12-1998

Factors Affecting The Movements of Rainbow Trout (Oncorhynchus mykiss) in Lake Ogallala, Nebraska

Tadd M. Barrow
University of Nebraska-Lincoln

FACTORS AFFECTING THE MOVEMENTS OF RAINBOW TROUT (*Oncorhynchus mykiss*) IN LAKE OGALLALA, NEBRASKA

by

Tadd M. Barrow

A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Natural Resource Sciences

Under the Supervision of Professor Edward J. Peters

Lincoln, Nebraska

December, 1998

FACTORS AFFECTING THE MOVEMENTS OF

RAINBOW TROUT (*Oncorhynchus mykiss*), IN

LAKE OGALLALA, NEBRASKA.

Tadd M. Barrow, M.S.

University of Nebraska, 1998

Adviser: Edward J. Peters

In October 1997, Lake Ogallala was treated with rotentone to eliminate non-game fish competitors with rainbow trout, and in June 1998 an aeration system was installed in the north basin of the lake to increase dissolved oxygen levels. These measures were intended to deter movement of trout from Lake Ogallala. Our objectives were to evaluate the treatment effects upon rainbow trout movements. Selected hatchery-reared rainbow trout were implanted with ultrasonic transmitters and released with 3,000-5,000 other trout stocked in February and May, 1997 and 1998. In 1997 (before) and in 1998, after the management treatments, trout were tracked weekly to determine their movements within the lake. In 1997, 66% of fish implanted in February, and 50% of fish implanted in May remained in the lake for the 60-day life of the transmitters. In 1998, 70% of the fish implanted in February and 80% of the fish implanted in May remained in the lake for 60 days. The higher percentage of fish remaining in the lake in 1998 correlates directly with higher dissolved oxygen concentrations and increased macroinvertebrate densities which resulted from management treatments.

ACKNOWLEDGMENTS

Over the past two years many people have been instrumental in the success and completion of this project. First and foremost, I would like to thank my major professor Dr. Edward J. Peters for all his advice, input, suggestions, editing and overall time spent throughout this program. It was Dr. Peters who gave me a start in the fisheries field by allowing me to work on the shovelnose sturgeon project. With that project I gained a new perspective on research, data collection, and the overall rewards of fisheries work, for that experience I am gratefully thankful.

I would also like to thank Dr. Richard S. Holland and Dr. Kyle D. Hoagland for being members of my graduate program committee and for their ideas, assistance and advice throughout the study. Thanks to Tyler Pearson for assistance in data collections, progress reports and very long one day trips to hatcheries to implant fish. Thanks to Chad Taylor for assistance in collections, and discussion of ideas as the project was in its early stages. Added thanks go to Ryan Hochstein and Larry Vrtiska, both spent a great deal of time assisting in field collections, working long odd hours and at times in less than ideal weather conditions. Other thanks go to Carmen Blausey who contributed numerous hours of work in the lab analyzing samples, as well as periodic field work. I would also like to thank Cory Reade for periodic field collections, as well as fellow graduate students in the Department of Forestry, Fisheries and Wildlife for their aid and support. Statistical support was provided by Dr. Linda J. Young, University of Nebraska at Lincoln, Biometry Department.

Special thanks go to Darrol Eichner, Fisheries Research Biologist, Nebraska Game and Parks District IV for collaboration, discussion, mechanical support, and overall assistance. Thanks to Monte Madsen, Supervisor, Nebraska Game and Parks District IV for overall aid and allowing us the use of equipment. A great deal of appreciation is extended to those working at the Calamus and Rock Creek fish hatcheries. Their extensive cooperation, care of fish and use of facilities made surgical procedures seem effortless.

Finally, I would also like to thank Katherine Barrow for her assistance, personal support and drive to succeed. The constant support she provided was a great aid in helping me fulfill not only the goals of this project, but many other goals in life.

Funding for this project was provided by the Federal Aid to Sport Fish Restoration project F-112-R in conjunction with a joint project supported by the Institute of Agriculture and Natural Resources, University of Nebraska at Lincoln, and the Nebraska Game and Parks Commission, Lincoln, Nebraska.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICIES

Appendix Page

INTRODUCTION

The rainbow trout (*Oncorhynchus mykiss*) is very popular among anglers throughout the United States and Canada. It's native range includes the eastern Pacific Ocean and freshwater lakes and rivers, mainly west of the Rocky Mountains, from northwest Mexico to Alaska. Rainbow trout are not native east of the continental divide (Scott and Crossman 1973). They were first introduced into waters outside their native range in 1874, and by 1971 were established in 39 of 45 states in which they were not originally native (Willers 1981). Although many streams and rivers throughout the Midwest currently maintain reproducing populations of rainbow trout, Lake McConaughy on the North Platte River in Nebraska is the only reservoir in the Great Plains that supports a self-sustaining population of rainbow trout (Tomelleri and Eberle 1990; Van Velson 1974).

Of all salmonids, the rainbow trout is most often selected for stocking due to its sportfish qualities and its easy propagation in hatcheries. Most states rear rainbow trout in hatcheries to supply lakes, ponds and streams with a put, grow and take fishery. A primary objective of stocking catchable trout is to provide recreational fishing in heavily used areas where natural reproduction cannot meet public demand. Fish that move out of these areas can be considered a loss to this objective (Moring and Buchanan 1978).

Movements

Dispersal of stocked salmonids is highly variable (Jenkins 1971). Parsons (1956) determined that tagged trout moved freely throughout Dale Hollow Reservoir, with many fish being captured 49-56 km downstream from the release point. Hanson and Stauffer (1971) discovered that 69% of stocked rainbow trout exhibited down lake movements. Many Great Lakes rainbow trout studies have reported long range movements. In Lake Ontario a typical trout may move an estimated 12 km/day (Haynes et al. 1986). In Lake Superior, seven trout were caught 20-360 km from their spawning stream (Niemuth 1970), and Hansen and Stauffer (1971) reported commercial catches in Lakes Ontario and Erie of rainbow trout released in Lake Huron . Kelso and Kwain (1984) tracked trout with ultrasonic transmitters in Batchawana Bay, Lake Superior; after 14 days, only 40% of the tagged fish could be found in the bay.

Movements may coincide with the time of year or the time of day. Ruggerone et al. (1990) found that trout moved significantly less at night than during the day. In a Lake Michigan tributary, 75% of fish greater than 226 mm migrated during May (Stauffer 1972). Parsons (1956) found that after initial dispersal following stocking, smaller rainbow trout (<250mm) generally remained in the same area. Haynes et al. (1986) hypothesized that rainbow trout in Lake Onatario move off shore when spring thermal fronts concentrate various insect species, which serve as a preferred prey.

Dissolved oxygen

The solubility and dynamics of oxygen distribution in lakes are also basic to understanding the distribution, behavior and growth of aquatic organisms (Wetzel 1983). Salmonids require higher levels of dissolved oxygen than do most cool and warm water game species. At concentrations of 6 mg/l, rainbow trout begin to show signs of stress which include slowing of the heart rate (Davis 1975, Weithman and Haas 1984). Mathias and Barica (1985) found that rainbow trout mortality related closely to dissolved oxygen concentrations at or below 5 mg/l, and Weithman and Haas (1984) concluded that exposure to a 2.5 mg/l concentration of dissolved oxygen for longer than 24 hours is lethal to rainbow trout. There have been no direct observations showing that reduced dissolved oxygen levels cause trout to move from an area. However, solubility of oxygen is affected nonlinearly by temperature, and increases considerably in cold water (Mortimer 1981).

Temperature

Numerous studies have shown that temperature has a direct effect upon the movements and distribution of rainbow trout. Rainbow trout prefer cold water, with some strains capable of enduring waters as warm as 25°C, a temperature that would be lethal to brook, brown, and cutthroat trout (Tomelleri and Eberle 1990). Changes in water temperature are a major factor affecting salmonid movements in reservoirs. Temperatures greater than 20°C caused brown trout (*Salmo trutta*) to move from a coolwater reservoir, and although reservoir temperatures later cooled to less than 19°C in early September, the fish never returned (Garrett and Bennett 1995). Overholz et al. (1977) found that rainbow trout selected water temperatures of 21°C or less, and avoided shallow water where temperatures exceeded 20°C. Brown and rainbow trout abandoned the Firehole River in Yellowstone National Park before summer water temperature reached 24°C and entered a smaller tributary stream which remained below 17°C throughout the summer (Kaya et al. 1977). Horak and Tanner (1964) found that 82% of rainbow trout captured in vertical gill nets were in water temperatures ranging between 15.5 and 20°C. Cherry et al. (1975) showed that rainbow trout acclimated to 6°C preferred temperatures of 10.6-11.7°C. In Lake Ontario, trout were observed using temperatures ranging from 5.0-14.4°C, and once nearshore temperatures exceeded 10°C, most rainbow trout moved off shore to cooler waters (Haynes et al. 1986).

Diet

A rainbow trout's diet consists of various invertebrates including cladocerans, copepods, decapods, larger crustaceans, insects, snails and leeches. Rainbow trout (>300 mm) will occasionally eat fish eggs as well as other fish and crayfish (Scott and Crossman 1973). Jude et al. (1987) studied diet and prey selection of Lake Michigan salmonids. Rainbow trout diets were dominated by invertebrates in the spring and summer, with prey fish numbers increasing in the fall. Stomachs of small rainbow trout (<300 mm) had the highest proportions of invertebrates, but salmonids >300 mm preferred alewife which made up 55-82% of stomach contents by weight. Chinook salmon diets were composed of fish and invertebrates in the spring and summer. Fish, predominately alewife (*Alosa pseudoharengus*) dominated in the fall. Coho (*Oncorhynchus kisutch*) and chinook salmon (*Oncorynchus tshawytscha*) diets were about 80% alewife by weight. In addition, Parsons (1956) determined that small rainbow trout fed almost entirely upon benthic invertebrates (chironomids).

Along with benthic invertebrates and fish, zooplankton can make up a substantial portion of salmonid diets. Selection by rainbow trout for *Daphnia* sp. is due to their inability to retain smaller zooplankton on their widely spaced gill rakers (Galbraith 1967; Wong and Ward, 1972). The proportion of gill raker spaces under 1.1 mm decreases as the size of the fish increases, thus favoring rainbow trout that select larger zooplankton (*Daphnia* sp.). In Stager Lake, Michigan, 96% of the *Daphnia* eaten by rainbow trout were larger than 1.3 mm; despite the abundance of smaller copepods and cladocerans, very few were found in rainbow trout stomachs (Galbraith 1967). In Flaming Gorge Reservoir, Wyoming-Utah, large bodied *Daphnia* sp. composed a substantial portion of the diet of lake dwelling trout (Schneidervin and Hubert 1987). In East Canyon Reservoir, Utah, rainbow trout fed extensively on 1.5-2.5 mm *Daphnia* (Tabor et al. 1996). Brynildson and Kempinger (1973) found that hatchery trout grew poorly when stocked in Wisconsin lakes with fewer than ten *Daphnia* $\geq$1 mm per liter.

Dietary interspecific competition is common among fish species. Competition for food between rainbow trout and other species is a factor that limits rainbow trout stocking success (Schneidervin and Hubert 1987). Competition with yellow perch (*Perca flavescens*) caused a 50% reduction in the growth rates of stocked brook trout (*Salvelinus fontinalis*), splake (*Salvelinus namaycush* X *Salvelinus fontinalis*) and rainbow trout, and reduced the survival of stocked brook trout in a small Ontario lake (Fraser 1978). Yellow perch predation inshore has been shown to replace alewife predation offshore, keeping zooplankton sizes suppressed in all areas of Lake Michigan

(Jude et al. 1987). Yellow perch introduction also led to major changes in the food habits of stocked salmonids. Dipteran larvae and pupae were the only major food that did not decrease or disappear from salmonid stomachs after the introduction of yellow perch (Fraser 1978).

It is well documented that alewife change zooplankton composition in lakes from large daphnid and copepod dominated systems to small rotifer and *Bosmina* sp. (Brooks and Dodson 1965; Urban and Brandt 1993; Kohler and Ney 1981; and Mills et al. 1992). Small *Daphnia* (< 1 mm) have a lower caloric value per unit weight and are harder to detect than larger *Daphnia* (Tabor et al. 1996). This causes trout to switch to alternative prey when zooplankton lengths fall below 1.3 mm. Janssen and Brandt (1980) suggested that the adaptation of alewife to follow their prey may give them a competitive advantage. Lackey (1969) reported that alewife fed primarily on zooplankton during the summer, but also fed extensively on dipteran larvae when available.

Macrophytes

Macrophytes provide cover for juvenile fish and aquatic invertebrates, these invertebrates are essential for trout growth and maintenance. A decrease or elimination of macrophytes has a tremendous impact on the benthic community, as invertebrates no longer have ample cover and become susceptible to predation. Unproductive benthos leads to an increased dependence on zooplankton by fish (Schneidervin and Hubert 1987). Many nongame fish species have been documented as having negative impacts upon macrophytes. Crowder and Painter (1991) showed that common carp (*Cyprinus carpio*) damage macrophyte stands necessary for benthic invertebrate habitat. LaCasse and Magnan (1992) found that white suckers (*Catostomus commersonii*) have an impact on littoral habitats in Laurentian Shield lakes. Sucker species have a long digestive tract that allows for a longer retention time to digest plant material. Marrin and Erman (1982) found that detritus and aquatic plants comprised 68% by volume of the Tahoe sucker (*Catostomus tahoensis*) diet. Harris and Gutzmer (1996) showed that herbivory and sediment disturbance by carp and white sucker was partly responsible for the macrophyte decline in Lake Ogallala.

STUDY SITE

The construction of Kingsley Dam in 1941, owned and operated by Central Nebraska Public Power and Irrigation District (CNPPID), on the North Platte River in western Nebraska, created C. W. McConaughy Reservoir, a 14,000 ha irrigation impoundment commonly called to as Lake McConaughy. Lake Ogallala is a 263 ha reservoir immediately below Lake McConaughy that consists of two basins. The main basin, oriented north to south, is 103 ha with a maximum depth of 12 m and a mean depth of 7 m. The Keystone Basin, oriented east and west, is 160 hectares with a maximum depth of 4 m and a mean depth of 2 m (Figure 1). Lake Ogallala acts as a catchment lake for water moving from Lake McConaughy through the Kingsley Hydro Electric Power Plant. Because the intake lies in the hypolimnion at approximately 43 m beneath the surface of Lake McConaughy, Lake Ogallala receives cool water (<20 C) year round, and is considered an important area for a put, grow and take trout fishery. From 1971 to 1990 an outstanding trout fishery quality developed in Lake Ogallala (Madsen and Eichner 1996).

In 1985 the installation of the hydroelectric plant resulted in a number of physical, chemical, and biological changes that led to a decline in the trout fishery. Prior to the plant's operation, summer releases of anoxic Lake McConaughy water into Lake Ogallala became oxygenated during the discharge process. With the installation of the penstock, discharge was altered and very little aeration currently occurs (Madsen and Eichner 1996). Laux et al. (1996) found summer dissolved oxygen levels at or below 6 mg/l at all of their eight study sites in Lake Ogallala.

With the installation of the hydroelectric plant, considerably more fish entered Lake Ogallala. Alewife were stocked in Lake McConaughy from 1986-88, to supplement the gizzard shad population, and became well established in Lake Ogallala by 1990 (Madsen and Eichner 1996). Their introduction has caused a shift in zooplankton size structure by removing larger (>1 mm) individuals. Large carp, white sucker, and yellow perch populations were in direct competition with trout for benthic invertebrates. Foraging activity, and frequent water level fluctuations caused a decline in macrophytes and benthic invertebrate density and diversity. Fisher and LaVoy (1972) concluded that benthic invertebrate communities periodically exposed were lower in density and diversity than communities in continuously flooded areas.

The Nebraska Game and Parks Commission (NGPC) has taken a number of actions to enhance the trout fishery in Lake Ogallala. On October 10, 1997, a rotenone renovation was conducted to eradicate all fish. Their objectives were to increase water transparency, macrophyte production, zooplankton size and return of trout to anglers (Madsen and Eichner 1996). Upon detoxification of the rotenone, rainbow trout, brown trout, chinook salmon, and yellow perch were stocked. Rainbow trout were the most abundant species stocked due to angler preference and ease of rearing. Brown trout become piscivorous at a smaller size than most other salmonids and were stocked to partially control incoming alewife. In the Great Lakes region, brown trout have shown very significant growth when fed a steady diet of alewife. Staley (1966) warned that brown trout should be stocked in lakes with caution because large individuals tend to accumulate in substantial numbers as voracious predators and are seldom caught by anglers. Yellow perch were also stocked to please anglers who traditionally fished the lake for perch. On June 4, 1998 an aeration system was installed to destratify the north basin and bring oxygen depleted water from the hypolimnion to the surface where it could be oxygenated. During the months of July, August and Semptember, the NGPC has sought to obtain dissolved oxygen concentrations of 6 mg/l or more, one meter from the bottom.

The purpose of this study was to investigate the movements of stocked rainbow trout in Lake Ogallala in relationship to time of year, availability of suitable water temperatures, availability of suitable dissolved oxygen concentrations, and the abundance of food items. Determining the factors affecting fish movements and obtaining a better understanding of the actual numbers of trout that leave the lake will benefit future management decisions.

METHODS

Ultrasonic telemetry was used to determine movement patterns and habitat preferences of rainbow trout in Lake Ogallala. Choosing a transmitter attachment method that does not negatively affect a fishes "natural" movements is important to obtaining accurate data. Gastric implants have been shown to affect the growth and feeding of salmonids (Adams et al. 1998), and swimming performance in rainbow trout was impaired by externally attached transmitters (Mellas and Haynes 1985). Since surgical implantation, does not affect the mortality or growth of rainbow trout (Lucas 1989), or growth, feeding or swimming behavior in other salmonids (Moore, Russell and Potter 1990), it was chosen as the method of transmitter attachment for this study. Marty and Summerfelt (1986) noted adverse effects on fish physiology and behavior as the ratio of transmitter weight to fish weight increased. Implanted fish resembled (in length and weight) those being stocked, but were selected so that transmitter size did not exceed 2% of total body weight (Winter 1983). The average weight of trout stocked was 200 g; to meet the <2% body weight requirements, a 3.3 g transmitter package requires a minimum weight of 170g. In 1997, 15 and 47 day transmitters were used, in 1998, improvements in batteries allowed for 60-day transmitters with no increase in package size.

Fish were anesthetized with MS222 at a rate of 45 mg/l (Summerfelt and Smith 1990). Upon loss of equilibrium, a 5-10 mm incision was made near the midventral line approximately 3 mm anterior to the pelvic girdle. The incision was only deep enough to penetrate the peritoneum and allow insertion of the transmitter into the body cavity (Summerfelt and Smith 1990). Two to three sutures were needed to properly close the incision. Upon completion fish were placed into a 378 liter tank with fresh circulating water to complete recovery. The time from incision to release into the recovery tank was approximately 4 to 8 min. Fish began showing "normal" swimming activity approximately 10 min. after release into the recovery tank. There was 100% survival of fish from surgical procedures.

Fish were tracked daily in the summer months (May to August) and weekly at other times of the year using a Sonotronics USR-5W receiver and directional hydrophone. Fish were located partially by triangulation using the hydrophone (Winter 1983), but typically by traveling in a straight line toward the strongest signal until passing the signal source. If the signal was stationary in the water column as the boat passed over, a sonar graph was used to locate the fish, depth of the water, depth of the fish within the water column, bottom features, and association with other fish. In water less than 2 m fish would often move, making it impossible to position directly over head. Commonly, these movements would be perpendicular to the boat path. The boat's direction was then changed to the new direction and the fish followed until three such perpendicular movements were made. After three direction changes, tracking of a particular fish ceased and habitat measurements were taken in the area of movement. A meter was used to measure the dissolved oxygen concentration, and temperature of the water in the area and at the depth where the fish was found.

In 1998 a permanent monitoring station was placed on the Nebraska Public Power District (NPPD) canal to document fish leaving the lake. A hydrophone, USR-90 receiver and a palmtop computer were used to record signals in the vicinity of the station. This system logged the time, date, and transmitter number for each transmitter fish that passed by the station.

The lake was divided into four segments to more easily quantify movements of rainbow trout. Segments A, B and C are dominated by deep water (>3 m), with shallow waters (<3 m) ending approximately 5 m from shore, segment D has shallow waters throughout. Macrophyte growth in segments A, B and C is relatively sparse in contrast to that of segment D. Segment A ("north basin") is a very "lake like", with little or no mixing from the hydropower plant, therefore strong stratification occurs during the summer months. Segment B ("south basin"), stratifies on the north end and receives very little water mixing, however the southern end of segment B receives some mixing from hydropower plant operations. Segments C and D can be classified as riverine when the hydropower plant is in operation. The delineation between the two segments is that segment C is directly below the power plant and has an average of depth of 5 m, whereas segment D ("keystone basin") is shallow with an average depth of 2 m (Figure 2) (Laux et al. 1996).

Weekly occurrence in segments A through D by individual stocking groups was analyzed using a Nass goodness of fit test. Nass employs a correction factor to Pearsons chi-squared test allowing analysis of data sets where expected values are small (Young 1998). Without the correction factor, a standard chi-square test would consistently over estimate the p-value and the test statistic. Significance level was evaluated at the P=0.05 level for the most frequently used segment of the lake by week, by stocking, before and after the renovation.

Additional water quality measurements were taken to improve the understanding of the habitat composition of the lake. To better understand the water quality of each segment, water temperature and dissolved oxygen profiles were taken bi-monthly at the surface and at 1-m intervals to the bottom.

Stepwise logistic regression was used to determine the factors most important in determining trout movements. Individual date, dissolved oxygen, and temperature from biweekly water quality and individual fish location readings were examined with the model.

Food habit analysis was done on fish collected twice a month (May to September) at all eight sites using boat electrofishing. Up to ten rainbow trout were preserved in formalin and returned to the laboratory for stomach content identification and enumeration. All other trout captured were returned to the water following length and weight measurements.

Benthic invertebrate samples were collected bi-monthly in 1997-98 using an Ekman dredge. Three samples (outer, middle, inner) were collected at each sampling station along a transect perpendicular to the shore. The outer sample was taken approximately 50 m from shore, the mid 15 m and the inner 3-5 m from shore. Samples were hand sieved in the field and preserved in 5% formalin.

Benthic invertebrate comparisons among segments A, B, C, and D and benthic invertebrate abundance between outer and inner zones at the eight permanent sampling sites were analyzed using a one-way ANOVA (α =0.1).

An F-test for two sample variances ($P \leq 0.05$), was used to compare the overall numbers of white sucker, carp, yellow perch and alewife captured before and after the renovation.

RESULTS

The Nebraska Game and Parks Commission stocked 3000 to 5000 rainbow trout per stocking into Lake Ogallala from February 1997 to June 1998 (Table 1). Six to 15 trout with transmitters were included in each of six stockings. Fifty-one rainbow trout were surgically implanted with ultrasonic transmitters two days prior to stocking into Lake Ogallala. Time needed to track and record observations at each fish, as well as signal interference limited the number of individuals implanted per stocking.

The proportion of individuals remaining in the Lake for the life of the transmitters ranged from 22% to 100%. For the first 15 days of the transmitter life, 78% of fish remained within the lake, 72% from 16-47 days and 70% from 48-60 days, respectively. Overall, 65% of all stocked fish remained in the lake for the duration of their transmitters (Table 1), with 35% of fish leaving the system for the North Platte River or the NPPD canal prior to the guaranteed life of the transmitter. Fish #247 was captured in Lake Ogallala via electrofishing 83 days after stocking. Close observation of the incision and the sutures revealed complete healing with no signs of infection or abnormalities.

In 1997, prior to the renovation, 21 implanted fish were released into segment A. Twelve fish (57%) remained within the lake for the life of their transmitters, and nine fish spent an average of 23.7 days in the lake before leaving (Figure 3; Appendix 1). After the renovation in 1997 and 1998, 30 fish were released into segment A. Twenty-one fish (70%) remained in the lake for the lives of their transmitters, and nine fish spent an average of 24 days in the lake before leaving (Figure 4; Appendix 2). Extrapolating the percentages of study trout that stayed in the lake to the overall number stocked, it was estimated that 6,941 to 12,178 trout remained in Lake Ogallala in 1997 prior to the renovation. After the renovation, it is estimated that 10,385 to 14,837 stocked remained in Lake Ogallala for at least 60 days (Table 2). The scanning receiver in the canal logged 8 of a possible 9 rainbow trout that left the system. Two fish that stayed in the lake for 60 days, were detected by the data logger 120 days later.

Weekly fish distribution throughout the lake was summarized as segment by segment movements (Figure 3-4; Appendix 1-2). All stockings took place at the north end of segment A, and 78% of all fish remained within segment A for 2 weeks before moving to other lake segments. Transmitter fish remained close to one another for the first 7-10 days after stocking. Because, ultrasonic transmitters are on the same frequency, a cluster of three or more fish sounds like "wind chimes" making it impossible to distinguish individual transmitter signals. Once fish began dispersing from segment A, they used segments B and C infrequently (Table 3), moving many times between A, B and C before settling into an area. Generally, after the first 3 weeks the fish would establish a "home range" and remain close to that area for several weeks. Twenty-two of the 51 implanted fish spent some time in segment D. Of the 20 fish spending more than a week in segment D, 18 (90%) never returned to another segment of the lake (Appendix 1 and 2).

Two fish stayed in the lake for the duration of the transmitter (60 days), and were located in the canal 120 days later, verifying the notion that fish leave the lake and enter the NPPD canal. Twenty-nine percent of all transmitters continued working beyond the guaranteed life.

In 1997 and 1998 trout were found in dissolved oxygen levels ranging from 1 to 18.5 mg/l and 3 to 19.8 mg/l, respectively. The most frequent concentration at fish locations was 7.1 to 8 mg/l in 1997 and 12.1 to 13 mg/l in 1998, with 73% of all fish occurring between 6.1 and 13 mg/l (Figure 5).

In 1997 and 1998 trout were found at temperatures ranging from 1 to 20.4 °C and 3 to 21.7 °C, respectively. Over both years, showed the highest frequency occurred from 14.1-15 °C, and 84% of all fish were found between 9.1 and 18.0 °C (Figure 6).

Stepwise logistic regression of biweekly water quality data combined with fish locations revealed that the model is a good fit within the error for 1997 (0.6798) and 1998 (0.355), verifying that dissolved oxygen, temperature and time of year were the most important variables affecting trout movements. Without taking temperature and dissolved oxygen availability measurements at each fish's location, it was not possible to determine its significance on trout distributions using this model.

In 1997 and 1998 water depth at a fish's location ranged from 0.6-12.0 meters and 0.6-11.5 meters, respectively. The most frequently used water depth was 0-0.91 meters in 1997 and 0.91 to 1.8 meters in 1998. 1997 and 1998 combined showed that 69% of recorded water depths were less than 3 m (Figure 7).

In 1997 and 1998 depth of rainbow trout in the water column ranged from 0.5-11.3 and 0.91-11.0 meters respectively, with 68% in 1997 and 92% in 1998 of the fish locations being in the upper meter. A combination of the two years revealed that 77% of the fish locations were within the upper meter of the water column (Figure 8). A closer examination of fish locations by segment shows that numerous fish were found throughout the relatively shallow segment D, with a high abundance of fish near the outlet structures. The majority of fish found in segments A, B and C were 10-30 meters from shore on shallow flats that were very close to the drop off to deeper water (Figure 9).

On June 3, 1997 stratification in segment A yielded dissolved oxygen concentrations less than 6 mg/l at four meters. These conditions continued through the summer and early fall (Figure 10). On June 4, 1998 aerators installed in segment A resulted in summer concentrations greater than 6 mg/l at depths of 8 m (Figure 11). Annual dissolved oxygen and temperature profiles for sites 1-8 are summarized in Appendix 3.

Pre-renovation stomach analysis of electrofished rainbow trout from 1997 revealed that chironomid larvae/pupae made up 81% by numbers of stomach contents in segment A, 91% in segment B, 38% in segment C, 14% in segment D. No terrestrial insects were found in the stomach contents of fish from segments A or B. However segments C and D yielded 4% and 24% terrestrial insects by number, respectively. Hemiptera made up 17% of trout diets in segment A, 4% in segment B, 41% in segment C, and 16% in segment D (Figure 12; Table 4). Zooplankton made up less than 1% by number of organisms found in stomachs during 1997-98.

The 1998 post-renovation food habits revealed chironomid larvae and pupae made up 38.9% by numbers of stomach contents in segment A, 25.8 % in segment B, 62.7 % in segment C and 73.4% in segment D. Hemiptera made up 36.8% of trout diets in segment A, 13.2% in segment B, 27% in segment C, and 16.3% in segment D. Gastropods made up 24.3% in segment A, 19.1% in segment B, 8.8% in segment C, and 7.8% in segment D. Prior to the renovation gastropod use by numbers was 0.38% of fish diets, but in 1998 increased to 15% (Figure 12; Table 4).

Trout often feed opportunistically, therefore it is important to understand not only the food used by trout, but the overall abundnace of food within each lake segment. Segment A had a total of 131 organisms at the inner zone as compared to 16 at the outer zone. Similarly, site 8 (part of segment C) had 353 organisms at the inner zone and 144 organisms at the outer zone. Site 6 which is located in the center of segment D had 641 organisms at the inner and 711 organisms at the outer zones, respectively (Figure 13). A single factor analysis of variance of the benthic community showed that in 1997 there was a significant difference ($P \leq 0.05$) in numbers when comparing segments A vs. C, A vs. D, B vs. D, and C vs. D but no significant difference when comparing segments A vs. B or B vs. C (Table 5). In comparing the inner and outer sampling zones of all eight sites at a 0.1 value, site 1 (segment A) is the only site where a significant difference (P=0.09) occurred (Table 6). Subsequent analysis revealed that there was a significant difference (P=0.01) of available organisms sampled at site six in July 1997 (442 organisms) versus those sampled in July 1998 (1793 organisms) at the same site.

Visual inspection revealed that there was very little macrophyte growth in segments A, B and C, whereas macrophytes in segment D were abundant. Although there was no direct measurement of macrophytes from year to year, the relative abundance increased considerably the year following renovation.

Combined May and July gill netting, frame netting and electrofishing data revealed that the total numbers of fish decreased as a result of the renovation (Figure 14). Total number of white suckers captured before the renovation in 1997 (419 individuals) was significantly greater (P=0.007) from those captured after the renovation in 1998 (3 individuals), total number of carp captured in 1997 (56) was significantly greater (P=0.035) from those captured in 1998 (7), and total number of yellow perch captured in 1997 (83) was not significantly greater (P=0.47) from 1998 capture totals (55). Total number of alewife captured in 1997 (461) was significantly greater (P=0.012) from those captured in 1998 (247) (Table 7).

DISCUSSION

Typical movements of a rainbow trout during the transmitter life revealed that fish used segment A (P<0.05) during the first few weeks after stocking. They then moved throughout segments B and C for about a week, before settling in segment D. Over, 90% of fish found in segment D stayed there for the remainder of the transmitter life (Figure 4; Table 3; Appendix 1-2).

Most rainbow trout in Lake Ogallala remained in areas where dissolved oxygen was over 6 mg/l. However, 11% of fish observations occurred at levels below 6 mg/l (Figure 5), where signs of stress have been documented (Davis 1975, Mathias and Barica 1985, Weithman and Haas 1984). It was common for mid to late summer dissolved oxygen values in segment D to fluctuate near 6 mg/l with very low readings occurring in the early morning, increasing by noon and remaining above 6 mg/l into the evening hours (Appendix 3). Fish never moved far between daily locations during times of low dissolved oxygen. This may be a natural response to reduce aerobic work, therefore reducing oxygen intake. At low dissolved oxygen concentrations the active metabolic rate of rainbow trout is reduced to bare maintenance requirements, many times restricting it from performing external work (Fry 1957).

Since 84% of rainbow trout were found at temperatures between 9.1 and 18°C (Figure 6), temperature selection in Lake Ogallala is similar to that reported by Horrak and Tanner (1964) in Horsetooth Reservoir. Only 1% of all fish measurements occurred in waters greater than 20°C, a temperature which in previous studies caused fish to move out of a lake (Garrett and Bennett 1995). Temperatures greater than 20°C are limited to the upper meter in Lake Ogallala. Individual fish that were found in waters greater than 20°C did not leave the lake, presumably due to the availability of cooler water in deeper portions of the lake. The water temperature in the upper three meters where the vast majority of trout occurred (Figures 7-8), never exceeded their thermal tolerance (Appendix 3). Fish were found in a wide range of dissolved oxygen and temperature values, which may have been a function of the availability of those levels within the lake. As these levels change throughout the year, so do the levels at which fish were found. More readings taken in mid summer could have revealed a tolerance for higher temperatures and lower dissolved oxygen.

Rainbow trout in Horsetooth Reservoir, Colorado were most frequently captured at depths of 6.7 m (Horrak and Tanner 1964). In Lake Ogallala, the upper meter supported 69% of the study fish (Figure 7). With such a high number of fish occurring in relatively shallow segment D it is logical that the overall majority of all fish would appear in the upper meter. However, even those fish found in deeper segments (A, B, and C) frequented waters in the upper meter. The majority of fish found in these segments were located 1-10 meters from shore (Figures 9-10; Table 6) in the upper meter near a deep water edge.

The high percentage of fish found in shallow water can be attributed to the availability of food organisms in these areas. With benthic invertebrates comprising 50% of diets by number (Figure 13), it is important to understand their distribution throughout the lake. Benthic invertebrate sampling in 1997 revealed differences in abundance according to distance from shore within a sampling site (Figure 14; Table 5). The outer samples from each was approximately 50 meters from shore, whereas the inner section was approximately 4 meters from shore (keeping in mind that at segments other than D, fish were generally found 1-10 meters from shore). Sites 1 and 8 (Figure 2) consistently had water deeper than 4 meters at the outer section. The inner section of all eight sites were characterized by water depths of 1-2 meters. The lower number of organisms at the outer portions of sites 1 and 8 can be directly linked to the bottom 5-10 meters of the water column being oxygen depleted during mid summer (Appendix 1-2). Prosser and Brown (1962) noted that chironomids suspend feeding when oxygen levels are low. The higher abundance of invertebrates at site 6 within segment D, (Figure 14) is a result of the uniformly shallow configuration of this segment.

Macrophytes support macroinvertebrates that supply food for the trout fishery in Lake Ogallala. Herbivory and disturbance by rough fish was in part responsible for the decline in macrophyte production (Harris and Gutzmer 1996). After the removal of benthic foraging fish, the abundance of macrophytes and numbers of aquatic invertebrates in shallow water areas increased significantly. The percent increase in trout usage of gastropods in 1998 vs. 1997 (Figure 13), was likely a result of increased overall gastropod abundance, which correlated with an increase in macrophyte densities throughout the lake. Macrophytes can currently be found in most of segment D and a shallow corner near site 2 in segment B. Both areas had relatively few stands of macrophytes prior to the renovation.

Interspecific competition limits the abundance of invertebrates available in Lake Ogallala. Although large zooplankton can make up a significant portion of a rainbow trouts diet in many lakes (Galbraith 1967, Schneidervin and Hubert 1987, Tabor et al 1996, Brynildson and Kempinger 1973), high densities of alewife in Lake Ogallala remove large zooplanktors (Laux et al. 1996), forcing trout to utilize an alternative food source (Figure 13). Alewife are well documented in changing zooplankton community size structure from large to small individuals (Brooks and Dodson 1965; Urban and Brandt 1993; Kohler and Ney 1981; and Mills et al. 1992). As a result of alewife zooplanktivory, many systems undergo trophic cascade. The renovation was effective at removing non-game species from the lake (Figure 15; Table 7), however hydro-power operations from Lake McConaughy constantly bring new fish into Lake Ogallala.

To provide multispecies angling, yellow perch were stocked into Lake Ogallala in 1998. Yellow perch have been directly linked to causing a reduction in rainbow trout growth rates (Fraser 1978) and have been shown to compete directly with trout (Jude et al. 1978; Fraser 1978). Yellow perch stocked in Lake Ogallala, at a very small numbers when compared to trout, likely have the ability to reproduce. Successfull perch recruitment will lead to increased competition with rainbow trout in future years. It may be important to better understand to what degree yellow perch densities impact the rainbow trout community of Lake Ogallala.

CONCLUSIONS

Results of this study indicate that dissolved oxygen, temperature, time of year and food availability determine the distribution of rainbow trout within Lake Ogallala. It is clear that trout relate not only to available temperatures and dissolved oxygen values, but show a strong relation to the abundance of food. The overall abundance of fish in Segment D, and the high frequency of fish near the shore in segments A, B and C was attributed to the greater availability of invertebrates in these areas. These areas of the lake may be similar to shallow raceways where the fish are reared. If the fish have become conditioned to raceway type conditions, which readily provide vital resources (temperature, dissolved oxygen and food) they may select similar habitats in Lake Ogallala.

The renovation resulted in a removal of non-game species that competed with trout for invertebrates, as well as allowed macrophyte densities to increase in 1998. These two factors led to an increase in invertebrate densities, which may help explain why 13% more fish stayed in the lake after the renovation. Although, the addition of the aeration system increased dissolved oxygen levels throughout the water column of segment A, there were still a greater proportion of the study fish located in segment D (Figure 4; Table 3; Appendix 2). From the initial post-renovation year of study, it appears the renovation had a positive effect upon the trout fishery, the removal of benthic foraging species allowed macrophytes to re-establish, leading to increased habitat for aquatic invertebrates, and improving overall food availability for trout. However, it will be important to monitor changes in trout movements, growth and condition as populations of competitors increase throughout the next several years.

LITERATURE CITED

Adams, N. S., D. W. Rondorf, S. D. Evans and J. E. Kelly. 1998. Effects of surgically and gastrically implanted radio transmitter on growth and feeding behavior of juvenile chinook salmon. Transactions of the American Fisheries Society 127:128-136.

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

Brynildson, O. M. and J. J. Kempinger. 1973. Production, food and harvest of trout in Nebish Lake, Wisconsin. Wisconsin Department of Natural Resources. Technical Bulletin no. 65.

Cherry, D. S., K. L. Dickson, and J. Cairns Jr. 1975. Temperatures selected and avoided by fish at various acclimation temperatures. Journal of Fisheries Research Board of Canada 32: 485-491.

Crowder, A., and D. S. Painter. 1991. Submerged macrophytes in Lake Ontario: current, knowledge, importance, threats to stability, and needed studies. Canadian Journal of Fisheries and Aquatic Science 48(8): 1539-1545.

Davis, J. C. 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian Species: a Review. Journal of Fisheries Research Board of Canada 32(12): 2295-2332.

Dickson, I. W., and R. H. Kramer. 1971. Factors influencing scope for activity and active and standard metabolism of rainbow trout (*Salmo gairdneri*). Journal of Fisheries Research Board of Canada 28: 587-596.

Fisher, S. G. and LaVoy, A. 1972. Differences in littoral fauna due to fluctuating water levels below a hydroelectric dam. Journal of Fisheries Research Board of Canada 29(10): 1472-1476.

Fraser, J. M. 1978. The effect of competition with yellow perch on the survival and growth of planted brook trout, splake, and rainbow trout in a small Ontario lake. Transactions of the American Fisheries Society 107(4): 505-517.

Fry, F. E. J. 1957. The aquatic respiration of fish. Pages 1-63. *in* M. E. Brown, editor. The physiology of fishes. Academic Press Inc., New York.

Galbraith, M. G. Jr. 1967. Size-selective predation on *Daphnia* by rainbow trout and yellow perch. Transactions of the American Fisheries Society 96(1): 1-10.

Garrett, J. W. and D. H. Bennett. 1995. Seasonal movements of adult brown trout relative to temperature in a coolwater reservoir. Transactions of the American Fisheries Society 15: 480-487.

Hansen, M. J. and T. M. Stauffer. 1971. Comparative recovery to the creel, movement and growth of rainbow trout stocked in the Great Lakes. Transactions of the American Fisheries Society. (2): 336-349.

Harris, D. D. and M. P. Gutzmer. 1996. Macrophyte production, fish herbivory, and water quality in a tailwater reservoir-Lake Ogallala, Nebraska. Transactions of the Nebraska Academy of Sciences 23: 29-35.

Haynes, J. M., D. C. Nettles, K. M. Parnell, M. P. Voiland, R. A. Olson, and J. D. Winter. 1986. Movements of rainbow steelhead trout *Salmo gairdneri* in Lake Ontario and a hypothesis for the influence of spring thermal structure. Journal of Great Lakes Reservoirs 12(4): 304-313.

Horak, D. L., and H. A. Tanner. 1964. The use of vertical gill nets in studying fish depth distribution, Horsetooth Reservoir, Colorado. Transactions of the American Fisheries Society. 93: 137-145.

Janssen, J. and S. B. Brandt. 1980. Feeding ecology and vertical migration of adult alewives (*Alosa pseudoharengus*) in Lake Michigan. Canadian Journal of Fisheries and Aquatic Sciences 37: 177-184.

Jenkins, T. M. Jr. 1971. Role of social behavior in dispersal of introduced rainbow trout (*Salmo gairdneri*). Journal of Fisheries Research Board of Canada 28: 1019-1027.

Jude, D. J., F. J. Tesar, S. F. Deboe, and T. J. Miller. 1987. Diet and Selection of Major Prey Species by Lake Michigan Salmonines, 1973-1982. Transactions of the American Fisheries Society 116: 677-691.

Kaya, C. M., L. R. Kaeding, and D. E. Burkhalter. 1977. Use of a cold-water refuge by rainbow and brown trout in a geothermally heated system. Progressive Fish-Culturist 39: 37-39.

Kelso, J. R. M., and Kwain, W. H. 1984. The post spawning movement and diel activity of rainbow trout, *Salmo gairdneri*, as determined by ultrasonic tracking in Batchawana Bay, Lake Superior, Canada. Canadian Field- Naturalist 98: 320-330.

Kohler, C. C. and J. J. Ney. 1981. Consequences of an alewife die-off to fish and zooplankton in a reservoir. Transactions of the American Fisheries Society 110: 360-369.

LaCasse, S. and P. Magnan. 1992. Biotic and abiotic determinants of the diet of brook trout, *Salvelinus fontinalis*, in lakes of the Laurentian Shield. Canadian Journal of Fisheries and Aquatic Sciences 49(5): 1001-1009.

Lackey, R. T. 1969. Food interrelationships of salmon, trout, alewives, and smelt in a Maine lake. Transactions of the American Fisheries Society

Laux, E. A., M. T. Porath and E. J. Peters. 1996. Alewife and trout studies in Lake Ogallala, final report. University of Nebraska Institute of Agriculture and Natural Resources Department of Forestry, Fisheries and Wildlife.

Lucas, M. C. 1989. Effects of implanted dummy transmitters on mortality, growth, and tissue reaction in rainbow trout *Salmo gairdneri* Richardson. Journal of Fish Biology 25:577-585.

Madsen, M. L. and D. Eichner. 1996. Lake Ogallala management plan: January 1997-December 2001. Nebraska Game and Parks Commission.

Marrin, D. L., and D. C. Erman. 1982. Evidence against competition between trout and nongame fishes in Stampede Reservoir, California. North American Journal of Fisheries Management 2: 262-269.

Marty, G. D. and R. C. Summerfelt. 1986. Pathways and mechanisms for expulsion of surgically implanted dummy transmitters from channel catfish. Transactions of the American Fisheries Society 115:577-589.

Mathias, J. A. and J. Barica. 1985. Gas supersaturation as a cause of early spring mortality of stocked trout. Canadian Journal of Fisheries and Aquatic Science 42:268-279.

Mellas, E. J. and J. M. Haynes. 1985. Swimming performance and behavior of rainbow trout *Salmo gairdneri* and white perch *Morone americana*: effects of attaching telemetry transmitters. Canadian Journal of Fisheries and Aquatic Sciences 42:488-493.

Mills, E. L., R. O'Gorman, J. DeGisi, R. F. Herberger, and R. A. House. 1992. Food of alewife *Alosa pseudoharengus* in Lake Ontario before and after the establishment of *Bythotrephes cederstroemi*. Canadian Journal of Fisheries and Aquatic Sciences 49: 2009-2019.

Moore, A., I. C. Russell and E. C. E. Potter. 1990. The effects of intraperitoneally implanted dummy acoustic transmitters on the behavior and physiology of juvenile Atlantic salmon *Salmo salar*. Journal of Fish Biology 37:713-721.

Moring, J. R. and D. V. Buchanan. 1978. Downstream movements and catches of two strains of stocked trout. Journal of Wildlife Management 42(2): 329-333.

Mortimer, C. H. 1981. The oxygen content of air-saturated fresh waters over ranges of temperature and atmospheric pressure of limnological interest. Mittenlugen International Association of Theoretical and Applied Limnology 22: 23 pp.

Niemuth, W. 1970. A study of migratory lake run trout in the Brule River, Wisconsin: part II, rainbow trout. Wisconsin Department of Natural Resources, Fish Management Report No. 38

Overholtz, W. J., A. W. Fast, R. A. Tubb and R. Miller. 1977. Hypolimnion Oxygenation and its Effects on the Depth Distribution of Rainbow Trout (*Salmo gairdneri*) and Gizzard Shad (*Dorosoma cepedianum*). Transactions of the American Fisheries Society 106(4): 371-375.

Parsons, J. W. 1956. The trout fishery of the tailwater below Dale Hollow Reservoir. Transactions of the American Fisheries Society. 85: 75-92.

Prosser, C. L., and F. A. Brown. 1962. Comparative animal physiology, 2nd ed. W. B. Saunders and Co., London.

Ruggerone, G. T., T. P. Quinn, I. A. McGregor, and T. D. Wilkinson. 1990. Horizontal and vertical movements of adult steelhead trout, *Onchorynchus mykiss*, in the Dean and Fisher Channels, British Columbia. Canadian Journal of Fish and Aquatic Science 47: 1963-1969.

Schneidervin, R. W. and W. A. Hubert. 1987. Diet overlap among zooplanktophagous fishes in Flaming Gorge Reservoir, Wyoming-Utah. North American Journal of Fisheries Management 7:379-385.

Scott, W. B. and E. J. Crossman. 1973. Freshwater fishes of Canada. Department of Ichthyology and Herpetology. Royal Ontario Museum, Toronto, Canada.

Summerfelt, R. C. and L. S. Smith. 1990. Anesthesia, surgery, and related techniques Pages 213-272 *in* C. B. Schreck and P. B. Moyle, editors. Methods for fish biology. American Fisheries Society, Bethesda, Maryland.

Staley, J. 1966. Brown Trout. pp. 23-242. Inland fisheries management. Department of Fish and Game, Sacramento, California, Stauffer, T. M. 1972. Age, growth, and downstream migration of juvenile rainbow trout in a Lake Michigan tributary. Transactions of the American Fisheries Society (1): 18-28.

Tabor, R. and C. Luecke and W. Wurtsbaugh. 1996. Effects of *Daphnia* availability on growth and food consumption of rainbow trout in two Utah Reservoirs. North American Journal of Fisheries Management 16: 591-599.

Tomelleri, J. R. and M. E. Eberle. 1990. Fishes of the Central United States. University of Kansas Press. Lawrence, Kansas.

Urban, T. P., and S. B. Brandt. 1993. Food and habitat partitioning between young - of- year alewives and rainbow smelt in southeastern Lake Ontario. Environmental Biology of Fishes 36: 359-372.

Van Velson, R. C. 1974. Self-sustaining rainbow trout (*Salmo gairdneri*) population in McConaughy Reservoir, Nebraska. Transactions of the American Fisheries Society 1: 59-64.

Weithman, A. S. and M. A. Haas. 1984. Effects of dissolved-oxygen depletion on the rainbow trout fishery in Lake Taneycomo, Missouri. Transactions of the American Fisheries Society 113: 109-124.

Wetzel, R. G. 1983. Limnology, 2nd edition. Harcourt Brace Jovanovich, Inc. Orlando, Florida.

Willers, W. B. 1981. Trout biology an anglers guide. University of Wisconsin Press. Madison, Wisconsin.

Winter, J. D. 1983. Underwater biotelemetry. Pages 371-396. *in* L. A. Nielsen and D. L. Johnson, editors. Fisheries Techniques. American Fisheries Society, Bethesda Maryland.

Wong, B. and F. J. Ward. 1972. Size selection of *Daphnia pulicaria* by yellow perch (*Perca flavescens*) fry in West Blue Lake, Manitoba. Journal of Fisheries Research Board Canada 29: 394-436.

Young, L. J. 1998. Statistical Ecology. Chapman and Hall, publishers. New York, NY.

FIGURES AND TABLES

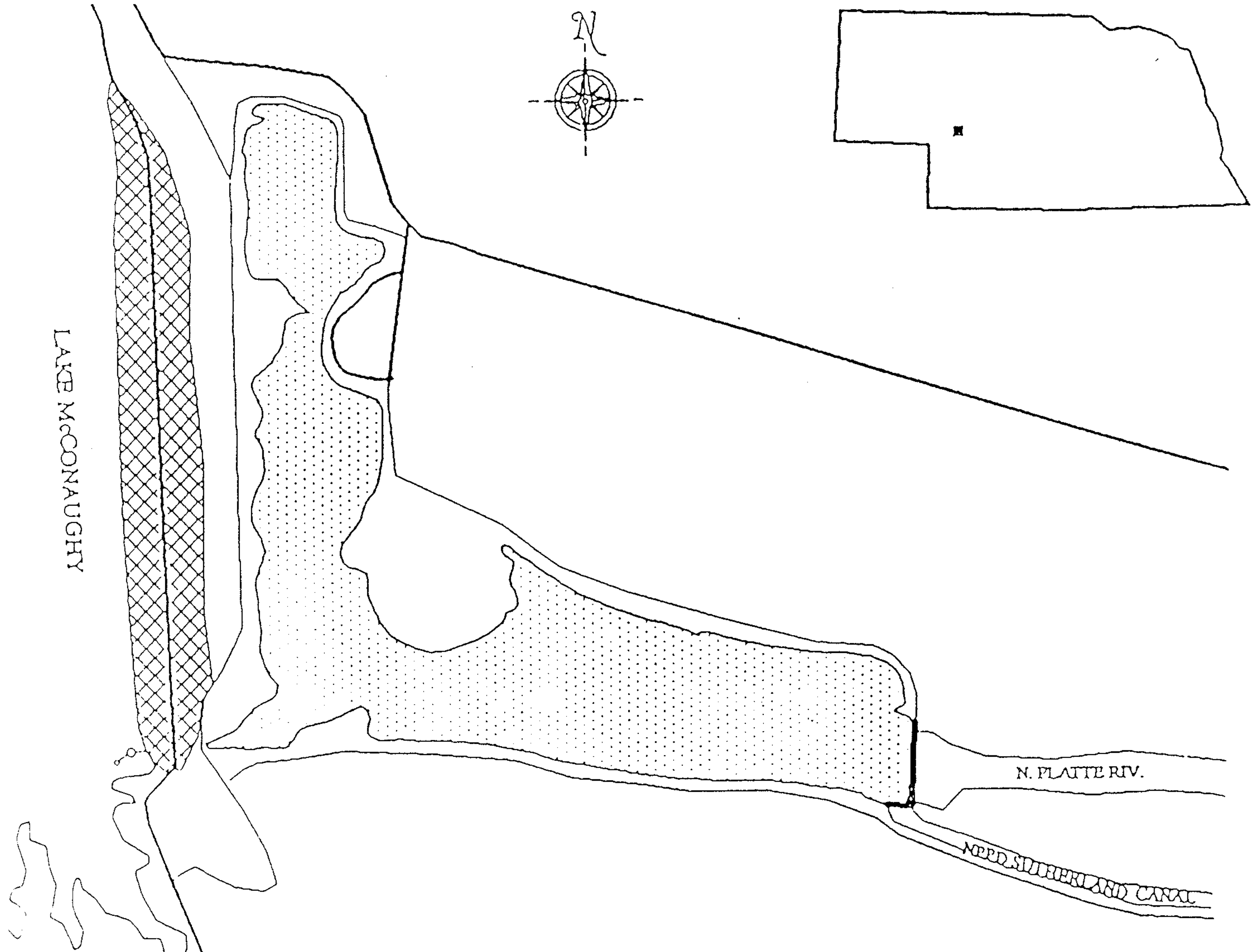


Figure 1. Location of Lake Ogallala within Nebraska. (Taken with permission from Madsen and Eichner 1996.)

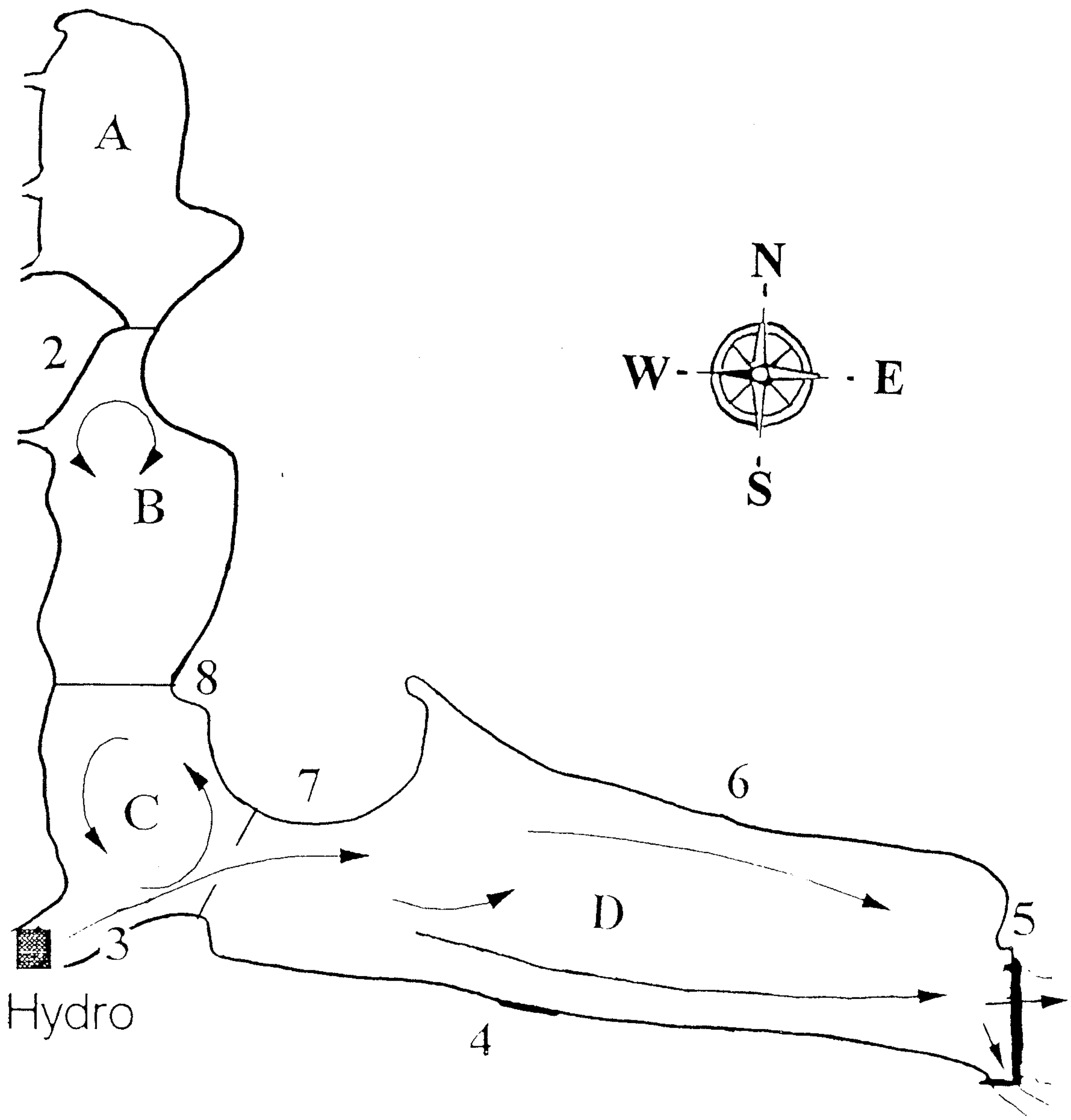


Figure 2. Lake Ogallala with segment divisions, locations of eight permanent sampling sites and arrows designating patterns of water movement.

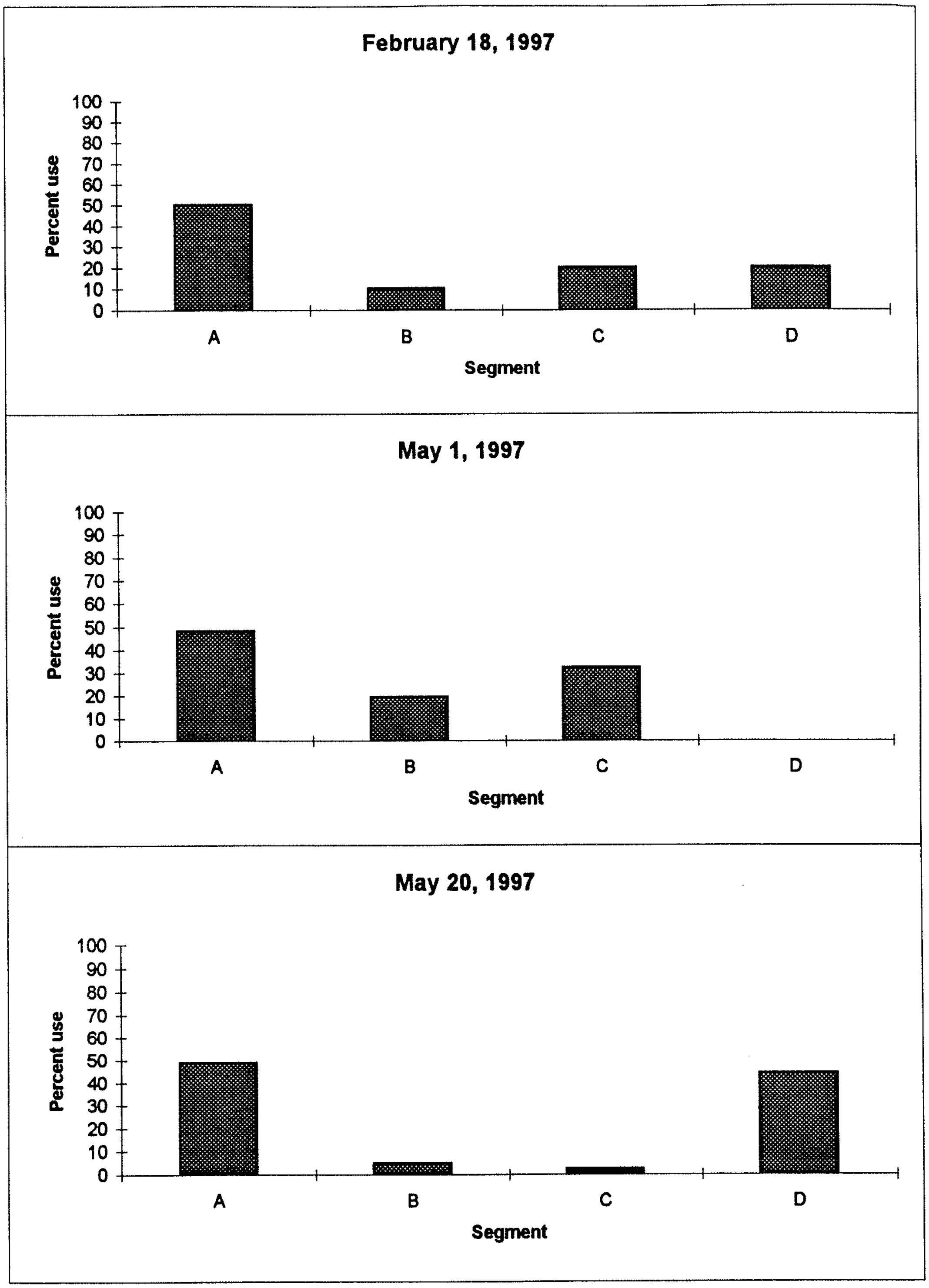


Figure 3. Percent use of each segment of Lake Ogallala by rainbow trout before the renovation.

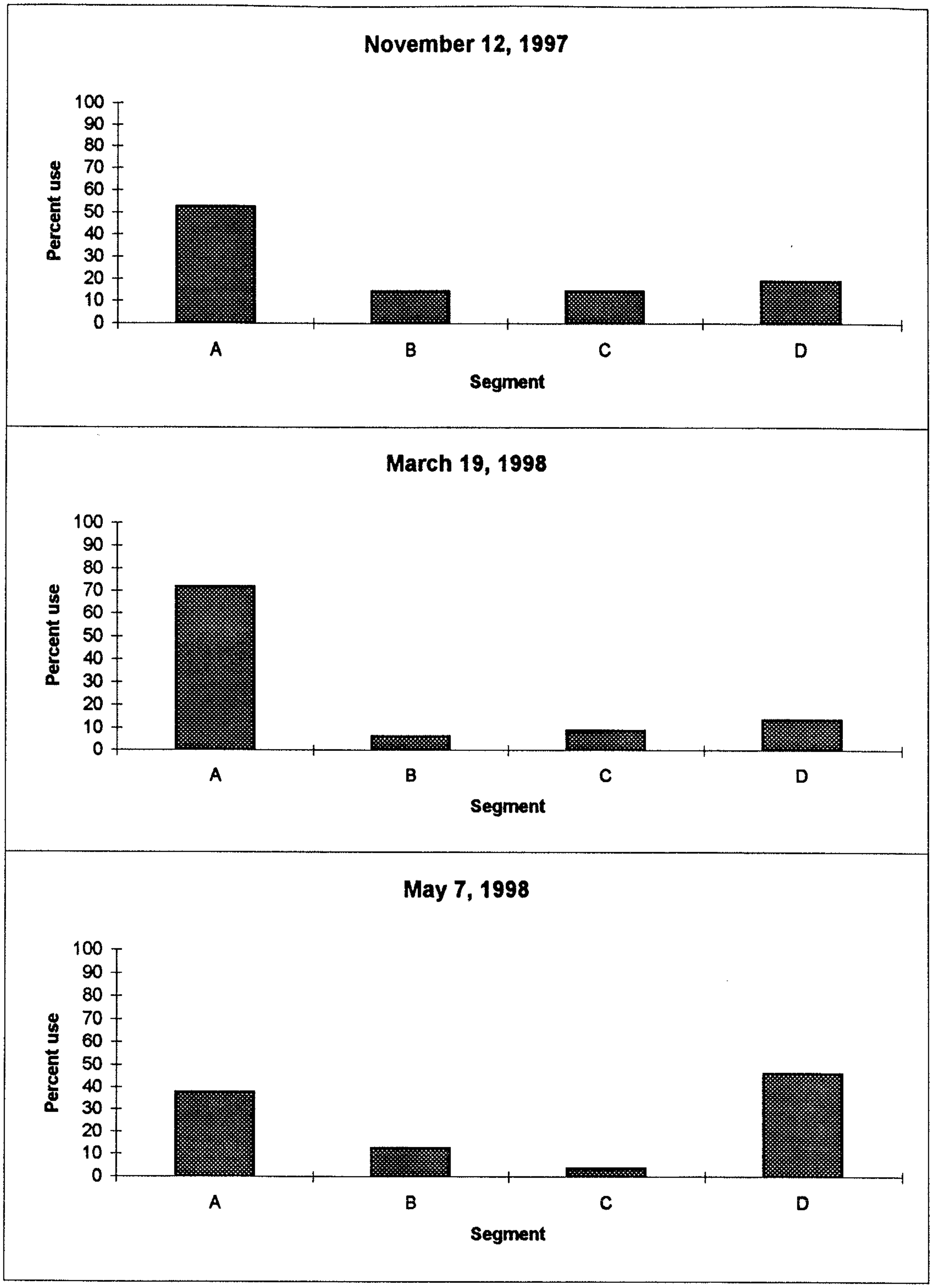


Figure 4. Percent use of each segment of Lake Ogallala by rainbow trout after the renovation

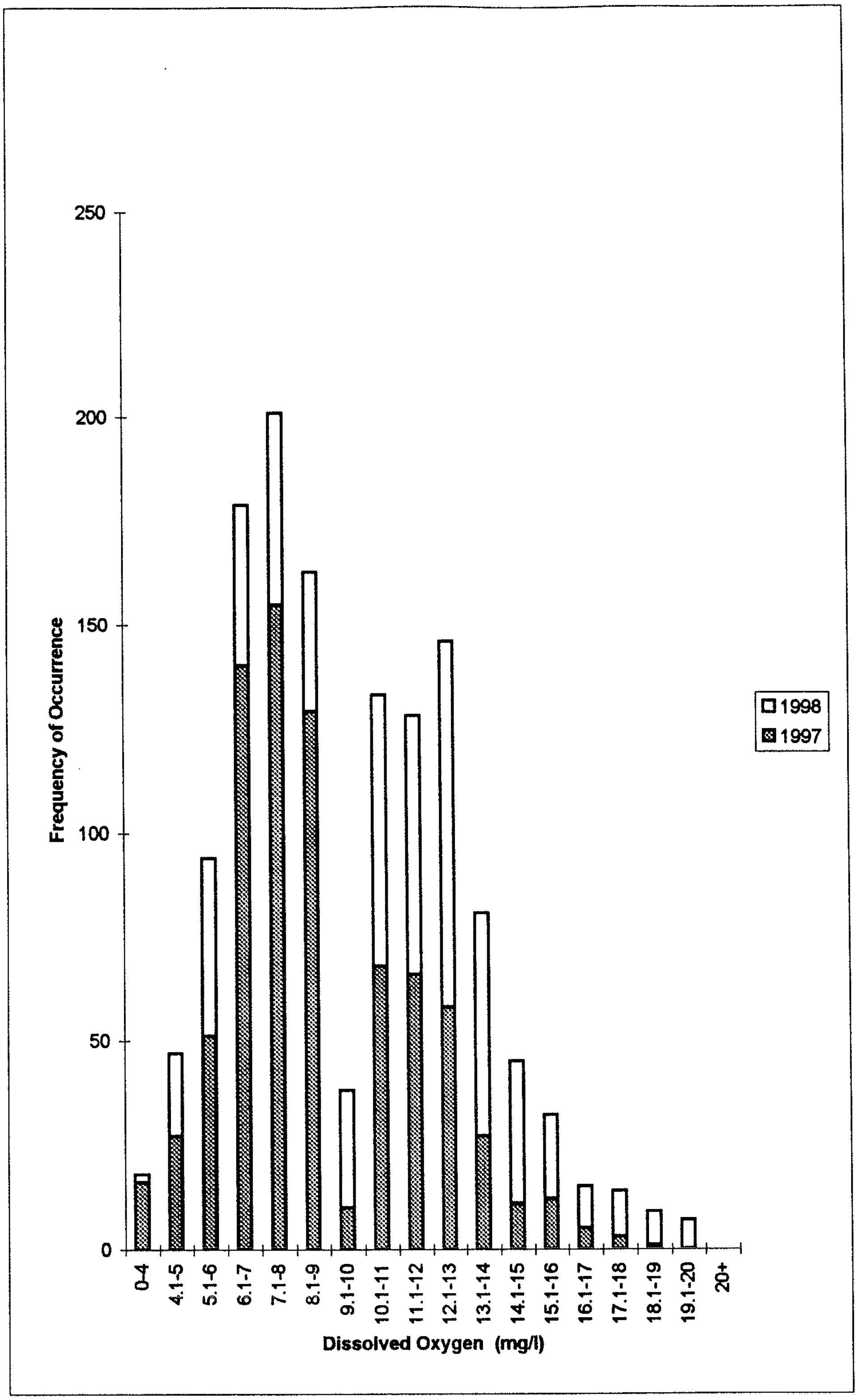
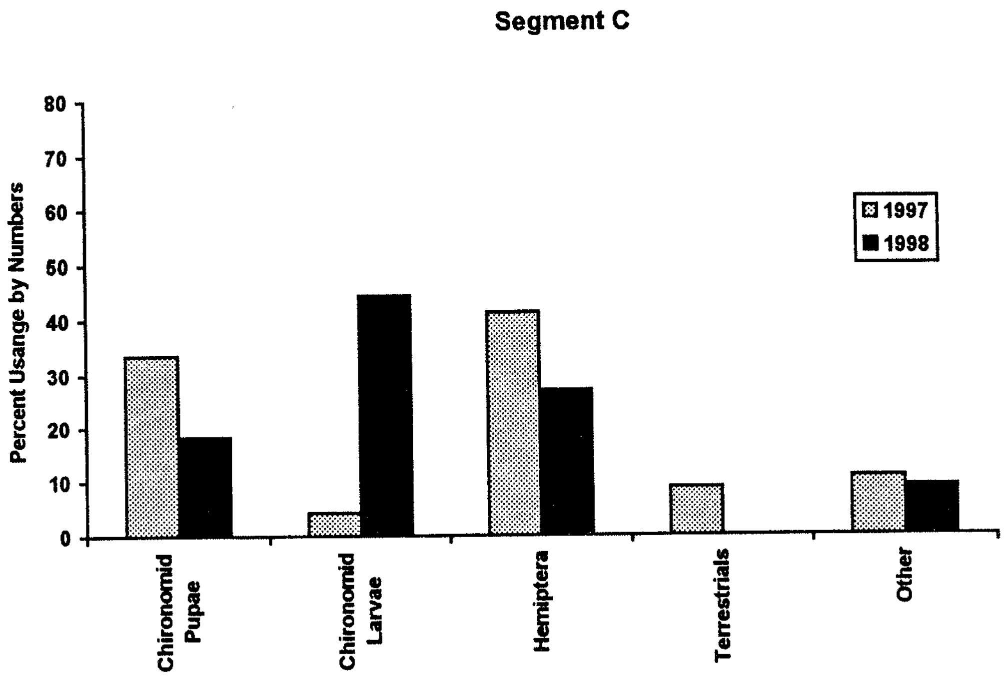


Figure 5. Frequency of use of dissolved oxygen concentrations at positions where rainbow trout were located in Lake Ogallala, 1997-98.



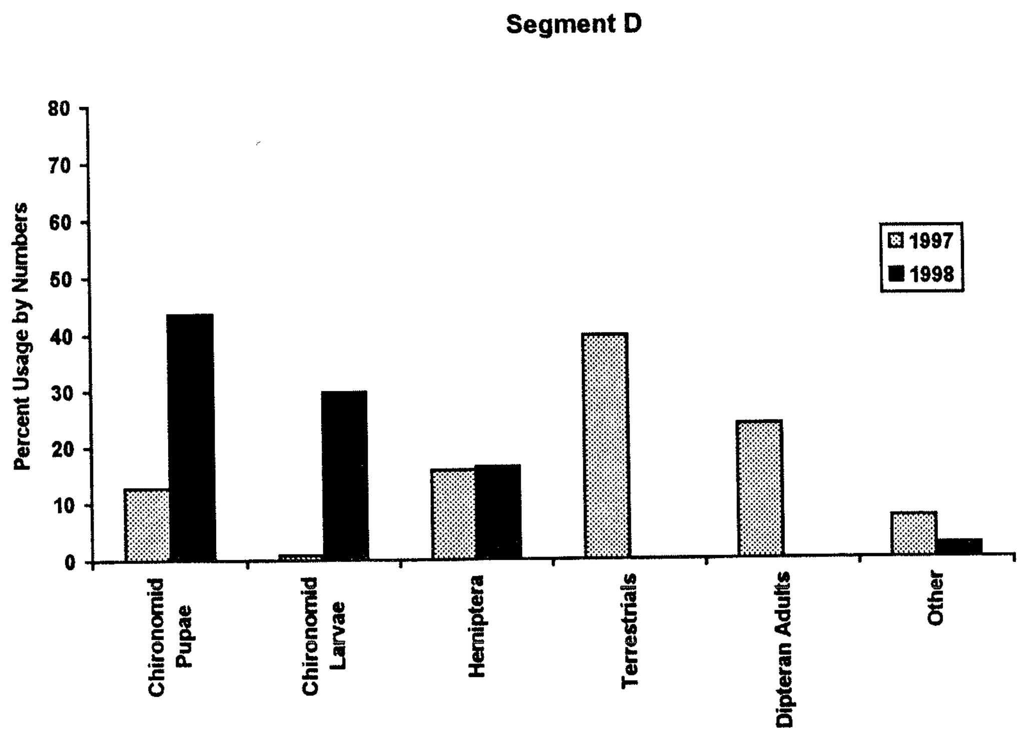


Figure 13 continued.

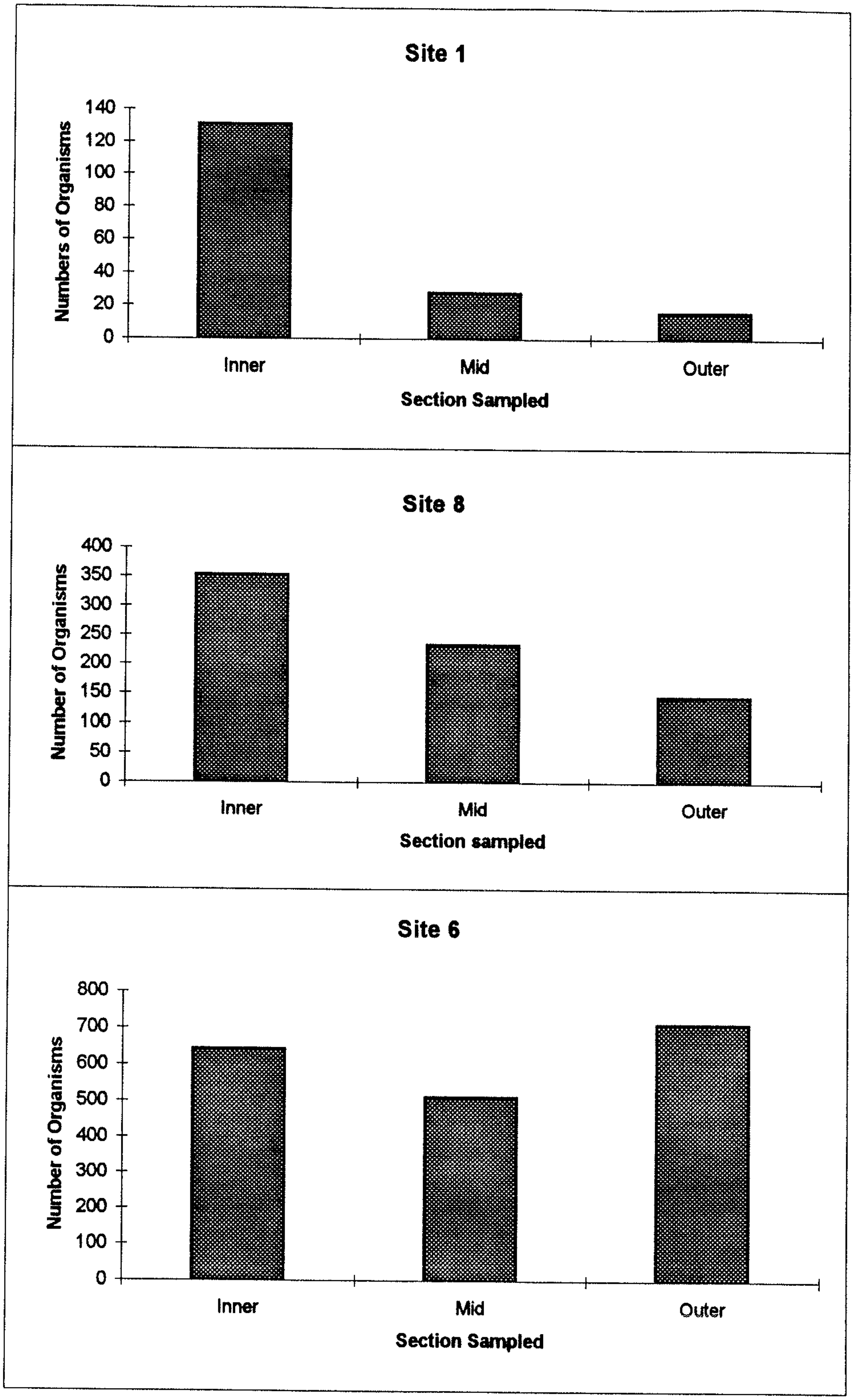


Figure 14. Total number of benthic invertebrates sampled from Lake Ogallala at each section within sites 1, 8 and 6 during 1997.

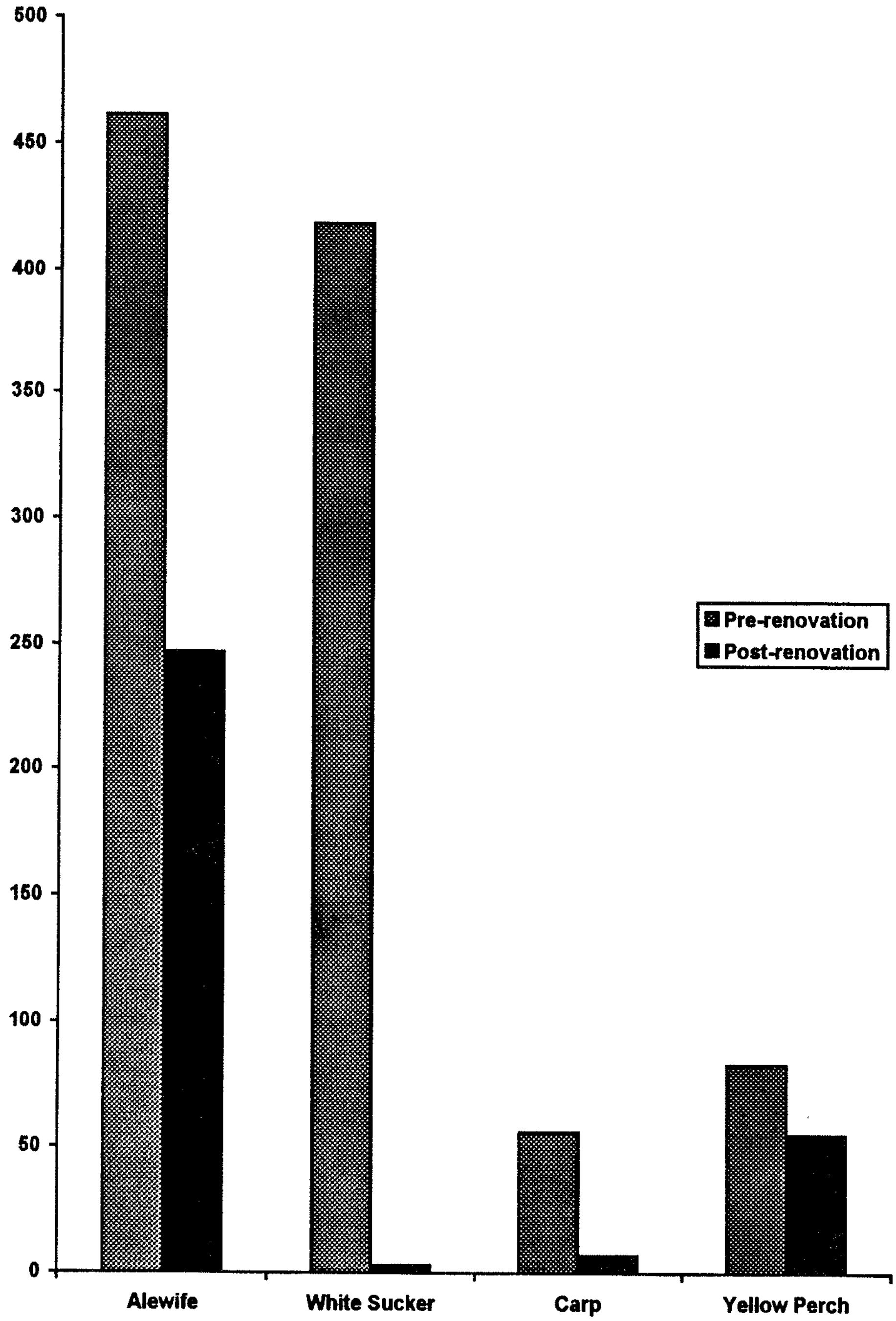


Figure 15. Overall numbers of selected rainbow trout competitors captured from Lake Ogallala via frame netting, gill netting and electrofishing before and after the renovation.

Table 1. Summary of implanted rainbow trout at each stocking in Lake Ogallala, Nebraska.

Date of Stocking	Transmitter life (days)	Selected Dates	Segment of fish release	Number of fish with implants	Number of fish leaving early	Mean days staying in lake	Total staying through selected dates	Percent staying through selected dates	Number staying through trans. life	Percent stayed
2/18/97	15		A	6	2	6.0			4	67
5/1/97	47		A	6	0	--			6	100
		0-15		6	0	--	6	100		
		16-47		6	0	--	6	100		
5/20/97	47		A	9	7	28.8			2	22
		0-15		9	2	12.0	7	78		
		16-47		9	5	29.8	2	22		
11/12/97	47		A	10	3	11.3			7	70
		0-15		10	2	4.0	9	80		
		16-47		10	1	26.0	9	70		
3/19/98	60		A	10	3	20.3			7	70
		0-15		10	2	6.0	8	80		
		16-47		10	0	0	8	80		
		48-60		10	1	49.0	7	70		
5/7/98	60		A	10	3	31.3			7	70
		0-15		10	1	8.0	9	90		
		16-47		10	2	43.0	7	70		
		48-60		10	0	0	7	70		

Table 2. Extrapolated number of fish staying in Lake Ogallala through the transmitter life.

Date Stocked	Number Implanted	Total Number Stocked	Number of Study Fish Staying	Expanded Number of Fish Staying
2/18/97	6	3728	4	2482
5/1/97	6	4320	6	4320
5/20/97	9	4130	2	916
11/12/97	10	4484	7	3138
3/19/98	10	5300	7	3710
5/7/98	10	5053	7	3537

Table 3. Stocking by stocking, week by week nass goodness of fit p-values and segment most frequently used by rainbow trout during those weeks.

Stocking Date	Week	P-value	Segment most frequently used
2/18/97	2/18/97	0.5993	A
	2/24/97	0.6151	A
5/1/97	5/1/97	0.0062*	A
	5/5/97	0.5993	A
	5/12/97	0.5607	A/C
	5/19/97	0.6151	C
	5/26/97	0.6151	C
	6/2/97	0.6151	C
	6/9/97	0.6151	C
	6/16/97	0.6767	C/B
5/20/97	5/20/97	0.0001*	A
	5/26/97	0.0001*	A
	6/2/97	0.3985	D
	6/9/97	0.0062*	D
	6/16/97	0.0245*	D
	6/23/97	0.0134*	D

*Value is statistically significant at the 0.05 level.

Table 3 continued.

Stocking Date	Week	P-value	Segment most frequently used
11/12/97	11/12/97	0.0001*	A
	11/17/97	0.8273	D
	11/24/97	0.3985	C/D
	12/1/97	0.8273	A
	12/8/97	0.0084*	A
3/19/98	3/19/98	0.0001*	A
	3/23/98	0.0001*	A
	3/30/98	0.0001*	A
	4/6/98	0.0001*	A
	4/13/98	0.0001*	A
	4/20/98	0.3986	A
	4/27/98	0.3986	A
	5/4/98	0.8273	A
	5/11/98	0.2755	D
	5/18/98	0.6151	D
5/7/98	5/7/98	0.0001*	A
	5/11/98	0.033*	A
	5/18/98	0.7709	A/B
	5/25/98	0.3473	D
	6/1/98	0.1631	D
	6/8/98	0.1829	D
	6/15/98	0.0135*	D
	6/22/98	0.005*	D
	6/29/98	0.0015*	D
	7/6/98	0.0062*	D

*Value is statistically significant at the 0.05 level.

Table 4. Percent by numbers of organisms obtained from rainbow trout stomach analysis in Lake Ogallala during 1997 and 1998.

1997 Rainbow Trout Food Habits

	Segment A	Segment B	Segment C	Segment D
Hemiptera				
Corixidae	12.7	0.7	3.6	8.0
Other	4.2	3.5	37.8	7.7
Chironomidae				
Larvae	19.1	78.8	4.2	0.9
Pupae	61.7	12.1	33.6	12.7
Gastropoda	0	0	0.1	2.3
Diptera Adults	2.1	3.2	10.8	23.7
Terrestrial	0	0	3.9	23.6
Hymenoptera	0	0	4.9	16.1
Other	0.2	1.7	1.1	5.0

1998 Rainbow Trout Food Habits

	Segment A	Segment B	Segment C	Segment D
Hemiptera				
Corixidae	36.8	13.2	27.0	16.3
Chironomidae				
Larvae	20.5	11.5	18.3	29.8
Pupae	18.4	14.3	44.4	43.6
Gastropoda	24.3	19.1	8.8	7.8
Fish parts	0	41.2	0	0
Other	0	0.7	1.5	2.5

Table 5. 1997 segment by segment statistical comparison of benthic invertebrate abundance in Lake Ogallala at the 0.05 level.

Segments compared	P-value
A vs. B	0.073
A vs. C	0.023
A vs. D	0.005
B vs. C	0.381
B vs. D	0.030
C vs. D	0.010

Table 6. 1997 one-way ANOVA (α=0.1) comparison of benthic invertebrate abundance at inner and outer zones of each site in Lake Ogallala.

Site	P-value
1	0.09
2	0.51
3	0.36
4	0.59
5	0.16
6	0.88
7	0.61
8	0.33

Table 7. Total number of documented trout competitors sampled via frame netting, gill netting and electrofishing in Lake Ogallala in 1997 and 1998.

Species captured	1997 total	1998 total	P-value
White Sucker	419	3	0.024
Common Carp	56	7	0.035
Yellow Perch	83	55	0.477
Alewife	461	247	0.012

Appendix 1. Segment by segment, weekly distribution of rainbow trout per stocking, in Lake Ogallala before the renovation.

Appendix 1

February 18, 1997 Stocking

Transmitter number

	249	258	276	339	348	367
Date						
Feb. 17-23	C	D	B	A	A	A
Feb. 24-March 2*	C	D		A		A

*Denotes week that guaranteed transmitter expires
Note: Refer to Figure 2 for lake segment by segment designations.

May 1, 1997 Stocking

Transmitter number

	267	285	294	375	384	456
Date						A
April 28-May 4	A	A	A	B	A	A
May 5-11	D	A	A	C	B	A
May 12-18	C*	A		C	B	A
May 19-25		A		C	B	A
May 26-June 1		C		C	B	A
June 2-8		C		C	B	A
June 9-15*		C		C	B	A
June 16-22		C			B	
June 23-29					B	
June 30-July 6					B	
July 7-13					B	
July 14-20					B	
July 21-27					B	
July 28-Aug. 3					B	
Aug. 4-10					B	

*Denotes week that guaranteed transmitter life expires.
Note: Fish #294 died half way through the second week

Appendix 1

May 20, 1997 Stocking

Transmitter number

	36	37	38	47	56	57	58	88	310
Date									
May 19-25	A	A	A	A	A	B	A	A	A
May 26-June 1	A	A	A	A	A	A	B	A	A
June 2-8	D	D	A	D	D	C		B	A
June 9-15	D	D	A	D		D		D	
June 16-22	D	D	A	D				D	
June 23-29		D				D		D	
June 30-July 6*		D				D			
July 7-13						D			

*Denotes week that guaranteed transmitter life expires.
Note: Fish # 57 active in segment D through 8/15/97.

Appendix 2. Segment by segment, weekly distribution of rainbow trout per stocking, in Lake Ogallala after the renovation.

Appendix 2

March 19, 1998 Stocking

Transmitter number

	239	248	257	266	275	284	293	338	355	445
Date										
Mar. 16-22	A	A	A	A	A	A	A	A	A	A
Mar. 23-29	A	A	A	A	A	A	A	A	A	A
Mar. 30-Apr. 5	A	A	A	A	A	A	A	A	A	A
Apr. 6-12	A	A	A	A	A	A	A	A	F	F
Apr. 13-19	A	A	A	A	A	A	A	A		
Apr. 20-26	C	A	B	A	A	D	A	C		
Apr. 27-May 3	D	A	B	A	A	D	A	C		
May 4-10	D	A	C	B	A	D	A	C		
May 11-17	D	F	D	D	B	D	A	C		
May 18-24*			D		B	D		C		

*Denotes week that guaranteed transmitter life expires

Note: Fish #239, 266, 275 were all active in their respective segments through 6/8/98.
Fish #293 was located in segment A through 6/1/98 and found in segment D on 6/28/98.
Fish #257 was located in segment D through 7/20/98.

Appendix 2

May 7, 1998 Stocking

Transmitter number

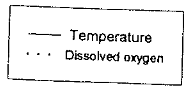
	96	283	337	345	347	356	364	365	374	446
Date										
May 4-10	A	A	A	A	A	A	A	A	A	A
May 11-17	A	B	A	B	C	A	A	A	A	B
May 18-24	B	C	A	B	D	A	D	B	A	
May 25-31			A	D	D	B		D	A	
June 1-7		D	A	D	D	B	D		A	F
June 8-14	C	D	A	D	D	B	D	D	A	
June 15-21		D	D	D	D	B	D	D	A	F
June 22-28	D	D	F	D	D	A/F	D	D	A	
June 29-July 5	D	D/F	F	D	D	F	D	D	A	
July 6-12	D	F	F	D	D	F	D	D	A	
July 12-19	D		F	D	D		D	D/F	A	

*Denotes week that guaranteed transmitter life expires.

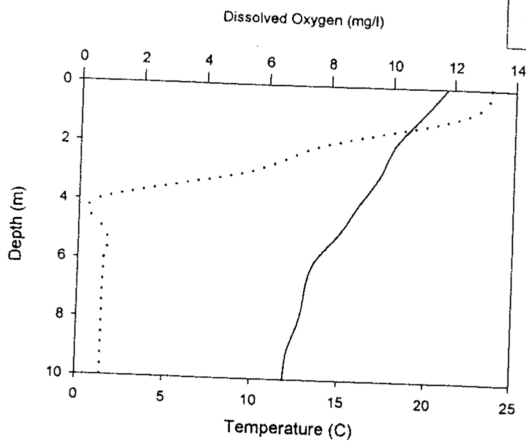
Note: Fish # 345 and 364 were found in segment D through 8/3/98.
Fish # 96, 347 and 374 were found in their respective segments through 8/10/98.

Appendix 3. 1997 and 1998 dissolved oxygen and temperature profiles taken from permanent sampling sites 1 through 8 in Lake Ogallala.

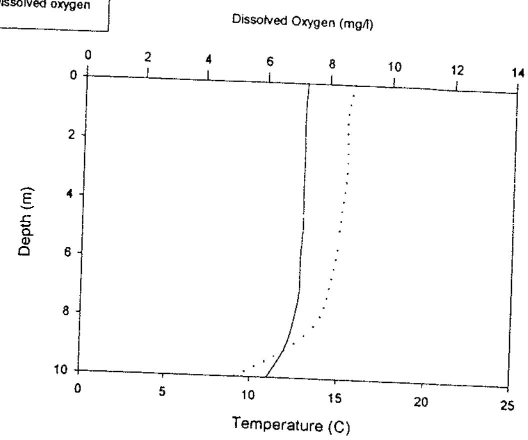
Site 1



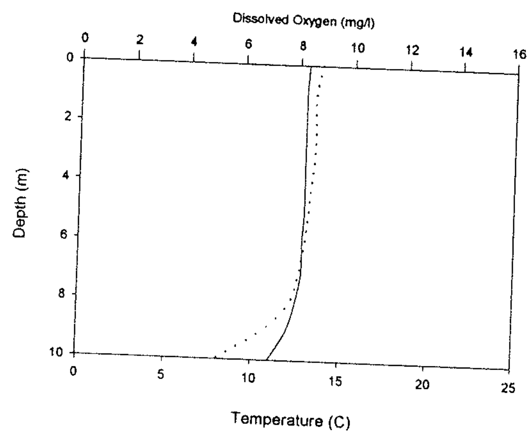
March 22, 1997



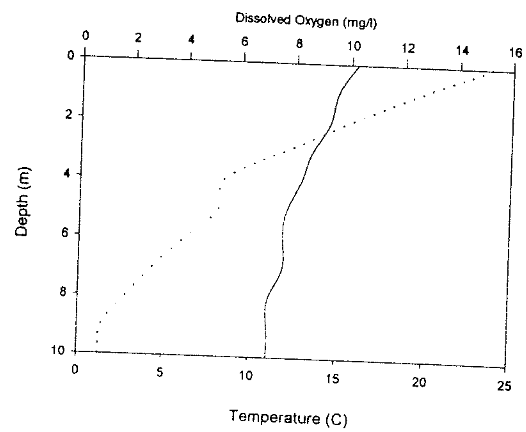
May 3, 1997



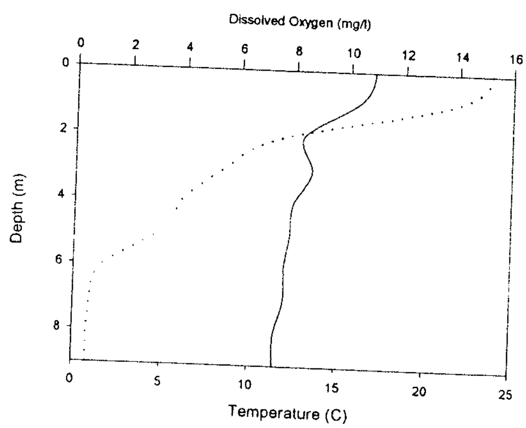
May 22, 1997



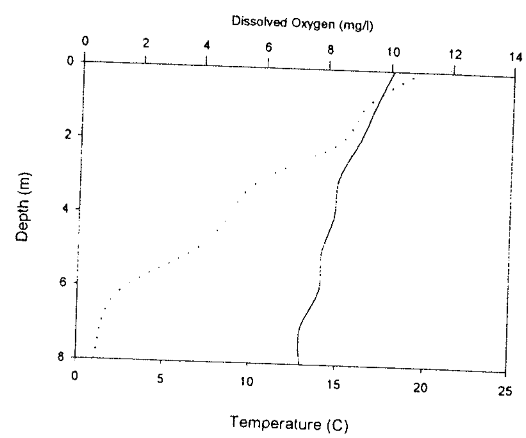
June 3, 1997



June 17, 1997

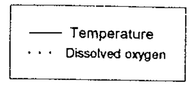


July 2, 1997

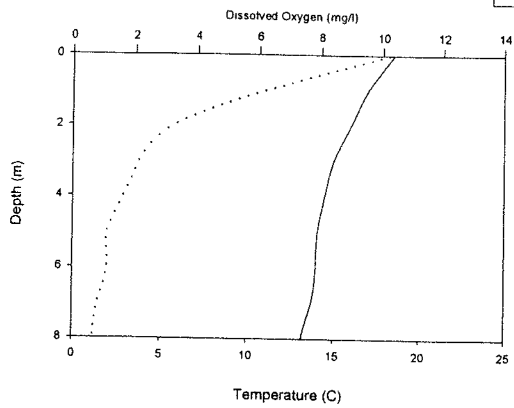


Appendix 3

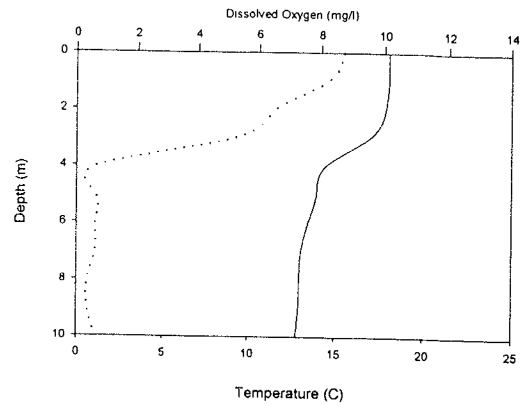
Site 1



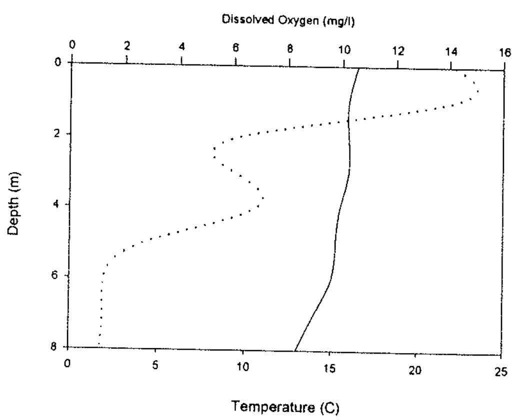
July 14, 1997



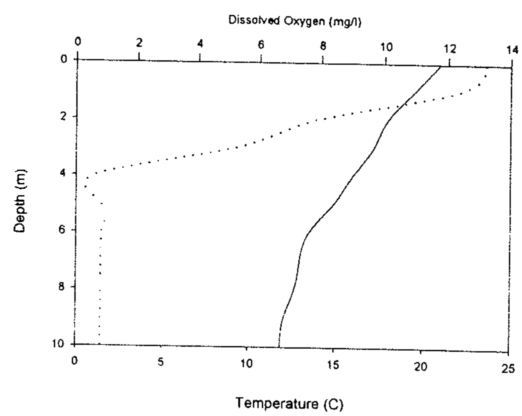
July 28, 1997



August 12, 1997



September 13, 1997

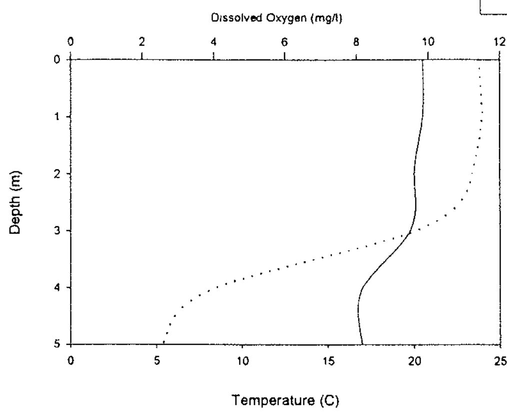


Appendix 3

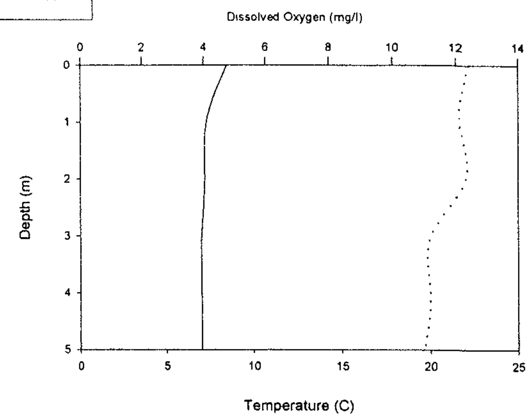
Site 2

— Temperature
· · · Dissolved oxygen

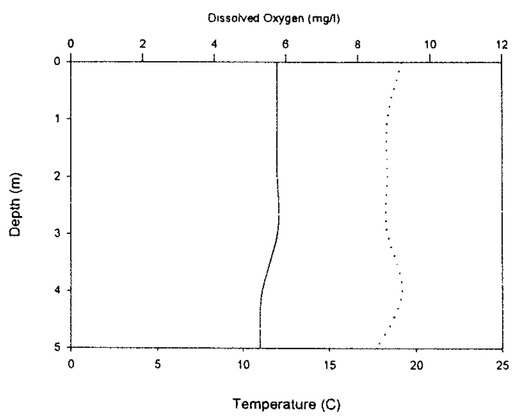
March 22, 1997



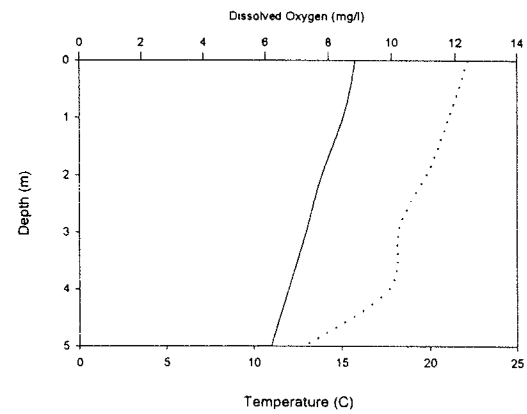
May 3, 1997



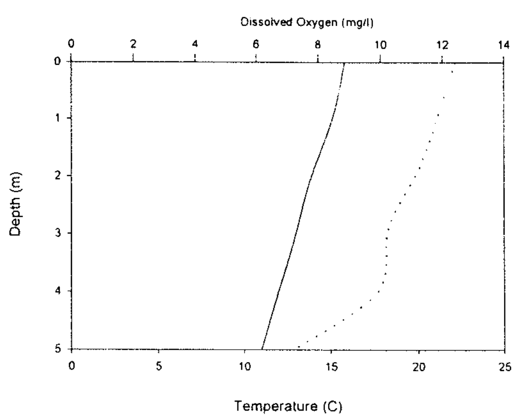
May 22, 1997



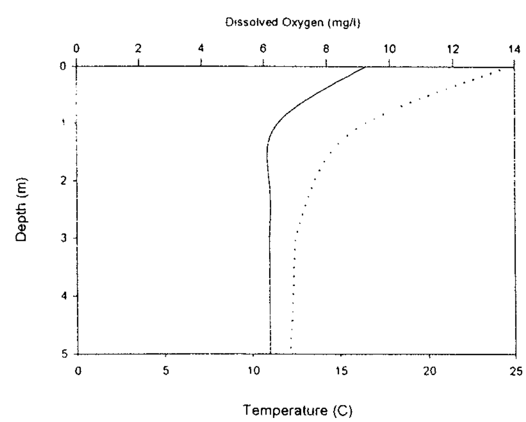
June 3, 1997



June 17, 1997

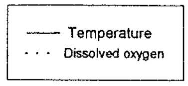


July 2, 1997

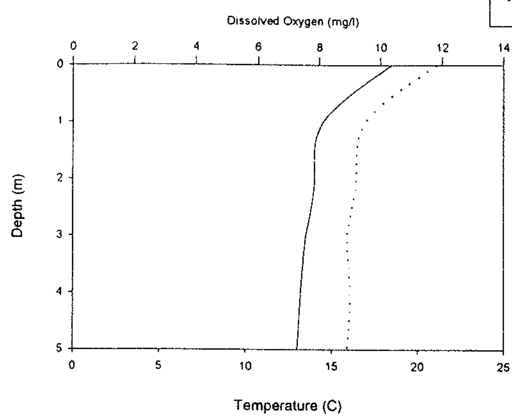


Appendix 3

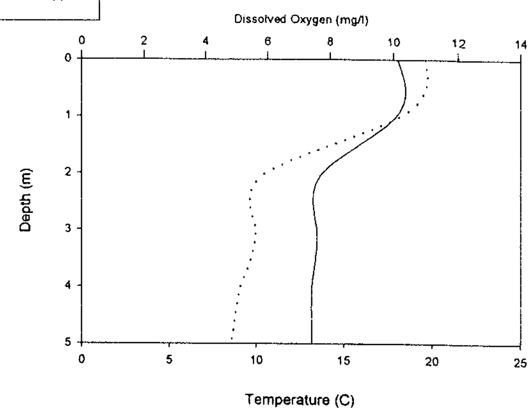
Site 2



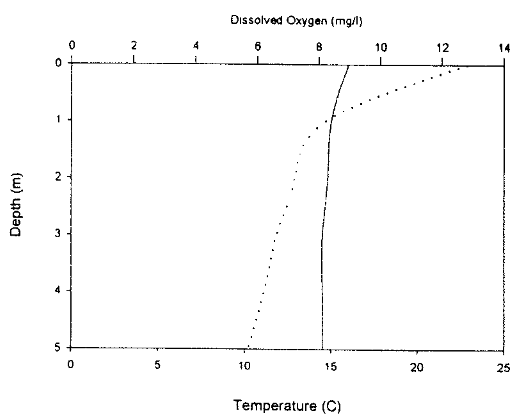
July 14, 1997



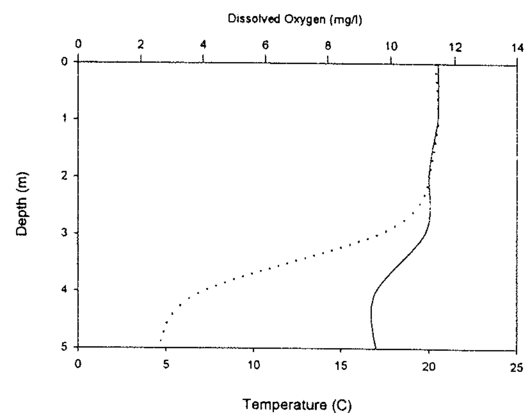
July 28, 1997



August 12, 1997



September 13, 1997

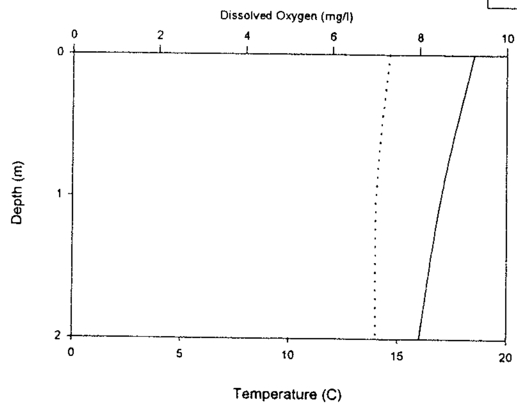


Appendix 3

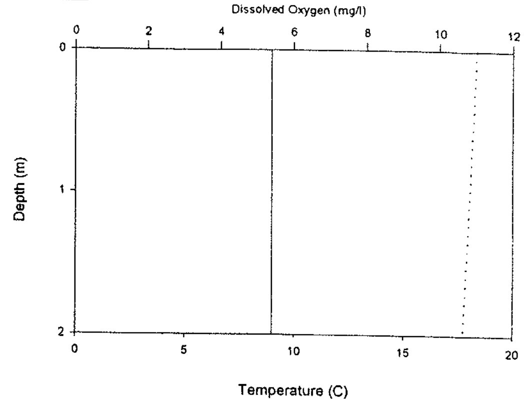
Site 3

— Temperature
· · · Dissolved oxygen

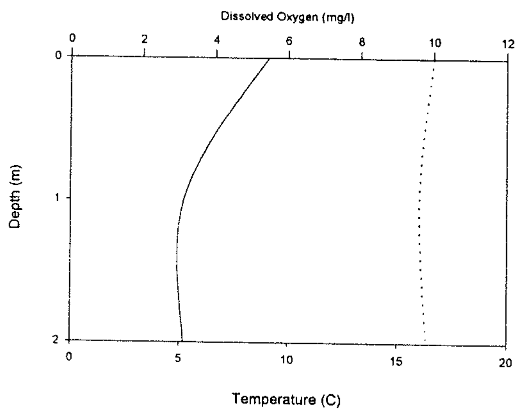
March 22, 1997



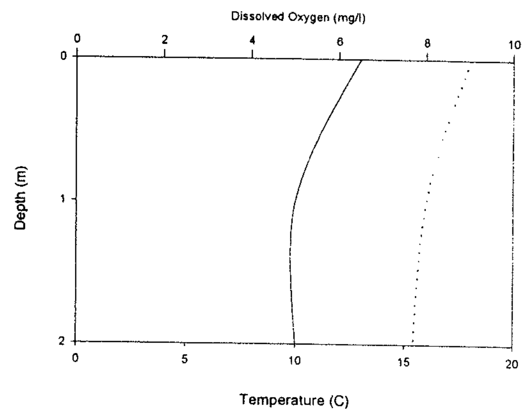
May 3, 1997



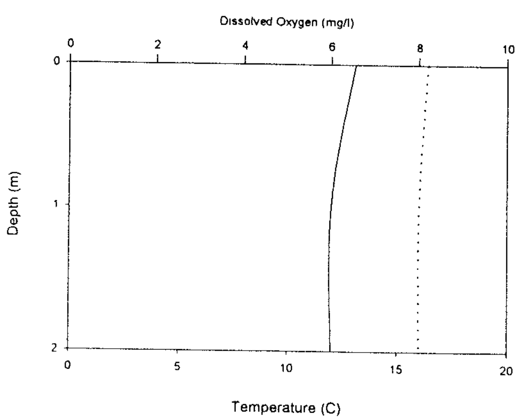
May 22, 1997



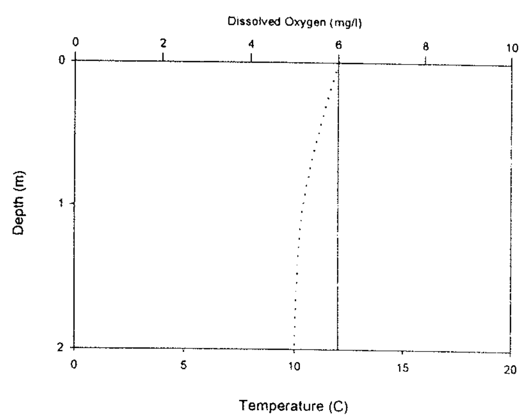
June 3, 1997



June 17, 1997



July 2, 1997

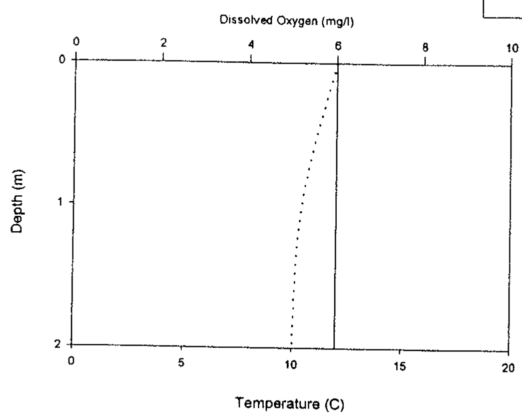


Appendix 3

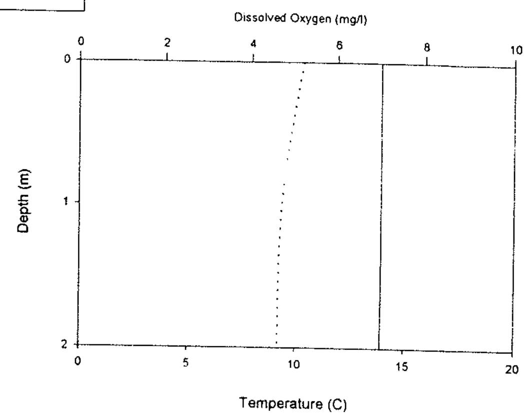
Site 3

—— Temperature
· · · Dissolved oxygen

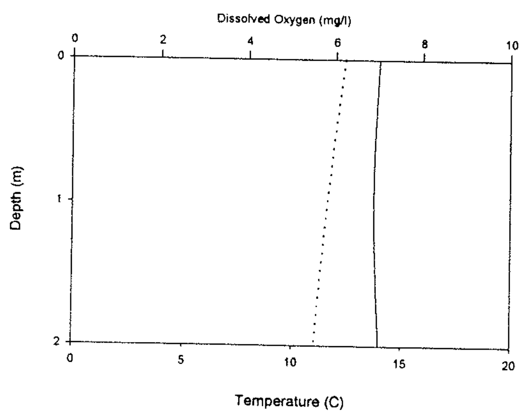
July 2, 1997



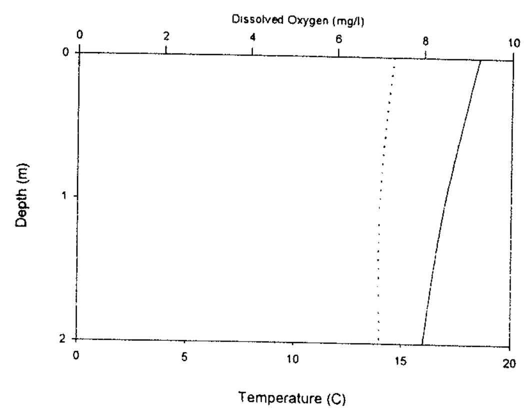
July 28, 1997



August 12, 1997

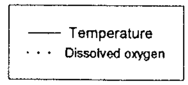


September 13, 1997

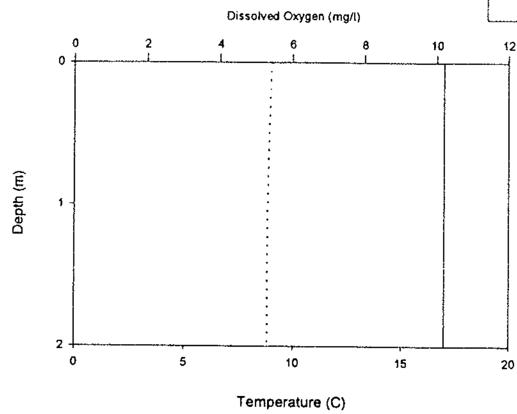


Appendix 3

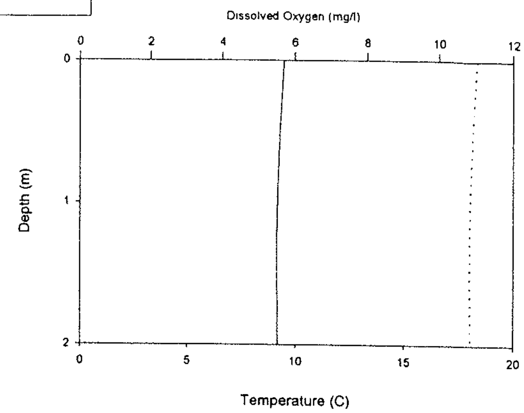
Site 4



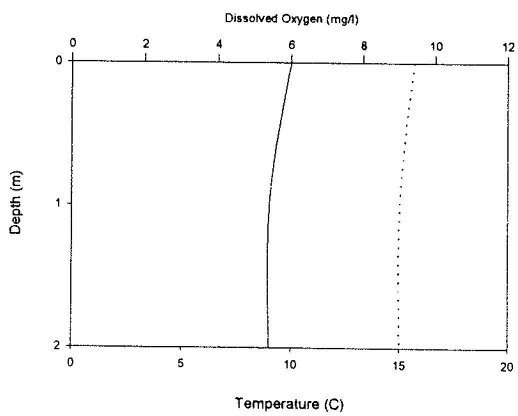
March 22, 1997



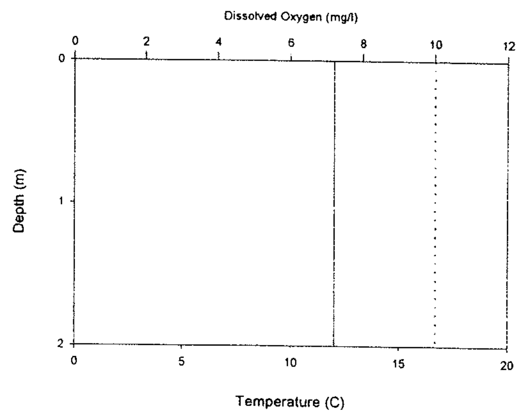
May 3, 1997



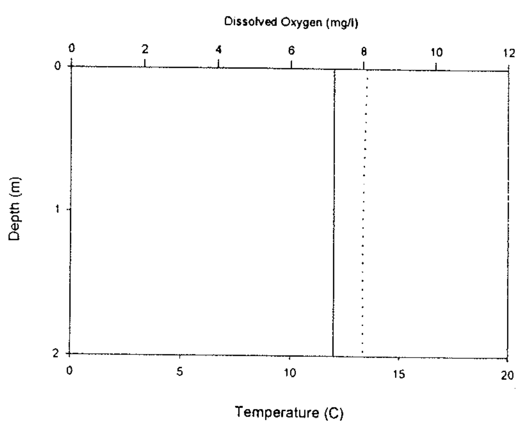
May 22, 1997



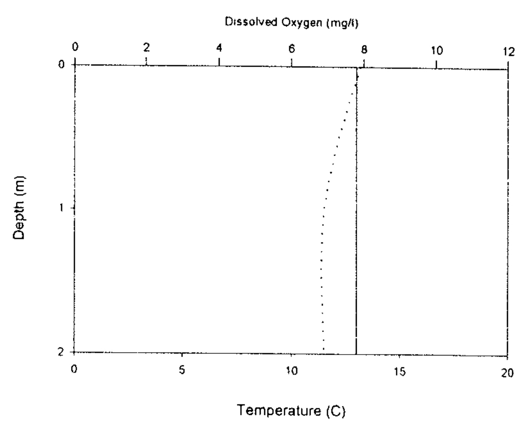
June 3, 1997



June 17, 1997

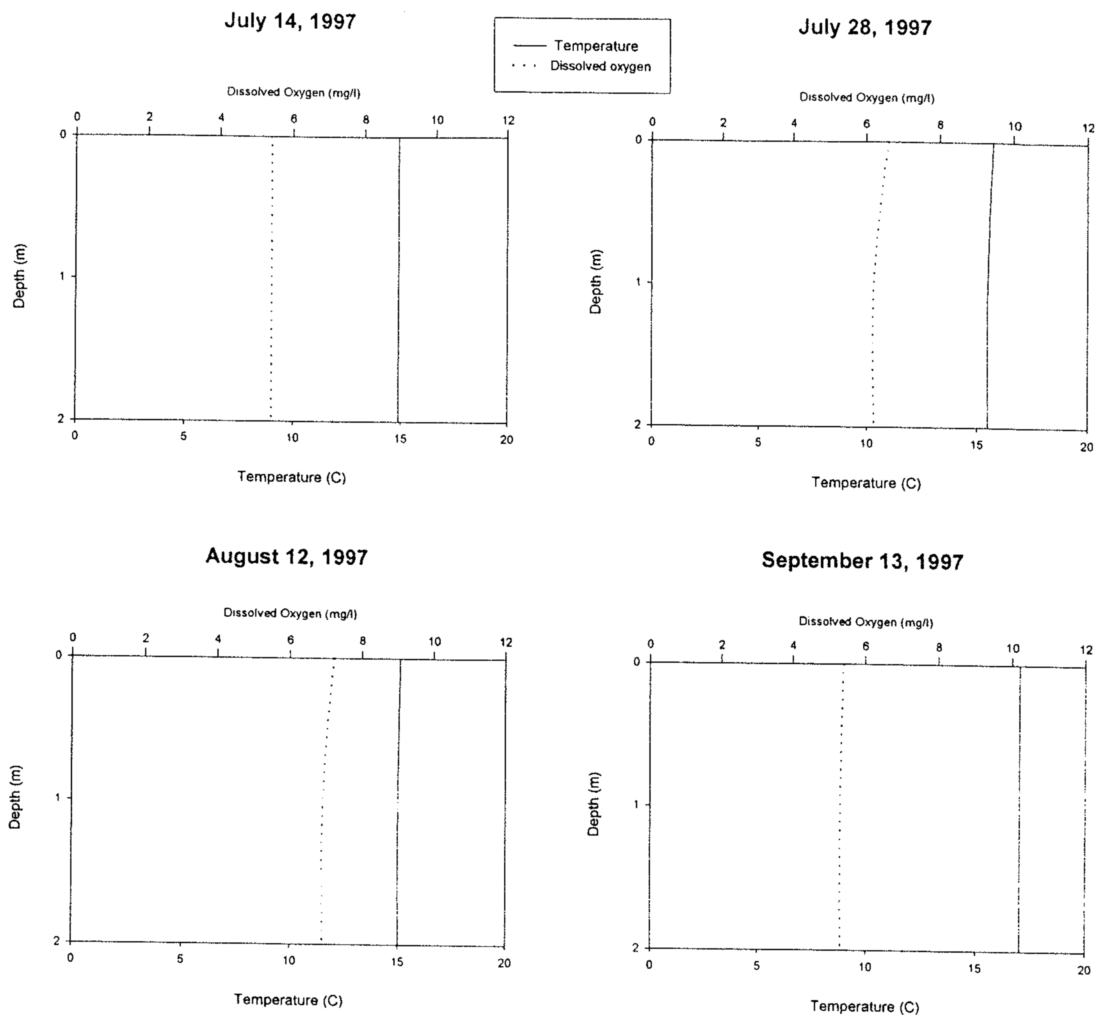


July 2, 1997



Appendix 3

Site 4

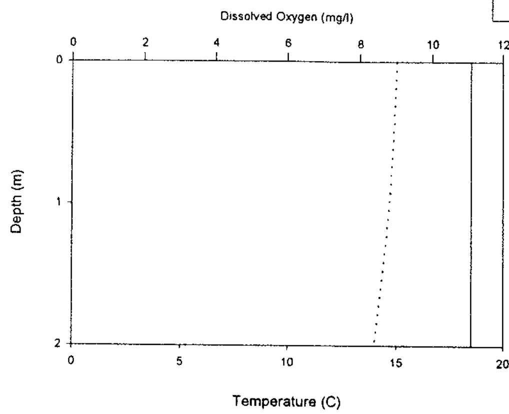


Appendix 3

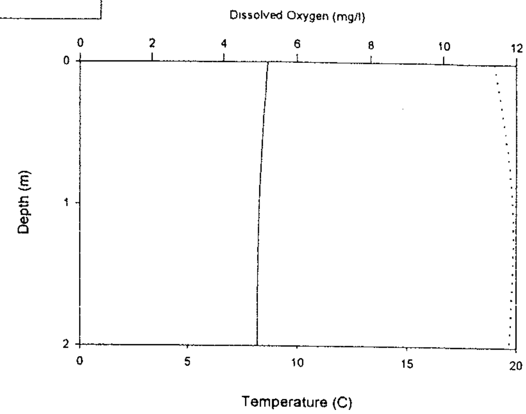
Site 5

— Temperature
· · · Dissolved oxygen

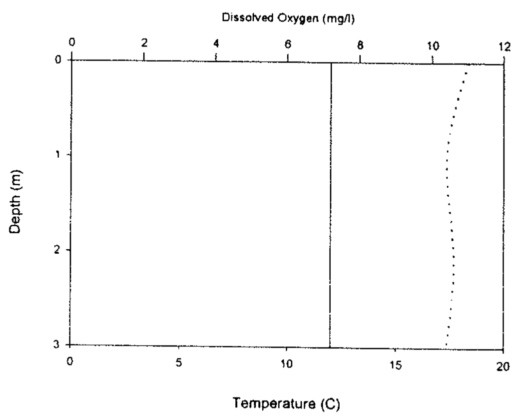
March 22, 1997



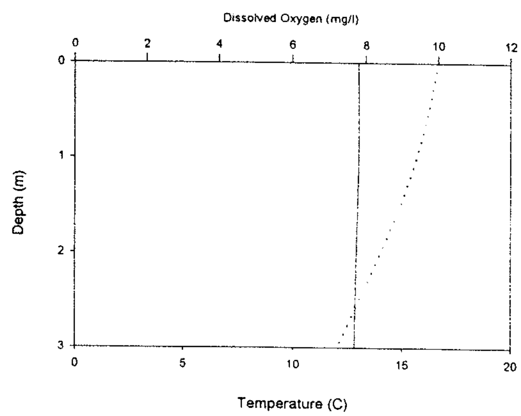
May 3, 1997



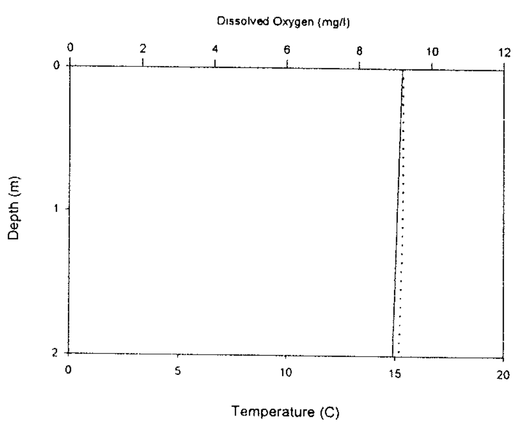
May 22, 1997



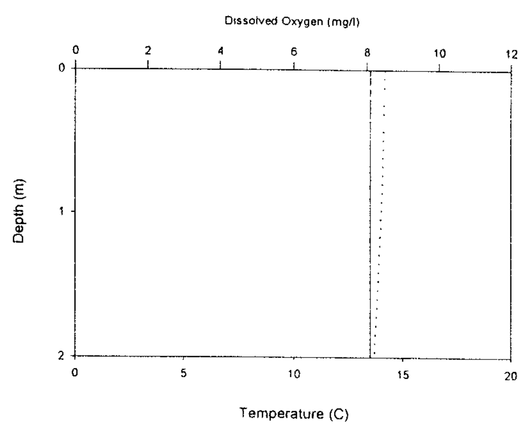
June 3, 1997



June 17, 1997

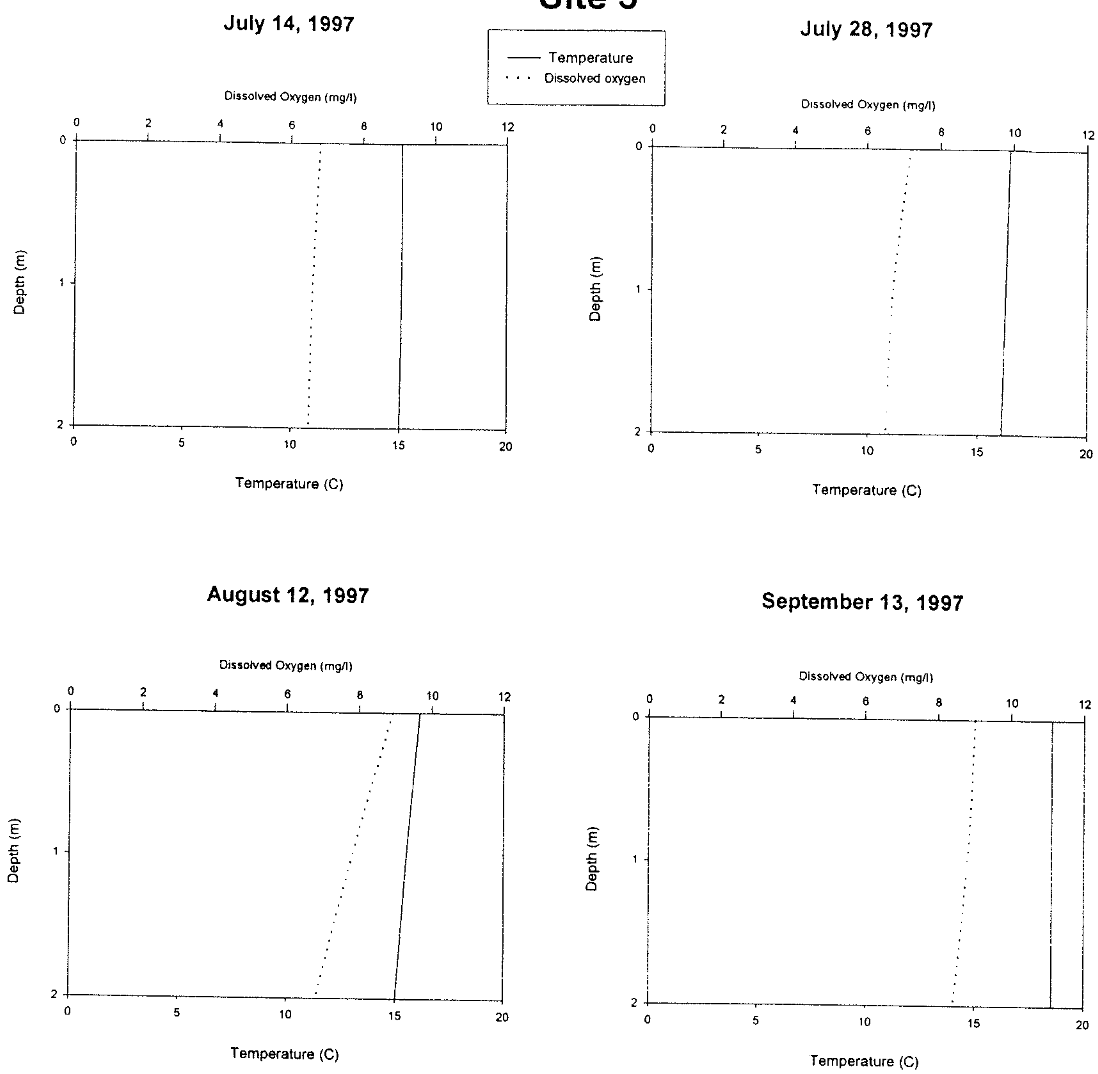


July 2, 1997



Appendix 3

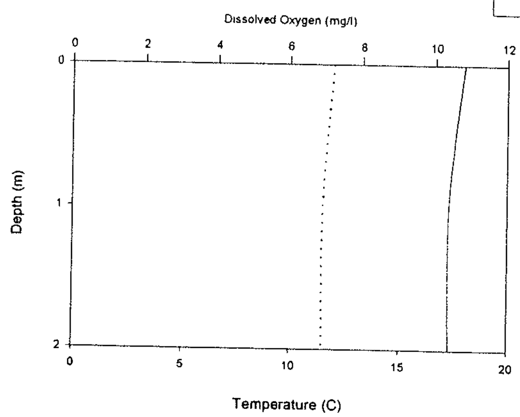
Site 5



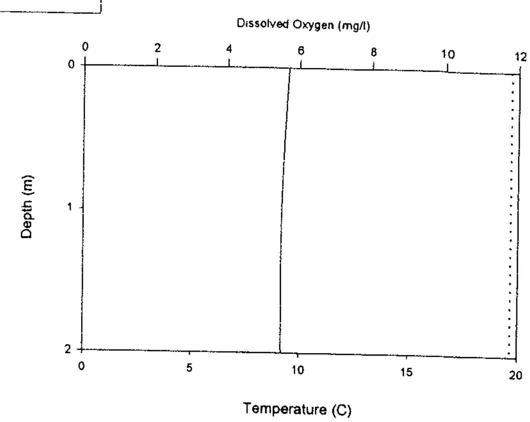
Site 6

— Temperature
· · · Dissolved oxygen

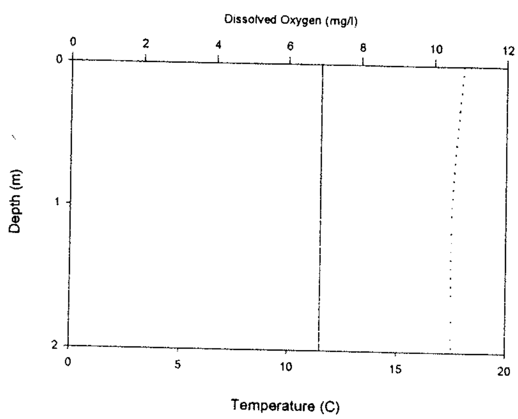
March 22, 1997



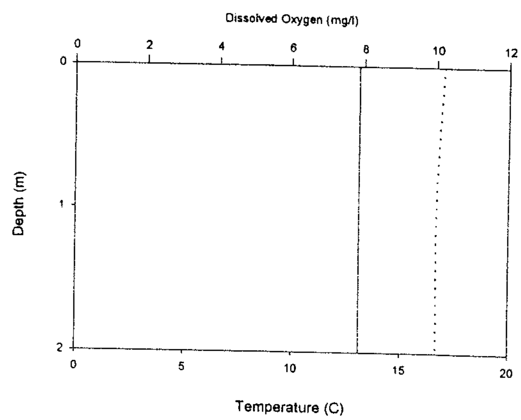
May 3, 1997



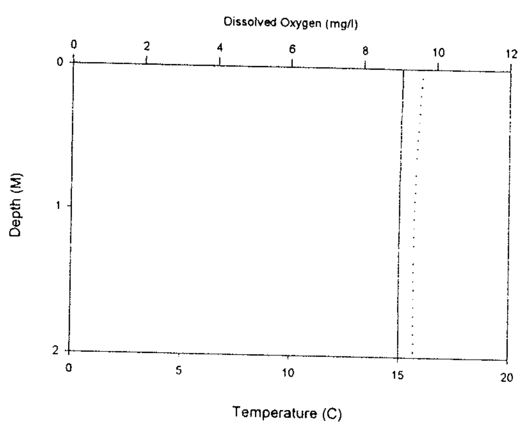
May 22, 1997



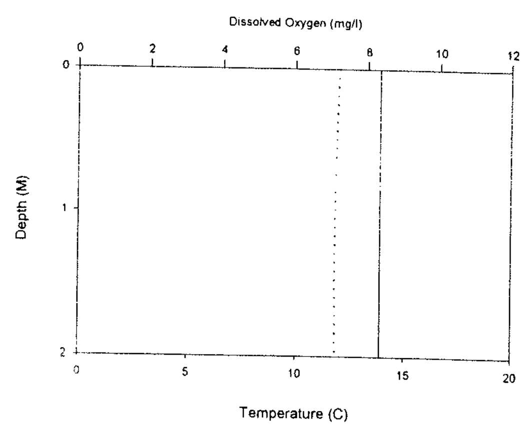
June 3, 1997



June 17, 1997



July 2, 1997

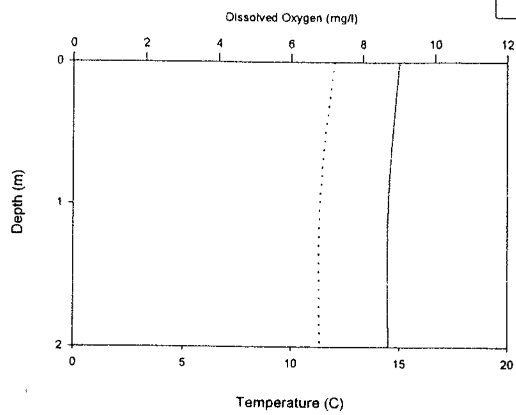


Appendix 3

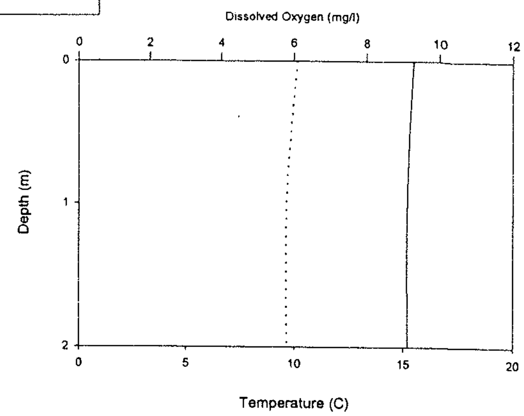
Site 6

— Temperature
· · · Dissolved oxygen

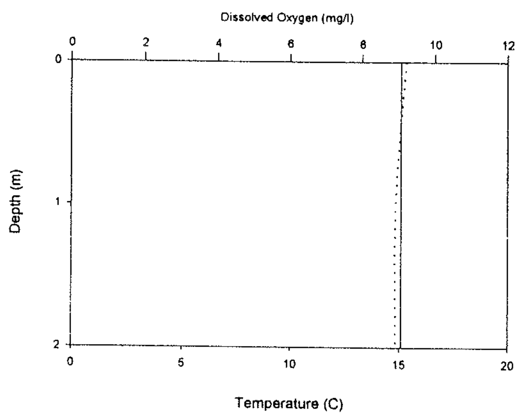
July 14, 1997



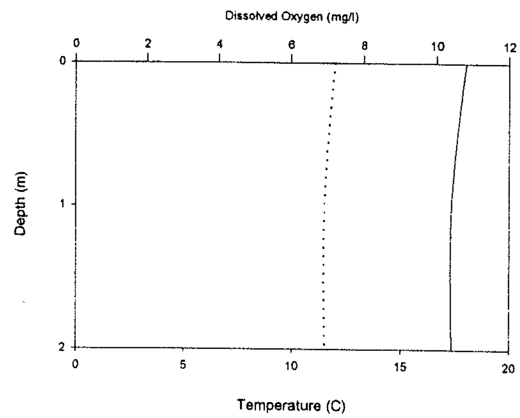
July 28, 1997



August 12, 1997

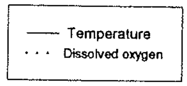


September 13, 1997

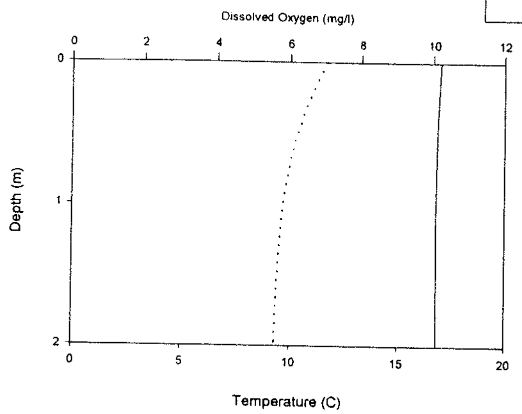


Appendix 3

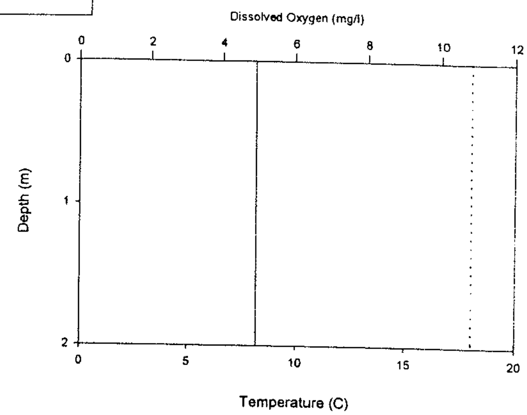
Site 7



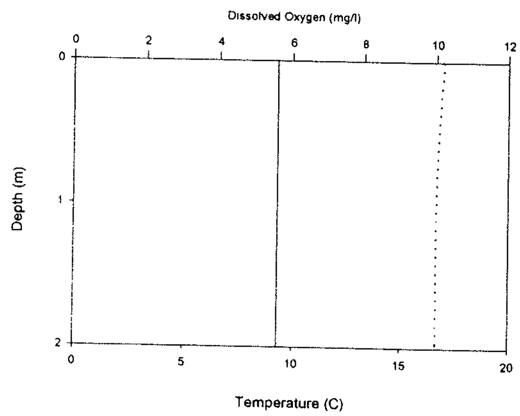
March 22, 1997



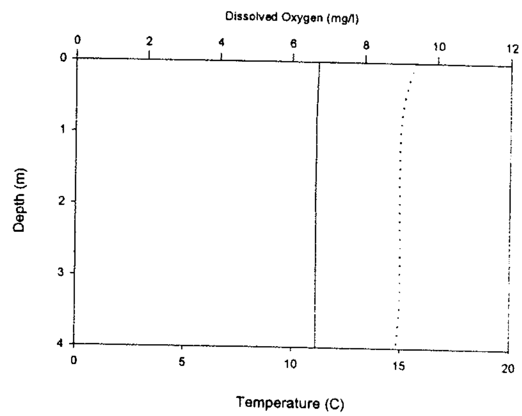
May 3, 1997



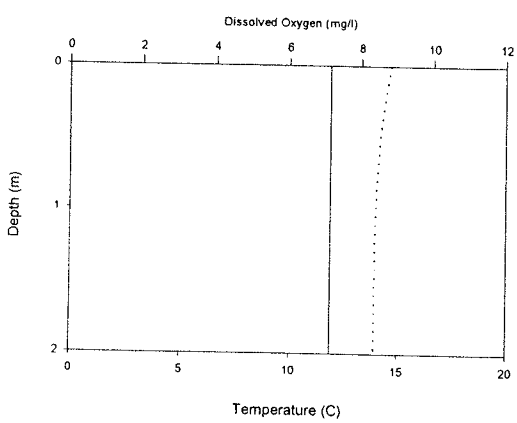
May 22, 1997



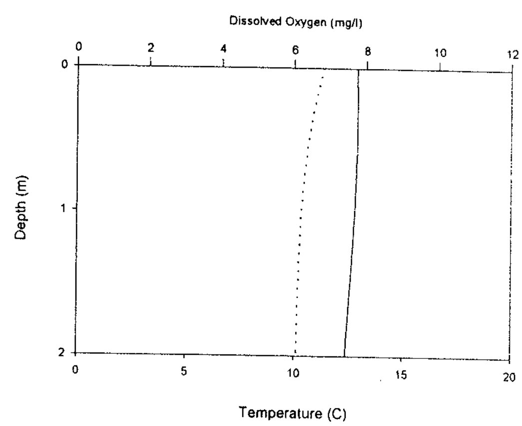
June 3, 1997



June 17, 1997

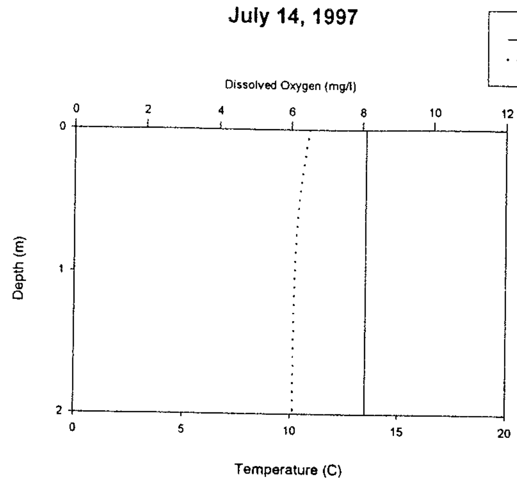


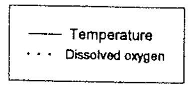
July 2, 1997

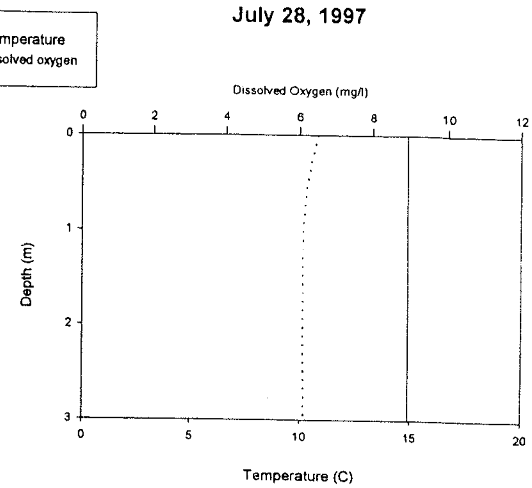


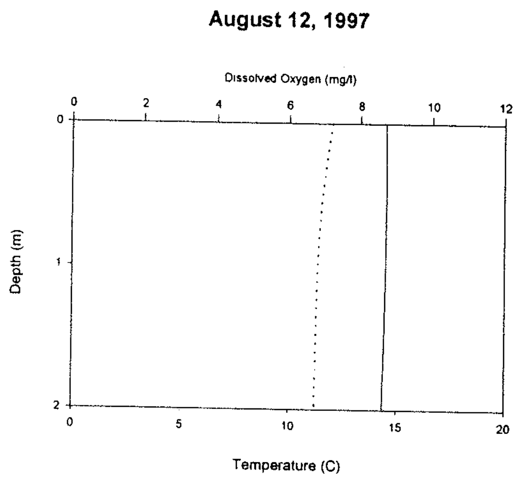
Appendix 3

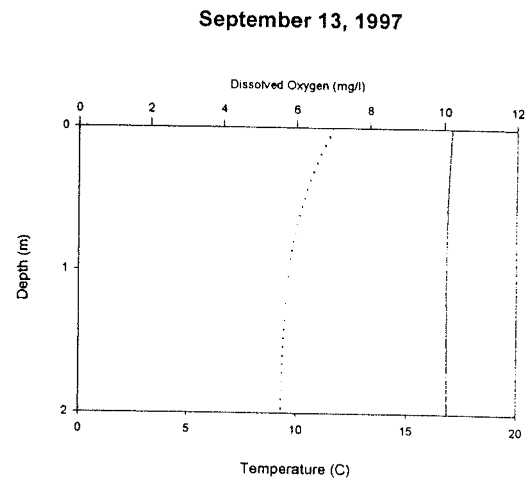
Site 7





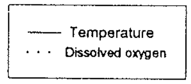




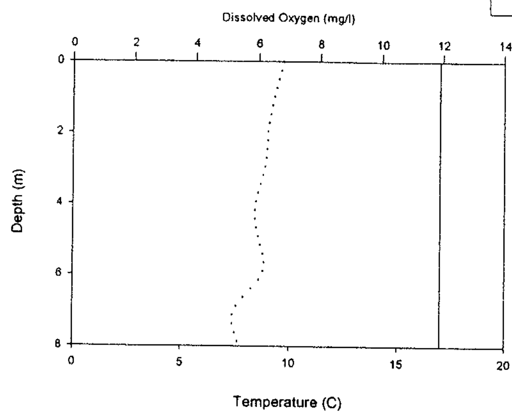


Appendix 3

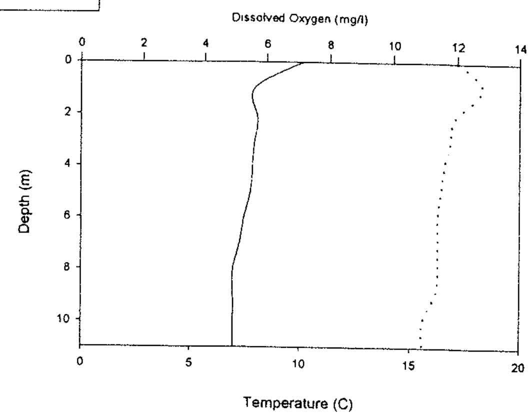
Site 8



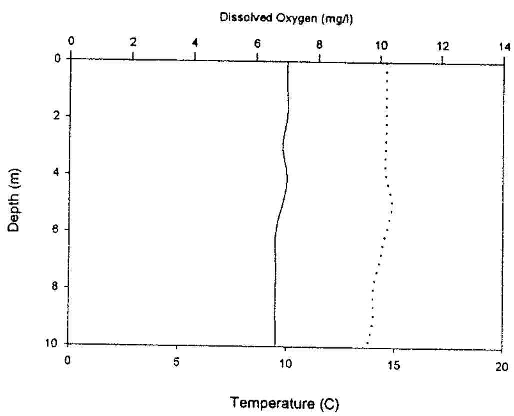
March 22, 1997



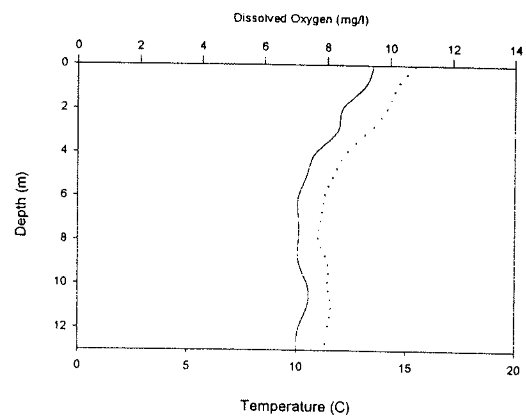
May 3, 1997



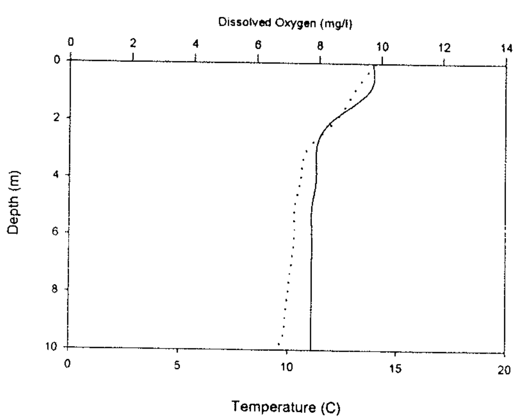
May 22, 1997



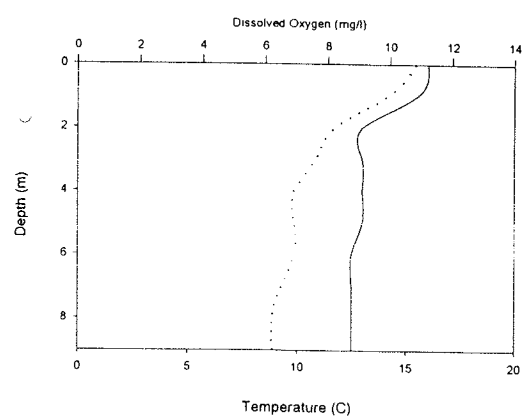
June 3, 1997



June 17, 1997

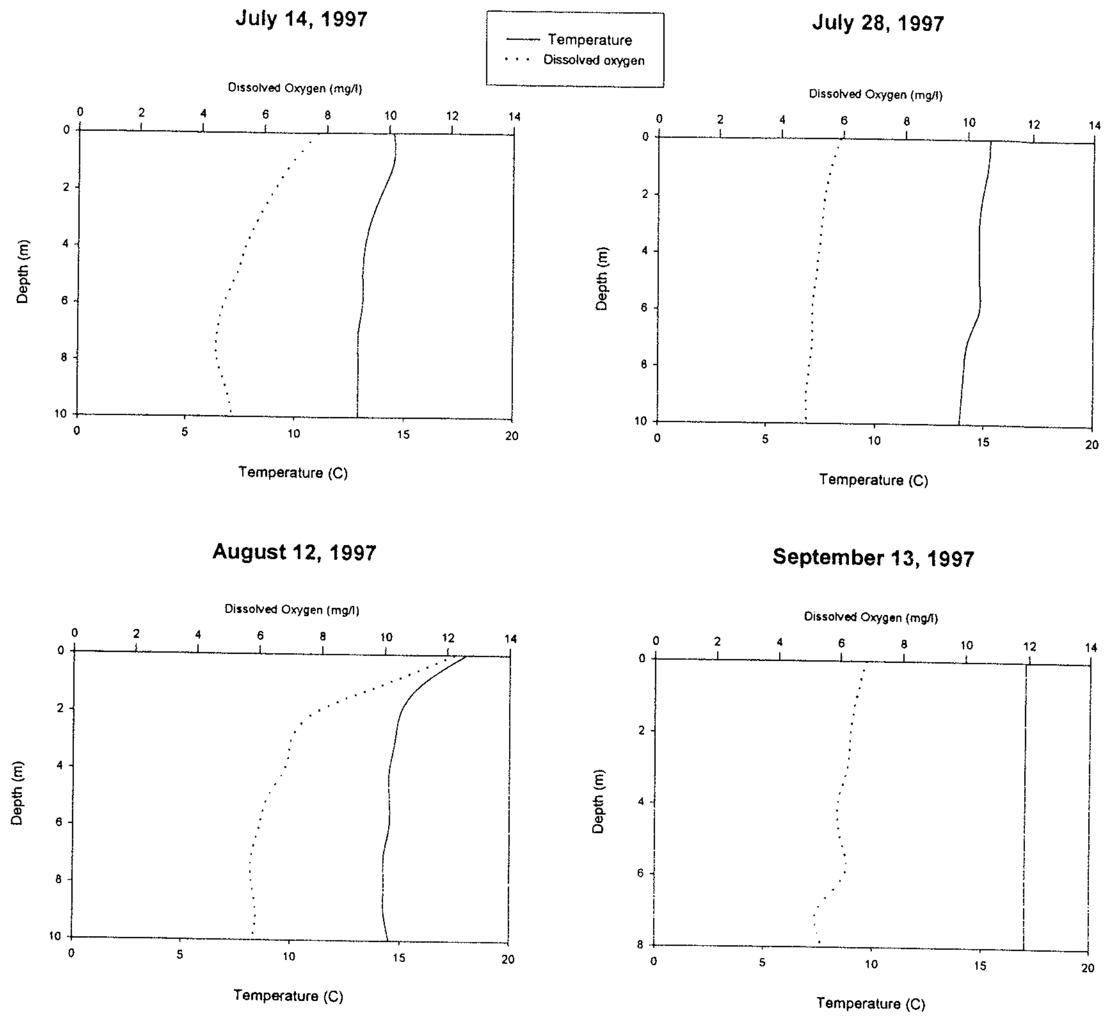


July 2, 1997



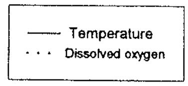
Appendix 3

Site 8

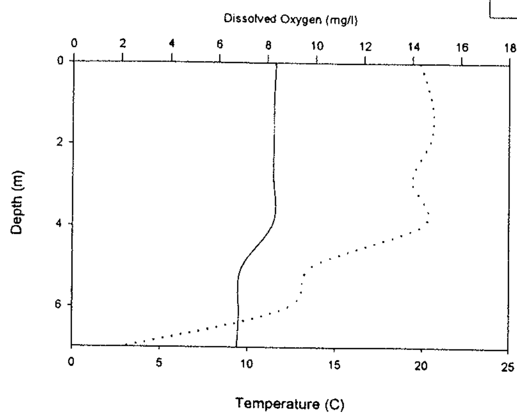


Appendix 3

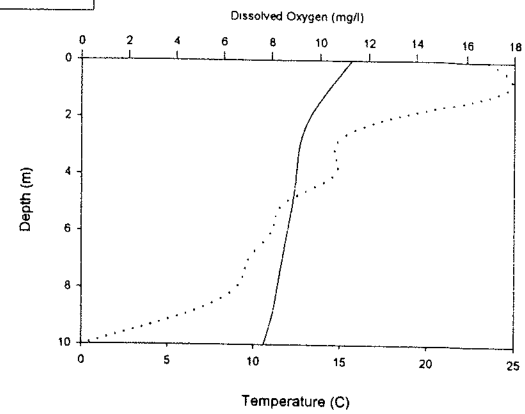
Site1



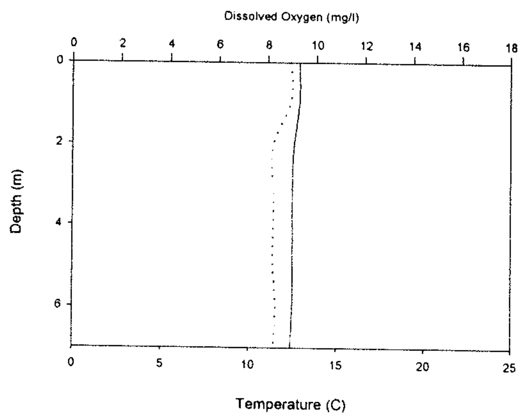
April 25, 1998



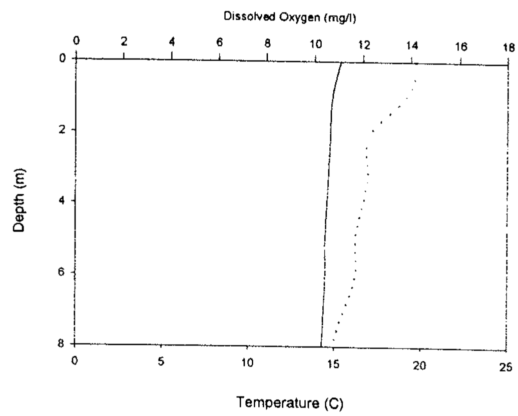
May 18, 1998



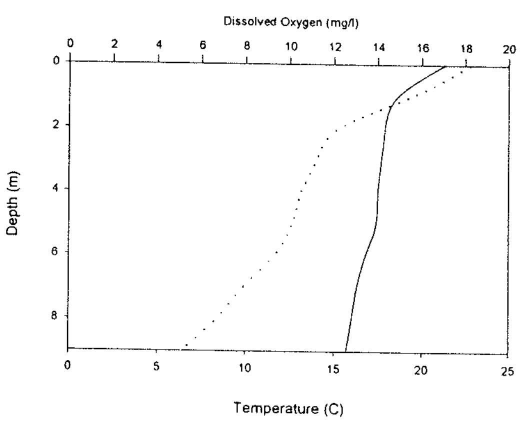
June 9, 1998



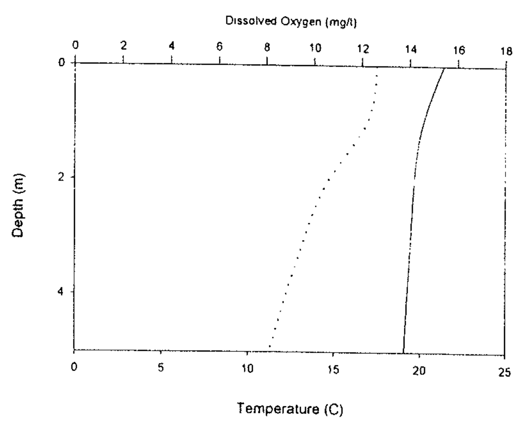
June 15, 1998



July 1, 1998

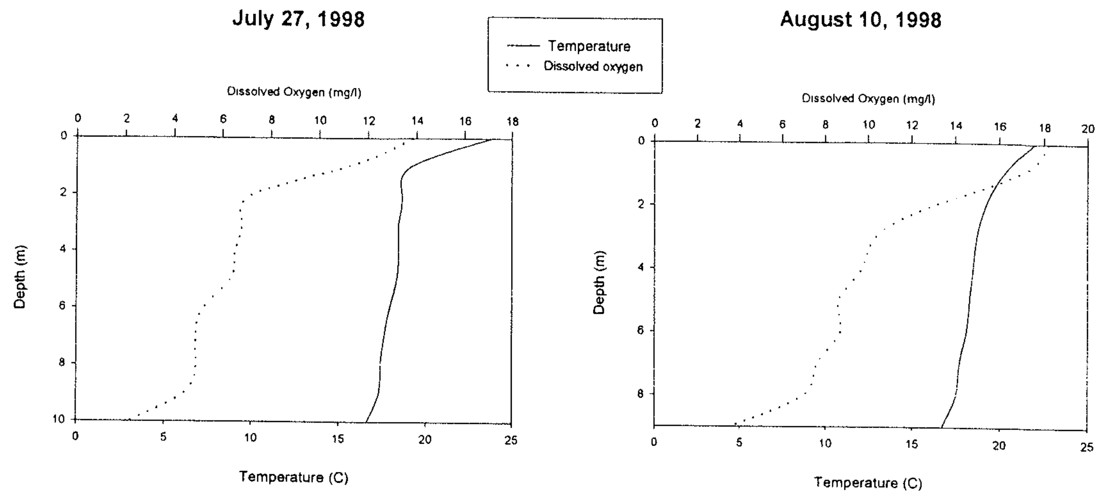


July 14, 1998



Appendix 3

Site 1

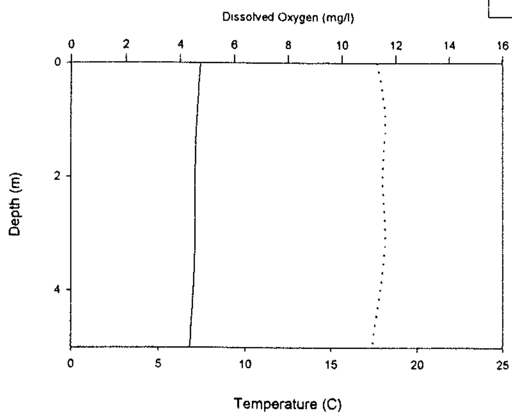


Appendix 3

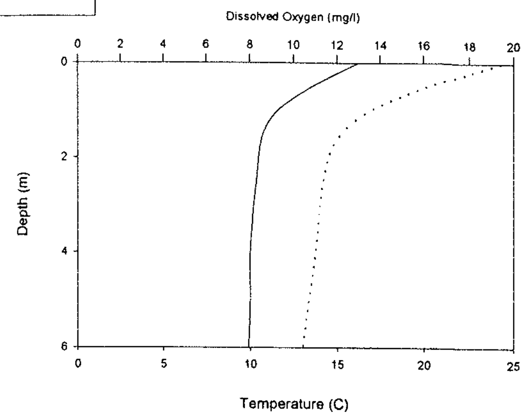
Site 2

Temperature
Dissolved oxygen

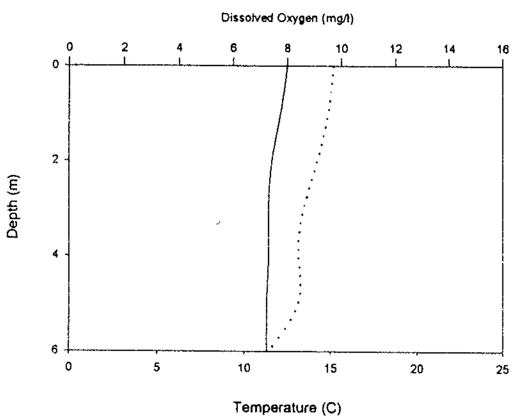
April 25, 1998



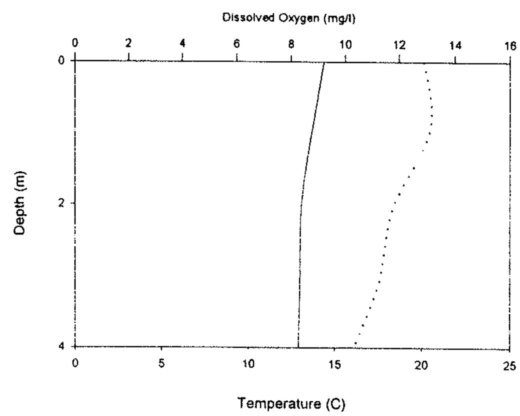
May 18, 1998



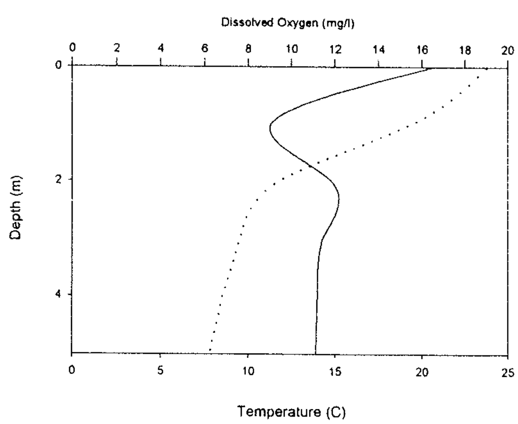
May 18, 1998



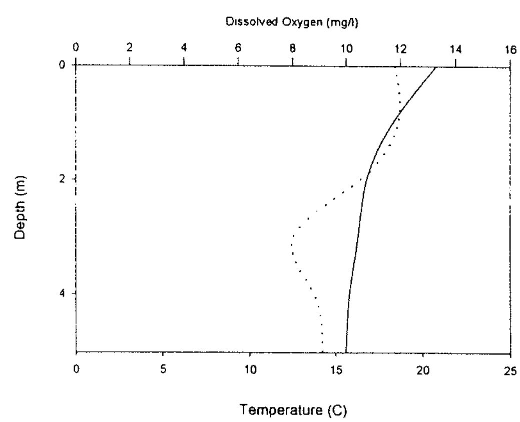
June 15, 1998



July 1, 1998

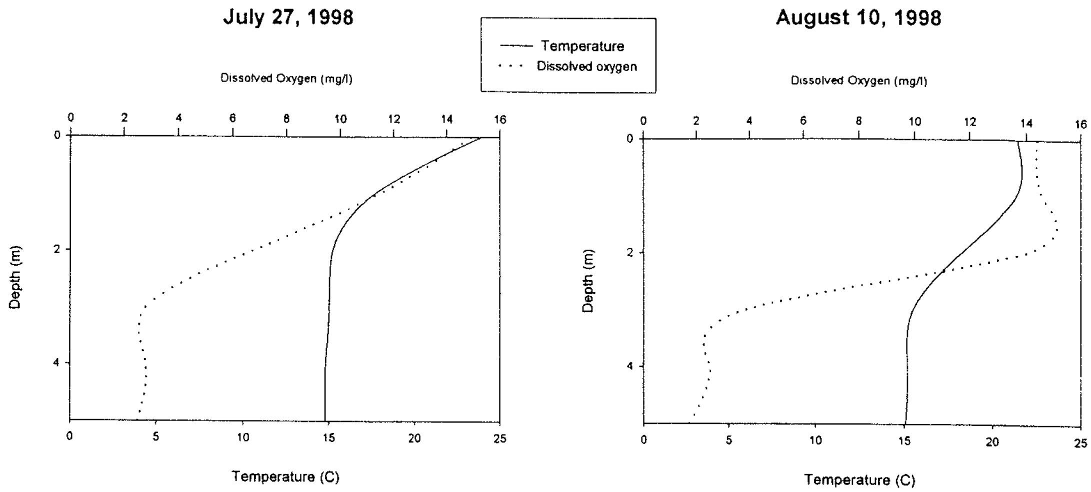


July 14, 1998



Appendix 3

Site 2

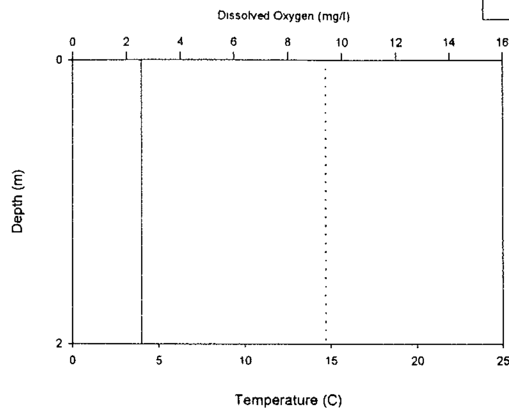


Appendix 3

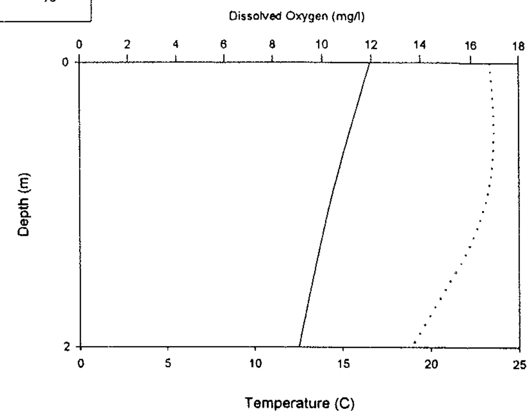
Site 3

— Temperature
· · · Dissolved oxygen

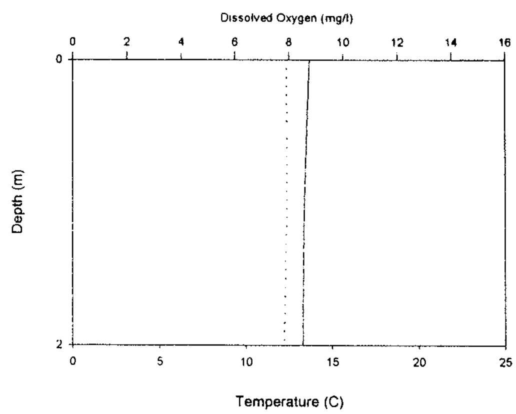
April 25, 1998



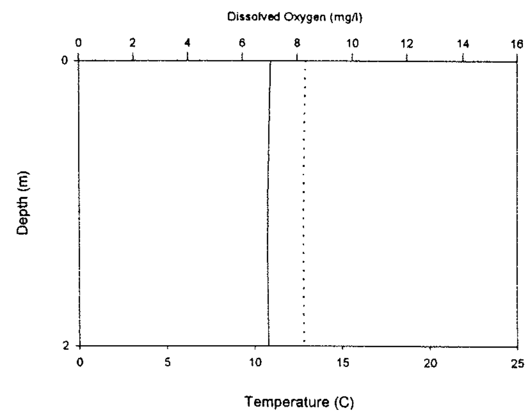
May 18, 1998



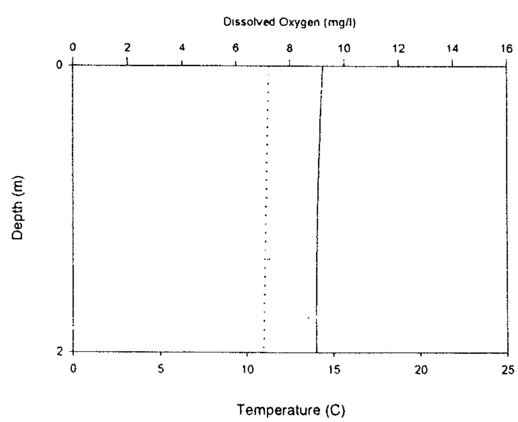
June 6, 1998



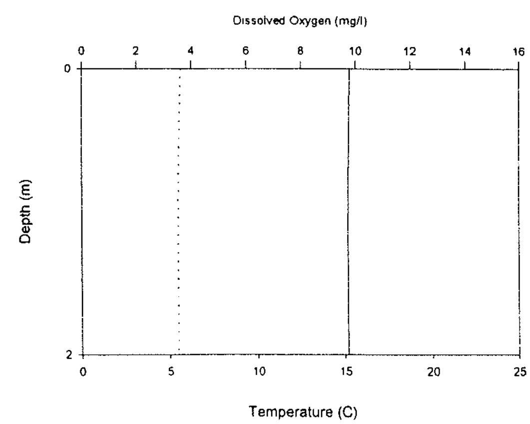
June 15, 1998



July 1, 1998

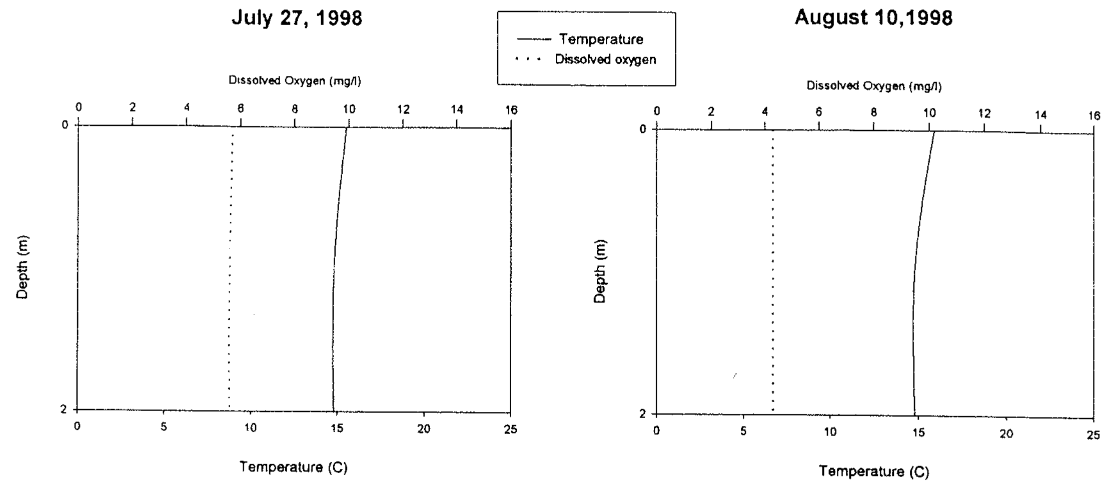


July 14, 1998



Appendix 3

Site 3

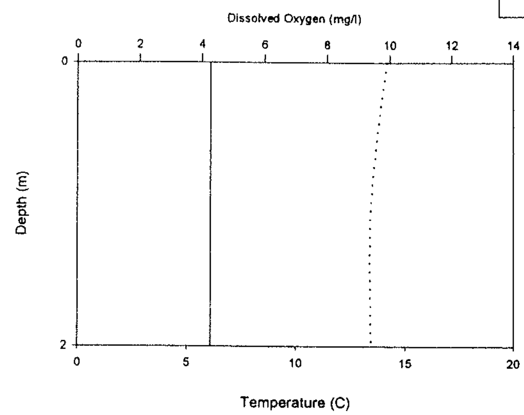


Appendix 3

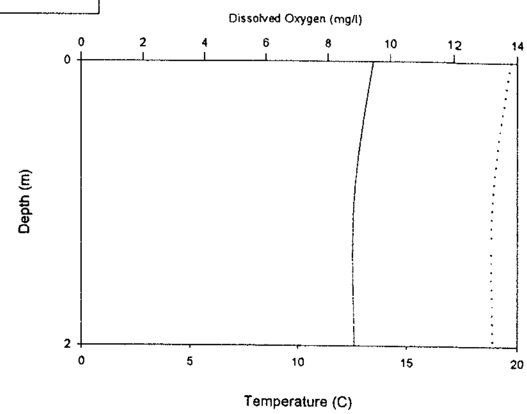
Site 4

Temperature
Dissolved oxygen

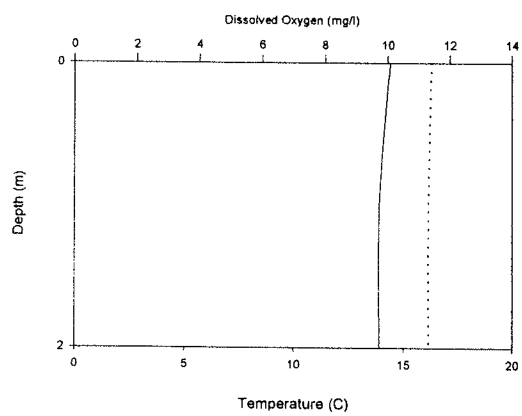
April 25, 1998



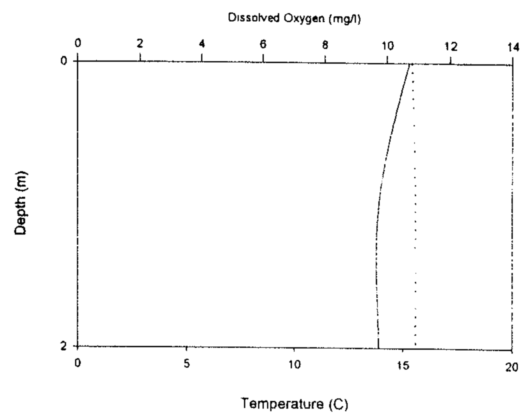
May 18, 1998



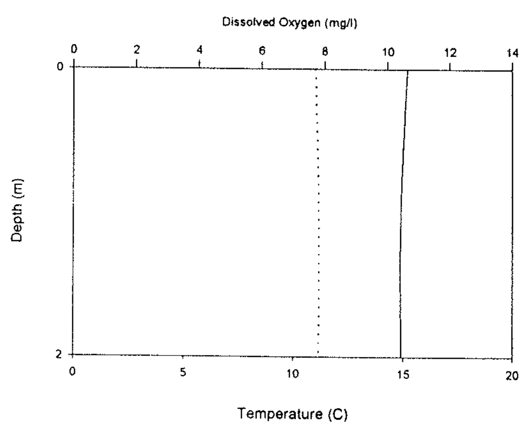
June 9, 1998



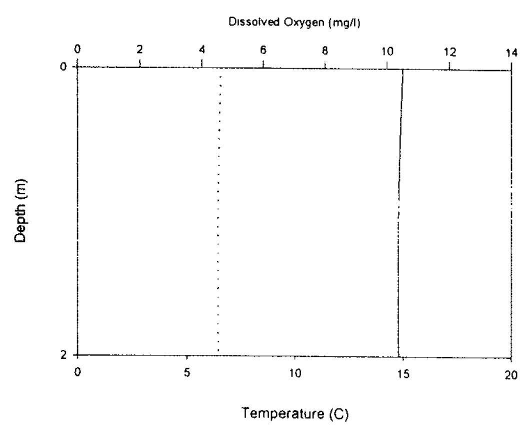
June 15, 1998



July 1, 1998



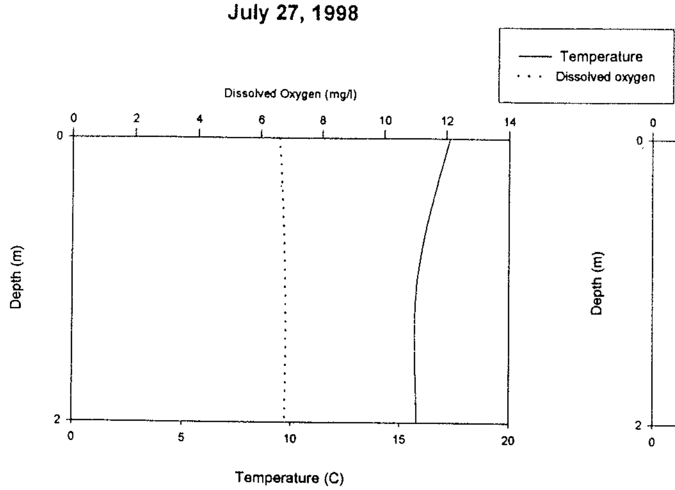
July 14, 1998



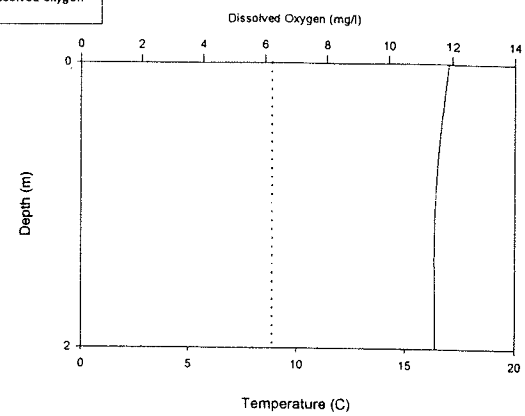
Appendix 3

Site 4

July 27, 1998



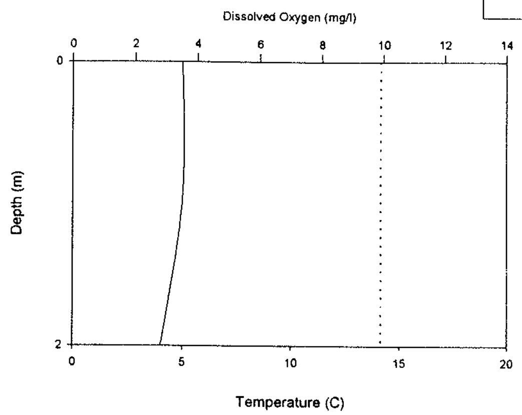
August 10, 1998



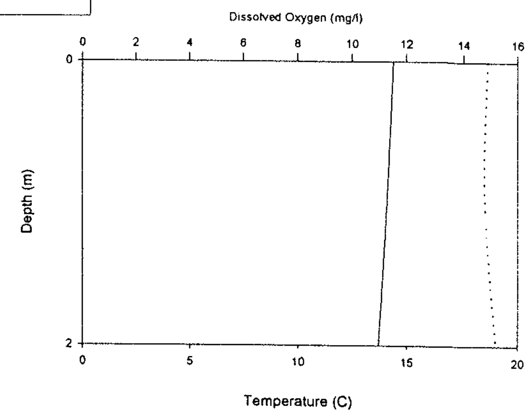
Site 5

— Temperature
· · · Dissolved oxygen

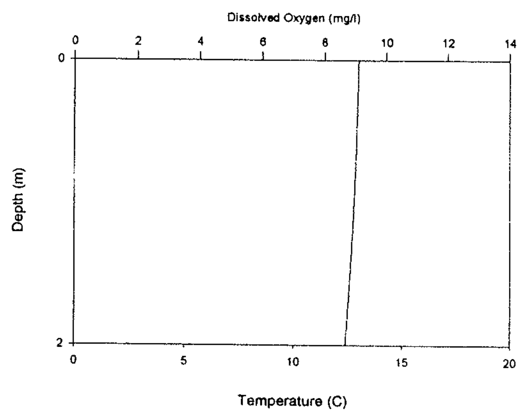
April 25, 1998



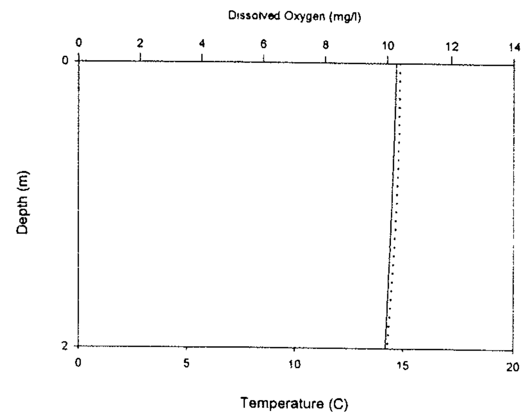
May 18, 1998



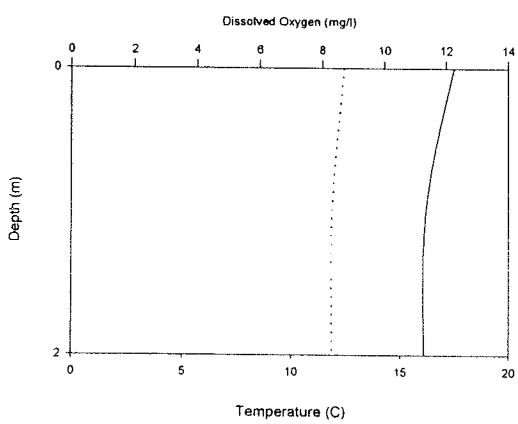
June 9, 1998



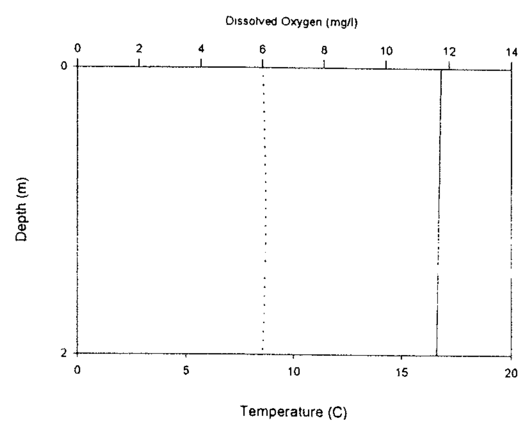
June 15, 1998



July 1, 1998

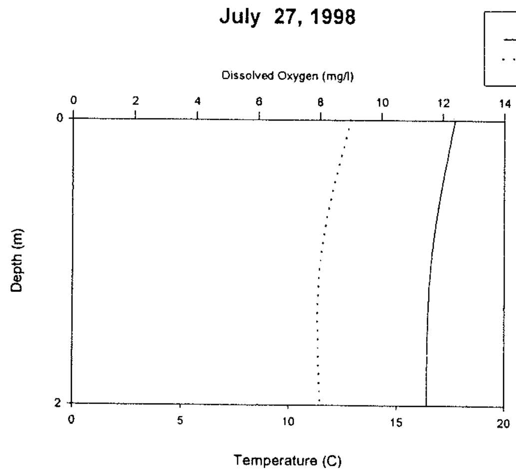


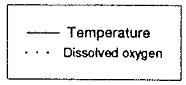
July 14, 1998

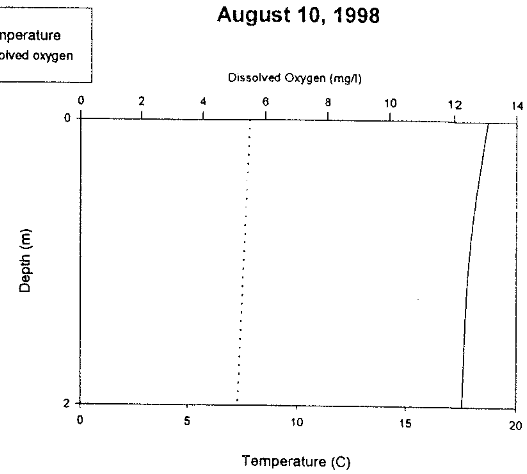


Appendix 3

Site 5



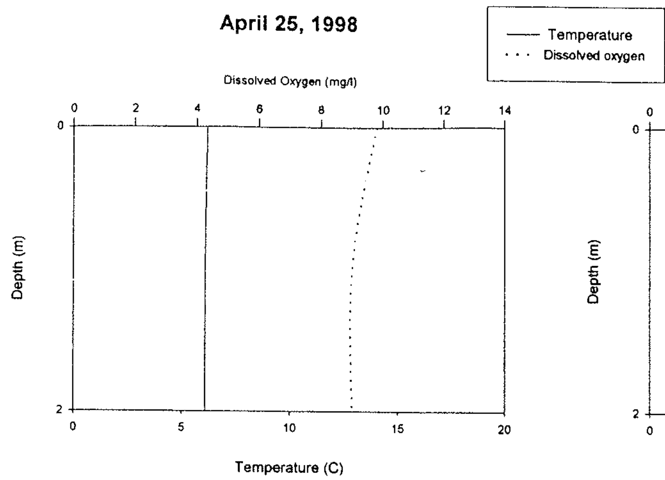




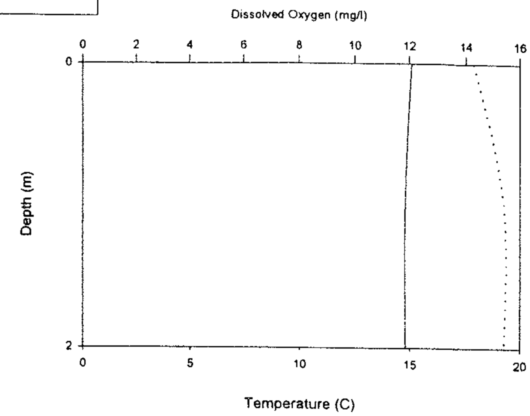
Appendix 3

Site 6

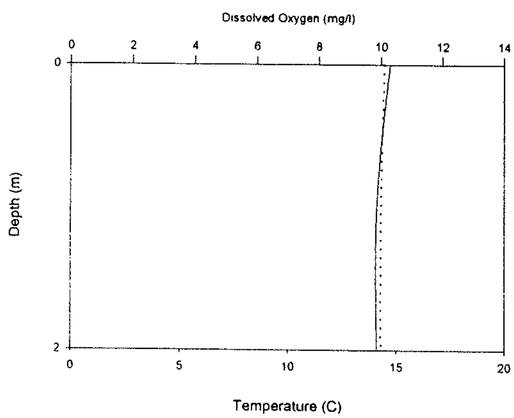
April 25, 1998



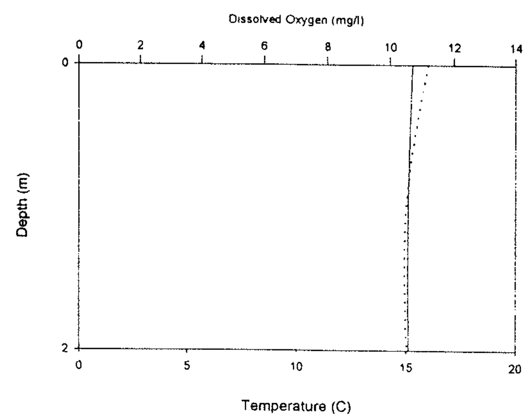
May 18, 1998



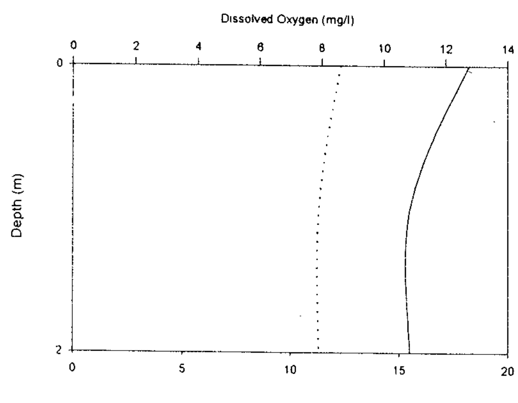
June 9, 1998



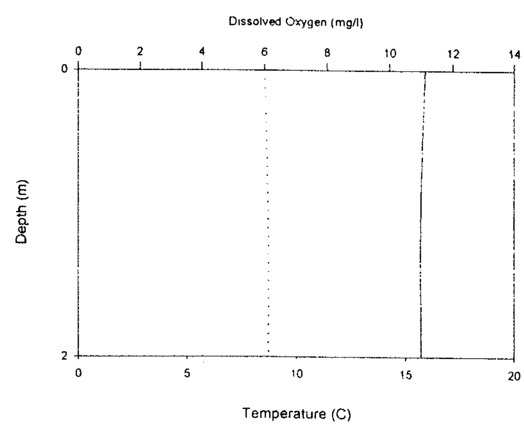
June 15, 1998



July 1, 1998

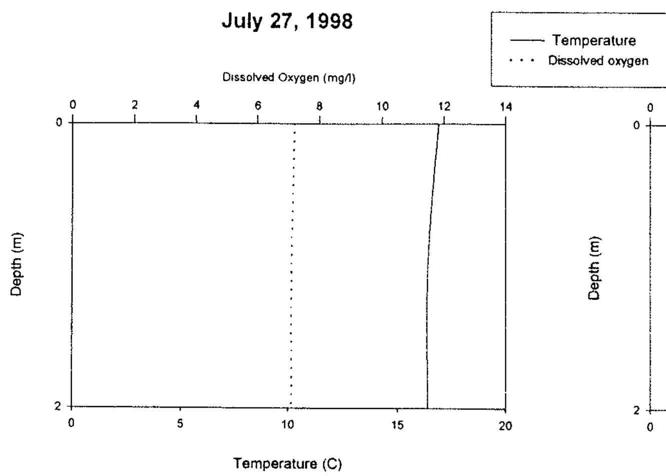


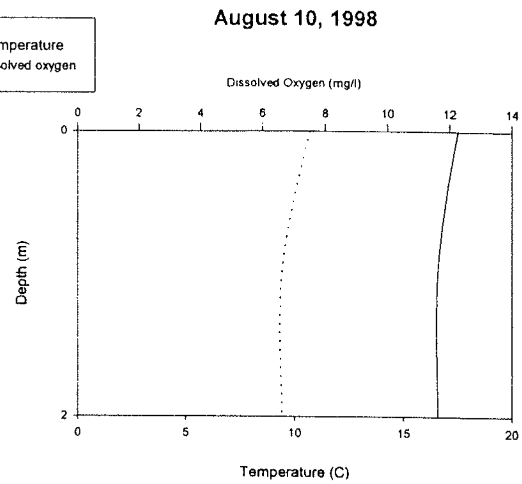
July 14, 1998



Appendix 3

Site 6



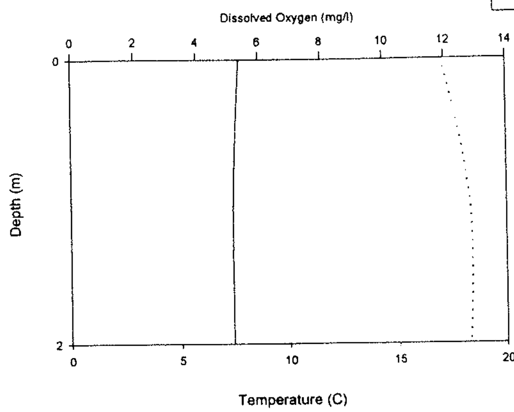


Appendix 3

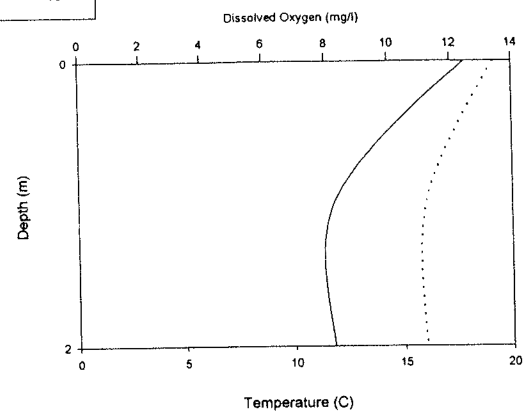
Site 7

— Temperature
· · · Dissolved oxygen

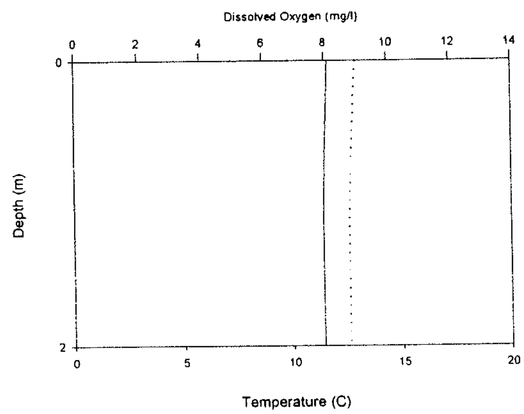
April 25, 1998



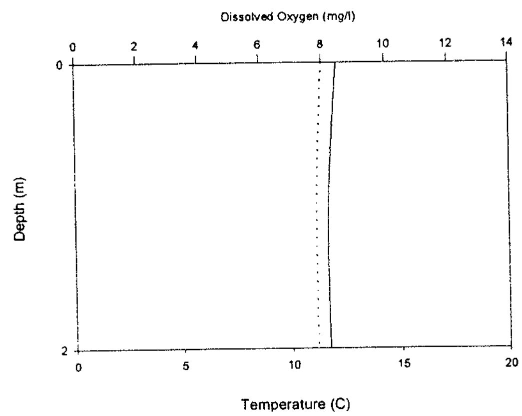
May 18, 1998



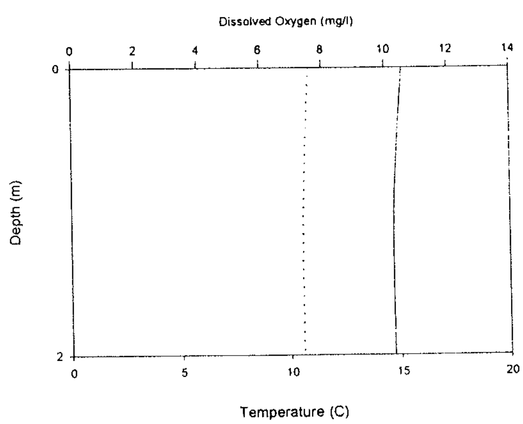
June 9, 1998



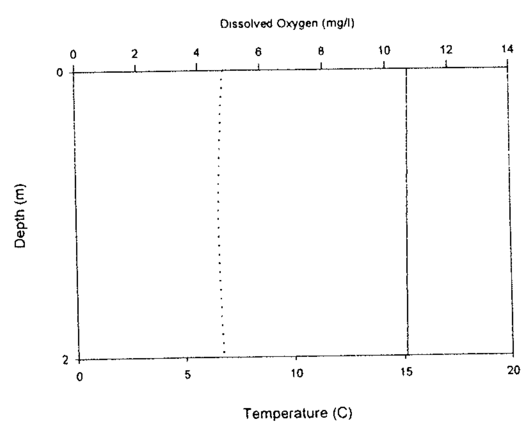
June 15, 1998



July 1, 1998

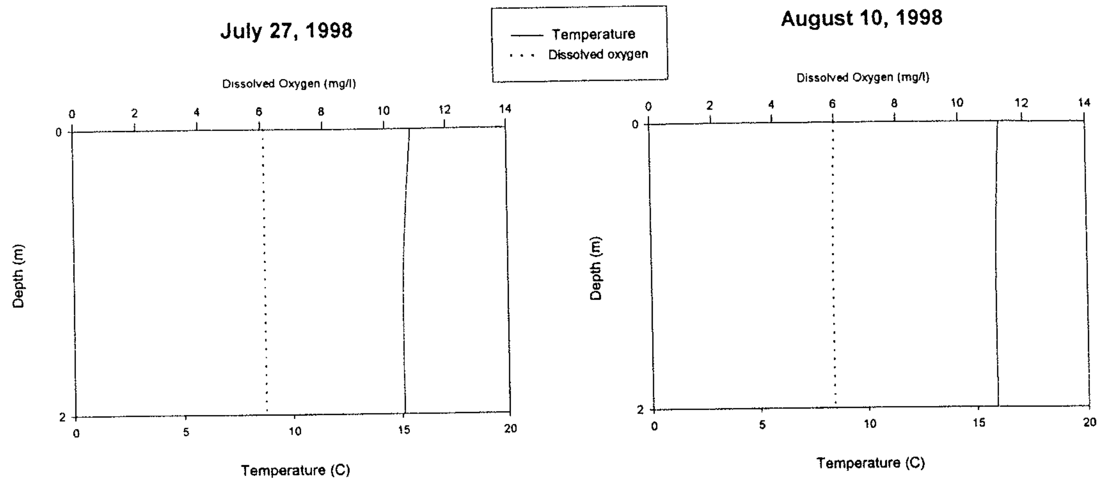


July 14, 1998



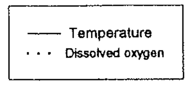
Appendix 3

Site 7

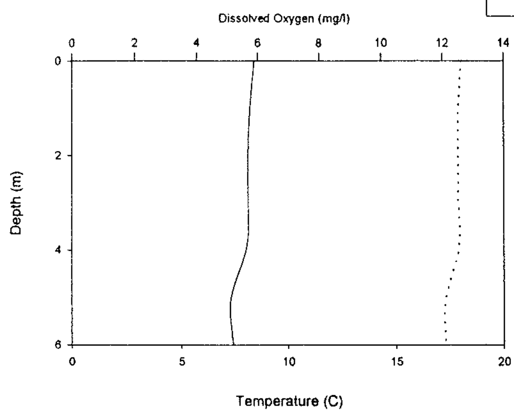


Appendix 3

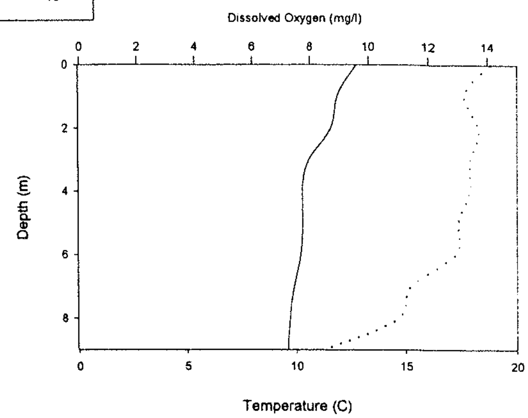
Site 8



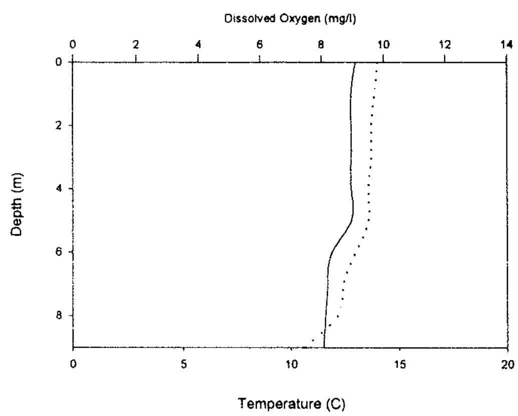
April 25, 1998



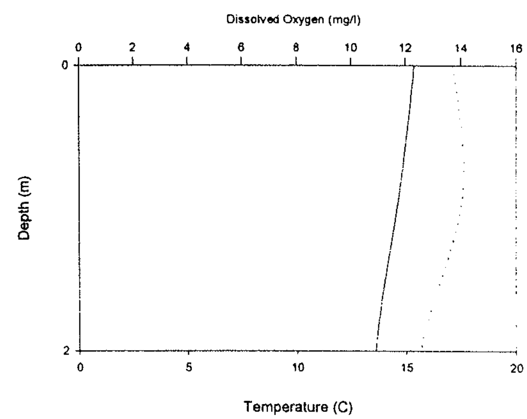
May 18, 1998



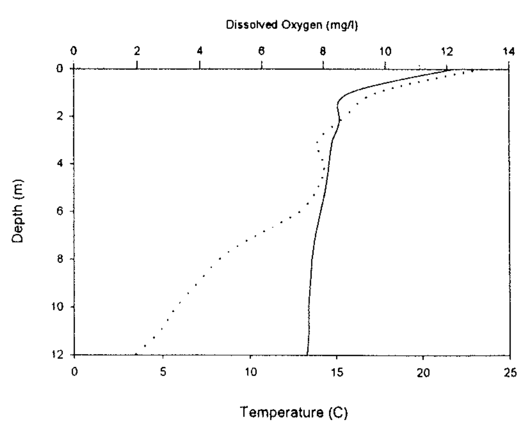
June 9, 1998



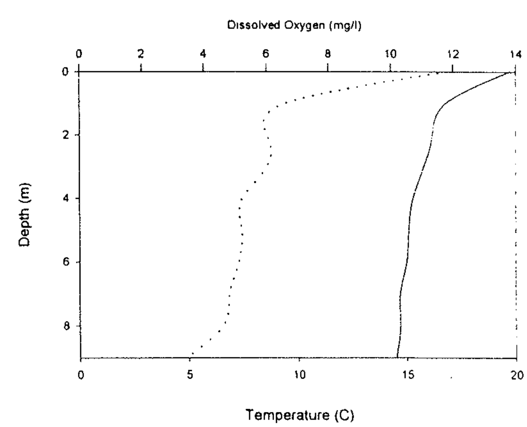
June 15, 1998



July 1, 1998



July 14, 1998



Appendix 3

Site 8