UNIVERSITY OF VICTORIA
DEPARTMENT OF BIOLOGY

THE EFFECTS OF HYPOLIMNETIC AERATION ON THE FISHERIES HABITAT OF ST. MARY LAKE, B.C.

WORK TERM REPORT
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ABSTRACT

The effects of hypolimnetic aeration on the fisheries habitat of St. Mary Lake were investigated. The lake experienced poor water quality which was caused by excessive internal phosphorus loading. The parameters considered were dissolved oxygen, water temperature, Secchi transparencies, and zooplankton communities. The quality of the sport fishery was also investigated.

Hypolimnetic oxygen concentrations increased after the aeration project began and anoxic conditions (< 10% saturation) were not seen after 1989. Hypolimnetic temperatures increased to a maximum of 17° C after aeration but remained well below the lethal limits for fish reported in the literature. Secchi transparency depths showed increases each year with a summer high of 5.5 m seen in June, 1990. Copepod (*Diaptomus oregonensis* adults and nauplii, Cyclopoida, and copepod nauplii) densities increased after aeration. The cladoceran *Diaphanosoma brachyurum* appeared in the zooplankton community after aeration and remained relatively stable, although increases in seasonal peaks were noted. Rotifers (*Keratella*) showed a general decreasing trend during the study period. Effects on the sport fishery are unclear. Some data indicated a decline in sport caught trout and bass of 43% and 44%, respectively, however many anglers reported no significant change in the trout fishery. It appeared that the introduction of steelhead trout (*Oncorhynchus mykiss*) may be related to changes in the spatial distribution or dietary habits of the

cutthroat trout (*O. clarki*). Other data suggested an increase in the mean size of cutthroat trout since aeration.

Based on these observations it was concluded that the fisheries habitat of St. Mary Lake has been enhanced through hypolimnetic aeration in three ways: increased dissolved oxygen concentrations, increased visibility, and increased densities of *Diaptomus oregonensis*, *Diaphanosoma brachyurum*, *Cyclops*, mysids, and copepod nauplii.

ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

Cultural eutrophication can have adverse effects on both the fisheries habitat and the overall water quality of a lake. One of the key characteristics is decreasing concentrations of dissolved oxygen (DO) in the bottom waters (hypolimnion) which reduces the amount of cold, oxygenated water available to salmonids. As these fish are forced up into the warmer, oxygenated strata of the lake (epilimnion), their metabolic rate increases and, without sufficient food supplies, both growth and survival rates are adversely affected (Nordin *et al.*, 1983). Increasing water temperatures also decrease the solubility of oxygen and aquatic organisms faced with these conditions must satisfy elevated oxygen demands while oxygen availability is decreasing (Houstan, 1982). Fish in eutrophic lakes may therefore be restricted to a thin layer of water between the cooler, oxygen deficient hypolimnion and the warmer epilimnion; this may eventually lead to mortalities (Larkin and Northcote, 1969).

St. Mary Lake is a productive, coastal lake which began showing signs of decreasing water quality in the early 1970's. The limiting nutrient was determined to be phosphorus with internal P loading as the major input source (Nordin *et al.*, 1983). A secondary nutrient source was determined to be runoff from areas of development within the watershed. St. Mary Lake has a long water residence time (4-6 years) because of low rainfall and a small watershed size to lake surface area ratio (Nordin *et al.*, 1983). Nutrient inputs from runoff accumulate in the sediments and can cause increased algal growth.

As the algae die off, sink, and decompose in the bottom waters, hypolimnetic DO is consumed. In the reducing conditions of an anoxic lower hypolimnion, P is released from the sediments and becomes biologically available to the phytoplankton causing further algal growth. Eventually the majority of the hypolimnion becomes oxygen depleted until the fall turnover exposes these waters to the atmosphere.

The first step in managing excess eutrophication is to identify the major sources of nutrient input. Once this is accomplished a suitable management strategy can be employed. In order to restore St. Mary Lake to a more natural condition, a hypolimnetic aerator was installed in 1985 and full operation began in 1987. Hypolimnetic aeration was designed to reduce internal P loading by oxygenating the hypolimnion which prevents the dissociation of P from the bottom sediments (Ashley, 1983). At the same time hypolimnetic aeration also creates a more suitable, oxygenated habitat for salmonids in the cooler hypolimnion without disrupting the thermocline (Nordin and McKean, 1982).

The purpose of this report is to examine the effects of hypolimnetic aeration on certain water quality parameters in St. Mary Lake and how they affect the fisheries habitat of the lake. The parameters considered were DO, temperature, Secchi transparency, and zooplankton species composition and numbers. In addition, available fisheries data were collected to determine the impact of aeration on fish size.

2.0 STUDY AREA

2.1 Site Description

St. Mary Lake is located on Saltspring Island, approximately 52 km north of Victoria (Figure 1), in the Coastal Douglas-fir biogeoclimatic zone. The lake has a surface area of 1.82 km^2, a volume of approximately 14,700 cubic decametres (dam^3), and a watershed of 5.3 km^2 (excluding the surface area of the lake).

St. Mary Lake provides domestic water for local water works, resorts, and private residences and is the major source of drinking water for the northern portion of Saltspring Island. A number of resorts are located along the shores of St. Mary Lake and recreational activities include boating, swimming, and sport fishing. Ministry of Environment (MOE) fisheries staff began stocking the lake with cutthroat trout (*Oncorhynchus clarki*) in 1977 and steelhead trout (*O. mykiss*) in 1984. Smallmouth bass (*Micropterus dolomieui*) were introduced in the 1930's and a successful population has since been established. In 1987 MOE fisheries staff installed 40 tire-reefs in an effort to enhance smallmouth habitat in St. Mary Lake.

2.2 Aeration System

The hypolimnetic aeration system in St. Mary Lake is of the full lift type which transfers water from the hypolimnion to the surface then back down again. The system has two identical units (Figure 2) in the deepest portion of the lake located approximately 775 m from a compressor on the west shore (Figure 3). Compressed air is moved to

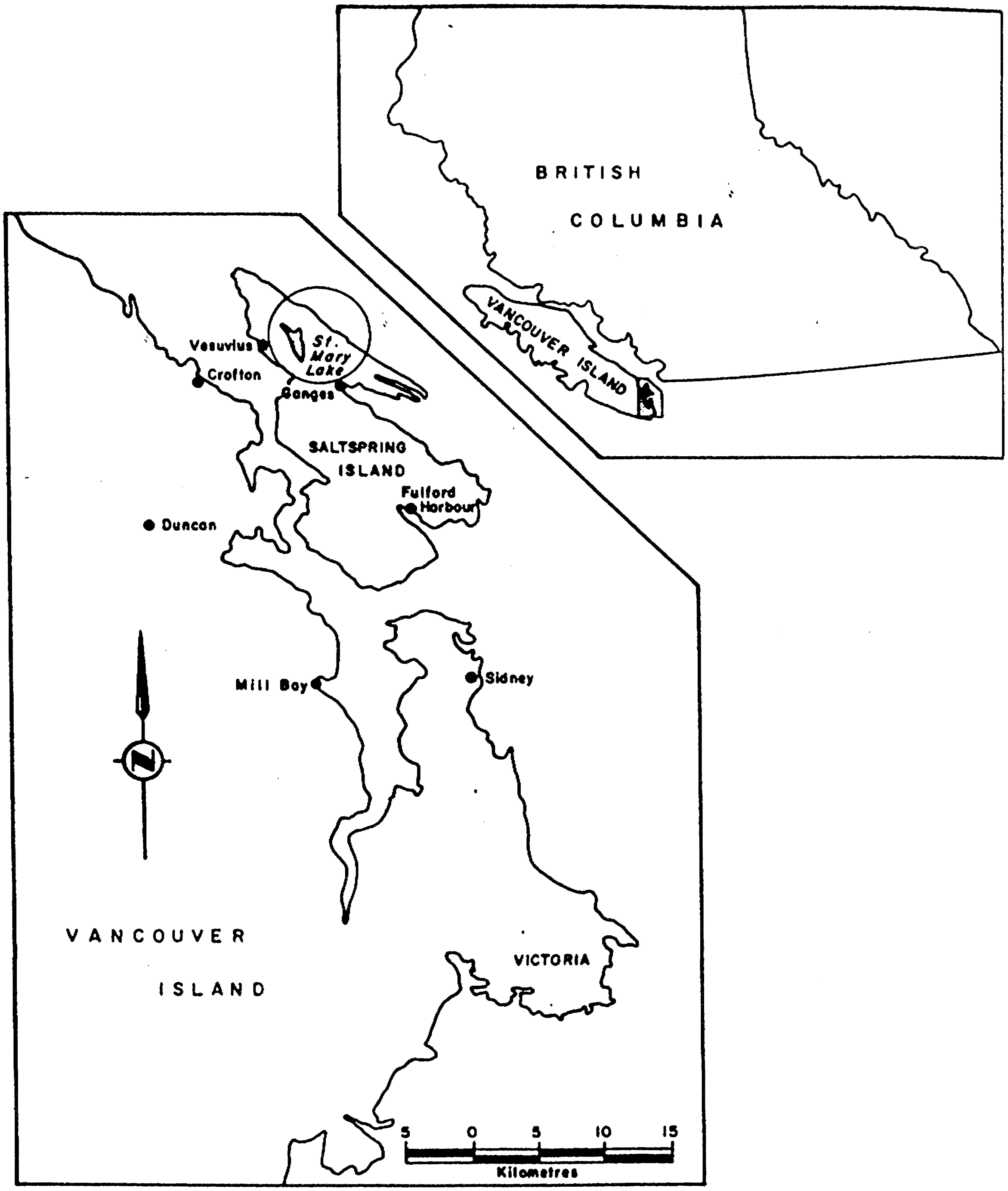
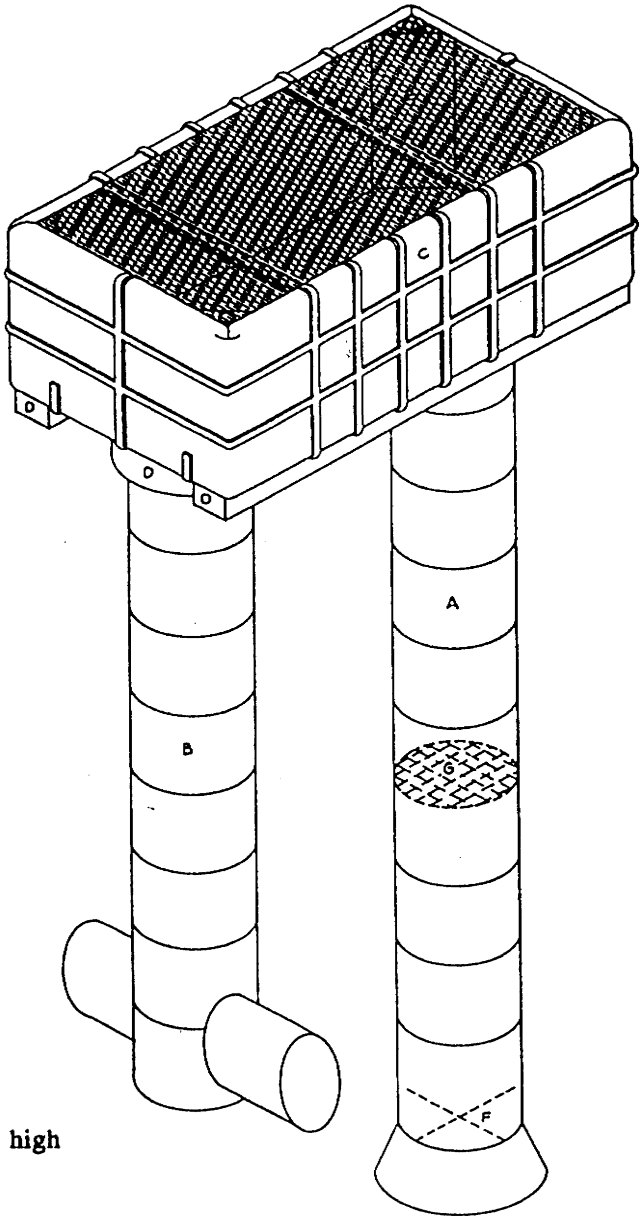


Figure 1: Location of St. Mary Lake (Nordin *et al.*, 1983)



A: Riser tube
    - length = 12 m
    - diameter = 1.5 m
B: Descending tube
    - length = 9 m
C: Separator box
    - 3 m wide x 5.8 m long x 2.1 m high
D: Foam floatation
E: Adjustable floatation
F: Diffuser
G: **Mixing plate**

Figure 2: Hypolimnetic aeration system used on St. Mary Lake (Ashley, 1988).

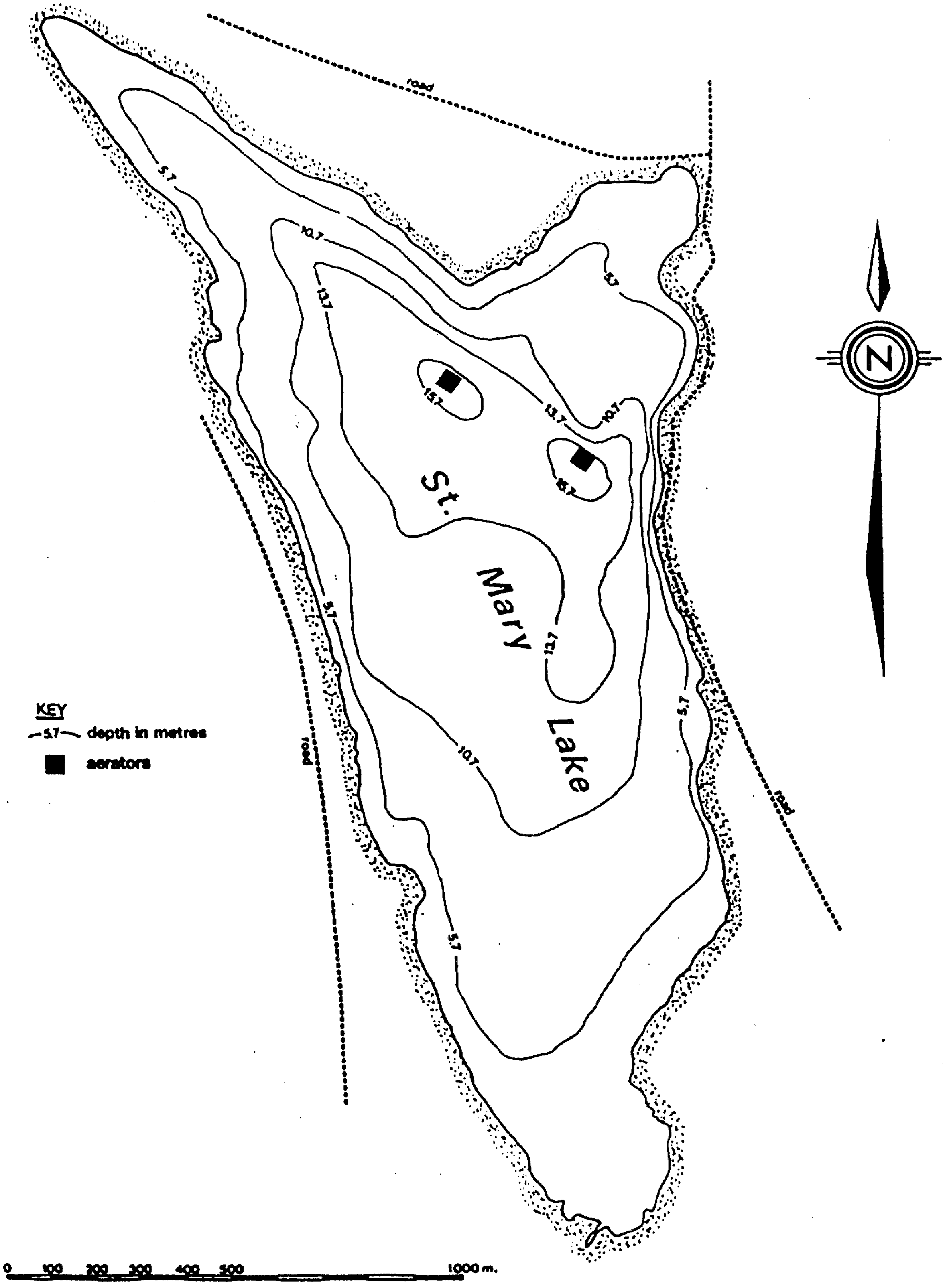


Figure 3: Location of aerators on St. Mary Lake (Halsey and Abbott, 1988).

the aeration units through a polyethylene line which splits and connects to each unit. The air is passed into the riser tube through a diffuser with a pore size of 140 µm. The small pore size provides small air bubbles which allow for more efficient oxygen transfer into the water inside the riser tube (Ashley and Hall, 1990). As the air bubbles ascend the riser tube an air-lift pump is created which generates a large volume - low velocity water flow (Ashley, 1983). When the oxygenated hypolimnetic water reaches the separator box, excess air escapes from the water to the air space inside the separator box. The separator box also acts as a floatation device which maintains the riser and descending tubes in a vertical position. The water inside the separator box rises slightly above the level of the lake and this creates a pressure which moves the water back to the hypolimnion through the descending tube. The descending tube has a split deflector at the bottom end to provide a wider distribution of oxygenated water and prevent the disturbance of bottom sediments. The system was generally in operation from mid-April to early October which coincides with the period of stratification.

3.0 METHODS

Dissolved oxygen and temperature readings for St. Mary Lake (site no. 1100104) were taken using a Yellow Springs Instruments (YSI) temperature-oxygen meter. From 1974 to 1978 readings were taken periodically in response to public complaints of deteriorating water quality. In 1979 MOE water quality staff began investigations to determine the cause of decreasing water quality and DO/temperature readings were taken monthly through the summers of 1979 and 1980, and monthly throughout 1981. In 1984 and 1985 readings were taken periodically throughout the summer. Readings were taken on a monthly basis starting in 1986 to assess the impact of the aeration units. Data were collected by MOE staff from 1986 to 1991; data were also collected by a private consulting firm in 1986 and 1987 as part of a creel census being conducted on the lake. These data were then used to construct depth-time diagrams to illustrate the annual trends in DO and temperature. A minimum of four consecutive months of data were required to construct time-depth diagrams for any given year.

Secchi depths, a measure of water transparency, were taken at the time of sampling and these data were graphed as a function of time. Zooplankton samples were collected using a vertical haul with a Wisconsin net (20 cm diameter opening) and preserved in formalin. Identifications were performed by the B.C. MOE Laboratory before 1989 and by Zenon Environmental Laboratories in Burnaby, B.C. after 1989. Dominant zooplankton groups were determined on the basis of numerical dominance and these were graphed as a function of time.

Fisheries data consisted of information submitted by individual anglers as well as data collected during MOE gill net capture efforts using sinking gill nets of variable mesh (1.9 cm - 11.4 cm). In many cases data collected included fish weight or length, but not both. Data which included both sets of information were used to construct log-log length/weight plots, by species (Appendix 2). These plots were used to estimate missing data points. Data were available for cutthroat trout in three time groups: 1952-1956, 1977-1979, and 1986-1988. Mean cutthroat weights and lengths for these periods were compared using a two sample *t*-test (Zar, 1984) at the 95% confidence level. Smallmouth bass and steelhead trout data were not graphed or tested statistically because of insufficient sample sizes. Qualitative information regarding the changes in the fisheries production of the lake before and after the installation of the aeration system was collected through telephone interviews with owners of various resorts on St. Mary Lake, as well as anglers who consistently fished the lake.

4.0 RESULTS

4.1 Hypolimnetic Dissolved Oxygen

The DO concentrations (% saturation) in St. Mary Lake are illustrated as time-depth diagrams in Figures 4a to 4d. Anoxic conditions (< 10% saturation) were seen in each year sampled from 1974 to 1985. The most extensive period of oxygen depletion was in August and September of 1981 when DO concentrations below 10% saturation were found from a depth of four metres to the bottom. In 1986, the hypolimnion remained oxygenated throughout the year with DO concentrations at a minimum of 40% in August and September at a depth of 13 m. In 1987 anoxic conditions occurred from mid August to the end of September in waters deeper than seven metres. In 1988, anoxic conditions only occurred for a brief period in June in waters deeper than 15 m. The hypolimnion of St. Mary Lake did not become anoxic in 1989, 1990, or 1991. Lowest DO concentrations for these years were 22% (Aug., '89), 33% (July, '90), and 18% (June, '91), all at a depth of 14 m.

4.2 Water Temperature

Water temperatures measured throughout the water column of St. Mary Lake are illustrated as time-depth diagrams in Figures 5a to 5d. Annual patterns in temperature distribution may vary greatly from year to year and are affected by sunlight, winds, and heat inputs from precipitation and runoff (Wetzel, 1983). Generally, St. Mary Lake becomes stratified in April due to thermally induced density differences between the warm, upper waters (epilimnion)

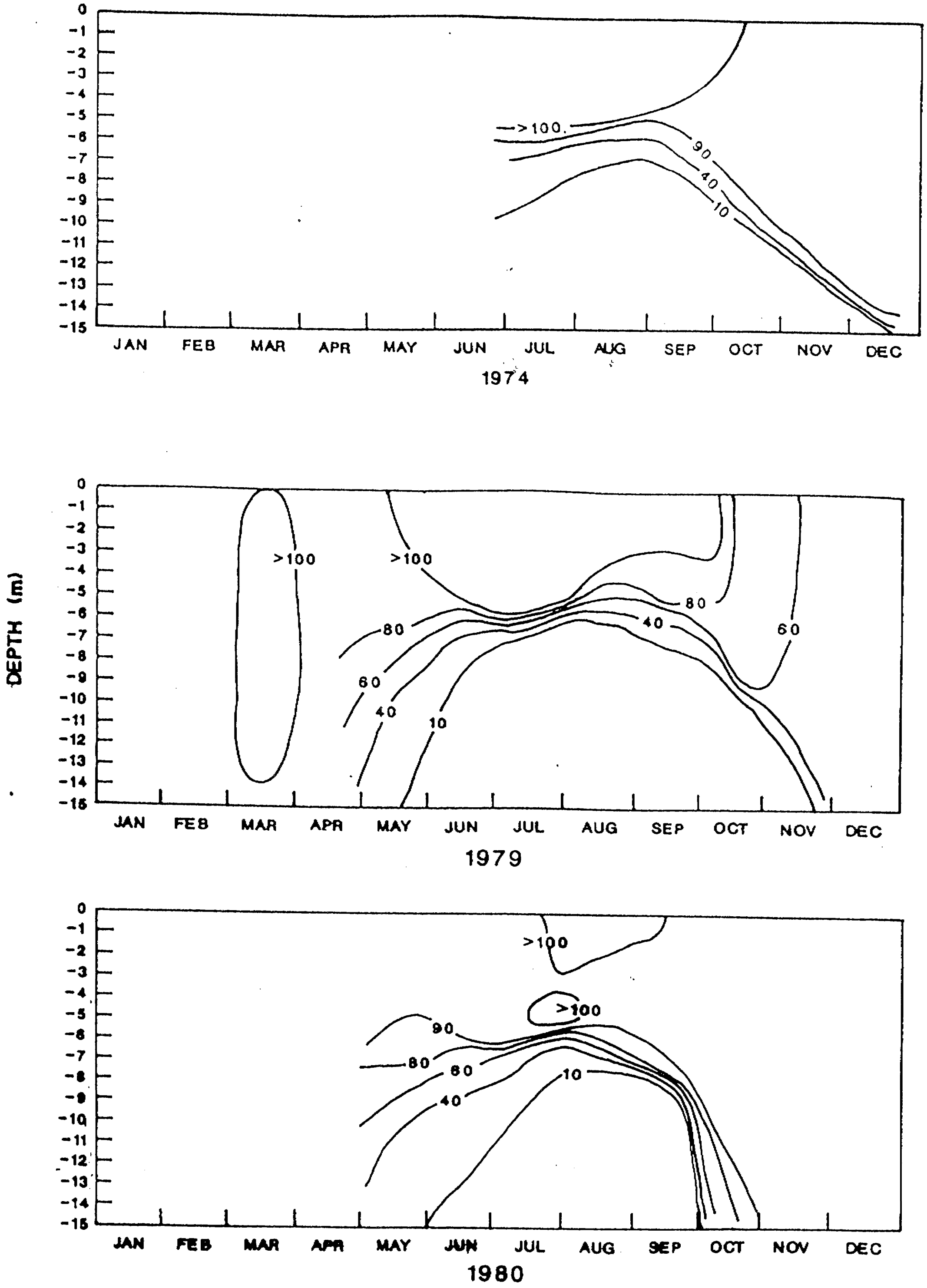


Figure 4a: DO concentrations (% saturation) in St. Mary Lake: 1974, 1979, 1980.

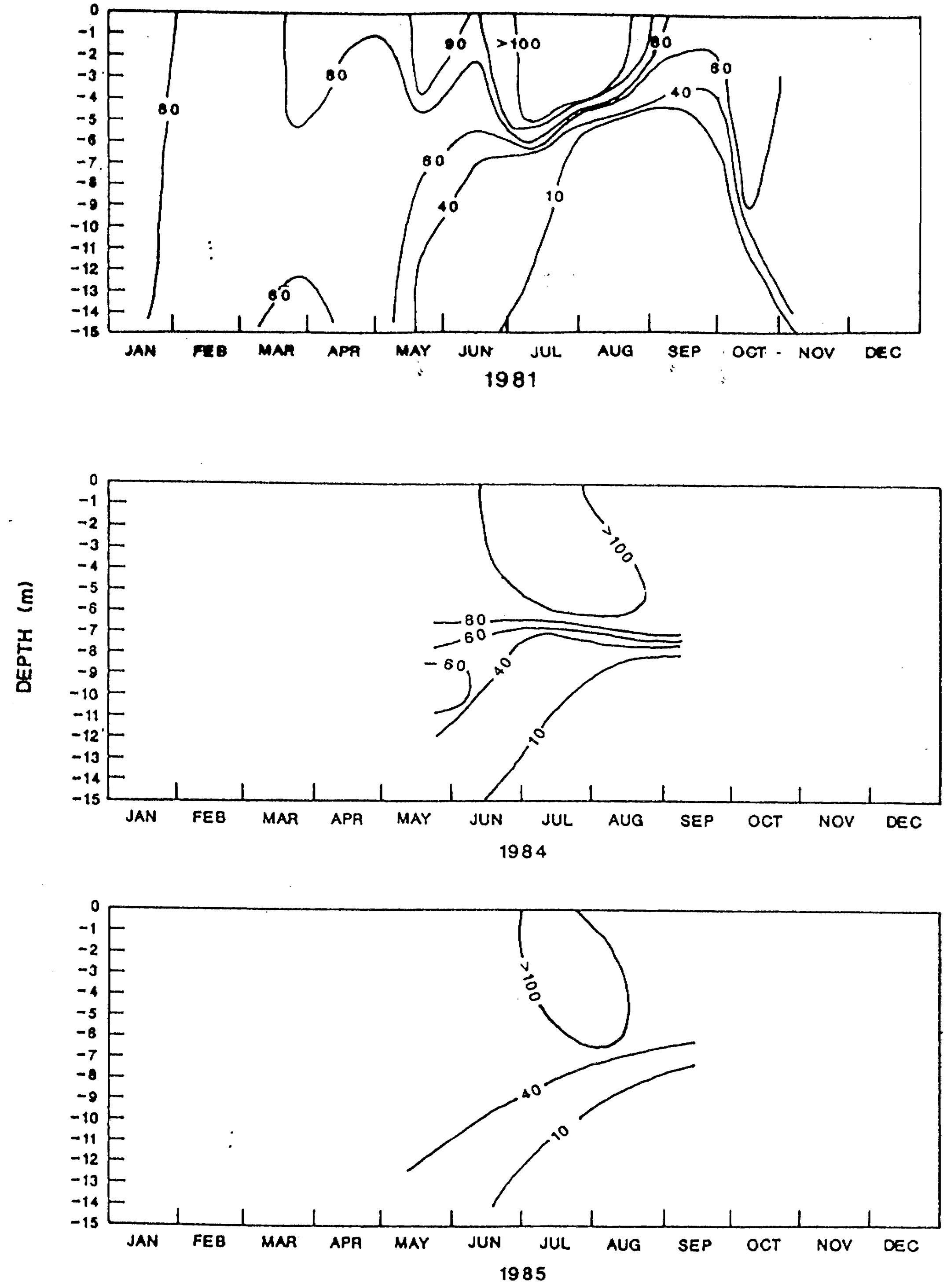


Figure 4b: DO concentrations (% saturation) in St. Mary Lake: 1981, 1984, 1985.

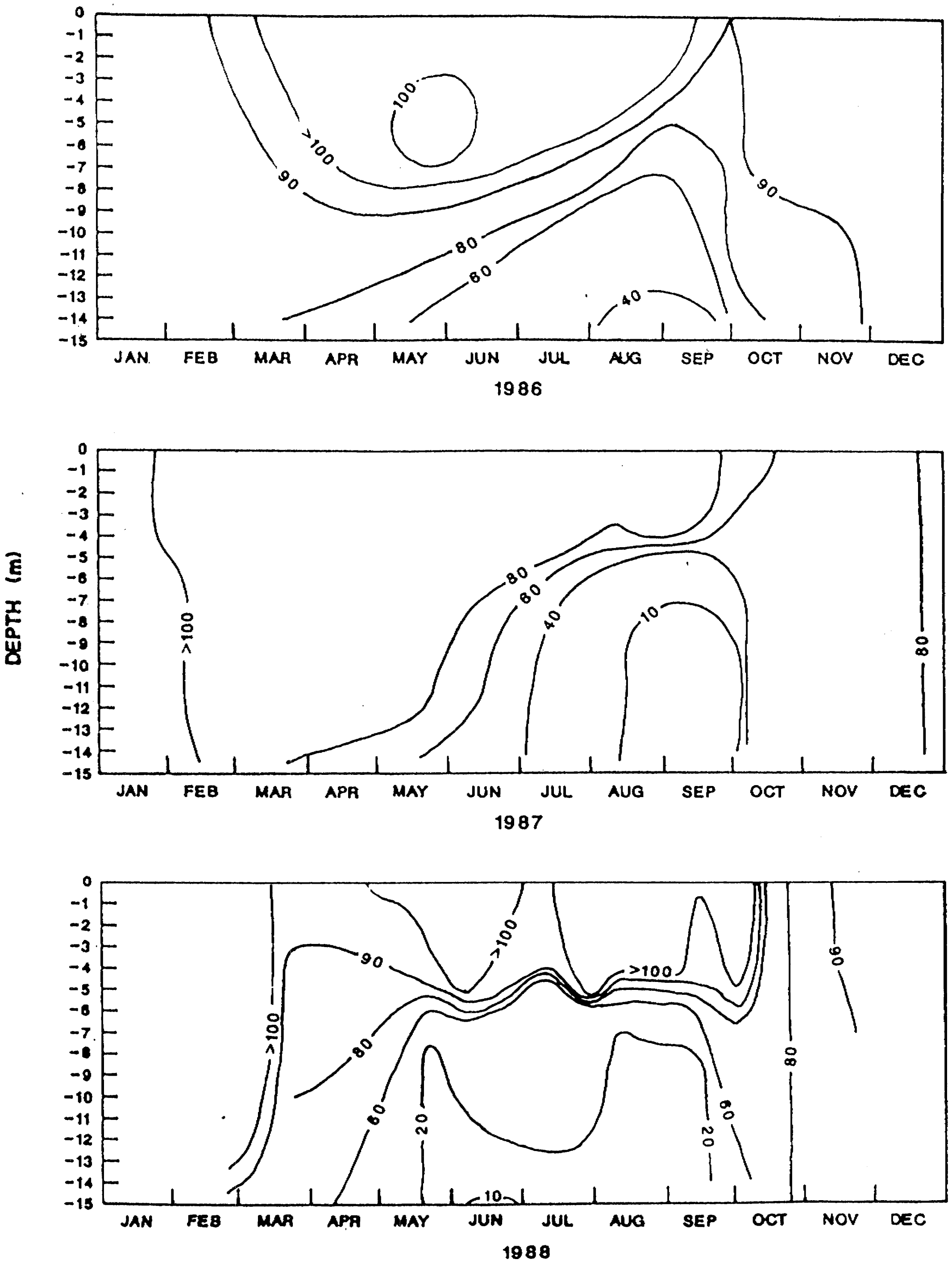


Figure 4c: DO concentrations (% saturation) in St. Mary Lake: 1986, 1987, 1988.

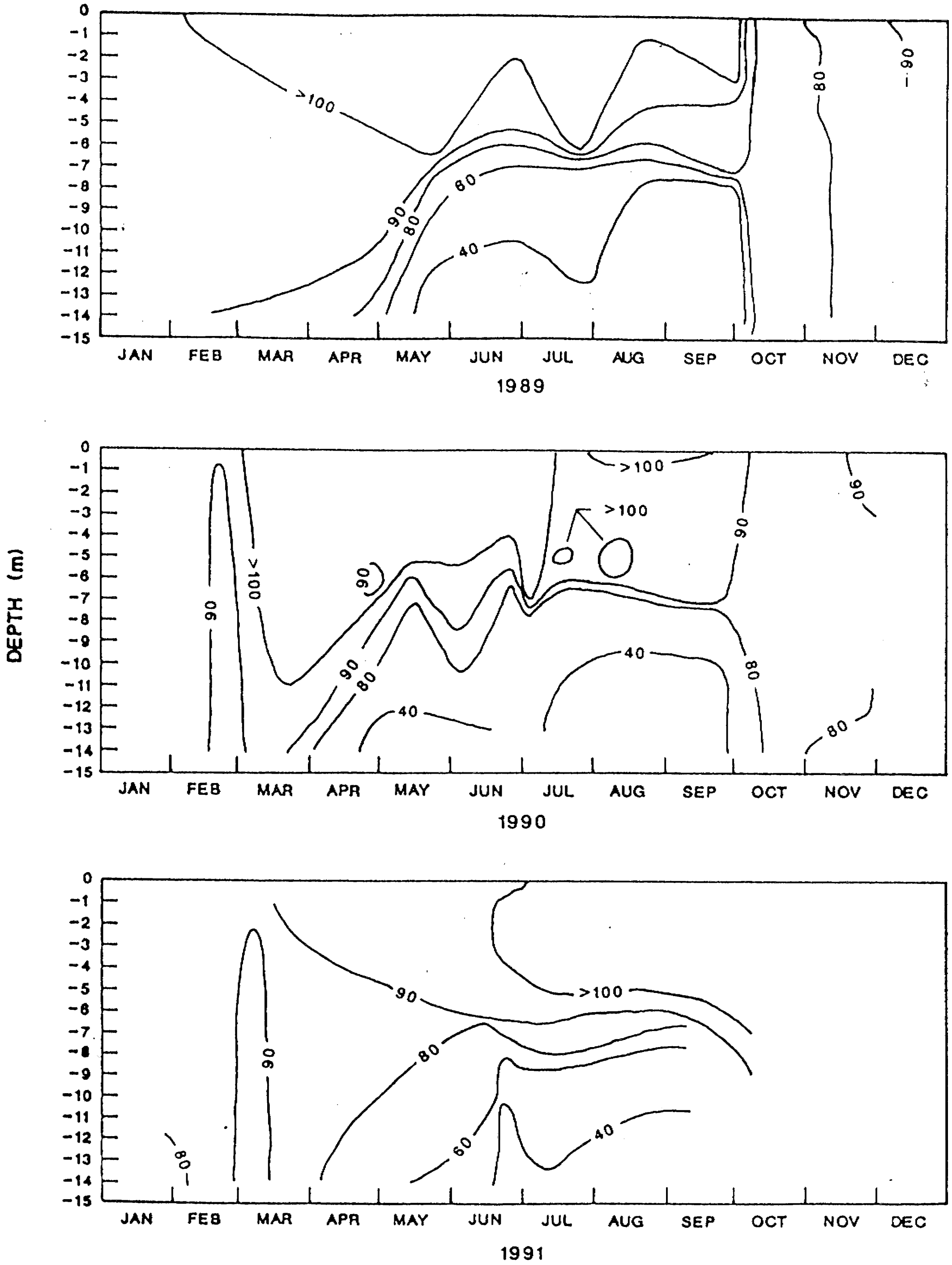


Figure 4d: DO concentrations (% saturation) in St. Mary Lake: 1989, 1990, 1991.

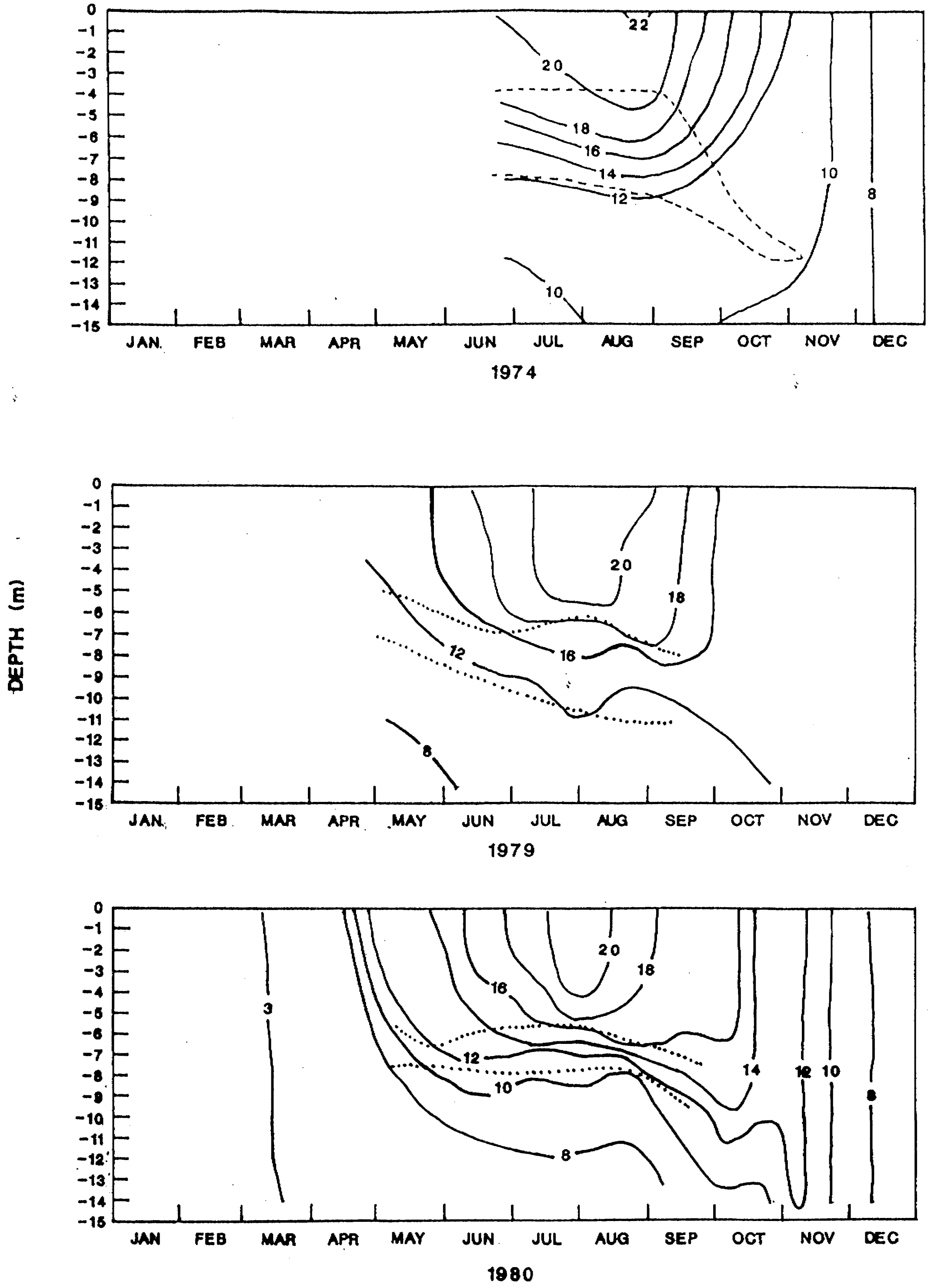


Figure 5a: Water temperatures in St. Mary Lake: 1974, 1979, 1980. The thermocline is denoted with a broken line.

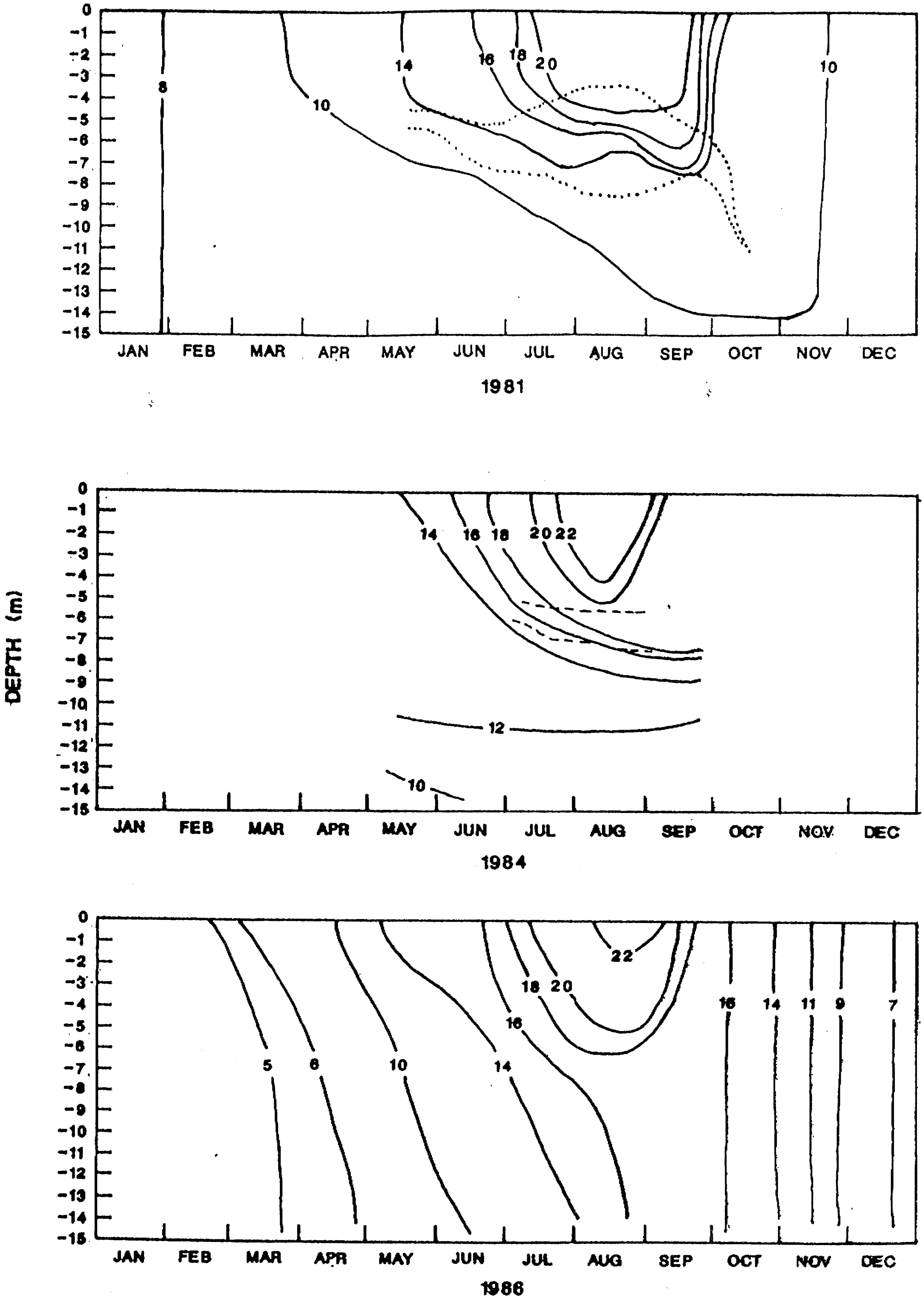


Figure 5b: Water temperatures in St. Mary Lake: 1981, 1984, 1986. The thermocline is denoted with a broken line.

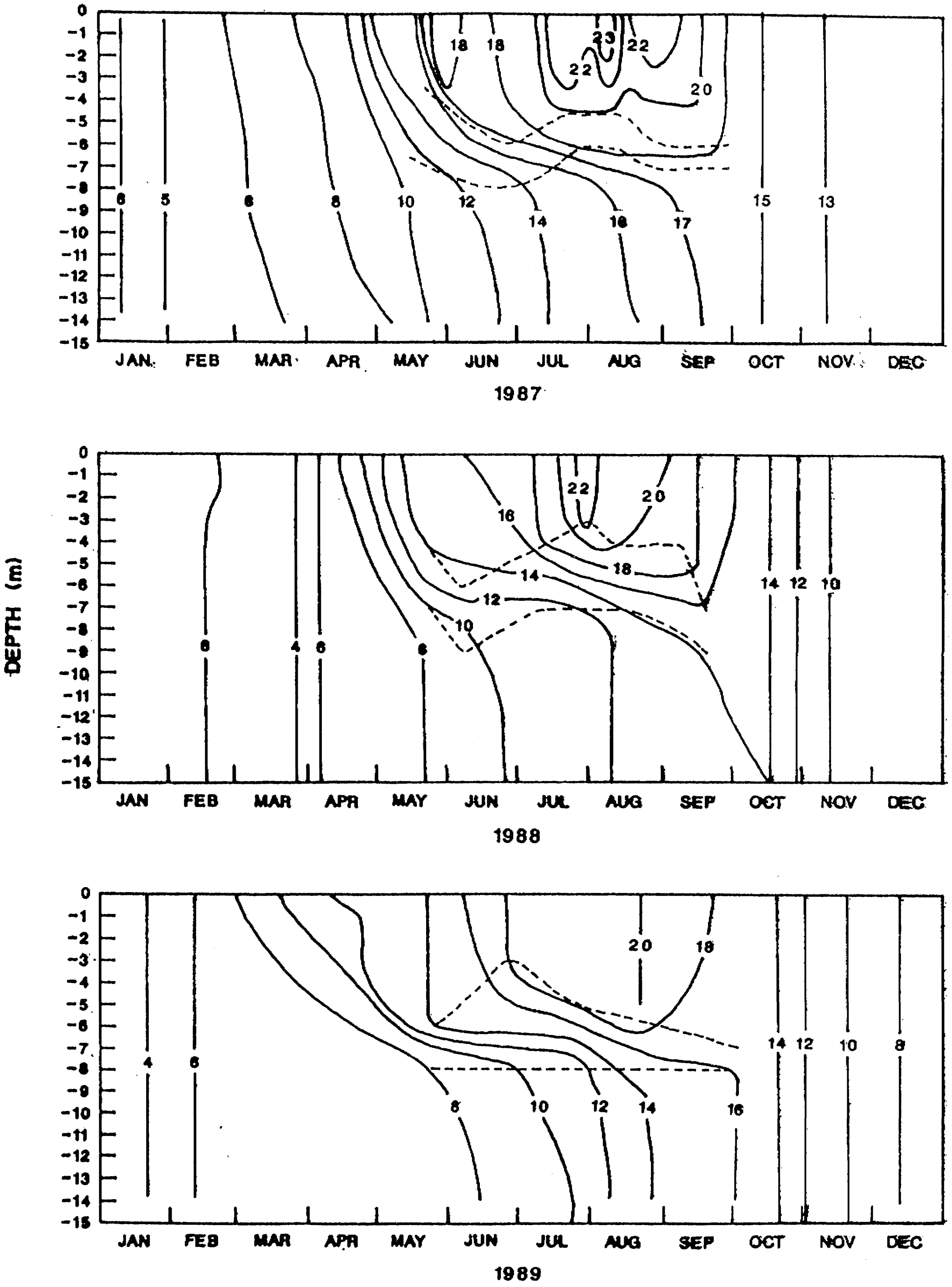


Figure 5c: Water temperatures in St. Mary Lake: 1987, 1988, 1989. The thermocline is denoted with a broken line.

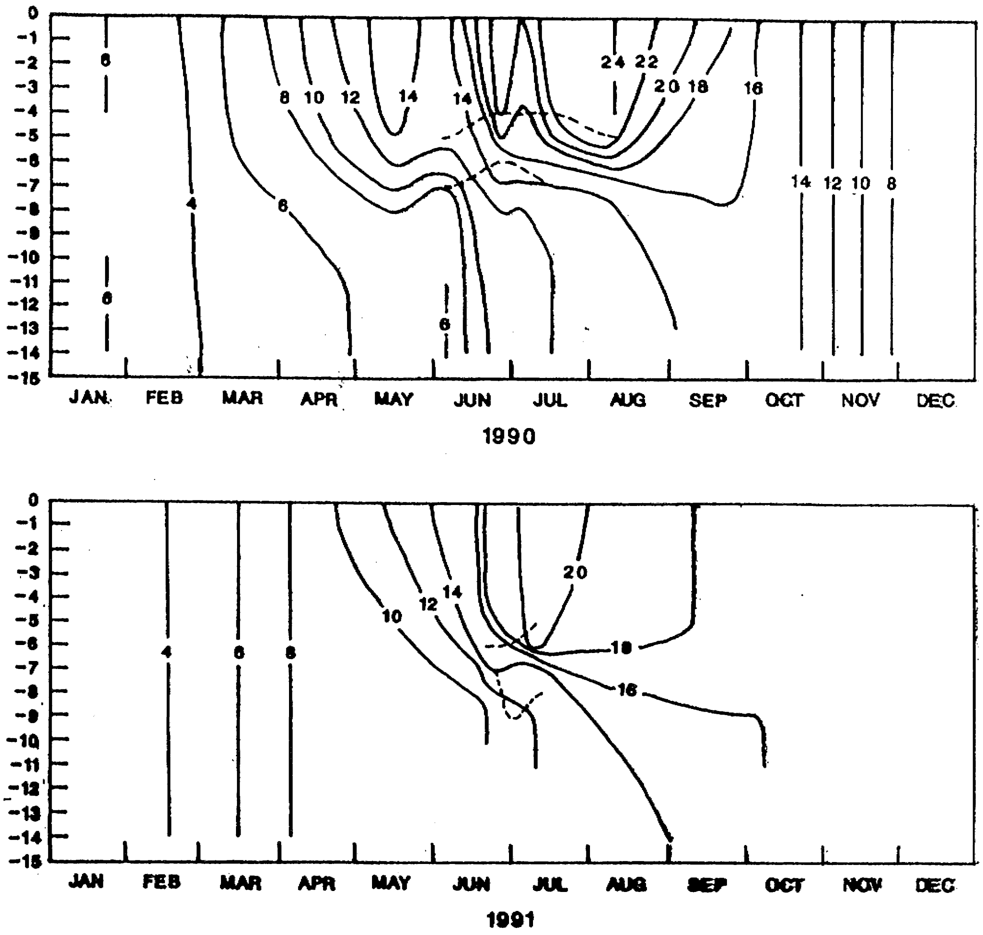


Figure 5d: Water temperatures in St. Mary Lake: 1990, 1991. The thermocline is denoted with a broken line.

and the cooler hypolimnion (Nordin *et al.*, 1983). These two layers are separated by the thermocline which is a plane of maximum temperature decrease. The upper limits of the thermocline ranged from three to six metres in May and decreased to six to eight metres in September. The lower limits ranged from five to eight metres in May and decreased to as deep as 11 m in September.

Overall hypolimnetic temperature appeared to warm after aeration. Hypolimnetic waters showed vertical isotherms under the thermocline indicating that the stratification within the hypolimnion before aeration was no longer occurring. This was likely caused by the cool hypolimnetic waters becoming exposed to the atmosphere during the aeration process, warmed, and passed back into the hypolimnion. As the temperature gradient decreases throughout the water column the difference in densities between the epilimnion and hypolimnion also decreases. It is the difference in densities between cool and warm waters, the cooler water being more dense, which causes a lake to stratify. As a result of the decreased temperature gradient the two layers are mixed more readily by wind and wave action and the stratification of the lake is not as stable as it was before aeration. The heat budget of the lake, that is, the amount of energy stored in the lake over an annual period, is also increased.

In 1986 the lake was destratified for most of the year. This was the result of testing the aeration system until the proper flow of water to maintain stratification was achieved which resulted in a constant mixing of the water column. The lower hypolimnion (14 m) temperature was much higher than that of past years reaching a maximum of 16° C in October.

4.3 Secchi Depth

The Secchi depths for June, July, and August (1972-1990) are illustrated in Figure 6. These data show an increasing trend in Secchi depths during summer stratification over this period of time. Secchi depths as a function of time are illustrated in Figures 7a to 7c. Secchi depths decrease to minimum values of 0.4 m in May and June of 1980. The highest values were seen in 1986 and this was likely due to the destratification of the lake as described in Section 4.2. Secchi

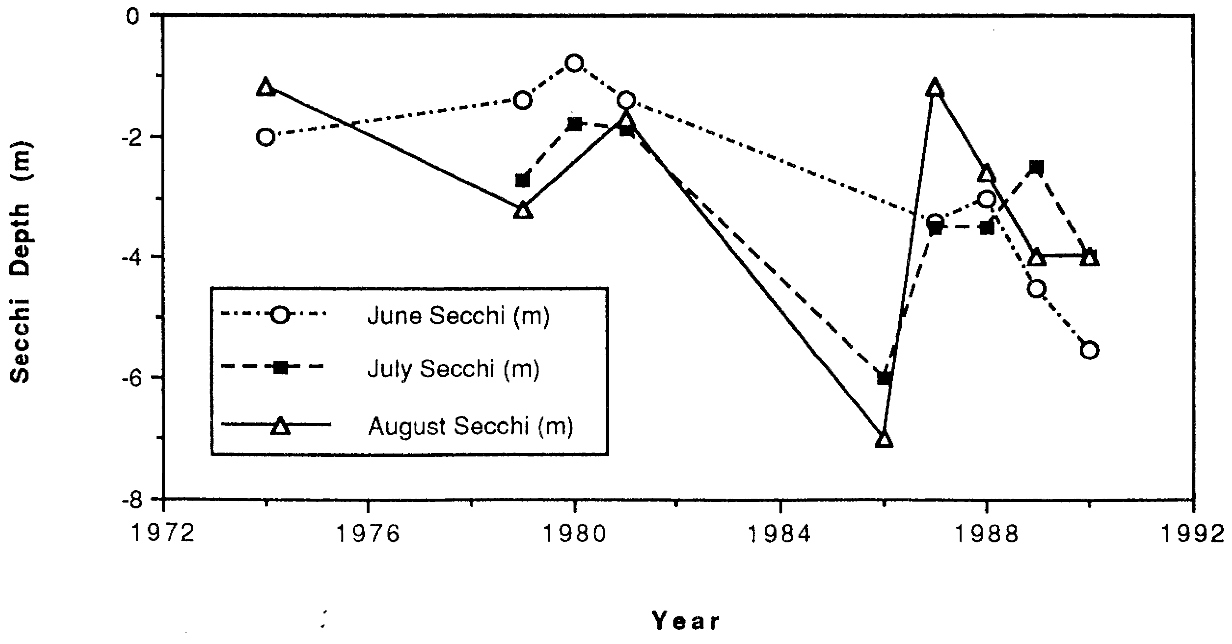


Figure 6: Summer Secchi depths for St. Mary Lake (1974 - 1990).

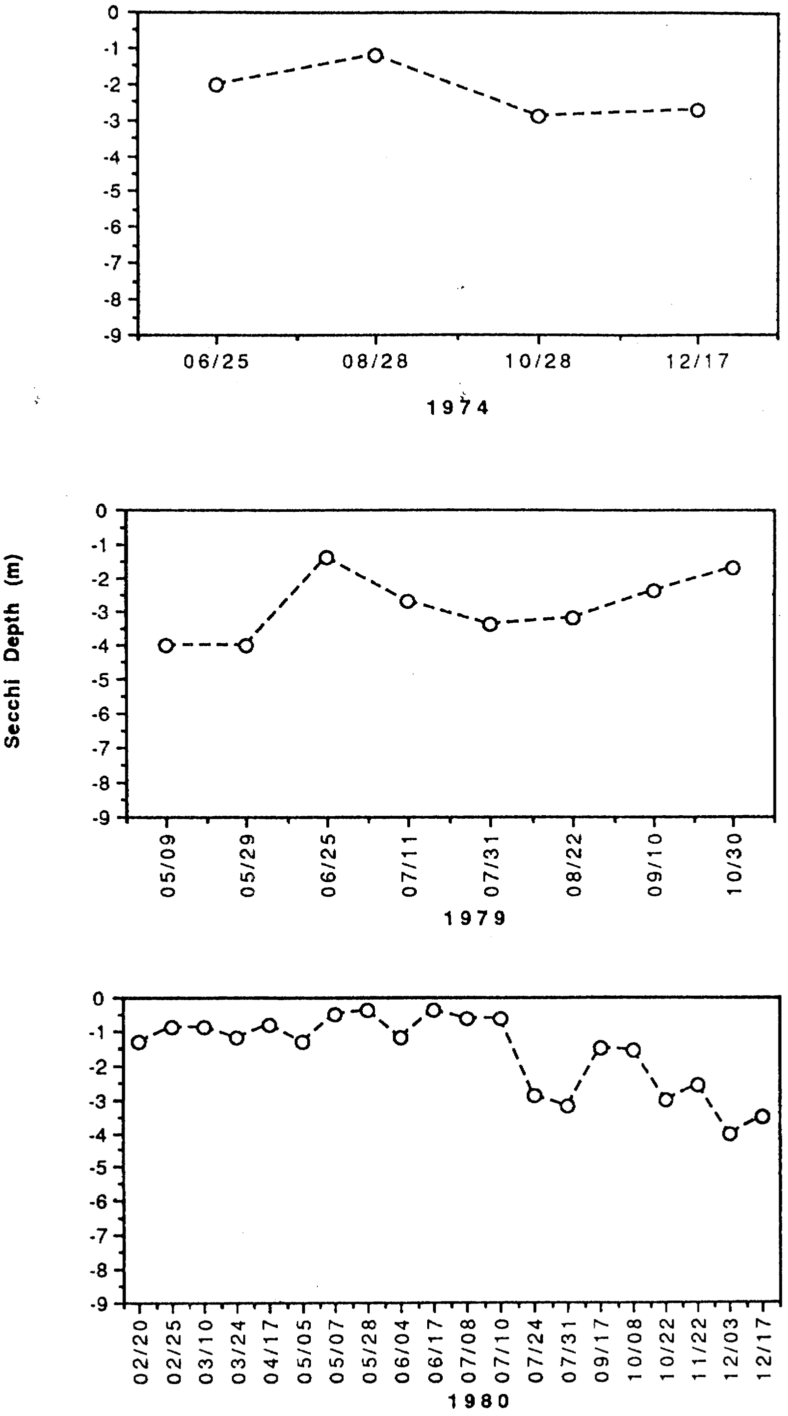


Figure 7a: Annual trends in Secchi depth in St. Mary Lake: 1974, 1979, 1980.

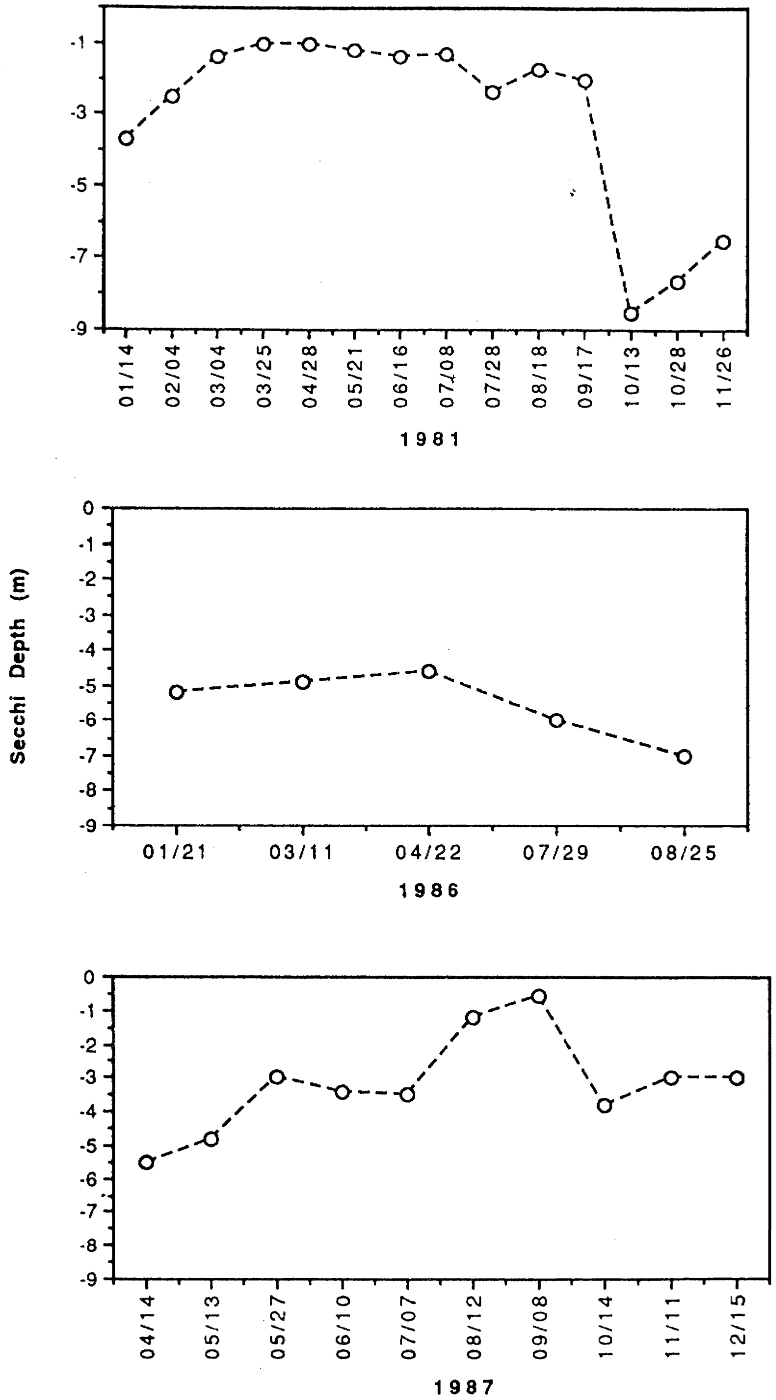


Figure 7b: Annual trends in Secchi depth in St. Mary Lake: 1981, 1986, 1987

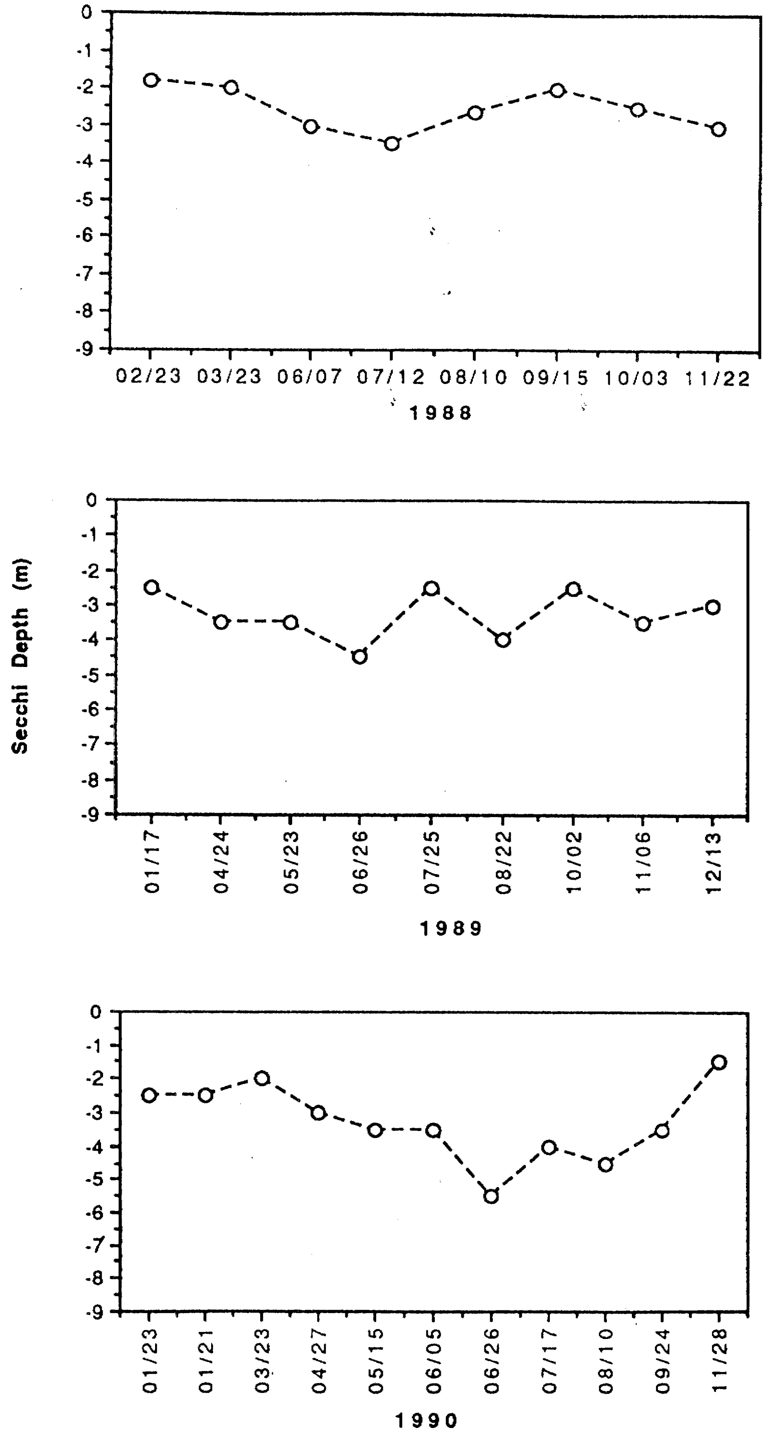


Figure 7c: Annual trends in Secchi depth in St. Mary Lake: 1988, 1989, 1990.

depths decreased to less than one metre in September of 1987, probably as the result of algal blooms due to an increase in available nutrients with the fall overturn. Excluding 1986 results, a maximum summer Secchi depth of 5.5 m was seen in June, 1990.

4.4 Zooplankton

The data collected in 1979/80 and 1987-1991 show the zooplankton community to be dominated by six groups of zooplankton. These included the calanoid *Diaptomus oregonensis* (adult and copepodite stages), copepod nauplii, copepod adults (Cyclopoida), mysids, the cladoceran *Diaphanosoma brachyurum*, and the rotifer *Keratella*. Total numbers captured for these groups are illustrated in Figures 8 to 13. *Diaptomus oregonensis* appeared to be present in low numbers in 1979/80; sample totals were considerably higher in the samples taken from 1987-1991. The same trend was also seen in data for *Cyclops* and copepod nauplii. Mysids were virtually nonexistent in 1979/80 with only one animal captured in eight samples taken. The 1987-1991 data showed a much higher abundance of mysids in St. Mary Lake with a high of 158 animals captured in April, 1990. *Diaphanosoma brachyurum* were not found in the 1979/80 samples but were abundant in the 1987-1991 samples. These data showed similar annual trends throughout this period with the highest densities found in July, 1988 (42,600 animals/sample) and June, 1989 (52,280 animals/sample). *Keratella* numbers were similar for both sample periods, with the majority of samples showing totals of less than 5,000 animals.

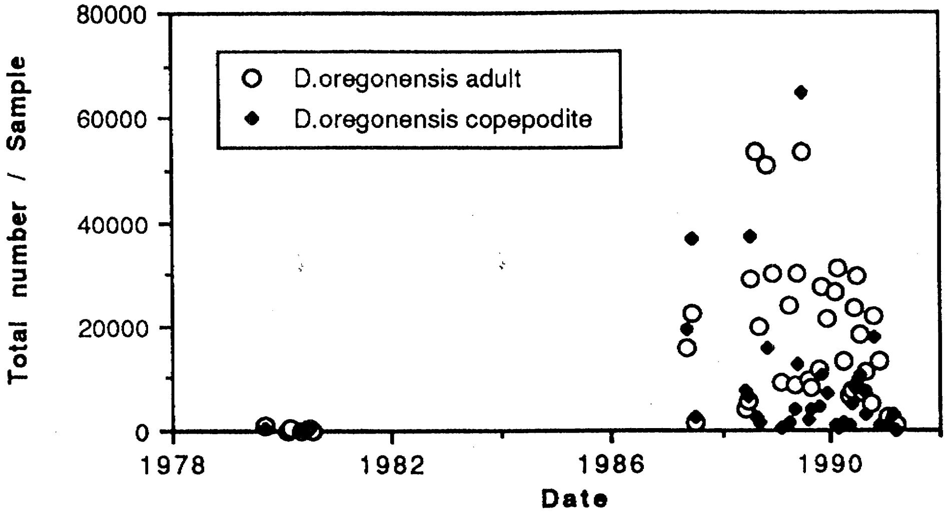


Figure 8: Total numbers of *Diaptomus oregonensis* adults and copepodites sampled from St. Mary Lake (1979-1991).

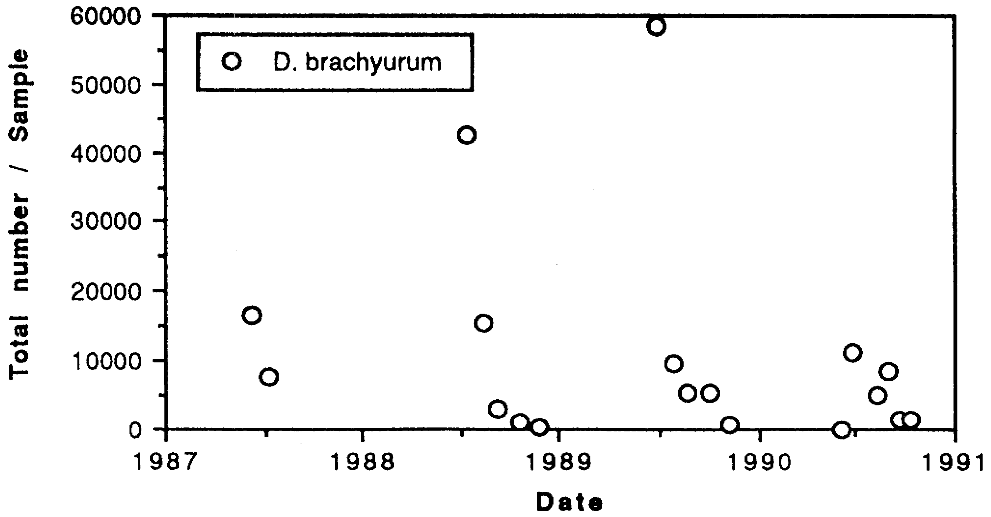


Figure 9: Total numbers of *Diaphanosoma brachyurum* sampled from St. Mary Lake (1987-1991).

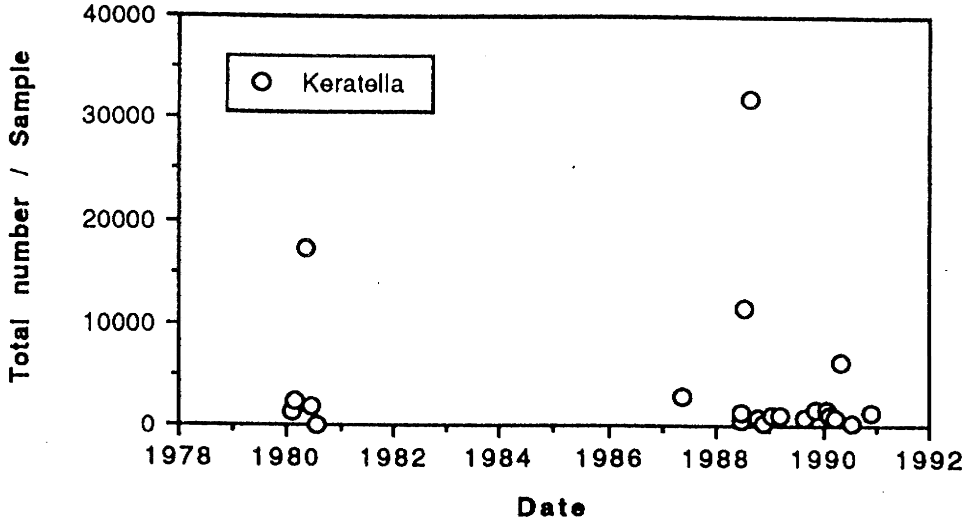


Figure 10: Total numbers of *Keratella* sampled from St. Mary Lake (1979-1991).

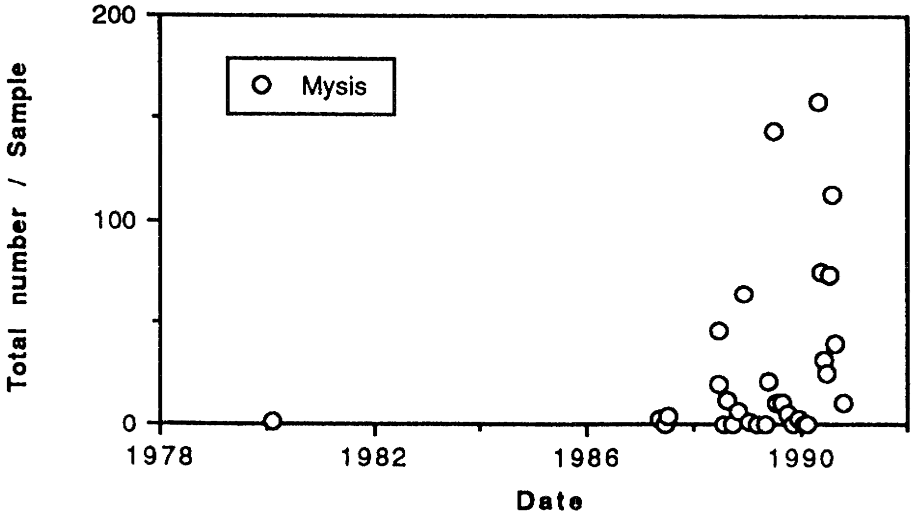


Figure 11: Total numbers of mysids sampled from St. Mary Lake (1979-1991).

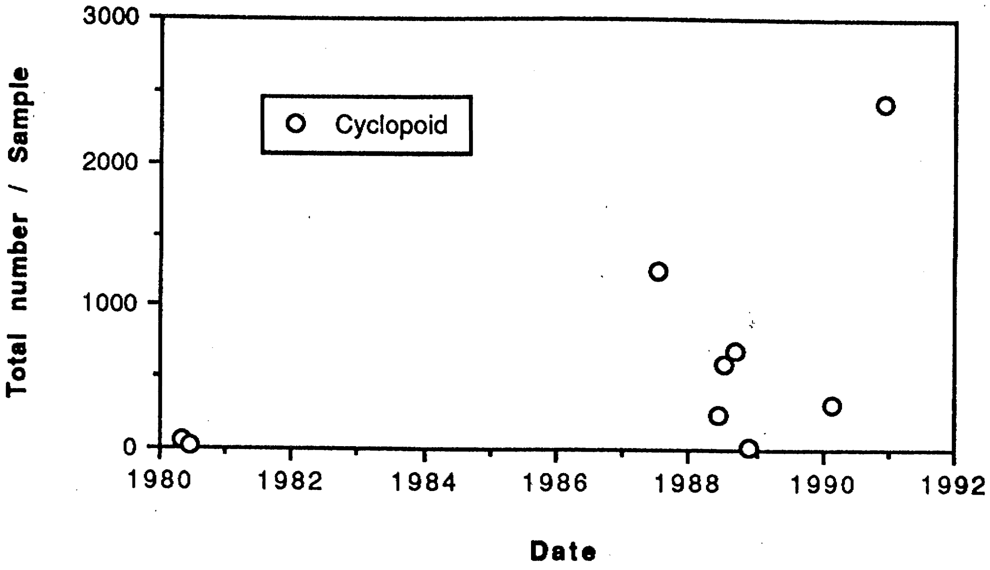


Figure 12: Total numbers of Cyclopoid copepods sampled from St. Mary Lake (1979-1991).

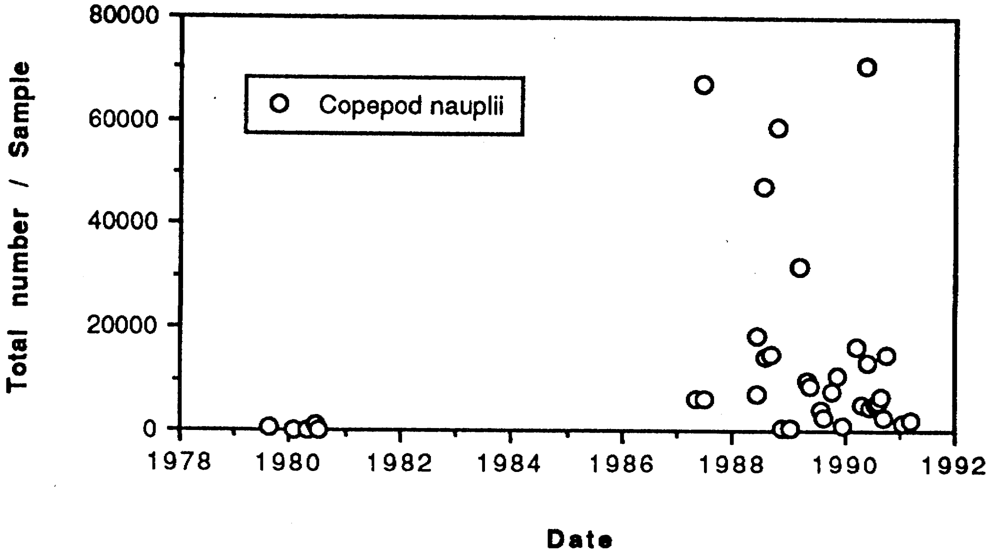


Figure 13: Total numbers of copepod nauplii sampled from St. Mary Lake (1979-1991).

Halsey and Abbott (1988) found the predominant prey items for trout to be *Daphnia pulex* and *Neomysis mercedis*, and noted that steelhead were more likely to select planktonic prey items while cutthroat trout were more likely to select larger items such as threespine stickleback (*Gasteroseus aculeatus*) or dragonfly larvae (*Zygoptera* spp.). *Daphnia pulex* were the dominant prey item in steelhead during the winter months of 1986/87 and *N. mercedis* were the dominant prey item during the summer months of 1987.

4.5 Fisheries

The available data for the weights and lengths of fish captured in St. Mary Lake are summarized in Tables 1 and 2, respectively. Mean cutthroat trout weights and lengths as a function of time are illustrated in Figures 14 and 15, respectively. Cutthroat trout weights and lengths appeared to decrease from 1952 to low values of 73 g and 18.9 cm in 1977. After this time lengths and weights showed a generally increasing trend which peaked in 1986 at 915 g and 43.8 cm. The mean weights and lengths of cutthroat trout captured during 1952-1955 were significantly larger than the means of those fish captured from 1977-1979 ($P \leq 0.005$). The mean weights and lengths of cutthroat trout captured from 1986-1988 were also significantly larger than those captured from 1977-1979 ($P \leq 0.005$).

Incomplete smallmouth bass data may have resulted from capture efforts concentrating on the open, epilimnetic areas of the lake preferred by salmonids, rather than the deeper, protected areas

Table 1: Mean weights (g) for fish angled and netted in St. Mary Lake (1952-1988).

Date	Species	n	Mean Weight (g)	Standard Deviation	Maximum (g)	Minimum (g)
52/08	Ct	7	1276	267	1472	707
	Bass	27	353	348	1133	3
55/06	Ct	7	1071	560	1800	200
55/07	Ct	2	1300	420	1600	1000
55/08	Ct	26	740	390	1400	200
55/09	Ct	83	840	520	3600	200
55/10	Ct	99	760	370	1800	300
55/11	Ct	9	780	320	1400	500
56/04	Ct	12	680	310	1400	300
77/07	Ct	5	73	14	92	57
	Rbt	1	862	0		
	Bass	29	422	261	1067	81
78/08	Ct	33	346	223	1063	161
	Bass	19	303	435	1358	4
79/08	Ct	9	128	58	240	66
	Bass	120	205	180	953	8
86/05	Ct	6	915	352	1221	400
	Rbt	10	667	176	920	440
87/06	Ct	13	502	224	783	62
	Rbt	12	624	434	1750	53
88/05	Ct	13	569	508	1425	100
	Rbt	6	107	33	150	65
	Bass	1	800	0		

favoured by bass. Steelhead were not stocked in St. Mary Lake until 1984 and this may be one reason for insufficient data for this species.

The results of catch efforts must be used with caution because the methods of capture were not standardized. Capture methods (angling or gillnet), net mesh size, set time and length, set location, and angling effort and expertise are all variables which may affect the results of capture efforts.

Table 2: Mean lengths (cm) for fish angled and netted in St. Mary Lake (1952-1988).

Date	Species	n	Mean Length (cm)	Standard Deviation	Maximum (cm)	Minimum (cm)
52/08	Ct	7	46.4	4.0	50.5	39
	Bass	27	24.0	11.7	42.0	7.0
55/06	Ct	7	44.7	9.6	55.3	26.6
55/07	Ct	2	49.4	5.4	53.2	45.5
55/08	Ct	26	39.4	8.0	50.9	26.6
55/09	Ct	82	41.5	7.9	69.7	26.6
55/10	Ct	98	40.6	6.4	55.3	26.6
55/11	Ct	9	41.1	5.5	50.9	36.1
56/04	Ct	12	39.3	5.5	50.9	30.4
77/07	Ct	5	18.9	1.2	20.5	17.5
	Rbt	1	43.0	0		
	Bass	29	29	6.0	41.0	17.5
78/08	Ct	33	30.9	5.5	46.4	24.7
	Bass	19	21.3	12	44.4	6.7
79/08	Ct	9	21.2	5.0	27.5	10.6
	Bass	120	21.2	7.8	39.5	8.1
86/05	Ct	6	43.8	6.2	49.0	35.5
	Rbt	10	38.1	3.4	42.5	34.0
87/06	Ct	13	35.9	8.7	46.0	18.0
	Rbt	12	41.2	11.4	61.5	17.1
88/05	Ct	13	29.8	13.2	51.0	16.3
	Rbt	6	19.3	1.6	22.0	17.5
	Bass	1	35.5	0		

Halsey and Abbott (1988) found that approximately half of the trout caught during their 1986/87 creel census were steelhead weighing up to two kilograms. They also found that catches for trout and bass were down from 1984 by 43% and 44%, respectively, despite a 19% increase in angler effort. Observations of resort owners ranged from reports of less trout of smaller sizes being caught to reports of good fishing with average sizes ranging from 0.9 kg to 2.3 kg. One report noted that the trout were now being located at greater depths than in the past. Bass fishing was always regarded as being good with

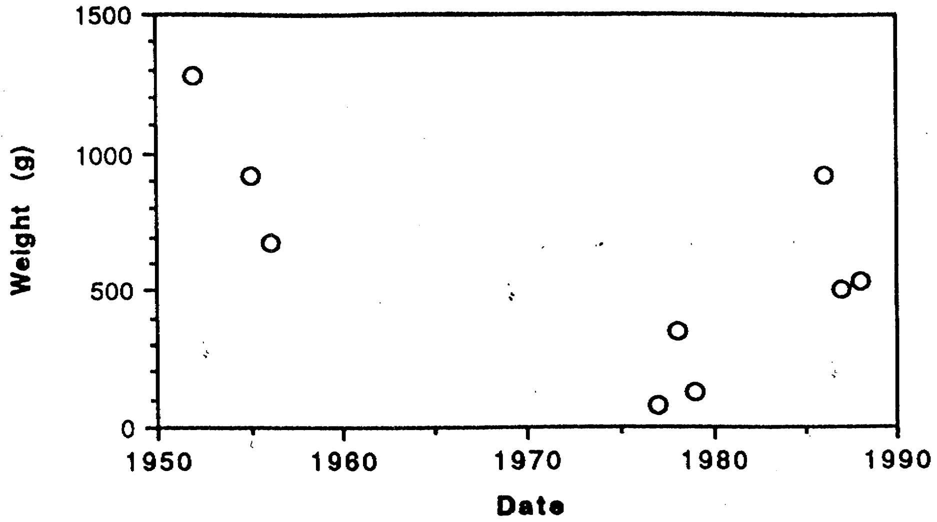


Figure 14: Mean cutthroat trout weights (g) for fish sampled from St. Mary Lake (1952-1988).

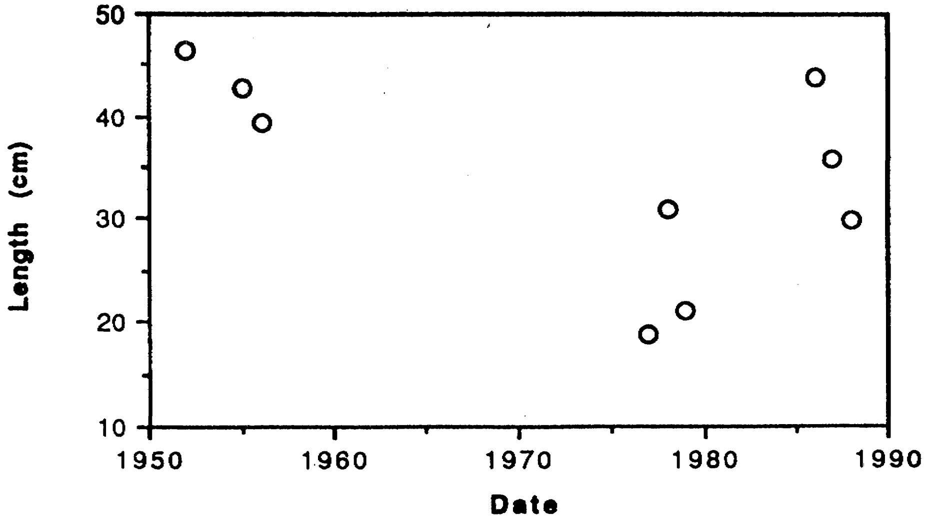


Figure 15: Mean cutthroat trout lengths (cm) for fish sampled from St. Mary Lake (1952-1988).

fish reaching 2.5 kg in weight. One local angler, who has consistently fished St. Mary Lake for the past 10 years, noted that the trout fishing had not changed noticeably since the aeration program had begun. His observations were that the trout were always healthy and stocky in appearance with average weights consistently in the 1.0 kg range. Members of a local fly fishing club, who have fished the lake since 1982, submitted their observations. According to these anglers St. Mary Lake possesses an excellent fishery with cutthroat trout historically averaging 0.9 kg to 1.4 kg. In the past five years, however, they have observed a steady decline in the frequency of cutthroat trout captures and an increase in steelhead captures; a cutthroat trout capture is now considered rare while steelhead weighing 2.3 kg are not uncommon. They noted that the stomach contents of those cutthroat trout and steelhead which were kept were identical consisting of chironomids, euphasids (probable misidentification), and bloodworms. They also noted that there had been no apparent changes in the chironomid hatches or in the size of caddis flies, damselflies, and dragonflies populations.

5.0 DISCUSSION

5.1 Hypolimnetic Dissolved Oxygen

The effects of low DO concentrations on freshwater fish, especially rainbow trout and largemouth bass (*Micropterus salmoides*), are well documented. Cutthroat trout and smallmouth bass data, however, are limited and for the purpose of this report it will be assumed that they show similar responses to varying concentrations of DO as rainbow trout and largemouth bass, respectively. At concentrations below 50% saturation rainbow trout have shown incomplete oxygen saturation of the blood (Irving *et al.*, 1941), reduction in heart rate (Randall and Smith, 1967), and reductions in maximum swimming speeds (Bushnell *et al.*, 1984; Jones, 1971). Dahlberg *et al.* (1968) found juvenile largemouth bass to show markedly reduced final swimming speeds at DO concentrations less than 62% saturation. Carlson and Siefert (1974) found depletions in DO to cause premature hatching of eggs, delayed time to first feeding, and reductions in growth of juvenile largemouth bass. Angling success in rainbow trout fisheries has also been shown to decrease with decreasing DO concentrations (Weithman and Haas, 1984).

Dissolved oxygen criteria developed by Davis (1975) states that optimum conditions for freshwater salmonids at 15° C and 20° C are 71% and 79% saturation, respectively. For non-salmonids the criteria is 60% saturation. These values allow for a high degree of safety for important fish stocks in prime areas. Using these criteria it can be shown that the amount of sufficiently aerated water in the water column of St. Mary Lake has been increased since the project started full operation in 1987. Examining the 80% saturation line in Figures 4a to 4d during late summer, a period when oxygen depletions can be expected, showed a gradual increase at the depth which it occurs, ranging from two to three metres in 1981 to seven metres in 1991. This observation suggests that the lake is now better suited for supporting salmonid species as well as the more tolerant non-salmonid species.

With an increase in the quality of habitat, one might expect an increase in angling success. This, however, was not the general consensus, based on interviews with resorts and anglers. It had been noted that angling success had remained constant throughout the period covered, and this may be due to a change in behavior of the fish since aeration. During summer stratification before aeration, salmonids may have moved into the warmer epilimnion to avoid the low DO conditions of the hypolimnion. Movement into warmer water would be associated with an increase in metabolism and, therefore, feeding. It is likely that the probability of catching a fish during this time would increase. When fish returned to the hypolimnion their feeding activity would decrease because of restrictions in the active metabolic rate caused by depressed DO concentrations (Fry, 1957) and lower water temperatures. With aeration of the hypolimnion an increase in metabolic rate may be expected, however because deeper waters are now more suitable for supporting aquatic life fish would be less likely to move into shallower waters and therefore less accessible to the average angler.

5.2 Water Temperature

The goal of hypolimnetic aeration is not to alter the temperature profile of a lake but to aerate the already cool hypolimnetic waters thereby enhancing fisheries habitat. However, most projects have reported that hypolimnetic temperatures may increase slightly because of the exposure of these waters to the atmosphere. When fish are forced out of waters with a preferred temperature into warmer waters (eg. because of low DO concentrations) the associated stresses may become evident. In the most extreme cases, excessive temperature will lead to mortality. Black (1953) reported 50% mortalities for rainbow trout fingerlings and largemouth bass exposed to 24° C and 29° C, respectively. Toxicants which cause increases in metabolic demand (eg. copper) or block oxygen uptake at the gills (eg. zinc) may be more active physiologically at higher temperatures because of increased respiration (Cairns *et al.*, 1975). Temperature changes may make a given chemical more toxic or may alter the lethal concentration of the chemical to an organism (Cairns *et al.*, 1975). Increasing temperatures have been associated with decreased growth in sockeye salmon (*Oncorhynchus nerka*), coho salmon (*O. kisutch*), and brown trout (*Salmo trutta*) (Elliot, 1975; Averett, 1969; Brett *et al.*, 1969). Hokanson *et al.* (1973) showed a decrease in the fecundity of brook trout (*Salvelinus fontinalis*) with increasing water temperature.

The preferred temperatures of rainbow trout reported in the literature varied from 13° C to 21° C, depending on life stage and acclimation temperature (Cherry *et al.*, 1977; McCauley and Huggins, 1976; Spigarelli, 1975; McCauley and Pond, 1971; Javaid and Anderson, 1967; Horak and Tanner, 1964; Garside and Tait, 1958). The temperature range for rainbow trout acclimated at 6° C was 5° C to 13° C. For rainbow trout acclimated at 24° C the temperature range was 19° C to 25° C. As the acclimation temperature decreased the difference between acclimation temperature and preferred temperature increased (Cherry *et al.*, 1977; Ferguson, 1958), suggesting that rainbow trout are more adaptable when acclimated at lower temperatures. The reported preferred temperature range of smallmouth bass ranged from 12° C to 31° C depending on life history and season - an indication of acclimation temperature (Cherry *et al.*, 1977; Reynolds and Casterlin, 1976; Reutter and Herdendorf, 1974; Barans and Tubb, 1973; Ferguson, 1958). Smallmouth bass appeared to be more tolerant of excess temperature than rainbow trout showing a temperature range of 26° C to 33° C when acclimated at 30° C.

The hypolimnetic temperature of St. Mary Lake has increased during the summer stratification period since the aeration project began; the increase has not exceeded 17° C which is well below the lethal limits of fish suggested by the literature. This increase in temperature may enhance the fisheries habitat of the lake by raising the metabolic rate of the fish. This would cause an increase in feeding activity and therefore the probability of angler success. The size of fish, however, may decrease because of increased maintenance without an increase in food availability. Stuntz and Magnuson (1976) suggested fish will only seek cooler water temperatures once they begin to lose weight; as long as there is an adequate hypolimnetic food supply fish should remain active and continue to grow.

5.3 Secchi Depth

The increasing Secchi depths, since aeration, are indicative of decreasing phytoplankton populations and can be characterized by chlorophyll-*a* content. According to Dillon and Rigler (1975) a Secchi depth of 0.4 m indicates a chlorophyll-*a* content in excess of 25.0 µg/L which is typical of eutrophic lakes (Wetzel, 1983). A Secchi depth of 5.5 m, as seen in June of 1990, indicates a chlorophyll-*a* content of 2.0 µg/L which is typical of oligotrophic lakes (Wetzel, 1983). Because fish locate zooplankton visually (Heisey and Porter, 1977) increasing water clarity should improve the ability of trout and bass to see and capture prey items. This may be especially important for the survival of juveniles, which depend on zooplankton as the main part of their diet.

5.4 Zooplankton

Eutrophication indirectly influences zooplankton communities within a lake by increasing primary production, altering phytoplankton biomass and species composition, and depleting hypolimnetic oxygen (Ravera and Euratom, 1981). Nutrient inputs result in increasing phytoplankton biomass, but these only benefit zooplankton communities if the species are suitable as food (Ravera, 1980). Small phytoplankton species (nannoplankton) have been found to be more prominent in oligotrophic lakes than in eutrophic lakes (Haney, 1973; Gliwicz, 1967) and in these conditions it is generally accepted that the larger, herbivorous zooplankton will dominate over the smaller species because the former are the more efficient filter feeders (Ravera, 1980; Hall *et al.*, 1976). Diaptomids are more suited to oligotrophic waters because of their high filtering capacity and high ingestion rate of algae having a small cell size (Ravera, 1980). *Keratella* have generally been considered indicators of eutrophic conditions (Ravera, 1980; Gannon and Stemberger, 1978). *Diaptomus oregonensis* densities increased greatly after hypolimnetic aeration of St. Mary Lake while *Keratella* densities showed a general decreasing trend. This observation may suggest a shift in the trophic state of the lake.

In general, freshwater copepods are not as an important a prey item in fish diets as cladocerans, with various studies on stomach contents of young fish showing 1% to 95% cladocerans by volume (Pennak, 1978). The diets of the sportfish found in St. Mary Lake shift with increasing size. Rainbow trout, cutthroat trout, and smallmouth bass all depend on zooplankton as juveniles but switch dominant prey items as they mature to include fish as a main component of their diet (Scott and Crossman, 1979). The success of the adult populations is therefore influenced by the success of the juvenile populations, which in turn are influenced by the success of the zooplankton communities.

Halsey and Abbott (1988) reported the cladoceran *Daphnia pulex* and the mysid *Neomysis mercedis* to be the dominant prey items in St. Mary Lake trout, based on stomach contents; neither was numerically dominant in plankton tows. The fact that these are dominant in stomach contents is likely related to their large size and therefore their increased vulnerability to visual feeding trout. It is interesting to note that *D. pulex* was an abundant prey item in the winter months of 1986/87 but not in the late spring and summer months of 1987. This may be related to the destratification of St. Mary Lake in 1986 caused by the testing of the aerator system (Section 4.2). Warmer temperatures resulting from destratification of the lake may have caused a peak in *D. pulex* numbers earlier than would normally be expected.

Diaphanosoma brachyurum (a cladoceran) numbers have remained relatively stable throughout the period since aeration and this may be the result of constant predation by fish. The increase in copepod numbers may then be explained if they are of secondary importance in the diets of fish and therefore allowed to exploit changes in the phytoplankton community. Mysid numbers were also seen to increase noticeably since aeration and this may reflect a greater abundance of smaller zooplankters which serve as suitable prey items. Increases in mysid abundance may also be related to increased hypolimnetic oxygen concentrations (Wetzel, 1983). Mysids, because of their large size (up to 30 mm), may be an important food source for fishes, especially for species inhabiting deep waters (Pennak, 1978).

5.5 Fisheries

For optimum cold water fisheries conditions to exist an equilibrium must occur in which there is sufficient algal growth of the appropriate species to provide food for zooplankton communities but not enough algal growth to cause hypolimnetic oxygen depletion (Lee *et al.*, 1991). When this equilibrium is not maintained and increasing eutrophication results, a shift in fish species composition from cold water species, such as trout, to coarse species like carp is generally noted (Lee *et al.*, 1991; Beeton, 1965). Lee *et al.* (1991) demonstrated that an increase in phosphorus loadings within a lake were associated with increases in fish yield, however the authors did not indicate whether individual species abundance changed. Furthermore, the authors state that the relationship cannot apply to a "put and take" fishery, such as St. Mary Lake. Ranta *et al.* (1992) found no evidence of a relationship between water quality parameters and fish catches on small, oligotrophic Finnish lakes, however, they captured fish using gill nets and may have observed different results if the fish were angled, as reported by Weithman and Haas (1984) (Section 5.1). Ranta *et al.* (1992) also noted that variations in biotic (predation, competition) and abiotic factors (spawning habitat, shelter) may influence fish populations in different lakes to a greater degree than water quality parameters.

Eutrophication may have adverse effects on spawning and rearing habitats within the affected lake (Lee *et al.*, 1991; Larkin and Northcote, 1969; Davis, 1961; Trautman, 1957), reproductive capabilities of the fish (Beeton, 1965), and the fisheries habitat of waters downstream of the affected lake (Lee *et al.*, 1991). However it is difficult to determine the effects, if any, that eutrophication and the subsequent aeration project has had on the St. Mary Lake sport fishery. The available data suggests that the mean size of cutthroat trout may have increased between 1977 and 1988 but further data collection would be required to determine if this trend has continued. Regular stocking efforts since 1981 may have offset any adverse effects on trout populations. Experienced anglers have reported that the quality of the overall trout fishery has not changed significantly, however Halsey and Abbott (1988) reported decreased angling success rates for both trout and bass. Halsey and Abbott (1988) suggested that the decline in angling success was caused by increasing water temperature, drought, and development within the St. Mary Lake watershed. This decrease may have also been related to the degree of angling experience possessed by those interviewed, with catch rate increasing with angler experience (Weithman and Haas, 1984). Smallmouth bass have not been stocked in St. Mary Lake since their original introduction and the fact that their numbers continued to thrive may illustrate their tolerance to increased water temperature and lower DO concentrations. It may be desirable to replicate the Halsey and Abbott (1988) creel census in order to determine any changes in angling success since 1987.

The fact that some anglers were finding fish at greater depths may be related to an increase in hypolimnetic DO concentrations. The increase would provide more favorable conditions, during summer stratification, for salmonids by reducing metabolic stress in the cooler hypolimnion. The decline in cutthroat trout captures experienced by the fly fishermen may be related to the introduction of steelhead into St. Mary Lake. Restockinig of cutthroat trout has continued and in greater numbers than steelhead, however the steelhead which have been stocked were generally of a more advanced life stage. One Saltspring Island resident angler noted that in mid November, 1992, 90% of the trout being caught in St. Mary Lake were cutthroats, however, this included all angling methods. The known presence of cutthroat trout in the lake along with a decline in fly caught cutthroats suggests a shift in the cutthroat niche, either spatially, dietary, or both, as a result of steelhead introduction. Cutthroat trout and steelhead have been shown to occupy different areas of the same stream (Hartman and Gill, 1968) and cutthroat trout and Dolly Varden char occupying the same lake have shown evidence of segregation on both a spatial and dietary basis (Andrusak and Northcote, 1971). In Andrusak and Northcote (1971) the cutthroat trout were found to occupy and feed in the littoral areas of the lake while the Dolly Varden char occupied the offshore areas and fed primarily on benthic organisms. The introduced steelhead of St. Mary Lake may now be outcompeting the cutthroat trout for the littoral habitat, forcing the cutthroat to utilize other areas of the lake. This niche shift may also be the result of an ability of the cutthroat trout to utilize areas of the lake other than the littoral zone, thereby reducing competition with the steelhead.

6.0 CONCLUSIONS

The hypolimnetic aeration of St. Mary Lake appears to have enhanced the fisheries habitat of the lake in three ways: increased dissolved oxygen concentrations, increased visibility, and increased densities of certain zooplankters. The hypolimnion of the lake no longer experiences anoxic conditions during the period of summer stratification. A cool, oxygenated hypolimnion provides salmonids with a habitat which exerts less stress on the metabolic rate of the fish. Increased Secchi transparencies indicate increased visibility, enhancing the prey capture abilities of the fish. Increases in densities of zooplankters such as *Diaptomus oregonensis*, *Diaphanosoma brachyurum*, *Cyclops*, copepod nauplii, and mysids may be beneficial to both juvenile and adult fish populations. Hypolimnetic water temperatures have increased slightly since aeration, however they remain well below the lethal limits for trout and bass suggested by the literature.

The sport fishery of St. Mary Lake appears to be doing well but the affects of eutrophication and hypolimnetic aeration, if any, are unclear. This may be because any adverse effects may be offset by cutthroat trout and steelhead trout stocking efforts which began in 1977.

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Appendix 1

Stocking Records For St. Mary Lake

Table 1: Summary of stocking records for St. Mary Lake. Ct = cutthroat trout, St = steelhead trout.

Date	Species	Total	Weight (g)	Stage
77/01/01	Ct	3,500	12.5	underyearling
78/01/01	Ct	15,000	39.0	underyearling
81/03/01	Ct	4,890	61.3	underyearling
81/04/01	Ct	5,300	62.5	underyearling
82/03/01	Ct	3,000	66.6	underyearling
84/03/01	Ct	10,000	32.7	underyearling
84/08/29	St	500	0.7	parr
84/08/29	St	8,152	2.6	parr
85/03/21	St	8,326	10.4	parr
85/04/01	Ct	10,000	45.4	underyearling
86/03/01	Ct	10,000	29.4	underyearling
86/06/04	St	10,003	19.7	smolt
87/03/01	Ct	8,000	31.7	underyearling
87/03/12	St	6,588	22.8	smolt
88/03/01	Ct	10,022	38.3	underyearling
88/03/07	St	10,471	31.5	yearling
89/04/04	Ct	10,000	41.0	yearling
89/04/13	St	11,723	29.3	smolt
90/03/21	Ct	10,011	33.9	yearling
90/03/21	St	10,247	26.9	smolt
90/06/18	Ct	1,822	0.2	fry
91/03/20	St	10,530	37.3	smolt
91/04/10	Ct	10,000	32.2	yearling
91/10/25	Ct	3,286	12.6	fingerling
92/03/09	Ct	10,000	30.3	yearling
92/03/13	St	7,424	25.4	yearling
92/09/10	Ct	5,000	28.0	fingerling

Appendix 2

Log - log Weight / Length Relationships For St. Mary Lake Sportfish

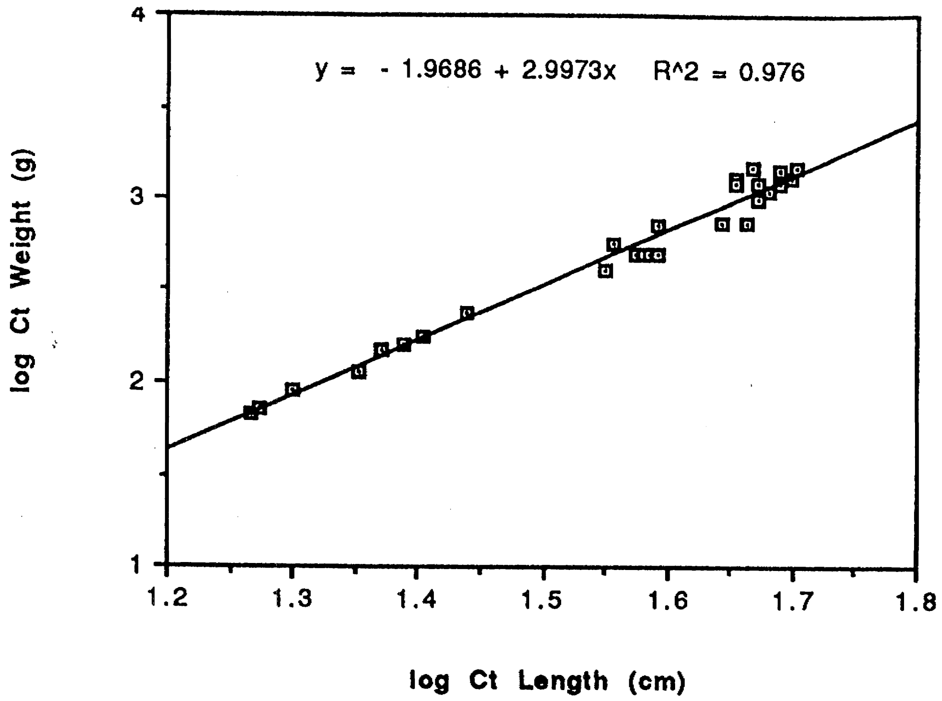

Figure 1: Log-log length/weight relationship for St. Mary Lake cutthroat trout.

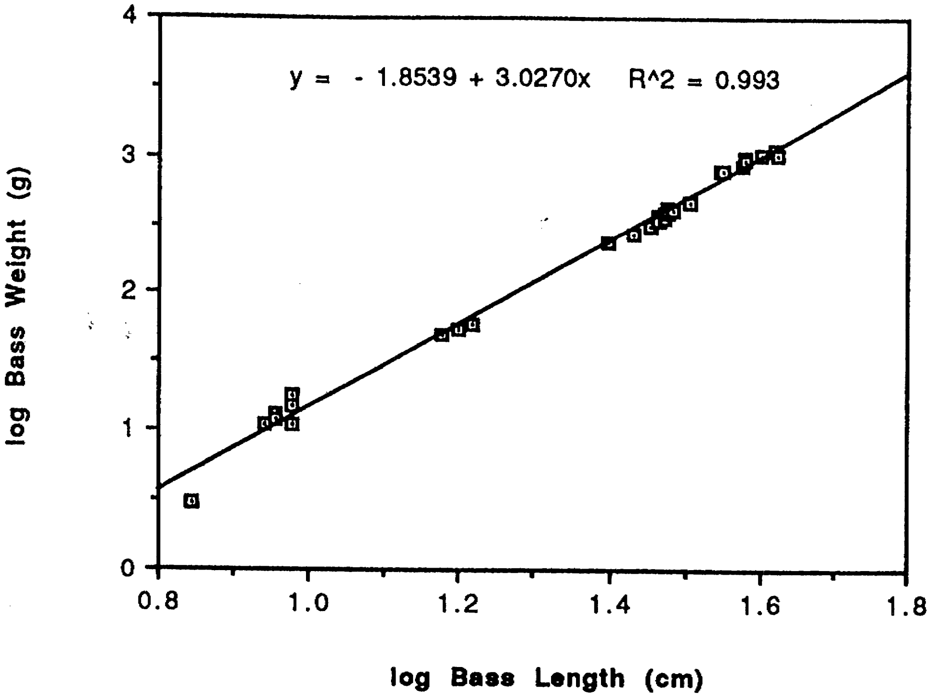

Figure 2: Log-log length/weight relationship for St. Mary Lake smallmouth bass.

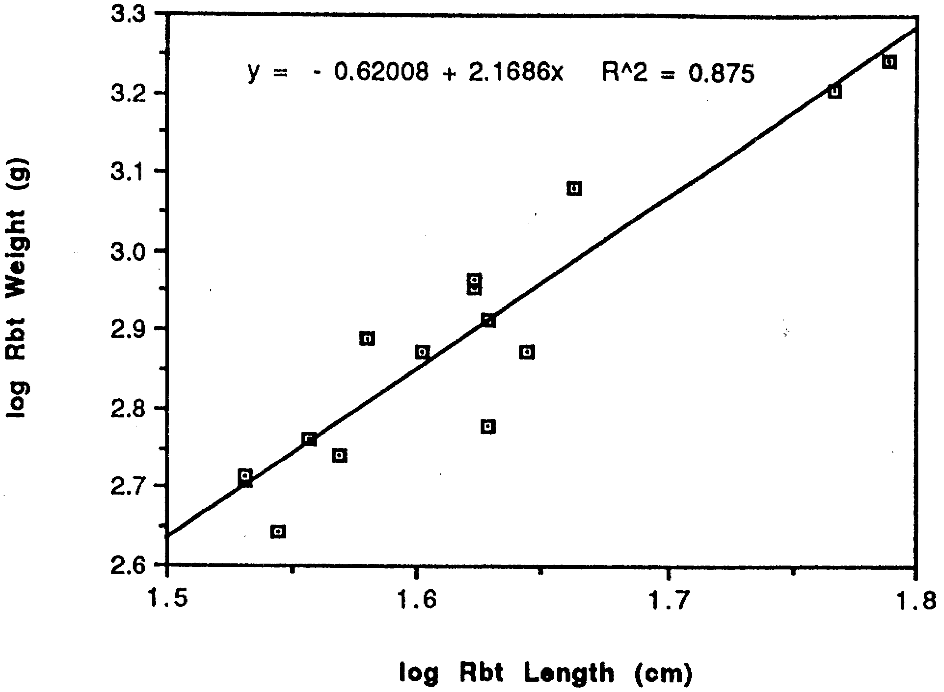

Figure 3: Log-log length/weight relationship for St. Mary Lake rainbow trout.