnia pulex (continued)

Reference Site 1 (S1)

Depth (m)	May 17	Jun 03	Jun 04 01:30	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 06
1	0.0	0.0	5.2	13.9	10.5	0.0	0.0	0.0	-
3	2.3	10.5	1.7	3.5	7.0	0.0	0.0	0.0	-
5	5.8	7.0	0.0	27.9	7.0	0.0	3.5	10.5	-
7	1.0	1.4	0.0	7.0	13.9	12.8	3.5	9.3	-
9	2.8	0.0	1.7	7.0	7.0	15.1	0.0	2.3	-
11	0.0	1.4	1.7	7.0	8.1	8.1	0.0	0.0	-
13	0.5	1.4	1.2	1.7	7.0	6.2	0.0	3.5	-
15	0.0	0.0	1.7	0.0	7.0	2.9	0.0	0.0	-
17	-	0.6	0.0	5.2	5.0	6.2	0.0	0.0	-
19	-	0.0	1.2	8.7	4.6	3.1	0.0	0.0	-
21	0.6	0.0	0.0	7.0	1.2	0.9	2.3	0.0	-
23	-	0.0	1.7	7.0	3.5	0.9	0.0	0.0	-
25	1.2	2.3	0.0	7.0	2.3	1.2	0.0	1.7	-
27	-	0.0	-	0.0	2.3	1.5	0.0	1.2	
29	-	0.0	-	0.0	2.3	0.1	0.0	1.2	-
31	-	0.0	-	-	1.2	-	0.0	-	-
Mean Den	**1.2**	**1.5**	**1.2**	**6.9**	**5.3**	**3.9**	**0.6**	**2.0**	**-**
Epi Med Z	**4.8**	**3.8**	**1.3**	**4.9**	**5.5**	**8.2**	**6.0**	**6.1**	**-**
Hyp Med Z	*****	*****	**14.0**	**19.8**	**14.7**	**14.9**	*****	*****	**-**

(Table 3 continued)

b) Daphnia pulex (continued)

Reference Site 2 (S2)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	2.3	10.5	13.9	0.0	0.0
3	0.0	0.0	9.3	0.0	0.0
5	0.0	7.0	18.6	1.2	0.0
7	0.0	8.7	16.3	15.1	2.3
9	0.0	27.9	12.8	7.0	1.2
11	0.3	1.7	8.1	1.7	0.0
13	0.0	3.5	2.9	1.2	3.5
15	0.0	2.3	4.1	1.2	2.3
17	-	5.2	1.7	1.2	0.6
19	-	0.0	5.2	3.5	0.0
21	0.0	7.0	2.9	1.2	0.0
23	-	5.2	3.5	0.3	0.0
25	0.0	8.7	1.2	1.0	0.0
27	-	3.5	1.2	1.2	0.0
29	-	5.2	0.6	1.7	0.0
31	0.0	2.3	0.6	1.0	0.0
33	-	1.7	1.2	0.7	0.0
35	0.0	0.0	0.0	0.3	0.6
37	-	0.0	1.2	0.7	0.0
39	-	0.0	1.2	0.6	0.0
41	0.0	0.0	0.6	0.7	0.0
43	-	0.6	1.7	0.4	0.0
45	0.0	1.2	1.2	0.7	0.0
47	-	0.0	0.6	-	0.0
49	-	0.6	-	-	-
Mean Den	**0.1**	**4.1**	**4.6**	**1.9**	**0.4**

(Table 3 continued)

c) Daphnia galeata mendotae

Treatment Site 1 (N1)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	0.0	20.9	27.9	5.2	1.2
3	0.0	52.3	25.5	26.7	3.5
5	0.0	17.4	15.1	16.3	3.5
7	0.0	15.7	9.3	23.2	4.6
9	0.0	7.0	3.5	4.1	2.3
11	0.0	1.7	6.4	2.3	1.2
13	0.0	0.0	1.2	1.7	0.0
15	0.0	3.5	1.2	1.2	0.6
17	-	5.2	0.0	2.3	0.6
19	0.0	0.0	0.6	0.0	0.0
21	-	-	-	-	0.6
Mean Den	**0.0**	**12.4**	**9.3**	**8.3**	**1.6**

c) Daphnia galeata mendotae (continued)

Treatment Site 2 (N2)

Depth (m)	May 17	Jun 03	Jun 04 01:30	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 06
1	0.0	0.0	9.9	55.7	87.1	3.1	0.0	7.0	0.0
3	0.0	0.0	13.9	34.8	55.7	30.2	3.5	13.9	10.5
5	0.0	0.0	5.2	27.9	27.9	46.4	2.3	45.3	0.0
7	0.0	0.0	8.7	31.4	13.9	9.3	27.9	9.3	0.0
9	0.0	0.0	1.7	15.7	0.0	3.5	13.9	0.0	7.0
11	0.0	0.0	1.7	0.0	5.8	2.9	0.0	0.0	0.0
13	0.0	0.0	3.5	0.0	3.5	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	3.5	1.7	2.3	10.5	0.0	0.0
17	-	0.0	0.0	3.5	3.5	4.6	0.0	0.0	0.0
19	-	0.0	0.0	7.0	5.8	1.2	2.3	0.0	0.0
21	0.0	0.0	0.0	7.0	4.6	1.2	2.3	0.0	0.0
23	-	0.0	0.0	0.0	2.3	1.2	0.0	0.0	1.7
25	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0
27	-	0.0	0.0	0.0	7.0	0.0	0.0	2.3	0.0
29	-	0.0	0.0	11.6	7.0	0.0	0.0	0.0	0.0
31	0.0	-	-	0.0	-	2.3	0.0	0.0	-
Mean Den	**0.0**	**0.0**	**3.0**	**12.4**	**15.2**	**6.8**	**3.9**	**4.9**	**1.3**
Median Z	*****	*****	**3.8**	**4.6**	**3.0**	**4.9**	**7.8**	**4.8**	**3.8**

(Table 3 continued)

c) Daphnia galeata mendotae (continued)

Reference Site 1 (S1)

Depth (m)	May 17	Jun 03	Jun 04 01:30	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 06
1	0.0	0.0	15.7	20.9	52.3	0.0	0.0	23.2	-
3	0.0	7.0	12.2	17.4	48.8	4.6	3.5	38.3	-
5	0.0	7.0	7.0	20.9	31.4	16.2	7.0	3.5	-
7	0.0	1.4	5.2	17.4	0.0	5.8	10.5	2.3	-
9	0.0	0.0	1.7	1.7	0.0	3.5	7.0	4.6	-
11	0.0	0.0	0.0	0.0	2.6	3.5	0.0	10.5	-
13	0.0	0.0	0.0	0.0	3.5	3.9	7.0	3.5	-
15	0.0	0.0	0.0	0.0	2.3	3.5	9.3	4.6	-
17	-	0.0	0.0	1.7	1.2	1.5	4.6	0.0	-
19	-	0.0	0.0	3.5	2.3	2.3	0.0	4.6	-
21	0.6	0.0	0.0	0.0	2.3	0.9	0.0	0.0	-
23	-	0.0	0.0	0.0	8.1	0.9	2.3	0.0	-
25	0.6	0.0	0.0	7.0	0.0	1.6	4.6	0.0	-
27	-	0.0	-	0.0	4.6	0.9	0.0	2.3	-
29	-	0.0	-	0.0	0.0	0.2	9.3	2.3	-
31	-	0.0	-	-	0.0	-	0.0	-	-
Mean Den	**0.3**	**1.0**	**3.2**	**6.0**	**10.0**	**3.3**	**4.1**	**5.1**	**-**
Median Z	*****	**4.2**	**2.9**	**4.7**	**3.1**	**7.3**	**13.3**	**3.4**	**-**

(Table 3 continued)

c) Daphnia galeata mendotae (continued)

Reference Site 2 (S2)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	0.0	38.3	31.4	4.1	1.2
3	0.0	13.9	29.0	3.5	2.3
5	0.0	31.4	20.9	2.3	4.6
7	0.0	15.7	3.5	16.3	13.9
9	0.0	15.7	3.5	4.6	2.3
11	0.0	1.7	0.0	1.2	0.6
13	0.0	1.7	1.2	1.7	0.6
15	0.0	2.3	1.2	0.6	0.0
17	-	0.0	0.0	0.6	0.0
19	-	0.0	1.2	1.2	0.0
21	0.0	1.7	0.6	0.6	0.6
23	-	8.7	2.3	0.0	0.0
25	0.0	0.0	0.0	1.7	0.0
27	-	0.0	0.6	0.7	0.0
29	-	1.7	0.0	0.0	1.2
31	0.0	0.0	0.0	1.4	0.6
33	-	3.5	0.0	0.9	0.0
35	0.0	1.7	0.0	0.5	0.0
37	-	0.0	0.6	0.2	0.0
39	-	1.2	1.7	0.0	0.0
41	0.0	0.0	0.6	0.2	0.6
43	-	1.2	2.3	0.8	0.0
45	0.0	1.2	1.7	0.2	0.6
47	-	1.2	1.2	-	0.0
49	-	0.0	-	-	-
Mean Den	**0.0**	**5.7**	**4.3**	**1.9**	**1.2**

(Table 3 continued)

d) Bosmina longirostris

Treatment Site 1 (N1)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	2.3	0.0	0.0	0.0	0.0
3	1.2	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	1.7	0.0
11	0.0	0.0	0.0	0.0	0.6
13	0.3	0.0	0.6	1.2	0.6
15	0.0	0.0	1.7	1.2	0.6
17	-	0.0	0.0	0.0	0.0
19	0.3	1.7	0.6	2.9	0.0
21	-	-	-	-	0.0
Mean Den	**0.4**	**0.2**	**0.3**	**0.7**	**0.2**

(Table 3 continued)

d) Bosmina longirostris (continued)

Treatment Site 2 (N2)

Depth (m)	May 17	Jun 03	Jun 04 01:30	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 06
1	1.7	3.5	0.6	0.0	3.5	0.0	0.0	0.0	0.0
3	4.6	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	0.0
7	0.3	0.0	3.5	0.0	3.5	1.2	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0
11	0.3	0.0	0.0	0.0	0.0	1.2	0.0	4.6	0.0
13	0.0	0.0	5.2	0.0	0.0	1.5	3.5	0.0	0.0
15	0.0	0.0	0.0	0.0	8.7	0.0	0.0	0.0	0.0
17	-	0.0	0.0	3.5	8.1	0.0	0.0	0.0	0.0
19	-	0.0	0.0	3.5	8.1	0.0	2.3	0.0	0.0
21	0.0	0.0	0.0	13.9	3.5	1.2	0.0	0.0	0.0
23	-	0.0	1.7	13.9	7.0	0.0	0.0	0.0	0.0
25	0.0	0.0	3.5	17.4	8.1	3.5	0.0	0.0	0.0
27	-	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0
29	-	0.0	1.7	23.2	20.9	2.3	0.0	0.0	0.0
31	0.0	-	-	34.8	-	2.3	0.0	0.0	-
Mean Den	**0.4**	**0.3**	**1.3**	**6.9**	**5.2**	**0.9**	**0.4**	**0.3**	**0.0**
Median Z	*****	*****	**12.9**	**28.3**	**23.1**	**24.3**	*****	*****	*****

(Table 3 continued)

d) Bosmina longirostris (continued)

Reference Site 1 (S1)

Depth (m)	May 17	Jun 03	Jun 04 01:30	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 06
1	0.0	17.4	1.7	0.0	0.0	0.0	0.0	0.0	-
3	0.0	7.0	17.4	0.0	0.0	1.2	0.0	0.0	-
5	1.2	0.0	5.2	0.0	0.0	0.0	10.5	0.0	-
7	0.0	2.8	3.5	0.0	0.0	0.0	0.0	0.0	-
9	0.0	0.0	0.0	0.0	7.0	2.3	0.0	2.3	-
11	0.3	1.4	1.7	3.5	2.6	0.0	0.0	0.0	-
13	0.0	0.0	0.0	3.5	9.3	5.4	7.0	0.0	-
15	0.0	1.2	0.0	5.2	3.5	0.6	0.0	0.0	-
17	-	0.6	0.0	0.0	2.3	1.5	0.0	0.0	-
19	-	0.6	0.0	5.2	2.3	1.5	0.0	0.0	-
21	0.0	1.4	0.0	0.0	3.5	0.9	0.0	0.0	-
23	-	1.9	1.7	0.0	1.2	0.0	0.0	0.0	-
25	0.0	0.0	0.0	13.9	0.0	0.5	0.0	0.0	-
27	-	2.3	-	3.5	0.0	0.2	0.0	0.0	-
29	-	0.5	-	0.0	1.2	0.0	0.0	0.0	-
31	-	0.0	-	-	0.0	-	0.0	-	-
Mean Den	**0.1**	**2.3**	**2.4**	**2.3**	**2.1**	**0.9**	**1.1**	**0.2**	-
Median Z	*	**2.3**	**3.6**	**20.0**	**12.7**	**13.3**	*	*	-

(Table 3 continued)

d) Bosmina longirostris (continued)

Reference Site 2 (S2)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	1.2	0.0	0.0	0.0	0.0
3	1.2	0.0	0.0	0.0	0.0
5	1.2	0.0	0.0	0.0	0.0
7	0.3	0.0	1.2	0.0	0.0
9	0.0	1.7	3.5	1.2	0.0
11	0.3	0.0	7.0	0.6	0.0
13	0.0	3.5	4.1	0.6	0.0
15	0.3	2.3	4.1	1.7	0.6
17	-	8.7	1.2	0.0	0.6
19	-	8.7	2.3	0.0	0.0
21	0.0	5.2	0.6	0.0	0.0
23	-	1.7	0.6	0.0	0.0
25	0.2	5.2	0.0	0.3	0.0
27	-	1.7	0.0	0.0	0.0
29	-	0.0	3.5	0.0	0.0
31	0.2	3.5	1.2	0.0	0.0
33	-	0.0	0.6	0.1	0.0
35	0.0	0.0	0.0	0.3	0.0
37	-	0.0	0.6	0.2	0.0
39	-	1.2	0.6	0.0	0.0
41	0.0	0.6	0.6	0.5	0.0
43	-	0.6	0.0	0.0	0.0
45	0.0	0.0	0.6	0.2	0.0
47	-	0.0	0.0	-	0.0
49	-	0.0	-	-	-
Mean Den	**0.2**	**1.8**	**1.3**	**0.2**	**0.1**

(Table 3 continued)

e) Diaphanosoma leuchtenbergianum

Treatment Site 1 (N1)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	0.0	0.0	0.0	2.9	27.9
3	0.0	0.0	2.3	1.2	23.2
5	0.0	0.0	0.0	1.2	8.1
7	0.0	0.0	1.2	2.3	4.6
9	0.0	1.2	0.0	0.0	2.3
11	0.0	0.0	0.0	0.6	1.2
13	0.0	0.0	0.0	0.0	0.6
15	0.0	0.0	0.0	0.0	1.7
17	-	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0
21	-	-	-	-	1.2
Mean Den	**0.0**	**0.1**	**0.4**	**0.8**	**6.4**

(Table 3 continued)

e) Diaphanosoma leuchtenbergianum (continued)

Treatment Site 2 (N2)

Depth (m)	May 17	Jun 03	Jun 04 01:30	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 06
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	7.0
3	0.0	0.0	0.0	0.0	0.0	0.0	17.4	13.9	13.9
5	0.0	0.0	0.0	0.0	0.0	2.3	7.0	0.0	17.4
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	17.4
9	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	3.5
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0	[illegible]
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]
17	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	-	-	0.0	-	0.0	0.0	0.0	-
Mean Den	**0.0**	**0.0**	**0.0**	**0.2**	**0.0**	**0.2**	**1.5**	**1.2**	**3.9**
Median Z	*	*	*	*	*	*	**3.4**	**3.0**	**5.0**

(Table 3 continued)

e) Diaphanosoma leuchtenbergianum (continued)

Reference Site 1 (S1)

Depth (m)	May 17	Jun 03	Jun 04 01:30	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 06
1	0.0	0.0	0.0	0.0	0.0	2.3	0.0	18.6	-
3	0.0	0.0	0.0	0.0	0.0	0.0	13.9	10.5	-
5	0.0	0.0	0.0	0.0	0.0	9.3	0.0	10.5	-
7	0.0	0.0	0.0	0.0	0.0	0.0	3.5	2.3	-
9	0.0	0.0	0.0	0.0	0.0	0.0	10.5	2.3	-
11	0.0	0.0	0.0	0.0	0.0	1.2	0.0	3.5	-
13	0.2	0.0	0.0	0.0	0.0	0.8	0.0	7.0	-
15	0.0	0.0	0.0	0.0	0.0	1.2	0.0	4.6	-
17	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
19	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
23	-	0.0	0.0	0.0	0.0	0.0	0.0	2.3	-
25	0.0	0.0	0.0	0.0	0.0	0.2	2.3	1.7	-
27	-	0.0	-	0.0	0.0	0.2	0.0	0.0	-
29	-	0.0	-	0.0	0.0	0.1	0.0	0.0	-
31	-	0.0	-	-	0.0	-	4.6	-	-
Mean Den	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.9**	**2.2**	**3.0**	**-**
Median Z	*	*	*	*	*	*	**8.0**	**4.5**	**-**

(Table 3 continued)

e) Diaphanosoma leuchtenbergianum (continued)

Reference Site 2 (S2)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	0.0	0.0	0.0	0.6	39.5
3	0.0	0.0	2.3	1.7	29.0
5	0.0	0.0	1.2	1.7	22.1
7	0.0	0.0	1.2	2.3	9.3
9	0.0	0.0	0.0	0.0	2.3
11	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	1.2	1.2
15	0.0	0.0	0.0	0.0	0.0
17	-	0.0	0.0	0.0	0.6
19	-	0.0	0.0	0.0	0.6
21	0.0	0.0	0.0	0.0	0.6
23		0.0	0.0	0.3	1.2
25	0.0	0.0	0.0	0.0	0.0
27	-	0.0	0.0	0.0	0.6
29	-	0.0	0.0	0.0	0.6
31	0.0	0.0	0.0	0.0	1.2
33	-	0.0	0.0	0.0	0.0
35	0.0	0.0	0.0	0.1	0.6
37	-	0.0	0.0	0.2	0.6
39	-	0.0	0.0	0.0	0.0
41	0.0	0.0	0.0	0.0	0.0
43	-	0.0	0.0	0.0	0.0
45	0.0	0.0	0.0	0.0	1.2
47	-	0.0	0.0	-	0.6
49	-	0.0	-	-	-
Mean Den	**0.0**	**0.0**	**0.2**	**0.4**	**4.7**

(Table 3 continued)

f) cyclopoid copepods

Treatment Site 1 (N1)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	53.4	3.5	3.5	4.6	23.2
3	11.6	3.5	4.6	3.5	24.4
5	15.1	7.0	2.3	1.2	9.3
7	10.1	1.7	2.3	9.3	12.8
9	2.8	7.0	4.6	2.3	4.6
11	3.5	7.0	4.1	2.9	5.8
13	2.4	1.7	1.7	0.6	4.6
15	4.2	7.0	2.3	1.2	6.4
17	-	1.7	3.5	0.0	4.6
19	6.3	7.0	7.0	2.3	1.7
21	-	-	-	-	7.0
Mean Den	**11.6**	**4.7**	**3.6**	**2.8**	**9.5**

(Table 3 continued)

f) Cyclopoid copepods (continued)

Treatment Site 2 (N2)

Depth (m)	May 17	Jun 03	Jun 04 01:30	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 06
1	19.2	7.0	7	3.5	7.0	1.2	0.0	2.3	7.0
3	34.8	8.7	1.7	7.0	7.0	1.2	0.0	3.5	7.0
5	15.1	11.1	10.5	13.9	27.9	7.0	2.3	7.0	7.0
7	5.9	5.6	3.5	13.9	10.5	7.0	27.9	16.3	17.4
9	4.9	5.6	15.7	19.2	7.0	1.2	3.5	10.5	13.9
11	6.3	9.8	19.2	10.5	13.9	1.7	4.6	4.6	5.2
13	2.8	7.4	26.1	24.4	18.6	0.8	0.0	2.3	3.5
15	3.5	8.1	20.9	24.4	20.9	0.8	0.0	0.0	8.7
17	-	9.3	16.3	41.8	15.1	2.3	0.0	4.6	3.5
19	-	6.4	22.6	10.5	19.7	1.2	0.0	3.5	7.0
21	5.2	8.4	3.5	17.4	19.7	3.5	2.3	3.5	3.5
23	-	31.4	15.7	20.9	17.4	9.3	3.5	7.0	7.0
25	1.2	13.9	13.9	52.2	25.5	12.2	10.5	7.0	10.5
27	-	32.5	13.9	43.5	27.9	9.3	3.5	7.0	5.8
29	-	19.0	10.5	58.1	50.5	11.6	10.5	10.5	17.4
31	2.9	-	-	110.3	-	11.6	10.5	13.9	-
Mean Den	**7.5**	**12.3**	**13.4**	**29.5**	**19.2**	**5.1**	**4.9**	**6.5**	**8.3**
Epi Med Z	**2.9**	**3.5**	**4.2**	**5.2**	**5.1**	**4.9**	**7.0**	**6.9**	**6.6**
Hyp Med Z	**16.5**	**23.2**	**16.7**	**25.8**	**22.8**	**26.1**	**27.0**	**25.8**	**23.3**

(Table 3 continued)

f) cyclopoid copepods (continued)

Reference Site 1 (S1)

Depth (m)	May 17	Jun 03	Jun 04 01:30	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 06
1	12.2	41.8	33.1	13.9	20.9	1.2	0.0	7.0	-
3	29.0	62.7	61	13.9	3.5	2.3	0.0	10.5	-
5	18.6	55.7	27.9	17.4	20.9	1.2	17.4	10.5	-
7	4.9	36.2	33.1	24.4	17.4	1.2	10.5	13.9	-
9	0.3	20.9	34.8	15.7	7.0	1.2	3.5	7.0	-
11	3.5	25.1	22.6	19.2	17.4	0.0	0.0	3.5	-
13	1.4	18.1	24.4	26.1	15.1	2.3	3.5	0.0	-
15	1.2	19.7	20.9	13.9	10.5	3.5	4.6	0.0	-
17	-	15.7	17.4	17.4	4.6	4.6	0.0	0.0	-
19	-	14.5	19.7	15.7	16.3	4.6	0.0	4.6	-
21	0.6	13.9	19.7	24.4	17.4	7.4	2.3	7.0	-
23	-	15.8	24.4	24.4	22.1	1.4	0.0	0.0	-
25	3.5	19.7	20.9	24.4	16.3	1.2	2.3	0.0	-
27	-	17.4	-	48.8	3.5	2.4	0.0	1.2	-
29	-	12.5	-	17.4	5.8	1.3	0.0	1.2	-
31	-	12.8	-	-	2.3	-	0.0	-	-
Mean Den	**5.7**	**25.2**	**27.7**	**21.1**	**12.6**	**2.3**	**2.8**	**4.0**	**-**
Epi Med Z	**3.4**	**3.8**	**3.5**	**5.7**	**5.0**	**4.1**	**5.8**	**4.3**	**-**
Hyp Med Z	**17.5**	**18.5**	**16.0**	**21.9**	**20.2**	**19.7**	**14.6**	**20.1**	**-**

f) cyclopoid copepods (continued)

Reference Site 2 (S2)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	29.0	3.5	2.3	1.2	5.8
3	27.9	0.0	2.3	0.6	7.0
5	24.4	0.0	0.0	2.9	7.0
7	3.8	7.0	5.8	3.5	17.4
9	2.4	1.7	10.5	3.5	7.0
11	1.4	8.7	4.6	2.9	7.5
13	2.4	1.7	3.5	1.2	5.2
15	1.7	7.0	7.0	1.2	3.5
17	-	3.5	5.8	0.6	1.7
19	-	8.7	2.9	3.5	2.3
21	0.0	8.7	4.1	2.9	1.2
23	-	13.9	4.6	0.3	0.6
25	2.4	12.2	4.6	1.0	0.6
27	-	7.0	1.7	0.9	0.6
29	-	5.2	1.2	0.7	0.0
31	1.2	8.1	2.3	2.1	0.6
33	-	10.5	1.2	0.0	0.0
35	1.4	5.2	0.0	0.5	1.2
37	-	3.5	0.0	0.5	0.6
39	-	5.2	1.2	0.6	0.0
41	1.4	2.9	3.5	0.3	0.0
43	-	2.9	1.2	0.8	0.0
45	2.4	9.3	1.2	0.6	0.0
47	-	0.6	0.6	-	0.6
49	-	1.7	-	-	-
Mean Den	**5.0**	**5.5**	**3.0**	**1.4**	**2.9**

(Table 3 continued)

g) Diaptomus oregonensis

Treatment Site 1 (N1)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	4.6	3.5	0.0	7.0	17.4
3	0.0	0.0	1.2	7.0	37.2
5	0.0	0.0	2.3	2.3	17.4
7	0.0	10.5	5.8	3.5	7.0
9	0.0	4.6	8.1	4.6	0.0
11	0.0	8.7	7.0	2.3	1.2
13	0.0	1.7	2.3	1.7	0.0
15	0.0	3.5	2.3	3.1	0.0
17	-	10.5	3.5	2.3	0.0
19	0.0	1.7	2.3	3.5	0.0
21	-	-	-	-	1.2
Mean Den	**0.5**	**4.5**	**3.5**	**3.7**	**7.4**

(Table 3 continued)

g) Diaptomus oregonensis (continued)

Treatment Site 2 (N2)

Depth (m)	May 17	Jun 03	Jun 04 01:30	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 06
1	0.0	1.7	4.1	3.5	10.5	4.6	0.0	11.6	3.5
3	0.0	1.7	5.2	0.0	7.0	8.1	59.2	10.6	10.5
5	0.0	1.4	3.5	3.5	10.5	4.6	0.0	13.9	17.4
7	0.0	0.0	1.7	10.5	7.0	8.1	3.5	7.0	13.9
9	0.0	0.0	1.7	5.2	3.5	1.2	0.0	17.4	3.5
11	0.0	0.0	0.0	3.5	5.8	5.8	0.0	0.0	1.7
13	0.0	0.0	0.0	0.0	0.0	6.2	0.0	0.0	0.0
15	0.0	0.0	0.0	7.0	7.0	3.1	0.0	0.0	0.0
17	-	0.0	2.3	3.5	3.5	3.5	7.0	4.6	0.0
19	-	0.0	3.5	3.5	3.5	5.8	0.0	0.0	0.0
21	0.0	0.0	1.7	3.5	7.0	5.8	0.0	0.0	0.0
23	-	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	2.3	1.7	0.0	0.0	0.0
27	-	1.2	0.0	0.0	0.0	0.0	0.0	4.6	1.2
29	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.6	-	-	0.0	-	2.3	0.0	0.0	-
Mean Den	**0.1**	**0.4**	**1.6**	**2.7**	**4.5**	**3.9**	**4.4**	**4.4**	**3.4**
Median Z	*****	*****	**5.5**	**9.7**	**7.7**	**11.5**	**3.2**	**5.8**	**5.4**

(Table 3 continued)

g) Diaptomus oregonensis (continued)

Reference Site 1 (S1)

Depth (m)	May 17	Jun 03	Jun 04 01:30	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 06
1	3.5	13.9	1.7	3.5	13.9	0.0	3.5	11.6	-
3	1.2	0.0	12.2	0.0	10.5	13.9	41.8	3.5	-
5	2.3	7.0	3.5	7.0	7.0	7.0	3.5	10.5	-
7	0.0	1.4	0	13.9	3.5	3.5	0.0	34.8	-
9	0.0	0.0	1.7	7.0	7.0	10.5	7.0	2.3	-
11	0.0	2.8	1.7	5.2	7.0	9.3	7.0	3.5	-
13	0.5	2.8	1.2	1.7	3.5	3.9	0.0	10.5	-
15	0.0	0.0	1.7	3.5	2.3	2.3	4.6	4.6	-
17	-	0.0	0	3.5	3.5	3.1	4.6	0.0	-
19	-	0.0	0	0.0	1.2	2.3	0.0	0.0	-
21	0.0	0.0	1.2	3.5	1.2	0.9	4.6	3.5	-
23	-	0.0	1.7	3.5	0.0	1.4	0.0	7.0	-
25	0.0	0.0	1.7	0.0	0.0	2.6	2.3	5.2	-
27	-	1.2	-	0.0	0.0	0.9	0.0	1.2	-
29	-	0.5	-	1.7	0.0	0.5	2.3	0.0	-
31	-	0.0	-	-	0.0	-	4.6	-	-
Mean Den	**0.5**	**1.9**	**2.2**	**3.6**	**3.8**	**4.1**	**5.4**	**5.8**	**-**
Median Z	*****	**4.3**	**4.1**	**8.4**	**4.8**	**9.3**	**3.9**	**7.4**	**-**

(Table 3 continued)

g) Diaptomus oregonensis (continued)

Reference Site 2 (S2)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	0.0	3.5	4.6	4.1	27.9
3	0.0	0.0	3.5	4.1	18.6
5	0.0	0.0	1.2	4.6	10.5
7	0.0	1.7	5.8	4.6	1.2
9	0.0	7.0	1.2	5.8	1.2
11	0.0	1.7	1.7	2.3	2.9
13	0.0	3.5	5.2	2.3	1.2
15	0.0	1.2	6.4	3.5	1.2
17	-	1.7	5.2	1.2	0.6
19	-	3.5	1.7	0.6	1.7
21	0.0	1.7	1.2	2.9	0.0
23	-	3.5	1.7	0.7	0.6
25	0.0	0.0	1.7	2.1	0.6
27	-	1.7	0.6	1.2	0.0
29	-	0.0	0.6	0.7	0.6
31	0.0	0.0	1.2	0.3	0.0
33	-	1.7	2.9	1.5	0.6
35	0.0	1.7	0.0	1.0	0.0
37	-	1.7	0.0	0.8	0.6
39	-	1.2	0.0	0.6	0.0
41	0.0	0.0	1.2	0.3	1.2
43	-	0.6	1.2	1.5	0.6
45	0.0	0.0	1.2	1.2	0.0
47	-	0.6	0.6	-	0.6
49	-	0.0	-	-	-
Mean Den	**0.0**	**1.5**	**2.1**	**2.1**	**3.0**

Table 4. Abundance (animals/L) of major zooplankton taxa at Treatment sites 1 and 2 (N1, N2) and Reference sites 1 and 2 (S1, S2) in Amisk Lake during winter 1990. Samples were collected near mid-day. Mean densities for the whole water column (Mean Den) are listed for the populations at all sites on each date. Median depths (Median Z) of populations are given for sites N2 and S1 only; an asterisk (*) indicates that mean density was too low (i.e. < 1 animal/L) for calculation of median depth.

a) Daphnia longiremis

Treatment Site 1 (N1)

Depth (m)	Feb 28
1	0.0
3	0.0
5	0.0
7	1.2
9	0.0
11	0.0
13	0.0
15	0.0
17	0.0
19	0.0
Mean Den	**0.1**

Treatment Site 2 (N2)

Depth (m)	Jan 17	Feb 28
1	0.0	2.3
3	0.0	1.2
5	0.0	0.0
7	0.0	0.0
9	0.0	0.0
11	0.0	0.0
13	0.0	0.0
15	0.0	0.0
17	0.0	0.6
19	0.0	0.0
21	0.0	0.0
23	0.0	0.0
25	0.0	0.0
27	0.0	0.0
29	1.2	0.0
31	0.0	0.6
Mean Den	**0.1**	**0.3**
Median Z	*	*

(Table 4 continued)

a) Daphnia longiremis (continued)

Reference Site 1 (S1)

Depth (m)	Jan 16	Feb 27
1	0.0	3.5
3	0.0	2.3
5	0.0	3.5
7	0.0	0.0
9	0.0	0.0
11	0.0	0.0
13	0.0	0.0
15	0.0	0.0
17	0.0	0.0
19	0.0	0.0
21	0.0	0.0
23	0.0	0.0
25	0.6	0.0
27	0.0	0.0
29	0.0	0.0
31	0.0	0.0
Mean Den	**0.0**	**0.6**
Median Z	*	*

Reference Site 2 (S2)

Depth (m)	Feb 27
1	0.0
3	0.0
5	0.0
7	0.0
9	0.0
11	0.0
13	0.0
15	0.0
17	0.0
19	0.0
21	0.0
23	0.0
25	0.0
27	0.0
29	0.0
31	0.0
33	0.0
35	0.0
37	0.0
39	0.0
41	0.0
43	0.0
45	0.0
47	0.0
Mean Den	**0.0**

(Table 4 continued)

b) Daphnia pulex

Treatment Site 1 (N1)

Depth (m)	Feb 28
1	3.5
3	0.0
5	0.0
7	1.2
9	1.2
11	0.0
13	1.7
15	1.7
17	1.2
19	2.9
Mean Den	**1.3**

Treatment Site 2 (N2)

Depth (m)	Jan 17	Feb 28
1	5.2	0.0
3	0.0	0.0
5	3.5	0.0
7	3.5	0.0
9	1.7	1.2
11	0.0	2.9
13	3.5	1.2
15	1.2	0.0
17	2.3	0.0
19	0.0	0.0
21	1.2	0.0
23	4.1	0.0
25	0.0	0.0
27	1.7	0.0
29	3.5	0.0
31	2.3	1.7
Mean Den	**2.1**	**0.4**
Median Z	**13.7**	*****

(Table 4 continued)

b) Daphnia pulex (continued)

Reference Site 1 (S1)

Depth (m)	Jan 16	Feb 27
1	8.7	4.6
3	0.0	0.0
5	1.2	0.0
7	1.7	1.2
9	1.7	0.0
11	0.0	0.0
13	1.2	0.6
15	4.6	0.0
17	2.3	0.0
19	0.6	0.0
21	3.5	0.0
23	2.3	0.0
25	2.3	0.0
27	0.6	0.6
29	6.4	0.0
31	7.0	0.6
Mean Den	**2.8**	**0.5**
Median Z	**20.2**	*****

Reference Site 2 (S2)

Depth (m)	Feb 27
1	0.0
3	0.0
5	0.0
7	0.0
9	0.0
11	0.6
13	0.0
15	0.0
17	1.2
19	0.0
21	0.0
23	0.6
25	0.0
27	0.6
29	2.3
31	0.6
33	0.0
35	1.2
37	1.7
39	1.2
41	1.2
43	1.7
45	1.7
47	8.1
Mean Den	**0.9**

(Table 4 continued)

c) Daphnia galeata mendotae

Treatment Site 1 (N1)

Depth (m)	Feb 28
1	0.0
3	0.0
5	0.0
7	0.0
9	0.0
11	0.0
13	0.0
15	0.0
17	0.0
19	0.0
Mean Den	**0.0**

Treatment Site 2 (N2)

Depth (m)	Jan 17	Feb 28
1	3.5	0.0
3	1.7	0.0
5	0.0	0.0
7	0.0	0.0
9	0.0	0.0
11	0.0	0.0
13	0.0	0.0
15	0.0	0.0
17	0.0	0.0
19	1.2	0.0
21	0.0	0.0
23	0.0	0.0
25	0.0	0.0
27	0.0	0.0
29	0.0	0.0
31	0.0	0.0
Mean Den	**0.4**	**0.0**
Median Z	*	*

(Table 4 continued)

c) Daphnia galeata mendotae (continued)

Reference Site 1 (S1)

Depth (m)	Jan 16	Feb 27
1	0.0	0.0
3	0.0	0.0
5	1.2	0.0
7	3.5	0.0
9	0.0	0.0
11	0.0	0.0
13	0.0	0.0
15	0.0	0.0
17	0.0	0.0
19	0.0	0.0
21	0.0	0.0
23	0.0	0.0
25	0.0	0.0
27	0.0	0.0
29	0.0	0.0
31	0.0	0.0
Mean Den	**0.3**	**0.0**
Median Z	*	*

Reference Site 2 (S2)

Depth (m)	Feb 27
1	0.0
3	0.0
5	0.0
7	0.0
9	0.0
11	0.0
13	0.0
15	0.0
17	0.0
19	0.0
21	0.0
23	0.0
25	0.0
27	0.0
29	0.0
31	0.0
33	0.0
35	0.0
37	0.0
39	0.0
41	0.0
43	0.0
45	0.0
47	0.0
Mean Den	**0.0**

(Table 4 continued)

d) Bosmina longirostris

Treatment Site 1 (N1)

Depth (m)	Feb 28
1	0.0
3	0.0
5	0.0
7	0.0
9	0.0
11	0.6
13	1.7
15	0.0
17	0.0
19	0.0
Mean Den	**0.2**

Treatment Site 2 (N2)

Depth (m)	Jan 17	Feb 28
1	0.0	0.0
3	0.0	0.0
5	2.3	1.2
7	0.0	0.0
9	0.0	0.0
11	0.0	1.7
13	2.9	1.2
15	2.3	0.6
17	3.5	0.0
19	2.9	0.0
21	1.2	0.0
23	0.6	1.2
25	0.6	0.6
27	1.7	0.0
29	0.0	0.6
31	0.6	2.3
Mean Den	**1.2**	**0.6**
Median Z	**17.2**	*****

(Table 4 continued)

d) Bosmina longirostris (continued)

Reference Site 1 (S1)

Depth (m)	Jan 16	Feb 27
1	0.0	0.0
3	0.0	0.0
5	0.0	0.0
7	0.0	0.0
9	0.0	0.0
11	1.7	0.0
13	0.0	0.0
15	1.7	0.6
17	0.6	0.6
19	1.2	1.2
21	0.6	0.6
23	0.6	0.0
25	1.2	0.6
27	0.6	0.0
29	1.2	0.0
31	0.0	0.6
Mean Den	**0.6**	**0.3**
Median Z	*	*

Reference Site 2 (S2)

Depth (m)	Feb 27
1	0.0
3	0.0
5	0.0
7	0.0
9	0.0
11	0.6
13	0.6
15	0.0
17	1.2
19	0.6
21	0.0
23	0.6
25	0.0
27	0.0
29	0.6
31	0.0
33	0.0
35	0.6
37	0.6
39	0.6
41	0.0
43	1.2
45	0.6
47	2.3
Mean Den	**0.4**

(Table 4 continued)

e) Diaphanosoma leuchtenbergianum

Treatment Site 1 (N1)

Depth (m)	Feb 28
1	0.0
3	0.0
5	0.0
7	0.0
9	0.0
11	0.0
13	0.0
15	0.0
17	0.0
19	0.0
Mean Den	**0.0**

Treatment Site 2 (N2)

Depth (m)	Jan 17	Feb 28
1	0.0	0.0
3	0.0	0.0
5	0.0	0.0
7	0.0	0.0
9	0.0	0.0
11	0.0	0.0
13	0.0	0.0
15	0.0	0.0
17	0.0	0.0
19	0.0	0.0
21	0.0	0.0
23	0.0	0.0
25	0.0	0.0
27	0.0	0.0
29	0.0	0.0
31	0.0	0.0
Mean Den	**0.0**	**0.0**
Median Z	*	*

(Table 4 continued)

e) Diaphanosoma leuchtenbergianum (continued)

Reference Site 1 (S1)

Depth (m)	Jan 16	Feb 27
1	0.0	0.0
3	0.0	0.0
5	0.0	0.0
7	0.0	0.0
9	0.0	0.0
11	0.0	0.0
13	0.0	0.0
15	0.0	0.0
17	0.0	0.0
19	0.0	0.0
21	0.0	0.0
23	0.0	0.0
25	0.0	0.0
27	0.0	0.0
29	0.0	0.0
31	0.0	0.0
Mean Den	**0.0**	**0.0**
Median Z	*	*

Reference Site 2 (S2)

Depth (m)	Feb 27
1	0.0
3	0.0
5	0.0
7	0.0
9	0.0
11	0.0
13	0.0
15	0.0
17	0.0
19	0.0
21	0.0
23	0.0
25	0.0
27	0.0
29	0.0
31	0.0
33	0.0
35	0.0
37	0.0
39	0.0
41	0.0
43	0.0
45	0.0
47	0.0
Mean Den	**0.0**

(Table 4 continued)

f) cyclopoid copepods

Treatment Site 1 (N1)

Depth (m)	Feb 28
1	59.2
3	62.7
5	22.1
7	7.0
9	8.1
11	8.1
13	34.8
15	19.2
17	8.1
19	10.5
Mean Den	**24.0**

Treatment Site 2 (N2)

Depth (m)	Jan 17	Feb 28
1	17.4	60.4
3	17.4	51.1
5	9.3	25.5
7	15.7	16.3
9	15.7	25.5
11	8.7	23.8
13	10.5	21.5
15	8.7	12.2
17	7.5	19.2
19	11.0	11.6
21	7.0	11.6
23	9.9	11.6
25	7.5	12.8
27	13.4	14.5
29	10.5	11.6
31	13.9	14.5
Mean Den	**11.5**	**21.5**
Median Z	**15.5**	**9.5**

(Table 4 continued)

f) cyclopoid copepods (continued)

Reference Site 1 (S1)

Depth (m)	Jan 16	Feb 27
1	13.9	211.3
3	7.0	120.8
5	7.0	102.2
7	7.0	49.9
9	10.5	33.7
11	5.2	27.3
13	7.0	23.2
15	13.4	16.3
17	5.2	11.0
19	5.2	12.8
21	5.8	8.1
23	4.1	8.1
25	7.5	5.8
27	6.4	7.0
29	12.2	6.4
31	7.0	6.4
Mean Den	**7.8**	**40.6**
Median Z	**14.7**	**3.9**

Reference Site 2 (S2)

Depth (m)	Feb 27
1	11.6
3	54.6
5	25.5
7	18.6
9	4.6
11	8.1
13	8.1
15	9.3
17	7.0
19	8.7
21	2.3
23	4.6
25	3.5
27	4.6
29	3.5
31	7.5
33	7.5
35	4.6
37	3.5
39	9.3
41	6.4
43	7.5
45	11.0
47	16.3
Mean Den	**10.3**

(Table 4 continued)

g) Diaptomus oregonensis

Treatment Site 1 (N1)

Depth (m)	Feb 28
1	[illegible]
3	[illegible]
5	[illegible]
7	1.2
9	0.0
11	0.6
13	1.7
15	8.7
17	1.2
19	0.6
Mean Den	**2.5**

Treatment Site 2 (N2)

Depth (m)	Jan 17	Feb 28
1	0.0	0.0
3	3.5	1.2
5	1.2	5.8
7	0.0	5.8
9	1.7	3.5
11	3.5	4.1
13	1.2	3.5
15	4.1	0.6
17	0.6	1.2
19	4.6	2.3
21	1.2	1.2
23	4.1	0.6
25	1.7	0.0
27	3.5	0.6
29	4.1	0.6
31	1.7	1.7
Mean Den	**2.3**	**2.0**
Median Z	**19.1**	**9.8**

(Table 4 continued)

g) Diaptomus oregonensis (continued)

Reference Site 1 (S1)

Depth (m)	Jan 16	Feb 27
1	1.7	3.5
3	1.7	0.0
5	2.3	0.0
7	0.0	1.2
9	3.5	1.2
11	0.0	0.0
13	0.6	0.0
15	0.6	0.6
17	1.2	0.6
19	0.6	0.0
21	0.6	0.6
23	0.6	0.6
25	1.2	1.7
27	1.2	0.0
29	3.5	0.0
31	2.3	1.2
Mean Den	**1.4**	**0.7**
Median Z	**17.3**	*

Reference Site 2 (S2)

Depth (m)	Feb 27
1	2.3
3	0.0
5	0.0
7	0.0
9	0.0
11	1.2
13	0.6
15	0.6
17	0.0
19	0.0
21	0.6
23	0.0
25	1.2
27	0.6
29	2.9
31	0.6
33	0.6
35	1.2
37	1.2
39	1.2
41	2.3
43	1.7
45	1.7
47	0.6
Mean Den	**0.9**

V. Appendix B: Dissolved Oxygen and Water Temperature Data for Amisk Lake

Table 1. Dissolved oxygen (mg/L) profiles at Treatment site 2 (N2) and Reference site 1 (S1) in Amisk Lake, on zooplankton collection dates in summer 1988 and winter 1989. Profiles were done at mid-day unless otherwise indicated. Dissolved oxygen concentrations were determined by Carpenter's (1965) modification of the Winkler method.

Treatment Site 2

Depth (m)	Jun 27	Jul 11	Aug 07	Sep 19	Jan 10	Mar 06
3	11.0	10.7	13.1	7.4	9.3	7.3
9	4.2	4.5	1.8	7.2	9.5	7.2
18	3.1	2.0	1.6	0.5	8.1	6.4
24	2.1	1.6	1.1	0.2	6.8	6.1
27	1.9	1.5	0.9	0.2	6.3	5.8

Reference Site 1

Depth (m)	Jun 27	Jul 11	Aug 07	Sep 19	Jan 11	Mar 07
3	11.0	9.7	13.3	7.5	8.1	5.6
9	4.3	1.9	1.4	6.3	7.2	5.6
18	1.8	1.0	0.8	0.0	7.4	4.2
24	0.5	0.5	0.7	0.0	5.5	3.0
27	0.6	0.5	0.8	0.0	4.7	2.0

Table 2. Dissolved oxygen (mg/L) profiles at Treatment site 2 (N2) and Reference sites 1 and 2 (S1, S2) in Amisk Lake, on zooplankton collection dates in summer 1989 and winter 1990. Profiles were done at mid-day unless otherwise indicated. Dissolved oxygen concentrations were determined by Carpenter's (1965) modification of the Winkler method.

Treatment Site 2

Depth (m)	May 17	Jun 03	Jul 04	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 07	Jan 17	Feb 28
3	12.9	12.1	10.8	10.7	10.6	10.8	10.2	9.5	8.7	8.4
8	7.8	9.3	6.3	6.7	5.2	3.0	2.3	1.4	8.5	8.3
18	7.8	6.3	3.3	3.9	3.3	2.1	2.5	1.8	8.3	8.2
21	7.1	5.7	2.5	3.0	2.5	2.2	2.4	1.3	8.2	7.8
24	6.9	6.0	1.9	2.0	1.9	1.5	1.4	1.7	8.0	7.3
27	7.0	5.7	1.6	1.5	1.6	1.2	1.2	0.6	7.6	6.9
30	6.9	5.3	1.7	1.6	1.3	1.0	1.0	0.5	7.2	6.8

Reference Sites 1 and 2(*)

Depth (m)	May 17	Jun 03	Jul 04	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 07	Jan 16	Feb 27
3	13.2	11.9	10.6	10.5	11.1	11.3	11.7	9.7	7.5	6.4
8	7.5	10.3	6.1	6.2	4.6	2.8	3.1	1.6	7.2	6.1
18	5.3	5.9	2.7	1.9	1.4	0.7	0.8	0.4	6.1	5.0
21	4.6	4.8	1.3	1.0	0.7	0.3	0.5	0.3	5.8	4.8
24	4.0	3.3	1.0	0.6	0.4	0.3	0.5	0.2	5.6	4.7
27	3.6	2.8	0.4	0.3	0.1	0.3	0.4	0.0	5.4	4.3
30	2.9	2.0	0.0	0.0	0.0	0.1	0.3	0.0	5.1	4.2
*27	3.4	-	0.7	0.0	0.0	-	-	0.0	4.2	4.3
*30	3.0	-	0.6	0.0	0.0	-	-	0.0	4.1	2.8
*40	2.7	-	0.4	0.0	0.0	-	-	0.0	2.3	0.1
*45	3.0	-	0.7	0.0	0.0	-	-	0.0	1.2	0.4

Table 3. Temperature (C) profiles at Treatment site 2 (N2) and Reference site 1 (S1) in Amisk Lake, on zooplankton collection dates in summer 1988 and winter 1989. Readings were taken at mid-day.

Treatment Site 2 (N2)

Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20	Jan 10	Mar 06
1	19.3	18.6	19.0	14.1	0.1	2.2
2	19.3	18.5	19.0	14.1	2.2	2.7
3	19.1	18.5	19.0	14.1	2.5	2.8
4	18.1	18.5	19.0	14.1	2.7	2.8
5	17.1	18.4	19.0	14.1	2.8	2.8
6	16.1	17.3	18.9	14.1	2.8	2.9
7	14.9	17.1	17.3	14.1	2.9	2.9
8	12.9	13.2	14.2	14.1	2.9	2.9
9	10.5	10.7	10.6	14.1	2.9	2.9
10	8.7	9.5	10.0	12.4	2.9	2.9
11	7.9	8.8	9.5	10.0	2.9	2.9
12	7.7	8.5	9.0	10.0	2.9	2.9
13	7.6	8.2	9.0	10.0	2.9	2.9
14	7.6	8.0	8.8	9.9	2.9	2.9
15	7.4	8.0	8.8	9.7	3.0	2.9
16	7.4	7.9	8.8	9.6	3.0	2.9
17	7.4	7.9	8.6	9.5	3.0	3.0
18	7.3	7.8	8.5	9.5	3.0	3.0
19	7.2	7.8	8.5	9.5	3.0	3.0
20	7.2	7.7	8.5	9.5	3.1	3.0
21	7.2	7.7	8.4	9.5	3.1	3.0
22	7.1	7.7	8.4	9.4	3.1	3.0
23	7.1	7.6	8.4	9.4	3.1	3.0
24	7.1	7.6	8.3	9.4	3.1	3.0
25	7.0	7.5	8.3	9.4	3.2	3.0
26	7.0	7.5	8.2	9.4	3.2	3.0
27	6.9	7.5	8.2	9.4	3.2	3.0
28	6.9	7.5	8.2	9.4	3.2	3.0
29	6.9	7.5	8.2	9.4	3.2	3.0
30	6.9	7.5	8.2	9.4	3.3	3.0
31	6.9	7.5	8.2	9.4	3.3	3.0

(Table 3 continued)

Reference Site 1 (S1)

Depth (m)	Jun 27	Jul 11	Aug 07	Sep 20	Jan 11	Mar 07
1	19.3	18.1	19.2	14.5	1.8	1.5
2	19.3	18.0	19.2	14.5	2.5	2.8
3	19.3	18.0	19.2	14.5	2.7	2.9
4	19.3	17.6	18.5	14.5	2.8	3.0
5	19.3	17.5	17.4	14.5	2.9	3.0
6	16.8	17.1	16.8	14.5	3.0	3.0
7	15.2	16.2	15.2	14.5	3.0	3.0
8	13.3	13.7	11.5	14.5	3.1	3.0
9	10.4	10.5	10.2	14.2	3.1	3.1
10	9.1	9.1	9.6	13.2	3.1	3.1
11	8.4	8.6	9.3	11.3	3.1	3.1
12	8.1	8.2	8.9	10.8	3.1	3.1
13	7.7	7.7	8.5	10.2	3.1	3.2
14	7.5	7.4	8.0	8.8	3.1	3.2
15	7.3	7.2	7.5	7.3	3.1	3.2
16	6.9	6.8	7.1	6.8	3.1	3.2
17	6.5	6.5	6.9	6.1	3.2	3.2
18	6.3	6.0	6.4	5.7	3.2	3.2
19	6.1	5.7	6.0	5.5	3.3	3.2
20	5.8	5.3	5.6	5.4	3.3	3.2
21	5.6	5.1	5.2	5.3	3.3	3.2
22	5.3	5.0	5.0	5.1	3.3	3.2
23	5.1	5.0	5.0	5.0	3.4	3.2
24	5	5.0	5.0	5.0	3.4	3.2
25	5.0	4.9	5.0	4.9	3.5	3.3
26	5.0	4.8	5.0	4.8	3.4	3.3
27	4.8	4.7	5.0	4.7	3.4	3.3
28	4.8	4.7	5.0	4.7	3.4	3.3
29	4.7	4.6	5.0	4.7	3.4	3.3
30	4.7	4.6	5.0	4.7	3.4	3.3
31	4.7	4.5	5.0	4.7	3.4	3.3

Table 4. Temperature (C) profiles at Treatment sites 1 and 2 (N1, N2) and Reference sites 1 and 2 (S1, S2) in Amisk Lake, on zooplankton collection dates in summer 1989 and winter 1990. Readings were taken at mid-day unless otherwise indicated.

Treatment Site 1 (N1)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	11.8	17.9	19.5	21.1	17.8
2	11.7	17.8	19.4	21.0	17.4
3	8.8	17.7	19.3	20.9	17.4
4	7.8	17.6	19.2	20.8	17.3
5	7.2	16.8	18.1	19.3	17.3
6	7.0	12.9	14.2	15.5	17.1
7	6.8	10.8	11.8	12.8	14.4
8	6.7	9.9	10.3	10.7	12.2
9	6.4	9.1	9.5	9.9	11.6
10	6.3	8.9	9.2	9.4	10.6
11	6.2	8.6	8.9	9.1	10.3
12	6.1	8.4	8.7	8.9	10.2
13	6.0	8.1	8.4	8.6	10.1
14	5.9	8.0	8.3	8.5	10.0
15	5.7	7.9	8.2	8.4	10.0
16	5.7	7.8	8.1	8.3	9.9
17	5.6	7.7	8.0	8.3	9.8
18	5.5	7.7	8.0	8.2	9.8
19	5.5	7.5	7.8	8.1	9.7
20	5.4	7.4	7.8	8.1	9.7
21	5.3	-	-	-	-

(Table 4 continued)

Treatment Site 2 (N2)

Depth (m)	May 17	Jun 03	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 06	Jan 17	Feb 28
1	12.5	13.5	17.8	19.9	21.9	23.9	24.3	17.8	2.5	2.3
2	10.3	12.3	17.8	19.7	21.6	23.5	23.5	17.4	2.6	2.4
3	8.7	11.8	17.5	19.4	21.3	23.5	22.5	17.2	2.7	2.4
4	8.3	10.7	17.5	18.0	21.0	21.6	21.6	17.2	2.7	2.4
5	7.2	10.0	15.4	16.6	18.0	19.8	20.2	17.1	2.8	2.4
6	6.9	9.8	11.5	13.8	15.6	16.8	16.9	16.9	2.9	2.4
7	6.8	9.3	10.2	10.9	12.1	13.1	13.4	15.4	2.9	2.4
8	6.7	8.6	10.0	10.2	10.2	12.1	11.8	11.4	2.9	2.4
9	6.4	8.0	9.5	9.5	9.8	11.2	11.1	11.0	2.9	2.4
10	6.3	7.6	9.3	9.2	9.3	10.6	10.4	10.9	2.9	2.4
11	6.1	7.4	8.8	8.9	9.1	10.1	10.0	10.8	2.9	2.4
12	5.9	7.2	8.6	8.7	9.0	9.9	9.6	10.7	2.9	2.4
13	5.8	7.1	8.4	8.5	8.8	9.7	9.5	10.6	2.9	2.4
14	5.8	7.0	8.3	8.4	8.6	9.6	9.5	10.1	2.9	2.4
15	5.7	7.0	8.0	8.2	8.5	9.5	9.5	10.0	2.9	2.4
16	5.7	6.8	7.9	8.1	8.5	9.4	9.4	9.8	2.9	2.4
17	5.6	6.6	7.8	8.0	8.4	9.3	9.2	9.7	2.9	2.4
18	5.5	6.5	7.6	7.9	8.3	9.2	9.2	9.5	2.9	2.4
19	5.5	6.5	7.5	7.8	8.3	9.2	9.2	9.4	2.9	2.4
20	5.5	6.5	7.5	7.8	8.2	9.2	9.1	9.4	2.9	2.4
21	5.5	6.5	7.4	7.7	8.1	9.1	9.1	9.4	3.0	2.5
22	5.4	6.4	7.3	7.7	8.1	9.1	9.0	9.2	3.0	2.5
23	5.4	6.4	7.3	7.6	8.1	9.0	9.0	9.2	3.0	2.5
24	5.4	6.4	7.3	7.6	8.0	9.0	8.9	9.2	3.0	2.5
25	5.4	6.4	7.3	7.6	8.0	9.0	8.9	9.1	3.0	2.5
26	5.4	6.4	7.3	7.6	8.0	8.9	8.9	9.0	3.0	2.6
27	5.3	6.4	7.2	7.5	8.0	8.9	8.9	9.0	3.0	2.6
28	5.3	6.3	7.2	7.5	8.0	8.9	8.9	9.0	3.0	2.6
29	5.3	6.3	7.2	7.5	8.0	8.9	8.9	8.9	3.0	2.6
30	5.3	6.3	7.2	7.5	7.9	8.9	8.9	8.9	3.0	2.6
31	5.3	-	7.0	7.5	7.9	8.9	8.8	-	3.0	2.7

(Table 4 continued)

Reference Site 1 (S1)

Depth (m)	May 17	Jun 03	Jul 03	Jul 11	Jul 25	Aug 11	Aug 12 01:30	Sep 06	Jan 16	Feb 27
1	12.0	13.6	17.9	19.8	22.6	23.3	-	16.1	1.9	1.1
2	11.9	13.1	17.7	19.3	22.5	22.5	-	16.1	2.5	2.5
3	11.8	12.7	17.1	18.9	22.4	22.0	-	16.0	2.9	2.7
4	11.6	12.6	16.8	17.8	22.3	21.5	-	15.9	3.0	2.7
5	10.6	12.1	16.1	16.7	17.5	20.8	-	15.9	3.0	2.7
6	8.6	9.9	14.2	14.4	16.4	17.2	-	15.0	3.1	2.7
7	8.0	9.3	11.0	12.1	12.2	14.3	-	13.3	3.1	2.7
8	6.8	8.7	9.9	10.9	11.2	12.4	-	11.2	3.1	2.8
9	6.5	8.5	9.2	9.6	10.4	11.1	-	11.1	3.1	2.8
10	6.4	8.3	8.8	9.2	9.7	10.1	-	11.0	3.2	2.9
11	6.2	8.0	8.5	8.7	9.4	9.5	-	10.9	3.2	2.9
12	6.1	7.8	8.2	8.5	9.1	9.2	-	10.4	3.2	2.9
13	5.9	7.4	7.9	8.2	8.8	9.1	-	9.7	3.2	2.9
14	5.7	7.2	7.6	7.9	8.3	8.8	-	9.5	3.2	2.9
15	5.5	6.9	7.4	7.6	7.9	8.5	-	9.1	3.2	2.9
16	5.3	6.8	7.0	7.3	7.4	8.1	-	8.6	3.2	2.9
17	5.2	6.6	6.8	7.0	7.1	7.8	-	8.1	3.3	2.9
18	5.2	6.2	6.6	6.7	6.9	7.4	-	7.5	3.3	2.9
19	5.1	6.1	6.2	6.4	6.7	7.1	-	7.1	3.3	2.9
20	4.8	6.1	6.0	6.1	6.5	6.7	-	6.9	3.3	2.9
21	4.8	5.9	5.8	5.8	6.3	6.4	-	6.6	3.3	2.9
22	4.7	5.7	5.5	5.6	6.2	6.2	-	6.5	3.3	2.9
23	4.6	5.6	5.4	5.4	6.0	6.1	-	6.3	3.3	2.9
24	4.6	5.3	5.3	5.3	5.7	6.0	-	6.1	3.3	2.9
25	4.6	5.0	5.2	5.2	5.6	5.8	-	6.0	3.3	2.9
26	4.6	4.8	5.0	5.2	5.5	5.7	-	6.0	3.3	2.9
27	4.5	4.7	5.0	5.1	5.4	5.7	-	5.8	3.3	2.9
28	4.5	4.7	5.0	5.1	5.3	5.6	-	5.8	3.3	2.9
29	4.5	4.7	5.0	5.0	5.2	5.5	-	5.8	3.3	2.9
30	-	4.7	5.0	5.0	5.1	5.5	-	5.8	3.3	2.9
31	-	4.7	4.9	5.0	5.1	5.5	-	-	3.3	2.9

(Table 4 continued)

Reference Site 2 (S2)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
1	11.4	17.9	20.4	22.9	16.6
2	11.3	17.9	20.2	22.5	16.5
3	11.0	17.2	19.8	22.3	16.4
4	10.9	17.0	19.6	22.2	16.3
5	10.5	16.5	17.3	18.0	16.3
6	9.3	14.0	15.0	15.9	15.8
7	7.9	12.3	12.7	13.1	12.3
8	7.4	10.5	11.1	11.7	11.5
9	7.2	9.7	10.2	10.7	11.3
10	6.5	9.0	9.4	9.8	11.0
11	6.4	8.5	9.0	9.5	10.9
12	6.2	8.1	8.7	9.2	10.8
13	6.1	8.0	8.4	8.8	10.1
14	5.9	7.7	8.1	8.4	9.2
15	5.5	7.5	7.8	8.1	8.5
16	5.2	7.2	7.5	7.7	8.3
17	5.0	6.7	7.0	7.3	8.0
18	5.0	6.4	6.6	6.7	7.7
19	4.9	6.1	6.3	6.4	7.0
20	4.9	5.9	6.0	6.1	6.8
21	4.8	5.8	5.8	5.8	6.7
22	4.7	5.7	5.7	5.7	6.6
23	4.6	5.6	5.6	5.6	6.4
24	4.5	5.3	5.5	5.6	6.3
25	4.5	5.2	5.4	5.5	6.1
26	4.5	5.1	5.3	5.4	6.0
27	4.4	5.1	5.2	5.3	6.0
28	4.4	5.0	5.2	5.3	6.0
29	4.4	5.0	5.1	5.2	5.9
30	4.4	5.0	5.1	5.1	5.8

(Table 4 continued)

Reference Site 2 (S2) (continued)

Depth (m)	May 17	Jul 03	Jul 11	Jul 25	Sep 06
31	4.4	5.0	5.1	5.1	5.7
32	4.4	5.0	5.1	5.1	5.7
33	4.3	5.0	5.0	5.0	5.7
34	4.3	5.0	5.0	5.0	5.7
35	4.2	5.0	5.0	5.0	5.6
36	4.2	5.0	5.0	5.0	5.6
37	4.2	5.0	5.0	5.0	5.6
38	4.2	5.0	5.0	5.0	5.6
39	4.2	4.9	5.0	5.0	5.6
40	4.2	4.9	4.9	4.8	5.5
41	4.2	4.9	4.9	4.8	5.5
42	4.2	4.9	4.9	4.8	5.5
43	4.2	4.9	4.9	4.8	5.5
44	4.2	4.9	4.9	4.8	5.5
45	4.2	4.9	4.8	4.7	5.5
46	-	4.9	4.8	4.7	5.4
47	-	4.9	4.8	4.7	-
48	-	4.8	4.8	4.7	-
49	-	-	-	-	-

VI. Appendix C: Morphometric Characteristics of Amisk Lake

Table 1. Morphometric characteristics of Amisk Lake, Alberta. (Data from Prepas, E.E. 1990. Amisk Lake. p. 225-231 *In* P. Mitchell and E.E. Prepas [ed.] Atlas of Alberta Lakes. Univ. Alberta Press, Edmonton, AB.)

	Total	North Basin	South Basin
Elevation (m)	611.70		
Surface area (km^2)	5.15	2.33	2.82
Volume (m^3)	7.97×10^7	2.51×10^7	5.46×10^7
Maximum depth (m)	-	34	60
Mean depth (m)	15.5	10.8	19.4
Shoreline length (km)	24.62	-	-
Mean annual lake evaporation (mm)	636	-	-
Mean annual precipitation (mm)	517	-	-
Mean water residence time (y)	8	-	-
Control structure	Ducks unlimited (Canada) rock-filled timber weir		