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OPERATIONAL EFFECTS OF IRRIGATION AND PUMPED/STORAGE
ON THE ECOLOGY OF BANKS LAKE, WASHINGTON

by

Q. J. Stober, R. W. Tyler, J. A. Knutzen, D. Gaudet,
C. E. Petrosky and R. E. Nakatani

FINAL REPORT
June 1973 to September 1977
Contract Number 14-06-100-7794 (Neg.)

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Director

TABLE OF CONTENTS

	Page
LIST OF TABLES	viii
LIST OF FIGURES	x
1.0 EXECUTIVE SUMMARY	1
2.0 ACKNOWLEDGMENTS	4
3.0 PREFACE	6
4.0 LAKE LIMNOLOGY	8
4.1 Introduction	8
4.2 Description of Study Area	9
4.3 Materials and Methods	16
4.3.1 Physical Measurements	16
4.3.2 Chemical Measurements	17
4.3.2.1 Temperature, Conductivity, Dissolved Oxygen, pH, ORP	17
4.3.2.2 Hardness and Alkalinity	18
4.3.2.3 Nitrate, Phosphorus, Silica and Ions	19
4.3.3 Biological Measurements	20
4.3.3.1 Phytoplankton	20
4.3.3.2 Primary Production	21
4.3.3.3 Zooplankton Abundance	23
4.3.3.4 Zooplankton Biomass Estimate	24
4.3.4 Feeder Canal Measurements	24
4.4 Results	24
4.4.1 Water Temperature	24
4.4.1.1 Seasonal Effects	24
4.4.1.2 Convergence Zone	30
4.4.1.3 Lake Stratification	30
4.4.2 Dissolved Oxygen	33
4.4.3 Transparency	41

	Page
4.4.4 Water Chemistry	41
4.4.4.1 pH	41
4.4.4.2 Conductivity, Alkalinity and Hardness	46
4.4.4.3 Cations and Anions	51
4.4.4.4 Silica	53
4.4.4.5 Plant Nutrients	57
4.4.4.5.1 Orthophosphate	57
4.4.4.5.2 Total Phosphorus	62
4.4.4.5.3 Nitrates	62
4.4.5 Biological	66
4.4.5.1 Phytoplankton	66
4.4.5.2 Primary Production	75
4.4.5.3 Zooplankton Composition and Abundance	79
4.4.5.4 Potential Input of Zooplankton	89
4.4.5.5 Zooplankton Biomass Estimates	92
4.5 Discussion	95
4.5.1 Physical Limnology	95
4.5.1.1 Temperature	95
4.5.1.2 Transparency	96
4.5.2 Chemical Limnology	98
4.5.2.1 pH	98
4.5.2.2 Ions and Conductance	98
4.5.2.3 Silica	100
4.5.2.4 Plant Nutrients	100
4.5.3 Biological Limnology	105
4.5.3.1 Phytoplankton	105
4.5.3.2 Primary Production	108
4.5.3.3 Zooplankton Abundance	110
4.5.3.3.1 <i>Bosmina</i>	110
4.5.3.3.2 <i>Daphnia</i>	111
4.5.3.3.3 Nauplii	113
4.5.3.3.4 <i>Cyclops</i>	114
4.5.3.3.5 <i>Diaptomus</i>	115
4.5.3.3.6 Feeder Canal Pumping Effects	115
4.5.3.4 Zooplankton Biomass Estimates	117

	Page
5.0 FISH POPULATION MONITORING	120
5.1 Introduction	120
5.2 Materials and Methods	121
5.3 Results and Discussion	123
5.3.1 Historical Reservoir Operation	123
5.3.2 Yellow Perch	127
5.3.2.1 Distribution	127
5.3.2.2 Water Level Fluctuation	131
5.3.2.3 Length-Frequency Analysis	135
5.3.3 Lake Whitefish	138
5.3.3.1 Distribution	138
5.3.3.2 Estivation	144
5.3.3.3 Water Level Fluctuation	147
5.3.3.4 Length Frequency Analysis	148
5.3.4 Kokanee	151
5.3.4.1 Distribution	151
5.3.4.2 Water Level Fluctuation	156
5.3.4.3 Length Frequency Analysis	158
6.0 KOKANEE FRY STUDY	162
6.1 Introduction	162
6.2 Materials and Methods	163
6.2.1 Spawning Observations	163
6.2.2 Kokanee Egg Planting	165
6.2.3 Water Temperature Record	168
6.2.4 Fry Trap Development and Operation	168
6.3 Results and Discussion	172
6.3.1 Kokanee Spawning	172
6.3.2 Survival of Planted Kokanee Eggs	173
6.3.3 Development of Planted Kokanee Eggs and Alevins	176
6.3.4 Emergence of Naturally-Spawmed Kokanee Fry	180
6.3.5 Emergence of Lake Whitefish Fry	184
6.3.6 Emergence of Yellow Perch Fry	184

	Page
6.3.7 Dissolved Oxygen	184
6.3.8 Predator Screening	185
6.3.9 Effect of Drawdown on Spawning and Incubation	185
7.0 SPORT FISHERY 1975-76	190
7.1 Length-Weight Analysis of Fishes in the Creel, 1975-76	190
7.1.1 Yellow Perch	190
7.1.2 Kokanee	190
7.1.3 Chinook Salmon	193
7.1.4 Rainbow Trout	193
7.2 Economic Reevaluation of the 1975-76 Fishery	198
8.0 FISH ENTRAINMENT (IRRIGATION CANAL)	201
8.1 Introduction	201
8.2 Irrigation Canal	202
8.3 Materials and Methods	205
8.4 Results	218
8.4.1 Relative Abundance	218
8.4.2 Yellow Perch	220
8.4.3 Kokanee	226
8.4.4 Lake Whitefish	229
8.4.5 Longnose Sucker	234
8.4.6 Carp	234
8.4.7 Rainbow Trout	237
8.4.8 Chinook Salmon	237
8.4.9 Prickly Sculpin	238
8.4.10 Mountain Whitefish	238
8.4.11 Peamouth	240
8.4.12 Pumpkinseed Sunfish	240
8.4.13 Black Crappie	240
8.4.14 Other Species	240
8.5 Discussion	243
8.5.1 Gear	243
8.5.2 Factors Affecting Entrainment	245
9.0 FISH ENTRAINMENT (FEEDER CANAL)	250
9.1 Introduction	250

	Page
9.2 Description of Feeder Canal	250
9.3 Materials and Methods	251
9.3.1 Sampling Gear	251
9.3.2 Generation Mode	252
9.3.3 Irrigation and Pumpback Mode	254
9.4 Results	256
9.4.1 Irrigation and Pumpback Mode	256
9.4.2 Kokanee	256
9.4.3 Carp	260
9.4.4 Prickly Sculpin	260
9.4.5 Other Game Fish	260
9.4.6 Other Nongame Fish	261
9.4.7 Generation Mode	261
9.5 Discussion	265
10.0 SUMMARY AND DISCUSSION	269
10.1 Aquatic Environment	269
10.2 Fish Population Ecology	271
10.3 Kokanee Fry Study	276
10.4 Sport Fishery	278
10.5 Fish Entrainment (Irrigation Canal)	279
10.6 Fish Entrainment (Feeder Canal)	280
10.7 Management Implications	282
11.0 REFERENCES	286
11.1 Lake Limnology	286
11.2 Fish Population Monitoring	290
11.3 Kokanee Fry Study	290
11.4 Sport Fishery	290
11.5 Fish Entrainment	291
A.8.1 APPENDIX	292

LIST OF TABLES

Table		Page
4.1	Morphometric characteristics of Banks Lake	13
4.2	Average percent dissolved oxygen saturation by depth strata for Banks Lake from April 1975 to December 1975	37
4.3	Average percent dissolved oxygen saturation by depth strata in Lake Roosevelt and Banks Lake from January through October 1976	38
4.4	Average pH by depth strata in Banks Lake from April through December 1975	44
4.5	Average pH by depth strata in Lake Roosevelt and Banks Lake from January through October 1976	45
4.6	Mean conductivity ($\mu\text{mhos}/\text{cm}^2$) for Banks Lake and Lake Roosevelt forebay for 1975 and 1976	47
4.7	Mean alkalinity (mgCaCO_3/l) for Banks Lake and Lake Roosevelt forebay for 1975 and 1976	48
4.8	Calcium-magnesium hardness (mgCaCO_3/l) in Banks Lake and Roosevelt forebay during 1975 and 1976	49
4.9	Concentration of selected ions in Banks Lake for the months of April through September 1975 and quarterly thereafter, beginning January through September 1976, and Lake Roosevelt forebay ions from March to September 1976	52
4.10	Calcium concentration (mg/l) in Banks Lake and Lake Roosevelt forebay during 1975 and 1976	54
4.11	Magnesium concentration (mg/l) in Banks Lake and Lake Roosevelt forebay during 1975 and 1976	55
4.12	Silica (mg/l) in Banks Lake and Lake Roosevelt forebay during 1975 and 1976	56
4.13	Paired T-tests and Pearson r correlation coefficients for mean monthly chlorophyll a values between Stations 1 through 6 in Banks Lake and between Station 1 and selected depth strata in Lake Roosevelt (FDR) forebay	67
4.14	Species of crustacean zooplankton identified from Banks Lake samples. (Courtesy of Mr. Rufus Kiser).	80

Table	Page
4.15 Banks Lake dry weight biomass (mg/m^3) estimate for crustacean zooplankton and percent of biomass for major groups of organisms from April 1975 to March 1976	94
4.16 Trophic status of Banks Lake with respect to various parameters (modified from Karp 1975)	102
4.17 Comparisons between Canyon Ferry and Banks Lake	104
4.18 A comparison of average zooplankton biomass from several lakes with Banks Lake (modified from Schindler and Noven 1971)	118
6.1 Matrix of information pertinent to experimental kokanee egg planting in Banks Lake, 1976	166
6.2 Mean dates of hatching and emergence and accumulated temperature units of the planted eggs	178
6.3 Occurrence of kokanee and whitefish fry in sculpin stomachs	187
8.1 Total estimated entrainment through the irrigation canal by species during the 1975 and 1976 irrigation seasons (March - October)	219
8.2 Mode length (mm) of lake whitefish entrained in the irrigation canal in 1975 and 1976	233
9.1 Total estimated entrainment through the feeder canal for each species during the 1976 irrigation pumping season (March to October). Pumping was stopped for a 2-week period in April	257
9.2 Catch of fishes in the feeder canal during irrigation pumping in 1976	258
9.3 Summary of operating times, discharge volumes, and weeks sampled for P/G units 7 and 8	262
9.4 Summary of observations of entrained fishes of the feeder canal headworks during P/G operation, 1975 and 1976	264

LIST OF FIGURES

Figure	Page
4.1 Geographical location and features of Banks Lake, and locations of sampling sites	10
4.2 Banks Lake surface elevations relative to rates of irrigation water input and withdrawal, 1973 to 1976 (USBR)	12
4.3 Average water retention time of the regions north and south of the constriction near Steamboat Rock, Banks Lake . .	15
4.4 Banks Lake mean water temperatures at 4 meters versus mean monthly air temperatures, comparing Station 1 and Stations 2-6, for the period July 1973 to December 1974 . . .	26
4.5 Banks Lake mean water temperature at 4 meters versus mean monthly air temperature, comparing Station 1 and Stations 2-6, for the period January through December 1975. .	27
4.6 The mean air temperature versus the average water temperature of Banks Lake at 4 meters for Stations 1 and 2 through 6; and the water temperature at the feeder canal headworks and FDR Reservoir at the depth of water intake for the feeder canal and pumps; for the period January to October 1976	28
4.7 Banks Lake isotherms (July 23, 1975) showing the convergence zone north of kilometer 10, where cold water pumped in from FDR Reservoir descends under a warm epilimnetic layer south of kilometer 10	31
4.8 Monthly changes in water temperature in Banks Lake at 4-meter depth intervals at Stations 1, 2 and 3	32
4.9 Temperature at selected depth strata in FDR Reservoir forebay for the period February to October 1976	34
4.10 Temperature and percent dissolved oxygen saturation in FDR Reservoir forebay for July 28 and November 2, 1976 . . .	35
4.11 Monthly changes in water temperature in Banks Lake at 4-meter depth intervals at Stations 4, 5 and 6	36
4.12 Temperature and dissolved oxygen saturation curves for all stations during July 23 and November 24, 1975	40
4.13 Monthly changes in Secchi depth transparency in Banks Lake at Stations 1, 2 and 3, and FDR Reservoir forebay . . .	42
4.14 Monthly changes in Secchi depth transparency in Banks Lake at Stations 4, 5 and 6	43

Figure	Page
4.15 Average seasonal changes in alkalinity, hardness, and conductivity compared to distance from the north dam in Banks Lake, and FDR Reservoir forebay for the period February to October 1976	50
4.16 Average changes in silica concentrations compared to distance from the north dam during pumping and non-pumping periods in Banks Lake and FDR Reservoir forebay for 1975 and 1976	58
4.17 Mean monthly orthophosphate concentrations for Station 1, Stations 2 and 3 combined, and Stations 4, 5 and 6 combined; with the occurrence of feeder canal pumping and pump/generation from May 1974 to October 1976	59
4.18 Nutrient concentration at Banks Lake Station 1, feeder canal at the headworks, and FDR Reservoir forebay; with feeder canal pumping and pump/generation from November 1975 to October 1976	61
4.19 Mean monthly total phosphorus concentrations for Station 1, Stations 2 and 3 combined, and Stations 4, 5 and 6 combined; with the occurrence of feeder canal pumping and pump/generation from May 1974 to October 1976	63
4.20 Mean monthly nitrate concentrations for Station 1, Stations 2 and 3 combined, and Stations 4, 5 and 6 combined; with the occurrence of feeder canal pumping and pump/generation from May 1974 to October 1976	64
4.21 Chlorophyll <u>a</u> mean concentrations in Banks Lake at Stations 1, <u>2</u> and 3; with feeder canal pumping and pump/generation from September 1973 to October 1976	69
4.22 Chlorophyll <u>a</u> mean concentrations in Banks Lake at Stations 4, <u>5</u> and 6; with feeder canal pumping and pump/generation from September 1973 to October 1976	70
4.23 Chlorophyll <u>a</u> mean concentration for Banks Lake at Station 1, and FDR Reservoir forebay at 0 to 10 meters, and less than or equal to 20 meters, with pumping and pump/generation from January to October 1976	72
4.24 Average chlorophyll <u>a</u> concentration for Banks Lake and FDR Reservoir forebay during May to September in 1974 and 1975 and 1976. The chlorophyll <u>a</u> concentration in Rufus Woods Reservoir was six miles <u>below</u> Grand Coulee Dam. .	74
4.25 Carbon ¹⁴ primary production depth profiles comparing Stations 1, 4 and 6 in Banks Lake in 1975	76

Figure	Page
4.26 Carbon ¹⁴ primary production depth profiles comparing Stations 1, 4 and 6 in Banks Lake and FDR Reservoir forebay in 1976	77
4.27 Carbon ¹⁴ primary production comparing Stations 1, 4 and 6 in Banks Lake and FDR Reservoir	78
4.28 Changes in Banks Lake zooplankton abundance by month from September 1973 to October 1976 (Station 1)	81
4.29 Changes in Banks Lake zooplankton abundance by month from September 1973 to October 1976 (Station 2)	82
4.30 Changes in Banks Lake zooplankton abundance by month from September 1973 to October 1976 (Station 3)	83
4.31 Changes in Banks Lake zooplankton abundance by month from September 1973 to October 1976 (Station 4).	84
4.32 Changes in Banks Lake zooplankton abundance by month from September 1973 to October 1976 (Station 5)	85
4.33 Changes in Banks Lake zooplankton abundance by month from September 1973 to October 1976 (Station 6)	86
4.34 Changes in FDR Reservoir forebay zooplankton abundance for vertical net hauls from three depths, from February to October 1976	90
5.1 Schematic section through one transect illustrating sampling site for each gear type: 1) surface set horizontal gill nets (monthly), 2) bottom set horizontal gill nets (monthly), 3) vertical gill nets (monthly), 4) beach seine hauls (monthly), and 5) shoreline bottom set horizontal gill nets (quarterly, parallel to shoreline) .	122
5.2 Water inflow, outflow and level of Banks Lake from January 1951 through March 1977	124
5.3 Minimum annual Banks Lake elevations and drawdown for the period 1951-1976 (USBR data).	128
5.4 Month of occurrence of minimum Banks Lake elevation for each year from 1951 to 1976 (USBR data) * *	128
5.5 Vertical distribution of yellow perch offshore. Each point represents a 24-hr horizontal variable-mesh gill net sets: Four sets were made at each of the 4 transects monthly: 2 on the bottom of the water column	129

Figure	Page
5.6 Horizontal distribution of yellow perch. Each point represents 4 24-hr horizontal variable-mesh gill net sets: 2 at the bottom and 2 at the surface of the water column	130
5.7 The horizontal distributions of yellow perch from quarterly gillnet samples during 1976-77. The vertical axis represents the percent of the total catch for each season. The horizontal axis represents 12 sampling locations: east shore, mid-lake, and west shore at each of 4 transects	132
5.8 Yellow perch catch representing 4 24-hr horizontal variable sets: 2 at the surface and 2 at the bottom	133
5.9 Comparison of the fork length frequencies of yellow perch from annual gillnet catches	134
5.10 Observed spawning and estimated incubation seasons (1973-1977) of yellow perch superimposed over the water level regimes of these years, and projected to the histograms of estimated spawning depths, illustrating the proportion of incubation habitat exposed by lake level fluctuation	136
5.11 Distributions of yellow perch length frequencies from quarterly gillnet samplings from 1973 to 1976	137
5.12 Vertical distribution of lake whitefish offshore. Each point represents 8 24-hr horizontal variable-mesh gill-net sets. Four sets were made at each of the 4 transects monthly; 2 on the surface and 2 on the bottom of the water column	139
5.13 Horizontal distribution of lake whitefish. Each point represents 4 24-hr horizontal variable-mesh gillnet sets: 2 at the bottom and 2 at the surface of the water column. . .	140
5.14 The horizontal distribution of lake whitefish from quarterly gillnet samples during 1976-77. The vertical axis represents the percent of the total catch for each season. The horizontal axis represents 12 sampling locations: east shore, mid-lake and west shore at each of 4 transects	142
5.15 Offshore catches of lake whitefish. Large and small sizes are graphed together and separately. The catch of large lake whitefish is compared with water temperature at 4 meters	143
5.16 Echograms showing diel variation in vertical distribution of lake whitefish at Devil's Hole, Banks Lake, on August 14, 1976	145

Figure	Page
5.17 Vertical profiles of temperature, dissolved oxygen, and lake whitefish distribution at Devil's Hole during and after summer estivation	146
5.18 Observed spawning and incubation periods (1973-77) of lake whitefish superimposed over the water level regimens of these years, and projected to the histogram of estimated spawning depths, illustrating the proportion of incubation habitat exposed by water level fluctuation . . .	149
5.19 Length distribution and year class of lake whitefish caught in monthly and quarterly gillnet samples from 1973 to 1976 grouped by quarter	150
5.20 Vertical distribution of kokanee. Each point represents 8 24-hr horizontal variable-mesh gill-net sets. Four sets were made at each of the 4 transects monthly: 2 on the surface and 2 on the bottom	152
5.21 Horizontal distribution of kokanee. Each point represents the catch from 4 24-hr horizontal variable-mesh gill-net sets: 2 on the bottom and 2 on the surface	153
5.22 The spatial distributions of kokanee from quarterly gillnet samples during 1976-77. The vertical axis represents the percent of the total catch for each season. The horizontal plane represents 12 sampling locations: east shore, mid-lake, and west shore at each of 4 transects . . .	155
5.23 Total offshore catch of kokanee salmon, representing 16 24-hr gillnet sets: 8 on the surface and 8 on the bottom of the water column. This represents the combination of two days consecutive sampling at four transects	157
5.24 Observed spawning and estimated incubation periods (1973-77) of the kokanee salmon, superimposed over the water level regimes for these years, and projected to the histogram of observed spawning depths, illustrating the proportion of incubation habitat exposed by lake level fluctuation	159
5.25 Length distribution and year class of kokanee caught in monthly and quarterly gillnet samples from 1973 to 1977 grouped by quarter	160
6.1 Glass-bottomed pram used for underwater viewing	164
6.2 Kokanee fry emergent trap with detachable cod end	170
6.3 Number of live and dead kokanee observed during glass-bottom pram surveys in the primary spawning area in Banks Lake	174

Figure	Page
6.4 Map of Banks Lake indicating the areas where suitable shoreline spawning substrate occurred and where live kokanee spawners were observed. The prime kokanee spawning area is located in the southwest quarter of the lake	175
6.5 Fall, winter and spring water temperature regime (°C) at Station 6 with spawning, planting and egg development dates indicated	177
6.6 Accumulated temperature units and approximate time of emergence of egg plants in mesh bags made on October 27, November 11, and November 23, 1976	179
6.7 Weekly catch of emergent wild kokanee, lake whitefish and yellow perch fry in traps	181
6.8 Length frequency distribution of sculpins caught in screened (top) and unscreened (bottom) fry traps from April 19 through May 31, 1977	186
6.9 Kokanee spawning, incubation and emergence timing in relation to Banks Lake water surface elevation in 1976-77 indicating the amount of incubation habitat exposed	189
7.1 Monthly variation in the length frequency of yellow perch in the creel, 1975-76	191
7.2 Monthly variation in the length frequency of kokanee in the creel, 1975-76	192
7.3 Length-weight relationship of kokanee in the creel, 1975-76	194
7.4 Length frequency of chinook salmon in the creel, 1975-76	195
7.5 Length-weight relationship of chinook in the creel, 1975-76	196
7.6 Length frequency of rainbow in the creel, 1975-76	197
7.7 Length-weight relationship of rainbow trout in the creel, 1975-76	199
8.1 Detail of the extreme south end of Banks Lake, including the irrigation canal and the drainage channel	203
8.2 Average weekly rate of discharge (cfs) through the irrigation canal during 1975-76 (USBR data).	204

Figure	Page
8.3 Semi-diagrammatic detail of the downstream sampling and support gear fished from near the end of the concrete apron of the irrigation canal headworks	207
8.4 Net and frame which was fished from the downstream sampling site	209
8.5 Net and frame which was fished from the upstream sampling site. The frame was inserted into the trash rack slots located on either side of the outlet tunnels . . .	210
8.6 Downstream view of the upstream sampling site showing the tunnel openings and trash rack slots, the overhead support gear, sampling nets, and the vehicle-powered lifting apparatus	211
8.7 Total estimated weekly entrainment rates for yellow perch, kokanee, lake whitefish and long nose sucker through the irrigation canal in 1975 (solid) and 1976 (dashed)	221
8.8 Monthly surface and bottom water temperature in the south end of Banks Lake during the April-November irrigation seasons of 1975 and 1976	223
8.9 Monthly length frequency and year class of yellow perch caught in irrigation canal entrainment samples in 1975 . . .	224
8.10 Monthly length frequency and year class of yellow perch caught in irrigation canal entrainment samples in 1976 . . .	225
8.11 Monthly length frequency and year class of kokanee caught in irrigation canal entrainment samples in 1975 . . .	227
8.12 Monthly length frequency and year class of kokanee caught in irrigation canal entrainment samples in 1976 . . .	228
8.13 Monthly length frequency and year class lake whitefish caught in irrigation canal entrainment samples in 1975 . . .	231
8.14 Monthly length frequency and year class lake whitefish caught in irrigation canal entrainment samples in 1976 . . .	232
8.15 Total estimated weekly entrainment rated for carp, rainbow trout, chinook salmon and mountain whitefish through the irrigation canal in 1975 (solid) and 1976 (dashed)	235
8.16 Composite length frequency analysis of rainbow trout and carp caught in irrigation canal entrainment samples in 1975 and 1976	236

Figure	Page
8.17 Composite length frequency analysis of planted chinook salmon caught in irrigation canal entrainment samples in 1975 and 1976	239
8.18 Composite length-frequency analysis of rocky mountain whitefish caught in irrigation canal entrainment samples in 1975 and 1976	241
8.19 Total estimated weekly entrainment rates for peamouth and pumpkinseed sunfish through the irrigation canal in 1975 (solid) and 1976 (dashed)	242
9.1 Position of sampling apparatus in the flows during pump/generation and pump units at feeder canal headworks. . .	253
9.2 Length frequency and seasonal entrainment rate of kokanee in the feeder canal during irrigation pumping, 1976.	259
9.3 Monthly water temperature at 5 depth strata in FDR forebay (Stober et al. 1977)	267
9.4 Comparison between elevation of penstocks, spillway, and spill-discharge openings in Grand Coulee Dam and the monthly 95% level of fish target occurrence in FDR forebay, 1976-1977	268

1.0 EXECUTIVE SUMMARY

The ecological studies of Banks Lake demonstrated the physical, chemical and biological changes which occur in response to operational conditions resulting from irrigation water supply and pump-storage power generation. The lake is characterized by a two-pool system. The north pool, which extends from the north dam to the Steamboat Rock area, is directly influenced by the pumped input of water from FDR Reservoir. During the summer irrigation season the north pool was characterized by reduction of the temperature, transparency, retention time, and zooplankton abundance than similar properties in the south pool. During winter, water temperatures were warmer in the north pool. In addition, the north pool showed thorough mixing of the water column, greater concentrations of plant nutrients (nitrates and phosphates), and a correspondingly greater phytoplankton production than found in the south pool. Nitrate limitation occurred throughout the lake after pumping and drafting had ceased for a period of time. Zooplankton developed in the south pool, the more stable portion of the lake. In general, the lake is classified as a nitrate limited oligotrophic system.

Twenty-two species of fish were identified in Banks Lake. Yellow perch, lake whitefish, and kokanee comprised about 90 percent of the catch. Responses of the three major species indicated general avoidance of the reduced temperature, food supply, and increased water velocities in the north pool. Yellow perch remaining in the north pool exhibited lower growth rates and condition. All three species were dependent on the cladoceran zooplankton *Daphnia* as the major food source.

Extreme drawdown of the lake during spring 1973 and 1974 of 24.9 and 23.6 ft, respectively, reduced the reproductive success of yellow perch and kokanee salmon which are lakeshore spawning species. Lake whitefish, which utilize the same reproductive habitat were not seriously affected due to earlier emergence of the fry. The numbers of large perch and juvenile kokanee declined in the lake following these large drawdowns. The low abundance of the 1973 and 1974 year classes of kokanee was documented by gillnet and irrigation canal entrainment samples, shoreline spawner counts and the decline in the 1976 and 1977 sport fishery. A study of the kokanee reproduction in the lake indicated an October-November spawning season with egg incubation and fry emergence continuing until late May in 1977.

Fish loss due to entrainment occurred principally through the irrigation canal. The total estimated loss (19 species) was 432,608 and 218,178 in 1975 and 1976, respectively. Point estimates of the total entrainment of kokanee were 128,397 and 50,007 in 1975 and 1976, respectively. The majority of the kokanee entrained from the lake were mature age III. Loss of this age group through the irrigation canal in 1976 severely reduced the brood stock needed for the lake. Spawner counts declined to about 150 individuals in 1976 compared to about 10,000 spawners in 1975. The evidence clearly indicates that a year class of kokanee reduced by lake drawdown cannot sustain irrigation canal entrainment losses without serious reductions occurring in the population. Fish entrainment through the feeder canal was relatively minor compared to that observed in the irrigation canal.

Consideration of the magnitude, timing and rate of water level change in the operational management of the lake for irrigation water supply and power production can achieve a larger and more consistent production of sport fishes. Selective screening of the irrigation canal would retain adult kokanee in the lake to insure adequate spawning populations as well as reduce the loss of adult kokanee on which the concentrated sport troll fishery is dependent.

2.0 ACKNOWLEDGMENTS

This report presents the results of studies conducted by the Fisheries Research Institute, University of Washington, for the U.S. Bureau of Reclamation, Pacific Northwest Regional Office, Boise, Idaho. The Institute personnel responsible for the studies reported herein as well as in previous reports over the past 4 years are as follows:

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Ms. L. Jensen, Research Aide

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sampling. The assistance of Dr. D.A. McCaughran in reviewing the statistical analysis of the entrainment data is greatly appreciated. Part-time field and laboratory assistance was provided by Regina Gaffke, Steven Plakas, Joseph Jehovich, and Stephen Quinell.

3.0 PREFACE

This final report for contract #14-06-100-7794 contains the scientific results of the ecological studies of Banks Lake. This report was preceded by three annual reports in 1974, 1975, and 1976. This study was initiated in 1973 to determine the effects of the operation of two pump generator units (P/G 7 and 8) on the ecology and fish populations in the lake. It soon became evident during the early stages of this study that the lake was subjected to major influences due to annual operational changes in supply of irrigation water to the Columbia Basin Project. Determination of the operational effects on the lake related to irrigation water supply became the general focus of the project since it was obvious that the additional impacts of P/G operation could not be evaluated without that basic understanding of the system. Operation of P/G 7 and 8 since the initiation of the study has been limited due to mechanical difficulties, to infrequent and limited testing during the winter. Therefore, this report describes the ecological responses and impacts on the lake in its primary function as an irrigation equalizing reservoir. Inferences from these data regarding P/G operation have been drawn where possible.

The organization of this report is by subproject dealing with the limnology of the lake, fish population monitoring, kokanee fry study, 1975-76 sport fishery and fish entrainment through the irrigation and feeder canals. Fish entrainment of marked rainbow trout populations were also addressed in the Third Annual Report. A summary and discussion of the major findings along with management implications is also provided. This final report does not reiterate all the data reported in the Third

Annual Report, however, reference is made when conclusions have been based on previously reported data.

4.0 LAKE LIMNOLOGY

4.1 Introduction

The limnology of impounded waters continues to receive considerable attention (Hubbell 1967; Beckmann and Kutkuhn 1953; Hall 1971; Fraser 1972). This is not surprising, considering the fact that the United States has 5.25 million hectares (13 million acres) of artificial waters at maximum pool levels (Stroud 1966). As the requirements for water and energy increase, new impoundments will be established and existing reservoirs will be expanded. Biological information is needed, not only to improve our knowledge of the behavior of aquatic ecosystems, but also to provide vital background for the establishment of effective resource management programs, particularly where recreational use of artificial waters is important.

This comprehensive study of the limnology of Banks Lake was conducted to establish a data base for the assessment of the environmental impact of a pumped storage power generation facility at Grand Coulee Dam utilizing Banks Lake as the forebay reservoir. This data base will also describe the responses of the lake to changes imposed by the pumped input and withdrawal of irrigation water, its primary function as the equalizing reservoir for the Columbia Basin Irrigation Project. Determination of an ecological baseline under existing operating conditions and description of the effects of the input and withdrawal of irrigation water were of primary importance prior to the initiation of routine seasonal pumped storage power generation.

Specific objectives of the limnological studies were to document the temporal and spatial changes in certain aspects of the physical,

chemical and biological limnology (temperature, transparency, conductivity, pH, calcium-magnesium hardness, total alkalinity, dissolved oxygen, major plant nutrients, and ion composition), in the distribution and concentration of chlorophyll a as an index of phytoplankton abundance, $^{14}\text{CO}_2$ uptake as a measure of primary production rate by phytoplankton, and in the distribution and abundance of zooplankton.

The period from January 1975 to November 1976 is reported herein, with additional data included from June 1973. Lake Roosevelt forebay was also sampled from November 1975 to November 1976 to help clarify the effects of pumping and pump-generation on Banks Lake.

4.2 Description of Study Area

Banks Lake was established in 1951 by flooding 10,926.5 hectares (27,200 acres) along a 46.5-km (28.9-mile) section of the upper Grand Coulee between two earth-filled dams (Wolcott 1964) (Fig. 4.1). The Grand Coulee gorge is located in the high scrub desert of Central Washington. It was cut from the massive plain of lava flow by the Columbia River which was temporarily diverted from its present course by an ice blockage during recent glaciation. The present climate is one of hot, dry summers and cold, dry winters. Average summer daytime temperatures range from 23.9° to 29.4° C (75° to 85° F). January temperatures average from -9.4° to -1.1° C (15° to 30° F) with occasional extremes of -28.9° C (-20° F). Annual rainfall averages 27.5 cm (11 inches) (U.S. Bureau of Reclamation 1974). An ice cover lasting 1 to 3 months may develop on Banks Lake during severe winters; however, in recent years of this study complete ice cover was observed only during January and early February of 1974.

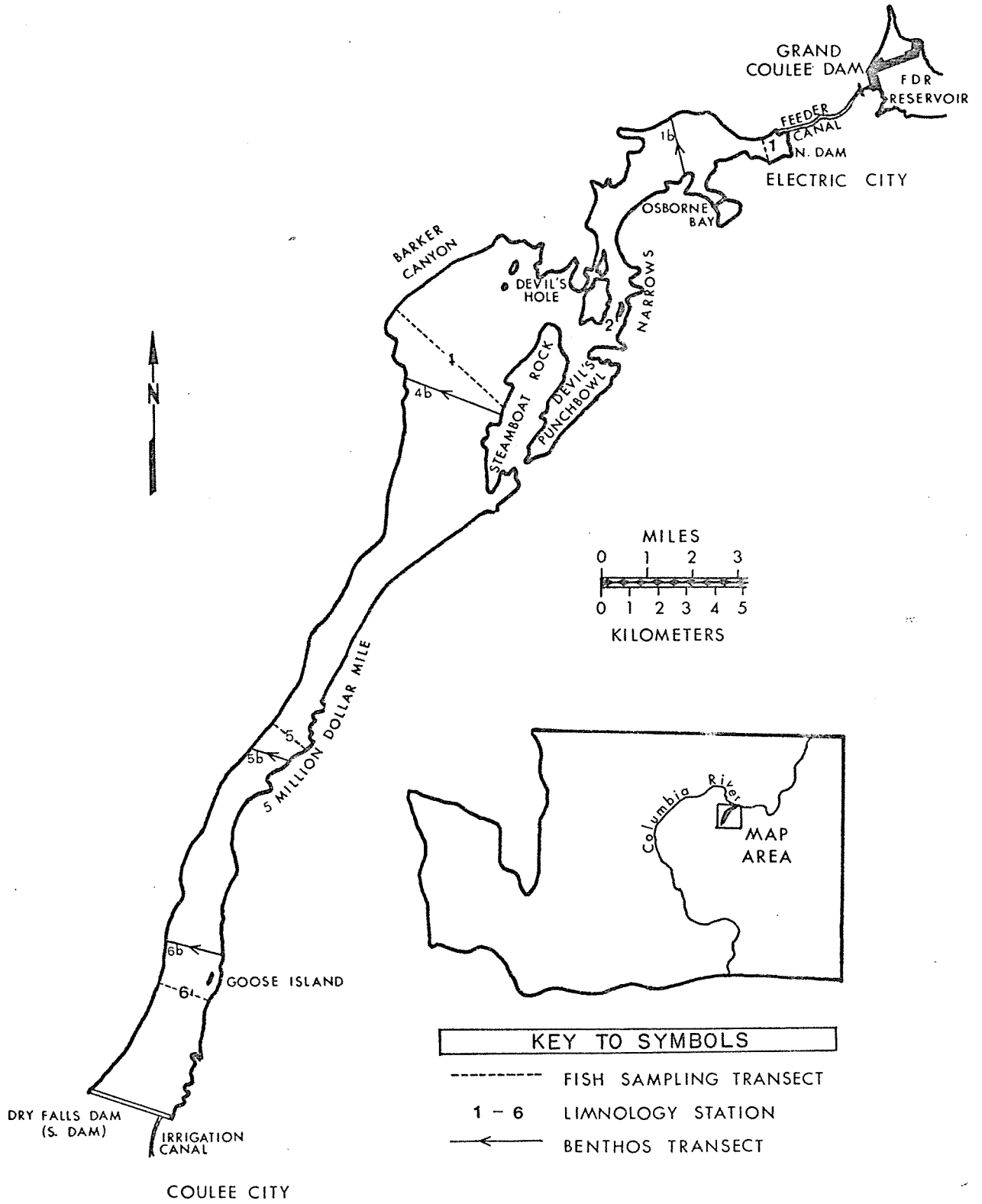


Figure 4.1 Geographical location and features of Banks Lake, and locations of sampling sites.

The North Dam constitutes the northern boundary of the lake. Dry Falls Dam (also known as South Dam) bounds the southern end of the lake. The pumping plant located at the left forebay of Grand Coulee Dam pumps water from Franklin D. Roosevelt Reservoir up 111.2 m (365 ft) into the 2.5-km (1.6-mile) long feeder canal which supplies water to Banks Lake adjacent to the North Dam. Some runoff and spring water enter Banks Lake but the volume of water contributed to the system from these sources is negligible compared with the pumped water supply.

The pumping plant contains six pumps, each rated at $45.3 \text{ m}^3/\text{sec}$ (1,600 cfs) and two pump generators, each rated at $49.6 \text{ m}^3/\text{sec}$ (1,750 cfs) in the pumping mode. Water for irrigation is withdrawn from Banks Lake through the irrigation canal headworks at Dry Falls Dam to supply the agricultural requirements on about 202,000 hectares (500,000 acres) of farmland in the Columbia Basin. The present maximum rate of irrigation withdrawal is $223.7 \text{ m}^3/\text{sec}$ (7,900 cfs). Variations in the operational rates of water supply and withdrawal to Banks Lake result in water level fluctuations of the lake. Rates of irrigation water input and withdrawal and changes in water level elevation from January 1973 to November 1976 are presented in Fig. 4.2. Maximum surface elevation is 478.5 m (1,570 ft) (Table 4.1) and at maximum drawdown the surface elevation is 469.4 m (1,540 ft). The annual drawdown does not normally exceed 4.6 m (15 ft) but during the study period drawdown reached 7.6 m (24.9 ft) and 7.2 m (23.6 ft) during the spring of 1973 and summer of 1974 (Fig. 4.2). The maximum width of Banks Lake is 8 km (5 miles); however, the mean width is considerably less. The mean lake depth at maximum elevation is

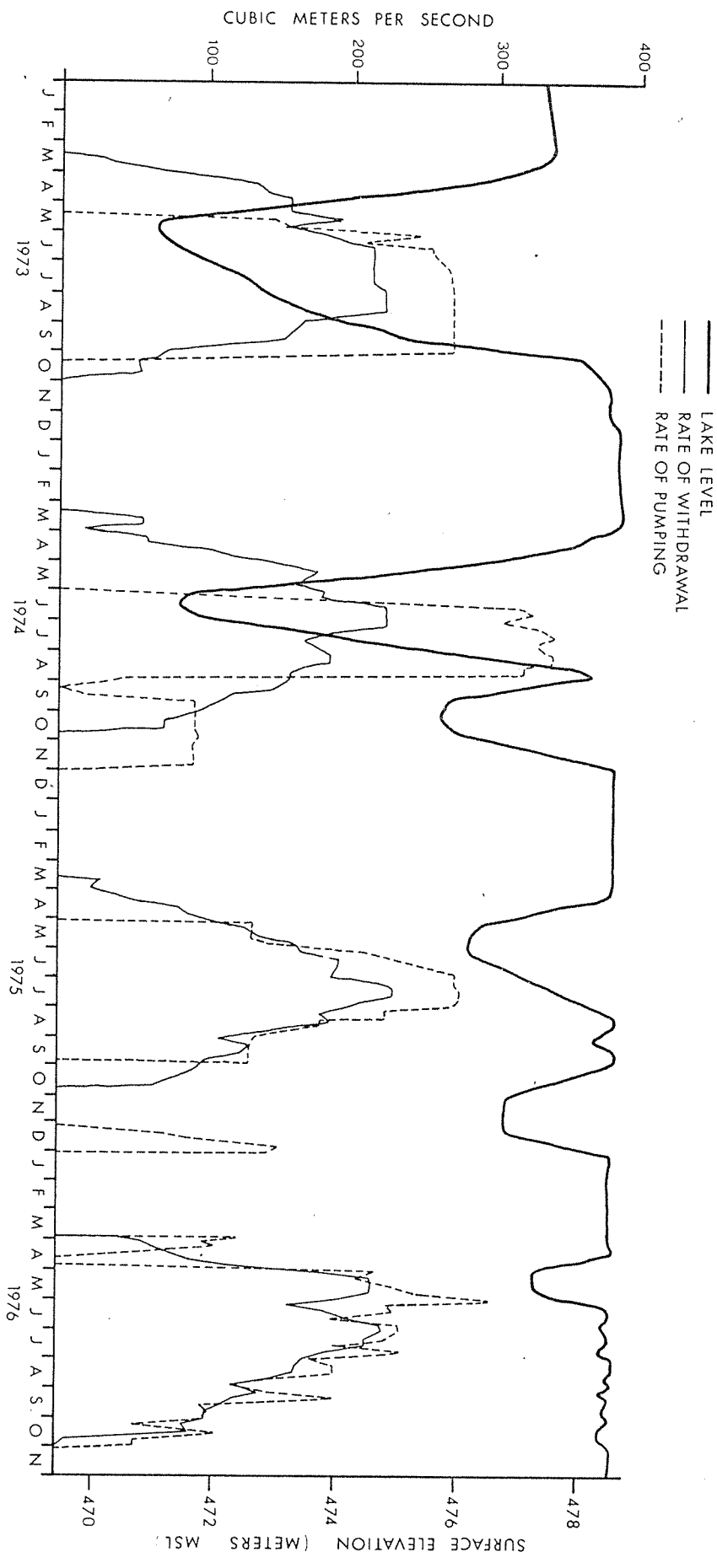


Fig. 4.2 Banks Lake surface elevations relative to rates of irrigation water input and withdrawal, 1973 to 1976 (USBR).

Table 4.1 Morphometric characteristics of Banks Lake.

	Elevation (m)	Area (ha)	Volume (ha m)	Maximum Length (km)	Maximum Width (km)	Mean Depth (m)	Perimeter (km)	Shoreline Development ¹
Maximum level	478.5	11,008	148,269	46.8	8.0	13.5	131.5	3.53
Irrigation drawdown:								
- 1.5 m	477.0	10,562	131,740	46.5	8.0	12.5		
- 4.6 m	474.0	9,384	101,394	46.5	7.9	10.8		
- 9.1 m	469.4	7,689	62,416	46.5	7.9	8.1	155.9	5.01

$$^1 \text{Shoreline Development} = \frac{\text{shoreline length}}{2 \left(\sqrt{\text{surface area} \times \pi} \right)}$$

13.5 m (41.1 ft) and the maximum depth is greater than 25 m (86.0 ft). The mean depth at surface elevation 469.4 m (1,540 ft) is 8.1 m (26.6 ft) (Table 4.1).

The lake perimeter is 131.5 km (81.7 miles) at maximum elevation and 155.9 km (96.8 miles) at maximum drawdown. Shoreline development (Welch 1948) is 3.53 at maximum elevation and 5.01 at maximum drawdown.

The average retention time of water (lake volume \div rate of withdrawal) was calculated for the north and south pools (volume north and south of Station 3, respectively; Fig. 4.1) at different elevations and withdrawal rates (Fig. 4.3). During peak withdrawal rates ($223.7 \text{ m}^3/\text{sec}$; 7,900 cfs), the average retention time ranged from 69 to 32 days in the south pool and 6.8 to 2.1 days in the north pool. The annual requirement has been approximately 271,366 hectare meters (2.2×10^6 acre-feet) in recent years, which represents potential replacement of the storage capacity approximately twice each year (USBR 1974). This occurs generally during the irrigation season beginning in March and ending in October.

Initial limnological investigations, carried out during July and August 1973, indicated that a minimum of six sampling stations was required to document the limnology of the reservoir. A monthly sampling schedule was established. On occasion, severe weather conditions precluded a partial or complete set of observations. No samples were obtained in February 1975. Only Station 1 was sampled in January 1975 and Stations 2 and 3 were not sampled in February 1976 due to ice cover.

Stations were established at midlake locations. Station 1 was located 0.2 km (0.1 miles) from the North Dam near the feeder canal discharge point. Station 2 was 10.8 km (6.7 miles) from the North Dam,

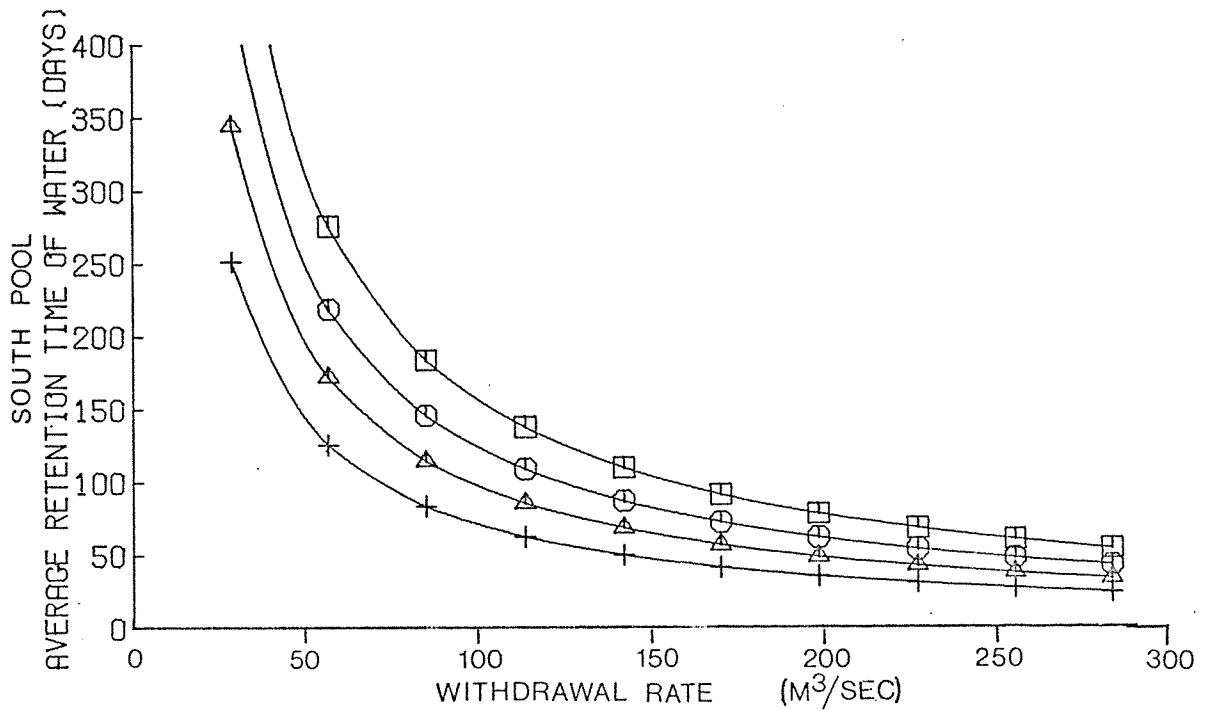
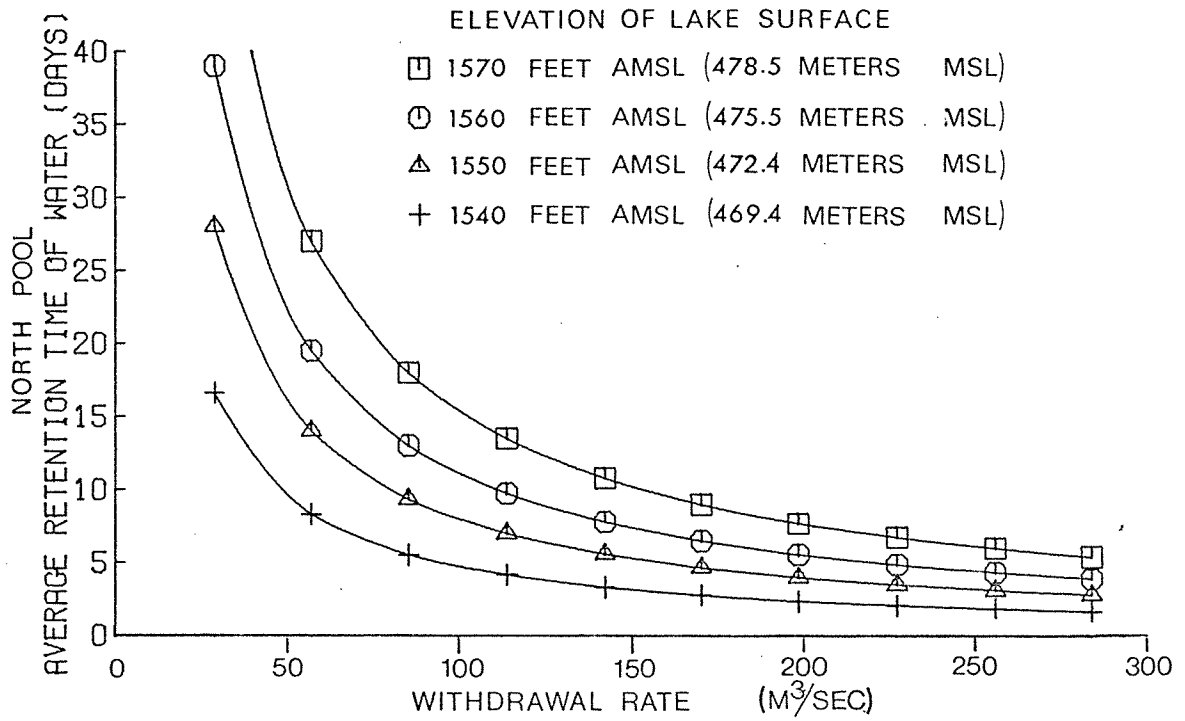


Fig. 4.3 Average water retention time of the regions north and south of the constriction near Steamboat Rock, Banks Lake.

in the area of the morphometric constriction. Station 3 was 11.9 km (7.4 miles) from the North Dam, south of the morphometric constriction. Station 4 was 18.0 km (11.2 miles) from the North Dam, west of the southern end of Steamboat Rock. Station 5 was 33.3 km (20.7 miles) from the North Dam, adjacent to Million Dollar Mile. Station 6 was 41.7 km (25.9 miles) from the North Dam, about 4.8 km (3.0 miles) from the irrigation water discharge structure. An additional sampling site was added in February 1976 in Lake Roosevelt (FDR) forebay. This site was located along the forebay log boom 0.5 km (0.3 miles) from the dam and 0.7 km (0.4 miles) from east and west shorelines.

4.3 Materials and Methods

4.3.1 Physical Measurements

During January and March 1975, in situ temperature was measured using an Applied Research temperature/conductivity probe. In April 1975 a Hydrolab Model 6D replaced this probe. Vertical temperature profiles were determined by recording temperature in 2-m depth intervals at each station. During summer stratification, 1-m intervals were measured in the region of the metalimnion.

Beginning in February 1976, temperature profiles were measured in FDR forebay. These were taken in the same manner as those in Banks Lake, except below the 20-m depth, readings were made every 4 m. The maximum Hydrolab cable length was 100 m, which reached to within 10 m of the bottom at full pool. The same depth locations were used for all probes of the Hydrolab in FDR forebay.

Transparency was measured with a standard 20-cm Secchi disc (Welch 1948). Readings were taken by lowering the disc over the shaded side of

the boat until it disappeared and then raising it until it became just visible. The mean of these two depths was recorded. All observations were made with the aid of polarizing sunglasses.

4.3.2 Chemical Measurements

4.3.2.1 Temperature, Conductivity, Dissolved Oxygen, pH, and ORP.

Beginning in April 1975 the Hydrolab Model 6D was used to make in situ measurements of depth, temperature, conductivity, dissolved oxygen, pH, and oxidation reduction potential (ORP). The Hydrolab Model 6D consists of a deck read-out scale, six measuring probes fitted in a plastic housing called the sonde, and a watertight cable connecting the deck unit to the sonde and the probes. These parameters were measured by lowering the sonde through the water column in 2-m intervals from surface to bottom. Each parameter was read in turn from the deck read-out scale. The thermistor temperature-sensing probe was also used to internally compensate all other readings to 25° C.

Dissolved oxygen was measured with a membrane-covered passive polarographic cell and recorded as mg/l. Prior to April 1975 dissolved oxygen had been determined by the azide modification of the Winkler titration, titrating with phenyl arsine oxide (U.S. Environmental Protection Agency 1974).

The pH was determined with a high sensitivity glass pH probe. Past pH measurements had not been in situ but made from field-collected water samples measured in the field laboratory on a Photovolt expanded pH scale.

Conductivity measurements were made with a 4-electrode temperature compensating probe. Before April 1975 conductivity had been measured

with a conductivity/temperature probe of the same design made by Applied Research.

The oxidation-reduction potential probe was platinum-tipped with a silver-silver chloride core. The silver-silver chloride electrode had a standard potential of approximately +200 millivolts with respect to the standard hydrogen electrode.

Water samples for chemical and chlorophyll a analysis were taken at three depths using three 2.5-liter Van Dorn bottles. Samples were taken at the surface, at 4 m, and near the bottom.

Starting in February 1976 samples were taken in FDR forebay. The depths of sampling were 1, 5, 10, 30, 50, 75, and 95 m, or near the bottom, through June. Beginning in July an additional depth was added at 20 m to help define stratification of nutrients and chlorophyll a. Some preliminary samples were taken near the shoreline of FDR Reservoir starting in November 1975.

4.3.2.2 Hardness and Alkalinity. Initially, total hardness and total alkalinity were determined by standard techniques (American Public Health Association 1971), modified according to the methods manual of the Hach Chemical Company. Beginning in April 1975, hardness was determined by the calculation method (APHA 1971) from the concentration of calcium and magnesium and was expressed as mg CaCO₃/l. Total alkalinity was determined by titration with sulfuric acid against bromocresol green-methyl red indicator and expressed in mg CaCO₃/l. Starting in August 1975 alkalinity was determined by standard techniques (APHA 1971) not modified by the Hach technique.

4.3.2.3 Nitrate, Phosphorus, Silica, and Ions. Water for nutrient analysis was placed in 500 ml "Nalgene" plastic bottles and acidified with one drop of 25 percent hydrochloric acid. Samples were packed in ice and transported to the Fisheries Research Institute water quality laboratory for analysis within 24 hr of collection. Ortho, hydrolyzable, and total phosphate was determined spectrophotometrically as phosphorus according to standard techniques (USEPA 1974). For the period from February to May 1976, total phosphorus was not reported because of contamination of the samples during processing.

Total nitrate nitrogen was determined by hydrazine reduction (Kamphake, Hannah, and Cohen 1967). A modification of this technique in which a chelating agent (Chelex) was used to complex metal ions which may have interfered with the determination was begun in May 1975.

Water chemistry analysis was expanded in April 1975 to include the measurement of major cations, anions and reactive silica. The concentration of calcium, magnesium, potassium, sodium, and iron was determined by flame atomic absorption spectrophotometry (USEPA 1974).

The colorimetric molybdosilicate method was used to measure reactive silica. Chloride concentration was determined by the automated colorimetric technique using ferric ammonium sulphate and saturated mercuric thiocyanate as the reactive reagents (USEPA 1974).

Sulphate levels were measured by the automated colorimetric method (Lazrus 1966). The samples were run through a cation exchange column to remove interfering cations and then reacted with barium chloride and methylthynol blue. The resulting sample was read on a colorimeter at 460 nm to determine the sulphate concentration in mg/l.

The measurements of calcium, magnesium, and silica were conducted monthly. The concentrations of potassium, sodium, and sulphate were determined monthly through September and quarterly thereafter. Because of undetectable levels of iron during the spring, iron analysis was discontinued after 3 months in June 1975. Additional water samples were taken for chloride analysis starting in September 1975 and quarterly thereafter. These samples were not preserved with hydrochloric acid.

4.3.3 Biological Measurements

4.3.3.1 Phytoplankton. Phytoplankton standing stock measurements were made by the determination of chlorophyll a concentrations according to the spectrophotometric method of Richards and Thompson (1952). One-liter water samples were taken at three depths at each station. One drop of saturated aqueous magnesium carbonate solution was added to each sample immediately after collection. The samples were kept cold and dark during transportation to the field laboratory where each was filtered through a Millipore RA (1.2 μ) filter under slight vacuum. The filters were dried and refrigerated in a darkened desiccator for analysis. Storage of samples before analysis was less than 2 weeks. The filters were dissolved in 90 percent aqueous acetone. Light absorbance of the resultant solutions was determined at wave lengths of 480, 510, 630, 645, 665, and 750 μ with a Bausch and Lomb Spectronic 20 colorimeter. Plant pigment concentrations were calculated according to the equations of Parsons and Strickland (1963).

A statistical analysis was conducted to test significant differences in chlorophyll a concentration between stations. The paired average monthly chlorophyll a values between stations were tested. Part of the

analysis used paired t-tests with the null hypothesis: No difference between monthly chlorophyll a between stations ($H_0: \mu_0 = 0$) and alternative hypothesis: Some difference between monthly chlorophyll a concentration between stations ($H_1: \mu_0 \neq 0$). The paired t-test reduced the effects of seasonal change if the monthly change in chlorophyll a values at the two stations compared was positively correlated. A Pearson r correlation coefficient indicated which stations were positively or negatively correlated. Those stations that were negatively correlated were tested using an unpaired t-test. The null hypothesis was: No difference between the mean chlorophyll a concentration between stations ($H_0: \mu_1 = \mu_2$); the alternative hypothesis was: Some difference between the mean chlorophyll a concentrations between stations ($H_1: \mu_1 \neq \mu_2$).

4.3.3.2 Primary Production. Measurement of primary production by phytoplankton was begun in May 1975. A procedure was used similar to that discussed by Vollenweider (1974), for in situ ^{14}C liquid scintillation method. Water samples were taken from 0, 1, 2, 3, and 5 m, and from a depth 2.5 to 4.5 times Secchi disc depth. Starting in August a sample was also taken from 7 m. Three pyrex 125-ml bottles were filled with this water for each depth. Two of the bottles were clear and one taped with black electrician tape and the top covered with tinfoil to prevent light penetration. Each bottle was inoculated with approximately 0.5 μ Ci of $\text{Na}_2^{14}\text{CO}_3$ using a Clay Adams Selectapette automatic pipet. At all times, except during filling and inoculation, the bottles were kept out of the light in a rectangular box with a sliding top (dark box). After inoculation each group of three bottles was attached to a wire spreader which was clipped to a loop of heavy gauge seine twine and lowered to

the appropriate depth. This line had a 0.2-kg weight attached below the deepest bottle to maintain its vertical position. After all the bottles had been lowered, the line was affixed to an 8-ft bar that was supported at either end by a 1.5 x 1.5 x 4-ft styrofoam float. These floats were then anchored at one end and left to incubate 4 to 6 hours during the mid-day period.

Solar radiation was recorded on a Belfort pyroheliometer during the day of incubation. The total available carbon was determined from pH, temperature, and alkalinity using a conversion table in Saunders, et al. (1962). Temperature and pH were measured in situ at each depth sampled. Alkalinity was determined from water samples at 1, 3, and 7 m and the depth of the deepest bottles.

After the bottles had incubated they were retrieved and put back in the dark box and taken to the field laboratory. Within 2 hours after retrieval the contents of each bottle were filtered through a 1.2 μ RA Millipore filter under 5 to 10 lb/in² vacuum. After the contents had been filtered, 20 to 40 ml of distilled water was filtered through each filter to wash nonassimilated Na₂¹⁴CO₃ from the filter. Each filter was then placed into a glass scintillation vial and 20 ml scintillation solution (1 liter toluene, 40 g Bio-Solv, 5 g PPO, 0.5 g POPOP) added to each. Vials were kept in the dark and returned to the University of Washington, College of Fisheries, Laboratory of Radiation Ecology, where the ¹⁴C activity of the filters was determined on a Packard Tricarb Model 3375 liquid scintillation counter.

Stations 1 and 4 were used as monthly index stations of lake primary production and Station 6 as a periodic comparison. To minimize the

effects of daily variation in light, both stations were measured on the same day. Since all operations were done from one boat, both stations could not be set simultaneously, but were staggered in their starting and retrieval time. Station 4 bottles were set 1.5 hours before Station 1 and picked up 0.5 hours before Station 1. Station 6 was sampled only on days when either Stations 1 or 4 were sampled. Some months were not reported because of severe weather conditions which inhibited sampling or when variations in technique prevented determination of $\text{Na}_2^{14}\text{CO}_3$ used. Carbon 14 primary production measurements in FDR forebay were conducted either one day before or one day after those in Banks Lake starting in February 1976.

4.3.3.3 Zooplankton Abundance. Zooplankton standing stock estimates for each station were determined from data obtained by vertical hauls of a 0.5-m diameter plankton net of 73 μ (no. 20) mesh (Edmondson and Winberg 1971). Duplicate hauls were made at each station from near the bottom to the surface, and from 4 m to the surface. Zooplankton hauls in FDR forebay were taken from 4, 20, and 95 m or near bottom to surface. The net was hauled with a Warn electric winch at an approximate speed of 30 m/min. Samples were preserved in 10 percent formalin through April 1974; later samples were preserved in 90 percent ethanol.

Zooplankton samples were diluted in the laboratory to a concentration of 100-200 organisms per ml. From two to four 1-ml subsamples from each sample were counted with a low power stereo microscope (10 to 300 times magnification) over a grid etched on a glass dish. Numbers of each genus of cladoceran and copepod and of copepod nauplii were recorded. The volume of water sampled was calculated by multiplying the net mouth

area by the distance hauled. The number of each zooplankton genus per m^3 was calculated. A flow meter was placed in the net opening to quantify the water volume sampled. The metered volume averaged 65 percent of the theoretical volume based on net opening and haul distance for the bottom-to-surface hauls in Banks Lake. But this average value could not be used as a conversion factor for zooplankton density because individual values varied widely between replicate hauls.

Taxonomic identification of zooplankton crustacean species was carried out by Mr. Rufus Kiser.

4.3.3.4 Zooplankton Biomass Estimate. An estimate of crustacean zooplankton dry weight biomass was made for the period from April 1975 to March 1976. During this period, monthly length measurements of 50 individuals of each major genera were made for all Banks Lake stations from the bottom to surface hauls. The lengths were used to estimate average weight for each genera from length-weight regression equations obtained from literature values.

4.3.4 Feeder Canal Measurements

Beginning in April 1976, all Hydrolab, chemical, and chlorophyll a measurements were taken where the incoming water first entered the feeder canal, at the headworks. Two water samples each were taken for water chemistry analysis and chlorophyll a concentration.

4.4 Results

4.4.1 Water Temperature

4.4.1.1 Seasonal Effects. The trends in lake temperature at 4-m depths for Stations 2 through 6 followed closely with seasonal air

temperature. The temperature patterns at Station 1 were more closely related to the temperature of the water at the depth of intake in FDR Reservoir (Figs. 4.4, 4.5, and 4.6). During the four summers of this study the mean maximum monthly air temperatures were 23.2° C, 22.5° C, 24.5° C, and 21.4° C in 1973, 1974, 1975, and 1976, respectively. July was the month of warmest average temperatures all years except for 1974 when August was the warmest month. Maximum air temperatures during the summer of 1975 and the winter of 1976 were warmer than comparable seasons during 1973 and 1974. A mean winter air temperature of -3° C occurred during January 1974.

Mean maximum summer water temperature for Stations 2 through 6 was 19.8° C in July 1975 (Fig. 4.5). The maximum water temperature at Station 1 was 19.2° C and did not occur until August 1975. The same pattern occurred in 1976. At Station 1 a maximum temperature of 17.5° C was reached in August. This was 1 month later than at Stations 2 through 6 where the maximum was 19.1° C. The temperature difference between Station 1 and Stations 2 through 6 resulted from the pumped input of irrigation water and reached as high as 4.6° C in July 1975.

A mean minimum winter water temperature of 0.9° C occurred at Stations 2 through 6 in January 1976. Minimum winter temperatures at Station 1 were higher during the period December 1975 through March 1976. The north end of the lake was warmer by 2.9°, 2.1°, 1.4° and 0.6° C during December 1975, and January, February and March 1976. This increase in temperature occurred in response to intermittent pumped input of warmer water from FDR Reservoir (Fig. 4.6). Pumping occurred during this time to refill the lake during December 1975 and due to pump

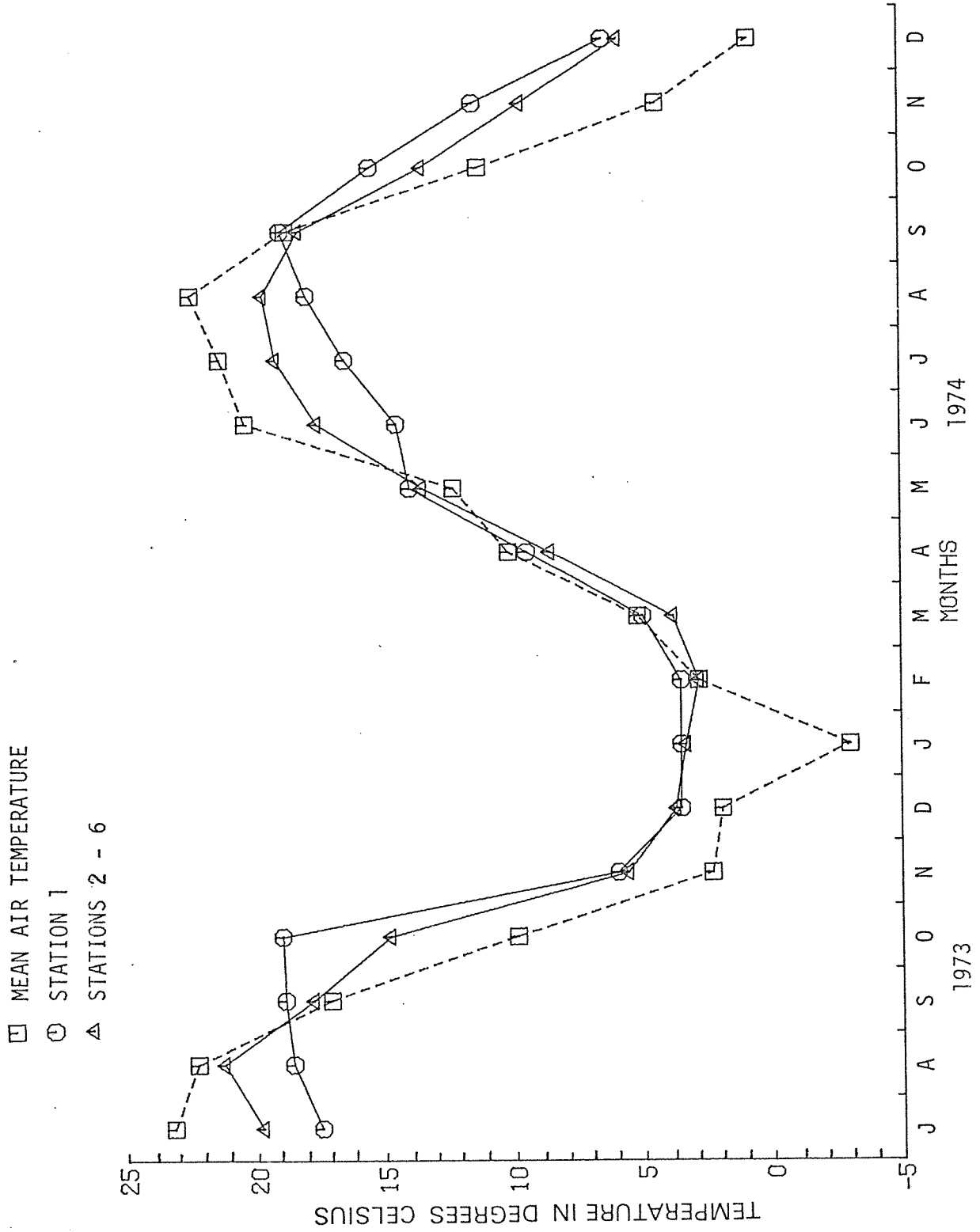


Fig. 4.4 Banks Lake mean water temperatures at 4 meters versus mean monthly air temperatures, comparing Station 1 and Stations 2-6, for the period July 1973 to December 1974.

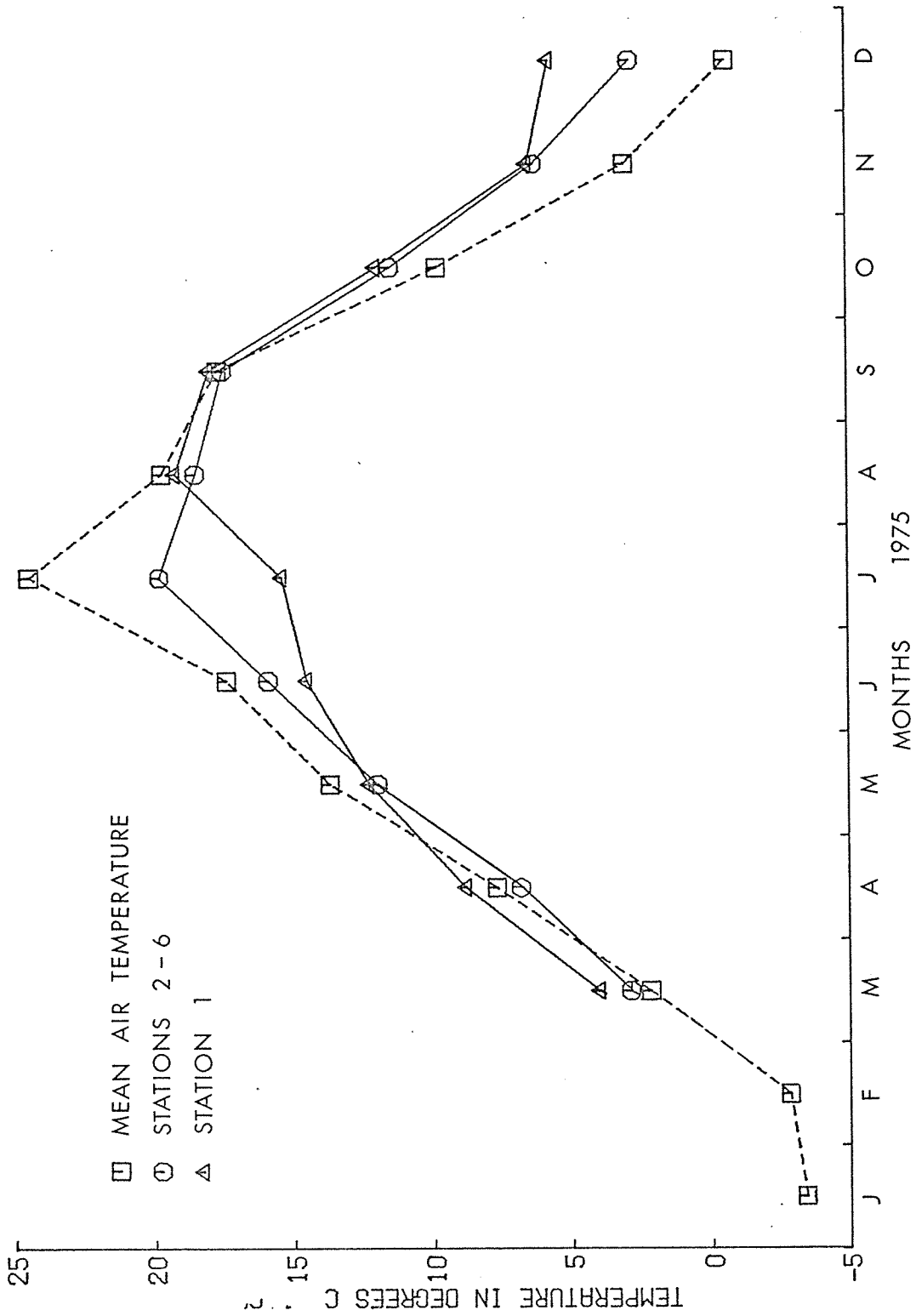


Fig. 4.5 Banks Lake mean water temperature at 4 meters versus mean monthly air temperature, comparing Station 1 and Stations 2 through 6, for the period January through December 1975.

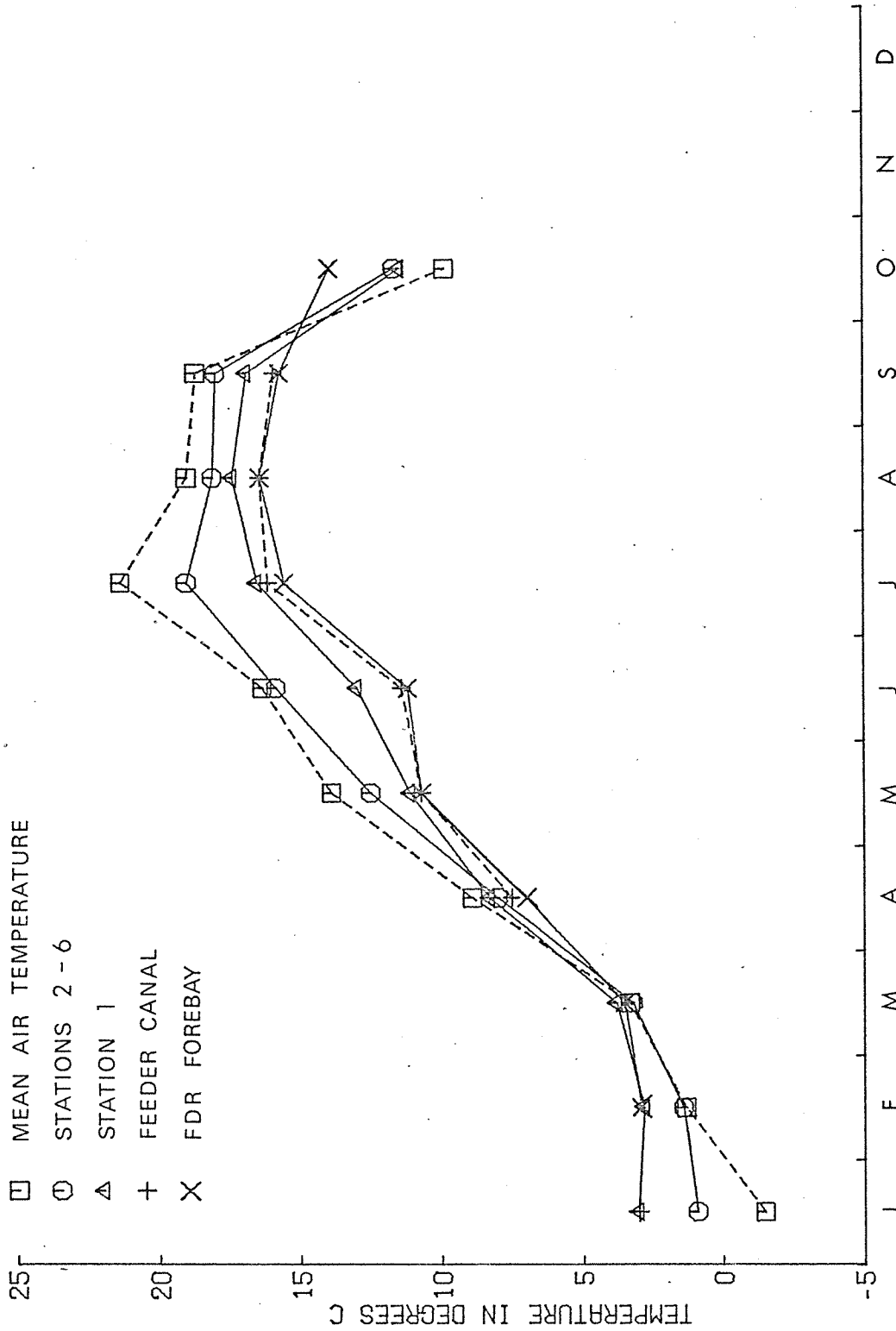


Fig. 4.6. The mean air temperature versus the average water temperature of Banks Lake at 4 meters for Stations 1 and 2 through 6; and the water temperature at the feeder canal headworks and FDR Reservoir at the depth of water intake for the feeder canal and pumps; for the period January to October, 1976.

generation (P/G) testing which occurred from January through March 1976. The lake was nearly homothermous during periods of spring and fall overturn. However, the main body of the lake (Stations 2 through 6) was cooler than Station 1 during March and April 1975. This suggests that higher temperatures occurred at Station 1 during December 1974 and January and February 1975 due to pumpback during P/G operation.

A similar summer divergence of temperature between Station 1 and Stations 2 through 6 noted in 1975 was apparent in 1973 and 1974 (Fig. 4.4). However, the homothermous fall temperature during 1975 did not occur during 1973 and 1974. Late fall pumping in these 2 years caused Station 1 to be warmer than Stations 2 through 6. Pumping stopped October 21, 1973, and at that time Station 1 was 4.2° C warmer than Stations 2 through 6. By November, Station 1 was only 0.4° C warmer, and in December, 0.2° C cooler than Stations 2 through 6. Pumping continued through November 30 in 1974, which maintained the temperature at Station 1, 0.7° , 2.0° and 1.8° C warmer than at Stations 2 through 6 during September, October and November, respectively.

The temperature data for FDR forebay at the depth of water intake for Banks Lake pumps and the feeder canal temperature at the headworks indicated the dependency of Station 1 temperature on that of the inflowing water (Fig. 4.6). Some increase in temperature ranging from 0.4° to 1.6° C greater than that at the pump intakes in FDR Reservoir occurred at Station 1 during spring and summer. However, the temperature at Station 1 more closely approximated the temperature of the inflow water than it did that of the air temperature. This is in contrast to Stations 2 through 6 temperatures, which followed seasonal changes in air temperature.

Station 1 did not follow the same temperature pattern as that of the inflow in October 1976. This may have been a result of the slowing of pumping during this month, and the large decrease in air temperature.

4.4.1.2 Convergence Zone. During the irrigation season a convergence zone was established in the lake approximately 12 km (7 miles) from the north dam. The convergence resulted from the flow of cooler water pumped into the north end of Banks Lake from FDR Reservoir during the late spring and summer and the drafting of irrigation water through the south dam which established a general southward flow through the lake. The basin narrows and shoals, forming a constricted zone of flow in the area of the convergence. An extremely sharp convergence occurred during August 1973 (Stober et al. 1975). The same phenomenon was observed during July 1974, 1975, and 1976, but was less pronounced than in 1973, due to an increase in the lake level which correspondingly increased the cross-sectional area of the channel. The July 1975 isotherms are shown as a typical convergence for a high-water year during summer pumping (Fig. 4.7). The convergence was also observed to shift northward with decreased flow and/or with increasing lake level.

4.4.1.3 Lake Stratification. The north 10 to 12 km (6 to 7 miles) of Banks Lake was cooler and nearly homothermous throughout the summer of 1975 and 1976 (Fig. 4.8). Maximum stratification at Station 1 was less than 1° C between the surface and 12-m depth except during May 1975 and June 1976 when it was 2° C. The lack of pronounced stratification resulted from pumped input of water for irrigation in the summer and pumpback during P/G operation in the winter. During summer irrigation season from June to October 1976 the depth of the pump intakes in FDR

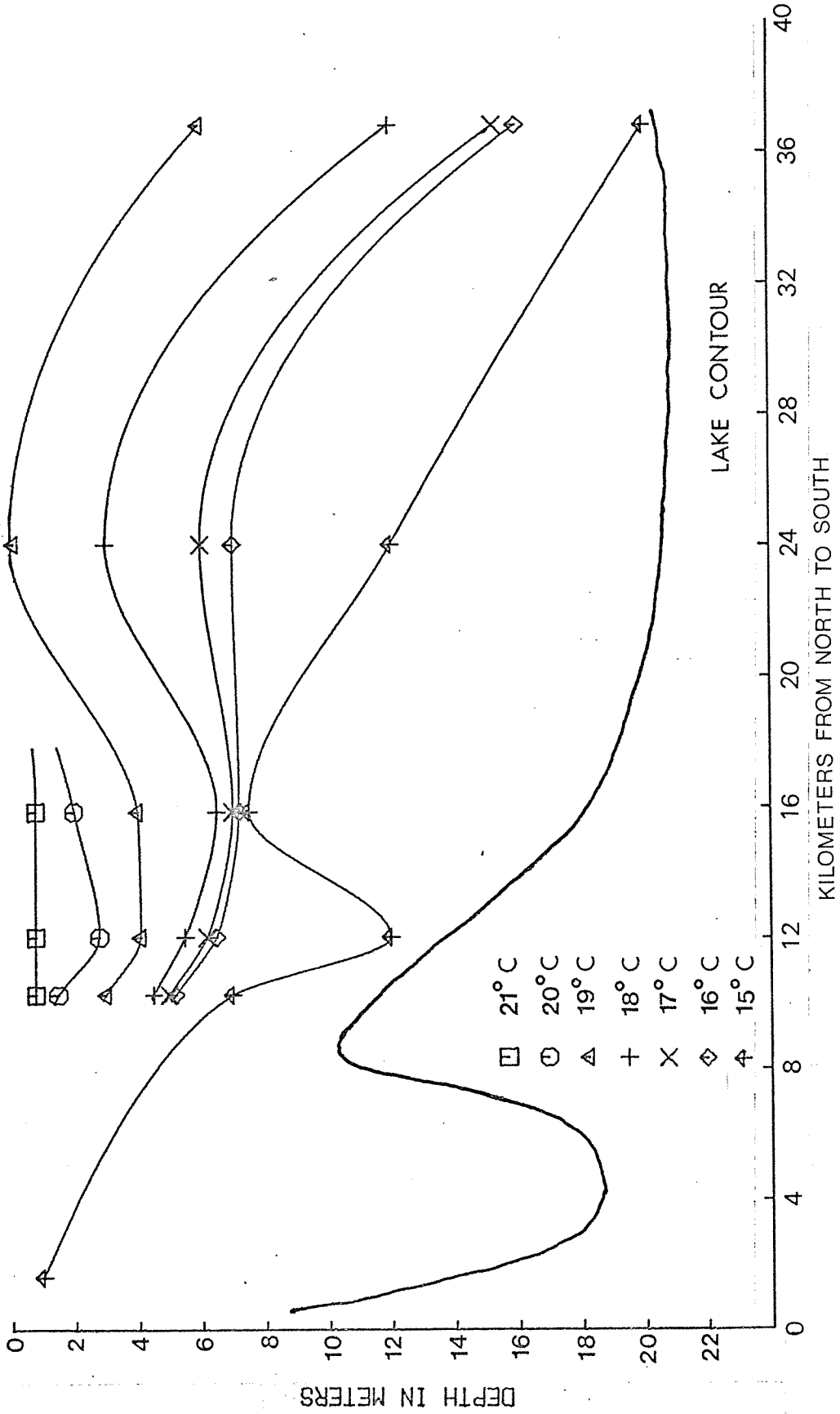


Fig. 4.7 Banks Lake isotherms (July 23, 1975) showing the convergence zone north of kilometer 10, where cold water pumped in from FDR Reservoir descends under a warm epilimnetic layer south of kilometer 10.

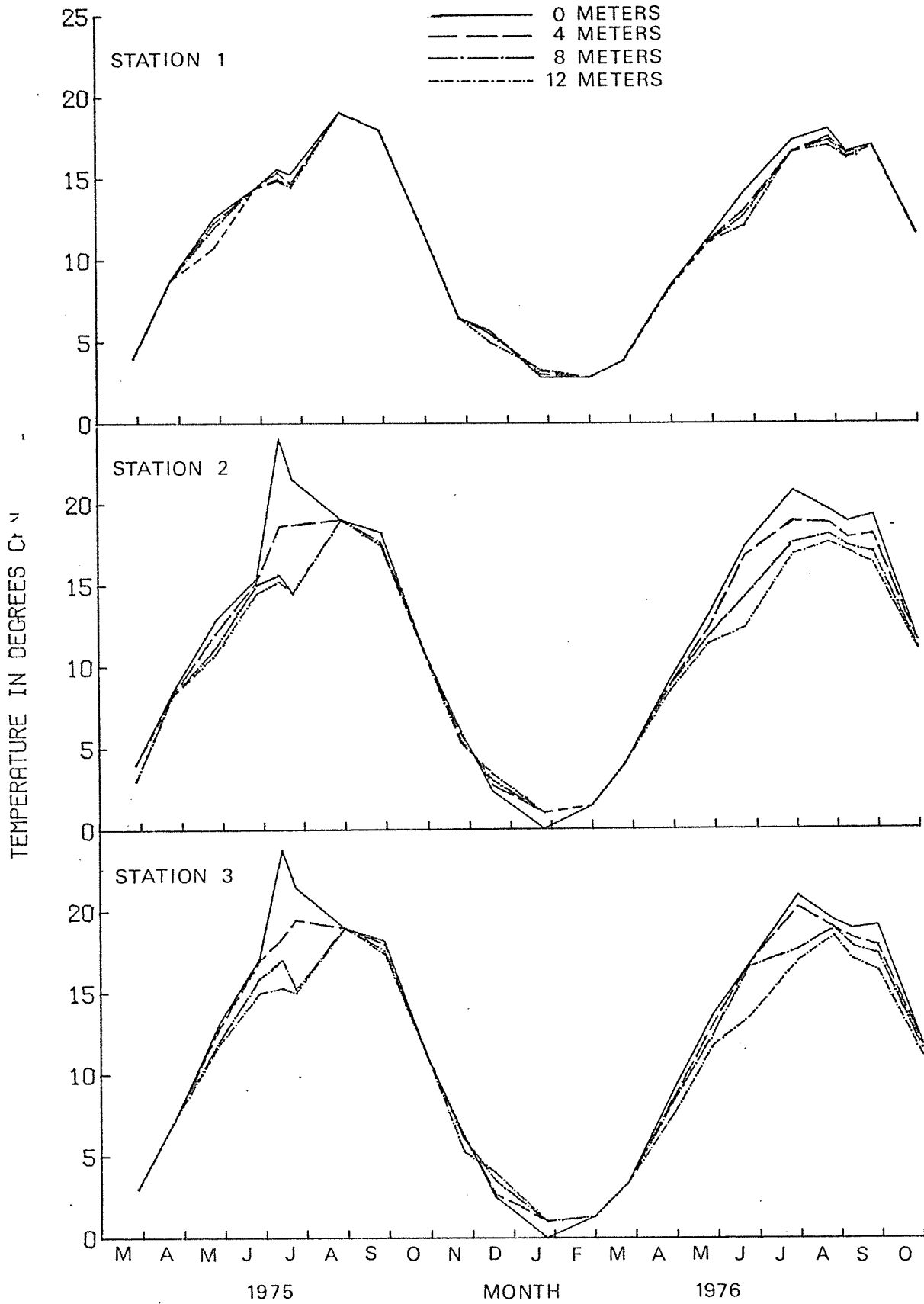


Fig. 4.8 Monthly changes in water temperature in Banks Lake at 4-meter depth intervals at Stations 1, 2 and 3.

forebay was 30 m, indicating that FDR Reservoir was held at full pool. The largest stratification in FDR forebay occurred above 20 m (Figs. 4.9 and 4.10). Therefore, the cool summer temperatures observed at Station 1 were caused by the input of cool hypolimnetic water taken from below the thermocline in FDR forebay. During the winter months, January to March 1976, the P/G operation maintained warm, unstratified temperatures greater than 2.8° C at Station 1. Vertical stratification began to develop at Stations 2 through 6 during May 1975 and became pronounced by July (Figs. 4.8 and 4.11). The lake became nearly homothermous during September 1975 and remained so as temperatures declined throughout the fall. Solid ice cover occurred only at Stations 2 and 3, on enclosed bays and near Dry Falls Dam during January 1976, while the rest of the lake remained largely ice-free throughout the winter. Vertical stratification began a month earlier in April 1976, and was most pronounced in July. Stratification persisted until late October at Stations 2, 3, and 4, but was absent at Stations 5 and 6 by September.

4.4.2 Dissolved Oxygen

Dissolved oxygen saturation was similar in 1975 and 1976. The saturation remained high both years, ranging from 54 to 122 percent in 1975 and 33 to 127 percent in 1976 (Tables 4.2 and 4.3). Lowest surface saturation occurred during mid-summer at Station 6, at 97 percent and 87 percent in 1975 and 1976, respectively. Highest saturation levels were at Stations 1, 2, and 3 most often in May, June, and July. Lowest saturation levels were near the bottom during July, August, and September both years at Stations 4, 5, and 6. The dissolved oxygen concentration average for the water column at Station 1 was higher than that at the

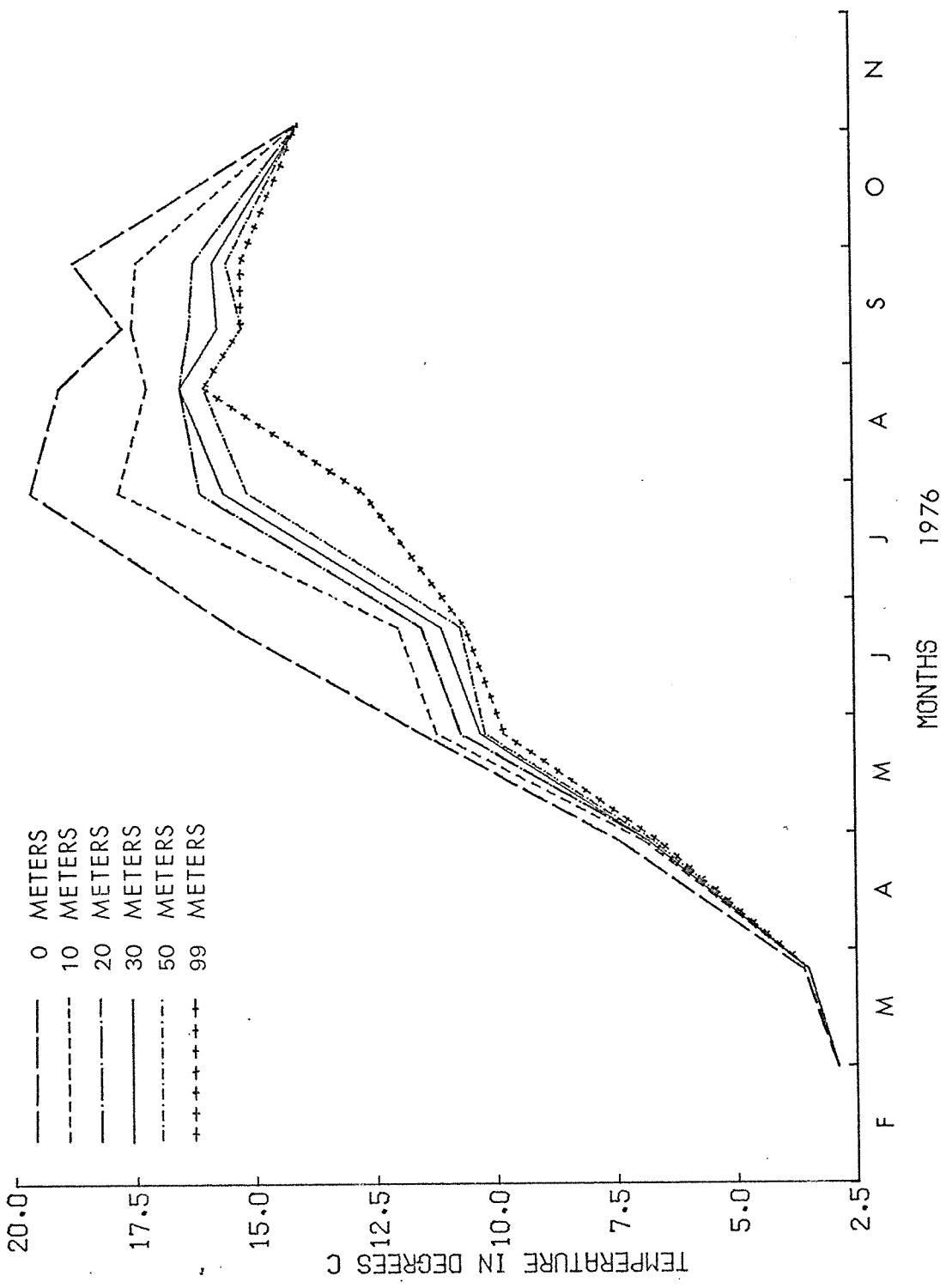


Fig. 4.9 Temperature at selected depth strata in FDR Reservoir forebay for the period February to October 1976.

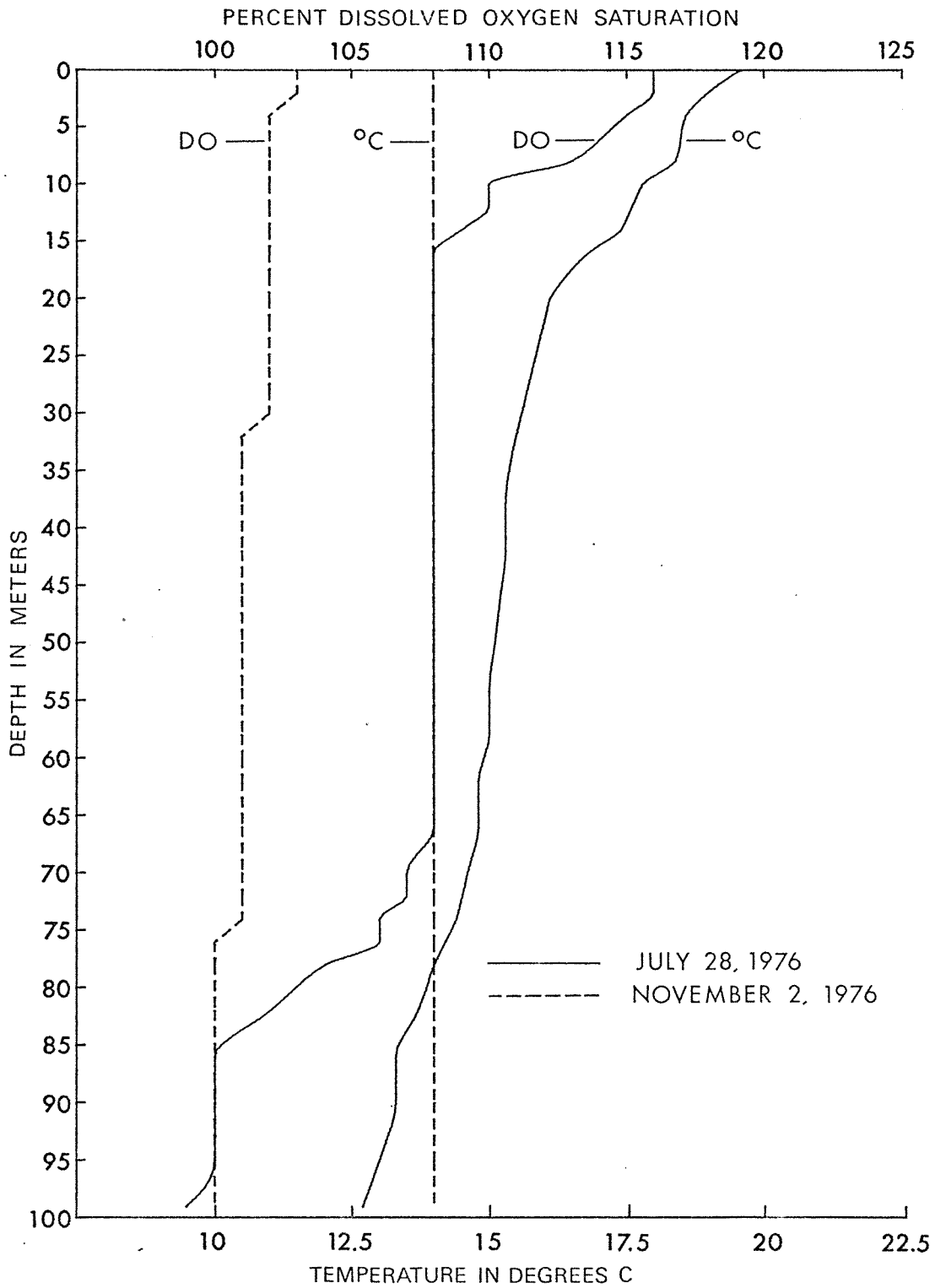


Fig. 4.10 Temperature and percent dissolved oxygen saturation in FDR Reservoir forebay for July 28 and November 2, 1976.

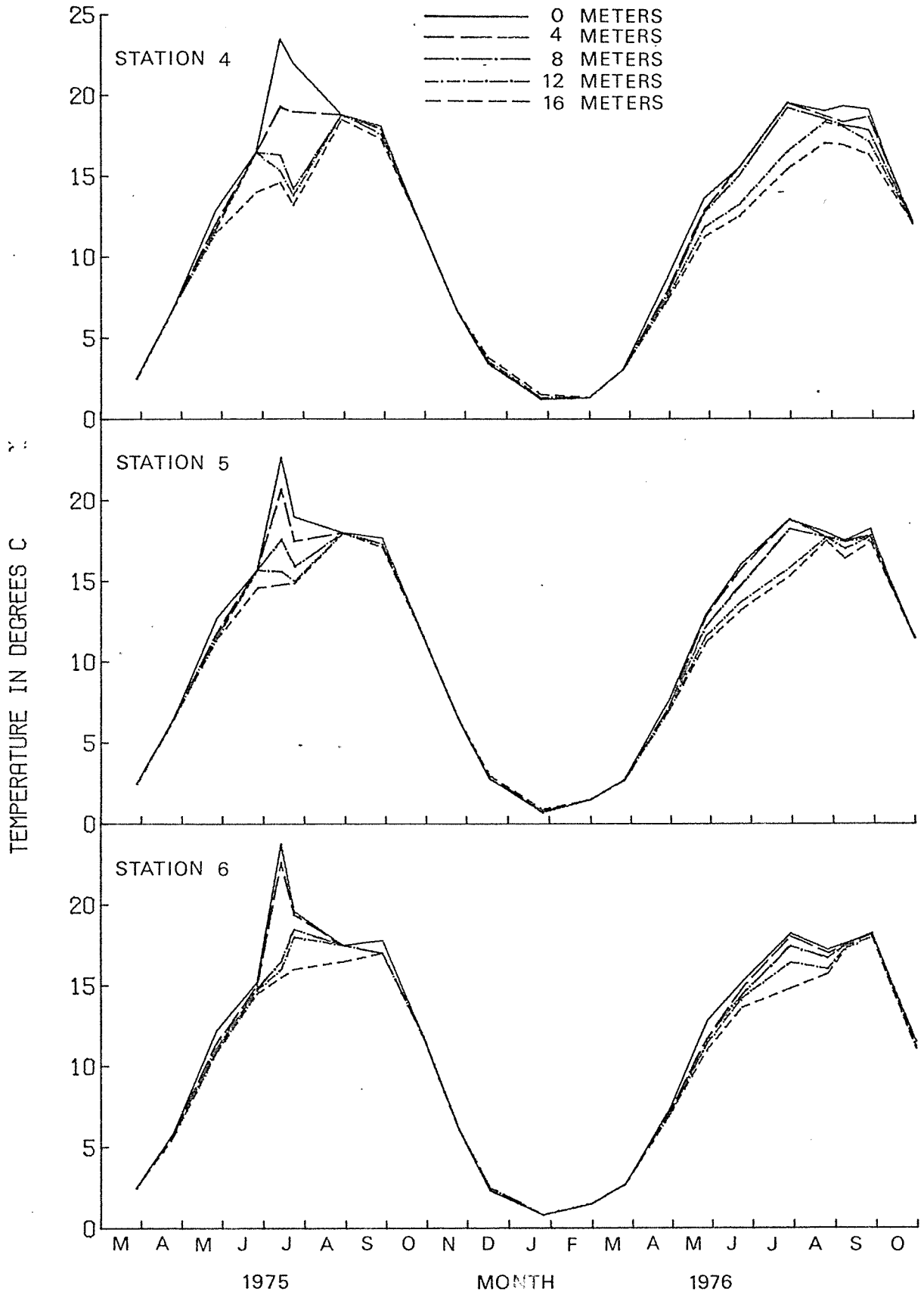


Fig. 4.11 Monthly changes in water temperature in Banks Lake at 4-meter depth intervals at Stations 4, 5 and 6.

Table 4.2 Average percent dissolved oxygen saturation by depth strata for Banks Lake from April 1975 to December 1975.

Station	Depth Strata	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean for each depth strata
1	*0-6	107	116	119	106	107	102	104	101	106	108
	**B4	110	112	115	98	106	102	104	101	105	106
	***W.C.	109	114	118	103	107	102	104	101	106	107
2	0-6	108	111	119	116	109	110	102	103	102	104
	B4	109	106	116	100	110	82	103	103	100	103
	W.C.	108	108	118	109	109	96	102	103	101	106
3	0-6	106	108	114	113	109	106	102	103	101	107
	B4	110	104	118	104	90	82	102	104	102	102
	W.C.	109	106	116	109	103	95	102	103	101	105
4	0-6	108	101	105	116	102	106	101	101	103	105
	B4	110	98	99	76	85	83	104	102	101	95
	W.C.	110	99	103	97	97	98	102	101	102	101
5	0-6	110	99	105	112	100	104	103	103	104	104
	B4	110	94	96	76	102	95	103	100	101	97
	W.C.	110	97	102	94	101	100	103	101	103	101
6	0-6	107	102	105	113	97	105	103	102	106	104
	B4	109	98	90	73	64	98	102	100	103	93
	W.C.	108	100	99	100	85	101	102	101	105	106
High		110	117	121	122	111	110	106	105	106	
Low		106	91	81	63	54	64	102	99	99	
Monthly Mean	0-6	108	106	111	113	104	106	103	102	104	106
	B4	110	101	106	89	93	90	103	102	102	100
	W.C.	109	104	109	102	100	99	103	102	103	103

*0-6 Mean of surface to 6 meters
 **B4 Mean of bottom 4 meters
 ***W.C. Mean of water column

Table 4.3 Average percent dissolved oxygen saturation by depth strata in Lake Roosevelt and Banks Lake from January through October 1976.

Station	Depth Strata	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Mean for each depth strata
Roosevelt	*0-6	+	111	111	110	125	118	115	119	110	103	114
	Intake	+	111	111	108	119	115	108	106	105	102	109
	B4	+	111	111	105	111	113	99	102	104	100	106
	W.C.	+	111	111	108	118	115	109	109	106	101	110
Banks 1	0-6	105	117	113	111	123	123	111	111	108	101	112
	B4	102	115	111	111	118	114	110	106	108	98	109
	W.C.	104	116	112	111	119	119	111	109	108	100	111
2	0-6	+	108	112	108	127	116	108	111	118	93	111
	B4	+	107	110	105	120	115	104	106	101	91	107
	W.C.	+	107	111	106	123	116	106	109	111	92	109
3	0-6	+	108	109	108	123	111	108	108	113	104	110
	B4	+	107	109	103	124	114	102	108	95	90	106
	W.C.	+	108	109	107	123	113	106	108	105	99	109
4	0-6	107	109	109	108	109	109	107	104	106	101	105
	B4	105	109	109	104	104	81	69	48	50	98	88
	W.C.	106	109	109	106	107	97	94	87	83	100	100
5	0-6	107	109	109	106	106	105	105	98	101	99	105
	B4	105	109	108	105	95	89	79	87	71	98	95
	W.C.	106	109	109	106	101	97	91	96	91	98	100
6	0-6	108	110	111	108	107	104	87	93	102	100	103
	B4	106	110	109	106	97	88	68	66	101	100	95
	W.C.	107	110	110	107	103	99	80	80	102	100	100
High Low		107	117	113	113	127	126	113	97	120	104	-
		100	107	108	102	90	79	56	35	33	69	-
Monthly Mean (Banks Lake only)	0-6	107	110	111	108	115	111	104	104	108	100	108
	B4	105	110	109	106	108	100	87	87	88	96	100
	W.C.	106	110	110	107	113	107	98	98	100	98	105

*0-6 = mean of surface to 6 meters

Intake = average D.O. 6 m above and below intake

B4 = mean of bottom 4 meters

W.C. = mean of water column

+ = no sample taken

depth of intake in FDR forebay all months except October. This indicated an increase in dissolved oxygen from mixing and/or increased primary production due to pumped input.

The effect of thermal stratification on oxygen saturation is shown in selected vertical profiles taken during July and November 1975 (Fig. 4.12). Turbulent mixing due to pumped input of water through the feeder canal resulted in very little change in both parameters throughout the water column during July at Station 1. Temperature stratification occurred during July at Stations 2 and 3 and the dissolved oxygen exhibited a clinograde curve with depth which remained above 90 percent saturation at the bottom. These levels remained high probably because pumping was pushing saturated cooler water into the lower strata from Station 1 and also the shallow depth allowed photosynthesis to proceed near the bottom. Stations 4, 5, and 6 showed the greatest reduction of dissolved oxygen with depth and vertical temperature stratification during July. The dissolved oxygen curves tended to follow the change in temperature, but continued to decrease toward the bottom. The thermal stratification had reduced mixing between the epilimnion and the hypolimnion. Reduction of oxygen occurred at the greater depths due to respiration being greater than photosynthesis. The November measurements showed that thermal stratification had broken down during the fall and water had become mixed from top to bottom at all stations. Dissolved oxygen thus became uniform at all depths.

The vertical profiles of dissolved oxygen saturation and temperature followed similar trends during stratification in FDR forebay in 1976 (Fig. 4.10). The dissolved oxygen saturation in July near the bottom

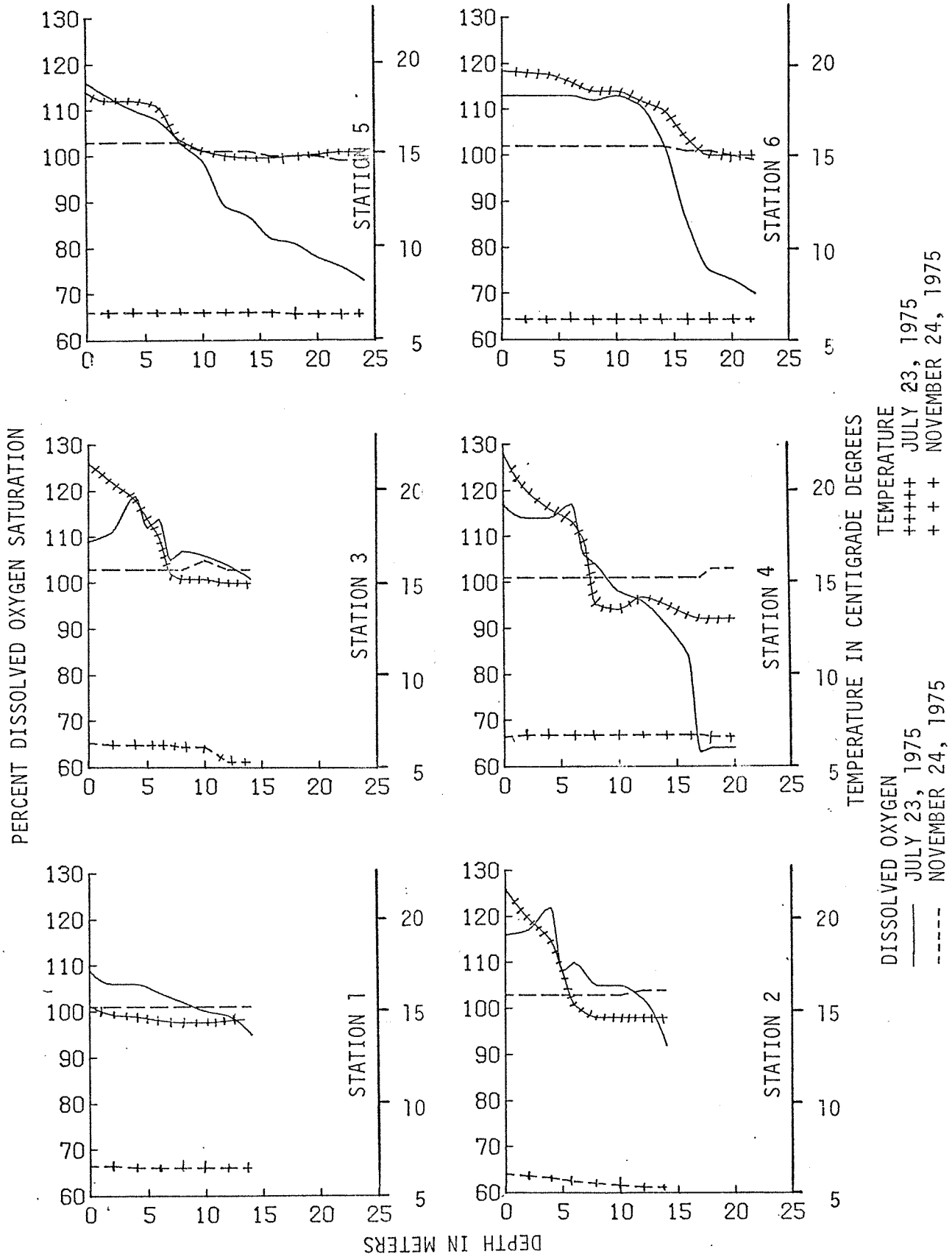


Fig. 4.12 Temperature and dissolved oxygen saturation curves for all stations during July 23 and November 24, 1975.

was the lowest observed for the summer but was still greater than 98 percent. Water temperature and dissolved oxygen became uniform from top to bottom by late October.

4.4.3 Transparency

Monthly water transparency measurements of Banks Lake from August 1973 to October 1976 showed temporal and spatial variation throughout the observation period (Figs. 4.13 and 4.14). Mean transparency depths at Stations 1 through 6 were 3.6, 3.1, 3.3, 4.1, 4.1, and 5.5 m, respectively. Values ranged from 1.0 to 10.0 m. Station 2 generally exhibited the lowest transparency while Station 6 exhibited the greatest. The Secchi depth in FDR forebay averaged 3.6 m from February to October 1976. Seasonally, Stations 1, 2, 3, and FDR forebay had late winter and early spring lows, which often coincided with phytoplankton blooms. In midwinter, these lows may have been more closely associated with silt, especially in FDR forebay. Generally, transparency was least in late winter and spring, increased during the summer and fall, and was greatest in late fall or early winter. No distinctive trends were apparent by season for Stations 4, 5, or 6.

4.4.4 Water Chemistry

4.4.4.1 pH. The in situ pH values ranged from 7.0 to 9.0 in Banks Lake from April 1975 to October 1976 (Tables 4.4 and 4.5). The highest values each year occurred in May 1975 and October 1976. The FDR maximum pH was observed in July and minimum in August. There was a general decrease in pH by depth in both reservoirs. Stations 1, 2, and 3 most

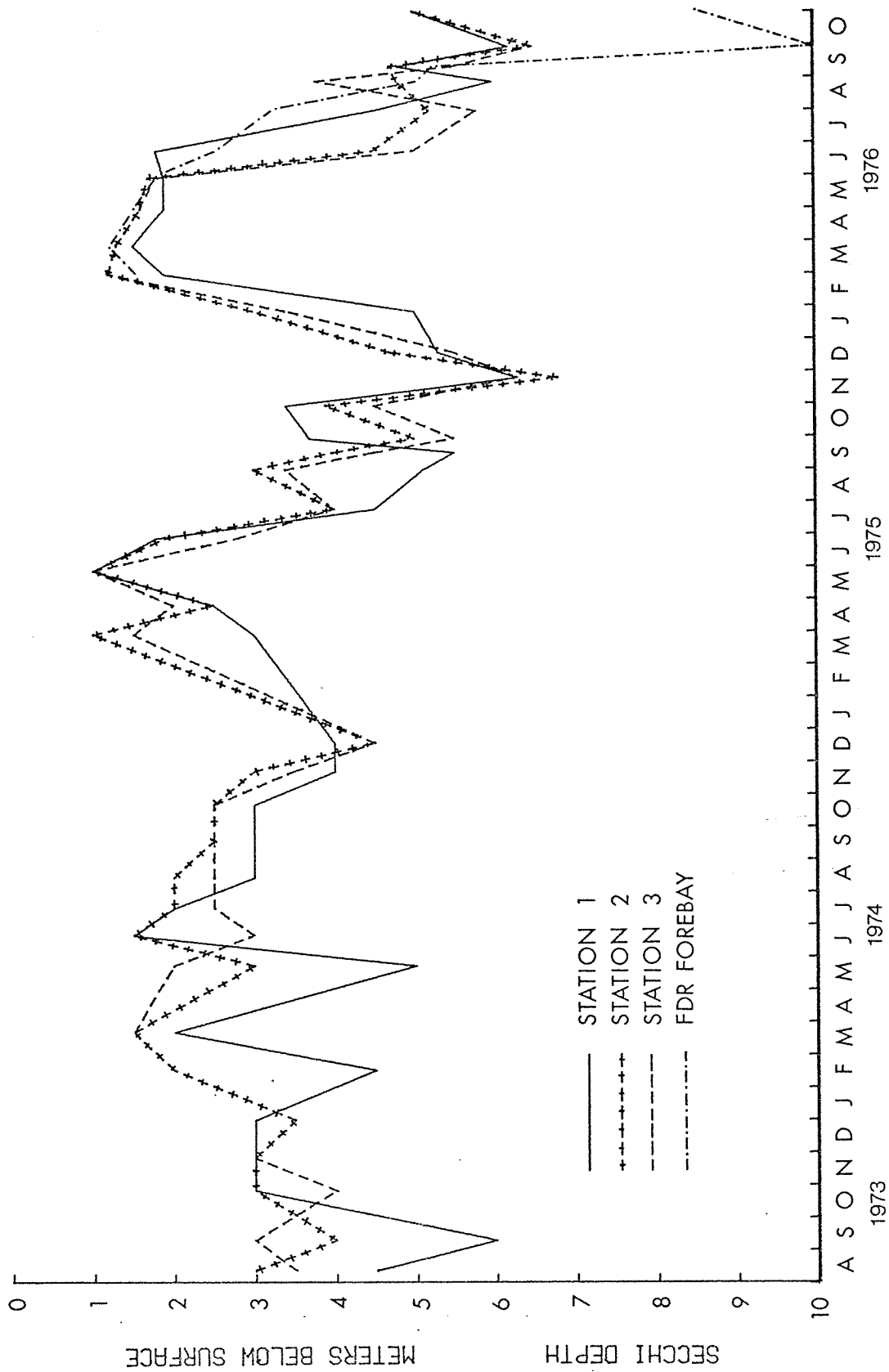


Fig. 4.13 Monthly changes in Secchi depth transparency in Banks Lake at Stations 1, 2 and 3, and FDR Reservoir forebay.

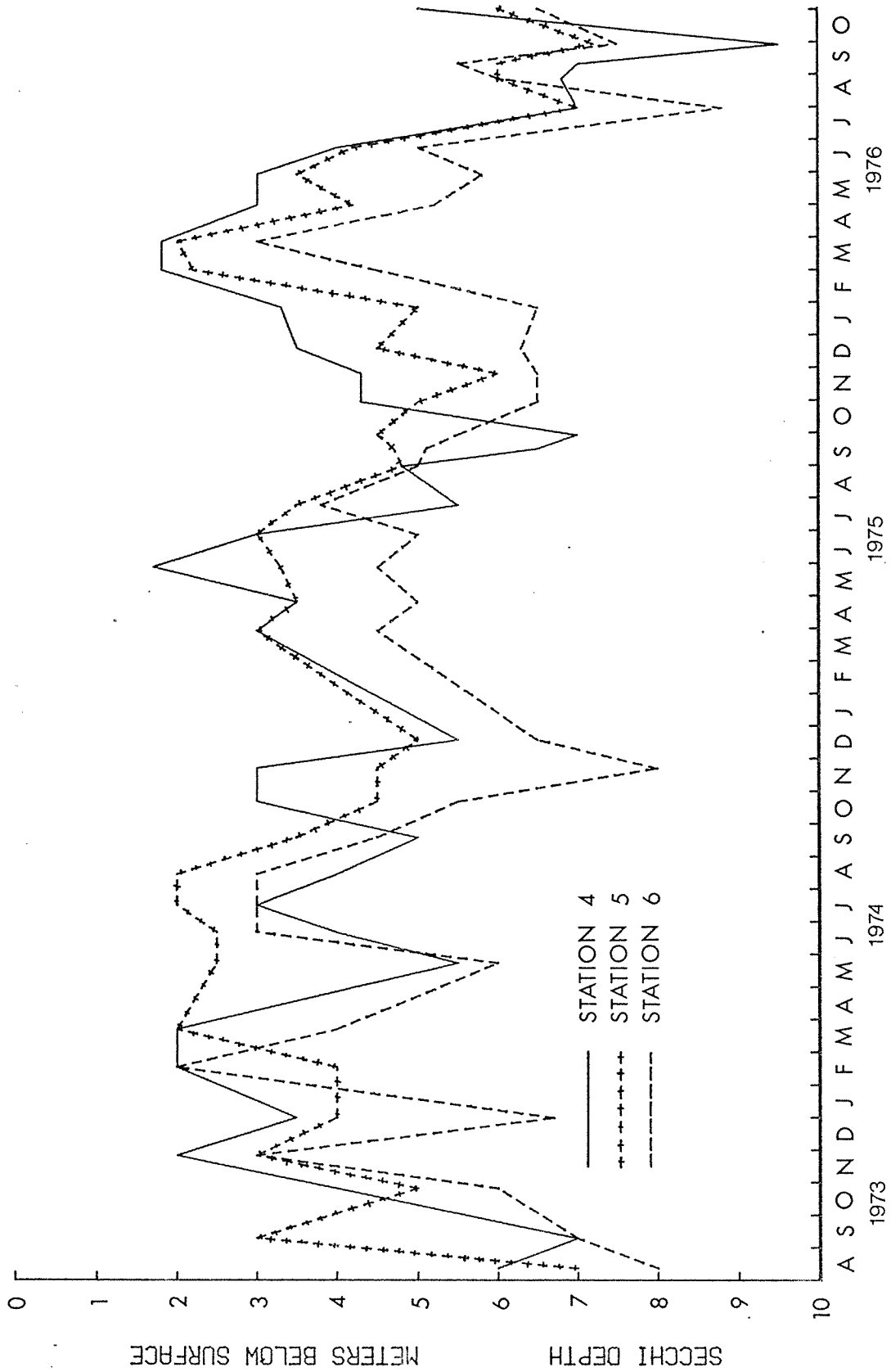


Fig. 4.14 Monthly changes in Secchi depth transparency in Banks Lake at Stations 4, 5 and 6.

Table 4.4. Average pH by depth strata in Banks Lake from April through December 1975.

Station	Depth Strata	April	May	June	July	August	Sept	Oct	Nov	Dec	Mean for each depth strata
1	*0-6	8.2	8.8	8.2	7.5	7.8	8.2	8.4	8.2	8.4	8.2
	**B4	8.2	8.6	8.0	7.6	7.7	8.0	8.3	8.2	8.5	8.1
	***W.C.	8.2	8.7	8.1	7.6	7.7	8.1	8.4	8.2	8.4	8.2
2	0-6	8.3	9.0	8.2	7.6	8.1	8.4	8.2	8.2	8.5	8.3
	B4	8.3	8.9	7.9	7.6	8.0	7.6	8.2	8.2	8.4	8.1
	W.C.	8.3	9.0	8.1	7.6	8.0	8.0	8.2	8.2	8.5	8.2
3	0-6	8.3	9.0	8.2	7.6	8.1	8.4	8.2	8.2	8.5	8.3
	B4	8.3	8.8	8.2	7.7	7.7	7.6	8.2	8.2	8.5	8.1
	W.C.	8.3	8.9	8.2	7.6	7.9	8.0	8.2	8.2	8.5	8.2
4	0-6	8.3	8.7	8.2	7.6	7.9	8.3	8.2	8.2	8.5	8.2
	B4	8.3	8.4	7.9	7.6	7.6	7.7	8.2	8.2	8.5	8.0
	W.C.	8.3	8.6	8.1	7.6	7.8	8.0	8.2	8.2	8.5	8.1
5	0-6	8.3	8.5	8.0	7.7	7.8	8.2	8.2	8.2	8.5	8.2
	B4	8.2	8.2	7.7	8.2	7.7	8.0	8.2	8.2	8.5	8.1
	W.C.	8.3	8.4	7.9	7.8	7.8	8.1	8.2	8.2	8.5	8.1
6	0-6	8.3	8.6	8.0	8.4	7.7	8.2	8.2	8.1	8.4	8.2
	B4	8.2	8.4	7.8	8.4	7.1	8.1	8.2	8.0	8.4	8.1
	W.C.	8.2	8.4	7.9	8.4	7.5	8.2	8.2	8.1	8.4	8.1
High		8.4	9.0	8.4	8.4	8.1	8.4	8.4	8.2	8.5	-
Low		8.1	8.2	7.6	7.5	7.0	7.4	8.2	7.8	8.4	-
Monthly mean for each depth strata	0-6	8.3	8.7	8.1	7.7	7.9	8.3	8.2	8.2	8.5	8.2
	B4	8.2	8.5	7.9	7.8	7.6	7.8	8.2	8.2	8.5	8.1
	W.C.	8.3	8.7	8.0	7.8	7.8	8.1	8.2	8.2	8.5	8.2

*0-6 = mean of surface to 6 meters

**B4 = mean of bottom 4 meters

***W.C. = mean of water column

Table 4.5 Average pH by depth strata in Lake Roosevelt and Banks Lake from January through October 1976.

Station	Depth Strata	Jan	Feb	March	May	June	July	Aug	Sept	Oct	Mean for each depth strata	
Roosevelt	*0-6	+	8.2	8.5	8.7	8.7	8.9	8.8	8.8	8.3	8.6	
	**B4	+	8.2	8.5	8.1	8.0	8.1	7.8	7.9	8.1	8.1	
	***W.C.	+	8.2	8.5	8.3	8.2	8.3	8.0	8.1	8.1	8.2	
	Ave. 6M above and below intake	+	8.1	8.5	8.4	8.2	8.3	7.9	8.1	8.1	8.2	
Banks	0-6		8.4	8.7	8.6	8.4	8.6	8.4	8.5	8.2	8.6	8.5
1	B4		8.4	8.8	8.7	8.3	8.4	8.3	8.1	7.9	8.2	8.5
	W.C.		8.4	8.7	8.6	8.4	8.5	8.2	8.3	8.0	8.4	8.4
2	0-6	+	8.4	8.5	8.7	8.5	8.6	8.6	8.7	8.7	8.6	
	B4	+	8.3	8.5	8.6	8.3	8.3	8.2	8.0	8.3	8.3	
	W.C.	+	8.4	8.5	8.6	8.5	8.5	8.5	8.4	8.5	8.5	
3	0-6	+	8.4	8.4	8.6	8.4	8.5	8.6	8.6	8.6	8.5	
	B4	+	8.4	8.4	8.5	8.4	8.1	8.4	7.8	8.4	8.3	
	W.C.	+	8.4	8.4	8.5	8.4	8.3	8.5	8.2	8.5	8.4	
4	0-6		8.4	8.4	8.4	8.4	8.4	8.5	8.4	8.3	8.5	8.4
	B4		8.3	8.4	8.4	8.2	8.1	7.8	7.7	7.5	8.1	8.1
	W.C.		8.4	8.4	8.4	8.3	8.2	8.2	8.1	7.9	8.3	8.2
5	0-6		8.3	8.3	8.4	8.3	8.4	8.4	8.3	8.4	8.5	8.4
	B4		8.3	8.4	8.4	8.1	8.2	7.9	8.0	7.9	8.2	8.2
	W.C.		8.3	8.3	8.4	8.2	8.3	8.2	8.1	8.1	8.3	8.2
6	0-6		8.3	8.3	8.4	8.3	8.4	8.4	8.3	8.3	8.3	8.3
	B4		8.2	8.4	8.4	8.2	8.3	8.0	7.7	8.1	8.1	8.2
	W.C.		8.3	8.3	8.4	8.3	8.4	8.2	8.0	8.2	8.2	8.3
High			8.4	8.8	8.7	8.7	8.7	8.7	8.7	8.8	8.9	-
Low			8.2	8.3	8.4	8.1	8.1	7.8	7.6	7.4	7.9	-
Monthly Mean for each depth	0-6		8.3	8.4	8.4	8.5	8.5	8.5	8.5	8.4	8.5	8.4
	B4		8.3	8.4	8.5	8.3	8.3	8.1	8.0	7.9	8.2	8.2
	W.C.		8.3	8.4	8.4	8.4	8.4	8.3	8.3	8.1	8.4	8.3
(Banks Lake only)												

*0-6 = mean of surface to 6 meters

**B4 = mean of bottom 4 meters

***W.C. = mean of water column

+ = no samples taken

(April excluded due to malfunction of pH probe.)

often had the highest values. During April 1976 a pH probe malfunctioned so values are not shown.

4.4.4.2 Conductivity, Alkalinity, and Hardness. Conductivity data collected from April 1975 to October 1976 averaged 118, 120, 120, 122, 123, and 123 umhos/cm² for Stations 1 through 6, respectively (Table 4.6). Mean conductivity in FDR forebay from February to October 1976 was 117 umhos/cm². The largest change with depth occurred at Stations 2 and 3 during June and July 1976. At that time the maximum difference between bottom and surface was 14 umhos/cm². The difference was due to the convergence north of Station 2, where relatively dilute water pumped in from FDR Reservoir was diving under the higher conductance water of the south pool in the region of Stations 2 and 3. The incoming water was completely mixed by the time it reached Station 4 because no difference in conductance occurred between surface and bottom during June and July at Station 4.

The range of average alkalinity and calcium-magnesium hardness for all Banks Lake stations were 56 to 58 and 57 to 59 mg CaCO₃/l, respectively. The FDR forebay average was 52 mg CaCO₃/l alkalinity and 55 mg CaCO₃/l hardness (Tables 4.7 and 4.8).

Conductivity, alkalinity, and hardness followed a similar trend during 1976 (Fig. 4.15). During the period preceding high runoff, February to April, FDR forebay had relatively high values for all three parameters.

The pump generation and pumping during this period caused Station 1 and, to a lesser extent, Stations 2 and 3 levels to be similar to that of FDR forebay. When peak runoff began in the Columbia River affecting

Table 4.6. Mean conductivity ($\mu\text{mhos}/\text{cm}^2$) for Banks Lake and Lake Roosevelt forebay for 1975 and 1976.

		Lake Roosevelt			Banks Lake						
		*0-6	Intake	W.C.	1	2	3	4	5	6	Mean
	April	-	-	-	120	120	120	115	115	114	117
	May	-	-	-	145	150	152	140	135	132	142
1	June	-	-	-	110	112	120	125	126	125	120
9	July	-	-	-	98	102	101	120	121	131	112
7	August	-	-	-	130	130	125	125	135	127	129
5	September	-	-	-	130	130	130	130	131	131	130
	October	-	-	-	120	120	120	120	120	120	120
	November	-	-	-	120	120	120	120	120	120	120
	December	-	-	-	113	110	110	110	109	109	110
	High	-	-	-	145	154	150	140	135	132	-
	Low	-	-	-	97	98	95	109	109	109	-
	Mean	-	-	-	121	122	122	123	124	123	123
	January	-	-	126**	114	-	-	110	108	108	111
	February	120	118	119	120	110	108	109	110	110	111
	March	136	136	136	125	125	118	120	110	111	118
1	April	137	138	138	144	143	141	132	130	130	137
9	May	112	114	114	114	120	124	140	140	138	129
7	June	105	115	114	114	119	123	128	135	138	126
6	July	116	118	115	117	121	121	124	129	130	124
	August	105	103	102	106	113	118	120	120	123	117
	September	106	105	103	100	105	105	115	124	123	112
	October	110	120	119	102	109	111	111	120	122	113
	High	138	138	138	145	145	145	140	140	138	-
	Low	105	100	100	100	102	100	105	108	108	-
	Mean	116	119	118	116	117	118	121	123	124	120
	GRAND MEAN	-	-	-	118	120	120	122	123	123	121

*0-6 = mean of surface to 6 meters

Intake = mean 10 meters above and below intake

W.C. = mean of water column

**feeder canal

Table 4.7. Mean alkalinity (mgCaCO₃/l) for Banks Lake and Lake Roosevelt forebay for 1975 and 1976.

		Lake Roosevelt			Banks Lake						
		*0-10	>20	W.C.	1	2	3	4	5	6	Mean
	April	-	-	-	68	67	70	70	70	68	69
	May	-	-	-	68	67	60	60	62	65	64
1	June	-	-	-	55	57	63	65	58	60	60
9	July	-	-	-	58	60	62	60	62	60	60
7	August	-	-	-	58	56	57	55	56	56	56
5	September	-	-	-	56	56	57	56	56	57	56
	October	-	-	-	58	57	58	57	57	57	57
	November	-	-	-	58	58	57	58	58	58	58
	December	-	-	-	58	58	58	57	57	57	58
	High	-	-	-	75	70	75	75	75	75	-
	Low	-	-	-	50	50	55	53	55	54	-
	Mean	-	-	-	60	60	60	60	60	60	60
	January	-	-	60**	58	-	-	57	56	54	56
	February	60	60	60	60	58	58	58	57	57	58
	March	59	57	58	59	59	58	56	56	56	58
1	April	60	60	60	63	63	62	59	59	58	61
9	May	48	49	48	48	53	52	59	58	58	55
7	June	48	53	51	51	54	54	55	58	59	55
6	July	50	52	51	50	53	54	54	55	56	54
	August	47	45	46	47	50	52	53	54	55	52
	September	47	46	46	47	48	48	52	54	54	51
	October	48	50	49	51	51	52	52	56	56	53
	High	62	60	62	63	63	62	60	60	59	-
	Low	47	46	46	46	46	42	51	53	54	-
	Mean	51	52	52	53	54	54	55	56	56	55
	GRAND MEAN	-	-	-	56	57	57	57	58	58	57

*0-10 = mean of surface 10 meters

>20 = mean equal to or greater than 20 meters

W.C. = mean of water column

**feeder canal

Table 4.8 Calcium-magnesium hardness (mgCaCO₃/l) in Banks Lake and Lake Roosevelt forebay during 1975 and 1976.

		Lake Roosevelt			Banks Lake						
		*0-10	>20	W.C.	1	2	3	4	5	6	Mean
	April	-	-	-	60	60	61	59	59	60	60
	May	-	-	-	59	62	62	60	60	60	61
1	June	-	-	-	54	56	58	63	61	61	59
9	July	-	-	-	54	55	56	59	58	59	57
7	August	-	-	-	54	54	57	54	56	54	55
5	September	-	-	-	55	56	56	56	56	56	56
	October	-	-	-	58	59	59	58	58	58	58
	November	-	-	-	65	64	63	64	62	63	64
	December	-	-	-	63	61	60	60	59	59	60
	High	-	-	-	65	65	69	68	63	64	-
	Low	-	-	-	52	52	52	53	52	53	-
	Mean	-	-	-	58	59	59	59	59	59	59
	January	-	-	65**	65	-	-	63	63	54	62
	February	71	67	69	68	67	65	65	66	66	66
	March	63	61	62	58	58	56	56	57	54	57
1	April	64	64	64	69	69	67	64	63	60	65
9	May	51	48	49	49	53	58	64	61	61	58
7	June	46	49	48	49	52	54	55	59	59	55
6	July	52	50	51	51	52	53	53	55	56	53
	August	54	52	52	52	53	56	56	56	59	55
	September	44	43	43	43	44	44	48	50	49	46
	October	58	59	59	55	58	56	58	59	59	56
	High	72	69	72	70	70	71	66	68	69	-
	Low	43	41	41	42	43	42	48	48	46	-
	Mean	56	55	55	56	57	57	58	59	58	58
	GRAND MEAN	-	-	-	57	58	58	59	59	58	58

*0-10 = mean of surface 10 meters

>20 = mean equal to or greater than 20 meters

W.C. = mean of water column

**feeder canal

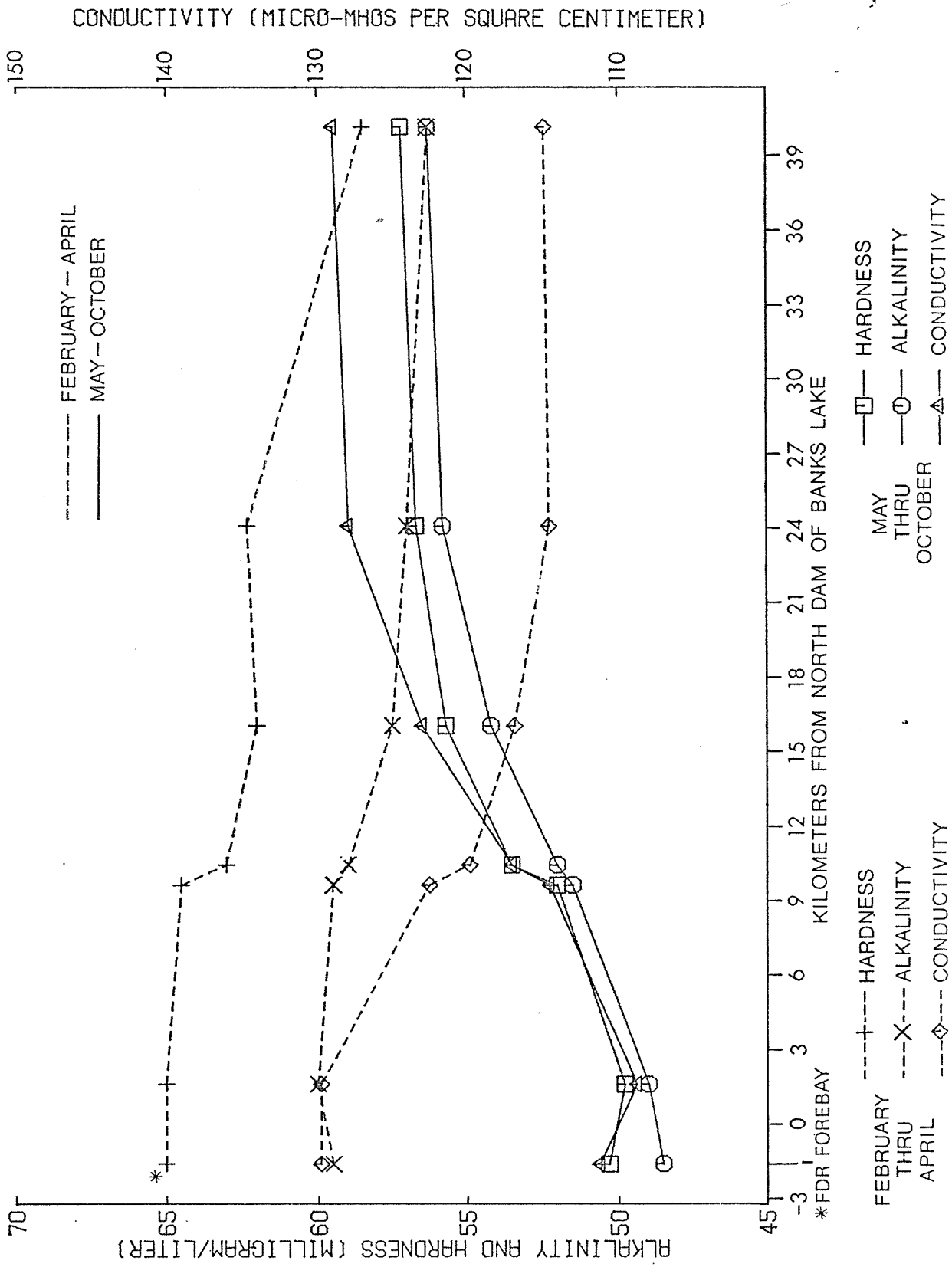


Fig. 4.15 Average seasonal changes in alkalinity, hardness, and conductivity compared to distance from the north dam in Banks Lake, and FDR Reservoir forebay for the period February to October 1976.

FDR Reservoir in May 1976, all three parameters showed a sizeable decrease (Tables 4.6, 4.7, and 4.8). These values remained low in FDR forebay during peak runoff months of May, June, July, and August. By October, when runoff had slowed, values began increasing.

These same phenomena of high levels of alkalinity, hardness, and conductivity during winter preceding runoff and reduced level during late spring and summer were observed in Rufus Woods Reservoir, below Grand Coulee Dam, in 1974 and 1975 (Stober et al. 1977). A similar reduction in conductivity during peak runoff months had been observed in FDR Reservoir at the mouth of the Spokane River in 1971 (Bishop and Lee 1972).

This input of dilute water during peak pumping months had an immediate effect at Station 1, but a gradual dilution occurred from north to south as pumped water mixed with the large volume of resident lake water.

As a result of inflow during both summer and winter, wide ranges of fluctuation of these values were apparent in the north pool of Banks Lake. But the most southerly portion of the lake (Station 6) showed only gradual changes after extended periods of pumping.

This pattern of dilution from north to south was not apparent in 1975, but the lowest values for all three parameters were observed at Station 1 during the peak runoff months of June and July 1975.

4.4.4.3 Cations and Anions. The concentrations of sodium, potassium, chloride, and sulphate are shown in Table 4.9. No trends were apparent by month or depth, but some changes were apparent by station. An increase in sodium and potassium concentrations occurred from north to south.

Table 4.9 Concentration of selected ions in Banks Lake for the months of April through September 1975 and quarterly thereafter, beginning January through September 1976, and Lake Roosevelt forebay ions from March to September 1976.

Ion	Station Averages					
	1	2**	3**	4	5	6
Na ⁺ (mg/l)	1.93	2.14	2.21	2.28	2.39	2.40
K ⁺ (mg/l)	0.77	0.806	0.836	0.851	0.884	0.890
***Cl ⁻ (mg/l)	0.408	0.456	0.437	0.451	0.459	0.475
SO ₄ ⁼ (mg/l)	11.71	10.63	11.14	10.79	10.67	10.85

Month	Banks Lake Average			
	Na ⁺ (mg/l)	K ⁺ (mg/l)	Cl ⁻ (mg/l)	SO ₄ ⁼ (mg/l)
1975 April	1.95	0.975	*	10.28
May	2.45	0.995	*	12.30
June	2.32	0.848	*	10.36
July	2.18	0.875	*	10.55
August	2.07	0.805	*	9.82
September	2.32	0.806	0.721	9.95
1976 **January	2.37	0.918	0.363	11.73
March	2.73	0.832	0.405	15.82
June	2.21	0.637	0.354	11.24
September	1.72	0.736	0.370	10.07

Month	Lake Roosevelt Average											
	Na ⁺ (mg/l)			K ⁺ (mg/l)			Cl ⁻ (mg/l)			SO ₄ ⁼ (mg/l)		
	0-10m	≤20m	W.C.	0-10m	≤20m	W.C.	0-10m	≤20m	W.C.	0-10m	≤20m	W.C.
1976 March	2.13	2.10	2.12	0.67	0.72	0.69	0.49	0.45	0.47	16.60	23.65	19.46
June	1.83	1.80	1.81	0.60	0.51	0.55	0.38	0.28	0.32	8.90	9.30	9.13
September	1.30	1.56	1.46	0.58	0.67	0.64	0.43	0.32	0.36	7.10	7.50	7.35
Average	1.75	1.82	1.80	0.62	0.63	0.63	0.43	0.35	0.38	10.87	13.48	11.98

* no samples taken

** Stations 2 and 3 not sampled in January

*** sampling initiated September 1975

The chloride values averaged lowest at Station 1 and highest at Station 6. In contrast to the other ions, sulphate was highest at Station 1. Average values of sodium, potassium, and chloride were lower and of sulphate, higher in FDR Reservoir than in Banks Lake during the 3 months it was sampled.

Calcium values were taken every month starting in April 1975 (Table 4.10). Calcium concentration for Banks Lake and FDR forebay ranged from 11.8 to 20.5 mg/l. The highest and lowest calcium concentrations in 1975 occurred in November and April, respectively. The magnesium concentrations taken monthly from April 1975 ranged from 2.8 to 5.9 mg/l (Table 4.11). The high values in 1975 occurred in April and low values in August. Magnesium and calcium followed similar trends in 1976; highest in the winter and lowest during summer and fall. Although no apparent trend occurred by station in 1975, in 1976 both ions averaged higher at Stations 4, 5, and 6 than in the northern stations or FDR forebay.

The oxidation-reduction potential (ORP) remained high during the period sampled. No consistent trends occurred by station or depth. The range in 1975 was from 190 to 360 mv. Lowest values occurred in June and highest in April. The potential in 1976 had highs of 370 mv in January and March and lows of 275 mv in September.

The ORP in FDR ranged from 295 to 370 mv from February to October 1976. The highest occurred in March and August, and lowest in July.

4.4.4.4 Silica. Mean water column reactive silica levels are shown for the period April 1975 to October 1976 (Table 4.12). Concentrations ranged from 0.39 to 3.93 mg/l in Banks Lake. Silica levels in the

Table 4.10 Calcium concentration (mg/l) in Banks Lake and Lake Roosevelt forebay during 1975 and 1976.

		Lake Roosevelt			Banks Lake						
		*0-10	<20	W.C.	1	2	3	4	5	6	Mean
	April	-	-	-	15.0	15.0	15.0	15.0	15.0	15.0	15.0
	May	-	-	-	15.4	17.0	17.1	16.6	16.5	16.0	16.4
1	June	-	-	-	15.3	15.7	16.5	17.9	17.7	17.8	16.8
9	July	-	-	-	14.0	15.0	15.2	16.0	15.3	15.6	15.2
7	August	-	-	-	15.6	15.4	15.7	15.1	14.5	14.9	15.2
5	September	-	-	-	15.1	15.4	15.0	15.1	15.6	14.9	15.2
	October	-	-	-	16.0	16.2	16.1	15.9	15.6	16.1	16.0
	November	-	-	-	19.1	18.5	18.1	18.6	18.1	18.2	18.4
	December	-	-	-	17.7	17.7	17.0	17.0	16.7	16.3	17.1
	High	-	-	-	19.6	19.0	18.7	19.3	18.3	18.4	-
	Low	-	-	-	13.7	13.9	13.5	14.0	14.2	14.4	-
	Mean	-	-	-	15.9	16.2	16.2	16.4	16.1	16.1	16.1
	January	-	-	-	17.3	-	-	17.8	17.9	15.4	17.1
	February	20.1	19.1	19.6	19.1	19.1	18.5	18.3	18.2	18.7	18.7
	March	17.4	16.7	17.1	16.0	16.4	15.6	15.5	15.9	15.4	15.8
1	April	17.8	18.1	17.9	19.6	20.0	19.4	18.6	17.8	17.3	18.8
9	May	13.9	12.8	13.4	15.8	14.5	16.0	18.1	17.2	16.8	16.4
7	June	12.3	13.3	12.8	13.2	14.6	15.0	15.3	16.4	16.3	15.1
6	July	14.7	14.1	14.4	14.3	14.7	14.9	15.1	15.0	15.4	14.9
	August	16.0	15.3	15.6	15.2	15.5	16.3	16.0	16.1	16.9	16.0
	September	12.8	12.3	12.5	12.0	12.7	12.5	13.2	13.5	13.6	12.9
	October	17.1	17.2	17.1	16.2	17.1	17.0	17.1	17.1	16.9	16.9
	High	20.4	19.6	20.4	20.1	20.5	20.4	18.9	18.8	19.9	-
	Low	11.9	11.8	11.8	11.8	12.5	12.1	12.9	12.9	13.6	-
	Mean	15.8	15.4	15.6	15.9	16.1	16.1	16.5	16.5	16.3	16.2
	GRAND MEAN	-	-	-	15.9	16.1	16.1	16.5	16.3	16.2	16.2

*0-10 = mean of surface 10 meters

<20 = mean equal to or less than 20 meters

W.C. = mean of water column

Table 4.11 Magnesium concentration (mg/l) in Banks Lake and Lake Roosevelt forebay during 1975 and 1976.

		Lake Roosevelt			Banks Lake						
		*0-10	<20	W.C.	1	2	3	4	5	6	Mean
	April	-	-	-	5.5	5.3	5.3	5.4	5.3	5.5	5.4
	May	-	-	-	4.4	4.4	4.6	4.5	4.6	4.8	4.5
1	June	-	-	-	3.9	4.0	4.2	4.2	4.2	4.1	4.1
9	July	-	-	-	4.2	4.3	4.5	4.4	4.5	4.5	4.4
7	August	-	-	-	4.0	4.1	4.1	4.2	3.9	4.1	4.1
5	September	-	-	-	4.2	4.3	4.3	4.3	4.3	4.3	4.3
	October	-	-	-	4.4	4.4	4.4	4.4	4.5	4.4	4.4
	November	-	-	-	4.2	4.2	4.1	4.2	4.3	4.2	4.2
	December	-	-	-	4.4	4.4	4.2	4.3	4.3	4.5	4.4
	High	-	-	-	5.7	5.5	5.5	5.7	5.2	5.9	-
	Low	-	-	-	3.8	3.9	3.8	4.0	3.9	4.1	-
	Mean	-	-	-	4.4	4.4	4.4	4.4	4.4	4.5	4.4
	January	-	-	-	4.5	-	-	4.5	4.5	3.9	4.4
	February	5.1	4.9	5.0	5.0	4.6	4.6	4.7	4.8	4.6	4.7
	March	4.8	4.6	4.7	4.3	4.2	4.2	4.2	4.1	3.9	4.1
1	April	4.7	4.7	4.7	4.9	4.8	4.6	4.4	4.5	4.2	4.6
9	May	3.9	3.9	3.9	3.9	4.1	4.4	4.8	4.7	4.7	4.4
7	June	3.6	3.9	3.8	3.8	3.7	4.1	4.1	4.4	4.3	4.1
6	July	3.7	3.7	3.7	3.7	3.7	3.9	3.9	4.3	4.1	3.9
	August	3.7	3.2	3.4	3.3	3.5	3.8	3.9	3.9	4.1	3.8
	September	3.1	3.0	3.0	3.1	3.1	3.0	3.7	3.9	3.7	3.4
	October	3.8	3.9	3.8	3.5	3.6	3.5	3.7	4.0	4.0	3.7
	High	5.2	5.1	5.2	5.0	5.0	4.9	5.2	5.2	4.7	-
	Low	3.0	2.8	2.8	3.0	2.9	2.8	3.5	3.8	3.6	-
	Mean	4.0	4.0	4.0	4.0	3.9	4.0	4.2	4.3	4.2	4.1
	GRAND MEAN	-	-	-	4.2	4.1	4.2	4.3	4.3	4.3	4.2

*0-10 = mean of surface 10 meters

<20 = mean equal to or less than 20 meters

W.C. = mean of water column

Table 4.12 Silica (mg/liter) in Banks Lake and Lake Roosevelt forebay during 1975 and 1976.

		Lake Roosevelt			Banks Lake						
		*0-10	<20	W.C.	1	2	3	4	5	6	Mean
	April	-	-	-	1.17	0.98	0.99	1.29	1.38	1.19	1.17
	May	-	-	-	3.00	1.90	1.77	0.93	0.87	1.13	1.60
1	June	-	-	-	2.23	1.95	1.42	1.35	1.18	1.12	1.54
9	July	-	-	-	1.88	1.56	1.49	1.49	1.30	1.32	1.51
7	August	-	-	-	1.87	1.60	1.73	1.67	1.63	1.70	1.71
5	September	-	-	-	1.50	1.60	1.47	1.53	1.40	1.33	1.47
	October	-	-	-	0.70	0.96	1.07	1.33	1.30	1.23	1.10
	November	-	-	-	0.65	0.70	1.01	1.06	1.10	1.03	0.93
	December	-	-	-	1.47	0.70	0.80	1.13	1.13	1.23	1.08
	High	-	-	-	3.10	2.20	2.20	1.80	1.90	1.80	-
	Low	-	-	-	0.44	0.39	0.70	0.90	0.80	0.94	-
	Mean	-	-	-	1.63	1.27	1.29	1.24	1.21	1.25	1.35
	January	-	-	2.30**	2.00	-	-	1.09	1.05	1.01	1.29
	February	2.51	2.47	2.49	1.54	1.08	1.02	1.02	1.14	1.21	1.17
	March	2.69	2.01	2.41	1.55	1.02	1.07	1.02	1.13	1.04	1.14
1	April	1.65	1.72	1.68	1.85	2.69	1.28	0.99	0.96	1.10	1.48
9	May	2.67	2.95	2.80	2.60	2.10	1.97	1.27	1.10	1.07	1.67
7	June	2.00	2.43	2.24	2.10	1.57	1.50	1.50	1.20	1.27	1.52
6	July	2.01	2.76	2.42	2.56	2.32	2.21	2.38	2.35	2.36	2.36
	August	1.81	2.10	1.99	1.91	1.83	1.86	2.41	2.22	2.37	2.10
	September	1.29	1.81	1.62	1.72	2.94	1.36	2.19	2.15	2.36	2.12
	October	1.65	1.66	1.66	1.30	1.19	1.66	1.41	1.86	1.78	1.53
	High	2.84	3.17	3.17	2.74	3.93	2.48	3.24	2.61	2.80	-
	Low	0.89	1.18	0.89	1.11	1.01	0.95	0.98	0.96	0.96	-
	Mean	2.03	2.21	2.19	1.91	1.86	1.54	1.53	1.40	1.53	1.64
	GRAND MEAN	-	-	-	1.78	1.57	1.41	1.39	1.31	1.41	1.50

*0-10 = mean of surface 10 meters

<20 = mean equal to or less than 20 meters

W.C. = mean of water column

**feeder canal

north pool were highly influenced by inflow water (Fig. 4.16). During the months when pumping occurred, concentrations at Station 1 averaged higher than other stations and were very similar to those in FDR forebay during that time. But when continuous pumping did not occur, values at Station 1 decreased, and were less similar to FDR forebay concentrations. Large changes in concentration occurred between Stations 1 and 3. Silica levels at Stations 4, 5, and 6 were similar to one another.

4.4.4.5 Plant Nutrients. Nutrient data are reported for the period from May 1974 to October 1976 for Banks Lake, except during the winter of 1975 and 1976 when ice cover prevented sampling. Additional nutrient data are reported from FDR forebay starting in November 1975, and from the feeder canal headworks beginning in April 1976.

4.4.4.5.1 Orthophosphate. Orthophosphate levels ranged from 0 to 28 $\mu\text{g}/\text{l}$ (as P) during the sampling period. A north-south gradient in orthophosphate level was evident when Station 1 was compared with Stations 2 and 3 combined, and Stations 4, 5, and 6 combined. The 1974 data indicate an increase in orthophosphate (Fig. 4.17) during May and June with slightly higher levels in the northern half of the lake. Orthophosphate decreased during the summer and increased during the fall. No clear response to pumped input of water was evident between stations in 1974.

A horizontal gradient occurred during the period May through September, 1975 during the pumped input of irrigation water from FDR Reservoir. Consistently higher orthophosphate levels were found at Station 1, with intermediate values at Stations 2-3, and consistently lowest values at Stations 4-5-6 (Fig. 4.17). Pumping of irrigation water ceased on

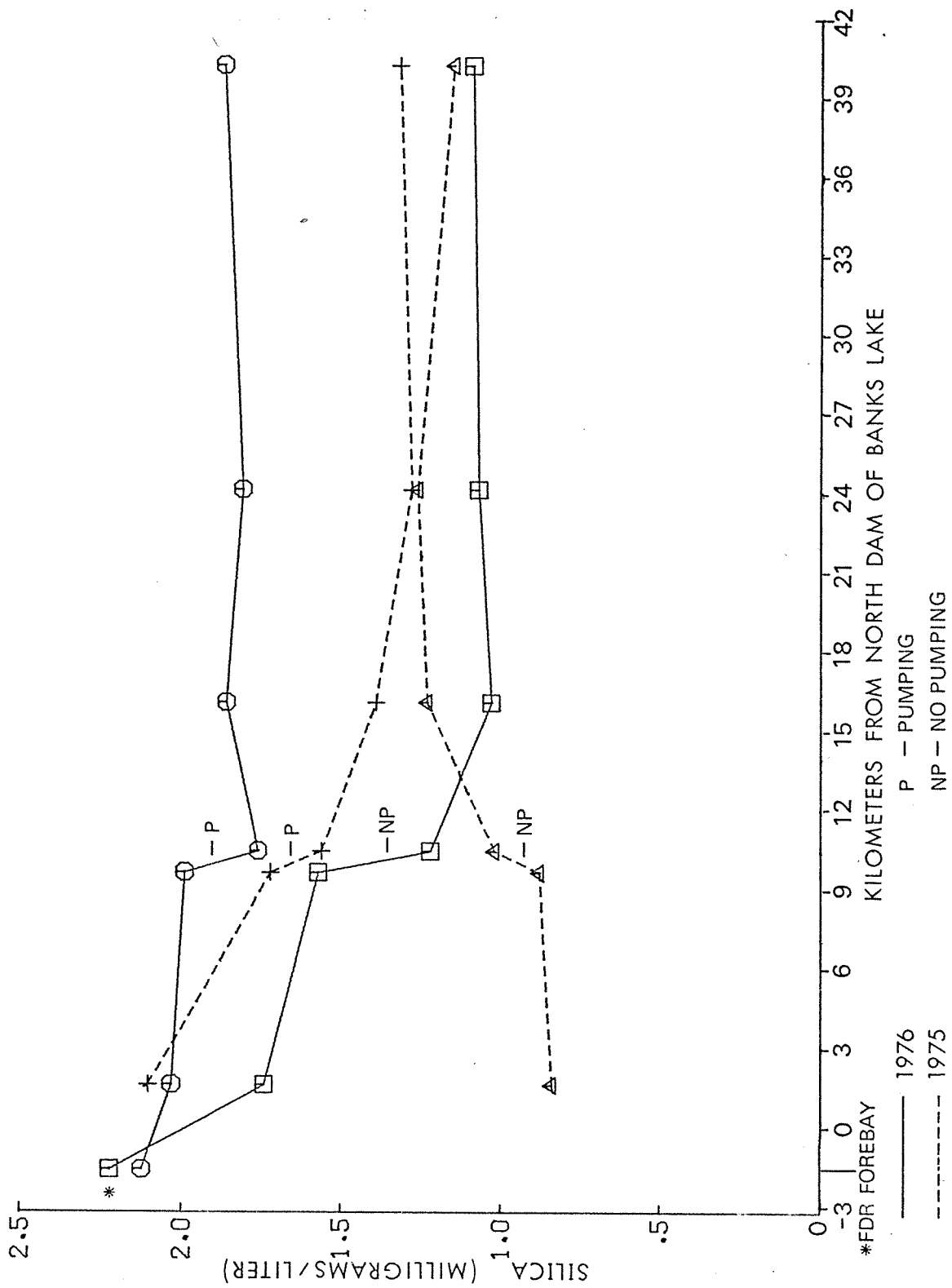


Fig. 4.16 Average changes in silica concentrations compared to distance from the north dam during pumping and non-pumping periods in Banks Lake and FDR Reservoir forebay for 1975 and 1976.

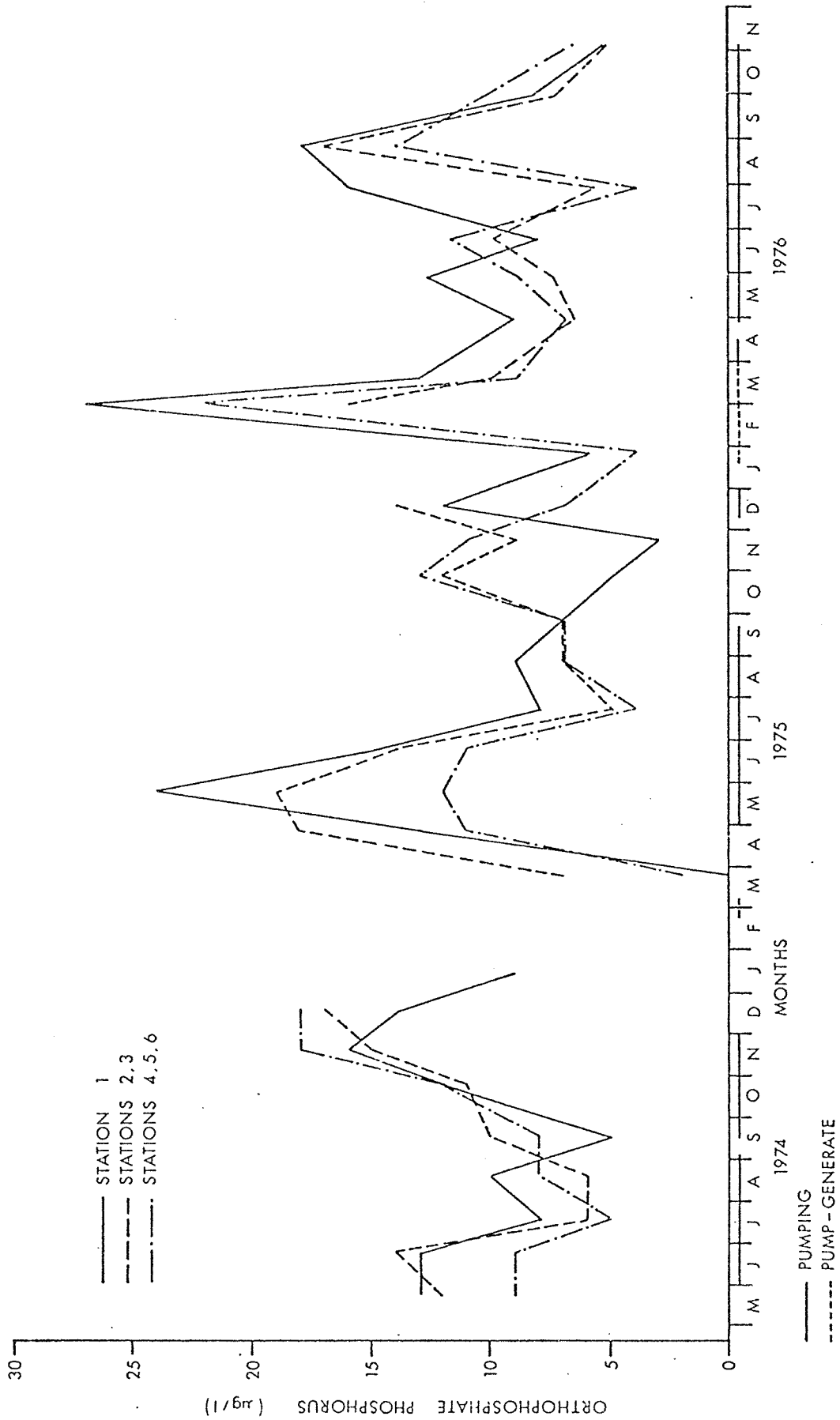


Fig. 4.17 Mean monthly orthophosphate concentrations for Station 1, Stations 2 and 3 combined, and Stations 4, 5 and 6 combined; with the occurrence of feeder canal pumping and pump/generation from May 1974 to October 1976.

September 21, 1975, and did not reoccur until December 9, 1975. Irrigation drafting from the reservoir stopped on October 21, 1975. After October 21, while conditions reverted to a lentic environment, the horizontal orthophosphate gradient was found to reverse, with minimum values at Station 1, intermediate values at Stations 2-3, and maximum values at Stations 4-5-6. Pumping to increase the reservoir level from 1,564 ft to 1,570 ft (full pool) was initiated on December 9, 1975, and completed December 31, 1975. Orthophosphate levels at Station 1 showed an increase from 4 $\mu\text{g}/\text{l}$ in November to 13 $\mu\text{g}/\text{l}$ in December following initiation of pumping.

Orthophosphate levels declined in January 1976 following the trend of the values in FDR forebay (Fig. 4.18). P/G 8 was operated during February and March 1976 resulting in a corresponding increase of orthophosphate from 6 $\mu\text{g}/\text{l}$ in January to 28 $\mu\text{g}/\text{l}$ in February 1976, at Station 1 (Fig. 4.17). Stations 2-3 and 4-5-6, were 16 and 23 $\mu\text{g}/\text{l}$, respectively, suggesting additional phosphates were added from winter rain and snow runoff and spring lake overturn.

Values at Station 1 declined from high February values to low values in April, after pumping had been discontinued for 2 weeks. The orthophosphates were lowest during May and June, and again in September and October 1976. During the months of irrigation pumping (May to October), Station 1 followed the same trend as observed in FDR Reservoir at water depths greater than 20 m, but averaged less, being 11.3 $\mu\text{g}/\text{l}$ in Banks Lake and 13.8 $\mu\text{g}/\text{l}$ in FDR forebay.

Orthophosphate concentrations for the May-October period, at Stations 2-3 and 4-5-6, though sometimes higher than Station 1, averaged less;

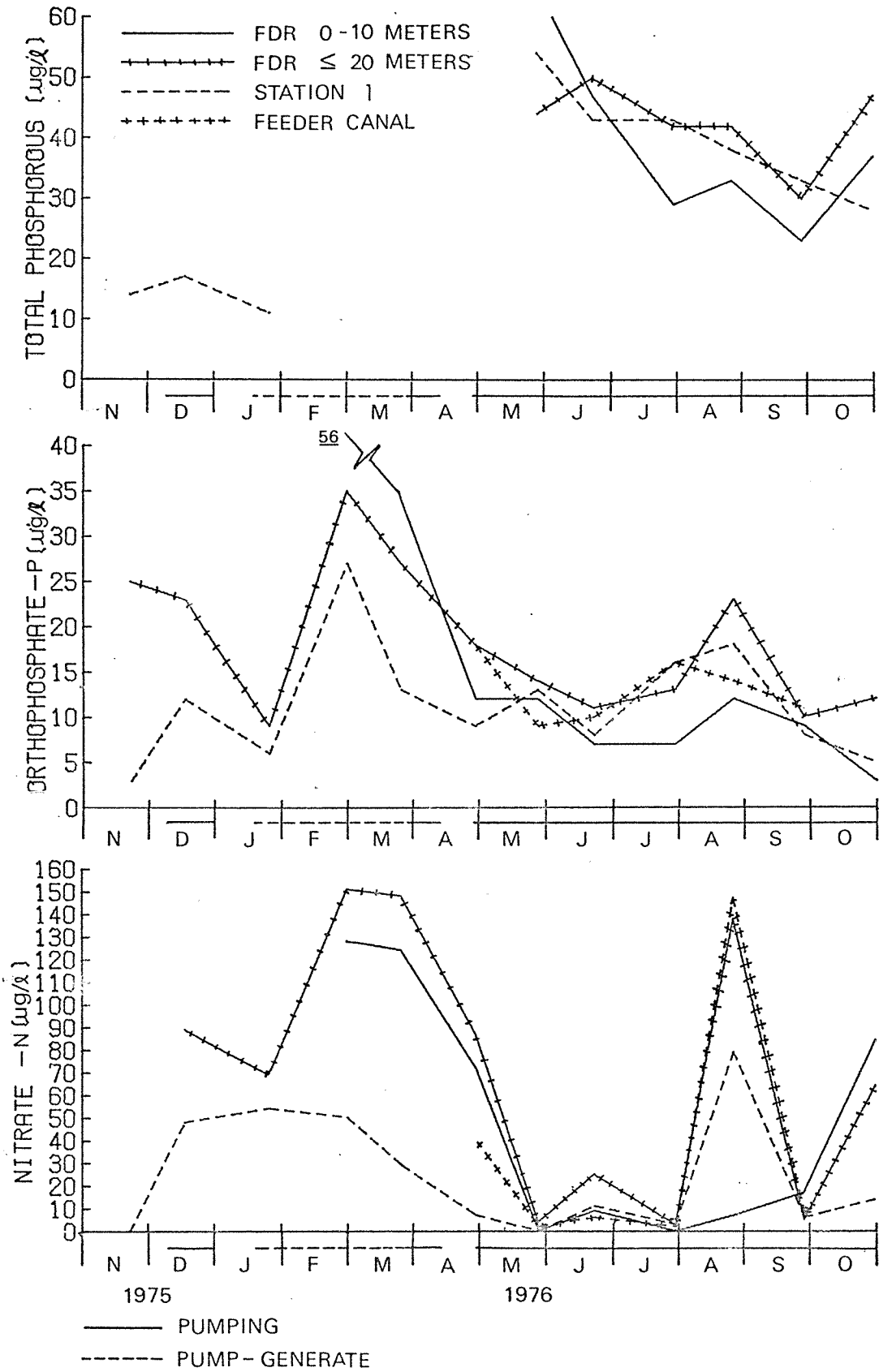


Fig. 4.18 Nutrient concentration at Banks Lake Station 1, feeder canal at the headworks, and FDR Reservoir forebay; with feeder canal pumping and pump/generation from November 1975 to October, 1976.

9.0 and 9.5 $\mu\text{g}/\text{l}$, respectively. The only north-south gradient observed in 1976 was between Stations 1 and 2-3; no reduction occurred at Stations 4-5-6.

4.4.4.5.2 Total Phosphorus. Amounts of total phosphorus (Fig. 4.19) ranged from a minimum of 7 $\mu\text{g}/\text{l}$ in August 1974 to a maximum of 49 $\mu\text{g}/\text{l}$ in June 1975. North-south gradients established in response to pumped input of water from FDR Reservoir and irrigation drafting followed closely those described for orthophosphate phosphorus. The total phosphorus levels in the water below the thermocline of FDR forebay closely approximated those at Station 1 in Banks Lake from May to October 1976 (Fig. 4.18).

4.4.4.5.3 Nitrates. Nitrate analysis indicated that concentrations were generally low in Banks Lake, particularly during the phytoplankton production season (Fig. 4.20). Rapid declines in concentrations at all stations were indicated from June to July 1974. Nitrate was unavailable at Stations 2 through 6 and only 3 $\mu\text{g}/\text{l}$ was found at Station 1. A north-south gradient occurred during October and November 1974. Concentrations at Stations 1, 2-3 and 4-5-6, were 19, 15, and 7 $\mu\text{g}/\text{l}$, respectively, in November, indicating a response to pumped input from FDR Reservoir. A decline to 4 $\mu\text{g}/\text{l}$ at Station 1 was evident by January 1975, following cessation of pumping at the end of November. Nitrates were limiting throughout most of the lake during March through November 1975.

The gradient reversed during July 1975, suggesting low supply from pumped input and/or rapid assimilation during June 1975 at Station 1 by abundant phytoplankton. The low levels of nitrates during summer pumping

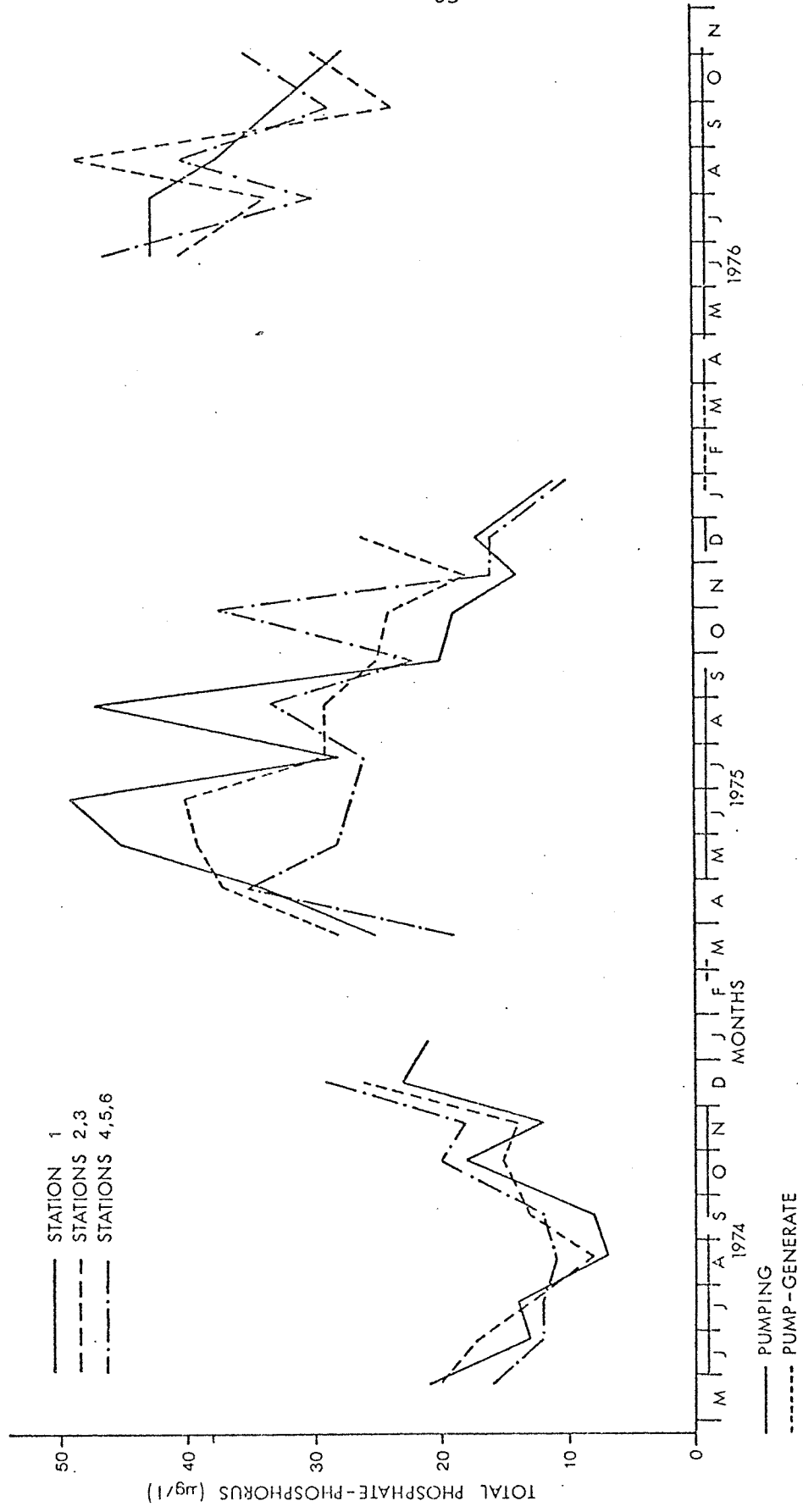


Fig. 4.19 Mean monthly total phosphorus concentrations for Station 1, Stations 2 and 3 combined, and Stations 4, 5 and 6 combined; with the occurrence of feeder canal pumping and pump/generation from May 1974 to October 1976.

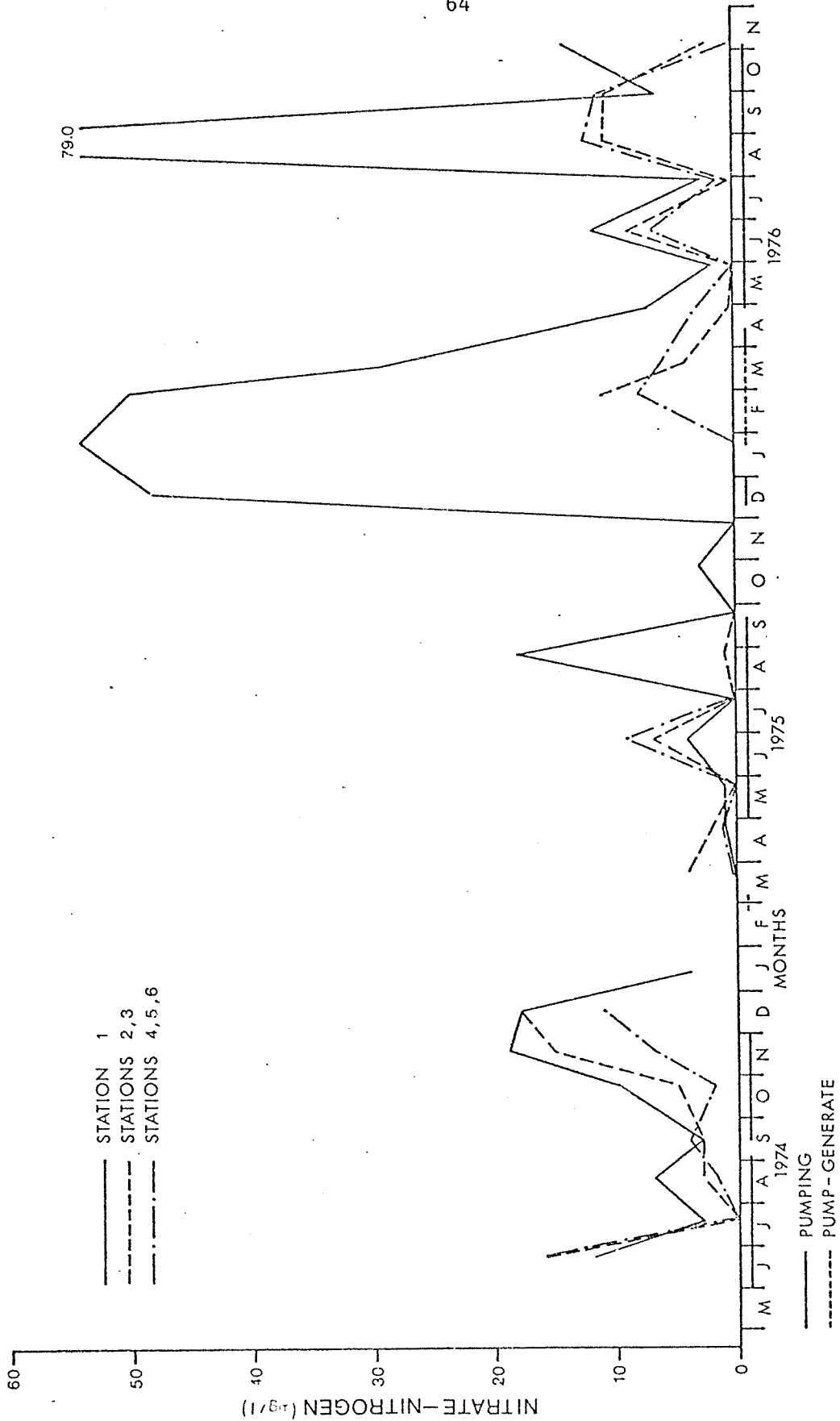


Fig. 4.20 Mean monthly nitrate concentrations for Station 1, Stations 2 and 3 combined, and Stations 4, 5 and 6 combined; with the occurrence of feeder canal pumping and pump/generation from May 1974 to October 1976.

could have resulted from low levels which were being pumped in from FDR Reservoir at that time. With cessation of pumping in late September 1975, nitrate levels in October declined to 0 except at Station 1. Nitrates were undetectable at all stations by November. The large increase in nitrates at Station 1 from 0 to 48 $\mu\text{g}/\text{l}$ in December 1975 was a result of pumped input of nutrients from FDR Reservoir (Figs. 4.18 and 4.20). Nitrate levels remained high in January and February 1976 at Station 1, being 54 and 50 $\mu\text{g}/\text{l}$, respectively. During this time, Stations 4, 5, and 6 remained at undetectable levels in January, and only showed a relatively slight increase to 8 $\mu\text{g}/\text{l}$ in February. Stations 2-3 only showed a minor increase to 11 $\mu\text{g}/\text{l}$ in February. The relatively high increase at Station 1 at this time must have been due to the input of high nitrate levels from pump/generation. The nitrate levels in FDR Reservoir were considerably higher, being 89, 69, and 151 $\mu\text{g}/\text{l}$ nitrates during December, January, and February, respectively. A steady decrease in nitrate concentrations occurred at all Banks Lake stations and FDR forebay from March to season lows in May.

During May, no detectable nitrates were found at Stations 2-3 or 4-5-6, but 2 $\mu\text{g}/\text{l}$ were present at Station 1. The low concentrations were partly due to small concentration (4 $\mu\text{g}/\text{l}$) in FDR Reservoir deep water that was being pumped into Banks Lake. Nitrate levels at Station 1, although of lower concentration, followed the same pattern as those of the deep water (greater than 20 m) in FDR forebay during the summer and early fall pumping. The dependence of nitrate levels at Station 1 on levels in FDR forebay was not always clearly defined, but was well-defined in August 1976 when the deep water of FDR, the feeder canal

water, and Banks Lake water peaked in nitrates while the surface water (0-10 m) of FDR remained low in nitrates (Fig. 4.18).

Nitrate concentrations increased in June, decreased in July, and peaked again in August at all stations. Station 1 had the highest levels at this time, except in September 1976, when Station 1 levels dropped to 6 $\mu\text{g}/\text{l}$, while the other stations were higher at 11 $\mu\text{g}/\text{l}$. This reduction was due to an input concentration of 5 $\mu\text{g}/\text{l}$ from FDR forebay. Station 1 was the only station to increase in October. The lack of increase at other stations may have resulted from reduced pumping at that time.

4.4.5 Biological

4.4.5.1 Phytoplankton. The chlorophyll a data indicate two functionally separate regions within the lake. The Pearson *r* correlation coefficient for 35 months of sampling showed highly significant ($p = .01$) linear relationships of chlorophyll a changes between Stations 1, 2 and 3 (Table 4.13). Highly significant ($p = .01$) correlations were also found between Stations 4, 5, and 6. With the exception of Stations 3 and 4, which were significantly correlated at the 5 percent level, no significant correlations were found between the three northern and three southern stations. This pattern of significant correlation between stations was most noticeable during months when feeder canal pumping had been occurring at least 2 weeks prior to sampling. Except for the two most adjacent stations (2 and 3) during nonpumping months, chlorophyll a changes were not correlated between stations and tended to peak independently of each other.

Table 4.13 Paired T-tests and Pearson r correlation coefficients for mean monthly chlorophyll a values between stations 1 through 6 in Banks Lake and between Station 1 and selected depth strata in Lake Roosevelt (FDR) forebay.

ALL MONTHS

FEEDER CANAL PUMPING

		Probability N = 35					
		1	2	3	4	5	6
Corr.	1		.942	.460	.003	<.000	<.000
	2	**	.683		.019	<.000	<.000
	3	**	.516	**	.907		<.000
	4		.117	.206	.332	*	.012
	5		-.123	.028	.168	**	.714
	6		-.221	.004	.168	**	.559
Coef.	1						
	2	**	.861				
	3	**	.698	**	.877		
	4		.133	.220	.398		.011
	5		-.112	.054	.256	**	.871
	6		-.311	-.101	.098	**	.664

		Probability N = 19					
		1	2	3	4	5	6
Corr.	1		.568	.678	.054	.008	.003
	2	**	.861		.085	.005	<.000
	3	**	.698	**	.877		<.000
	4		.133	.220	.398		.011
	5		-.112	.054	.256	**	.871
	6		-.311	-.101	.098	**	.664
Coef.	1						
	2	**	.861				
	3	**	.698	**	.877		
	4		.133	.220	.398		.011
	5		-.112	.054	.256	**	.871
	6		-.311	-.101	.098	**	.664

NO FEEDER CANAL PUMPING

		Probability N = 13					
		1	2	3	4	5	6
Corr.	1		.554	.684	.102	.049	.015
	2		.327	.267	.013	.008	.001
	3		.285	**	.983	.021	.014
	4		.058	.182	.213		.588
	5		-.194	.031	-.011	.204	
	6		-.033	.423	.435	.283	.181
Coef.	1						
	2		.194	.031	.031		
	3		.698				
	4		.117	.206	.332		.012
	5		-.123	.028	.168	**	.714
	6		-.221	.004	.168	**	.559

JAN-OCT. 1976^a

		Probability N = 10			
		1	0-10	20-B	WC
Corr.	1		.194	.031	.031
	0-10		.698		
	20-B		.727	*	
	WC		.798	*	
Coef.	1				
	0-10		.817	*	
	20-B		.882	**	
	WC		.875	**	

MAY-OCT. 1976^a

		Probability N = 7				
		1	0-10	20-B	WC	FD
Corr.	1		.377	.005	.008	.032
	0-10		.817	*		
	20-B		.882	**		
	WC		.875	**		
Coef.	1					
	0-10		.817	*		
	20-B		.882	**		
	WC		.875	**		
FD	1		.770			
	0-10		.770			
	20-B		.770			
	WC		.770			

a = FDR reservoir with station 1

0-10 = upper 10 meters mean

20-B = below 20 meters mean

WC = water column mean

FD = feeder canal mean (N=6)

* = significant at 5%

** = significant at 1%

Chlorophyll a values for Stations 1 to 6 during the 35 months averaged 3.30, 3.45, 3.14, 2.05, 1.68, and 1.38 $\mu\text{g}/\text{l}$, respectively. The results of t-tests indicate a significant difference ($p = .05$) in chlorophyll a between all stations, from Stations 2 to 6. This indicates a significant decreasing trend in chlorophyll a from north to south, starting from Station 2, in Banks Lake (Table 4.13).

A direct response to pumped input appeared at Stations 1 through 3, but was not evident in the rest of the lake (Figs. 4.21 and 4.22). For example, prior to the initiation of pumped input of irrigation water on June 1, 1974, chlorophyll a levels declined from February through May 1974. Upon initiation of pumping at an approximate rate of 328 cms (11,500 cfs), maximum chlorophyll a values were recorded in June with 7.5, 7.1, and 5.1 $\mu\text{g}/\text{l}$ at Stations 1, 2 and 3, respectively. A general seasonal decline occurred following this peak concentration. However, pumping declined and stopped briefly during the first week in September 1974. This interruption may have stimulated the observed September increase in chlorophyll a which was 3.3, 7.1, and 7.2 $\mu\text{g}/\text{l}$ at Stations 1, 2 and 3, respectively. A general decline was then observed through December 1974 with pumping at the rate of about 85.6 cms (3,000 cfs) from mid-September to December 1, 1974.

A seasonal increase in chlorophyll a levels was observed from December 1974 through March 1975. A decline, greatest at Station 1, occurred in April, immediately prior to the initiation of pumping in early May 1975. By late May a major increase in chlorophyll a concentrations of 10.7, 8.1 and 7.6 $\mu\text{g}/\text{l}$ were found at Stations 1, 2 and 3, respectively. Pumping of irrigation water increased from 0 in early May

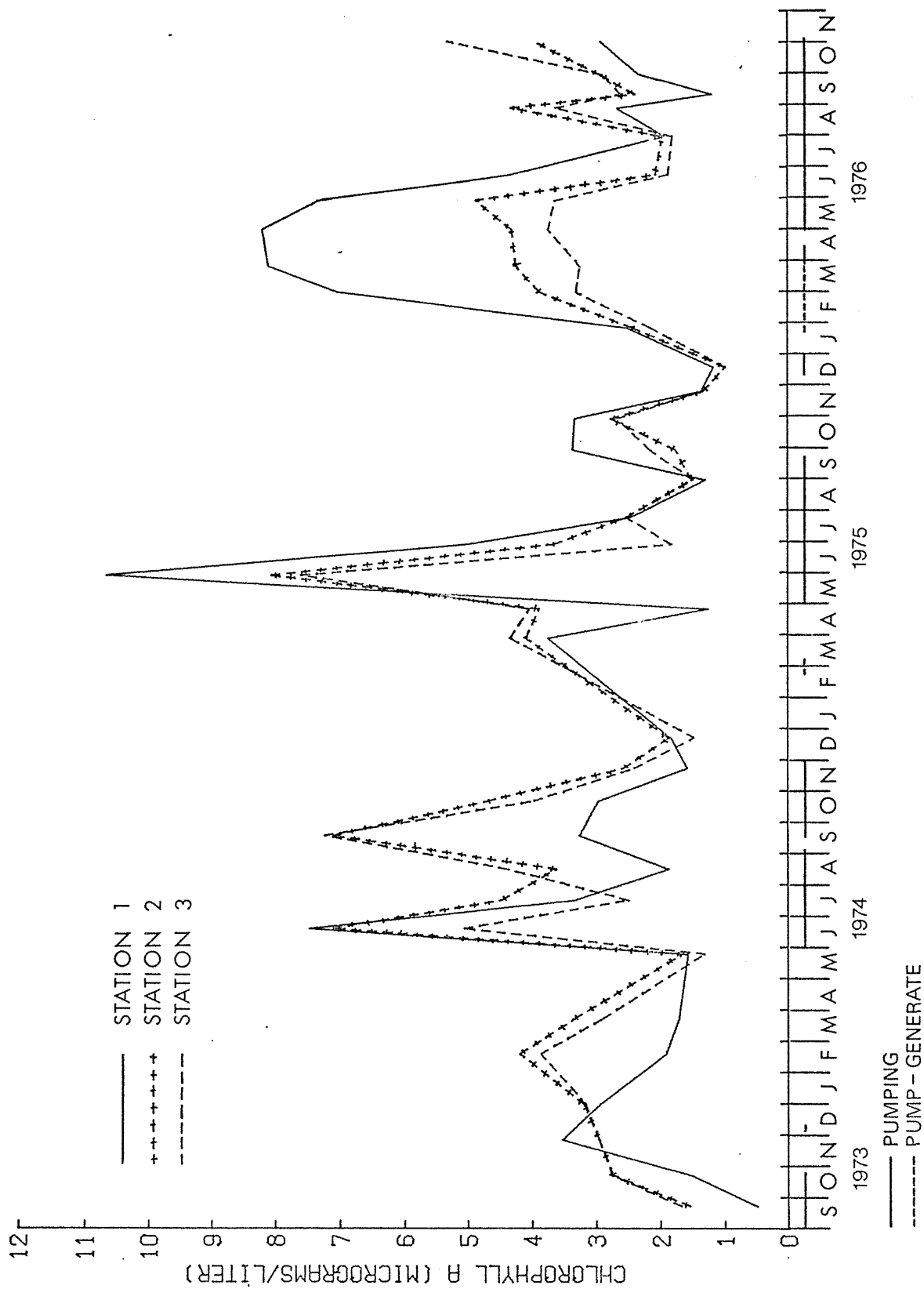


Fig. 4.21 Chlorophyll a mean concentrations in Banks Lake at Stations 1, 2 and 3; with feeder canal pumping and pump/generation from September 1973 to October 1976.

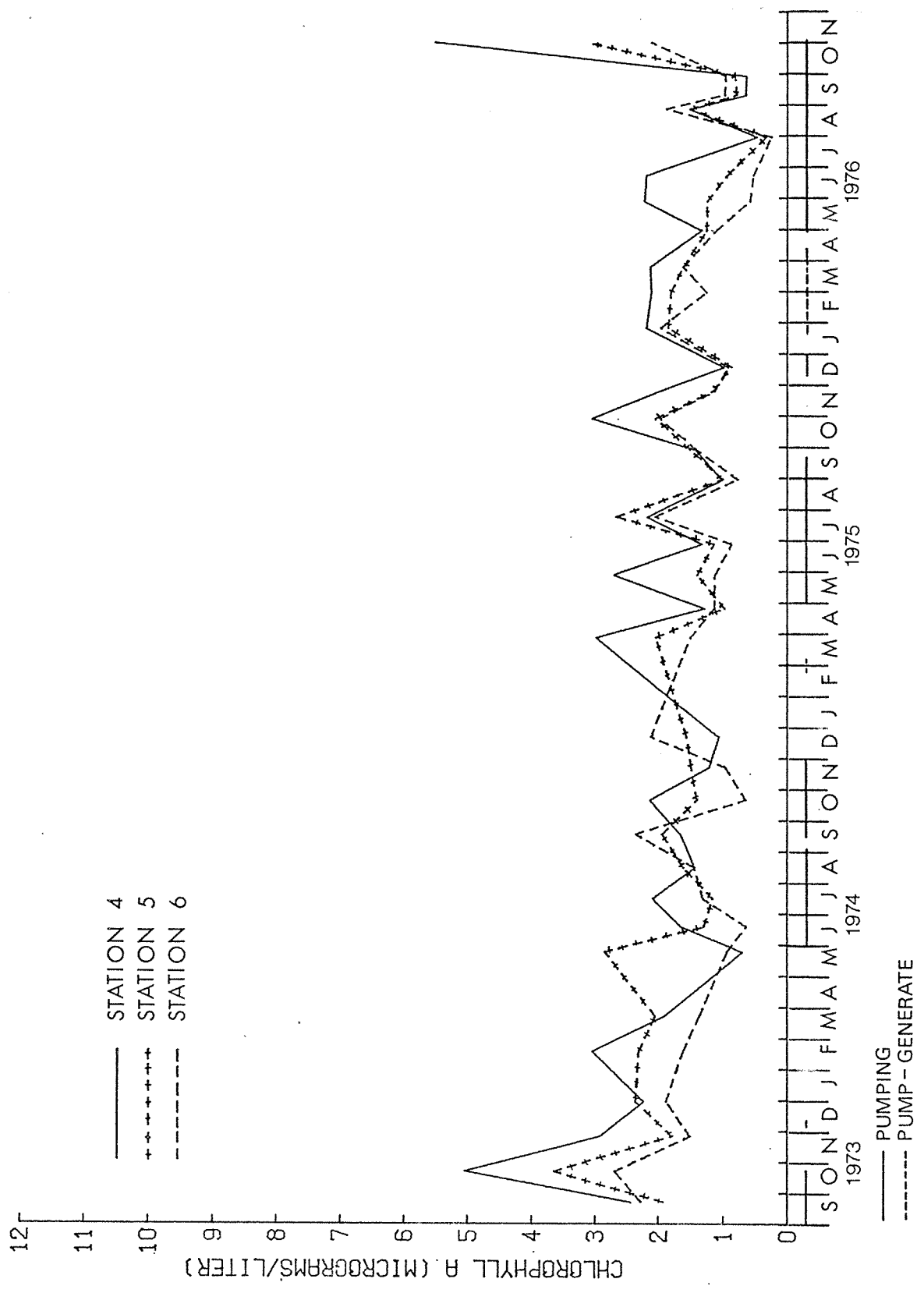


Fig. 4.22 Chlorophyll a mean concentrations in Banks Lake at Stations 4, 5 and 6; with feeder canal pumping and pump/generation from September 1973 to October 1976.

to 126 cms (4,500 cfs) by mid-May to about 204 cms (7,300 cfs) by the end of May. A seasonal decline in chlorophyll a was observed throughout the summer at Stations 1, 2 and 3; however, a small increase during September and October 1975 occurred. This followed the cessation of pumping between the last week of September and the first week of December 1975. Following pumping during December 1975 and P/G testing in February and March 1976, chlorophyll a levels showed a seasonal increase from low December levels of 1.2, 1.0 and 1.0 through March 1976, with 8.0, 3.8 and 3.0 $\mu\text{g}/\text{l}$ at Stations 1, 2 and 3, respectively. As can be seen in Figure 4.23, these increased chlorophyll a concentrations during this time were not due to pumped input of phytoplankton from FDR Reservoir, but were probably caused by nutrient input and mixing from pump-generation.

Chlorophyll a levels at Station 1 peaked at 8.2 $\mu\text{g}/\text{l}$ during April 1976. Concentrations were higher in FDR forebay at this time (11.1 $\mu\text{g}/\text{l}$) (Fig. 4.23). No pumping had occurred 10 days prior to sampling, so levels in FDR may have increased independently of Banks Lake. The 1976 summer and fall pattern of chlorophyll a for Stations 1, 2 and 3, were similar to 1975. Concentrations decreased from May to late August and early September and then increased in late September and October.

The low levels at Station 1 in late summer and fall resulted from pumped input which was deficient in chlorophyll a (Fig. 4.23). Chlorophyll a increased in the fall at Stations 1, 2 and 3 but not in FDR forebay, when pumping rates were reduced to 100 cms (3,500 cfs). This resulted in increased residence time in the north pool, especially at Stations 2 and 3. The statistical analysis indicated that chlorophyll a concentrations at Station 1 were both significantly correlated ($r^2 = .72$),

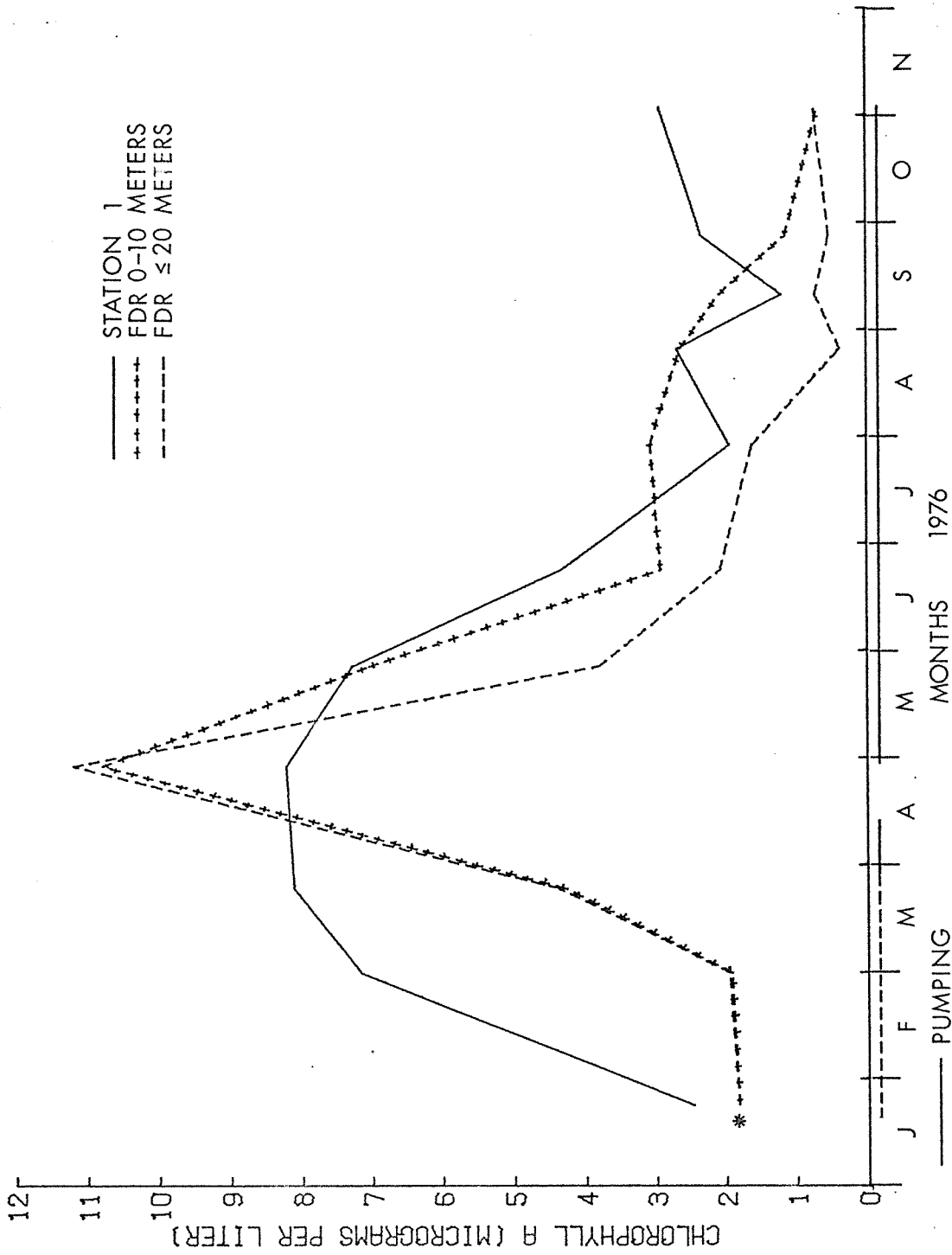


Fig. 4.23 Chlorophyll a mean concentration for Banks Lake at Station 1, and FDR Reservoir forebay at 0 to 10 meters, and less than or equal to 20 meters, with pumping and pump/generation from January to October 1976.

and significantly higher ($p = .031$), than FDR Reservoir deep water that was pumped into Banks Lake. This suggested that during peak pumping months phytoplankton abundance at Station 1, although higher, was being controlled by abundance in FDR forebay. Chlorophyll a maxima, stimulated by pumped input of water which occurred during the spring when chlorophyll a concentrations were normally expected to increase, showed a consistently decreasing gradient from Stations 1 to 3 (June 1974, May 1975, and May 1976), indicating that the direct effects of pumping were greatest on Station 1 and diminished successively at Stations 2 and 3. This theory does not conflict with the nutrient effects mentioned earlier. Nutrients still control phytoplankton production in Banks Lake as a whole, but the short residence time at Station 1 during peak pumping months would not allow large increases in phytoplankton over that being pumped in even if high nutrient supplies were present.

Chlorophyll a concentrations at Stations 4, 5, and 6 were consistently low. Peak values tended to occur in late fall or winter in the south pool (Fig. 4.22). These peaks were most apparent at Station 4 in October 1973, 1975, and 1976, with levels of 5.1, 3.1, and 5.5 $\mu\text{g}/\text{l}$, respectively. These data indicated the major phytoplankton blooms occurred in the north pool in spring, while only minor phytoplankton blooms occurred in the south pool during late fall or winter.

The general pattern of seasonal trends by stations for May to September is shown in Figure 4.24. The pumping schedule and lake elevation were similar in 1975 and 1976. Pumping was continuous both years from early May through most of September and drawdown was less than 2 m. But in 1974 pumping did not begin until early June and stopped for 2

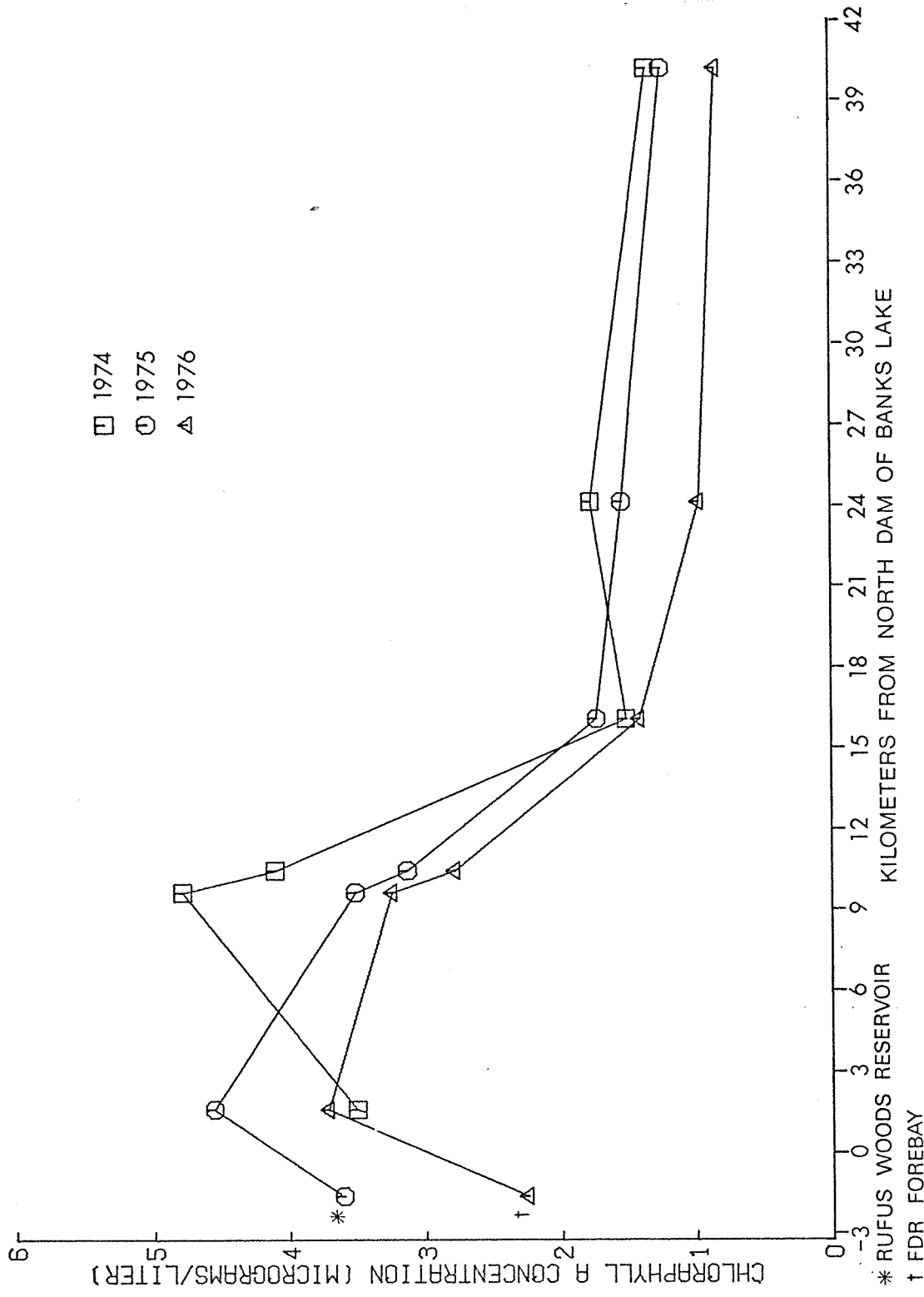


Fig. 4.24 Average chlorophyll a concentration for Banks Lake and FDR Reservoir forebay during May to September in 1974 and 1975 and 1976. The chlorophyll a concentration in Rufus Woods Reservoir was six miles below Grand Coulee Dam.

weeks in early September. Drawdown was also greater in 1974, being 7 m below full pool. As a result, the spring bloom of phytoplankton was missed in 1974, and the drawdown reduced the residence time of pumped water at Station 1, moving the phytoplankton biomass peak down the lake to Stations 2 and 3. But in 1975 and 1976, the spring input of phytoplankton from FDR forebay was concurrent with an increase in phytoplankton at Station 1, and a general decrease from north to south in Banks Lake.

4.4.5.2. Primary Production. Comparison of ^{14}C primary production at Stations 1, 4, and 6, and FDR forebay are illustrated by vertical profiles for 1975 (Fig. 4.25) and 1976 (Fig. 4.26). The results of t-tests indicated Station 1 was significantly higher ($p = .02$) than Stations 4 and 6. For the 9-month period from February to October 1976, no significant difference occurred between FDR forebay and Station 1. Production at Station 1 was only exceeded by that at Station 4 on November 2, 1976, when chlorophyll a levels at Station 4 were at their highest observed concentration (Fig. 4.27). Production measurement at Station 6 never exceeded that of Station 4 when measured on the same day.

Growing season primary production (May to October) was lower in 1976 than in 1975 at Stations 1 and 4. Production at Station 1 averaged 705 and 601 mg C/m^2 per day, and at Station 4 averaged 421 and 384 mg C/m^2 per day in 1975 and 1976, respectively.

The relative production between Stations 1 and 4 remained fairly constant for the 2 years. Station 4 production averaged 60 percent in 1975 and 64 percent in 1976 of Station 1 production. Growing season average production in FDR was 620 mg C/m^2 per day, which was similar to Station 1. In both years the largest divergence in primary production

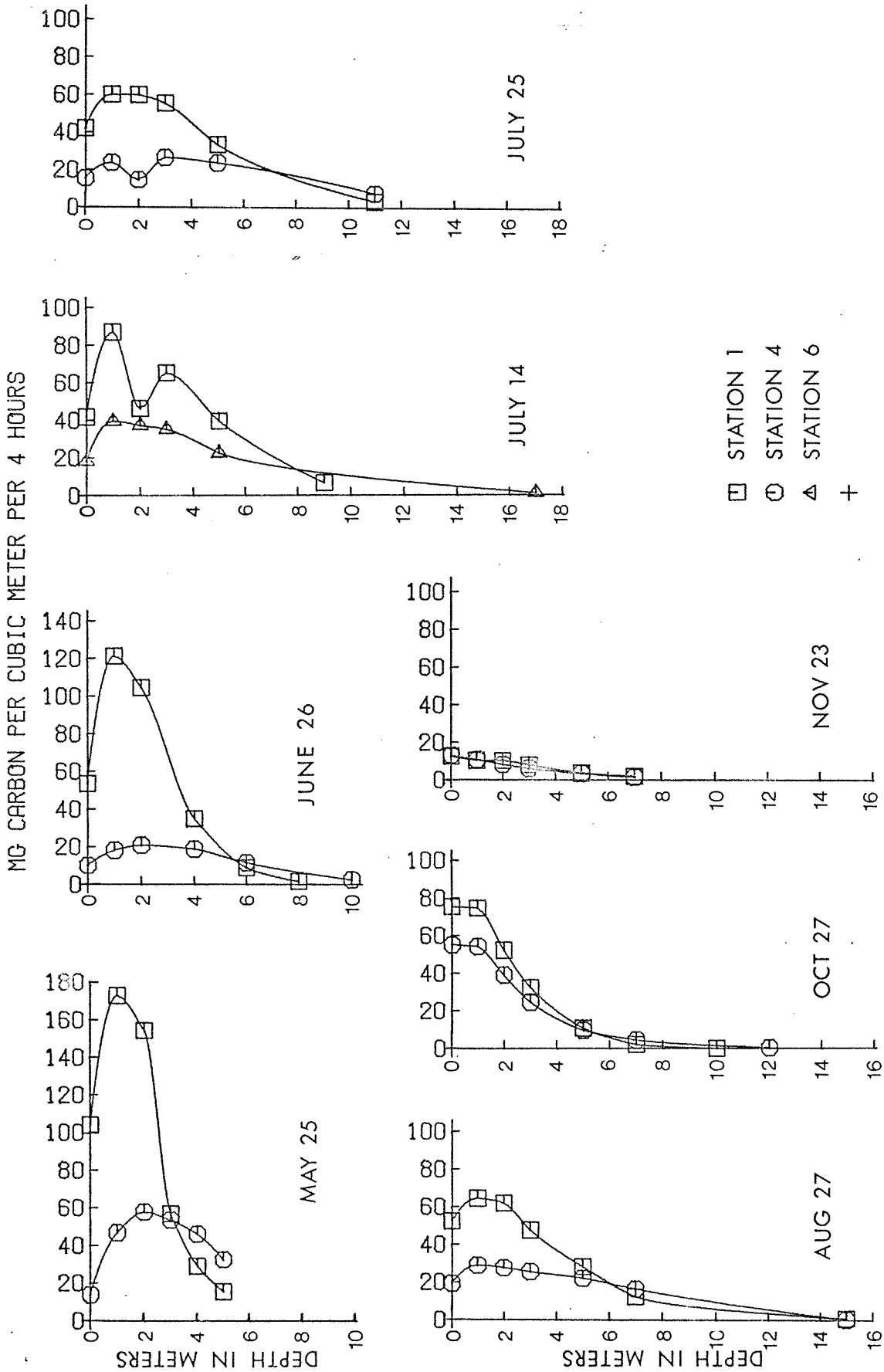


Fig. 4.25 Carbon¹⁴ primary production depth profiles comparing Stations 1, 4 and 6 in Banks Lake in 1975.

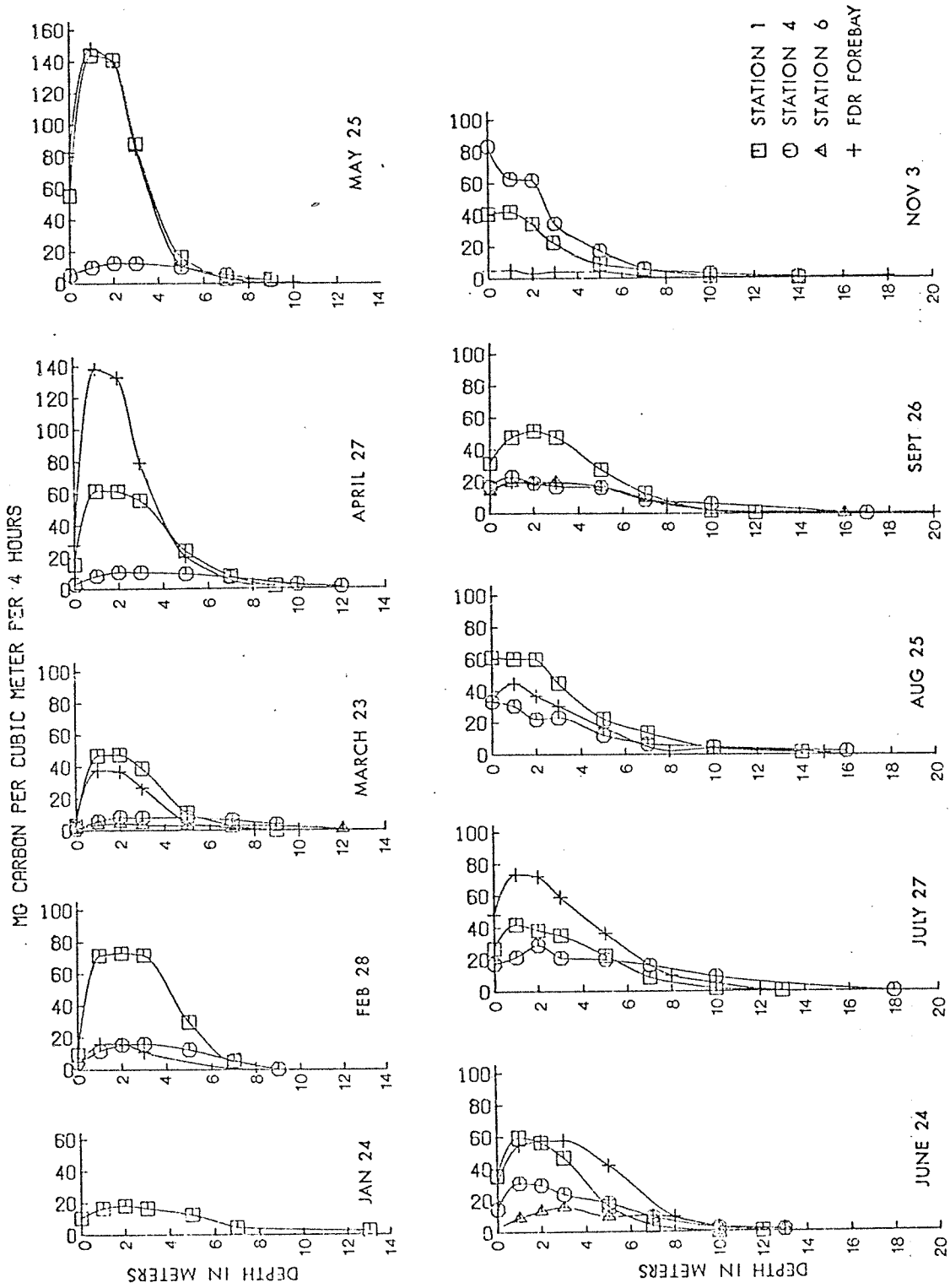


Fig. 4.26 Carbon¹⁴ primary production depth profiles comparing Stations 1, 4, and 6 in Banks Lake and FDR Reservoir forebay in 1976.

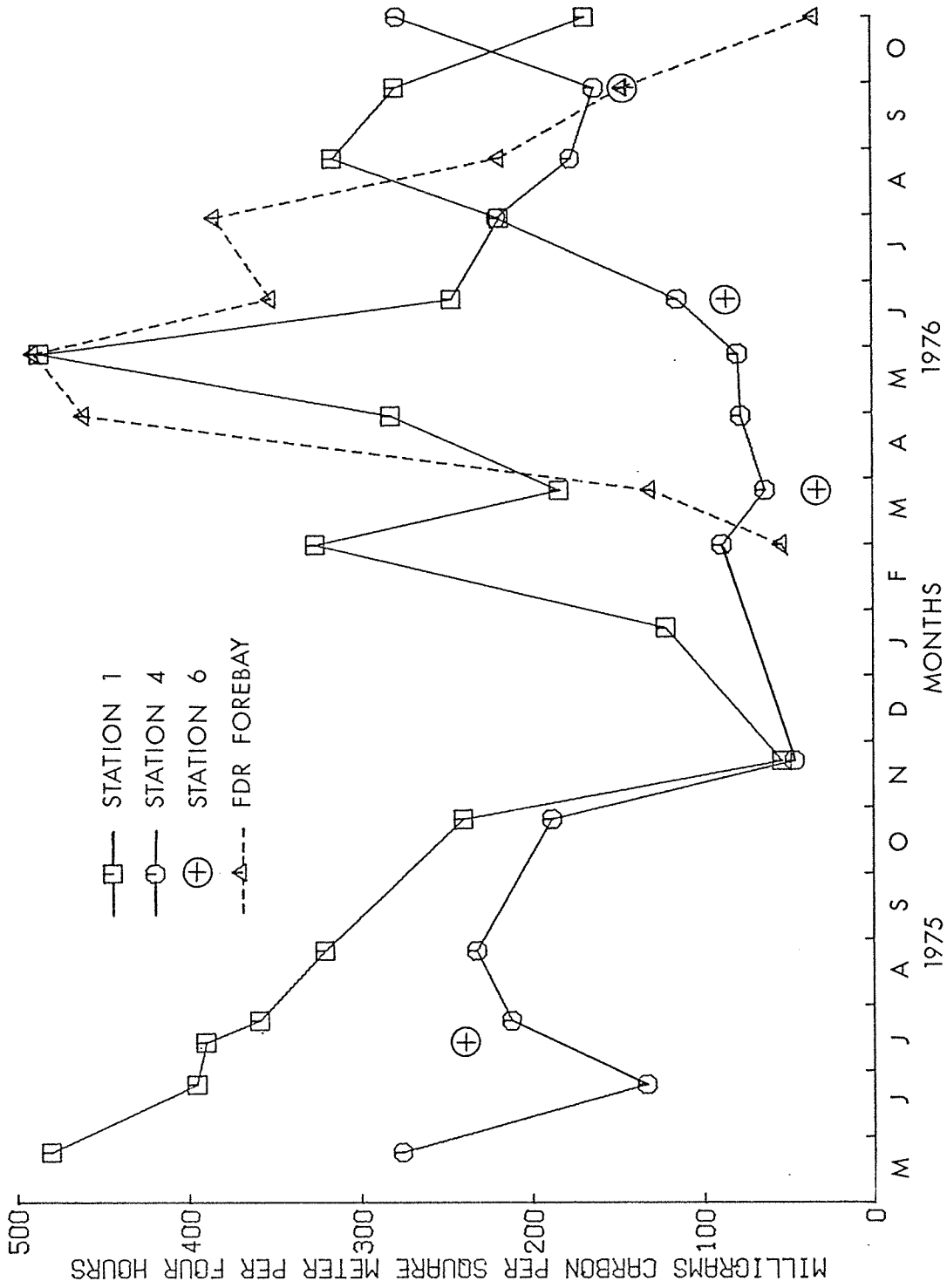


Fig. 4.27 Carbon¹⁴ primary production comparing Stations 1, 4 and 6 in Banks Lake and FDR Reservoir.

between Stations 1 and 4 occurred during May when high pumping rates and peak chlorophyll a were occurring at Station 1. Unlike chlorophyll a, monthly primary production at Station 1 and FDR forebay were not significantly correlated, suggesting different monthly trends.

4.4.5.3. Zooplankton Composition and Abundance. Sixteen species of crustacean zooplankton were identified from the samples (Kiser 1974, personal communication). Ten of these were cladocerans and six were copepods (Table 4.14). In addition, the rotifers *Keratella*, *Asplanchna* and *Kellicotia* were observed in small numbers.

The most frequently observed cladocerans were *Daphnia pulex* and *Bosmina longirostris*. The most frequently observed copepods were *Diaptomus ashlandii* and *Cyclops bicuspidatus thomasi*. Many of the species listed were encountered only rarely.

Quantitative analysis included five groups: *Diaptomus* spp., *Cyclops* spp., copepod nauplii, *Daphnia* spp., and *Bosmina* sp. With minor exceptions, the changes in zooplankton relative abundance observed in the upper 4 m were similar to those observed in the total water column (Figs. 4.28 to 4.33). In almost all cases the data indicate a higher concentration of zooplankton in the upper 4 m than at greater depth, although this difference may have been a function of the sampling gear used.

The greatest abundance of *Bosmina* occurred most often during the spring and early summer, but some distinct differences occurred between years and between stations. In 1974 and 1975, the highest abundance was at Station 1 during the period when feeder canal pumping occurred, with a peak concentration of 79,000/m³ on May 26, 1975, 3 weeks after pumping

Table 4.14 Species of crustacean zooplankton identified from Banks Lake samples. (Courtesy of Mr. Rufus Kiser).

Cladocera

Daphnia schodleri Sars 1862
Daphnia pulex Leydig 1860 amend Richard 1896
Daphnia galeata mendotae Birge 1918
Diaphanosoma brachyurum (Lieven) 1846
Bosmina longirostris (O. F. Muller) 1745
Ceriodaphnia lacustris Birge 1893
Ceriodaphnia quadrangula (O. F. Muller) 1785
Camptocerus rectirostris (Schödler) 1862
Chydorus sphaericus (O. F. Muller) 1785
Leptodora kindtii (Pocke) 1844

Copepoda

Diaptomus sicilis S. A. Forbes 1882
Diaptomus ashlandi Marsh 1893
Epischura nevadensis Lilljeborg 1889
Cyclops vernalis Fischer 1853
Cyclops bicuspidatus thomasi S. A. Forbes 1882
Cyclops agilis (Koch) 1838

ZOOPLANKTON ABUNDANCE IN BANKS LAKE STATION 1

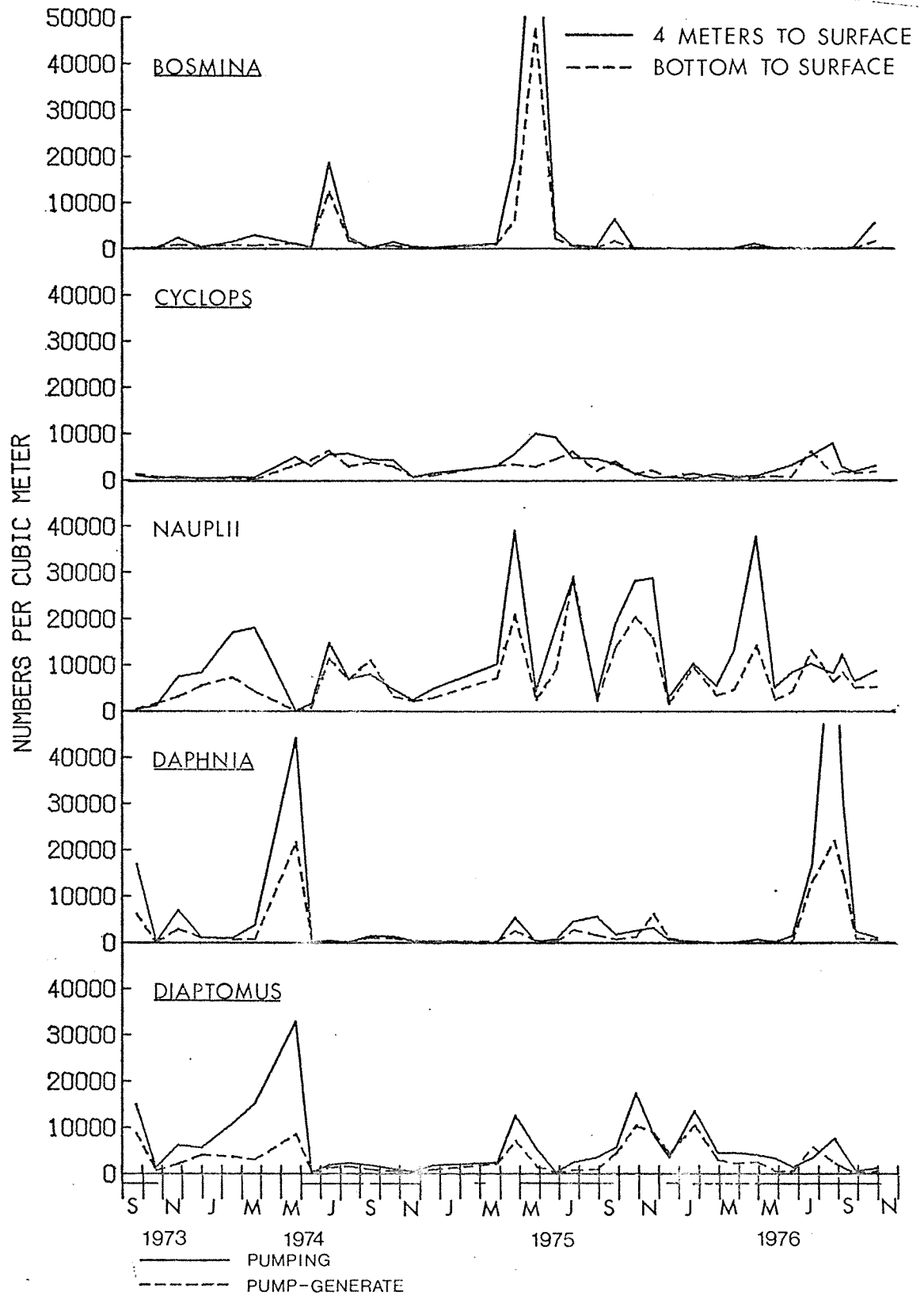


Fig. 4.28 Changes in Banks Lake zooplankton abundance by month from September 1973 to October 1976 (Station 1).

ZOOPLANKTON ABUNDANCE IN BANKS LAKE STATION 2

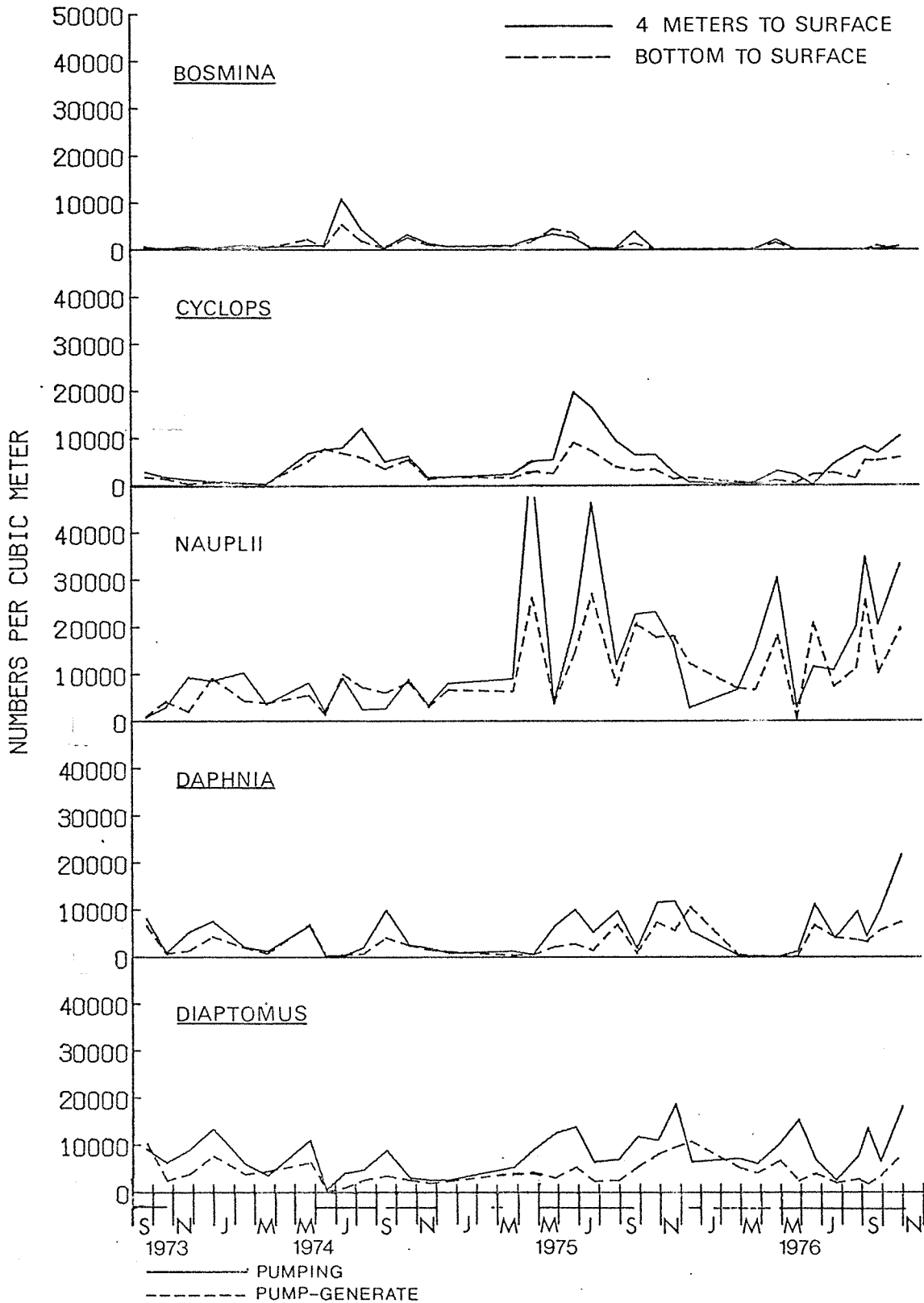


Fig. 4.29. Changes in Banks Lake zooplankton abundance by month from September 1973 to October 1976 (Station 2).

ZOOPLANKTON ABUNDANCE IN BANKS LAKE STATION 3

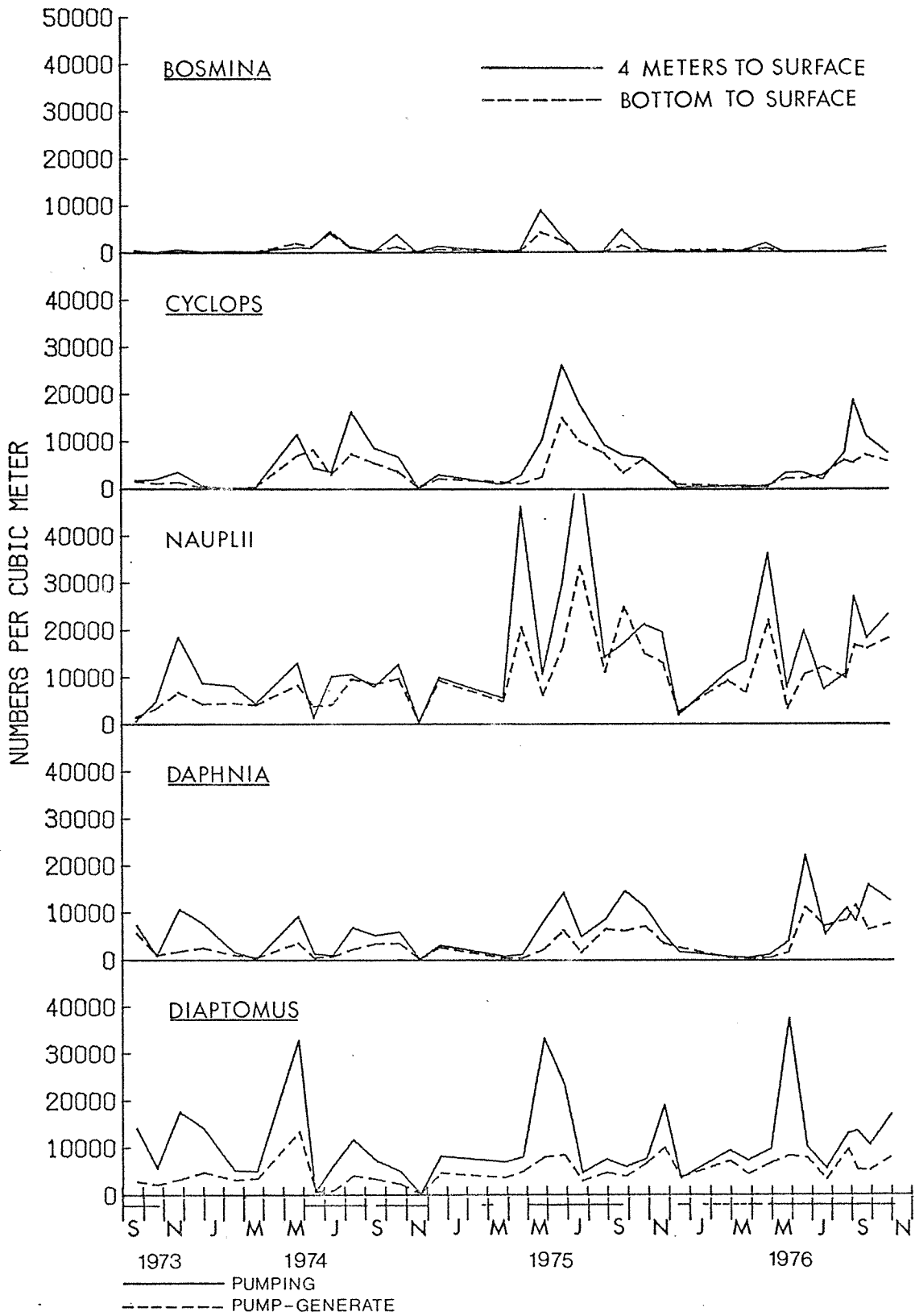


Fig. 4.30 Changes in Banks Lake zooplankton abundance by month from September 1973 to October 1976 (Station 3).

ZOOPLANKTON ABUNDANCE IN BANKS LAKE STATION 4

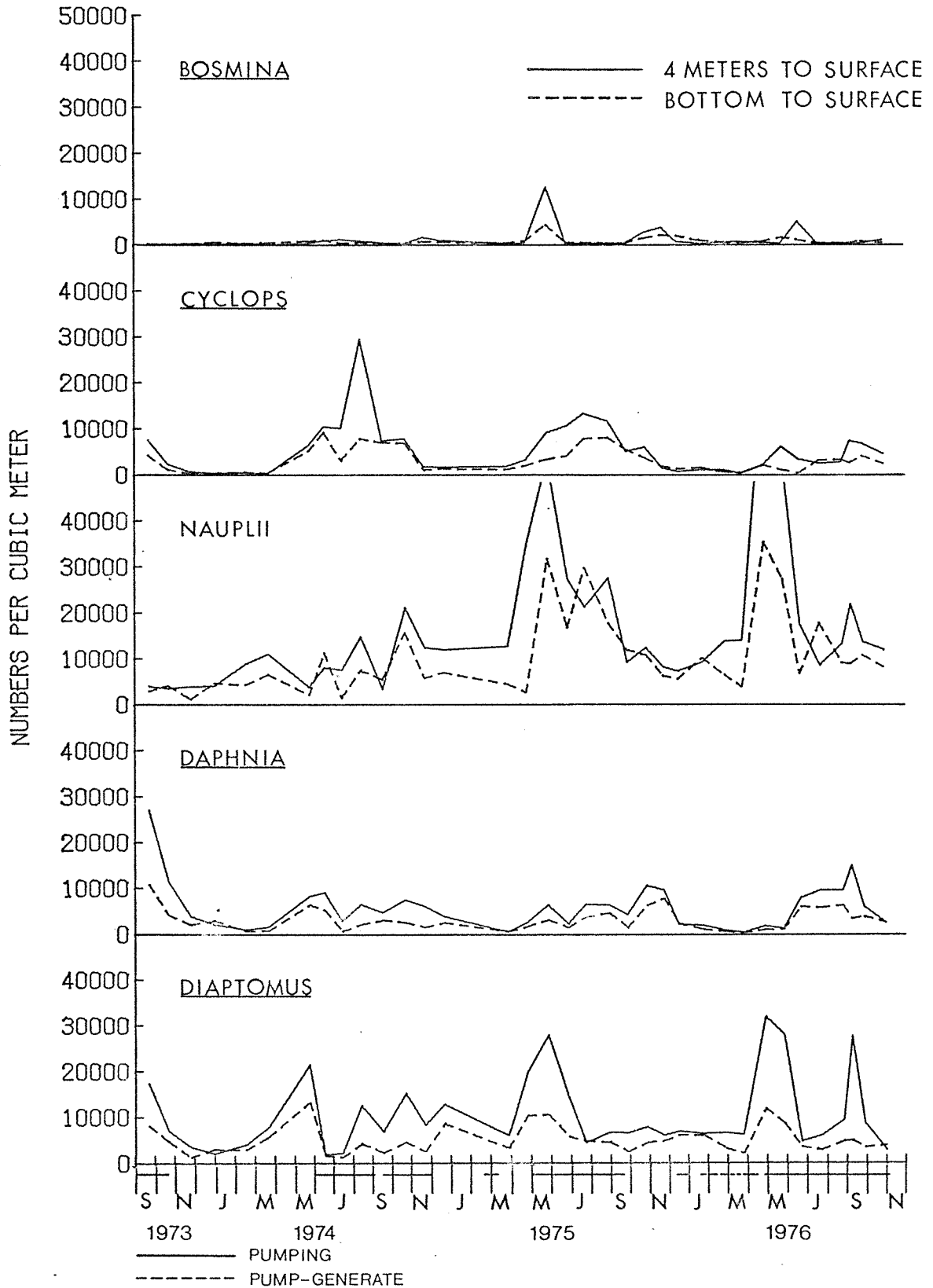


Fig. 4.31 Changes in Banks Lake zooplankton abundance by month from September 1973 to October 1976 (Station 4).

ZOOPLANKTON ABUNDANCE IN BANKS LAKE STATION 5

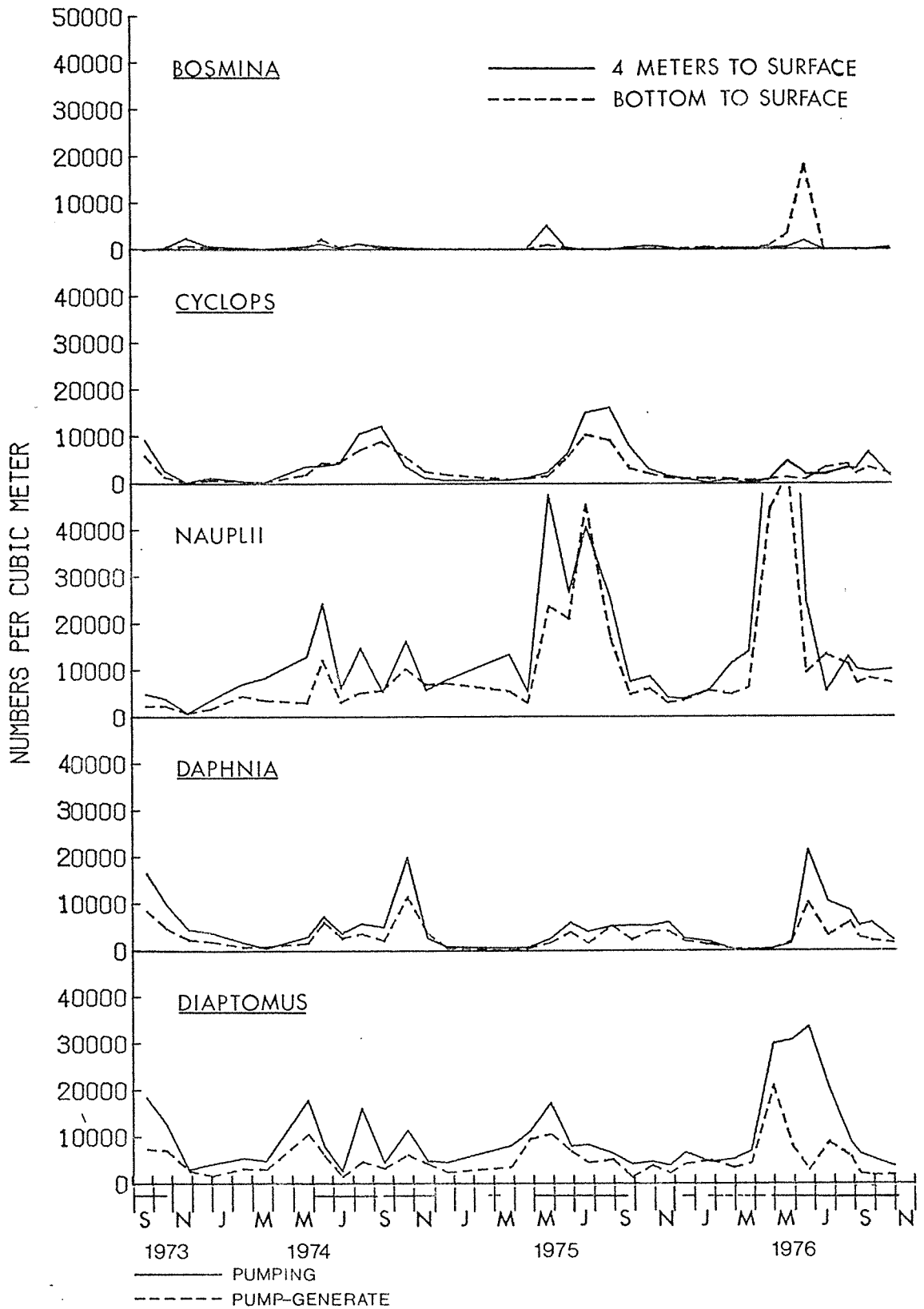


Fig. 4.32 Changes in Banks Lake zooplankton abundance by month from September 1973 to October 1976 (Station 5).

ZOOPLANKTON ABUNDANCE IN BANKS LAKE STATION 6

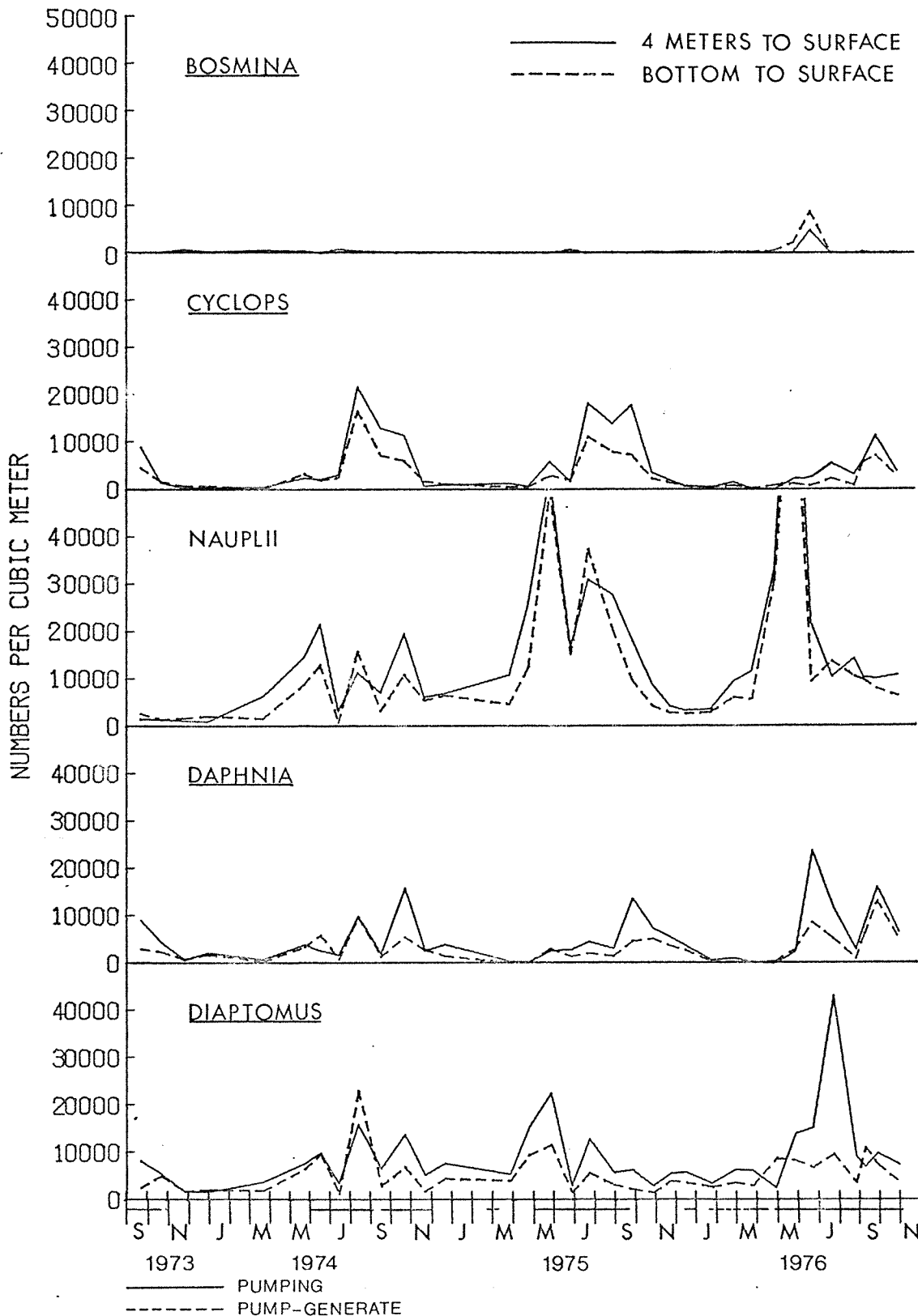


Fig. 4.33 Changes in Banks Lake zooplankton abundance by month from September 1973 to October 1976 (Station 6).

was initiated. In June 1974 *Bosmina* abundance was low, but by mid-July had peaked to a season high at Station 1 of 18,600/m³. Stations 2 and 3 followed similar trends but were of lesser abundance. During 1974 and 1975, peak abundance at Stations 4, 5, and 6 were sporadic and lower than at Stations 1, 2, and 3. Small peaks also occurred in the south pool during May and September. In 1976 the trend was reversed with greatest abundance occurring in the south pool and a maximum number of 18,100/m³ occurring in June at Station 5. Stations 1, 2, and 3 again were similar with a small peak occurring in April but maximum abundance not occurring until October at Station 1 with 5,600/m³.

The seasonally high abundance of *Cyclops* occurred from May to October in 1974, 1975, and 1976, with highest average abundance occurring in August 1974, July 1975, and September 1976. Although no trends were seen from north to south during the pumping season, Station 1 was most often the lowest in density.

The copepod nauplii showed several peaks of abundance during the sampling with similarities within Stations 1, 2, and 3, and within Stations 4, 5, and 6. The maximum nauplii average density for all stations during 1974, 1975, and 1976 occurred in June, July and May. Seasonal peaks in 1974 occurred in May, July, and October at Stations 2 and 3, and in June, August and October at Stations 4, 5, and 6.

In 1975, three peaks were prominent at Stations 1, 2, and 3, occurring in April, July and October. Only two distinct peaks occurred in May and July in the southern three stations.

In 1976, high abundance at Stations 4, 5, and 6 occurred in April, peaked in May, and was also high in June. Stations 1, 2 and 3 peaked in

April and September, but after pumping had begun were low in May. Average nauplii abundance from May to October each year increased from north to south. In all 3 years when pumping was begun in the spring, Stations 1, 2 and 3 showed a reduction in nauplii numbers, while the southern stations showed an increase in numbers. This suggests that pumping may have had a reducing effect on the number of nauplii at Station 1.

Daphnia and *Diaptomus* both increased to maximum numbers at Station 1 in May 1974 prior to initiation of pumping of irrigation water in June 1974. A rapid decline in numbers was evident by June, indicating that both genera were flushed southward in the lake and that no abundant source was pumped in from FDR Reservoir at that time. A similar buildup was not observed in May 1975 or 1976, probably due to an earlier initiation of pumping.

Spring abundance peaks of *Diaptomus* most often occurred in May at all stations, except Station 1, during 1974, 1975, and 1976. Stations 1, 2, and 3 had late fall peaks in October and November 1975. Highest average May-to-October abundance occurred at Station 6 in 1974 and at Station 3 in 1975 and 1976. The lowest average density occurred at Station 1 all 3 years. This suggests that Station 1 *Diaptomus* may be reduced during the pumping season and that Station 3 abundance may be unaffected in years when the water level remains high.

Peak abundance of *Daphnia* occurred at different times each year. During 1974, peaks occurred in May and in late summer and early fall. The peak abundance in 1975 at Station 2 through 6 occurred in late June, September, and November. Peaks at Station 1 occurred in April, July,

and August 1975. High abundance was observed at most stations in 1976 from June to October. The highest density of $73,100/m^3$ was observed at Station 1 in August.

4.4.5.4. Potential Input of Zooplankton. The abundance of zooplankton in FDR forebay for 4, 20, and 95 m to the surface are shown in Figure 4.34. The potential loss or avoidance of zooplankton and reduction of filtering efficiency over a 95-m tow makes these estimates of density questionable. Because of these reasons the 95-m tow was not considered comparable to other hauls, and was not used for comparison between Station 1 and FDR forebay density.

Feeder canal samples were taken periodically. Since these were collected in a different manner than vertical hauls, they were not used as a comparative measure of abundance, but were used as a qualitative measure. Only the 4- and 20-m to surface hauls were used for density estimates in FDR forebay and for comparison with Station 1 zooplankton densities.

Unlike Banks Lake, which had peaks of abundance of some zooplankton as early as April or May, FDR forebay remained low in abundance of all organisms until June and did not have peaks until July, August, or September.

The density of *Cyclops* in FDR forebay was the first to increase and peaked in July with $38,700/m^3$ in the 4-m haul, and remained high through September. The nauplii followed a similar trend remaining abundant from June to October. *Diaptomus* abundance remained low until late August and September, with maximum concentrations of $23,400/m^3$, occurring in August. *Bosmina* remained very scarce at less than $100/m^3$ for all months, with no

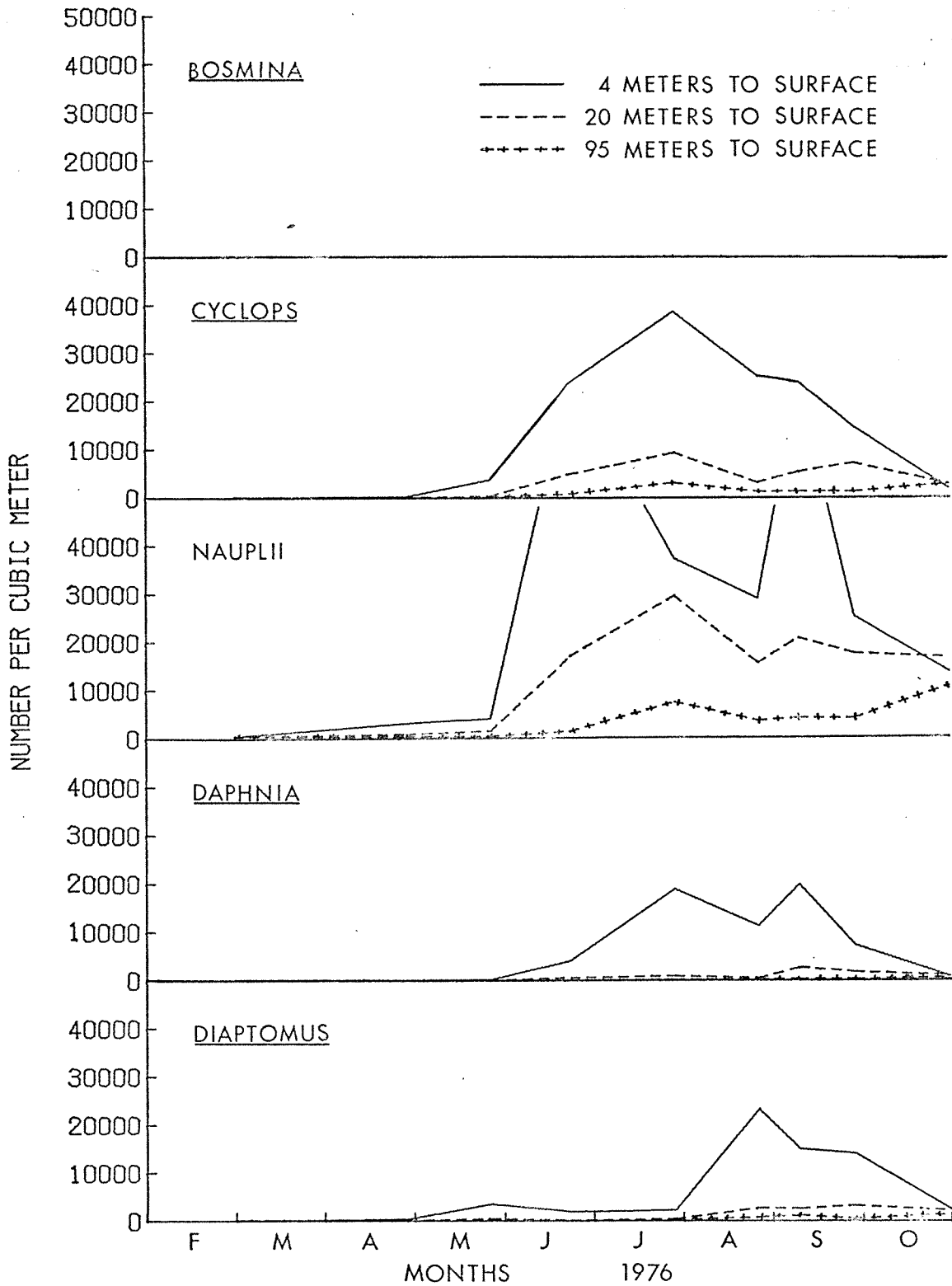


Fig. 4.34 Changes in FDR Reservoir forebay zooplankton abundance for vertical net hauls from three depths, from February to October 1976.

apparent peaks. *Daphnia* was abundant from July to September in the 4-m to surface hauls, and peaked on September 9 at 20,000/m³.

A comparison of zooplankton abundance between FDR forebay and Station 1 indicated noticeable differences between genera. Except for May, when concentrations were low in both reservoirs, *Cyclops* and nauplii density were greater in FDR than at Station 1 at both haul depths. Although *Bosmina* remained higher during pumping months at Station 1 for both depths, except for October when pumping had not reduced the density, Station 1 was very low with less than 400/m³. The *Daphnia* density for the 4-m to surface hauls in both reservoirs was similar, except for the peak months of August and early September, when Station 1 was much higher. The deep hauls showed the same trend, except Station 1 was also higher in July. The number of *Diaptomus* in the upper 4 m in FDR exceeded that at Station 1, except for July. From May to July, Station 1 abundance of *Diaptomus* was greater in the bottom to surface haul than the 20-m to surface hauls in FDR forebay. The reverse was true from August to October.

Feeder canal samples were taken from July to September 1976. The average percent composition, excluding nauplii, for *Diaptomus*, *Daphnia*, *Cyclops*, and *Bosmina*, was 14 percent, 6 percent, 78 percent, and less than 1 percent, respectively. *Diaptomus* and *Daphnia* were consistently low with a maximum of 27 percent and 17 percent, respectively, on September 9, 1976. The relative number of nauplii being pumped in was relatively high, being 75 percent of all zooplankton.

Not only were nauplii and *Cyclops* highest in abundance in the feeder canal, but they may be the least resistant to being pumped in.

Studies by Brooks and Woodward (1956) have shown that different species and life stages of zooplankton show varying degrees of resistance to being passively transported out of a lake. A comparison of relative composition in the feeder canal samples to that of the 20-m to surface haul in FDR indicated that *Diaptomus* and *Daphnia* were at least three times more resistant to being pumped in than are nauplii. *Cyclops* was only about 1.3 times more resistant than nauplii. This suggested that even if *Diaptomus* and *Daphnia* were abundant in FDR they were less likely to be pumped into Banks Lake than nauplii or *Cyclops*.

This apparent difference in resistance to entrainment may also be a result of depth selection since the comparison was with the upper 20 m and not with the depth of intake (30 m).

4.4.5.5. Zooplankton Biomass Estimates. Dry weight biomass estimates of zooplankton in Banks Lake were made from April 1975 to March 1976. Mean lengths for the major genera were taken monthly for each station. Except for *Bosmina*, the average weights were determined by using length-weight regressions from literature values for the most commonly occurring species in the lake. Length measurements in the length-weight equations were in millimeters and individual weight estimates in micrograms. *Diaptomus ashlandi* and *Cyclops bicuspidatus* were the most common copepods. Log-log length-weight regressions were taken from graphs in Pederson 1974, for these two species and were used for estimation of the weight of all *Diaptomus* spp. and *Cyclops* spp.

Diaptomus spp.

$$\log \text{ weight} = .817 + 2.424 \log \text{ length}$$

Cyclops spp.

$$\log \text{ weight} = .822 + 2.207 \log \text{ length}$$

A value of 0.34 μg was assigned to all nauplii according to studies by Schindler and Noven (1971).

A length-weight regression was calculated from the data presented by LeSeur (1960), for *Daphnia pulex*, the most common *Daphnia* species in Banks Lake. Because less than 1 percent of all *Daphnia* measured were greater than 2.25 mm, only the weights for lengths less than 2.25 mm were used in the length-weight regression.

Daphnia spp.

$$\text{weight} = - 10.51 + 10.15 \text{ length}$$

The average length for neonata, juveniles, and adults of *Bosmina longirostris*, was determined from all data and stations. The average weight used for neonata, juveniles and adults were 0.50, 1.04, and 2.00 μg , respectively (Pedersen 1974).

The average crustacean zooplankton biomass was highest in the summer and lowest in the winter (Table 4.15). An increasing trend occurred from April to July 1975, when maximum average dry weight was 89.6 mg/m^3 . After a decrease in September, values increased in October and showed a gradual decline from October 1975 to March 1976 to an average minimum of 14.0 mg/m^3 .

Considerable deviation from these trends was apparent at some stations. Station 1 had the lowest biomass for the peak pumping months June to September, but did not reach a maximum until late November. Station 2 and 3 both had very high maximum values relative to other

Table 4.15 Banks Lake dry weight biomass (mg/m^3) estimate from bottom-to-surface zooplankton tows for crustacean zooplankton and percent of biomass for major groups of organisms from April 1975 to March 1976.

Month	Average 1 to 6	Station					
		1	2	3	4	5	6
Apr	38.2	57.2	33.6	28.5	48.1	28.5	33.0
May	67.1	86.5	39.8	51.9	72.8	68.4	83.6
Jun	76.6	20.7	96.9	169.4	45.8	86.4	40.2
Jul	89.6	60.4	75.4	87.0	120.9	93.5	100.3
Aug	81.8	27.3	94.4	112.7	80.1	123.3	52.8
Sep	49.5	32.2	32.7	72.3	34.4	42.3	83.3
Oct	86.9	65.5	116.0	98.8	108.6	61.8	70.4
Nov	77.3	92.9	79.6	80.5	109.1	46.3	55.4
Dec	59.0	26.0	162.7	41.3	48.0	37.9	38.3
Jan	29.5	32.7	-	-	31.6	37.5	16.0
Feb	19.5	9.6	20.6	26.0	14.3	27.1	19.1
Mar	14.0	10.1	14.6	15.8	6.7	21.6	14.9
May to Oct Avg.	75.7	48.8	75.9	101.3	77.1	79.2	71.8
Apr & Nov to Mar Avg.	40.3	38.8	62.3	35.3	42.9	33.2	29.4
Apr to Mar Avg	53.8	43.8	66.9	68.3	60.0	56.2	50.6
<u>Organism: % of Biomass</u>							
<i>Daphnia</i>	a	43.6	22.0	45.1	51.0	49.1	45.0
	b	44.1	32.6	55.5	40.8	53.5	49.2
<i>Bosmina</i>	a	5.4	23.9	3.1	2.7	44.7	37.6
	b	1.8	4.6	1.0	1.1	1.6	0.6
<i>Cyclops</i>	a	20.1	19.6	21.7	18.1	1.3	0.7
	b	9.5	11.3	6.4	10.7	2.3	1.3
<i>Diaptomus</i>	a	22.6	25.6	23.4	22.2	7.8	11.0
	b	37.6	44.2	29.9	38.1	16.9	19.8
Nauplii	a	8.4	8.9	6.7	6.1	31.6	43.1
	b	7.1	8.2	7.2	9.3	23.7	21.9
					8.7	38.8	18.6
					4.4	8.5	11.4
					5.7	5.7	7.6

a May to October

b All other months

stations, which occurred in December and June, respectively. These two stations were the most closely associated with the shore (within 75 m) and may have been receiving some local littoral zooplankton that did not occur at the other stations. Stations 4, 5, and 6 followed similar trends, peaking in July or August. The lowest biomass for each station occurred in February or March 1976. The average biomass for May to October was lowest at Station 1 with 48.8 mg/m^3 and highest at Station 3 with 101.3 mg/m^3 . The lower biomass at Station 1 was probably the result of relatively zooplankton-deficient water being pumped in from FDR forebay. During the colder months, little difference was apparent between the stations, except for a maximum at Station 2 in December.

Daphnia was the major zooplankton biomass at all stations except Station 1 during May to October (Table 4.15). In the colder months, April 1975 and November to March 1976, the percent of *Daphnia* was about the same but was more varied between stations. The contribution of *Bosmina* to the total biomass was low, less than 4 percent at all stations except Station 1, where it was 24 percent during the productive months (May to October). During the less productive months, *Bosmina* was less than 5 percent at all stations.

4.5 Discussion

4.5.1 Physical Limnology

4.5.1.1. Temperature. The seasonal thermal characteristics of Banks Lake classify it as a modified dimictic lake (Hutchinson 1957). The characteristics of a partially stratified lake and river-run reservoir are apparent during the summer. The effects of pumping cold dense water into the north end of the lake which dives under a warm layer describes

the complex thermal characteristics of the lake (Karp 1975). This phenomenon of diving water causes a convergence zone (Hoffman and Jonez 1973).

The water temperature regime was influenced by lake level, schedule of irrigation pumping and pump-generation. High lake levels caused the convergence zone to occur north of Station 2 and created a greater temperature range from surface to bottom. During lower lake levels the convergence moved south to between Stations 2 and 3. The pumping and P/G in the winter and irrigation pumping in the summer caused the temperature regime of Station 1 to follow that of FDR forebay at the depth of intake in 1976. During the summer, the depth of intake in FDR Reservoir was about 30 m below the surface, drawing cool hypolimnetic water into Banks Lake. Similar patterns of temperature at approximately 30 m depth have been shown for Lake Roosevelt in past years (Sylvester 1953, and USGS 1972). Pumping from Lake Roosevelt has maintained higher winter, lower summer, and later peaking temperatures at Station 1 than occur in the remainder of Banks Lake.

Maximum surface temperatures occurred at Station 3 during all four summers. This suggested the lack of mixing of epilimnetic surface water with cold irrigation water from Lake Roosevelt in the region of the convergence. As air temperature cooled in the fall, stratification ended in mid-September in 1973 and 1974, and late August 1975, and September 1976.

4.5.1.2. Transparency. Secchi disc transparency was primarily influenced by phytoplankton standing stock and suspended sediment due to wave action, turbidity of pumped input and pump-related turbulence.

Much of the shoreline and lake bottom consisted of easily disturbed fine glacial till. Stations 2, 3, and 5 were most affected by the resuspension of fines due to wave action. Just north of Stations 2 and 5, shallow spits of land extend into the water. During wave action visible turbidity extended downwind from these shorelines. This wave-induced turbidity was measured at Station 5 in August 1975 when a visible line of turbid water extended across the lake resulting in a reduction of the Secchi depth from 4.2 to 2.1 m. Stations 4 and 6 were least affected by silt-induced turbidity, because Station 4 was located in the wildest portion of the lake and Station 6 was surrounded by a steep rocky shoreline. Although the local shoreline near Station 1 was rocky, turbulent mixing and input of suspended matter had the greatest effect on transparency. The transparency in FDR Reservoir was characteristically poor during all months except early fall (Farnest et al. 1963, Bishop and Lee 1972). Even though the incoming water from FDR was very clear in September and October 1976, Station 1 still had much lower Secchi depths indicating the effect of mixing on reducing the transparency.

The Secchi depth values of less than 3 m most often correlated with increased chlorophyll a values in the three northern stations. Autumn reduction in Secchi depth at these stations in October 1973 may have been caused by phytoplankton blooms after pumping was stopped. When pumping began in June 1974 and May 1975, peak chlorophyll levels and season low Secchi depths were observed. Similar phytoplankton blooms and reduced transparency were seen in fall 1975 and late winter 1976 when pumping or pump-generation was occurring. Station 6 consistently

averaged the greatest Secchi depth and lowest chlorophyll a concentration. Stations 4 and 5 Secchi depths did not appear to be correlated with phytoplankton levels.

4.5.2 Chemical Limnology

4.5.2.1. pH. The 1975 and 1976 pH readings were higher than those previously reported because they were measured in situ. This eliminated the effects of transportation and respiration which reduced prior measurements. The maximum pH occurred in May 1975 at the three northern stations concurrent with the maximum primary production rate. Higher pH values are expected in a low alkalinity lake during peak production from CO₂ depletion of the carbonate-bicarbonate system. This trend was not visible in 1976 but highest pH values did occur at the northern three stations and in FDR Reservoir where production rates were high. The lowest pH readings occurred in the summer near the bottom at the southern stations (4, 5, and 6) indicating respiration exceeded photosynthesis at that time.

4.5.2.2. Ions and Conductance. The ionic composition of Banks Lake water was dominated by calcium, magnesium, carbonate, and bicarbonate, which classifies the lake as a Type I system (Rainwater 1962). The ionic concentrations were similar to but slightly less than those reported for Lake Roosevelt (USGS 1972). The hardness levels indicated water of soft to moderately hard (Hem 1970). The alkalinities were low but consistent with other data reported for the area (Seattle Marine Laboratories 1974; USGS 1972). Alkalinity, hardness, and conductivity all showed similar patterns of change. The fluctuation in the north portion of the lake followed those of FDR forebay having highest levels during

the winter and lowest during the spring and summer, due to the diluting effects of the runoff. Because of the large volume of water in the south pool, responses to rapid change in concentration of the inflow water were very slow, maintaining a much narrower range and more stable ionic system.

The conductivity levels were low during the study but similar to other data reported for the Columbia Basin (USGS 1973; Bishop and Lee 1972). A conversion factor of 0.55 to 0.75 multiplied by conductance gave approximate values for total dissolved solids (TDS) (Hem 1970). The estimates of TDS would be 63-108 ppm, and average 78 ppm. These estimates may be low. During August 1976, TDS measurements were 105 and 129 ppm at Stations 1 and 4, respectively. The measured values more closely approximate literature values for this region than do the estimates. Kiser (1965) found TDS ranging from 88.6 to 118.8 ppm (mean: 95.4) at Steamboat Rock in 1965-66. Lake Roosevelt levels of TDS in 1971-72 ranged from 84 to 180 ppm (mean: 104) (USGS 1972). Studies done on the Columbia River in 1910-11 and Lake Roosevelt in 1951-52 (Sylvester 1953) showed mean TDS levels of 84 and 94 ppm, respectively. Although the mean value estimated for 1975-76 was slightly lower than all values shown, this value was only an estimate. It is doubtful that any real change has occurred since Kiser's work.

The oxydation-reduction potential (ORP) remained high, rarely dropping to 400 mv (hydrogen-standard electrode measurements) near the bottom. The high levels and lack of large reduction near the bottom during summer stratification characterize an oligotrophic lake (Welch 1952).

4.5.2.3. Silica. Silica has been shown to be a growth-limiting nutrient for the diatoms, *Asterionella formosa*, when levels were less than 0.5 mg/l (Lund 1950). Stations 1, 2, and 3 showed seasonal highs when pumping was initiated in May 1975. Silica declined throughout the season until levels of 0.5 mg/l were again approached in October and November after pumping had stopped. These low levels may have been partially responsible for season lows in primary production in November at Station 1. Silica levels at Stations 4, 5 and 6 averaged lower than the northern stations, but did not show limiting levels at any time in 1975 and 1976. The low levels of silica were not observed in 1976, but some pumping or P/G operation occurred in all months sampled, thus maintaining higher silica levels in the north pool of the lake. The silica concentration in FDR forebay and at Station 1 were similar during pumping in 1976, maintaining the highest silica levels in Banks Lake at Station 1. Since silica is a nutrient actively used by diatoms, the rapid reduction in average concentration from Stations 1 to 3 was probably the result of rapid production of diatoms in the north pool of Banks Lake.

4.5.2.4. Plant Nutrients. The sources of nutrient (N and P) in Banks Lake are highly dependent on season and level of lake drawdown. The major source of nutrient for the lake is input from FDR forebay during the pumping season. During the nonpumping season, internal recycling of nutrients is probably the major source. Most of this recycled nutrient had its origin in Lake Roosevelt. During winter runoff and spring melt, a supply of nutrient may come in from a few local streams and high plateau wheat fields above the lake. During low

drawdown years, like 1973 and 1974, decaying terrestrial vegetation that was covered by rising water after it had grown in the exposed shoreline areas may add nutrients to the lake system. Rada (1974) found that in a low drawdown year in Canyon Ferry Reservoir, nutrient supply appeared to increase due to increased release from the exposed areas.

Nutrient data plus chlorophyll a was used to classify the trophic status of north and south Banks Lake (Karp 1975). This table was expanded to include ^{14}C production and comparisons between 1974, 1975, and 1976 (Table 4.16). The loading rate of nitrogen and phosphorus was calculated by assuming the nutrient concentration at Station 1 was equal to the incoming water. Nutrient loading rates in 1976 were also calculated assuming concentrations equal to those in FDR forebay, at depths greater than 20 m. Supplies of phosphorus and nitrogen showed slight increases from 1974 to 1975 and large increases in 1976. The phosphorus supply far exceeded the minimum for a eutrophic classification all 3 years (Stamnes 1972; Vollenweider 1968). The nitrogen loading rate calculated using Station 1 values easily classified the lake as oligotrophic all 3 years. But using the values in the deep water from FDR Reservoir for 1976, the lake bordered on a mesotrophic classification. Winter mean concentration of orthophosphate and nitrate indicated the same classification of eutrophic and oligotrophic, respectively (Welch and Spyridakis 1972).

Chlorophyll a data suggested that the northern region was mesotrophic in 1974 but oligotrophic in 1975 and 1976. The southern region was oligotrophic all 3 years. Carbon 14 primary production measurements indicated that north and south pools of Banks Lake were mesotrophic both

Table 4.16 Trophic status of Banks Lake with respect to various parameters (modified from Karp 1975).

Criterion	Year	Banks Lake Values ^b			Eutrophic	Authority
		North	South	Total		
Chlorophyll <i>a</i> , µg/l (growing season mean) ^a	1974	4.2	1.6	2.8	0 - 4 10 - 1000	Welch and Spyridakis (1972)
	1975	3.7	1.5	2.6		
	1976	3.2	1.1	2.1		
Orthophosphate - P, µg/l (winter mean)	1974-75	15.8	19.6	17.8	> 10	Welch and Spyridakis (1972)
	1975-76	13.0	11.0	12.0		
Nitrate - N, µg/l (winter mean)	1974-75	17.8	9.6	13.8	> 300	Welch and Spyridakis (1972)
	1975-76	19.0	2.7	10.9		
Total P annual supply g/m ²	1974			.3	> .92	Vollenweider (1976)
	1975			.6		
	1976			1.2 (1.1) ^c		
Total N annual supply g/m ²	1974			.1	> 3.0	Stammes (1972) Vollenweider (1968)
	1975			.2		
	1976			.8 (2.0) ^c		
mg C/m ² /day (growing season mean) ^a	1975	770	451	610	30 - 100 1000 - 3000	Rhode (1969) Schindler and Nighswander (1970)
	1976	670	361	515		

^aMay to September

^bNorth Banks Lake = Stations 1-3; South Banks Lake = Stations 4-6

^cLoading rate using mean concentration in FDR forebay below 20 meters

years, according to Rhode (1969) and Schindler and Nighswander (1970). These classification schemes have been derived mainly from natural lakes. A comparison between Banks Lake and a reservoir of similar morphological and physical characteristics, Canyon Ferry Reservoir (Rada 1974), is made in Table 4.17. Canyon Ferry, similar to Banks Lake, also has a very high phosphorus loading rate (eutrophic) but a mesotrophic nitrogen loading rate according to Vollenweider (1968). Canyon Ferry has a much higher chlorophyll a level (9.8 µg/l) than Banks Lake (2.5 µg/l), approaching a eutrophic status (Welch and Spyridakis 1972). The most noticeable differences between the reservoirs that may account for the higher chlorophyll a in Canyon Ferry Reservoir was the higher nitrate-to-phosphate loading ratio (5.7 versus 1.4) and the higher nitrate and phosphate concentrations during the growing season. These differences suggest that the nutrients being pumped into Banks Lake may be less available during the growing season, and that of the two nutrients, nitrates are in extremely short supply. This example also indicates that the use of "classification schemes" derived from lake data should be used with caution with reference to a reservoir.

The effects of pumping and morphometry have separated the lake into two functionally separate pools that may vary slightly in size. The north pool most often encompasses the area from Station 3 to the north dam and represents less than 10 percent of the lake volume. During years when a high lake level is maintained the similarities in nutrients and chlorophyll a between Stations 1, 2, and 3 may be less distinct.

It is apparent from the nutrient levels that nitrogen is the most limiting nutrient in Banks Lake. The water that passes into southern

Table 4.17. Comparisons between Canyon Ferry and Banks Lake.

Parameter	Canyon ^a Ferry	Banks Lake	Unit
Elevation	1,161	479	m
Area	14,238	11,008	ha
Volume	253	148	ham x 10 ³
Mean Depth	17.8	13.5	m
Length	40.2	46.8	km
Maximum Width	7.2	8.0	km
Mean Retention Time	135	180(90) ^b	days
Shoreline Development	2.89	3.53	---
Maximum Surface Temperature	23.3	24.2	C
Ortho-Phosphate	31 ^c	10 ^c	µg/l
Nitrate	70 ^c	6 ^c	µg/l
Total Phosphorus	68 ^c	30 ^c	µg/l
Phosphorus Loading Rate	1.17	0.7(1.1) ^d	g P/m ² /year
Nitrogen Loading Rate	3.5	0.4(2.0) ^d	g N/m ² /year
NO ₃ :PO ₄ Inflow Ratio	5.2	1.4(2.8) ^d	Molar Wt N:P
Mean Chlorophyll <u>a</u>	9.8	2.5	µg/l
Primary Production	500	562	mg C/m ² /day

a Data from Rada, 1974

b Number in parentheses represents pumping season

c May to September average

d Number in parentheses represents concentrations in Lake Roosevelt forebay below 20 meters as input values.

Banks Lake has already been highly depleted of its nutrients, especially nitrate. This gradual loss of nitrate and its depletion from north to south is indicated by the N:P ratio. The N:P ratio ($\text{NO}_3:\text{PO}_4$) showed a gradual decline from north to south during 1974, 1975, and 1976. This ratio ranged from 0.0 to 1.9 in 1974; 0.0 to 2.0 in 1975; and 0.0 to 9.0 in 1976. The yearly average was less than 1.0 in 1974 and 1975 for all stations. In 1976 Station 1 N:P average was 2.1, while other stations remained below 0.5. This higher average at Station 1 was in direct response to winter pump-generation, increasing the ratio during the winter. The N:P ratio in FDR forebay was 2.9 for 1976, indicating a reduction and relatively more rapid use of nitrates from FDR to Station 1.

These ratios were extremely low in relation to algae cell composition. In saltwater systems, which are naturally nitrate-limited, average cell compositions have an N:P ratio of 7.2 to 1, with the lower range approaching 1.5 to 1 (Ryther and Dunstan 1971). The lower N:P ratio and low nitrate concentration was probably a major limiting factor in phytoplankton biomass formations. This limitation was more inhibiting in the south pool of Banks Lake than in the north.

4.5.3 Biological Limnology

4.5.3.1. Phytoplankton. The phytoplankton dynamics of north Banks Lake were controlled by irrigation water inflow. This became apparent when it was determined that during peak pumping the entire volume of water north of Station 3 was replaced once every 3 to 6 days. During the four major irrigation months, the maximum residence time for the area was less than 15 days. Prior to initiation of pumping in 1974 and

1975, Stations 1 to 3 showed either a low or declining chlorophyll a concentration. Seasonal maxima were found after pumping started at all three stations. This was followed by declining summer concentrations and a fall bloom. Rufus Woods Reservoir chlorophyll a data taken 6 miles below Grand Coulee Dam showed the same trends and similar concentrations as those found at Station 1 from the period May to August 1975 (Stober et al. 1977).

On three different occasions, during July and August 1975, chlorophyll a was determined in the feeder canal, although these levels were lower than those found at Station 1, the difference was not greater than 1 $\mu\text{g}/\text{l}$. During this period, the pumping rate was high and residence time of the north end was less than 15 days. These data suggest that chlorophyll a levels were similar to those being pumped in but some biomass increase occurred at Station 1, even during high rates of pumping.

The effect of reducing the flushing rate was apparent in all 4 years. After the cessation of pumping in October 1973, chlorophyll levels increased at all three stations in the north pool. Another increase was observed when pumping was stopped for 10 days in September 1974, and then resumed, residence time averaged greater than 30 days. At that time, peak chlorophyll levels occurred showing a season high at Station 3. Although chlorophyll levels were increasing in September 1975 when residence time was greater than 30 days, a postpumping peak did not occur until October.

The additional data from FDR forebay further helps explain the changes in chlorophyll a at the northern stations in Banks Lake. FDR Reservoir reaches a maximum early, in April and May, decreasing to lows

less than 1.0 $\mu\text{g}/\text{l}$ by August and remaining low in the fall. Station 1 follows this same pattern only during peak pumping months, increasing slightly but consistently over the incoming water concentration in 1976. The high correlation ($r = .88$) and significant difference ($P = .005$) between chlorophyll a levels in FDR forebay and Station 1 confirm this theory. During May and June 1976, incoming nutrients were low and chlorophyll a high, so no increase in phytoplankton biomass was possible beyond Station 1. By August 1976, incoming water was very dilute in chlorophyll a but nutrient concentrations had increased. Although Station 1 showed only a small increase in chlorophyll over incoming concentrations, the short residence time pushed the increased chlorophyll a and nutrients down the lake causing the peak in chlorophyll a to occur at Stations 2 and 3. When pumping stopped in early fall as it did in 1973, 1975, and 1976, retention time in the north pool increased and peaks in chlorophyll a occurred at Stations 1, 2, and 3.

The direct effect of nutrient input from pumping and its effect on phytoplankton biomass was demonstrated in winter of 1975-76. The pumping in December and pump-generation starting in late January and continuing through March caused nitrate and orthophosphate at Station 1 to reach maximum concentrations in January and February, respectively. The N:P ratio at Station 1 also increased during the December to March period, from 1.9 to 9.0 while remaining below 1.0 at all other stations. No immediate response to these levels was seen in December, probably because of light limitations.

In February and March, chlorophyll a levels at Station 1 were 7.05 and 8.11 $\mu\text{g}/\text{l}$. These were the highest winter chlorophyll a levels

recorded for Banks Lake. The concentration in FDR forebay at the time was much lower, only 1.94 $\mu\text{g}/\text{l}$ in February and 4.37 $\mu\text{g}/\text{l}$ in March. This data indicated that the chlorophyll a increase at Station 1 during the winter was in response to nutrient input from FDR forebay and not due to chlorophyll a input. Chlorophyll increases at Stations 2 and 3 at this time were similar to February 1974 levels and may have been in response to normal winter nutrient release and not input from FDR Reservoir.

Phytoplankton blooms in the north and south pools occurred at similar times within each pool but at different times between the two pools. This was demonstrated by the Pearson *r* correlation coefficient (Table 4.13). Stations 1, 2, and 3 were directly responding to pumping effects. But peaks at Stations 4, 5, and 6 were poorly defined and showed no direct effects from pumping.

The fall overturn seemed to have the greatest effect on Stations 4, 5, and 6, with small peaks in chlorophyll a occurring in September or October all 4 years. Spring blooms were sporadic and did not occur consistently between years or stations. The chlorophyll a levels in the south pool were much lower than the north pool. The significant decrease in chlorophyll a between all stations, from 2 through 6 (Table 4.13) was probably the result of the gradual reduction of nutrient supply as the water moved down the lake away from the main source of nutrient, FDR Reservoir.

4.5.3.2. Primary Production. The ^{14}C primary production measurements showed a distinctive gradient in Banks Lake with highest values in the north to lowest in the south. The paired t-tests showed significant differences between Stations 1, 4, and 6, confirming the decreasing

gradient away from the inflow. The seasonal decrease in production between 1975 and 1976 occurred at both Stations 1 and 4. This reduction followed that of lower chlorophyll a and was probably a result of reduced temperature (lowest maximum temperature in 4 years) and possibly reduced light (all sampling dates in 1975, except June, had higher light than the appropriate monthly sample date in 1976). A mean depth increase occurred from 1975 to 1976 for the 2 main growing months (May and June). Mean depth for May 1976 was 7 percent greater than 1975, and June 1976 was 13 percent greater than 1975. This increase could have caused a greater volume of water being below the euphotic zone allowing more phytoplankton to fall out of the productive region, resulting in lower production of biomass. No significant difference was apparent on a seasonal basis between Stations 1 and FDR, although Station 1 averaged slightly less. Except for May, production on any given month appeared to be quite different between the two stations. During May 1976, pumping was at a maximum 251 cms, (9,000 cfs). FDR Reservoir was not thermally stratified and the depth of intake was at 22 m, 8 m shallower than other pumping months. During May the water at Station 1 was probably more similar to that of FDR forebay surface water than any other month, accounting for the similarities in production.

From June to October, the water coming in was hypolimnetic water, with potentially different nutrient concentrations, phytoplankton density, and growth potential than that of the surface water of FDR Reservoir. Therefore a difference in production at that time would not seem unlikely.

4.5.3.3. Zooplankton Abundance.

4.5.3.3.1. Bosmina. The unique characteristics between north and south Banks Lake was also shown in the difference in zooplankton density and composition. The *Bosmina* population showed an annual average decrease from north to south in 1974 and 1975. But in 1976, the south pool had higher abundance than Stations 1, 2, and 3. The higher abundance in 1974 and 1975 and lower in 1976 may have been due to input from pumping. The possibility of *Bosmina* being pumped in from FDR Reservoir may be likely, but this theory is not confirmed by Rufus Woods data (Stober et al. 1977). The density in Rufus Woods was only about $500/\text{m}^3$ during May 1975, when levels were $50,000/\text{m}^3$ at Station 1 after pumping was in operation. However, some *Bosmina* species have been shown to be depth selective (Carlson 1974). His work with *Bosmina coregoni* in Lake Iliamna showed that during midday the major peak of abundance was between 20 and 40 m depth. If *Bosmina* were present in FDR forebay and were depth selective for 20 to 40 m there would be a greater susceptibility to being pumped into Banks Lake than washed down to Rufus Woods Reservoir. The FDR forebay sample of 1976 showed very few *Bosmina* present (less than $100/\text{m}^3$). But of the major genera sampled in the feeder canal, it was the only one to show a higher proportion in the canal than in FDR forebay. This suggests a depth selection favoring input into Banks Lake.

Pederson (1974) found that *B. longirostris* has a very short lifespan and could complete its life cycle in 19 days at 20°C . Although residence time in north Banks Lake during the pumping season was shorter than this, some resistance to being carried away in the outflow water (Brook

and Woodward 1956) may allow peaks of abundance to occur during midsummer when temperatures are high.

The large littoral area of the north pool may help to account for the highest abundance occurring there. Brooks and Dodson (1965) have shown *B. longirostris* to be a littoral species. Competition between *Bosmina* and *Daphnia* may inhibit *Bosmina* populations (Brooks 1968). The low population of *Bosmina* in 1976 at Station 1 was accompanied by the highest pumping season densities of *Daphnia*. This trend of low *Bosmina* when *Daphnia* peaks occurred was common in Banks Lake.

4.5.3.3.2. *Daphnia*. The *Daphnia* populations showed the same trends of higher abundance in the summer and lower abundance in the winter all 3 years, but some differences between stations and years were apparent. The *Daphnia* population in the north pool may have been greatly affected by pumping. An increasing trend in *Daphnia* abundance from 1974 to 1976 was seen at Stations 1, 2, and 3. Station 1 had the largest increase in average pumping season abundance from $500/\text{m}^3$ in 1974 to $6,200/\text{m}^3$ in 1976. Stations 2 and 3 showed similar increases from $1,500/\text{m}^3$ in 1974 to $4,100/\text{m}^3$ in 1976 at Station 2, and $2,100/\text{m}^3$ in 1974 to $7,000/\text{m}^3$ in 1976 at Station 3. Stations 4, 5, and 6 did not show this dramatic increase, but did have higher densities in 1976 than the previous 2 years. The increased *Daphnia* density from Station 1 to 3 and from 1974 to 1976 at all three stations may be from an increase in residence time in the north pool, a result of maintaining higher lake levels in 1975 and 1976. A trend of midsummer increased lake level and decreased pumping rate occurred from 1974 to 1976, resulting in longer water residence times in the north pool.

LeSeur (1960) in laboratory experiments has shown that a generation time (from egg to first young hatched) for *Daphnia pulex* could be completed in 11 days at 16° C. During midsummer temperatures at Stations 1, 2 and 3 were higher than 16° C. Higher temperatures should reduce the generation time somewhat. Even in 1976, average retention time in the north pool was less than 10 days. Brooks and Woodward (1956), however, have found in studies of lake outlets that zooplankton may resist outwash to varying degrees. They observed that densities of *Daphnia* in lake outlets were less than one-tenth that in the lake. This resistance to outflow and very short life cycle may help explain the large abundance of *Daphnia* during the 1976 pumping season at Stations 1, 2 and 3.

Input of *Daphnia* from FDR Reservoir may also be important at Station 1. The *Daphnia* density in 1974-75 pumping season was similar in fluctuation and density to that of Rufus Woods Reservoir, 6 miles below Grand Coulee Dam (Stober et al. 1977). The abundance in FDR Reservoir during 1976 in depths to 4 m was high enough to account for the density at Station 1 in all months except the peak value in August. But feeder canal samples for those months indicated that *Daphnia* could be resistant to outwash from FDR Reservoir into Banks Lake, or not found in abundance at the 30-m depth of intake.

The *Daphnia* population may be affected by predation of the three most abundant species of fish in Banks Lake (kokanee, lake whitefish, and yellow perch). *Daphnia* has been shown to make up more than 90 percent of the diets of these fish species in Banks Lake (Stober et al. 1976). Work by Lewis (1972) on Lake Odell, Oregon, suggests that kokanee may play a large role in controlling *Daphnia* populations. Lewis also

noted a decline in kokanee year class with low *Daphnia* density. The density in Lake Odell from May to October averaged 3,000 to 16,000/m³ from the period 1968 to 1973. Banks Lake density from May to October for all stations averaged 3,500, 3,200, and 5,400/m³ for 1974, 1975, and 1976, respectively. These densities were on the lower range of those found in the high kokanee-producing Lake Odell. It seems quite possible that the three main fish species in Banks Lake may be undergoing competition for *Daphnia* as well as controlling its density.

Lake Pend Orielle also has a highly productive kokanee fishery. Kokanee make up 96 percent of the creel, and average catch is 2.0 fish per hour (Irizarry and Ellis 1976). But *Daphnia* populations are much lower in this lake, averaging 1,390/m³ in 1974 and 70/m³ in 1975. *Daphnia* was a highly selected food when it was present (Bowler 1976). This suggests that although predation on *Daphnia* may be high, its abundance could be substantial enough to produce an excellent kokanee fishery in Banks Lake.

4.5.3.3.3. Nauplii. Peaks in the abundance of copepod nauplii occurred at different times in north and south Banks Lake. In all 3 years when pumping was initiated, Stations 1, 2, and 3 showed a decline in nauplii density. At the same time as the decline in the north pool, maximum seasonal abundance occurred at Stations 4, 5, and 6. The same pattern of abundance that occurred at Station 1 from May to August 1975 occurred in Rufus Woods, suggesting that the nauplii density in the north may be influenced by inflow concentrations.

Brook and Woodward (1956) found nauplii to be the least resistant crustacean zooplankton to be washed out of lakes. But nauplii were

still 2.5 times more dense in the lake than in the outflow water. The density in FDR forebay was consistently higher than Station 1, suggesting possible resistance in inflow pumping or lower density at the 30-m intake depth. Death from input pumps could also reduce the relative abundance at Station 1. The low resistance to outwash may cause the nauplii to be carried down the lake in a short period and account for their not appearing at Station 1.

Metamorphosis after being pumped may reduce the relative number of nauplii and increase *Cyclops* and *Diaptomus* abundance. Seasonal peaks of nauplii were apparent at all stations in spring and summer, and, in the north pool, an additional fall peak occurred. These peaks may correspond to new brood classes of *Cyclops* or *Diaptomus*.

4.5.3.3.4. Cyclops. *Cyclops* was the most consistent in seasonal abundance of all the zooplankton, showing midsummer and fall maximums and winter minimums at all stations. The average density was about the same in the northern and southern regions. The *Cyclops* density at Station 1 was lower than at other stations, but did not show a sharp drop when pumping was initiated. The high percentage of *Cyclops* in the feeder canal samples in July and August 1975 (53 percent and 77 percent, respectively), the July to September 1976 average (78 percent), and the similar density found in Rufus Woods Reservoir in 1975, suggested that *Cyclops* was the major genus of zooplankton being entrained into Banks Lake. *Cyclops* was second only to nauplii in being the least resistant to being pumped in relation to its density in FDR forebay. *Cyclops* density was consistently higher in FDR forebay than at Station 1 during 1976 pumping season. Its lower density at Station 1 may be from its

resistance to outflow from FDR forebay. The work of Brook and Woodward (1956) found copepodid and adult stages of *Cyclops strenus* to be 4.0 and 11.9 times higher in the lake than those in the outflow, respectively. Potential death from turbines may reduce the number being pumped into Station 1.

4.5.3.3.5. Diaptomus. *Diaptomus* usually had highest densities in May. Although high summer abundance occurred, they were usually not concurrent with *Cyclops* peaks. This may have been a result of the predatory nature of *Cyclops* (Rutner 1963) which may have been feeding on *Diaptomus*. *Diaptomus* averaged lower in abundance at Station 1 than any other station for the pumping season during all 3 years. This indicated that *Diaptomus* input was small. It composed 20 percent of the feeder canal samples in 1975, 14 percent in 1976, and was consistent with Rufus Woods density in 1975. Brook and Woodward (1956) indicated that *Diaptomus* should be about the same in resistance to outflow as was *Cyclops*.

Relative to FDR density, feeder canal samples indicated *Diaptomus* was at least 3 times more resistant to outflow than *Cyclops* or possibly 3 times less dense at the 30-m depth of intake. But the concentration in FDR forebay (upper 20 m) was no greater than those in Banks Lake until August to October when high abundance began to appear in FDR forebay. Their possibly higher resistance to outwash that would prevent them from being pumped into Banks Lake would also aid them in maintaining their location in the region of Station 1 and reduce their movement down the lake.

4.5.3.3.6. Feeder canal pumping effects. The influence of feeder canal pumping had several effects on the zooplankton composition

and abundance at Station 1 and possibly at Stations 2 and 3. Pumping prior to late June reduced all species of zooplankton because of the very low abundance of zooplankton in FDR Reservoir during this time. Pumping after late June tended to pump in *Cyclops* and nauplii in the highest abundance because of their low resistance to outwash and high abundance in FDR forebay. *Diaptomus* was the next highest in abundance in inflow but was relatively low compared to the rest of Banks Lake. *Bosmina* was probably very low in incoming water because of the low levels in FDR forebay but may be in high concentrations if present. Because low abundance of *Daphnia* in FDR Reservoir, its resistance to outwash, or its absence at the 30-m depth of intake, it was probably entrained in small quantities into Banks Lake.

Examination of potential lifespan showed a slightly different picture of which genera may occur at Station 1. Pederson (1974) found that *Diaptomus* and *Cyclops* had lifespans in excess of 150 days and *Bosmina* and *Daphnia* less than 20 days at 20° C. This indicated that during the summer pumping season, copepods would be greatly inhibited in maintaining a reproducing population in the north pool due to the rapid flushing rate (less than 10 days) and would be almost totally dependent on inflow concentrations of copepods for abundance in the north pool. But *Bosmina* and *Daphnia* would be more likely to maintain a reproducing population in the north during high summer temperatures. This theory helps to explain the occasional peaks of *Daphnia* and *Bosmina* at Station 1 during summer and early fall. In contrast, the longer retention times and warmer temperature in the south pool would have favored greater stability in the zooplankton community at that region.

4.5.3.4. Zooplankton Biomass Estimates. The biomass estimates showed marked differences between Station 1 and other stations. Station 1 had the lowest biomass (49.8 mg/m^3) during the pumping months of May to October. The other stations ranged from 72 to 101 mg/m^3 . *Daphnia* dominated the biomass at Stations 2 to 6 ranging from 45 to 51 percent, but was considerably less at Station 1 (22 percent). Although only 1 year of data was used, a different trend may occur during other years with different conditions. These data indicate that pumping altered the species composition and reduced the biomass at Station 1 relative to the rest of Banks Lake in 1975, the only year biomass data was obtained. Average lake biomass peaked in July but did not occur until November at Station 1. Stations 2 and 3, though close to Station 1, had considerably different trends in biomass. This may have been the result of littoral zooplankton biomass introduction and/or increased production of zooplankton as the water moved down the lake from Stations 1 to 3.

The biomass estimate for Banks Lake was compared with other lakes in Table 4.18. These estimates are varied in their accuracy. Many have been converted to dry weight by multiplying by 6 percent of wet weight. Different sampling methods have been used that could add considerable difference to the estimates. Assuming these estimates are similar in their error, Banks Lake zooplankton standing stock was in the middle range of an oligotrophic-mesotrophic lake and higher than all oligotrophic lakes listed. This classification would agree with that for the chlorophyll a concentrations listed in Table 4.16. Although biomass is not an indication of production, according to Table 4.18 there is a rough relation to production levels of the lake. Considering this concept, it

Table 4.18 A comparison of average zooplankton biomass from several lakes with Banks Lake (modified from Schindler and Noven 1971).

Source	Lake	Country	Crustacean Zooplankton		Method of Collection	Lake Type
			Dry Wt. (mg/m ³)	Dry Wt. (mg/m ³)		
1	Upinek	Poland	268	-	5-liter trap	pond/eutrophic
1	Piecek	Poland	147	-	"	dyst/eutrophic
1	Arklickie	Poland	144	-	"	pondlike
1	Lemiet	Poland	123	-	"	eutrophic
1	Zywy	Poland	82	-	"	eutrophic
1	Smolak	Poland	51	-	"	dystrophic
1	Maggiore	Italy	27	30	Tow net	oligotrophic
1	Erken	Sweden	540	540	Water bottle	eutrophic
1	Canyon Ferry Res.	USA	-	402	Kemmerer bottle	eutrophic
1	Severson	USA	1099	1126	Clark-Bumpus	eutrophic
1	Baikal	USSR	-	24-48	-----	oligotrophic
1	Clear	Canada	142	145	Tow net	oligo/mesotrophic
1	122	Canada	72	81	29-liter trap	oligo/mesotrophic
1	132	Canada	156	169	29-liter trap	oligo/mesotrophic
2	Banks Lake Res.	USA	49-79(76)*	-	Tow net	oligo/mesotrophic
3	Pend Orielle	USA	25	-	"	oligotrophic
4	Findley	USA	25	26	"	oligotrophic
4	Chester Morris	USA	20	21	"	oligotrophic
4	Sammamish	USA	52	53	"	mesotrophic

1. Schindler and Noven 1971 2. Present Study 3. Rieman & Falter 1976 4. Pedersen 1974

* Range and mean in brackets

was interesting to note that the biomass in Banks Lake was considerably higher than that in Lake Pend Orielle, another very productive kokanee lake.

5.0 FISH POPULATION MONITORING

5.1 Introduction

The fish population studies from June 1973 through December 1975 (Stober et al. 1976) showed a need for continued monitoring of the population ecology. This was evident due to the vulnerability of lake spawning kokanee salmon, yellow perch, and lake whitefish to lake level drawdown and entrainment and the long biological response time required to assess this relationship. The fish populations in Banks Lake were monitored during the past year to detect changes in the distribution and abundance of the age classes of those fish which were impacted by drawdown in 1973 and 1974. The extreme 24.9-ft drawdown of the lake in the spring of 1973 apparently imposed a substantial mortality on the 1973 year class (year class designated by year of fry emergence) of kokanee by stranding eggs and/or alevins in the lakeshore spawning beds. The low abundance of the 1973 kokanee year class was documented by several methods, including gillnet sampling in Banks Lake, sampling of fish entrained in the irrigation canal, and survey of lakeshore spawning. A drawdown of 23.6 ft occurred in the spring of 1974 and may have had similar effects on the abundance of the 1974 year class.

The detailed studies of the kokanee spawning, incubation of eggs and hatching success in the lake were required to monitor the size of kokanee year classes in order to determine the impact of lake drawdown. Our study of the 1973 year class clearly showed that full impact of the combined effects of extreme water level decline and irrigation canal entrainment may not be realized until the full 3-year life cycle has been completed and the size of the adult kokanee spawning population

becomes known. The abundance of spawning kokanee in the lake in 1976 was apparently reduced disproportionate to year class strength by entrainment through the irrigation canal. Because the monitoring of year class strength was most easily accomplished by gillnet sampling, the standardized monthly gillnetting, initiated in 1973, was reduced to quarterly intervals and continued during 1976-77, except that the March 1976 quarterly sample was omitted. This report includes the results of four quarterly samples from July 1976 through March 1977. While kokanee were of principal interest, the gillnet sampling yielded information on the relative abundance of yellow perch and lake whitefish as well as most other species resident in Banks Lake.

The objective of the quarterly gillnet sampling, therefore, was to continue the observations necessary to document the relative abundance of the common fish species with particular emphasis on kokanee.

5.2 Materials and Methods

The methods have been reported previously in the Third Annual Progress Report and various quarterly reports and therefore will be only reviewed briefly. The gillnets measured 30.5 m (100 ft) long by 1.8 m (6 ft) deep and were constructed of monofilament nylon in nine variable-mesh panels ranging from 2.5 to 12.7 cm (1 to 5 inches) and graduated in increments of 1.3 cm (1/2 inch).

The monthly sampling consisted of two consecutive 24-hr midlake sets at each of four transects (Fig. 5.1) followed by a 24-hr set on both the east and west shorelines. The midlake net array consisted of a surface horizontal net, a bottom horizontal net, and a vertical net which reached from surface to bottom. The shoreline array consisted of

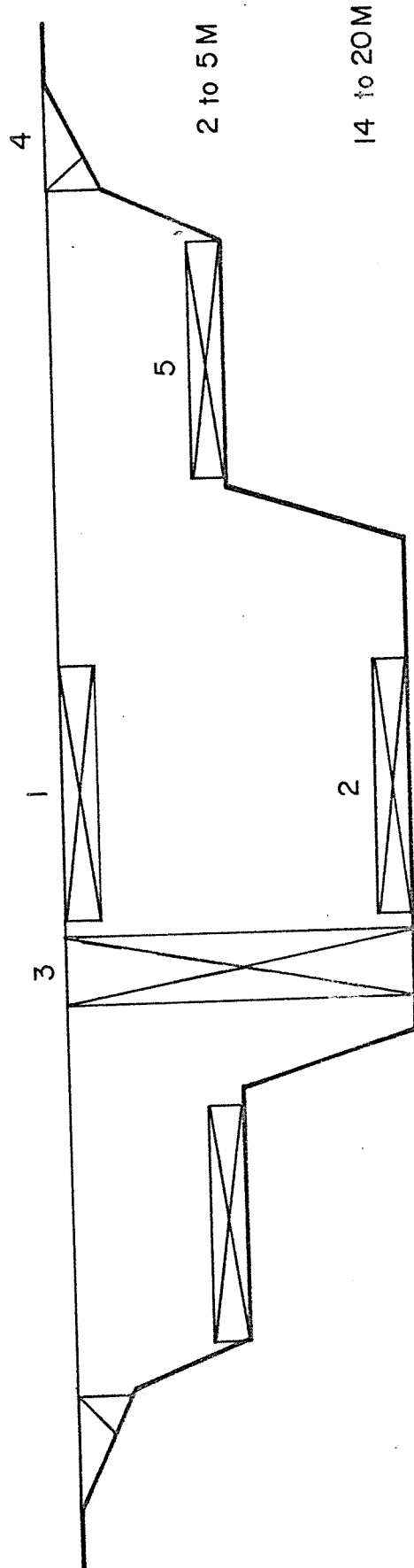


Fig. 5.1 Schematic section through one transect illustrating sampling site for each gear type: 1) surface set horizontal gill nets (monthly), 2) bottom set horizontal gill nets (monthly), 3) vertical gill nets (monthly), 4) beach seine hauls (monthly), and 5) shoreline bottom set horizontal gill nets (quarterly, parallel to shoreline).

two bottom horizontal nets set approximately 10 ft deep parallel to the shoreline. One net was set on rock substrate and the other on sand. The sampling thus enabled detection of spatial, vertical, seasonal and annual shifts in abundance within and between transects as compared to previous data.

The changes in catch trends observed during the 1976-77 sampling period are described. Observations not previously reported in the Third Annual Report have also been included. Results which followed closely the previously observed and reported trends are not elaborated herein.

Following reduction of the sampling interval from monthly to quarterly, some trends in the data were less obvious than before. In some instances the data failed to show well-defined trends which were previously apparent from the monthly samples. Nevertheless, it was felt the quarterly samples adequately indexed the seasonal relative abundance and distribution and therefore allowed comparisons between years.

5.3 Results and Discussion

5.3.1 Historical Reservoir Operation

The historical operating data for Banks Lake was plotted (Fig. 5.2) beginning with initiation of the Columbia Basin irrigation project in 1951. The annual pumped inflow, gravity outflow, and water level in Banks Lake is plotted. The discontinuous inflow exemplifies the annual water supply management strategies which must be maintained in order to meet the needs of irrigation, power generation, and fish and wildlife. Drafting rates have increased annually until recent years when the maximum flow through the existing Bacon Siphon and tunnel was reached. Lake elevation did not reach full pool until 1957 (Fig. 5.2). Since

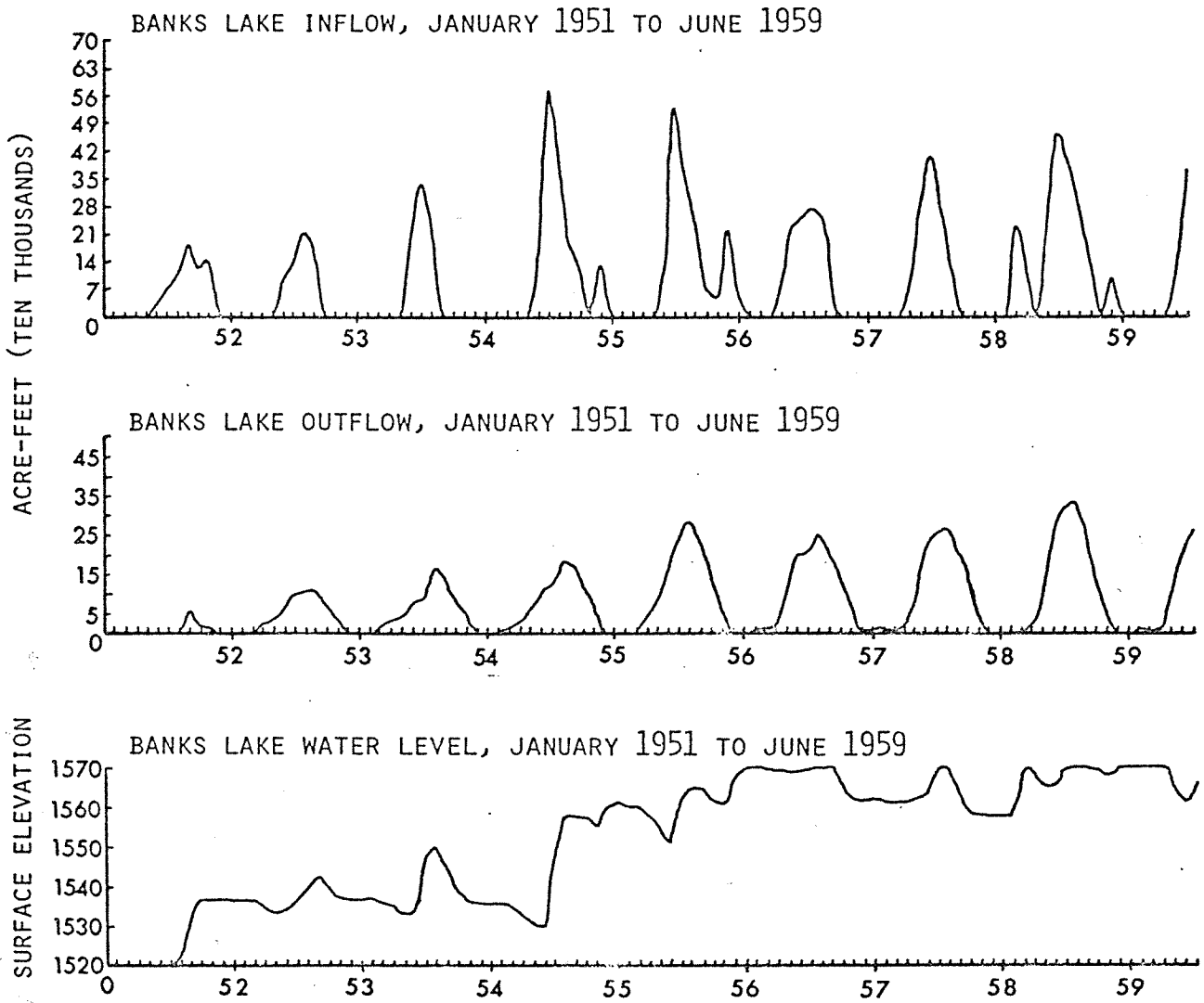


Fig. 5.2 Water inflow, outflow and level of Banks Lake from January 1951 through March 1977.

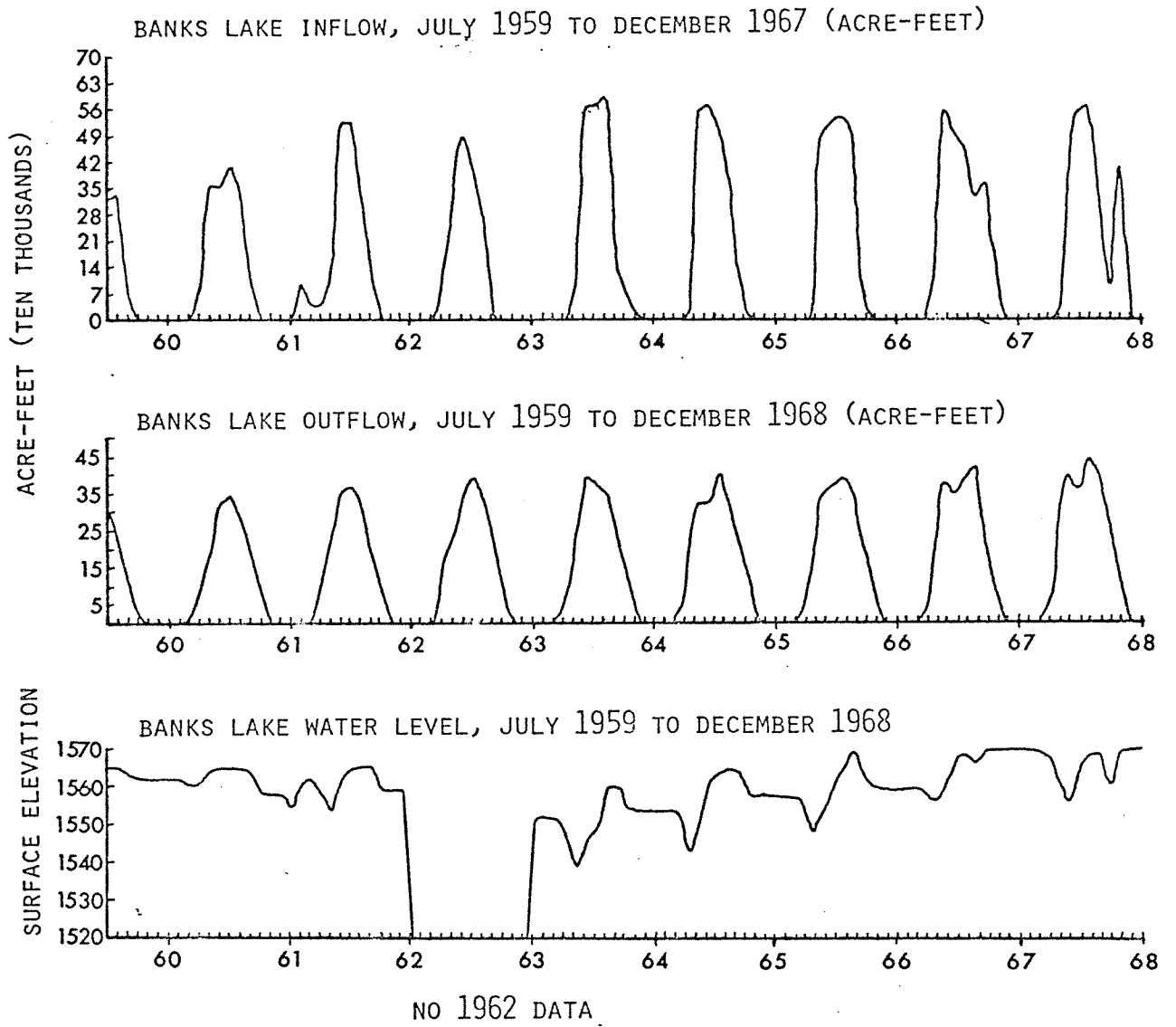


Fig. 5.2 (contd.)

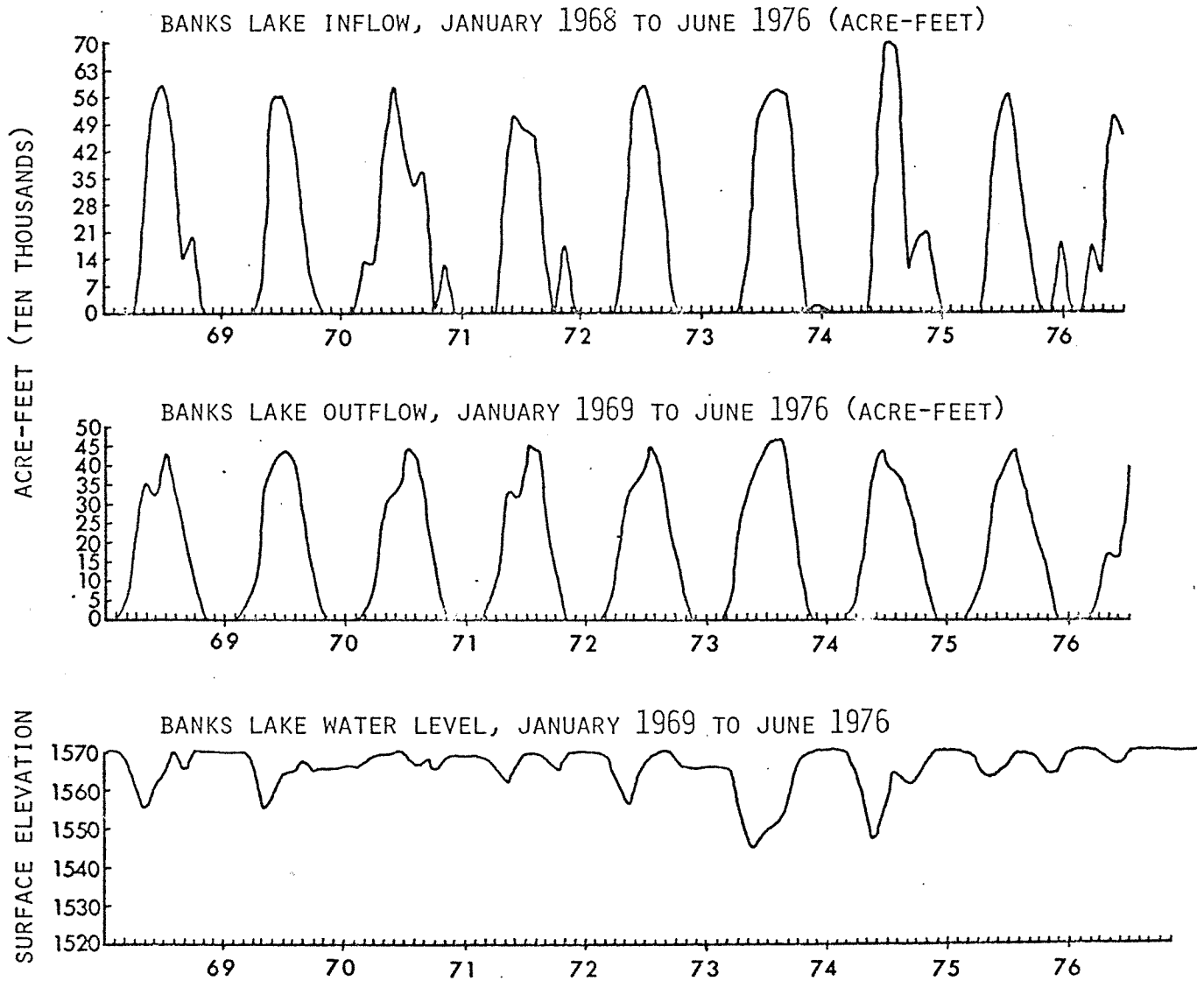


Fig. 5.2 (contd.)

that time, the amount of annual change in lake elevation has been unpredictable. Since 1966, lake drawdown has not exceeded 18 ft (Fig. 5.3), except for the extremes of 24.9 and 23.6 ft which occurred in 1973 and 1974. The minimum lake level has occurred most often during the month of May (Fig. 5.4). This results primarily due to spring irrigation drafting when makeup water is not pumped in due to drawdown of FDR Reservoir below the pump intakes.

5.3.2 Yellow Perch

5.3.2.1. Distribution. The seasonal trends in abundance and vertical distribution of yellow perch captured offshore with surface and bottom horizontal gillnets were similar in 1976-77 to those observed from 1973 to 1975. The catches were largest in September, and smallest in March (Fig. 5.5). Yellow perch were caught predominantly on the bottom throughout each year (Fig. 5.5), while very small surface catches were observed in the June-July period.

The horizontal distribution among the transects was based upon the combined analysis of 2 days of consecutive sampling with surface and bottom horizontal gillnets offshore at each transect (Fig. 5.6). The abundance of yellow perch was reduced at Transects 4, 5, and 6 in the 1976-77 period with the highest abundance at Transect 1 (Fig. 5.6). Abundance at all transects was lower when compared to the seasonal maxima observed in the 1973-75 period. Seasonal maxima occurred in September consistent with previous years and was due to the recruitment of smaller fishes into the samples. Recruitment of yellow perch in the south pool appeared to be substantially lower in 1976 than was observed during previous years of 1973-75.

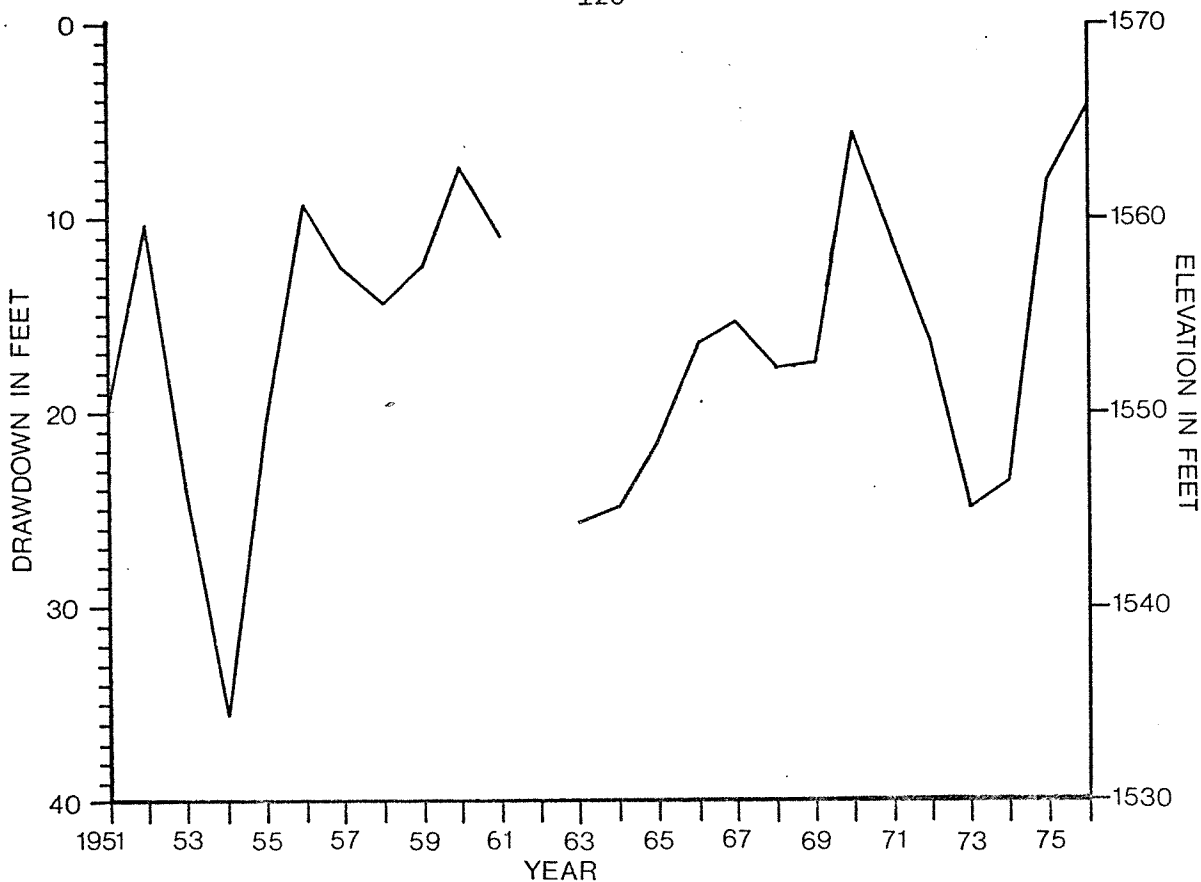


Fig. 5.3 Minimum annual Banks Lake elevations and drawdown for the period 1951-1976 (USBR data).

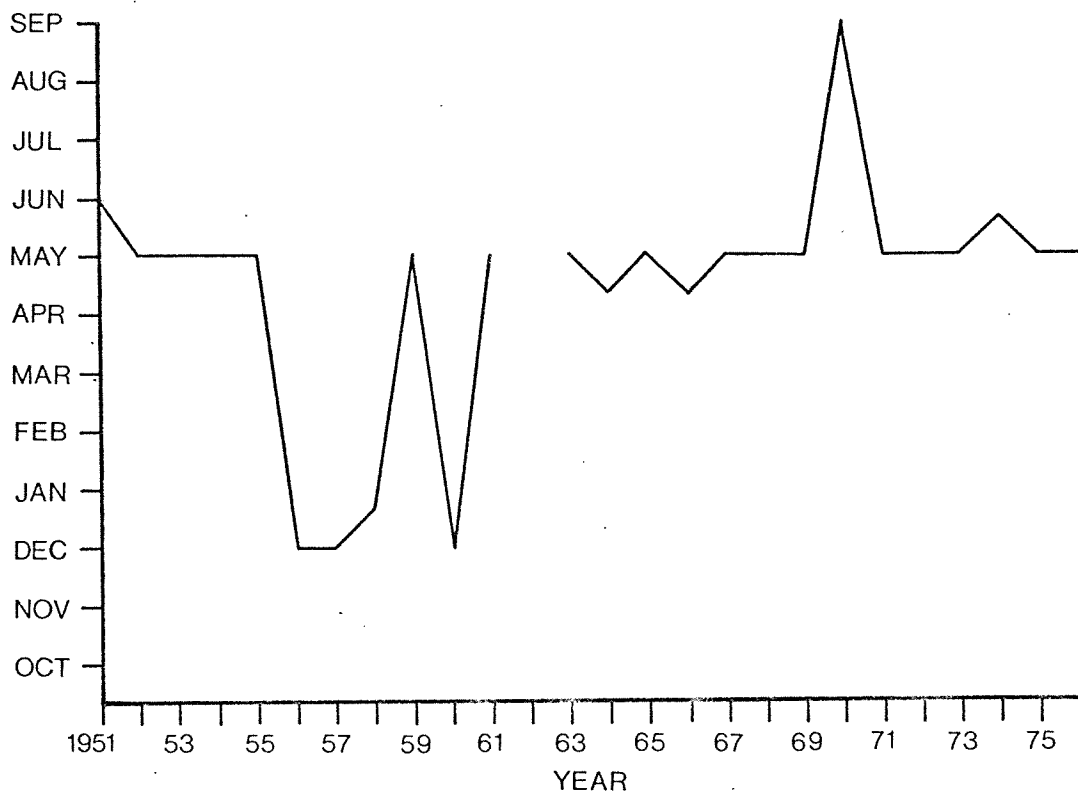


Fig. 5.4 Month of occurrence of minimum Banks Lake elevation for each year from 1951 to 1976 (USBR data).

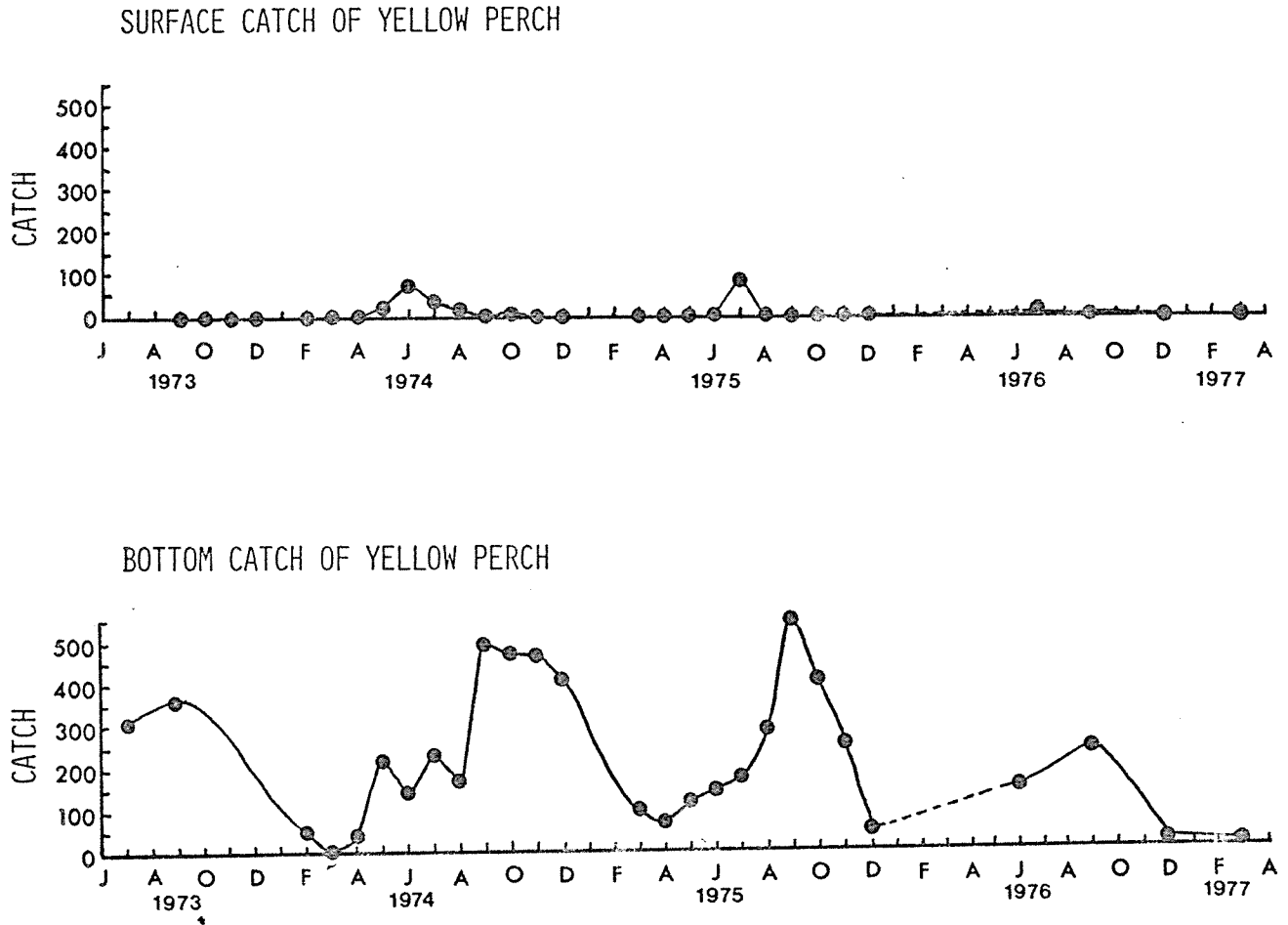


Figure 5.5 Vertical distribution of yellow perch offshore. Each point represents a 24-hr. horizontal variable-mesh gill net sets: Four sets were made at each of the 4 transects monthly: 2 on the bottom of the water column.

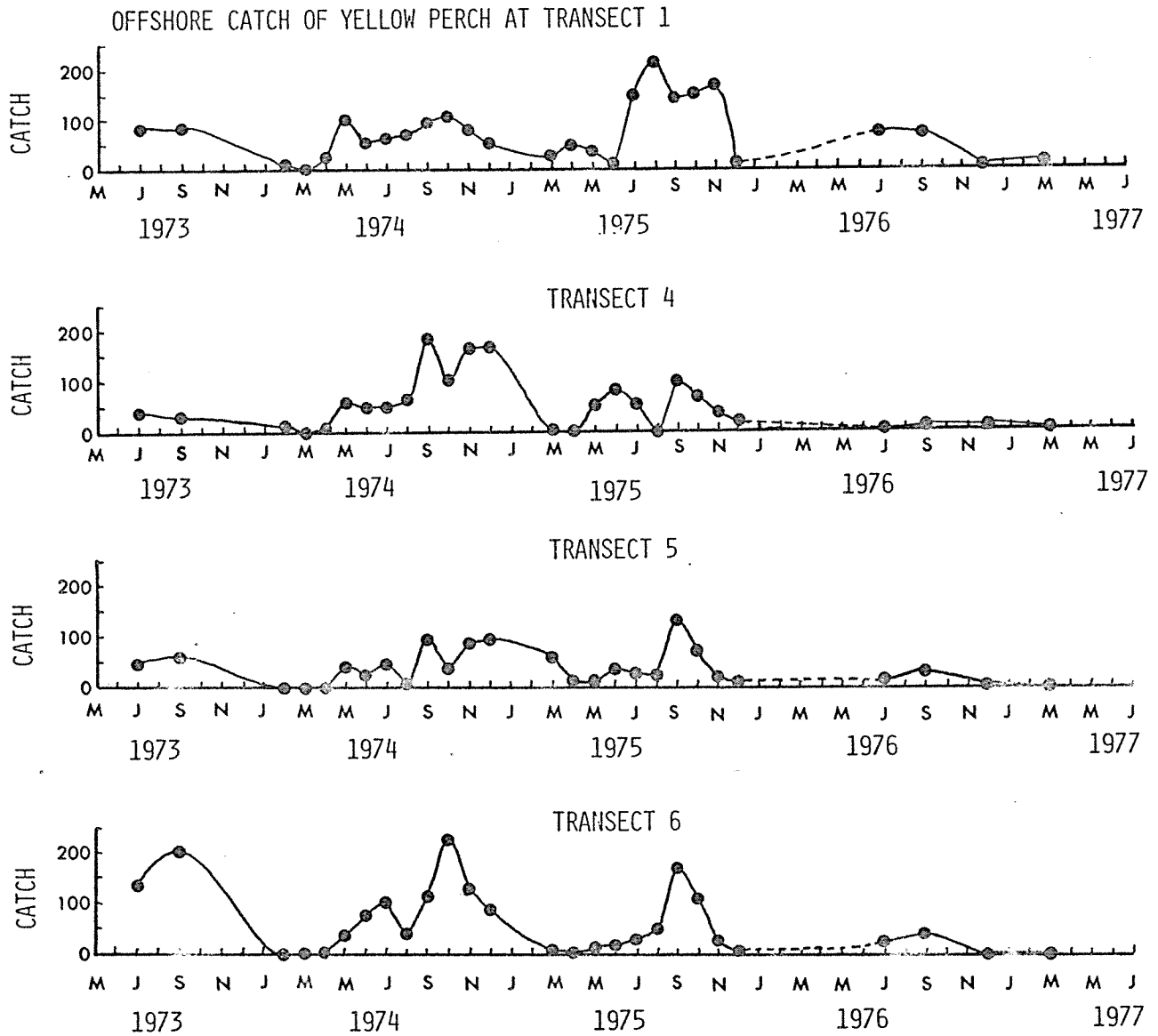
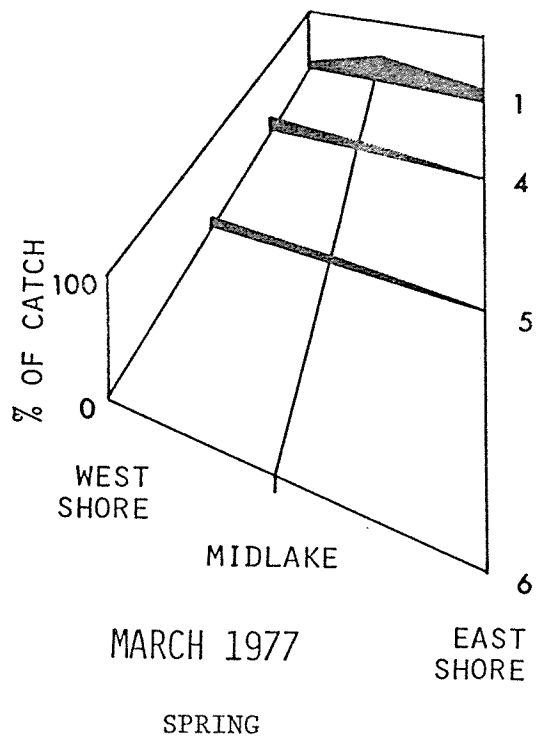
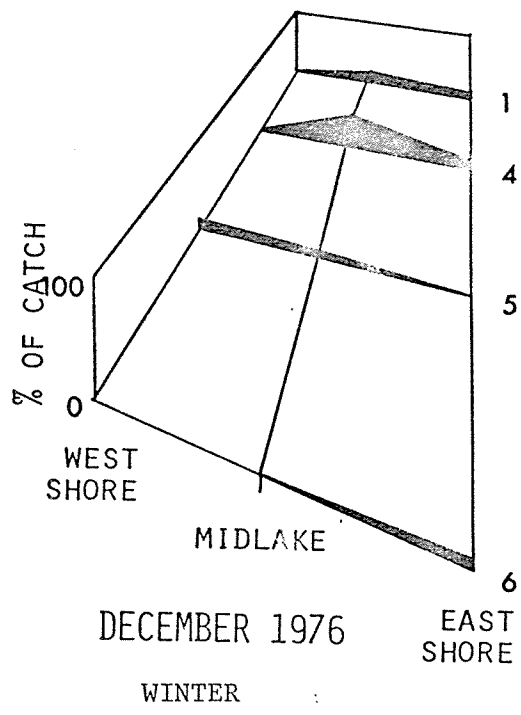
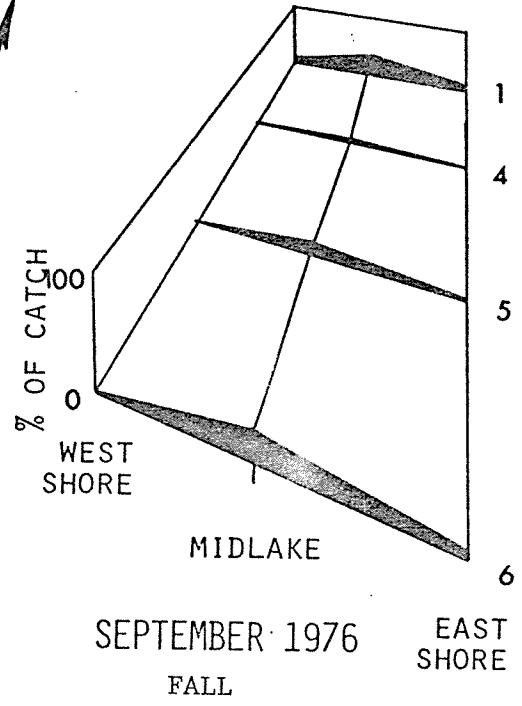
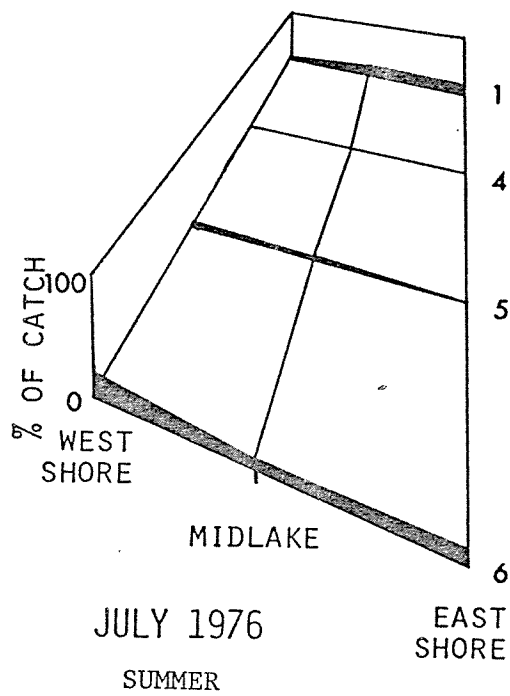


Fig. 5.6 Horizontal distribution of yellow perch. Each point represents 4 24-hr. horizontal variable-mesh gill net sets: 2 at the bottom and 2 at the surface of the water column.

Seasonal changes in the distribution of adult yellow perch were determined by comparing the percentages of the quarterly catches from each of the 12 sampling locations (Fig. 5.7). Most of the seasonal distribution patterns which were evident in the 1973-75 data did not appear in 1976-77. For example, the shoreward movement in March, which was distinct in 1973-75, was not repeated in 1976-77. Further, the previously observed offshore movement during September and December was apparent only during September in 1976-77 and did not occur in December. Highest CPUE correlated with summer seasonal thermal maxima (Fig. 5.8). Negative responses to pumped input of cooler water from FDR and the increased currents in the north pool could not be detected with quarterly sampling in 1976-77 as was demonstrated in June of both 1974 and 1975.

A comparison of length-frequencies between years showed a continued decline in the catch of individuals larger than 200 mm during the 1976-77 period (Fig. 5.9). In 1973, the frequency mode occurred at 225 mm, but in 1975, this size group was much less numerous in the catch than were the smaller yellow perch, size 140 to 200 mm. The frequency mode for the larger group in 1975 and 1976-77 had declined to 185 mm for both years. Reasons for the decline in the catch of large perch are not known.

5.3.2.2. Water Level Fluctuation. Perch spawning was little affected by the 3-ft irrigation drawdown during June of 1976. Spawning occurred during March and April principally at depths ranging from 1 to 10 m. Hatching followed primarily during May and early June, and by mid-June fry were schooled densely along the shorelines. The negligible effects of the drawdown in 1976 are illustrated in a multidiagrammatic



YELLOW PERCH

Fig. 5.7 The horizontal distributions of yellow perch from quarterly gillnet samples during 1976-77. The vertical axis represents the percent of the total catch for each season. The horizontal axis represents 12 sampling locations: east shore, mid-lake, and west shore at each of 4 transects.

SEASONAL TRENDS IN YELLOW PERCH CATCH AND TEMPERATURE AT TRANSECT 1

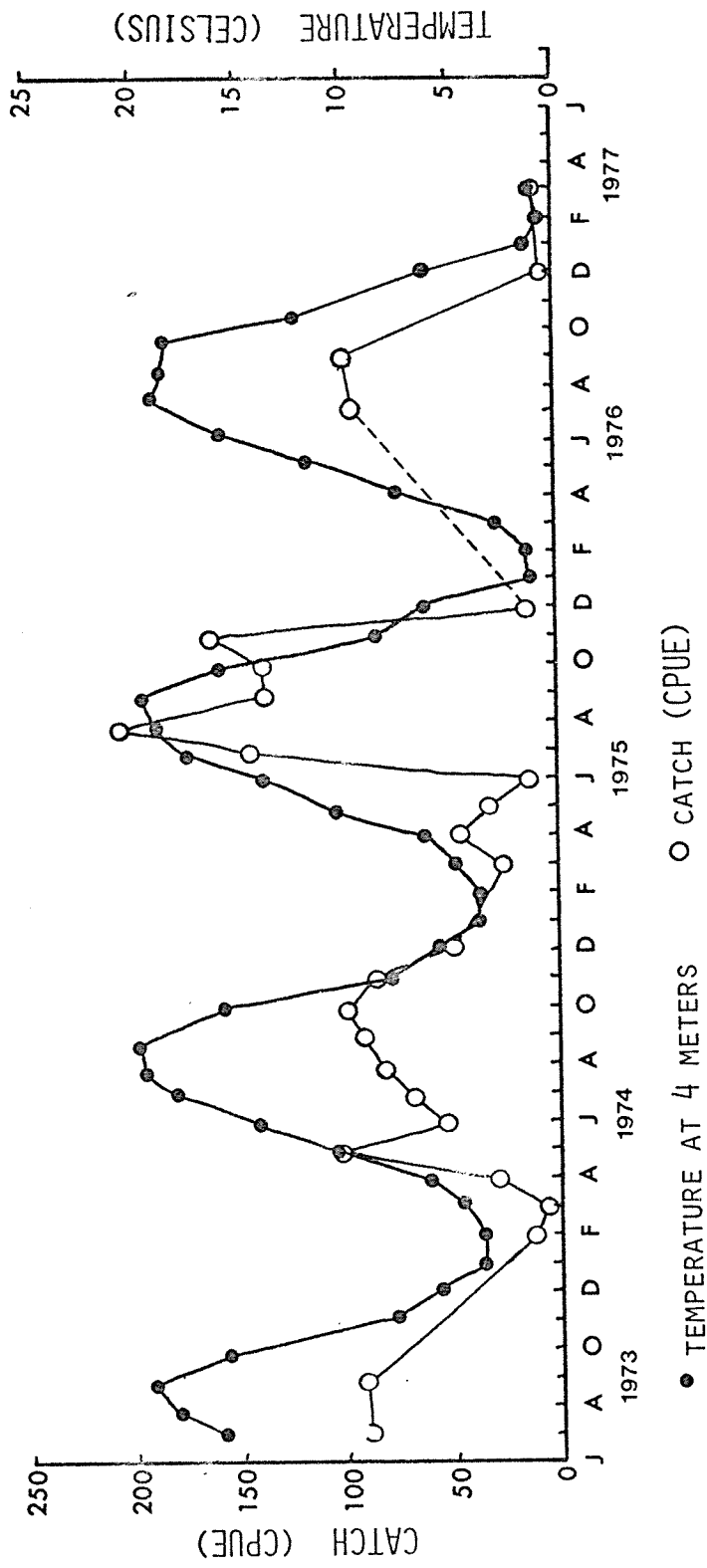


Figure 5.8 Yellow perch catch representing 4 24-hr. horizontal variable sets: 2 at the surface and 2 at the bottom.

FORK LENGTHS OF YELLOW PERCH

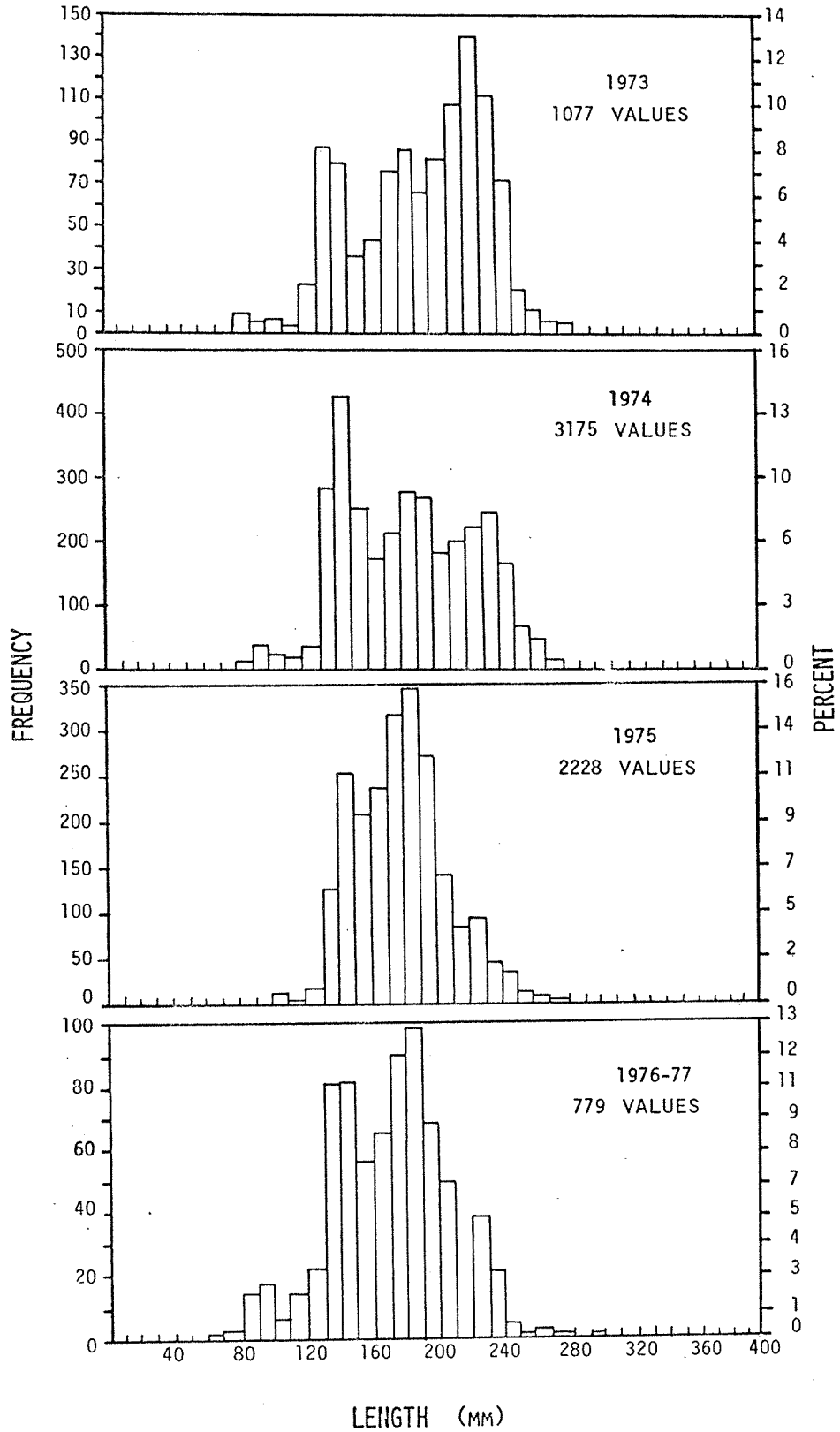


Fig. 5.9 Comparison of the fork length frequencies of yellow perch from annual gillnet catches.

scheme (Fig. 5.10) which projects the spawning and incubation periods onto a graph of the lake level. The extent of drawdown following the peak of spawning was then projected to a histogram showing the percentage of the incubating eggs which were stranded by the drawdown. In 1976 the relatively small drawdown affected only about 10 percent of the estimated egg deposition, which was a relatively minor amount in comparison with the large drawdowns of 1973 and 1974.

The reduced recruitment of yellow perch may have resulted from the higher lake level which was maintained during the 1976 irrigation season. The success of juvenile rearing may be related to the amount of shoreline rearing habitat which increases with large drawdowns benefitting the surviving juveniles because of a resultant increase in rearing habitat available during lower water level elevations. Lower lake levels also caused increased turbidity inshore which may have provided security for the juveniles in lieu of shoreline aquatic vegetation which was largely absent. Thus, the unusually high lake levels of 1976 may have resulted in less rearing habitat, less turbidity and may have resulted in reduced recruitment of juvenile yellow perch.

5.3.2.3. Length-Frequency Analysis. A length-frequency analysis was conducted on the gillnet samples each quarter from June-September 1973 (Fig. 5.11). Generally, such a comparison of length-frequency distributions would show growth increment of the age classes with time, however, at least two factors, sex and location of capture, are known to have introduced a wide variability into the samples and thereby masked size increment due to growth. Differences between the size of males and females as well as between and within transects have been observed. The

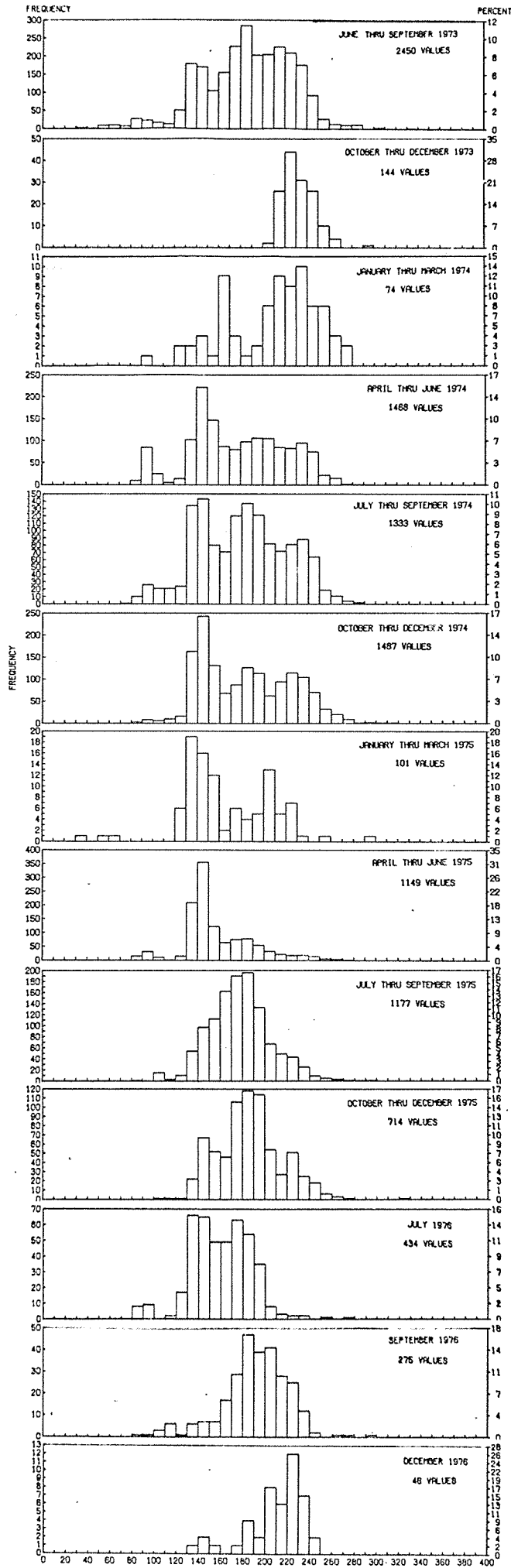


Fig. 5.11 Distributions of yellow perch length frequencies from quarterly gillnet samplings from 1973 to 1976

inconsistent pattern of size distribution obviated any attempt to isolate growth increments by year class in this comparison. The catch was obviously biased against age 0 perch due to selectivity of the gillnets. Recruitment of only the larger age 0 fish began in September of each year as indicated earlier in the seasonal changes in abundance. A likely estimate of the median length of the age 0 year class would be approximately 65 mm by December, based on growth analysis of 0 age perch in the beach seine catches for 1973-75.

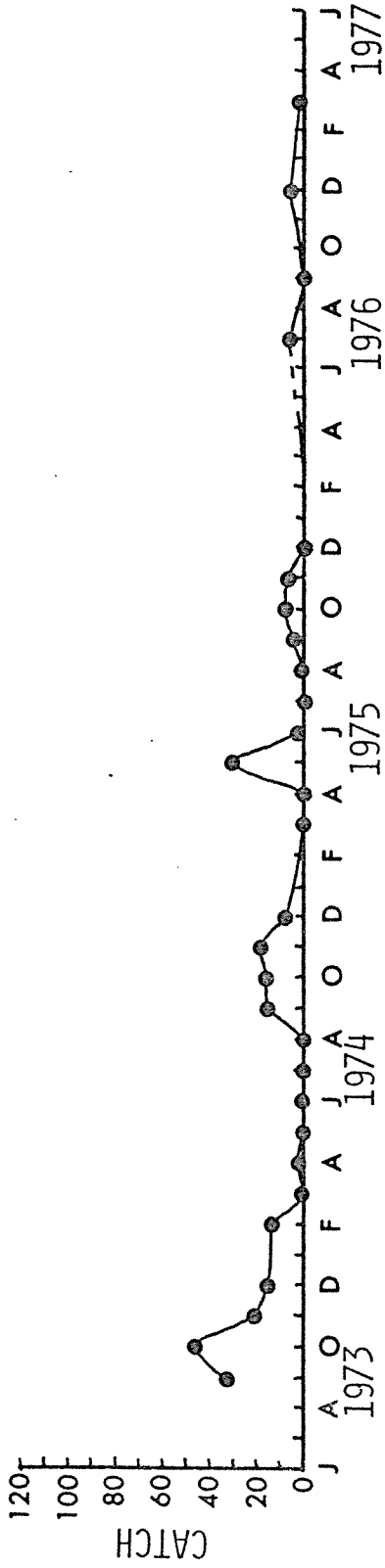
Median total length for yellow perch determined from aging by scale analysis indicated 160, 210, 235, 249, and 216 mm for ages II, III, IV, V, and VI, respectively. However, since these are average values based on the entire sample for the period 1973-75, considerably less variance would be expected to occur with quarterly length frequency modes. Survival of cohorts greater than the age IV appear to decline rapidly after January to March 1975 with no apparent recovery through December 1976.

5.3.3 Lake Whitefish

5.3.3.1. Distribution. The vertical distribution of lake whitefish in 1976-77 was similar to the distribution observed in 1974 and 1975 in which the bottom catches greatly predominated (Fig. 5.12).

The horizontal distribution among transects was similar to that observed in previous years. Generally the catches averaged largest at Transect 4 (Fig. 5.13). The July samples showed a north-south gradation in distribution with highest abundance at Transect 1 and lowest at Transect 6. A predominance of lake whitefish at Transects 1 and 4 during July was observed consistently in previous sampling and apparently

SURFACE CATCH OF LAKE WHITEFISH



BOTTOM CATCH OF LAKE WHITEFISH

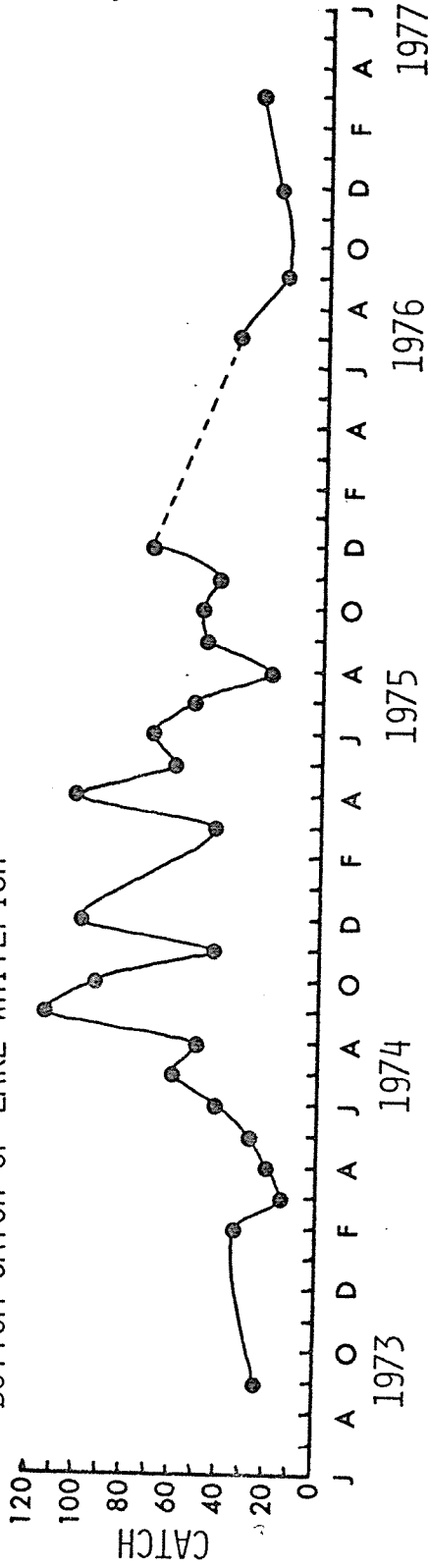


Fig. 5.12 Vertical distribution of lake whitefish offshore. Each point represents 8 24-hr. horizontal variable-mesh gill-net sets. Four sets were made at each of the 4 transects monthly: 2 on the surface and 2 on the bottom of the water column.

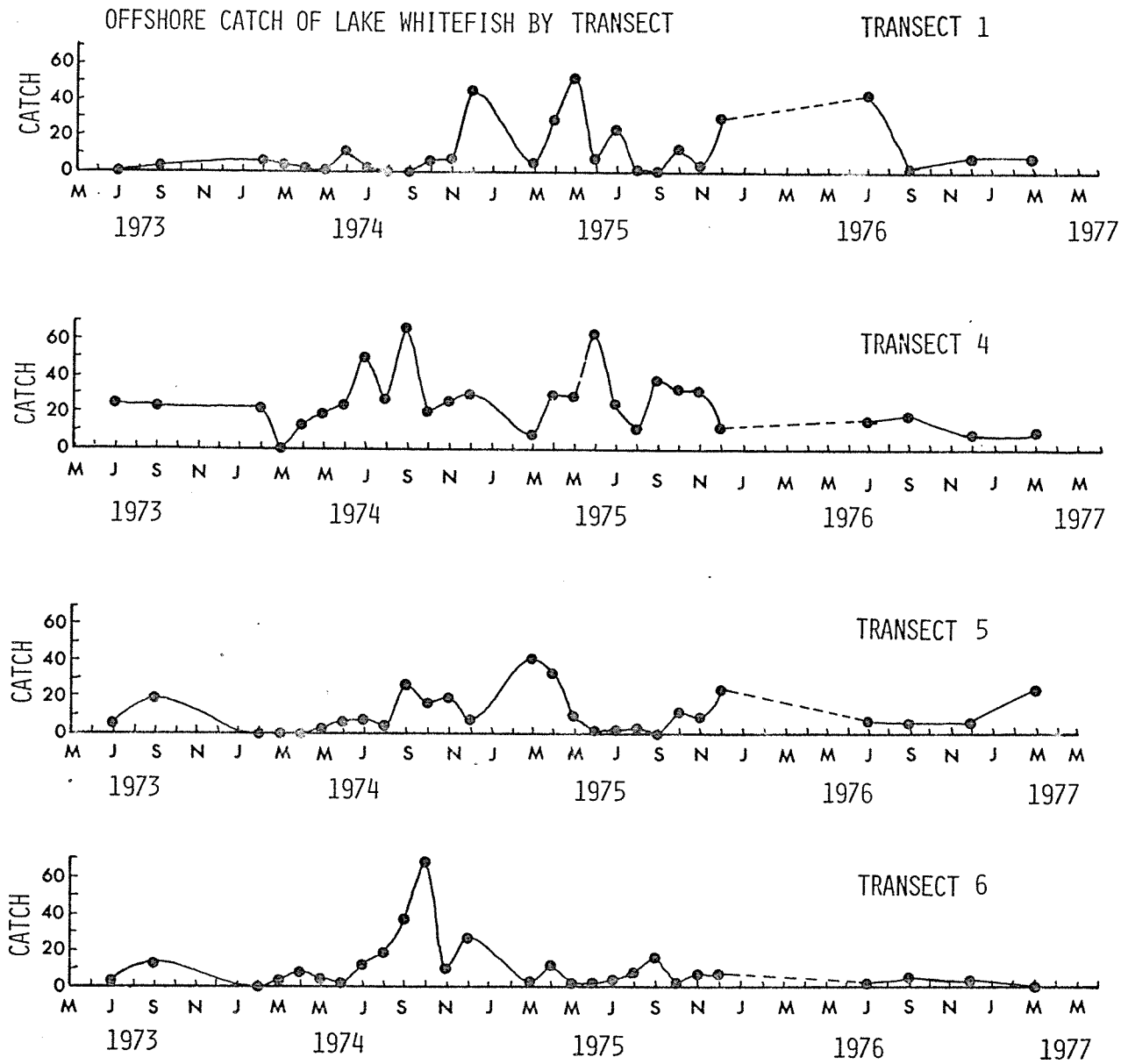


Fig. 5.13 Horizontal distribution of lake whitefish. Each point represents 4 24-hr. horizontal variable-mesh gillnet sets: 2 at the bottom and 2 at the surface of the water column.

reflected a movement into cooler water at a time when the ambient water temperature in Banks Lake exceeded the preferred thermal range.

The seasonal distribution of lake whitefish within and between transects is illustrated in three-dimensional graphs in Figure 5.14. Similar to previous years, the catch patterns reflect the movement of fish influenced by temperature, food availability, and spawning behavior. In July, when water temperatures were highest, the catches were largely from midlake and predominated in the north end (Transects 1 and 4). In September as the water temperatures cooled, the catches showed no consistent trend between inshore and offshore sites and were equally distributed at Transects 4,5, and 6. No whitefish were caught at Transect 1. The disappearance from Transect 1 probably resulted from the cooling of water temperatures in other parts of the lake which enabled whitefish to redistribute southward where zooplankton (*Daphnia*) were more abundant. Thus, the north pool appeared to act as a refuge for lake whitefish during the summer, but was abandoned when temperatures moderated and feeding was resumed.

December catches occurred almost entirely at the shorelines as a result of spawning activity. In March, the catches were mixed within and between transects, much as they were in September, except that small numbers were caught at Transect 1.

The offshore catch of large and small lake whitefish is compared in Figure 5.15. Differential behavior between size groups occurred during July, September, and December. Juveniles remained active during the summer months and did not exhibit spawning behavior in December. The adults estivated in Devils Lake during the summer and exhibited spawning

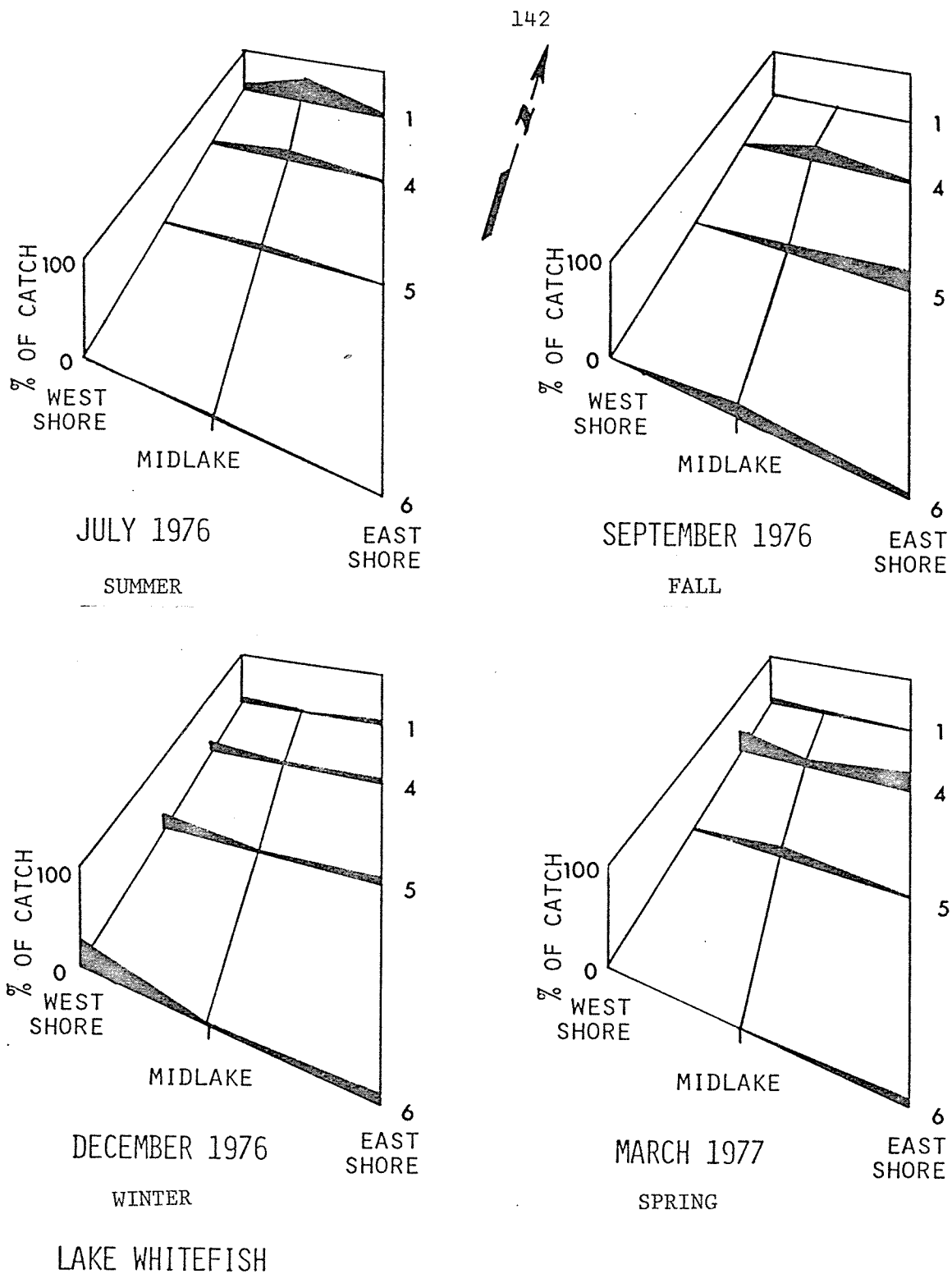


Fig. 5.14 The horizontal distribution of lake whitefish from quarterly gillnet samples during 1976-77. The vertical axis represents the percent of the total catch for each season. The horizontal axis represents 12 sampling locations: east shore, mid-lake and west shore at each of 4 transects.

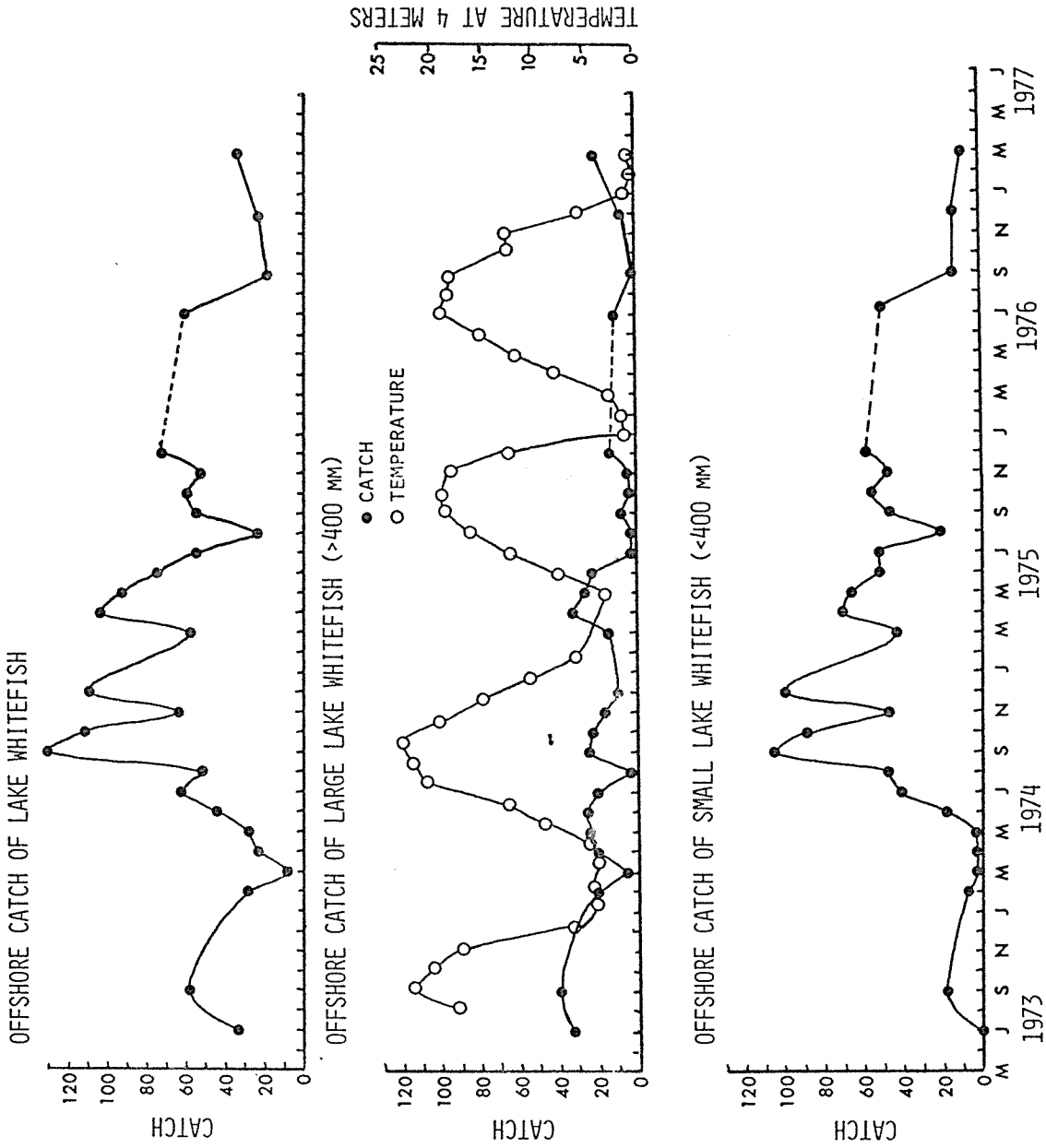


Fig. 5.15 Offshore catches of lake whitefish. Large and small sizes are graphed together and separately. The catch of large lake whitefish is compared with water temperature at 4 meters.

behavior in the late fall. The offshore catches of lake whitefish in these samples were predominately small individuals < 400 mm. The large lake whitefish > 400 mm predominated in the March samples because spawning was completed and movement was not yet restricted by thermal stratification.

5.3.3.2. Estivation. Many large lake whitefish (greater than 350 mm) estivated in the metalimnion during the summer when epilimnetic water temperature exceeded approximately 18° C. Whitefish moved to the deepest part of Banks Lake at Devils Hole near Station 3 and concentrated densely in a relatively narrow depth band ranging from 22 to 32 m deep over an area of approximately 82 acres. Individuals sampled from this population were exclusively large lake whitefish ranging in length from 355 to 467 mm and weighed from 650 to 1,295 g. Both males and females were present and were developing sexually. The stomachs of all individuals sampled were empty.

Comparative acoustical surveys of daytime and nighttime distributions on August 14 showed a 2-m upward movement of the upper limit of the whitefish concentration at night (Fig. 5.16). The daytime survey showed irregular upward projections of fish distribution above the main concentration.

Vertical profiles of temperatures and dissolved oxygen were taken on August 26 and October 20 before and after the concentration dispersed (Fig. 5.17). The August profile showed that the lake whitefish were concentrated in the metalimnion between 7.8° and 12.6° C. The dissolved oxygen content of the water in which the fish occurred ranged from 2.1

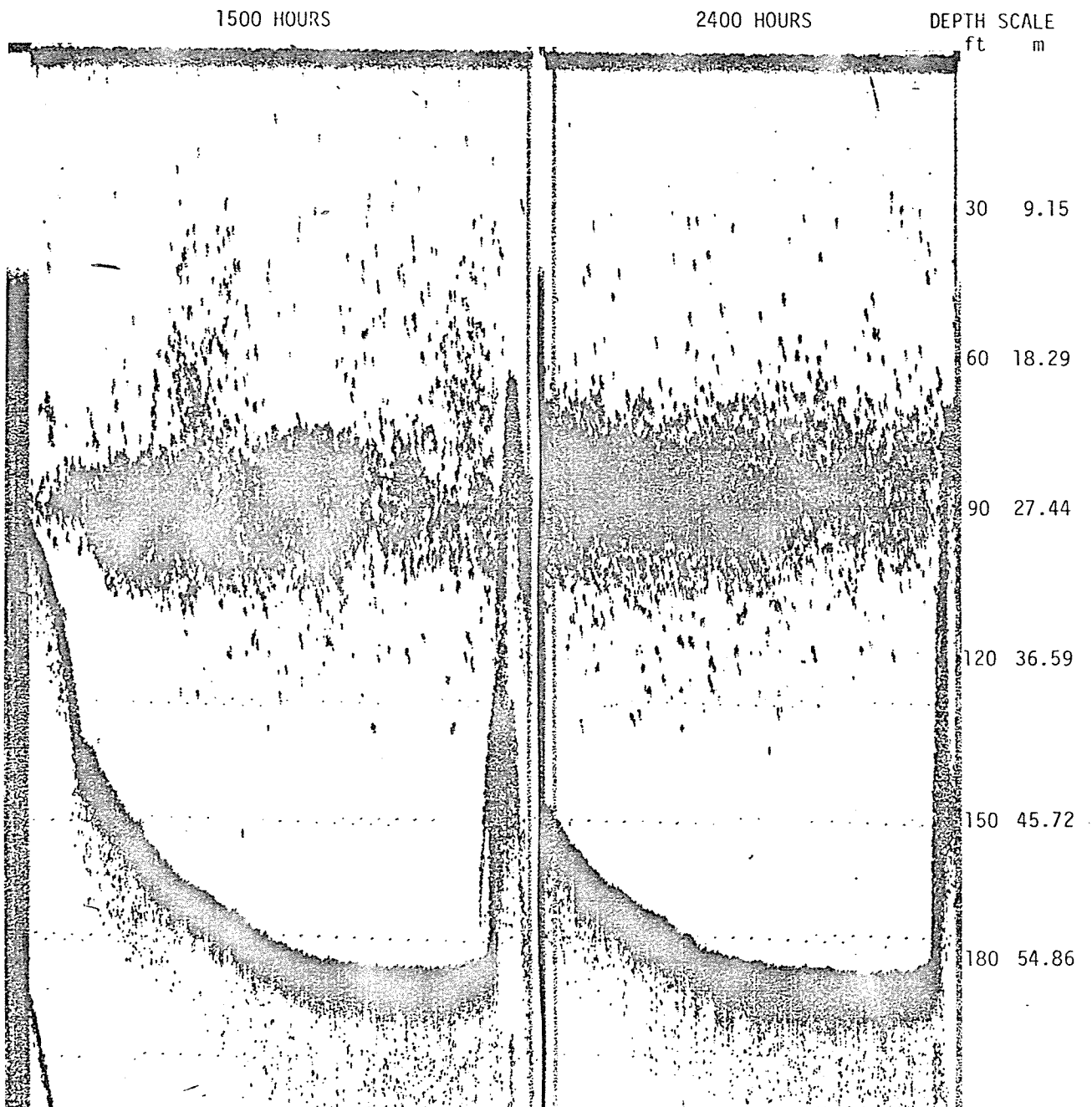


Fig. 5.16 Echograms showing diel variation in vertical distribution of lake whitefish at Devil's Hole, Banks Lake, on August 14, 1976.

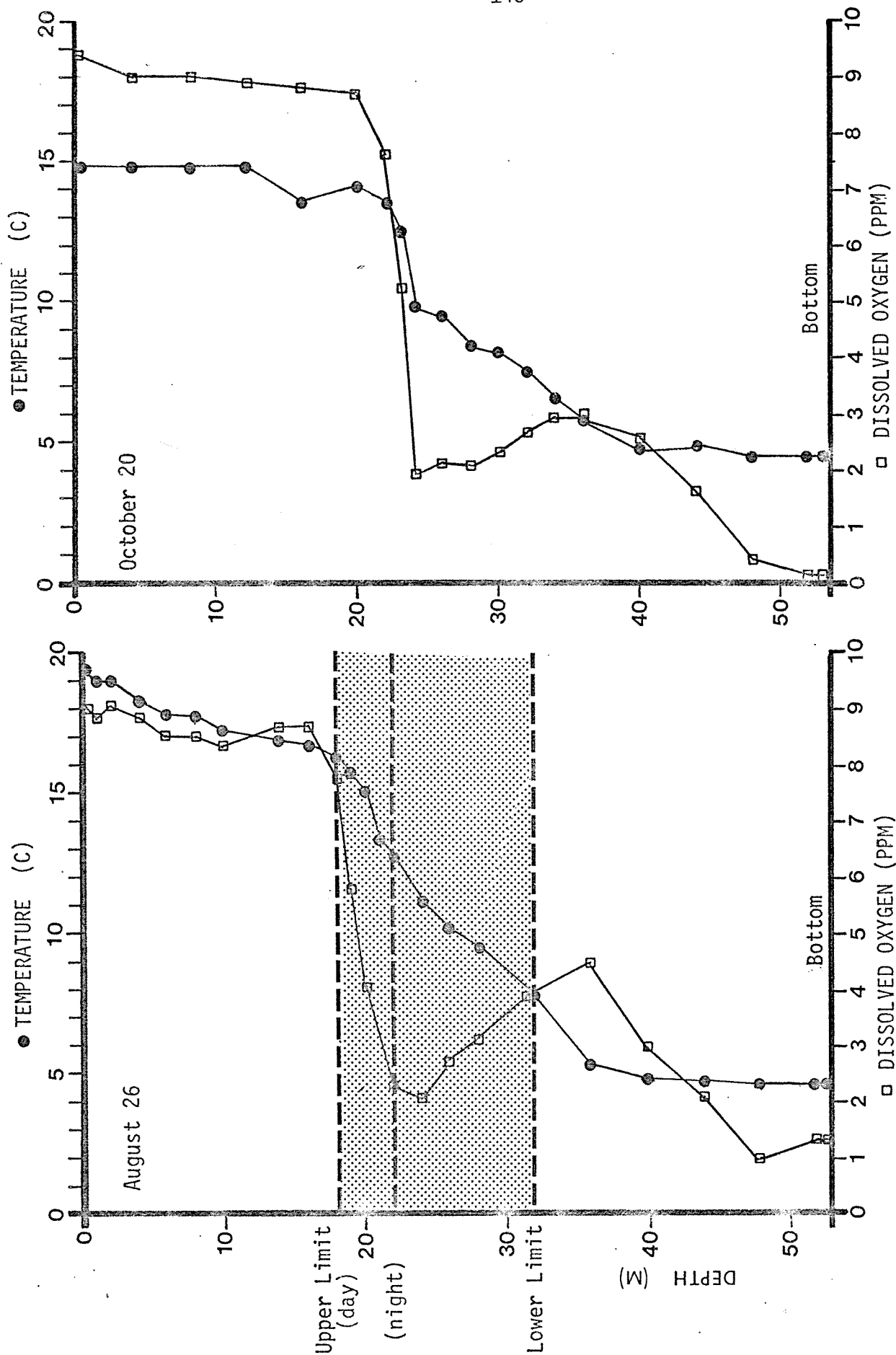


Figure 5.17. Vertical profiles of temperature, dissolved oxygen, and lake whitefish distribution at Devil's Hole during and after summer estivation.

to 3.9 ppm. A sharp drop in dissolved oxygen from 8.5 ppm at 19 m to 2.1 at 22 m coincided closely with the occurrence of the fish concentration.

The lake whitefish dispersed as the epilimnion cooled. An acoustical survey on October 13 showed that the concentration of fish between 22 and 32 m deep had disappeared but that numerous lake whitefish remained scattered throughout the Devils Hole area at depths ranging from 0 to 35 m. Whitefish at this time were noticeably absent from the water layer in which the lowest concentration of dissolved oxygen had previously occurred. Profiles of temperature and dissolved oxygen which were taken on October 20 after dispersal of the lake whitefish showed that while temperature in the epilimnion had fallen to $< 15^{\circ}$ C, the dissolved oxygen concentration remained much the same as on August 26. Thus, the oxygen depletion remained unchanged for approximately 2 weeks after the whitefish dispersed and this depletion probably remained until lake overturn. This depth interval below 22 m was avoided because of its low dissolved oxygen concentration.

Not all large lake whitefish estivated during summer. The stomachs of a small number which were caught by bottom horizontal gillnet at Stations 1, 4, 5, and 6 varied in fullness from empty to full, thus indicating varying degrees of feeding activity among those which remained outside the Devils Hole area.

5.3.3.3. Water Level Fluctuation. Lowered lake levels affect the success of lake whitefish spawning by reducing the available spawning habitat during the spawning season and by stranding eggs prior to hatching. During the winter of 1975-76 the lake level was lowered 6 ft

during operation of the P/G units. This drawdown removed potential spawning habitat from production and may have reduced survival of this year class (Fig. 5.18). However, since little is known about the importance of elevation in lakeshore spawning areas, the effects of this drawdown are unknown. Since the minimum lake elevation occurred during the spawning season in 1976, egg and fry stranding was not a factor in the limitation of year class strength. Irrigation drawdown in 1976 did not occur until emergence was largely completed and therefore could not have had a major effect on survival of the eggs.

During winter 1976-77 the P/G units were not operated and the lake level was maintained at elevation 1,570 ft. Irrigation drawdown began in March and probably affected some of the late-hatching eggs.

5.3.3.4. Length Frequency Analysis. A comparison of the length distribution of lake whitefish from monthly and quarterly gillnet samples is presented in Figure 5.19. It is apparent that growth ceased when the lake whitefish reached a length mode of 450 mm. As each developing year class approached 450 mm in length, their growth rate decreased and integrated gradually into the 450 mm mode. The 1974 year class was predominate numerically in the samples, since its recruitment into the gillnet catch in 1974. The 1975 and 1976 year classes were almost nonexistent in the samples.

Recruitment of juveniles into the gillnet catches began at about 100 mm in length. Growth of juveniles was fastest from April to December and nearly ceased from December to March. Because of the difficulty of identifying annuli on the scales of lake whitefish, determining the age of recruitment was not possible. The age of recruitment was therefore

HYPOTHETICAL MODEL ILLUSTRATING THE EFFECT OF WATER LEVEL FLUCTUATION ON THE INCUBATION HABITAT OF LAKE WHITEFISH.

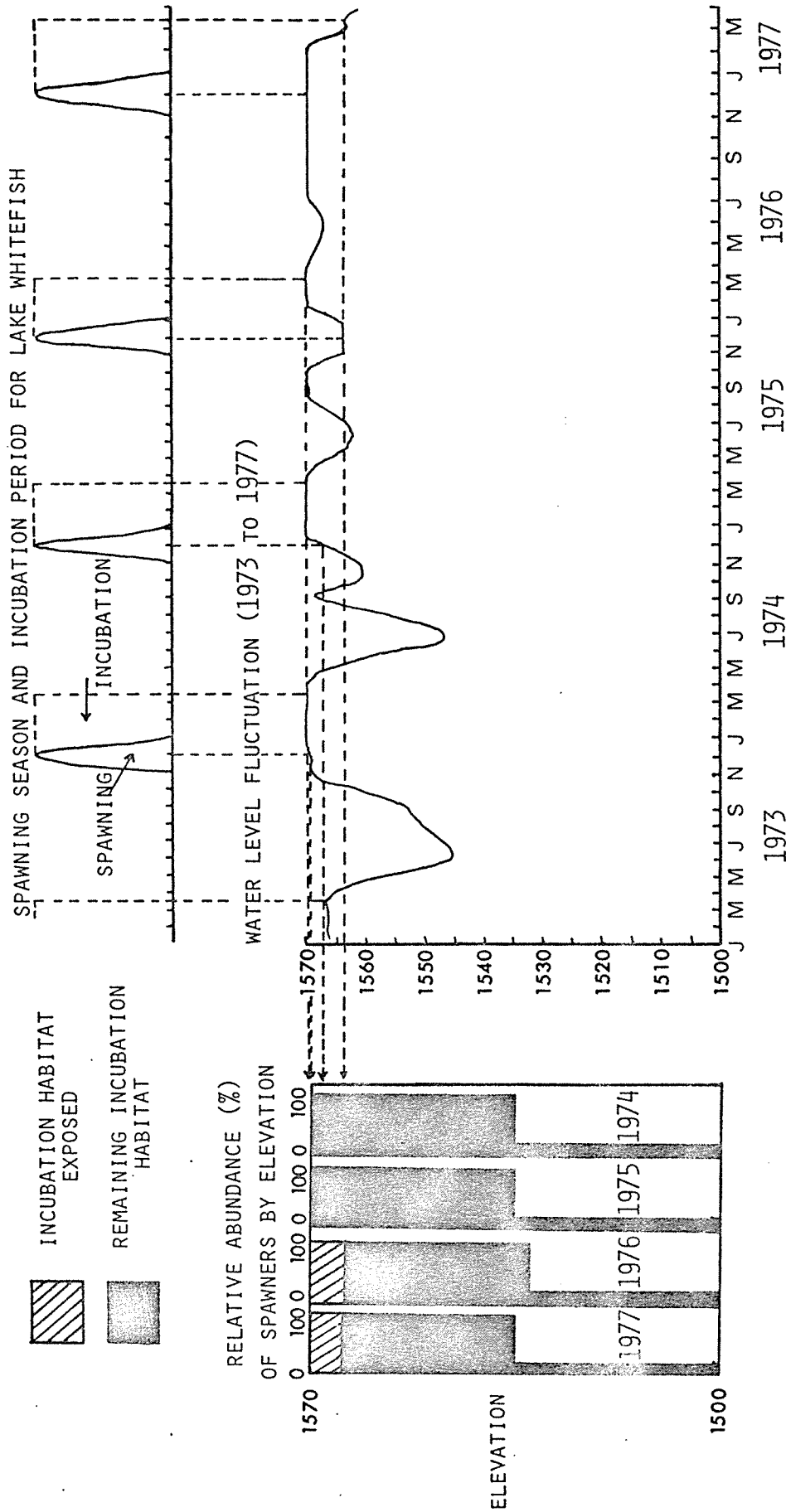


Fig. 5.18 Observed spawning and incubation periods (1973-77) of lake whitefish superimposed over the water level regimens of these years, and projected to the histogram of estimated spawning depths, illustrating the proportion of incubation habitat exposed by water level fluctuation.

inferred by projecting the progression of the quarterly length modes of the dominant age class in Figure 5.19 backwards to the 10 mm length at hatching. The projection intersects the 10-mm length during spring 1973, which implies that recruitment occurred at age I.

5.3.4 Kokanee

5.3.4.1. Distribution. The horizontal and vertical distributions of kokanee (age > I) were determined by comparing the quarterly gillnet catches within and between transects. The distributions and abundance of age 0 and I kokanee were not determined because no suitable sampling method was found.

From 1973 to 1975 kokanee were primarily surface oriented except during the summer months (Fig. 5.20) when greatest abundance occurred near the bottom, apparently in avoidance of warmer epilimnetic temperatures. The vertical distribution of kokanee in 1976-77 appeared to depart from the pattern observed in previous years. The catch at midlake was approximately equal between the surface and bottom nets in spite of epilimnetic temperatures 4° to 5° C above the preferred temperature of 15.6° C (Brett 1965). Winter (December and March) catches occurred almost entirely on the bottom. Besides the general decrease in kokanee abundance in 1976, the apparent change in vertical distribution patterns was probably due to sampling variability. There was little reason to suspect that the relatively minor changes in temperature patterns and zooplankton abundance which occurred in 1976, as compared with previous years, influenced the vertical distribution of kokanee.

Kokanee were most abundant at Transects 5 and 6 and least abundant at Transects 1 and 4 (Fig. 5.21) during the summer and fall of 1976.

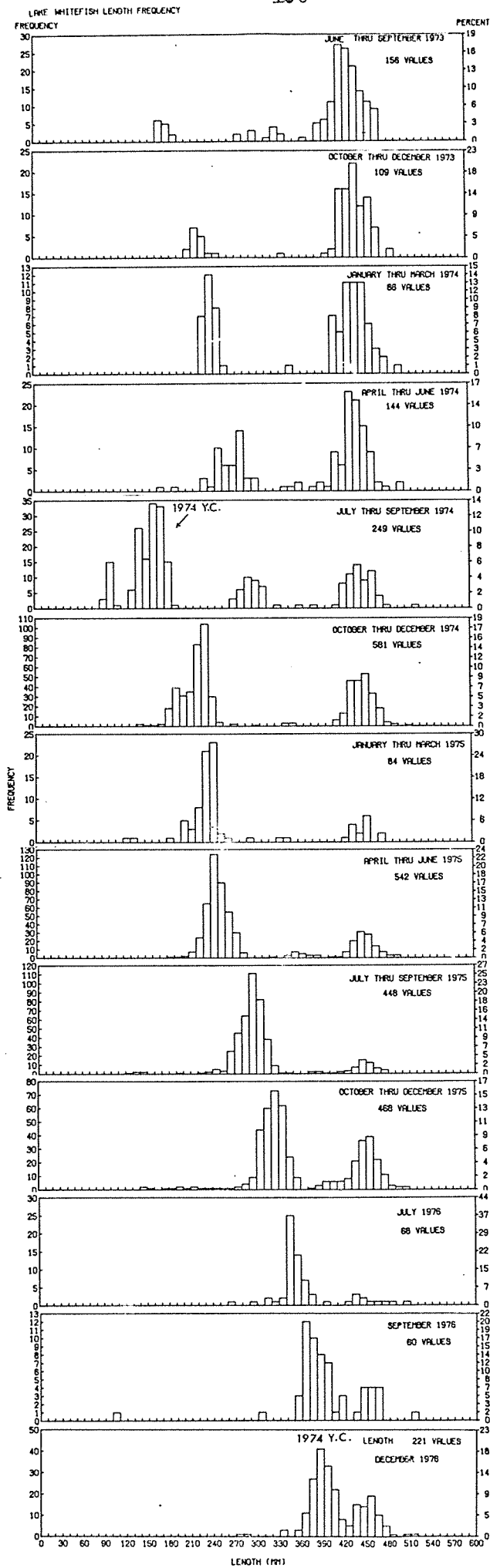


Fig. 5.19 Length distribution and year class of lake whitefish caught in monthly and quarterly gillnet samples from 1973 to 1976 grouped by quarter.

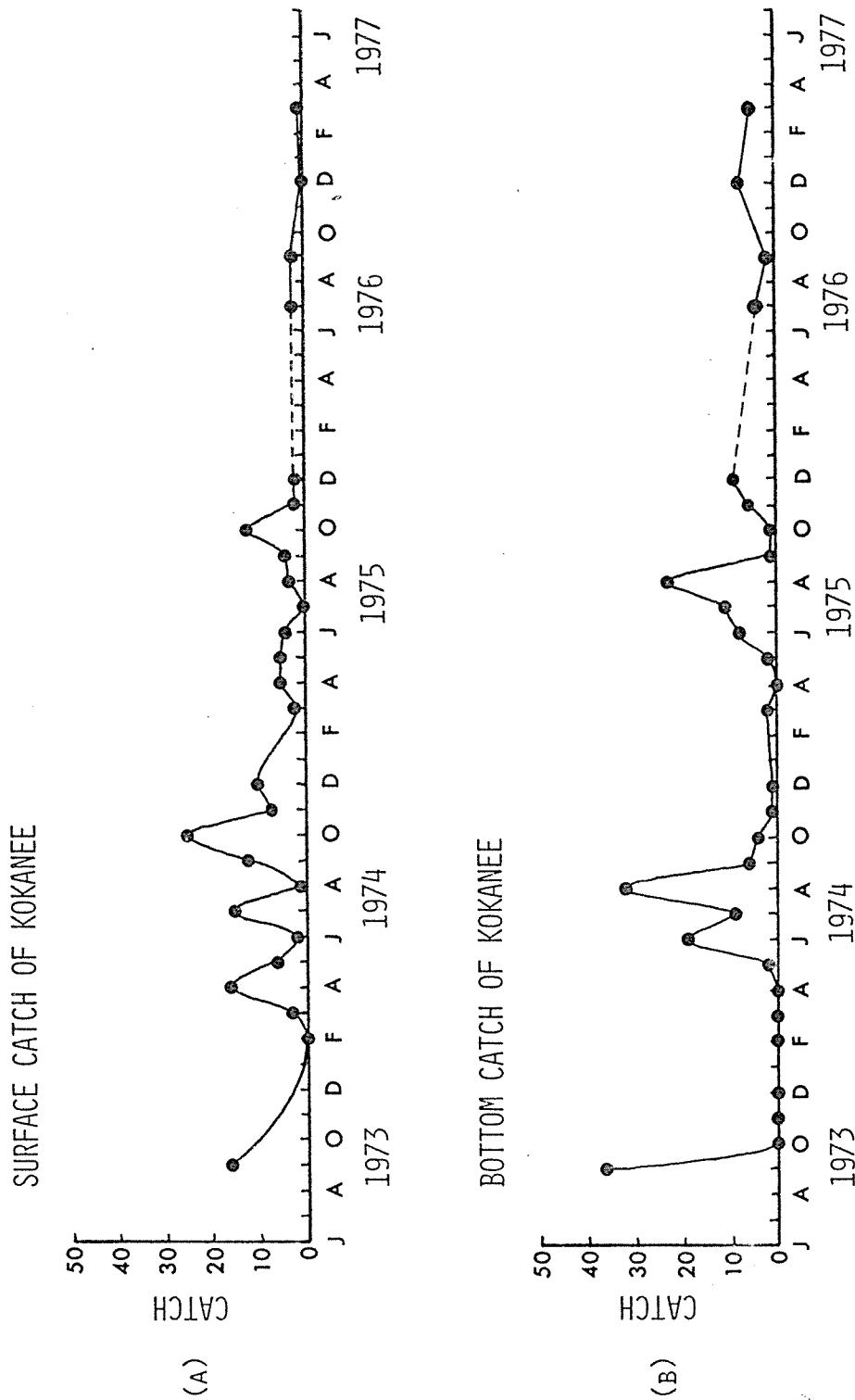
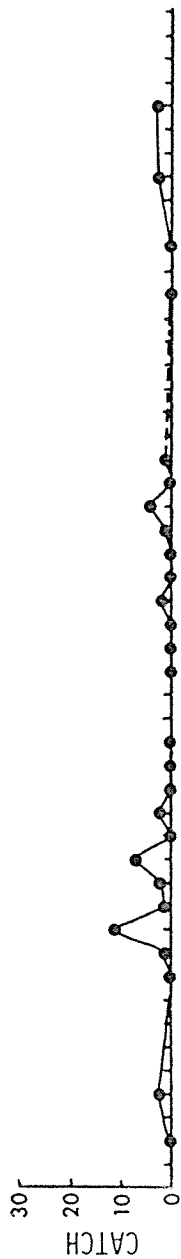


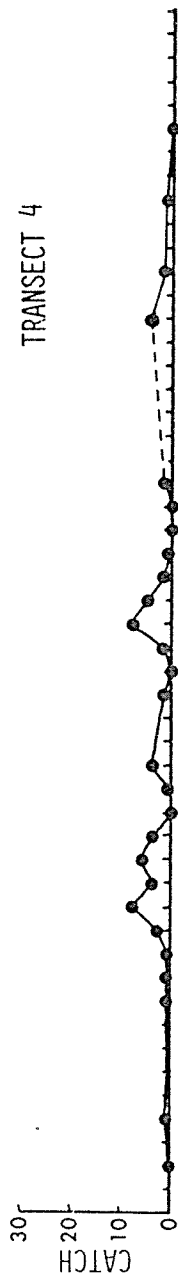
Fig. 5.20 Vertical distribution of kokanee. Each point represents 8 24-hr. horizontal variable-mesh gill-net sets. Four sets were made at each of the 4 transects monthly: 2 on the surface and 2 on the bottom.

TRANSECT 1

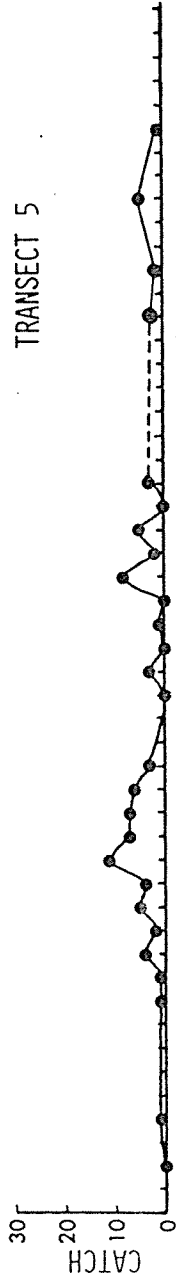
OFFSHORE CATCH OF KOKANEE BY TRANSECT



TRANSECT 4



TRANSECT 5



TRANSECT 6

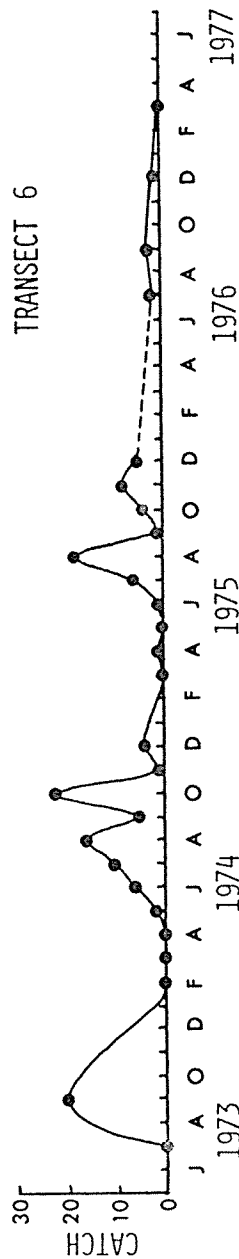


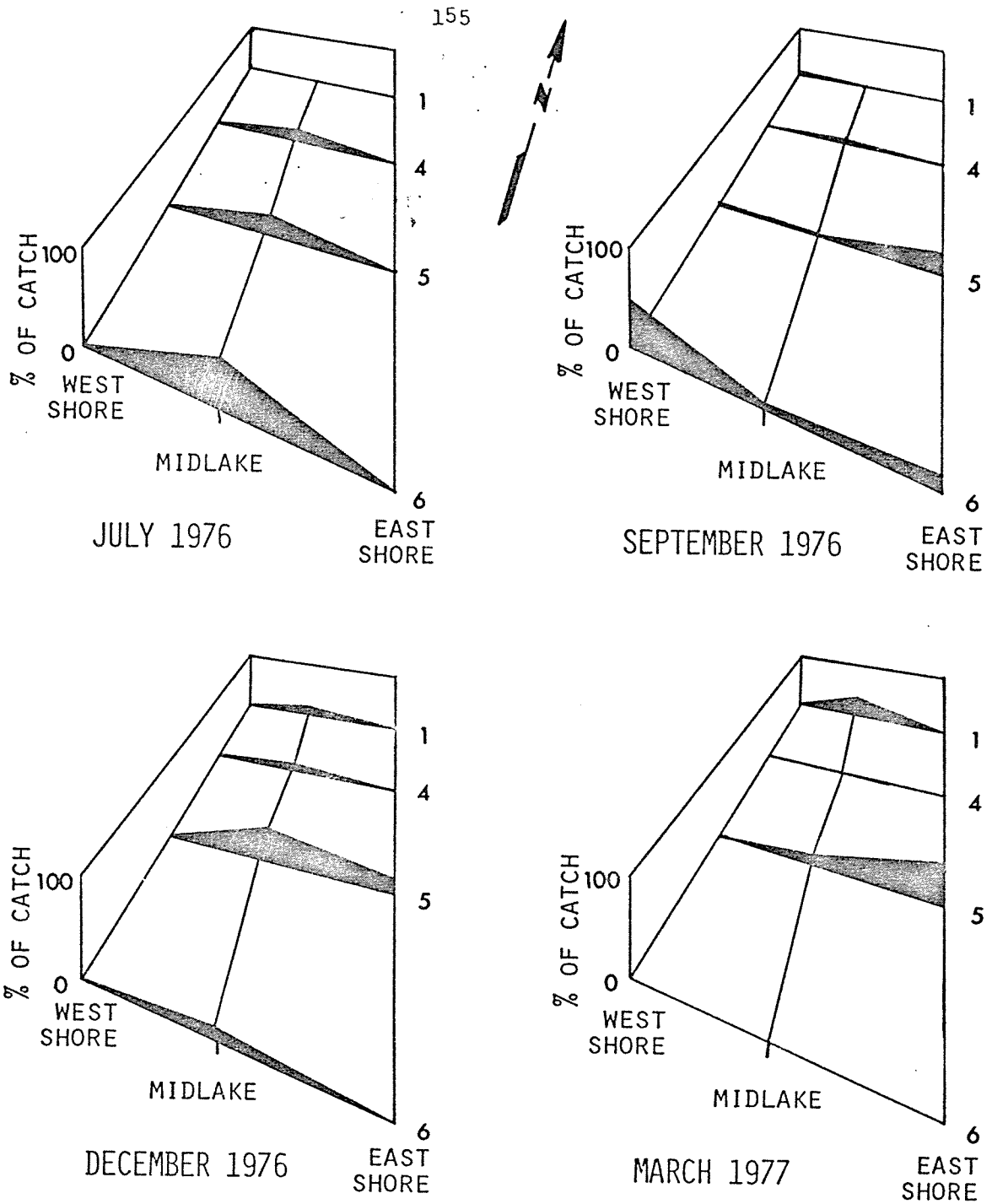
Fig. 5.21 Horizontal distribution of kokanee. Each point represents the catch from 4 24-hr. horizontal variable-mesh gill-net sets: 2 on the bottom and 2 on the surface.

The catches at Transect 1 increased in December 1976 and March 1977, while the catch declined at other transects. Neither pumping nor drafting affected the north pool of the lake during these periods.

Kokanee catches at inshore and offshore locations were comparable during the spring and fall and were highest offshore during the summer (Fig. 5.22). Catches made inshore during the fall were of maturing or spawning kokanee.

Temperature, food and spawning behavior explain much of the variation found in kokanee distribution in Banks Lake. The kokanee catch occurred entirely in the midlake gillnets during July, when water temperatures were highest. The avoidance of the shorelines in July was probably temperature-related even though the midlake catches did not show the expected vertical distribution. Kokanee avoided Transect 1 during July, the peak of irrigation pumping (Fig. 5.22), but ranged throughout the south pool and occurred in greatest numbers near the south dam. In September, as age III and IV kokanee reached sexual maturity, they concentrated along the shoreline spawning areas in the southern half of the lake. The shoreline catches were predominant in the September samples (Fig. 5.22). In December, distribution was principally offshore at each transect. Nearly the entire catch occurred at midlake at Station 1 and from the east shoreline at Station 5. Winter catches at Station 1 indicate that kokanee occupied the north pool during an extended period in which no pumped input into the north pool of Banks Lake occurred.

A decline in the offshore catch of age II kokanee in 1975 and age III kokanee in 1976 was apparent. The offshore catch consisted mainly



KOKANEE

Fig. 5.22 The spatial distributions of kokanee from quarterly gillnet samples during 1976-77. The vertical axis represents the percent of the total catch for each season. The horizontal plane represents 12 sampling locations: east shore, mid-lake, and west shore at each of 4 transects.

of small kokanee less than 300 mm, or age II (Fig. 5.23). The abundance of age II kokanee in 1977 appears to be roughly comparable with the 1974 abundance, even though the data points vary widely between samplings. To the extent that the 1974 and 1977 populations of age II kokanee are similar in number, the 1978 kokanee recruitment into the sport fishery should be similar to that which occurred in 1975. The catch of large kokanee (> 300 mm; ages III and IV) was small in December and March and was approximately equal to the catches of the previous winter. To the extent that 1976 and 1977 populations of age III kokanee are similar in number, the 1977 kokanee recruitment into the sport fishery should be similar to the reduced recruitment experienced in 1976.

5.3.4.2. Water Level Fluctuation. Indirect evidence strongly indicates that the large drawdown during spring 1973 substantially reduced the size of the kokanee year class which spawned in the fall of 1972 by stranding eggs and/or alevins in lakeshore spawning beds. The small size of the year class which emerged from the gravel in spring 1973 has been documented by several independent data sources including the small recruitment of age II kokanee into the gillnet catches in 1974, the small catch of kokanee by the sport fishery during the summer of 1976, the greatly reduced entrainment of kokanee into the irrigation canal (from 128,397 in 1975 to 50,007 in 1976), and the drastically reduced kokanee spawning population (from an estimated 7,500 in 1975 to < 150 in 1976). The extension of the egg incubation and larval stages of kokanee development well into the spring period of irrigation drawdown has been documented in Section 6. These studies indicate that early, extensive lake level drawdown during April, May, and perhaps early June,

such as those that took place during 1973 and 1974, cause substantial mortality of the eggs and/or alevins reducing the size of the year class.

This effect is illustrated in Figure 5.24, a multidiagrammatic scheme of the spawning and incubation seasons and the observed seasonal lake water level fluctuation with the depth distribution of lakeshore spawning kokanee. Although the lake drawdown in 1974 was nearly as great as in 1973, the timing was about 5 weeks later. This delay may have allowed for greater emergence of fry in 1974 than occurred during the 1973 drawdown, however, catch statistics do not indicate an increase in abundance in the 1974 year class.

As was discussed in the Third Annual Report, the fall lake level drawdowns during the 1974 and 1975 spawning seasons probably forced some spawning to occur at lower elevations. The success of spawning at various elevations and depths is presented in Section 6 for the 1976 brood year. The relatively small spring drawdowns of 1975 and 1976 probably had little impact on the survival of developing eggs and alevins because spawning took place at elevations below the level of drawdown.

5.3.4.3. Length Frequency Analysis. The length distributions of kokanee from the monthly and quarterly gillnet samples are compared for the period June 1973 through December 1976 in Figure 5.25. The progression of year classes (identified by year of fry emergence) from 1970 through 1975 is represented in this comparison. Several conclusions are apparent from this analysis. First, growth occurred almost entirely from April to October and virtually ceased during the late fall and winter. Second, annual growth averaged 137 mm with maximum growth

HYPOTHETICAL MODEL ILLUSTRATING THE EFFECT OF WATER LEVEL FLUCTUATION ON THE INCUBATION HABITAT OF KOKANEES

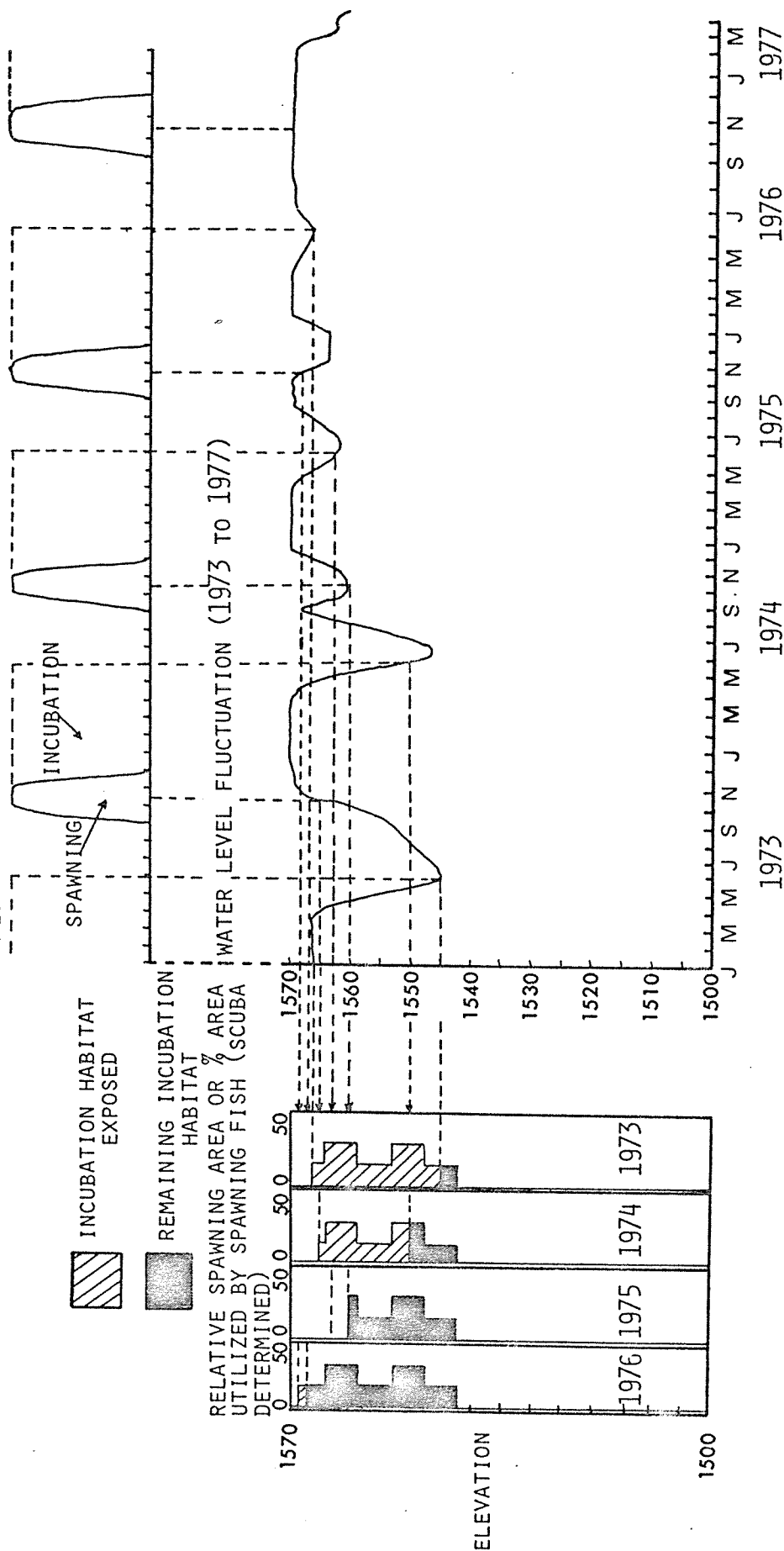


Fig. 5.24 Observed spawning and estimated incubation periods (1973-77) of the kokanee salmon, superimposed over the water level regimes for these years, and projected to the histogram of observed spawning depths, illustration the proportion of incubation habitat exposed by lake level fluctuation.

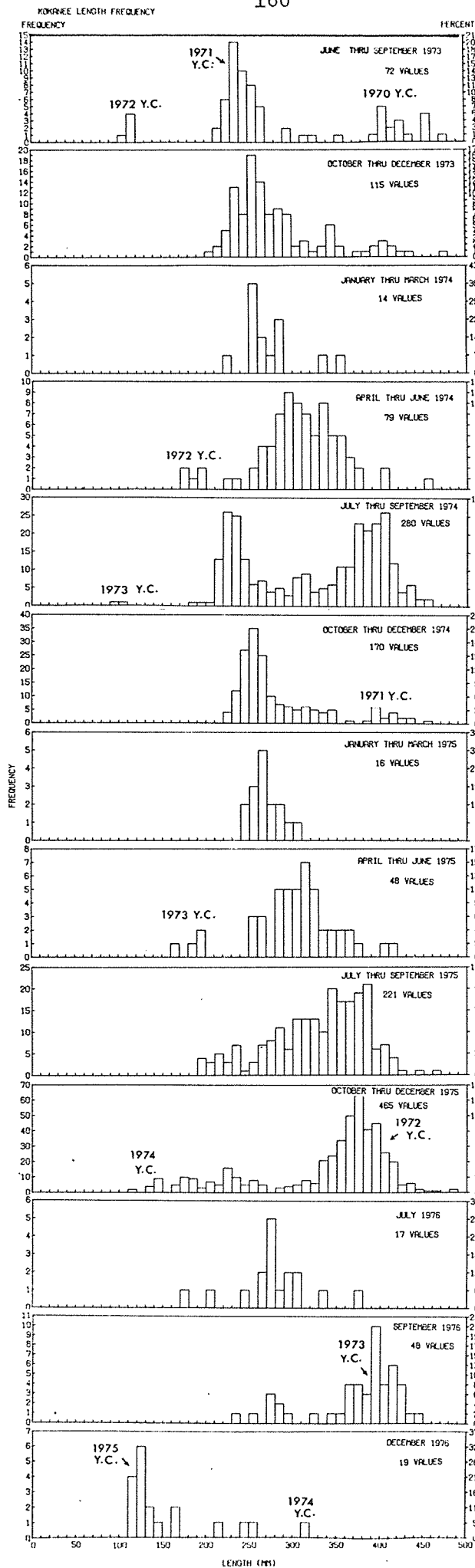


Fig. 5.25 Length distribution and year class of kokanee caught in monthly and quarterly gillnet samples from 1973 to 1977 grouped by quarter.

occurring during spring and summer which averaged 21 mm per month.

Third, the 1971 and 1972 year classes were numerous in the samples but the 1970, 1973, and 1974 year classes were small in number. Fourth, the 1974 year class was very sparsely represented in the catches and at this time appears to be smaller numerically than the small 1973 year class.

6.0 KOKANEE FRY STUDY

6.1 Introduction

The operation of Grand Coulee Dam as a major flood control reservoir on the Columbia River results in a large spring drawdown of FDR Reservoir below the pump intakes which supply water to Banks Lake. Irrigation drafting from Banks Lake begins in March and replacement pumping does not begin until May or June. Consequently, Banks Lake is drawn down annually during April, May, and June to meet demands for irrigation water.

The magnitude and timing of the drawdown of Banks Lake can apparently impose a significant impact on the survival of kokanee eggs and larvae which are produced from lakeshore spawning. Because the principle source of kokanee recruitment is from natural spawning along the shorelines, the drawdowns have greatly influenced the success of the kokanee sport fishing. Kokanee spawn at the bases of steep talus slopes at a number of locations throughout the lake but mainly along the southwest shoreline. Spawning occurs during October and November and emergence occurs approximately 6 months later during April and May. Spence (1965) and Duff (1973), after studying catch statistics and interviews with sports fishermen, report it is evident that large populations of kokanee occurred during years when spring drawdown averaged about 15 ft (1,555 ft msl) (Fig. 5.2). However, the extreme drawdowns of 24.9 and 23.6 ft which occurred in 1973 and 1974, respectively, were apparently instrumental in severely reducing the survival of the 1973 and 1974 year classes (Third Annual Report 1976). Prior to this study little was known about the timing of hatching and emergence and nothing was known about the

survival rate of eggs and alevins from shoreline spawning. Therefore, direct evaluation of the effects of drawdown on the kokanee population was not possible.

The general objectives of this study were to determine the effects of timing and magnitude of lake level drawdown on the survival of kokanee eggs and alevins in lakeshore gravel. Because little reference to sampling of eggs and alevins in lakeshore spawning beds appears in the literature, it was necessary to develop new sampling techniques. Specific efforts were directed at developing sampling techniques to determine such parameters as: 1) Locations, depths and numbers of kokanee spawning per unit area of shoreline; 2) developmental rates and survival to emergence of eggs and fry. These data may be applied to future water management strategies to maintain a viable sport fish population and to estimate year class strength during years when major drawdown is unavoidable.

6.2 Materials and Methods

6.2.1 Spawning Observations

A rapid means of surveying the 60-mile length of potential spawning shoreline was needed to identify the spawning locations and to estimate numbers of spawning kokanee. A plywood skiff measuring 2.4 x 1.1 m was fitted with a 60 x 60-cm window of 6.35-mm plexiglas (Fig. 6.1). A viewing cone constructed of 6.35-mm plywood was placed over the glass bottom to improve viewing efficiency by minimizing overhead light and glare. Viewing was done through a hole at the top of the cone which was cut to fit a diver's face mask.

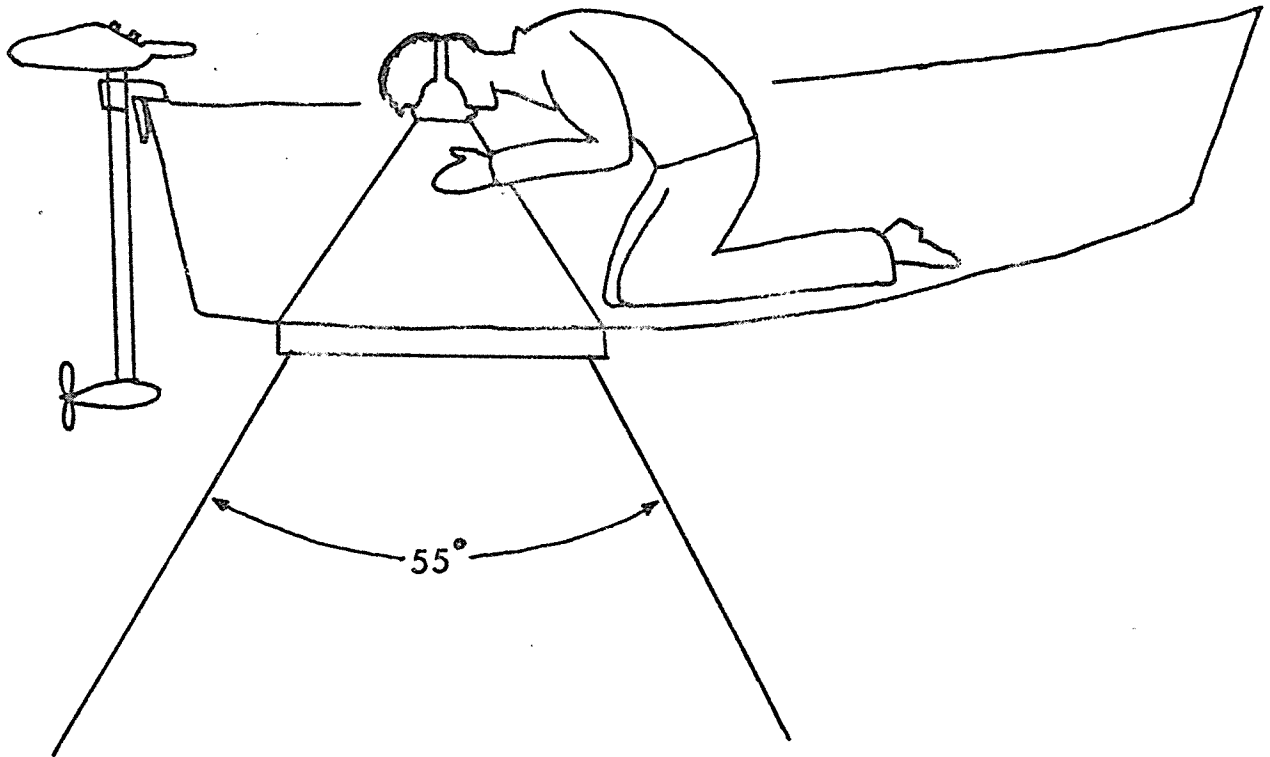
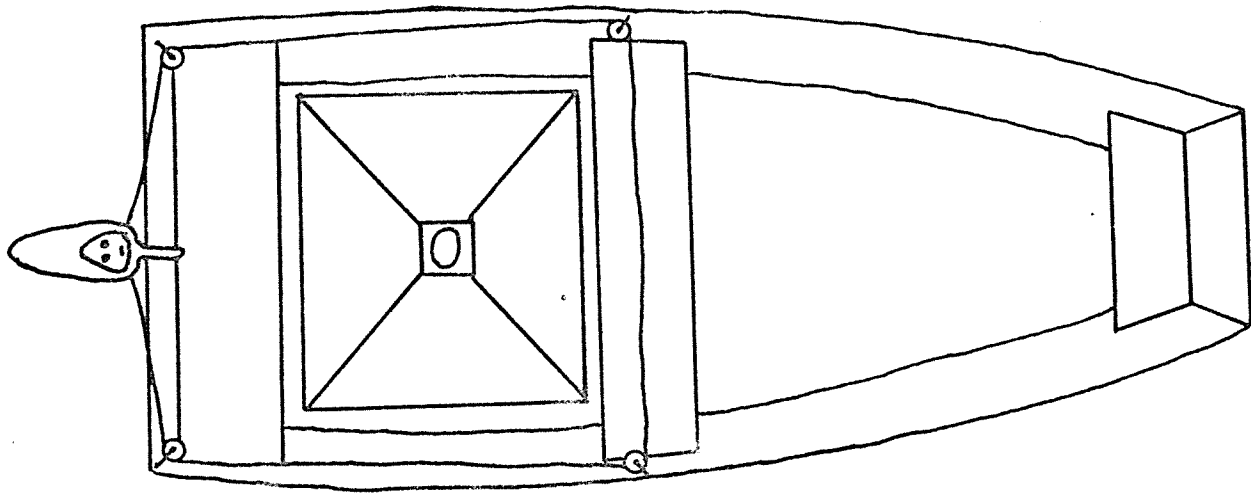


Fig. 6.1 Glass-bottomed pram used for underwater viewing.

A 12-volt electric motor with 5.9 kg thrust propelled the skiff from the stern. Steering was designed to permit the viewer to maneuver the skiff while viewing. During the weekly surveys the shoreline was paralleled at a rate of about 0.6 m/sec over an average depth contour of 5 m. The maximum depth of visibility was measured at 5 m on October 15. This depth gradually increased to 8 m by mid-November. Numbers of live and dead kokanee, as well as the spawning potential of the substrata, were observed and noted.

Surveys of intensively spawned areas were conducted biweekly by SCUBA divers. Data recorded included counts of live and dead kokanee, location, depth, and area of spawning.

6.2.2 Kokanee Egg Planting

It became apparent early in the 1976 spawning season that the population of spawning kokanee was extremely small and that natural egg deposition may be inadequate to provide a basis for determining development rate and survival. It was therefore necessary to supplement the natural spawning by importing green kokanee eggs from the Washington State Department of Game Hatchery at Lake Whatcom. Approximately 11,400 eggs in three groups of 3,800 eggs each were transported to Banks Lake during October and November.

Approximately 3,800 kokanee eggs were planted on each of three dates (October 27, November 11, and November 27) at depths of 10, 15, 20, and 25 ft (Table 6.1). All plants were made within an 800-m length of shoreline near Station 6, in an area where natural spawning was concentrated. Eggs were planted on natural shelves which occurred irregularly on the talus slope. The eggs for each planting were divided

Table 6.1 Matrix of information pertinent to experimental kokanee egg planting in Banks Lake, 1976.

Depth (ft)	Date			Total Eggs
	Oct 27	Nov 11	Nov 23	
10	10 Vibert, 50 eggs each	10 Vibert, 50 eggs each	10 Vibert, 50 eggs each	1500
15	10 Vibert, 50 eggs each; 10 mesh bags 50 eggs each; 6 free plants, 300 eggs each	10 Vibert, 50 eggs each; 10 mesh bags 50 eggs each	10 Vibert, 50 eggs each; 10 mesh bags 50 eggs each	1500 1500 1800
20			6 free plants, 300 eggs each	1800
25	10 Vibert, 50 eggs each	10 Vibert, 50 eggs each; 6 free plants 300 eggs each	10 Vibert, 50 eggs each	1500 1800
Total eggs: 3,800		3,800	3,800	11,400

into three lots. One lot of 1,500 was placed in groups of 50 eggs each inside 30 Vibert egg incubation boxes. A second lot of 500 was placed in groups of 50 each into 10 plastic mesh bags. The bags also contained two handfuls of gravel each. The remaining 1,800 eggs were planted as free eggs without containers. These were introduced into the gravel in groups of about 450 eggs each by pouring them into a 1-inch diameter plastic pipe which had been forced several inches into the gravel. The planting was designed to yield preliminary data on developmental rates and survival, as influenced by such variables as planting date, depth, and type of incubation container. Gravel measuring from 3-5 cm diameter was imported to the lakeshore for each series of plants and used to cover the containers and eggs to minimize effects of variations in substrate on development and survival of the eggs.

The planting matrix (Table 1) indicates the distribution of eggs with depth for each date. Each Vibert box was loaded with a 5-cm depth of the imported gravel and charged with 50 eggs. The Vibert box was made of rigid slotted plastic on all sides. Slot dimensions were larger on the bottom to allow fry to escape. The bags were made from 25- by 46-cm² pieces of 1-mm plastic mesh. The bags were also charged with a small quantity of gravel and 50 eggs each, and tied off at the top with twine. All containers were buried in depressions approximately 7 cm deep and covered with gravel. The sets of containers for each date were arranged in a circular configuration approximately 40 cm in diameter in order to facilitate later placement of fry traps. Gravel from around the planted eggs was mounded over the containers and additional gravel was hauled in to insure adequate burial of all containers under a minimum

of 5 cm of gravel. All containers and free egg plant sites were marked with 1-m lengths of polypropylene line which were color-coded for identification by depth and date.

The first egg plant was found 1 week later to have been badly disrupted by spawning kokanee. Subsequent egg plantings were protected by placing sections of 2.5-cm mesh chicken wire over the planting area and anchoring the edges with large cobble stones. This precaution prevented further disturbance by spawning fish.

6.2.3 Water Temperature Record

A Ryan recording thermograph was installed October 13 on the lake bottom 3 m deep near the primary spawning area of the west shoreline. Water temperature at average spawning depth was continuously recorded from October 13 to June 5 except during one period in January when the thermograph malfunctioned. Periodic measurements of water temperature were made with a Hydrolab for verification and to help interpolate missing data.

6.2.4 Fry Trap Development and Operation

The present fry trap design was based largely on experience gained from the construction and testing of fry traps in 1976. During February 1976, 100 emergent fry traps were deployed over the primary kokanee spawning area. These traps were constructed of low-cost wooden frames and plastic screen and sampled an area of the bottom 1-m^2 . The traps were inadequately constructed to withstand the effects of rockslides and wave action and all traps were destroyed. Based on this experience, a fry trap constructed of more durable materials was developed in 1977.

The trap was conical for maximum resistance to rockfall, gravel slides, and wave action. The cone was constructed of 20-gauge galvanized sheet metal (Fig. 6.2). The bottom edge of the cone was turned out to form a 5-mm lip for rigidity and to engage rocks which were piled against the outside for added stability. The cone measured 56.4 cm diameter by 48.8 cm high and sampled $1/4 \text{ m}^2$ of substrate. The slope of the cone was 60° , which allowed for efficient leading of fry into the cod-end (Collins 1974), and for good stability. An opening at the top measured 12 cm diameter. A removable cod-end, which fitted over the opening, incorporated several features enabling SCUBA divers to replace the cod-end easily without disturbing the cone. The cod-end was quickly and tightly attached and detached by means of two twist-lock fasteners. A fyke was built into the cod-end which prevented the catch from escaping while the cod-end was being replaced and transported underwater. The catch was easily removed at the surface by unscrewing a cap and pouring out the 2 liters of contained water.

The cod-ends were assembled from available heavy-gauge plastic products; a 2-liter polypropylene bottle from which the bottom was removed, and a polyurethane funnel with a slope which closely matched the slope of the cone. The stem of the funnel was cut to an opening of 16 mm and inserted into the cutaway bottom of the bottle to form a fyke. The bottle and funnel were joined by pop rivets.

On March 11, 40 traps were emplaced over the primary spawning area by divers. The traps were positioned to sample the emergence from the

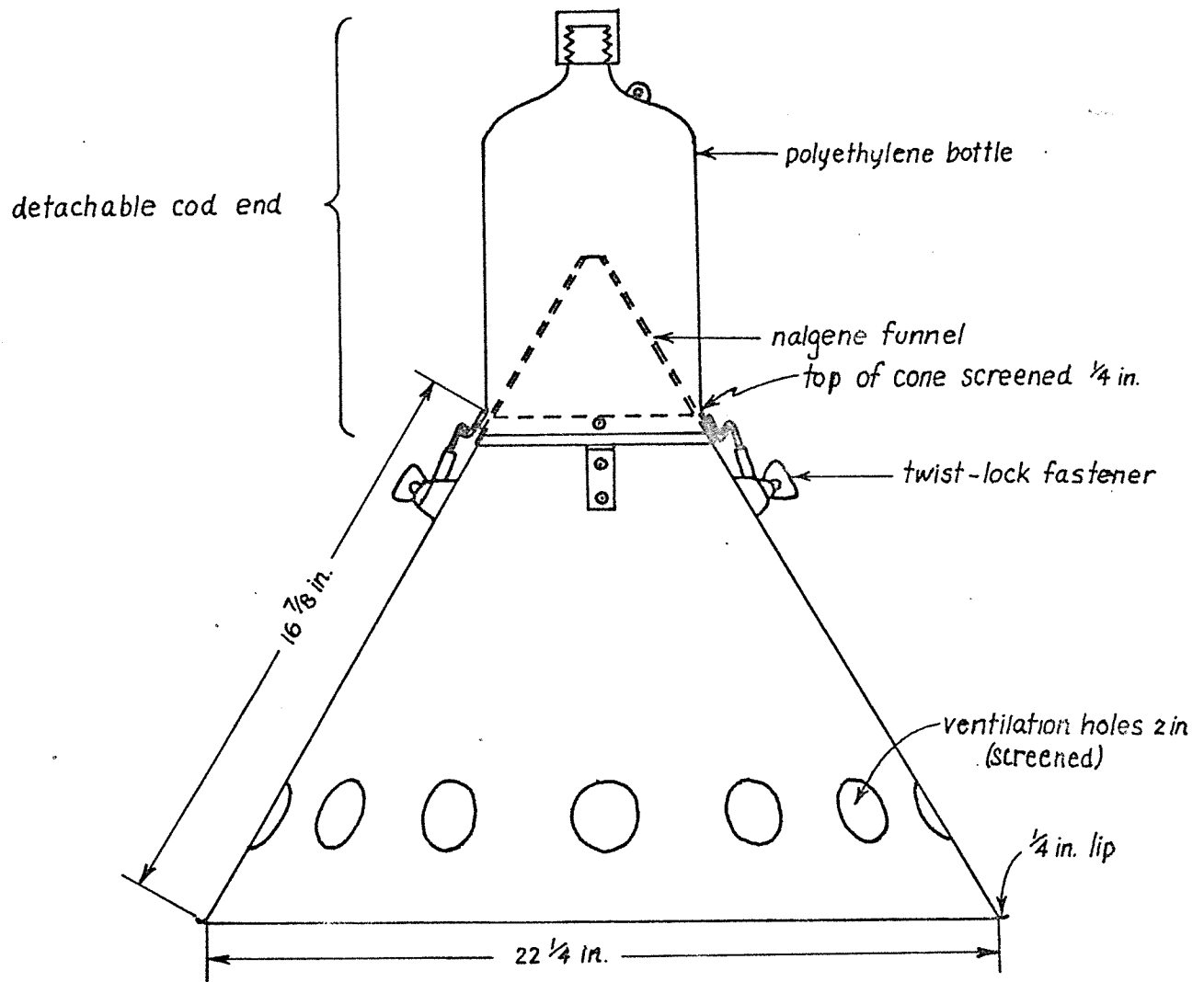


Fig. 6.2 Kokanee fry emergent trap with detachable cod end.

Vibert boxes, free-planted eggs, and naturally spawned eggs. No traps were placed over the mesh bags because the fry could not escape from them.

The cod-ends were exchanged weekly until June, by which time emergence had ceased. The contents of the cod-ends were poured through a strainer and all organisms captured were preserved in 5 percent formalin.

After several weeks it became apparent that sculpins were trapped along with the fry and constituted a source of error because they were feeding on the fry. Most of the cod-ends were subsequently screened by placing wire mesh over the top of the cone between the cone and the cod-end. The mesh was of stainless steel with 5-mm square openings. Some of the traps were left unscreened in order to determine the effects of screening on the catch rates of sculpin and fry. To facilitate this comparison, half of the traps which were placed over the natural spawning area were left unscreened.

Tests were conducted to determine whether the presence of the traps decreased the dissolved oxygen (DO) content of water inside the cone or within the underlying substrate. This was determined by inserting standpipes into the gravel inside and outside of five traps. DO readings were read from a meter at the surface while a diver lowered the probe into each of the standpipes.

To test the effect of ventilation holes in the cones on DO, five cones were ventilated by cutting 12 holes each of 5-cm diameter near the base. The holes were screened to prevent the escape of fry. The DO within the ventilated traps was measured on two occasions for comparison with measurements taken from the unventilated traps.

6.3 Results and Discussion

6.3.1 Kokanee Spawning

The numbers of kokanee spawning in 1976 were greatly reduced from 1975. Estimates of the 1975 kokanee spawning population by SCUBA observation ranged from 5,000 to 10,000 total. Spawning occurred in a number of places throughout the lake where suitable gravel existed and was most concentrated along the steep talus slopes of the southwest shoreline at Transects 5 and 6 (Third Annual Progress Report). As many as 250 to 300 spawners were observed per 30-m length of shoreline in this area. Spawning occurred in October and November on wave-built benches at depths ranging from 1 to 8 m. Eggs were deposited in rubble measuring from 2 to 150 mm diameter.

The 1976 survey was much more comprehensive in area coverage and frequency of observation than the 1975 survey. It revealed a drastically reduced spawning population for the entire lake. The peak number of spawners observed was 122. Although the surveys were relatively comprehensive, it is unlikely that all spawners were counted. The observed value therefore was adjusted upward by 25 percent to 153 to provide a more likely estimate of the 1976 spawning population. The spawning population was so small that spawning took place only in a few isolated locations. As in 1975, most spawning occurred along the southwest shoreline in the vicinity of Transect 6 (primary spawning area). A greater quantity of fine, clean material existed on the talus slopes at Transect 6 than elsewhere and was considered to be the reason for the concentration of spawners. This area was surveyed weekly by means of the glass-bottom skiff. The number of live and dead kokanee observed in

the primary spawning area are presented in Fig. 6.3. All other talus shorelines were surveyed biweekly.

Although prior surveys were conducted, the first spawners were observed on October 19. The water temperature on this date was 14.3° C at 3 m depth. Spawning peaked in mid-November and was completed by December 1, at which time the water temperature was 5.3° C. Spawning fish were most frequently observed schooled at a depth of 5 m. They were easily disturbed by the presence of the glass-bottom skiff and were not observed in digging or spawning activities.

Few spawning kokanee were observed outside the primary spawning area (Fig. 6.4). No live spawners were observed in the north pool; however, two dead, spawned-out kokanee were found 1/2 mile from the North Dam on the east shoreline. Potential spawning areas based on general observations of shoreline gravel type were also noted during the surveys and indicated in Figure 6.4.

6.3.2 Survival of Planted Kokanee Eggs

Between March 11 and May 17, mesh bags and Vibert boxes were periodically removed from each of the three plants in order to monitor egg development and survival rate.

Survival rate among the mesh bags varied greatly within each plant apparently due to the degree to which the bags were buried. Nearly all mortality occurred during or shortly after planting. Eggs which survived the first week after planting generally remained viable.

The mesh bags planted October 27 were partially exposed by spawning kokanee and suffered the greatest mortality. Only 13 percent survived

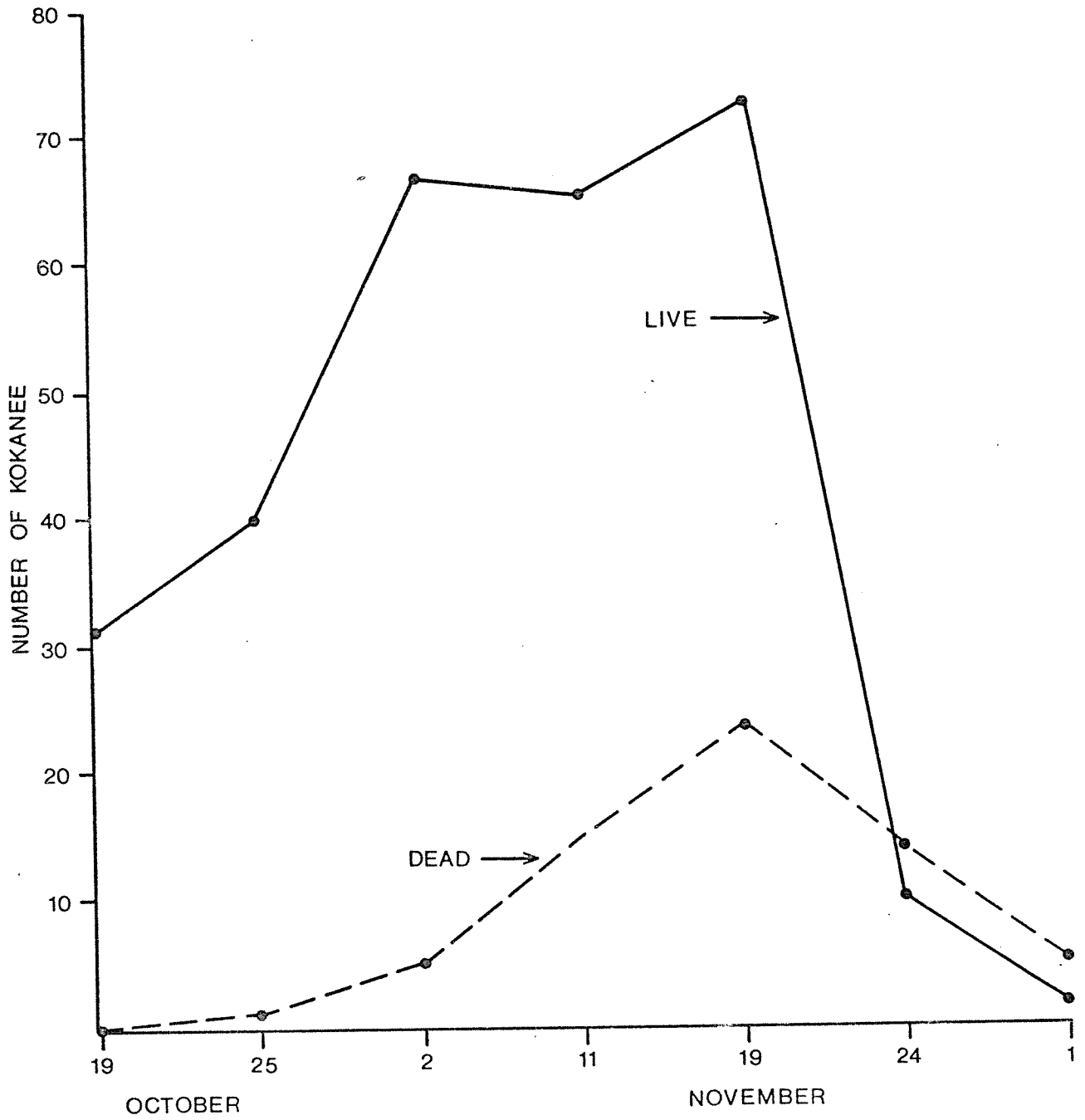


Fig. 6.3 Number of live and dead kokanee observed during glass-bottom pram surveys in the primary spawning area in Banks Lake.

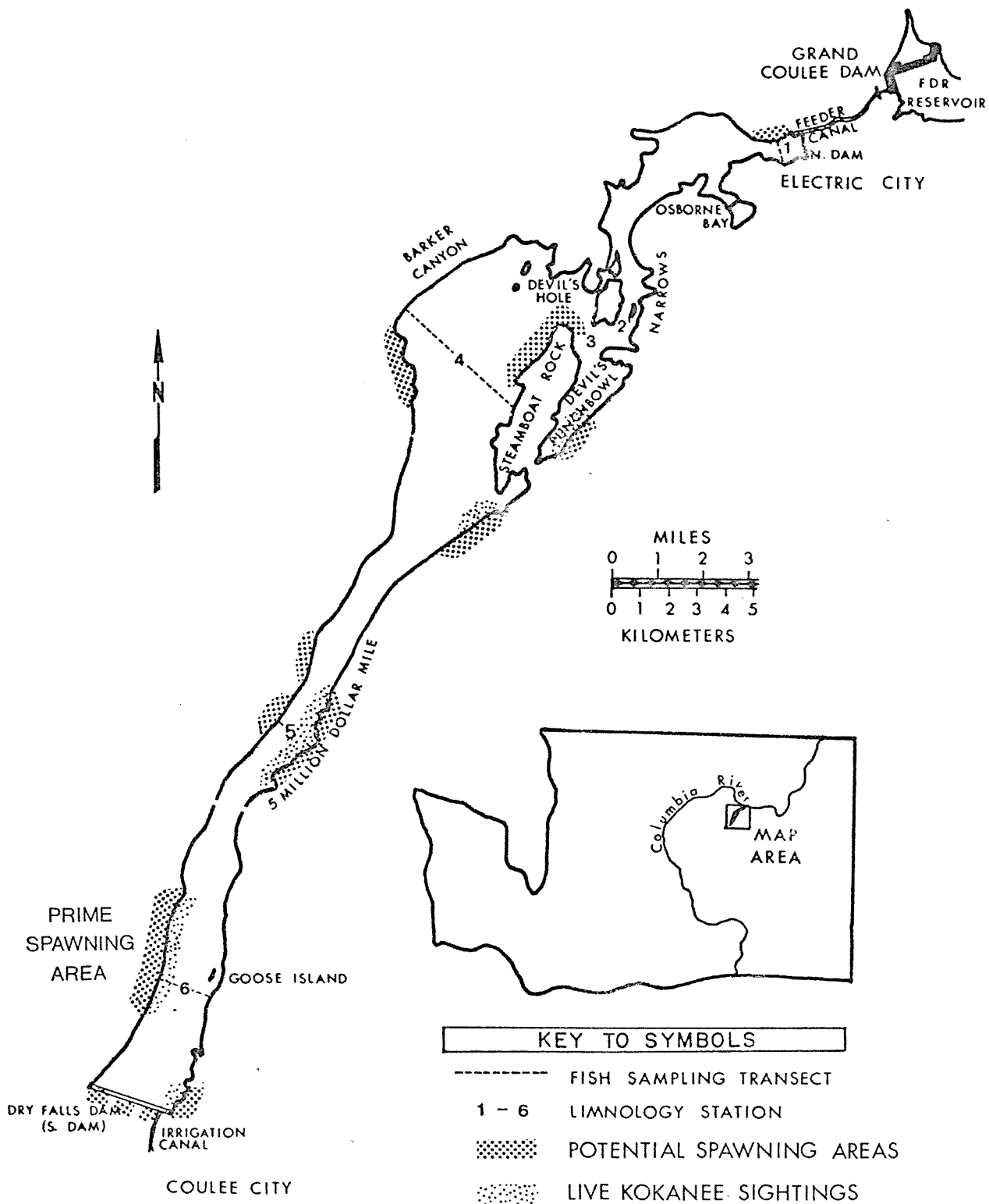


Fig. 6.4 Map of Banks Lake indicating the areas where suitable shoreline spawning substrate occurred and where live kokanee spawners were observed. The prime kokanee spawning area is located in the southwest quarter of the lake.

to yolk absorption. Of the eggs planted November 11, 20.3 percent survived, and of those planted November 23, 43.8 percent survived to yolk absorption.

Survival of eggs in the Vibert boxes was very low due to exposure to light. Because the boxes were relatively large and rigid, considerable gravel was required to completely bury them and they were exposed readily by gravel shift. In all, only 0.17 percent survival was experienced in the Vibert boxes.

The higher survival rate in the mesh bags is attributed to their smaller size which facilitated initial burying and to their pliability which resisted uncovering during gravel shift.

6.3.3 Development of Planted Kokanee Eggs and Alevins

The developmental rate of incubating eggs varies closely with water temperature above 32° F. Therefore, eggs develop rapidly in the fall and spring and slowly in the winter. The stage of development reached by a particular time postspawning is closely associated with accumulated time and temperature as measured in temperature units. A temperature unit (T.U.) is defined as 1° F over 32° F for a 24-hr period. A continuous record of temperature was available from a thermograph positioned near the primary spawning area (Fig. 6.5). Natural spawning, egg planting, hatching and emergence dates are indicated as observed along the ambient temperature curve.

The times of hatching and emergence and the accumulated temperature units of the planted eggs are summarized in Table 6.2 and Figure 6.6. These data resulted from analysis of the stage of development of eggs and alevins in the mesh bags. The actual date of emergence was not

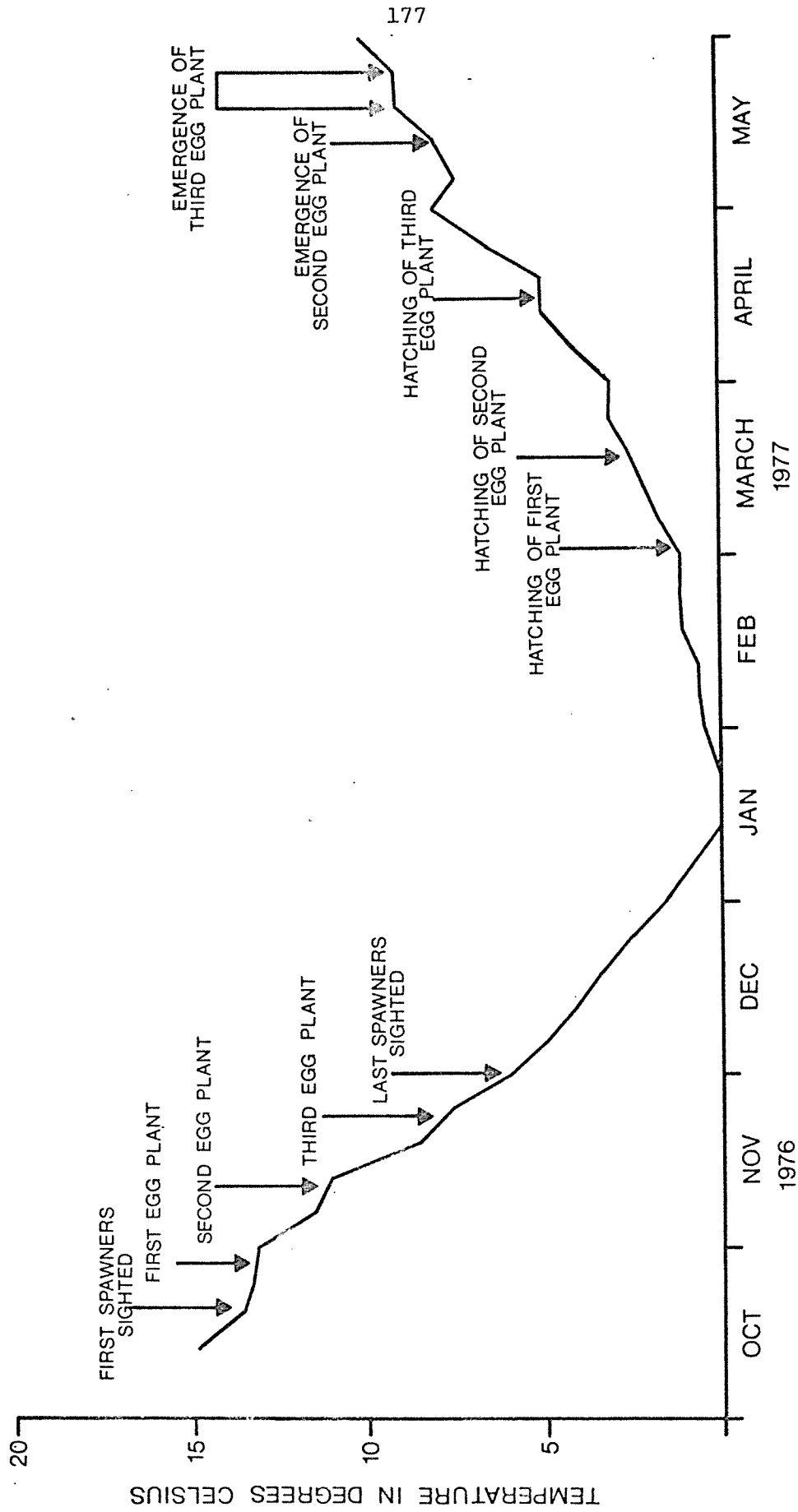


Fig. 6.5 Fall, winter and spring water temperature regime (°C) at Station 6 with spawning, planting and egg development dates indicated.

Table 6.2 Mean dates of hatching and emergence and accumulated temperature units of the planted eggs.

	Plantings		
	1	2	3
Planting Dates	October 27	November 11	November 23
Hatching Dates and T.U.'s	Mar 1-860	Mar 16-748	April 15-760
Emergence Dates and T.U.'s	Apr 14-1200	May 10-1230	May 17-1175

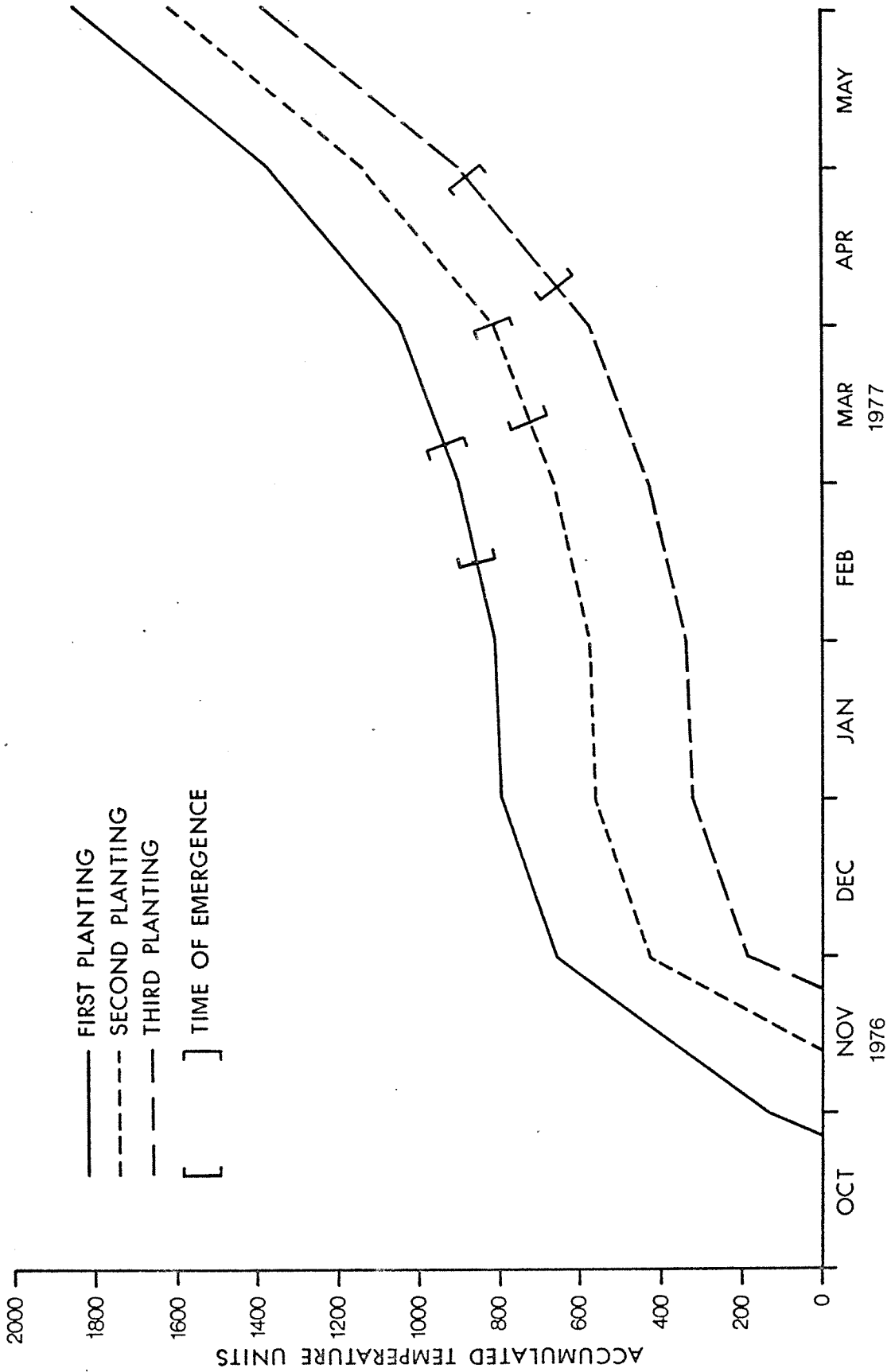


Fig. 6.6 Accumulated temperature units and approximate time of emergence of egg plants in mesh bags made on October 27, November 11, and November 23, 1976.

determined because the fry could not escape from the bags. However, it was possible to estimate the time of emergence because emergence coincided closely with complete absorption of the yolk sac. The individual dates of hatching and emergence and the T.U.'s ranged \pm 5 percent about the mean values of Table 6.2. In summary, eggs hatched inside the mesh bags approximately 5 months postspawning after 790 T.U.'s, and emerged (yolk absorbed) 6 months postspawning after 1,200 T.U.'s.

6.3.4 Emergence of Naturally-Spawned Kokanee Fry

Although 40 emergence traps were installed in the lake, about half became inoperable for varying periods of time due to burial by gravel slides. The principal cause of gravel slide was lake level drawdown, which lowered the zone of wave action to the level of unstable gravel slopes above the traps. Large amounts of gravel thus excavated by wave action were deposited at lower elevation on the talus slope. Because of the steep gradient, the added material rolled and slid downward eventually burying to some degree all of the traps below. The traps were undamaged by burial but became inoperable when buried to the top of the cone; a height of about 60 cm. The number of operable traps during the emergence period varied from 18 to 23.

Emergent fry in the naturally spawned area were captured during the period from March 29 to May 31 (Fig. 6.7). Peak emergence occurred midway in this period near the end of April. In all, 239 kokanee fry were captured. A total of five fry were caught in traps over the Vibert boxes. This small number resulted from high mortality due to inadequate burial of the boxes and resultant exposure of the eggs.

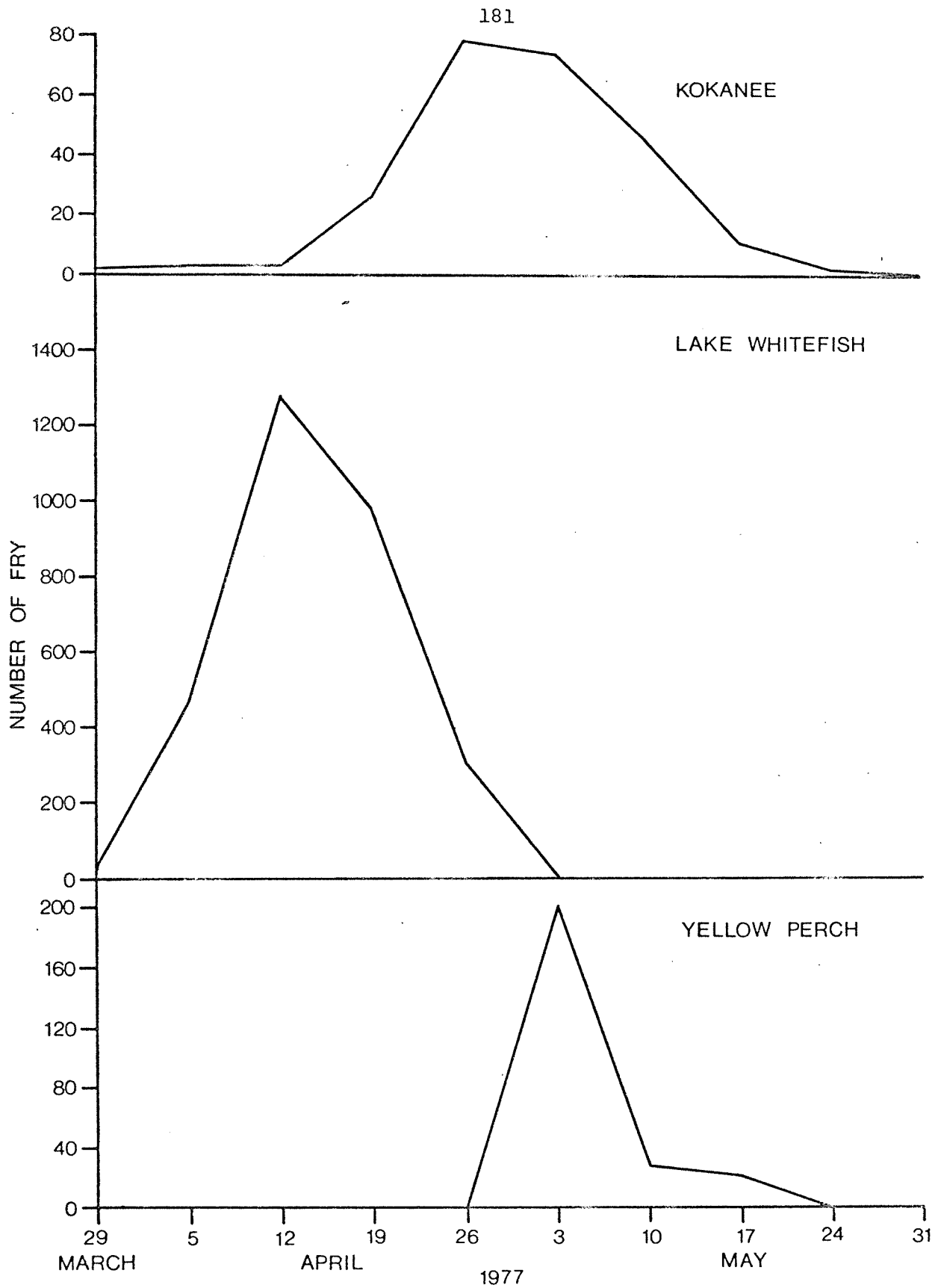


Fig. 6.7 Weekly catch of emergent wild kokanee, lake whitefish and yellow perch fry in traps.

The survival rate of eggs spawned naturally in the primary area was estimated roughly by comparing the theoretical deposition of eggs based on number of spawners with the estimated total fry emergence based on fry catches. The accuracy of the survival estimates is very tenuous because it depends on several estimates for which precise data are not available.

The area of primary spawning was measured as a means of estimating the density of deposited eggs for comparison with the density of emergent fry trapped. Factors complicating this measurement were: 1) The spawning kokanee shied when approached by divers or by the viewing pram and retreated from the spawning site; 2) individual redds were poorly defined due to the instability of the banks and rapid filling of depressions by sliding gravel; 3) the specific gravel size or range of sizes selected for by kokanee was not well-defined because of 1 and 2 above.

The limits of the primary spawning area were defined by judgment of surveyors as that area most commonly frequented by kokanee at first sighting, and as that area encompassing recognizable gravel-cleaning and redd-building activities. Repeated observations of the primary spawning site eventually provided an insight on the limits of area utilized. Measurements of these areas totaled 165 m².

The emergence from 15 traps covering a total area of 3.75 m² was sampled consistently throughout the spring. Because these traps were placed randomly within the limits of the measured area, the catches were representative of fry emergence for the entire measured area. The fry catches of the 15 traps totaled 239, which was extrapolated to 10,516 fry for the surveyed area.

The efficiency of the trap was unknown, but undoubtedly was less than 100 percent. The only available information on trap efficiency with kokanee fry is from laboratory experiments by Collins (op cit) in which screened, pyramid-shaped traps with a slope of 56 degrees were 69.9 percent efficient. Applying this value to the Banks Lake data increased the estimated fry emergence to 15,044.

The estimate of total spawners was best approximated from the abundance peak on November 11, at which time 73 live and 23 dead were observed. No information was obtained on redd life of spawners, or of the extent to which spent spawners left the area and thus were not included in the peak count. In the opinion of the surveyors, however, the peak spawner count closely approached the actual spawner count. For the purpose of estimating egg deposition, the peak spawner count was arbitrarily increased by 10 percent, from 96 to 102.6, to compensate for possible straying after spawning.

The average fecundity of Banks Lake kokanee had previously been determined to be 1,222 eggs per female (Third Annual Progress Report). Incomplete spawning was not considered to be an important source of error in the calculation of egg deposition because 10 dead, spent kokanee examined during November 1976 had spawned completely. Thus, the theoretical egg deposition of 102.6 spawners (51.3 females) was 62,688. Undoubtedly, eggs were lost during spawning to predators, namely the abundant spiny sculpin (Moyle 1977). Because this loss was not measured, an arbitrary value of 10 percent was assumed. This value is far less than an average predation loss, but was chosen because of the light density of spawning which reduced the chance for superimposition of redds. The

estimated egg deposition therefore was 56,419. The estimated survival rate from deposition to emergence based on trap catches of the naturally spawned eggs was 18.6 percent. Kokanee fry production was extremely low in the spring of 1977.

6.3.5 Emergence of Lake Whitefish Fry

A total of 2,968 whitefish fry was trapped incidentally in the prime kokanee spawning area between March 29 and May 2 (Fig. 6.7). Peak emergence occurred near April 12 when 1,244 fry were caught in 19 operable traps. The earlier emergence timing of lake whitefish may reduce the vulnerability of this species to annual spring irrigation drawdown as compared to kokanee.

6.3.6 Emergence of Yellow Perch Fry

Yellow perch occurred in the traps from April 26 to May 24. The peak of emergence was reached on May 3 (Fig. 6.7) when 200 were trapped.

6.3.7 Dissolved Oxygen

Measurements of dissolved oxygen were taken inside and outside of traps which were partially buried or not buried, and of traps which were ventilated or not ventilated. Dissolved oxygen was also measured inside standpipes inserted into gravel within the traps and outside the traps.

The highest dissolved oxygen concentrations were recorded outside the traps (ambient). Values ranged from 9.0 to 10.8 ppm. Slightly reduced concentrations (8.0 to 8.4 ppm) were recorded inside the traps which were unburied. Still lower concentrations were recorded inside the traps which were more than half buried by gravel slides. No differences in dissolved oxygen concentrations were observed between ventilated

and unventilated traps. Likewise, no differences were observed inside and outside the standpipes utilized for sampling.

The traps caused a slight reduction in dissolved oxygen level by blocking the circulation of water. This became more pronounced as the traps were buried. The blockage was not alleviated by the presence of screening near the bottom edge of the trap cone. Apparently, the circulation of water into the surface gravel was good, because no decrease in dissolved oxygen was observed inside the standpipes.

6.3.8 Predator Screening

The effects of predator screens were determined by comparing the catch of the screened versus unscreened traps. No difference was observed in the catch rate of kokanee and lake whitefish fry; therefore, the screens had no observed effect on trapping efficiency for these species.

The screens effectively prevented entry into the traps by sculpins > 55 mm, which eliminated most, but not all, predation of trapped fry and lake whitefish (Fig. 6.8). The stomachs of 144 trapped sculpins of all sizes contained 15 kokanee fry and 305 lake whitefish fry (Table 6.3). Sculpins > 55 mm accounted for 86.6 percent of ingested kokanee fry and 81.6 percent of ingested lake whitefish fry.

6.3.9 Effect of Drawdown on Spawning and Incubation

The lake level fluctuation during spawning and incubation in 1976 was moderate relative to past years (Fig. 4.2). During spawning, the water level was at or near full pool (elevation 1,570 ft). Eggs were deposited from 3 to 8 m subsurface (elevation 1,560 to 1,543 ft) and were most concentrated 5 m subsurface (elevation 1,553 ft). Spring

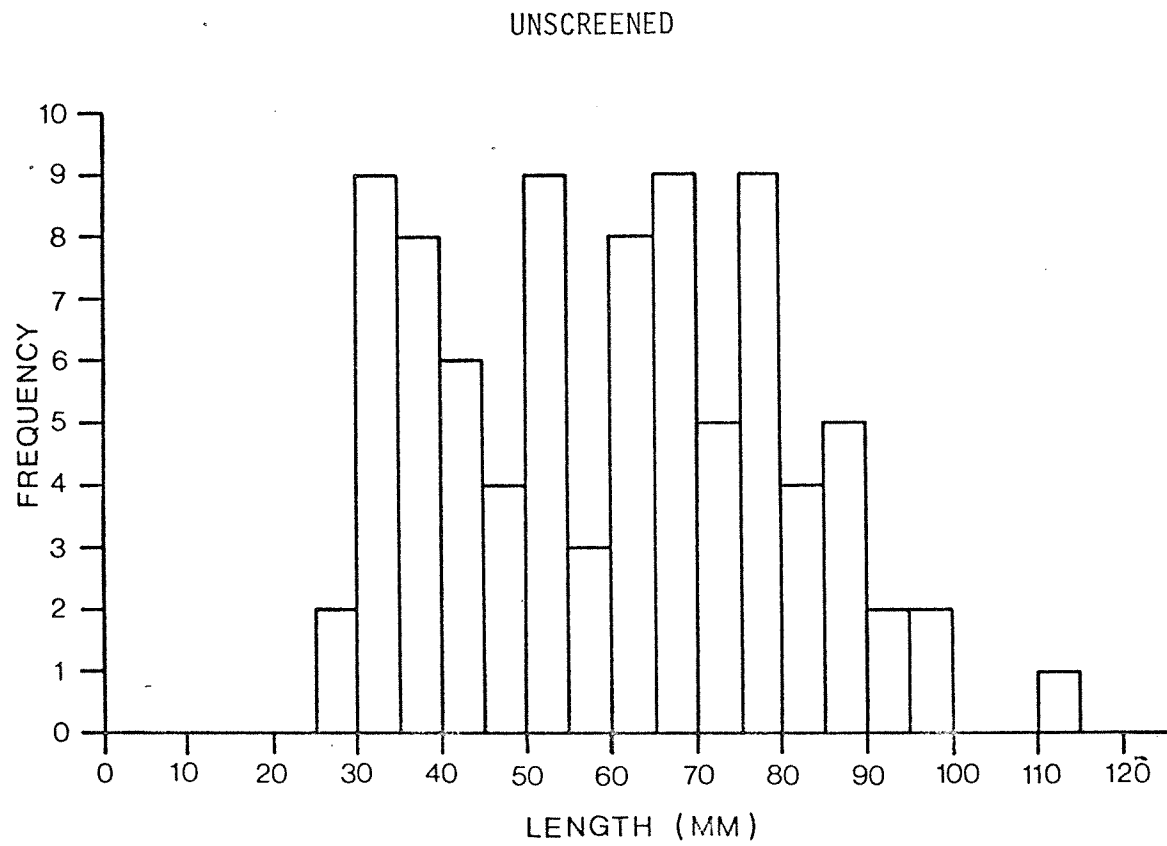
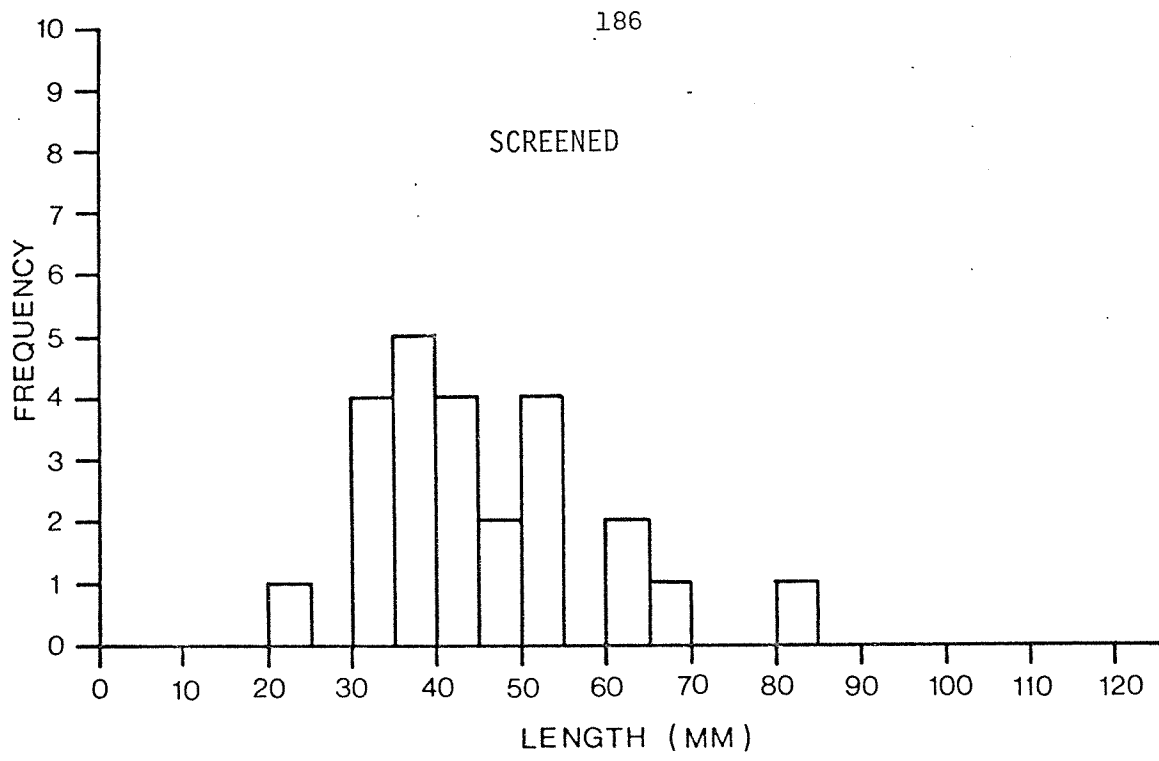


Fig. 6.8 Length frequency distribution of sculpins caught in screened (top) and unscreened (bottom) fry traps from April 19 through May 31, 1977.

Table 6.3 Occurrence of kokanee and whitefish fry in sculpin stomachs.

Date	Sculpin Size(mm)	No.	# of Kok.	# of Wh.Fish	\bar{x} Number per Sculpin		% Frequency of Occurrence	
					Kok.	Wh.Fish	Kok.	Wh.Fish
4/5	≤55	12	0	11	0	.91	0	13.0
	>55	30	0	73	0	2.4	0	87.0
4/12	≤55	5	0	30	0	6.0	0	16.2
	>55	13	0	156	0	12.0	0	83.8
4/19	≤55	4	0	10	0	2.5	0	66.6*
	>55	2	2	5	1	2.5	100	33.3
4/26	≤55	4	0	5	0	1.2	0	25.0
	>55	11	0	15	0	1.3	0	75.0
5/3	≤55	7	0	0	0	0	0	0
	>55	7	3	0	.42	0	100	0
5/10	≤55	3	1	0	.33	.66	12.5	0
	>55	8	7	6	.87	0	87.5	100
5/17	≤55	3	1	0	.33	0	50	0
	>55	10	1	0	.10	0	50	0
5/24	≤55	3	0	0	0	0	0	0
	>55	13	0	0	0	0	0	0
5/31	≤55	2	0	0	0	0	0	0
	>55	7	0	0	0	0	0	0
Total	≤55	43	2	56	.04	1.3	13.4	18.4
	>55	101	13	249	.12	2.4	86.6	81.6

drawdown began mid-March and continued beyond the incubation period (Fig. 6.9). The maximum drawdown of 3.1 m (elevation 1,560 ft) was reached in late April and coincided with peak emergence.

Because the maximum drawdown did not reach the upper level of spawning, little, if any, incubation habitat was exposed to dessication. However, because extensive amounts of shoreline materials were excavated and deposited at greater depth by wave action, most of the primary spawning area was covered by a layer of gravel. The depth of this layer varied from 0 to an estimated 2.2 m and at the elevation of maximum egg deposition (1,553 ft), averaged about 30 cm deep. Unfortunately, this occurrence was not foreseen and no method was available to assess the extent to which eggs and alevins were smothered or trapped.

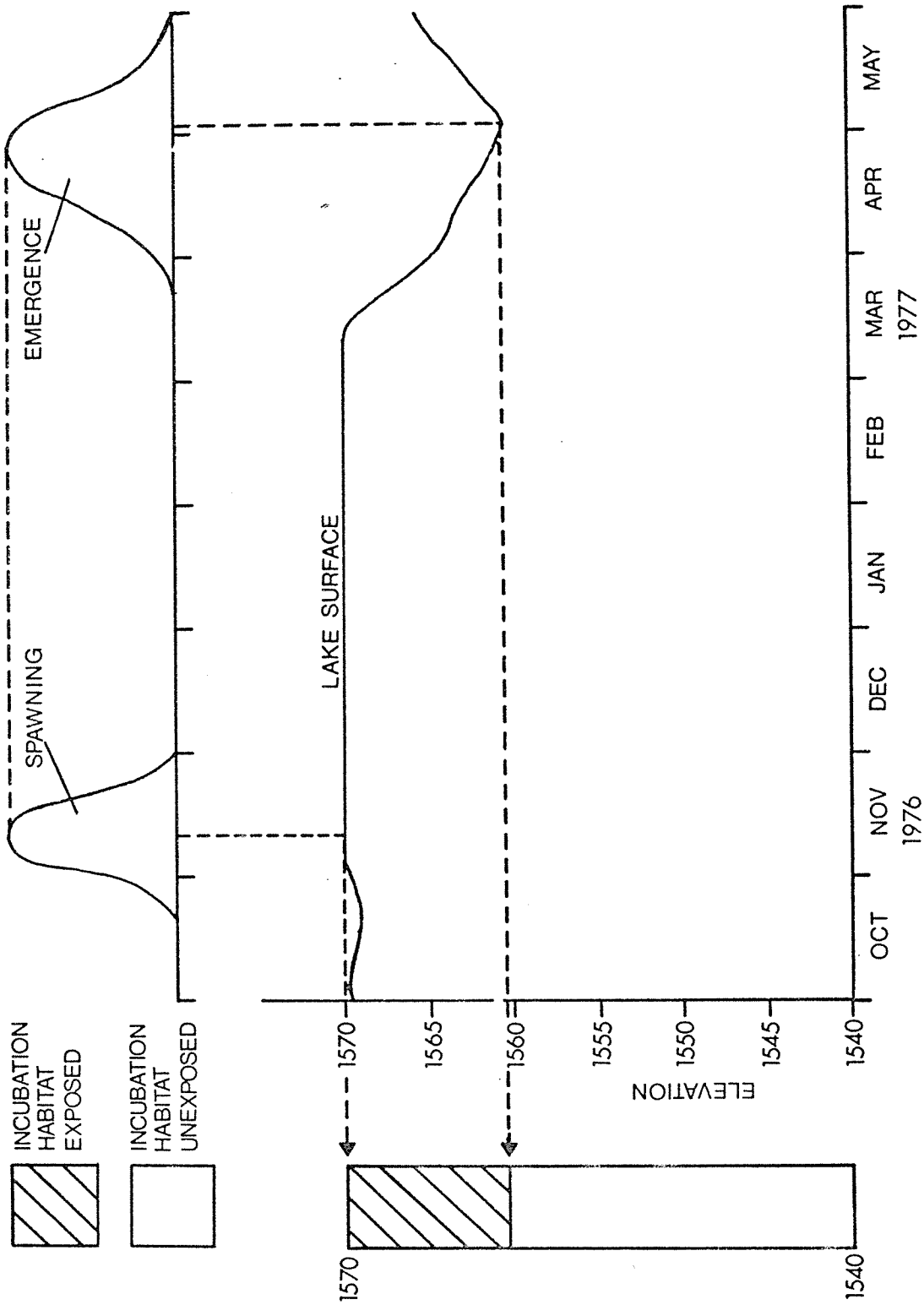


Fig. 6.9 Kokanee spawning, incubation and emergence timing in relation to Banks Lake water surface elevation in 1976-77 indicating the amount of incubation habitat exposed.

7.0 SPORT FISHERY 1975-76

7.1 Length-Weight Analysis of Fishes in the Creel, 1975-76

Length and weight measurements were taken from a portion of the angler creel during a census conducted from April 1, 1975 to March 31, 1976. These measurements were not reported in the Third Annual Report. Samples of the most abundant sport species, i.e., yellow perch, kokanee, rainbow, and chinook, were sufficiently large to characterize their length-frequency distributions.

7.1.1 Yellow Perch

Length measurements of yellow perch were taken during the period January through June (Fig. 7.1). These measurements indicated a changing length mode which started with a low in January of 175 mm, which increased steadily to a high in April, May and June. The size increase in the creel during April, May, and June was attributed to the shoreward movement of yellow perch for spawning, which increased the availability of larger individuals to the predominantly shore-based perch fishery.

7.1.2 Kokanee

Length measurements from the angler creel were taken during April through August 1975. A comparison of the monthly length frequencies (Fig. 7.2) showed that recruitment of juveniles into the sport fishery began at about 200 mm in length. These were age II fish which were the progeny of the 1973 spawning. As the recruitment of age II fish increased in May, the mean length of the creel decreased. This trend was reversed

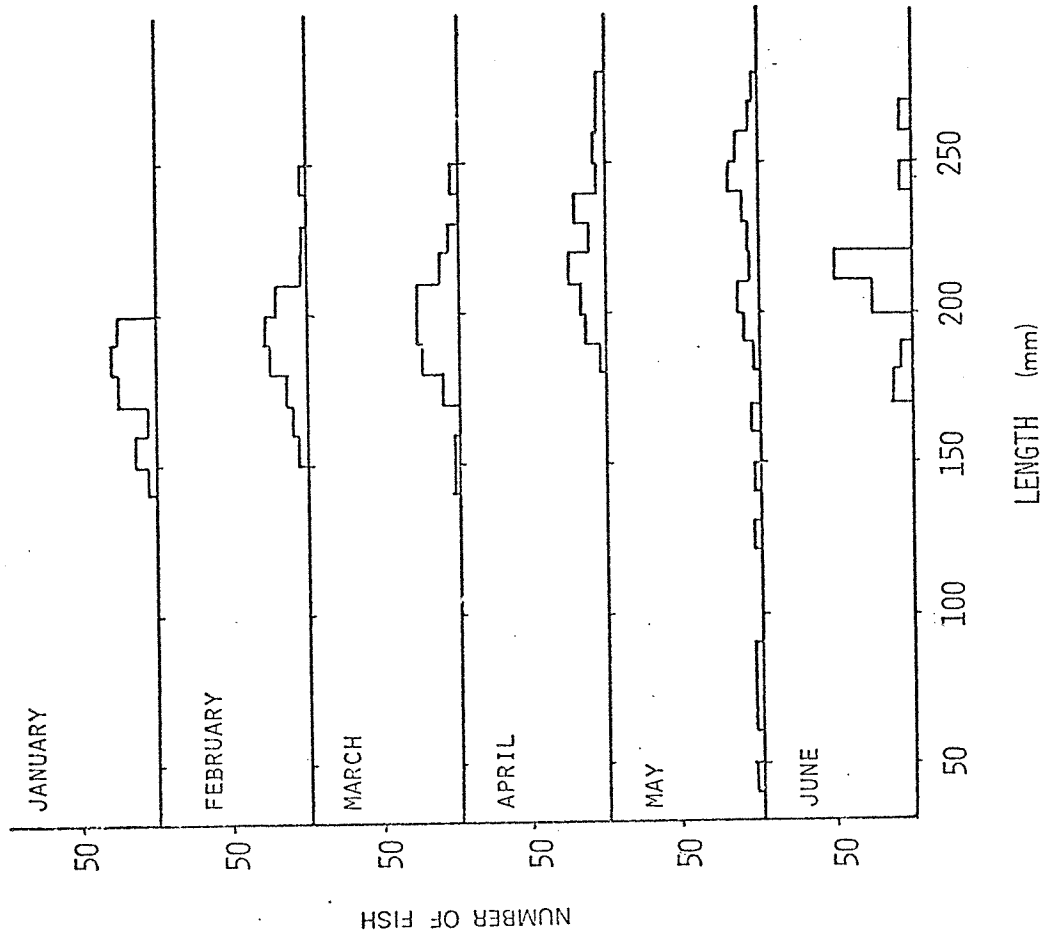


FIG. 7.1 Monthly variation in the length frequency of yellow perch in the creel, 1975-76.

in following months as the age II fish were fully recruited and growth and sexual maturation of the age III and age IV fish became dominant factors.

The relationship between length and weight of kokanee from the angler creel is shown in Fig. 7.3.

7.1.3 Chinook Salmon

Chinooks which were released in Banks Lake during August 1974 entered the creel during 1975. The length frequency of 122 chinooks sampled from the fishery in 1975 and of two chinooks sampled in 1976 is shown in Figure 7.4. The mean length of the 1975 catch was 295.6 mm. The two chinooks sampled in 1976 averaged nearly 100 mm larger.

The relationship between length and weight of chinooks from the angler creel is shown in Figure 7.5.

7.1.4 Rainbow Trout

The size distribution of rainbow trout in the angler creel is comprised of several modes which represent various hatchery plantings of even-sized juveniles. The plants most recently recruited into the creel are represented by the most distinct modes (Fig. 7.6).

Length measurements of rainbow from the angler creel were taken during the period January through May. The length frequencies are summarized into two time periods: April and May 1975; and January, February, and March 1976 (Fig. 7.6). The planting dates of rainbow comprising several of the frequency modes can be identified positively because some of the fish were marked by clipped adipose fins and tagged with magnetic wire nose tags. The rainbows which were planted during

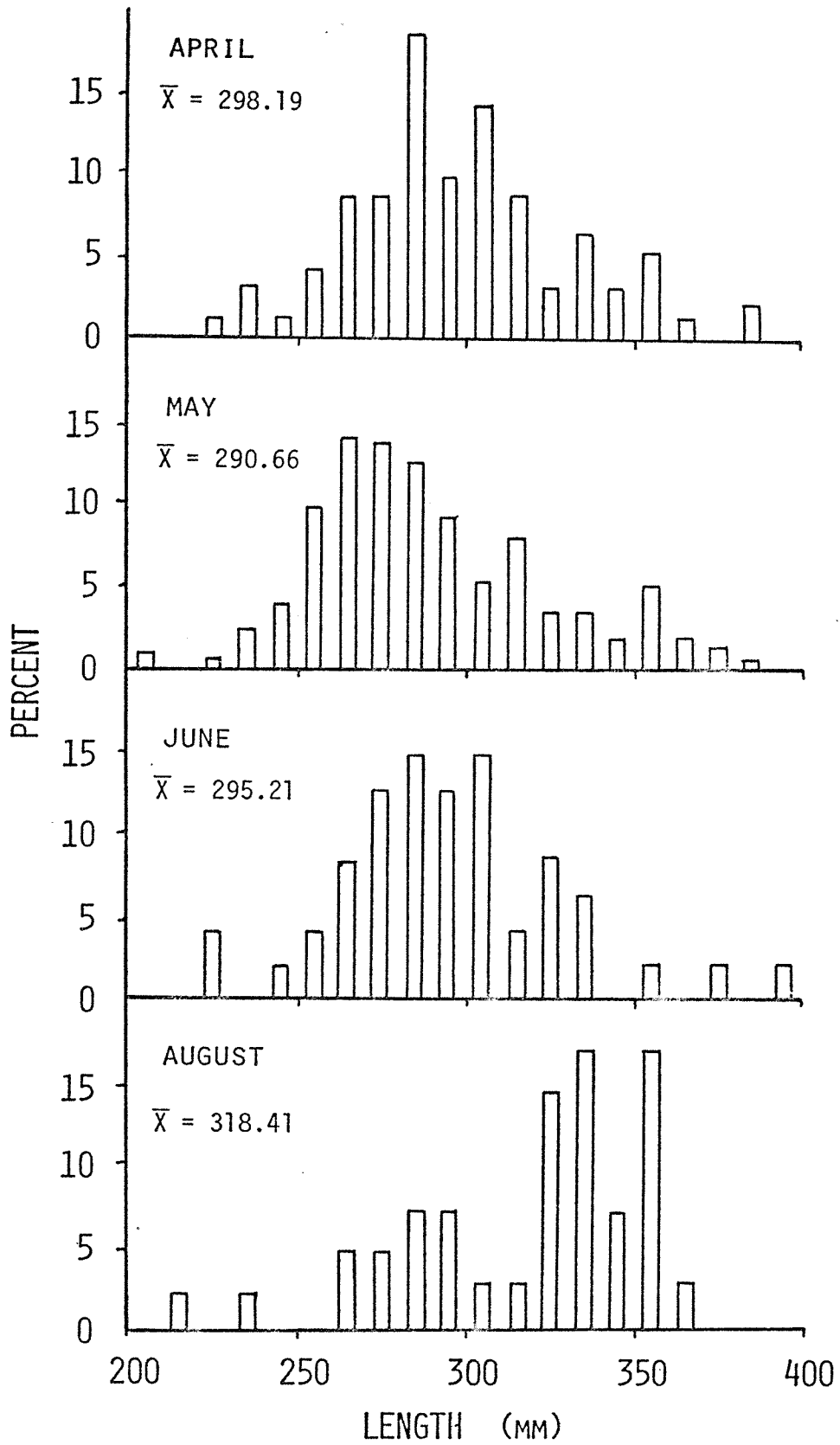


Fig. 7.2 Monthly variation in the length frequency of kokanee in the creel, 1975-76.

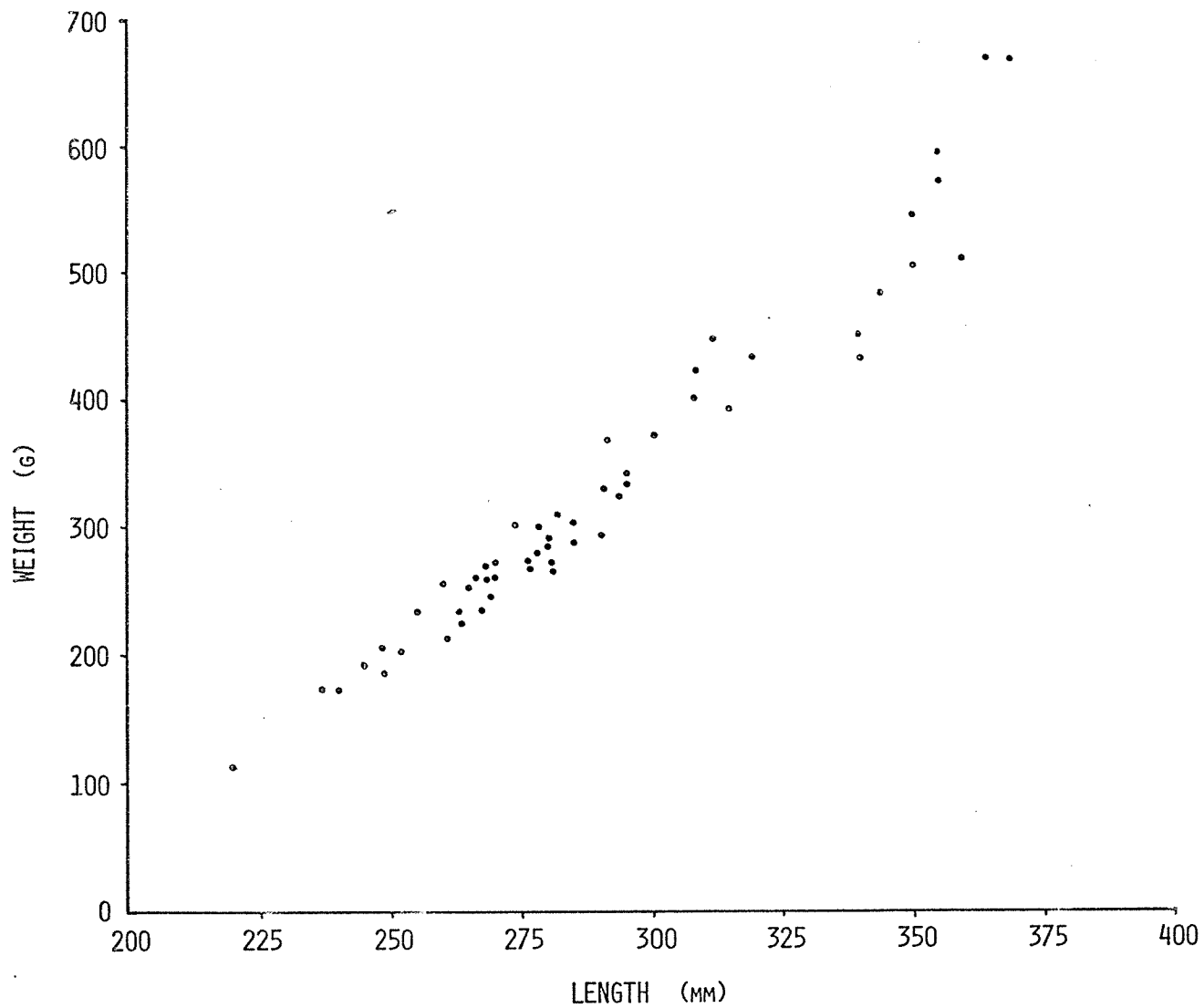


Fig. 7.3 Length-weight relationship of kokanee in the creel, 1975-76.

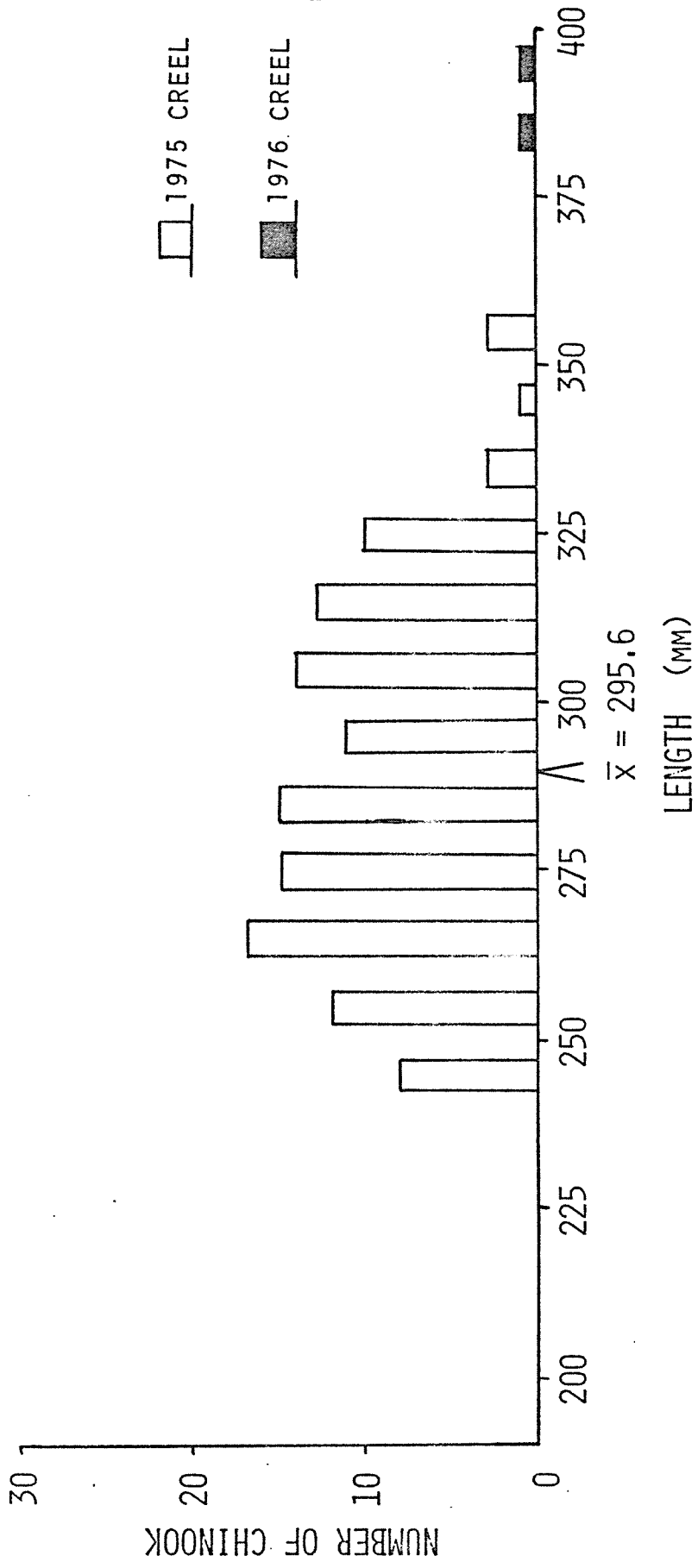


Fig. 7.4 Length frequency of chinook salmon in the creel, 1975-76.

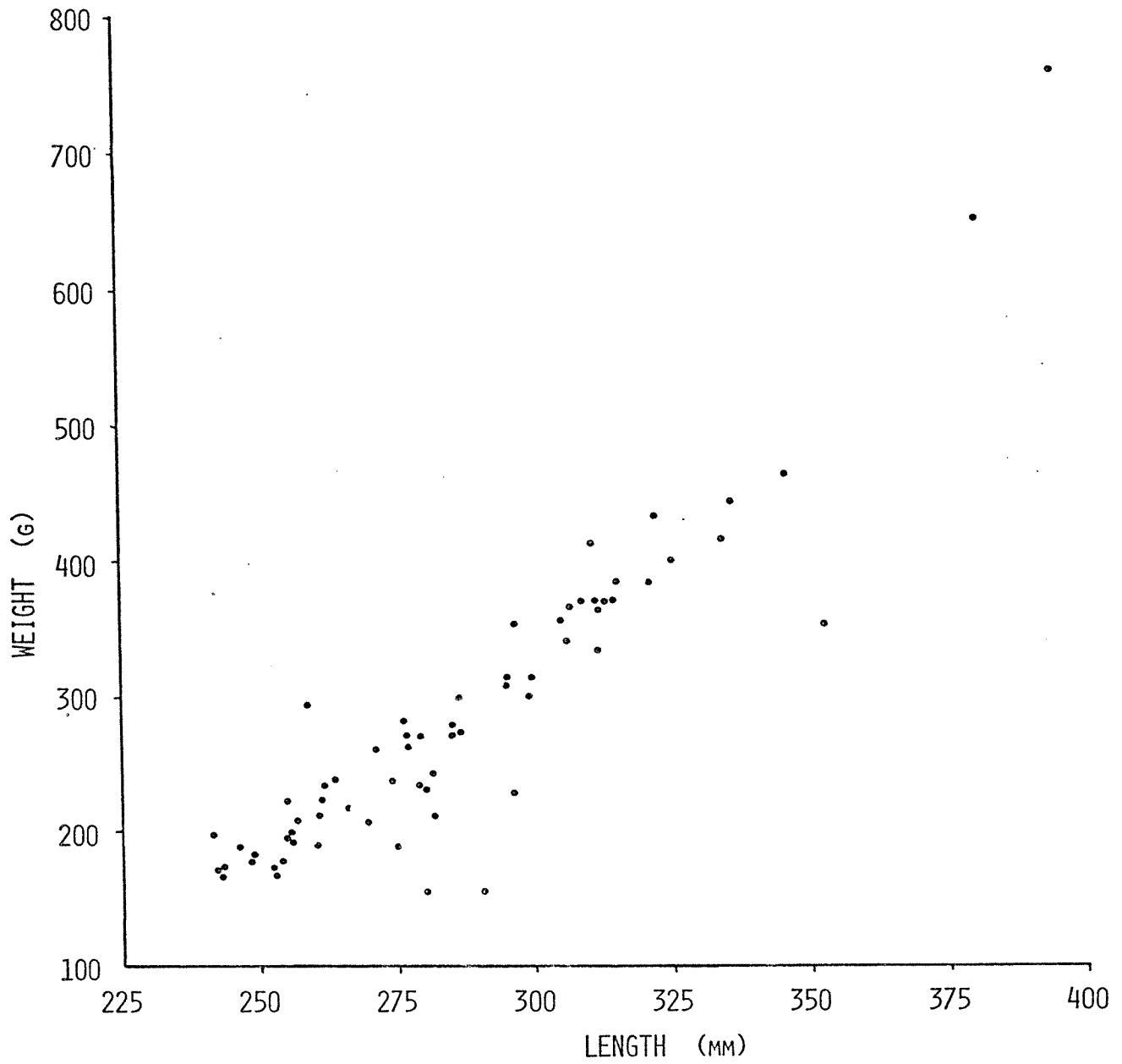


Fig. 7.5 Length-weight relationship of chinook in the creel, 1975-76.

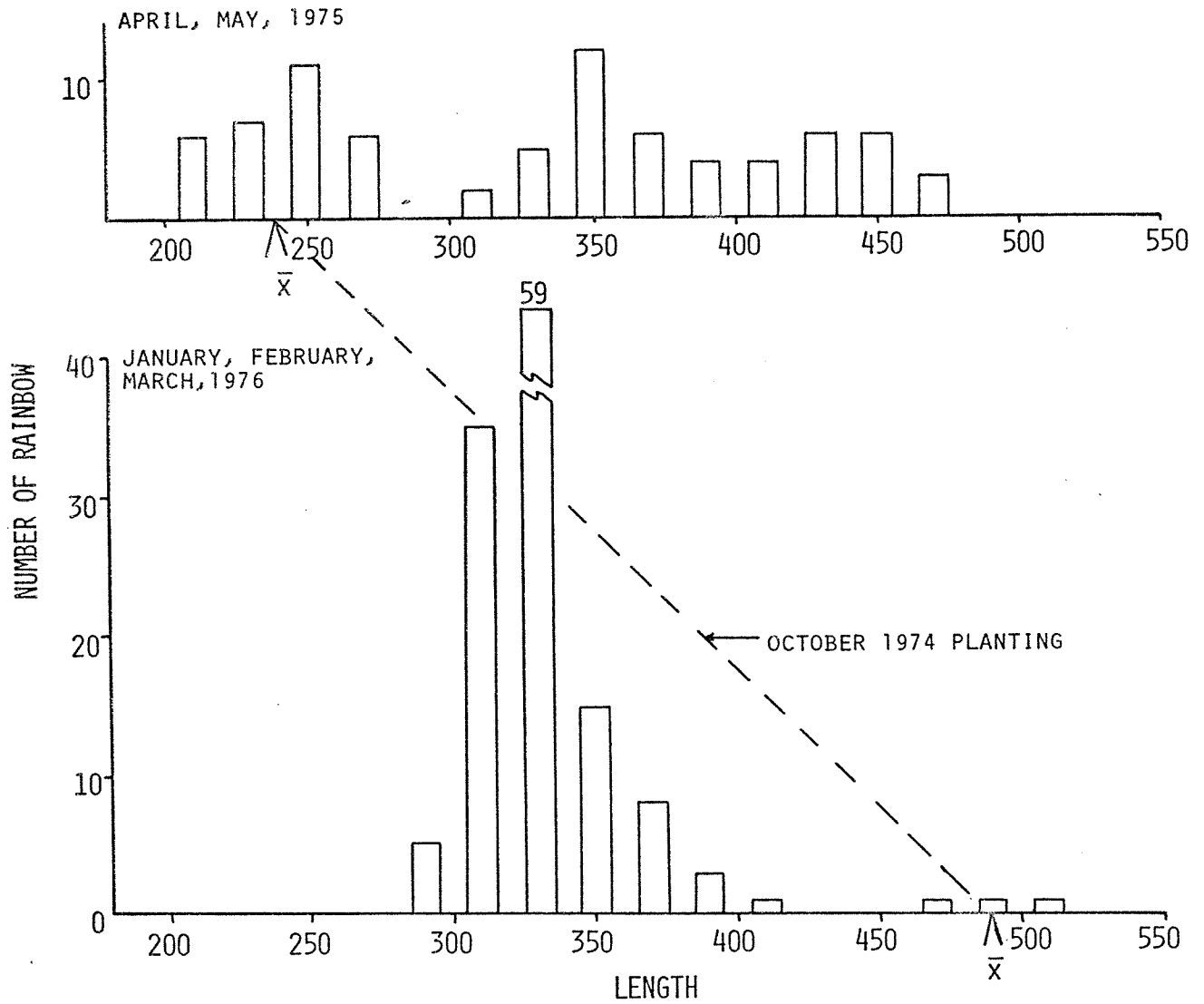


Fig. 7.6 Length frequency of rainbow in the creel, 1975-76.

fall 1974 first entered the creel during spring 1975. Their length during this 4-month period increased from 150 mm to 239 mm, or an increase of 89 mm. Rainbows from this plant also appeared in the spring 1976 creel, at which time they were approximately 490 mm long. The growth increment during this 10.5-month period averaged 251 mm. Total growth during the entire 14.5-month period averaged 340 mm, which is a monthly increment of 23.4 mm.

The relationship between length and weight of rainbows from the creel is shown in Figure 7.7.

7.2 Economic Reevaluation of the 1975-76 Fishery

An economic evaluation of the Banks Lake fishery was made in 1971-72 in which the annual value based on direct expenditure by anglers was estimated at \$1.6 million (Duff 1972). This estimate was calculated from a prediction formula derived from a 1969 state-wide survey of fishing costs (Washington Department of Game Economic Evaluation 1969). The formula predicted a 1976 cost of \$24.00 per angler-day. In the 1975-76 creel census conducted by the Fisheries Research Institute, the total angler use of Banks Lake was estimated at 350,866 hr, and the duration of an average fishing day was 4.5 hr. These data equate to 77,970 angler-days which entailed an estimated annual expenditure of \$1.8 million. However, the extensive use of Banks Lake during the summer by camper-trailer-boat equipped fishermen from distant population centers probably results in an average daily expenditure much above that for an average trout fishing lake in the State of Washington. Therefore, \$24.00 per angler day is very likely an underestimate. A more recent economic evaluation of fish and wildlife oriented recreation in general

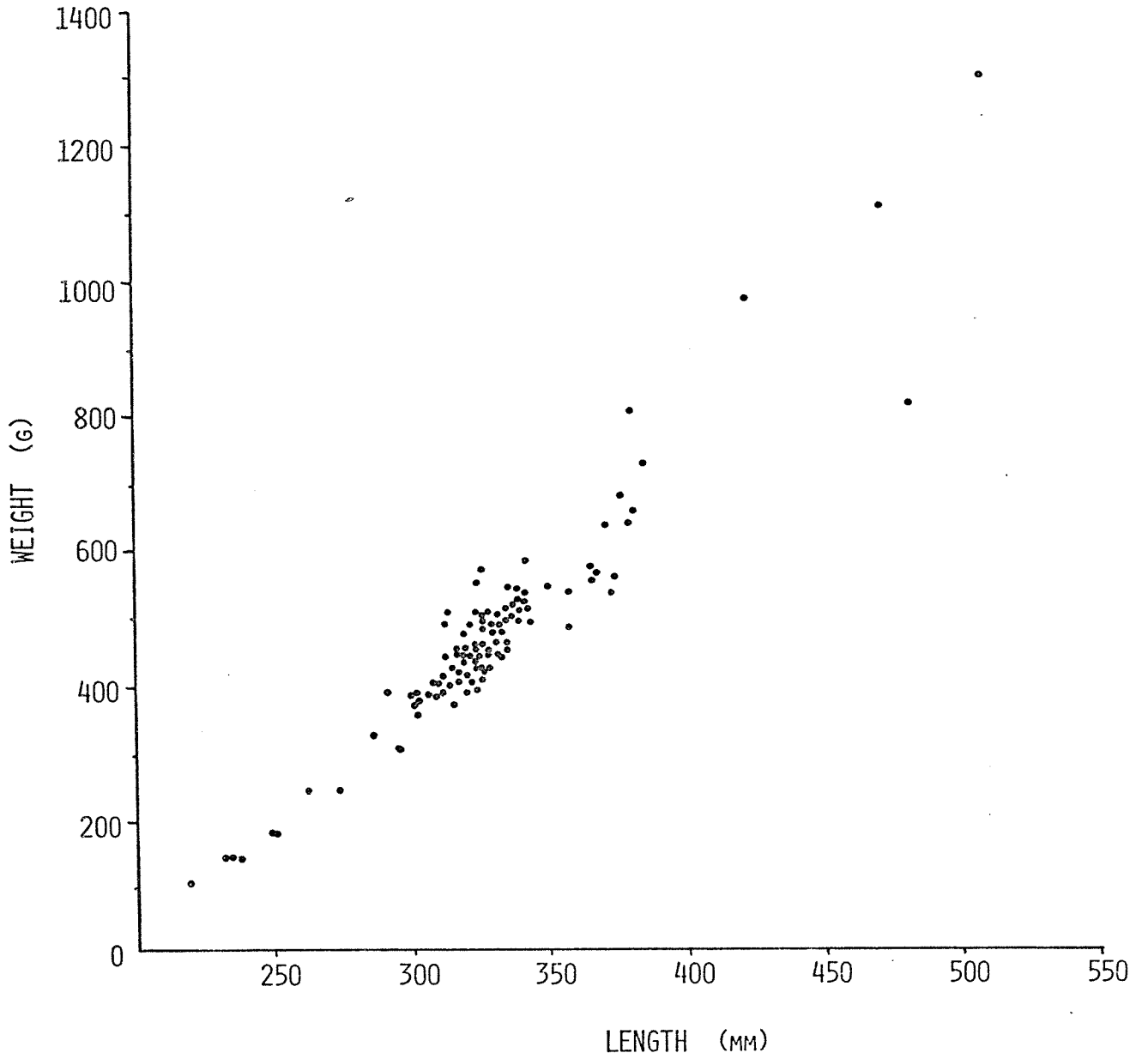


Fig. 7.7 Length-weight relationship of rainbow trout in the creel, 1975-76.

was undertaken in 1973 by the Environmental Research Group of Georgia State in which inland cold water fishing was evaluated on the basis of actual expenditures by anglers. An angler day in 1976 dollars was valued at \$40.83. When applied to the Banks Lake fishery, this value yielded an estimated annual expenditure of \$3.2 million. Irregardless of the economic criteria applied, the Banks Lake sport fishery is increasingly important to the residents of the State.

8.0 FISH ENTRAINMENT (IRRIGATION CANAL)

8.1 Introduction

Determination of fish entrainment into and out of Banks Lake was essential for the evaluation of the effects of pumping, pump/generation, and irrigation flows on the fish populations of the lake. The specific objectives of this portion of the study were to estimate the fish entrainment loss from Banks Lake by species, numbers, and biomass; and to assess the effects of this entrainment on the fish populations of the lake.

An appreciable amount of literature has been published regarding the entrainment of the "nonscreenable" biota (zooplankton and phytoplankton, larval fish and eggs) in aquatic systems. Most of this work concerns the evaluation of entrainment through the condenser cooling systems of thermal power plants.

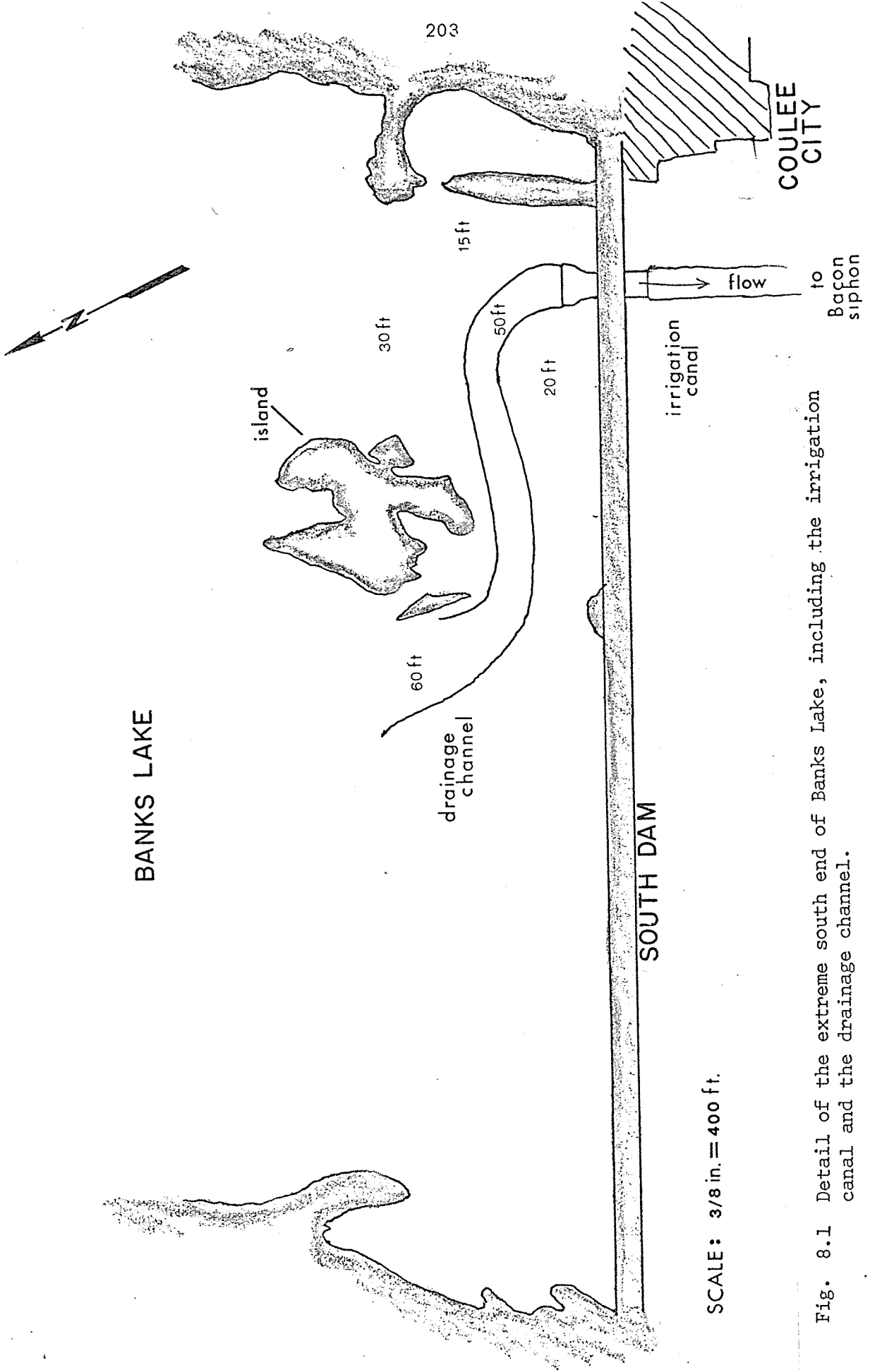
Studies of this sort are exemplified by the Proceedings of the Second Workshop on Entrainment and Intake Screening (1974) and the recent three volume series by Sharma, Freeman, and Stupka (1977). Another segment of the literature concerns the entrainment of fishes through the turbines of hydroelectric facilities. Bell et al. (1967) provide a rather extensive literature review on the subject and also discuss some of the fish sampling gear which has been used in entrainment studies. However, attempts in the literature to quantify the entrainment of a broad size range of fishes and numerous species in reservoir or pump storage systems have been notably sparse, no doubt due to the difficult sampling problems which must be overcome in each case.

Walburg (1971) has shown that many age 0 fish of several species are lost yearly from Lewis and Clark Reservoir on the Missouri River. Robbins and Mathur (1976) studied the effects of pump/generation entrainment of fishes on the ecology of Conowingo Pond and Muddy Run Pumped Storage Pond. Because of sampling problems, they were unable to assess either magnitude of fish entrainment or percentage mortality of those fish which passed through the pump turbines. Simmons (1971) also reported on assessment of the effects of pump/storage on the fishes of Leesville Reservoir. The study concluded that very few live fish were entrained from the upper impoundment (Smith Mountain Reservoir) into Leesville Reservoir.

8.2 Irrigation Canal

The irrigation canal (main canal) headworks are located in the South Dam, a short distance from Coulee City (Fig. 8.1). The canal was cut through basalt rock and extends south for 2.1 miles where it leads into Bacon Siphon. During the 7-month long irrigation season which began in March and ended in October for both years, the irrigation canal received a variable flow of Banks Lake water which reached a maximum rate of 7,900 cfs during July (Fig. 8.2). This water was used to irrigate approximately 500,000 acres of Columbia Basin farmland.

The headworks of the irrigation canal is constructed of concrete. A concrete apron extends 108 feet downstream into the canal where it abruptly ends. Six outlet tunnels, each 12 ft wide by 21 ft high, empty into the canal. Flow of water through each tunnel was regulated by a large radial gate. At maximum lake elevation, 1,570 ft, water was



SCALE: 3/8 in. = 400 ft.

Fig. 8.1 Detail of the extreme south end of Banks Lake, including the irrigation canal and the drainage channel.

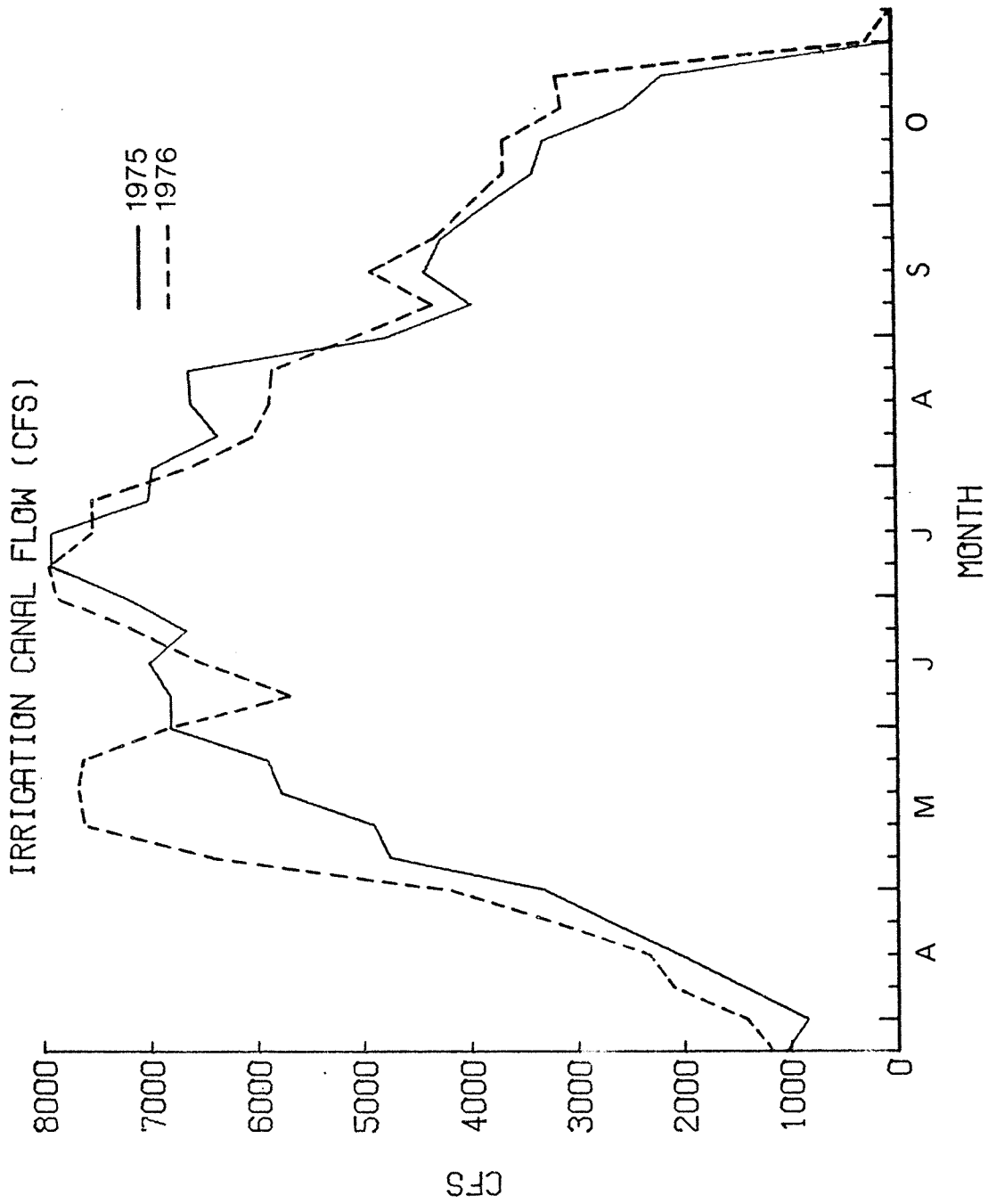


Fig. 8.2 Average weekly rate of discharge (cfs) through the irrigation canal during 1975,-76 (USBR data).

discharged under 30 ft of pressure head directly through the tunnels and into the irrigation canal.

8.3 Materials and Methods

In order to develop a scheme suitable for sampling fish entrainment through the irrigation canal, several problems unique to the canal had to be resolved. First was the determination of sampling sites. The downstream faces of the outlet tunnels appeared to be most suitable. It was determined that a net could be fished from a rigid frame inserted into the stop log slots located on both sides of each tunnel face. A net large enough to span the 12-ft width of an outlet tunnel would increase catch efficiency by minimizing net avoidance by entrained fish.

High current velocities posed a problem at this location. The current velocity was found to vary inversely with flow due to the backup of irrigation water from Bacon Siphon into the outlet tunnels. Higher flows resulted in higher water which backed up into the tunnels and more quickly dissipated the shooting flow through the tunnel outlets. With decreasing flow, the water level dropped and the shooting flow moved downstream. Thus, with the irrigation canal discharge rate below approximately 3,500 cfs, the water level at the tunnel faces was low and the water velocity was estimated at 35-40 fps. This quickly diminished to approximately 5 fps at the end of the concrete apron, 108 ft downstream. At the maximum discharge rate of 7,900 cfs, the water level at the tunnel faces was at the maximum depth of 21 ft and the current velocity along the canal decreased to 4.2 fps.

The problem with excessively high current velocities during the early and late irrigation season was satisfactorily resolved by locating

the initial sampling sites downstream 148 ft in lower velocity water. As irrigation canal discharge increased during the season, the sampling site was moved upstream to the foot of the concrete apron and later to the trash rack slots. Gradually diminishing discharge later in the season was accommodated by locating the sampling gear back downstream to the initial sampling sites.

The design and development of suitable fish sampling nets to meet the rigorous conditions in the canal had several requirements. Nets had to be designed to fish for extended periods of time, with the capability of withstanding the tension and wear associated with relatively high, constantly fluctuating water velocities. The mesh size was selected to catch and retain the broadest possible size range of each sport fish species with the least amount of selectivity.

Several different nets were tested at each of the three canal sampling sites, but gear description will be limited to only those nets which were used effectively during the 1975 and 1976 sampling seasons. On March 23, 1975, a net was placed in the midchannel white-water 148 ft downstream from the tunnel openings. The rectangular steel frame supporting the net was held against the current by 150-ft cable warps (1/4-inch diameter) and was hauled, set, and positioned by means of a 1/4-inch diameter cross-channel suspension cable and net retrieval line (Fig. 8.3). The net and frame were suspended by two blocks from the overhead cable. This sampling site was not used in 1976 in favor of a site farther upstream.

As the irrigation flow increased, water backed up from the Bacon Siphon to the canal headworks structure. This backup caused a decrease

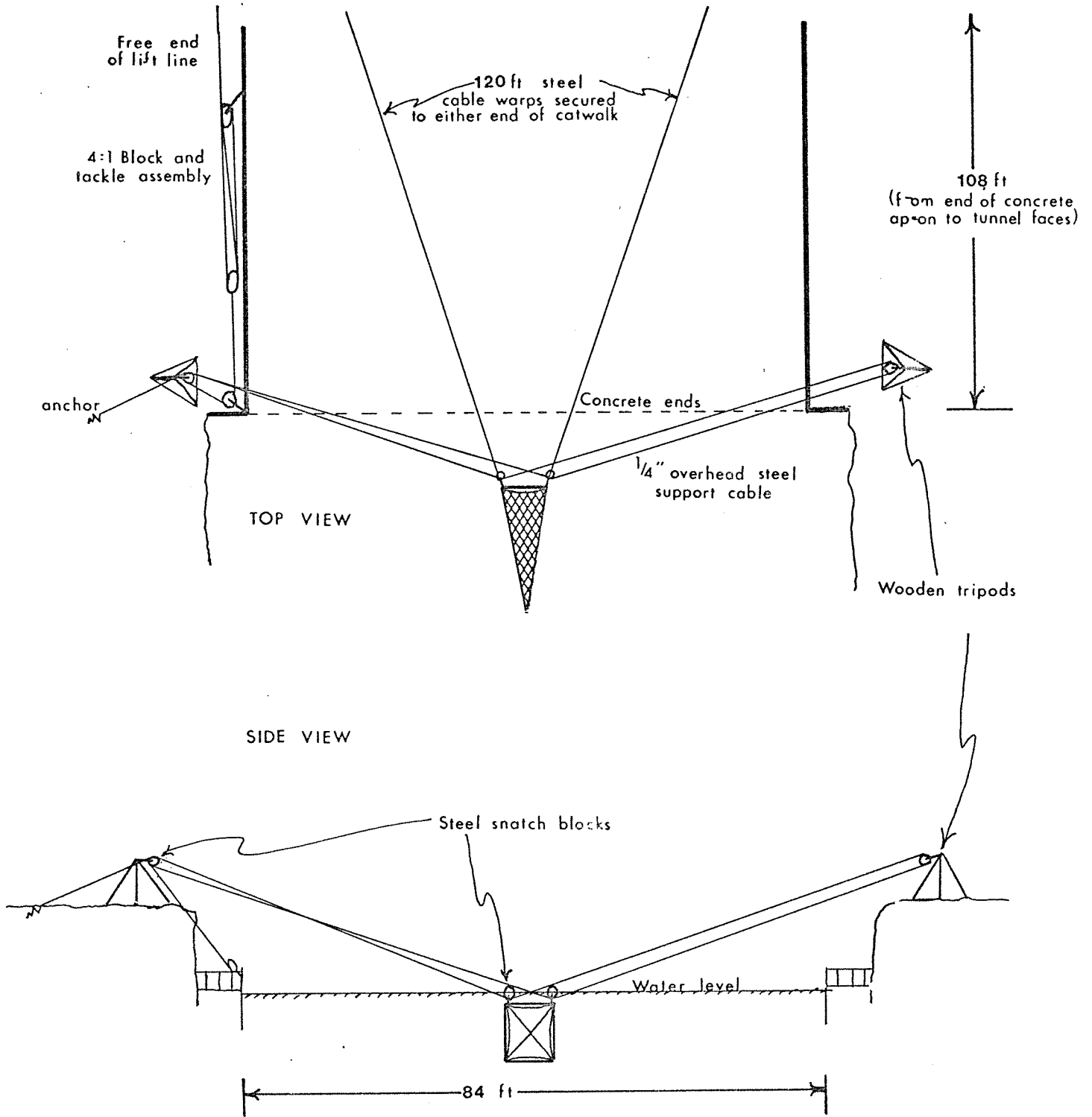


Fig. 8.3 Semi-diagrammatic detail of the downstream sampling and support gear fished from near the end of the concrete apron of the irrigation canal headworks.

in current velocity which necessitated moving the net and support gear upstream on May 8, 1975, to a new sampling site at the end of the concrete apron 108 ft downstream from the tunnel openings. This site was the only downstream site utilized during the 1976 sampling season. The sampling net which was standardized for use at these two downstream locations measured 6 x 8 ft at the opening and tapered back 18 ft to a 6-inch wide zippered cod end (Fig. 8.4). Mesh was constructed of #252 four-stitch knotless nylon and measured 1 inch stretched. The net was suspended at the four corners from a rigid frame measuring 6.5 ft wide x 8.5 ft high.

By May 22, 1975, the current velocity had further decreased to permit a net to be positioned upstream at the tunnel faces of the irrigation canal headworks. The net was suspended from a 14-ft wide x 12-ft high rectangular steel frame designed for insertion into the trash rack slots of each outlet tunnel (Fig. 8.5). The mesh fabric was 1 inch stretched #252 four-stitch knotless nylon. The net and frame were raised and lowered and moved from slot to slot by means of a lift line through two double blocks which were suspended from a 1/2-inch diameter overhead cable (Fig. 8.6). Lifting power was provided by attaching the lift line to a motor vehicle which was driven away slowly.

In 1975, two such nets were in place and fishing simultaneously in separate outlet tunnels by July 22. This configuration provided replicate catches per unit time and allowed assessment of differences in entrainment rates between the six outlet tunnels. This also enhanced statistical analysis of data.

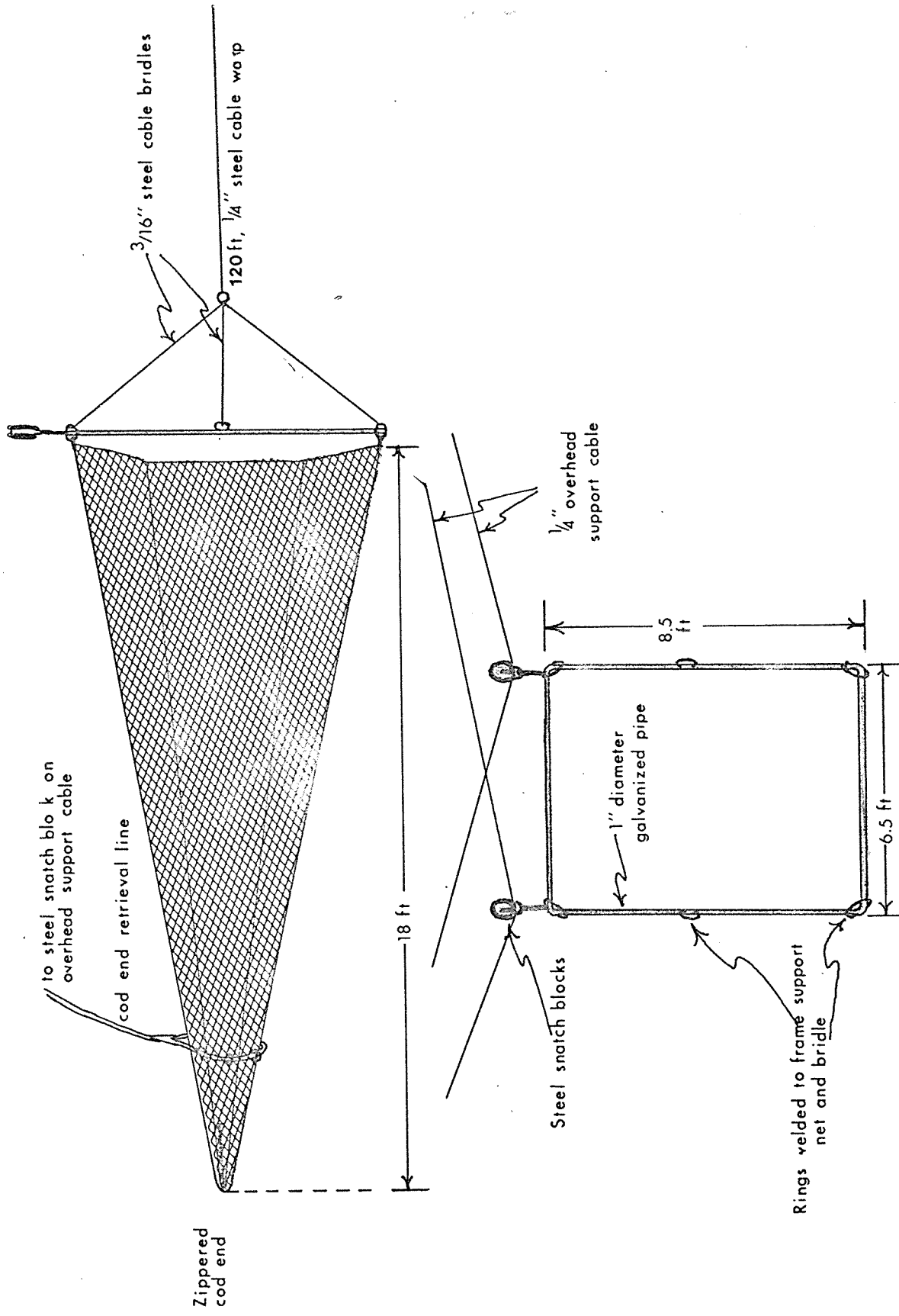


Fig. 8.4 Net and frame which was fished from the downstream sampling site.

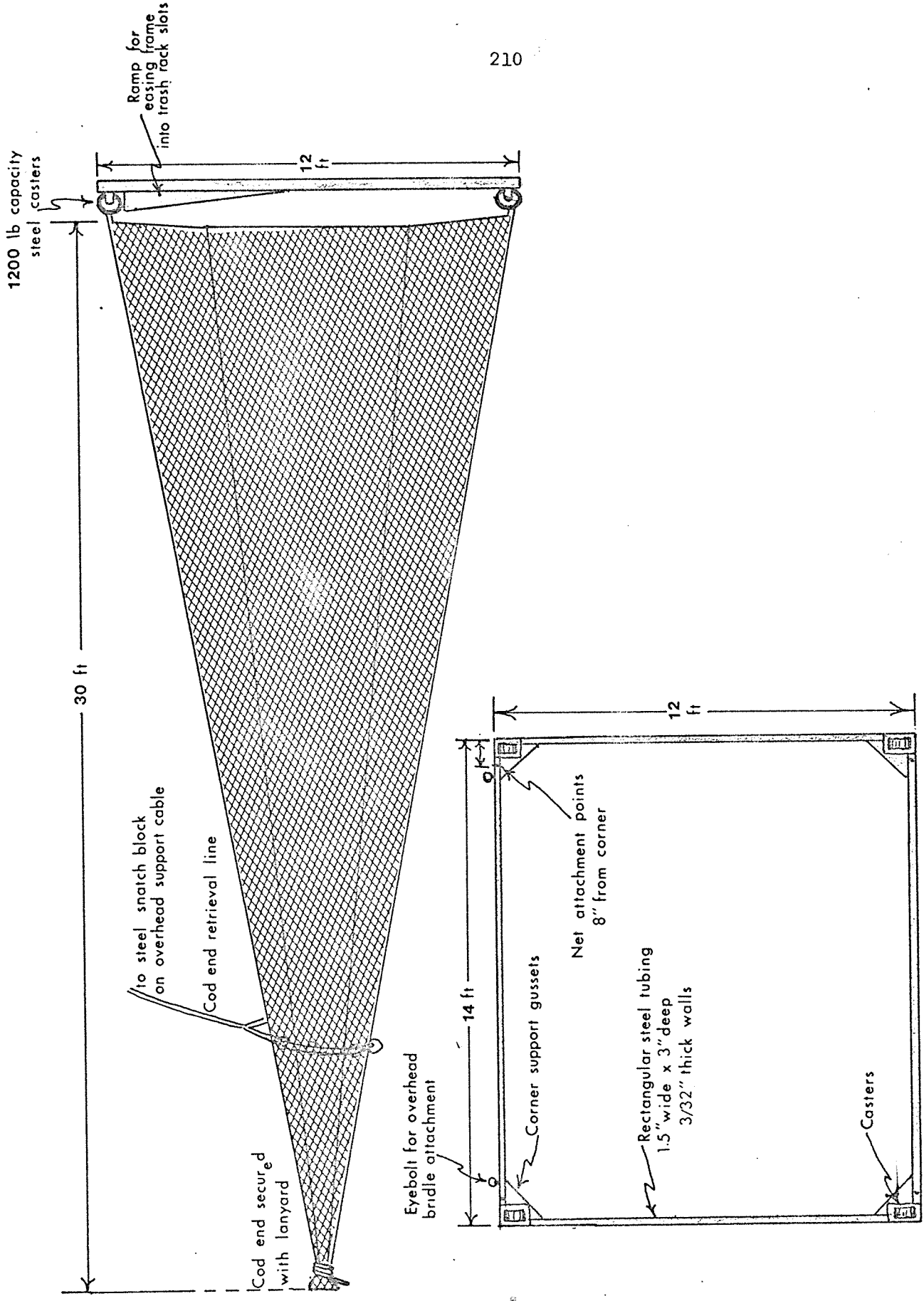


Fig. 8.5 Net and frame which was fished from the upstream sampling site. The frame was inserted into the trash rack slots located on either side of the outlet tunnels.

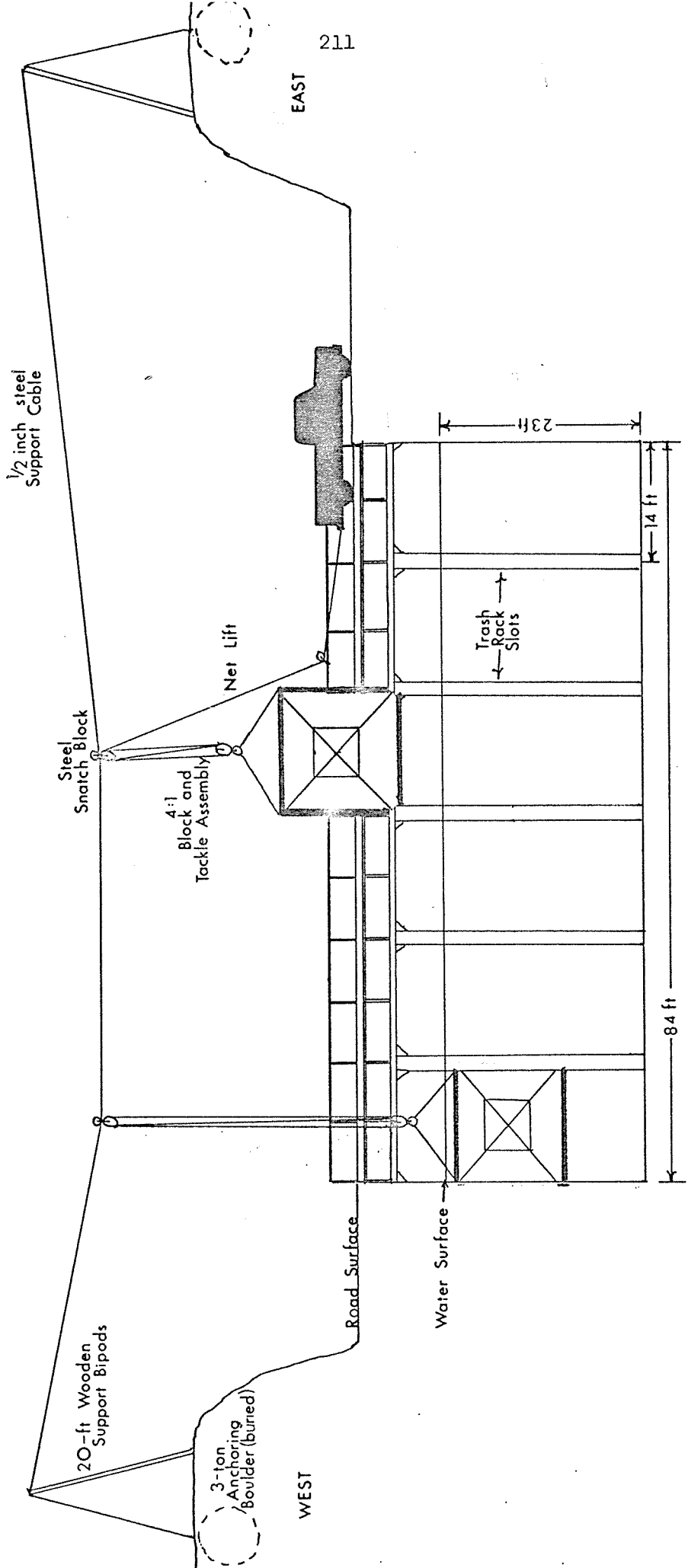


Fig. 8.6 Downstream view of the upstream sampling site showing the tunnel openings and trash rack slots, the overhead support gear, sampling nets, and the vehicle-powered lifting apparatus.

Later in the irrigation season, as the flow decreased and the water velocity increased, the sampling was moved downstream to the site at the end of the concrete apron. This site was utilized until the end of the season, employing the previously described 6- x 8-ft net.

In 1975, three consecutive days were usually sampled each week, but occasionally the sampling period was reduced because of gear failure. Removing the catch at 12-hr morning and evening intervals enabled the determination of the approximate diel variation in entrainment rates by species at the upstream site, where net avoidance was probably negligible, and gave indication of the extent of net avoidance at the downstream site where net avoidance probably occurred.

Each tunnel at the upstream sampling site was sampled for 1 full day each week in 1975 which enabled determination of the extent of entrainment bias between tunnels. The order of sampling between tunnels was partially randomized in that during a 3-day sampling period one net was fished in tunnels 1, 2, and 3 in random order, while the other net was fished in tunnels 4, 5, and 6 in random order. Complete randomization of the sampling order was not expedient because of the design of the net-handling apparatus; however, complete randomization was considered unnecessary in the present study.

The canal sampling schedule for 1975 at the upstream site included six consecutive 12-hr sets per week per net. Each gate received 1 day of sampling effort each week. For the two downstream sites, the sampling schedule also entailed six consecutive 12-hr sets per week. Catches were collected every morning and evening at all three sites.

In 1976, the same gear as described above was used in sampling the canal. The downstream net at the end of the concrete apron was first positioned on April 4, 1976, and fished during the first 4 weeks. Sampling duration ranged from 1 to 3 days per week, depending upon circumstances which included equipment failure and vandalism. The downstream net was removed when the flow reached 6,400 cfs and sampling was begun with the two upstream nets.

A sampling design was established in 1975 which enabled correction for bias in entrainment between the four inside and two outside gates. The extent of bias was determined by fishing one net continuously in gate 1, while the other net was fished randomly in the inside gates (gates 2 through 5). Later, after the bias had been determined, the schedule was changed to a consistent sampling of gates 1 and 4 during 2 consecutive days per week.

The catches were transported to the field laboratory in the pumphouse at Grand Coulee Dam for processing. Data recorded included number, species, length, weight, sex, stage of maturity, stomach fullness and content, obvious disease or parasites, and scales or otoliths. In 1975 the volume of water sampled by each net was determined weekly by suspending a digital flowmeter (Ocean Dynamic Model 2030) across the net opening for a timed period of approximately 20 min. The water depth at the site was also recorded. The flowmeter reading was used to calculate the average velocity, which, when multiplied by the area of the net opening, yielded a sample volume. In 1976, the water velocities were not measured but were calculated from information on total flow (from USBR water

reports) and from total discharge area (from observations of water depth at the net sites) according to the equation:

$$V_{fps} = \frac{\text{discharge (cfs)}}{\text{height of discharge} \times \text{width of canal.}}$$

Sample volume was then calculated according to the equation:

$$Q_s = V_{fps} \times \text{area sampled.}$$

All computations were carried out by a computer program written specifically for analysis of the entrainment data. The total entrainment of fish (number and biomass) was estimated at weekly intervals according to the following statistical procedure. The average daily catch (\bar{C}_i) was calculated for each week for each species using the following procedure:

$$\bar{C}_i = \frac{\sum C_{ij}}{\sum H_i} (24) \quad (1)$$

where,

C_{ij} = j^{th} catch in the i^{th} week, and

H_i = number of hr fished for each catch.

Weekly entrainment rates were estimated for each species by the expression:

$$T_i = \frac{\bar{C}_i \cdot Q_i \cdot n_i}{Q_{s_i}} \quad (2)$$

where,

T_i = estimated weekly entrainment rate

Q_i = average daily canal discharge rate (cfs) for weekly period

Qs_i = weekly rate of flow through nets in cfs

n_i = number of days in the week (usually 7).

The point estimate for the total (32 weeks) seasonal entrainment of each species through the irrigation outlet structure was calculated from:

$$T_c = \sum_{i=1}^{32} a_i \bar{C}_i = \sum_{i=1}^{32} T_i \quad (3)$$

where,

T_c = estimated total number entrained by species

$$a_i = \frac{Q_i n_i}{Qs_i}$$

The variance about the mean was calculated from the expression:

$$\text{Var} (\bar{C}_i) = \frac{\sigma^2}{n} = \frac{Si^2}{n} = \frac{Si}{\sqrt{n}} \quad (4)$$

The variance about the weekly estimated catch (T_i) was estimated from:

$$\text{Var} (T_i) = \left(a_i^2 \frac{Si}{\sqrt{n}} \right) \quad (5)$$

Assuming \bar{C}_i are independent random variables, then the $\text{Var}(\hat{T}_c)$ can be estimated from:

$$\text{Var}(\hat{T}_c) = \sum_{i=1}^{32} a_i^2 \text{Var}(\bar{C}_i) = \sqrt{\text{Var}(\hat{T}_c)} = \sqrt{\sum_{i=1}^{32} a_i^2 \frac{S_i}{\sqrt{n}}} \quad (6)$$

The interval estimate was then obtained from

$$T_c \pm Za \sqrt{\text{Var}(\hat{T}_c)}$$

where $Za = 95$ percent normal probability, critical value = 1.96.

In 1975, use of the Friedman two-way analysis of variance established that kokanee was the only species which showed any significant difference in rate of entrainment between the six outlet tunnels. Entrainment through the two outside tunnels was found to be significantly and consistently higher than entrainment through the four inside tunnels. In 1976, use of the Wilcoxin-matched pairs signed rank test was used to confirm the earlier observation. This test was justified by the use of only two sampling tunnels during the time kokanee were being entrained, and was considered to be a much more robust test than the Friedman. To establish the greatest precision in the calculation of T_c for kokanee, a weighted weekly average was calculated in the following manner:

$$\bar{C}_{wi} = \frac{1}{3} \left[\frac{\sum_{i=1}^{N_{oi}} C_{oij}}{N_{oi}} + 2 \frac{\sum_{i=1}^{N_{bi}} C_{bij}}{N_{bi}} \right] \quad (7)$$

where,

\bar{Cw}_i = weighted average daily catch for week i

N_{oi} = number of daily catches in the i^{th} week for outside gates

N_{bi} = number of daily catches in the i^{th} week for inside gates

Co_{ij} = j^{th} daily catch in i^{th} week for outside gates

Cb_{ij} = j^{th} daily catch in i^{th} week for inside gates

The weekly estimated entrainment rates (T_i) were then calculated from

$$T_i = a_i \bar{Cw}_i \quad (8)$$

Assuming that Co_{ij} and Cb_{ij} are independent random variables, an unbiased estimate of the weekly variance was then calculated by:

$$\text{Var} (a_i \bar{Cw}_i) = \frac{1}{9} \left[\frac{\sum_{i=1}^{N_{oi}} Co_{ij}^2 - N_{oi} \bar{Co}_i^2}{N_{oi} - 1} \right] + \frac{4}{9} \left[\frac{\sum_{i=1}^{N_{bi}} Cb_{ij}^2 - N_{bi} \bar{Cb}_i^2}{N_{bi} - 1} \right] \quad (9)$$

If N_{oi} or $N_{bi} = 1$, then $E(\text{Var}) = 0$, however, this was not the case.

The estimated seasonal entrainment was calculated in the same manner as before:

$$T_c = \sum T_i \quad (10)$$

The estimated total variance of the catch was found by:

$$\text{Var} (\hat{T}_c) = \sum_{i=1}^{32} a_i^2 \text{Var} (\bar{Cw}_i) \quad (11)$$

Assuming \bar{Cw}_i are independent random variables, the variance can then be used in calculating the interval estimates about T_c .

$$\hat{T}_C \pm Z_\alpha \sqrt{\sum_{i=1}^{32} a_i^2 \text{Var}(\bar{C}_{w_i})} \quad (12)$$

were $Z = 95$ percent normal probability, critical value = 1.96.

The random variable C_{ij} can be modeled by the Poisson distribution with parameter (λV) where λ = the average occurrence of fish in V the volume of water filtered through the sampling nets each day.

The value of V is very large, ranging from 6 million ft^3 to 54.5 million ft^3 per day. This caused the value of the parameter (λV) to become extremely large, so the Poisson was closely approximated by the Normal distribution. Because the sample statistics \bar{C}_i were used to calculate the point estimate \hat{T}_C , the central limit theorem applies and an even closer approximation to the Normal distribution was obtained. The assumption that \bar{C}_i are independent random variables therefore appears reasonable.

8.4 Results

8.4.1 Relative Abundance

Estimates of the numbers of fishes entrained through the irrigation canal during 1975 and 1976 are presented in Table 8.1. The species are listed in the order of relative numbers entrained for 1975. The estimated entrainment for all species for 1976 was 218,178 which was roughly half the total number of 432,608 fishes entrained during 1975. Total biomass entrained for 1976 was estimated to be 59,235 kg, which also was roughly half of the 103,215 kg estimated for 1975.

Relative order of abundance for all species remained approximately the same during 1976 except for lake whitefish, rainbow trout, and

Table 8.1 Total estimated entrainment through the irrigation canal by species during the 1975 and 1976 irrigation seasons (March ~ October).

	Estimated Total No. Entrained 1975	Interval Estimate $\alpha = .05$	Estimated Total No. Entrained 1976	Interval Estimate $\alpha = .05$	Relative No. % 1975	Relative No. % 1976	Estimated Total Weight (kg)		Relative Weight %	
							1975	1976	1975	1976
Yellow perch	241,528	+18,485	115,146	+63,796	.56	.53	10,748	5,906	.104	.100
Kokanee	128,397	+21,522	50,007	+ 8,477	.30	.23	59,210	22,556	.574	.381
Lake whitefish	19,326	+ 3,306	23,731	+ 8,474	.04	.11	12,272	15,850	.119	.268
Longnose sucker	9,895	+ 1,916	14,399	+ 5,749	.02	.07	5,937	7,940	.057	.134
Carp	8,495	+ 5,556	2,921	+ 1,295	.02	.01	9,845	5,255	.095	.089
Rainbow trout	7,183	+ 1,557	916	+ 580	.017	.004	2,694	544	.026	.009
Chinook salmon	6,976	+ 2,519	1,212	+ 674	.017	.01	1,150	337	.011	.006
Prickly sculpin	4,174	+ 1,290	5,657	+ 3,136	.01	.02	26	45	T	.001
Mountain whitefish	2,044	+ 1,054	1,211	+ 558	.005	.005	564	385	.005	.006
Peamouth	2,048	+ 873	1,692	+ 963	.005	.005	377	266	.004	.004
Pumpkinseed sunfish	1,148	+ 531	730	+ 652	.003	.003	71	28	.001	T
Black crappie	1,059	+ 584	218	+ 216	.002	.001	74	18	.001	T
Walleye	206	+ 249	189	+ 251	T	.001	196	64	.002	.001
Largemouth bass	56	+ 96	33	+ 82	T	T	28	30	T	T
Brown bullhead	38	+ 90	68	+ 138	T	T	13	11	T	T
Burbot	34	+ 94	-	-	-	-	10	-	T	-
Largescale sucker	-	-	13	+ 44	-	T	-	-	-	-
Dolly Varden trout	-	-	35	139	-	T	-	-	-	-
Total	432,608		218,178				103,215	59,235		

chinook salmon. Of these species, lake whitefish, was the only one to increase in relative abundance in the catch, while rainbow trout and chinook salmon decreased.

Nineteen of the 22 species known to occur in Banks Lake were caught in the entrainment samples in the irrigation canal by the end of the 1976 irrigation season. Only northern squawfish (*Ptychocheilus oregonensis*), brown trout (*Salmo trutta*), and bridgelip sucker (*Catostomus columbianis*) were not taken in the irrigation canal catch. None of these species is abundant in the lake and the former and latter species were captured infrequently only in the north end of Banks Lake.

8.4.2 Yellow Perch (*Perca flavescens*)

An estimated 115,146 yellow perch were entrained during the 1976 season as compared to 241,528 in the 1975 season. This was a decrease of 52 percent between years. Estimated biomass entrained in 1976 was 5,906 kg as compared to 10,748 kg in 1975. The relative abundance of yellow perch remained approximately the same both years. Yellow perch comprised 53 percent of the catch in 1976 and 56 percent in 1975, but due to their relatively small size (average weight in 1976, 51.3 g, and in 1975, 44.5 g) accounted for only 10 percent of the 1976 total estimated biomass and 10.4 percent of the 1975 biomass.

The perch entrainment in 1976 was bimodal, as it had been in 1975 (Fig. 8.7). The first mode occurred during the spawning season and was attributed to spawning activity. The second mode coincided with the warmest water temperature and was attributed to increased feeding activity.

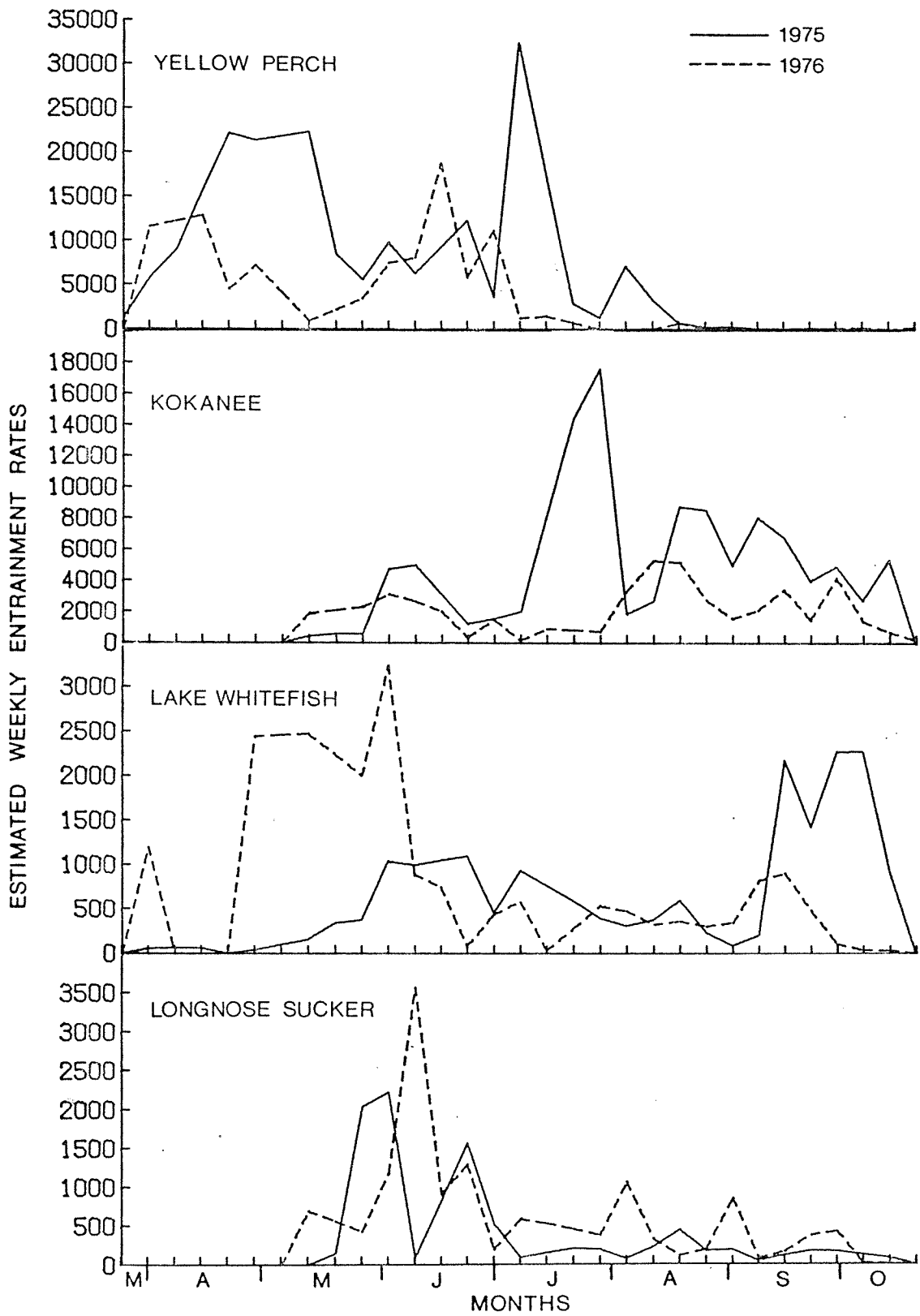


Fig. 8.7 Total estimated weekly entrainment rates for yellow perch, kokanee, lake whitefish and long nose sucker through the irrigation canal in 1975 (solid) and 1976 (dashed).

In 1976, the entrainment modes occurred approximately 3 weeks earlier than in 1975. The difference in timing is not explained by temperature differences between years (Fig. 8.8).

Diel differences in entrainment rates were noted during 1975 which were not apparent in 1976. From March to mid-May 1975, nearly all perch occurred in the night catches; by late May the daytime catch was equal to the night catches; and from early June until the end of the season daytime catches were nearly twice as large as nighttime catches.

A comparison of perch length frequencies between years revealed a 2-year predominance in the catch by the 1973 and 1974 year classes (Figs. 8.9 and 8.10). In 1975, the catch from April through July was composed entirely of the 1973 and 1974 year classes (ages I and II). After July these modes became less distinct and eventually merged. Likewise, in 1976 the catch from April through July was composed largely of the 1973 and 1974 year classes (now ages II and III). In August these year classes were greatly diminished in the catches and were absent in September and October. Also in August the 1975 and 1976 year classes entered strongly into the catch and continued so through September and October.

In summary, the age composition of entrained perch varied considerably between years. No age 0 perch were caught in 1975 but large numbers were caught in 1976. Age I perch were entrained during the entire irrigation season in 1975, but were absent until August in 1976.

Reasons for these differences are speculative but most likely they resulted from reduced abundances of age 0 and I-year-old perch and from delayed timing of their movement offshore. Delayed offshore movement of

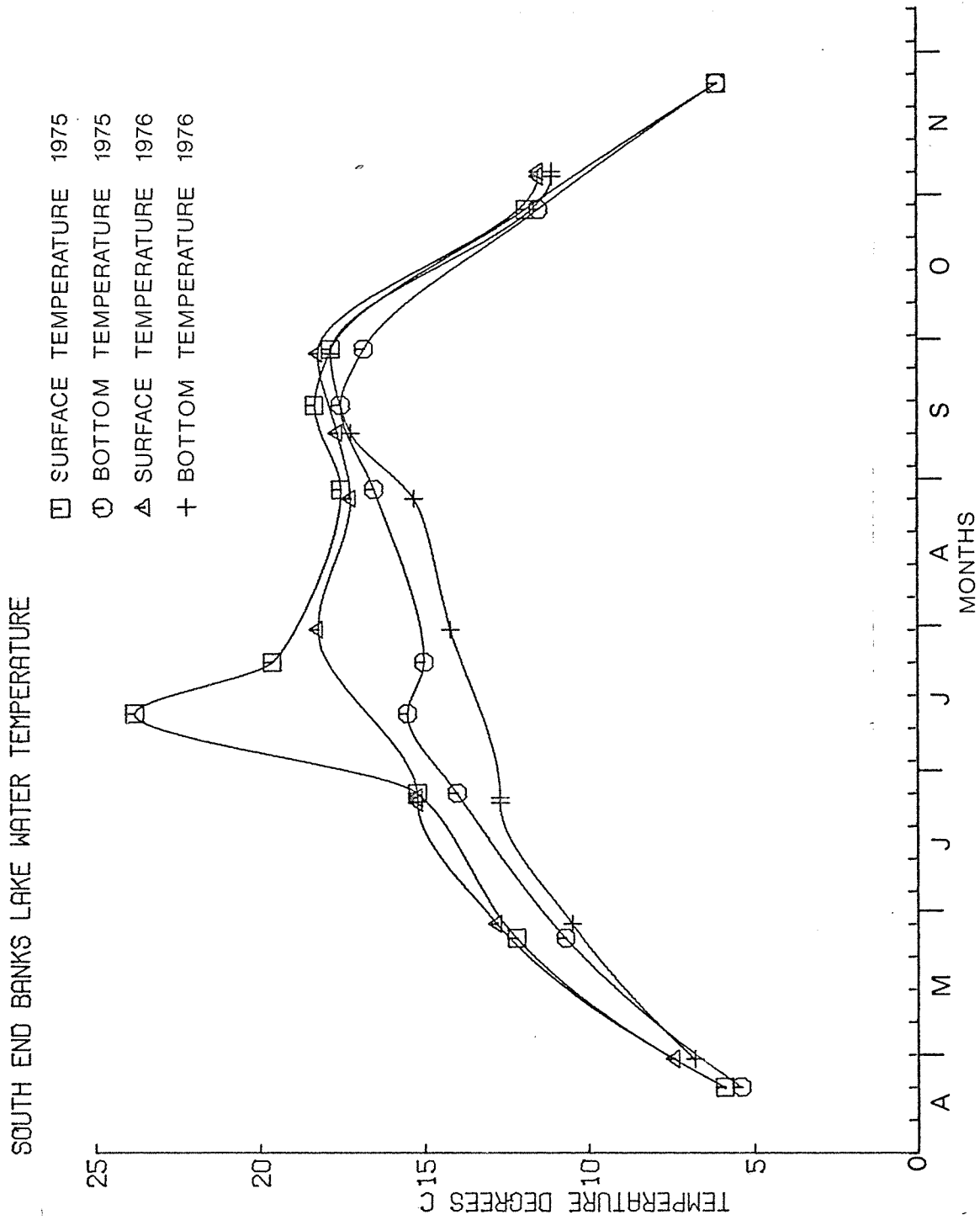


Fig. 8.8 Monthly surface and bottom water temperature in the south end of Banks Lake during the April-November irrigation seasons of 1975 and 1976.

YELLOW PERCH LENGTH FREQUENCY 1975

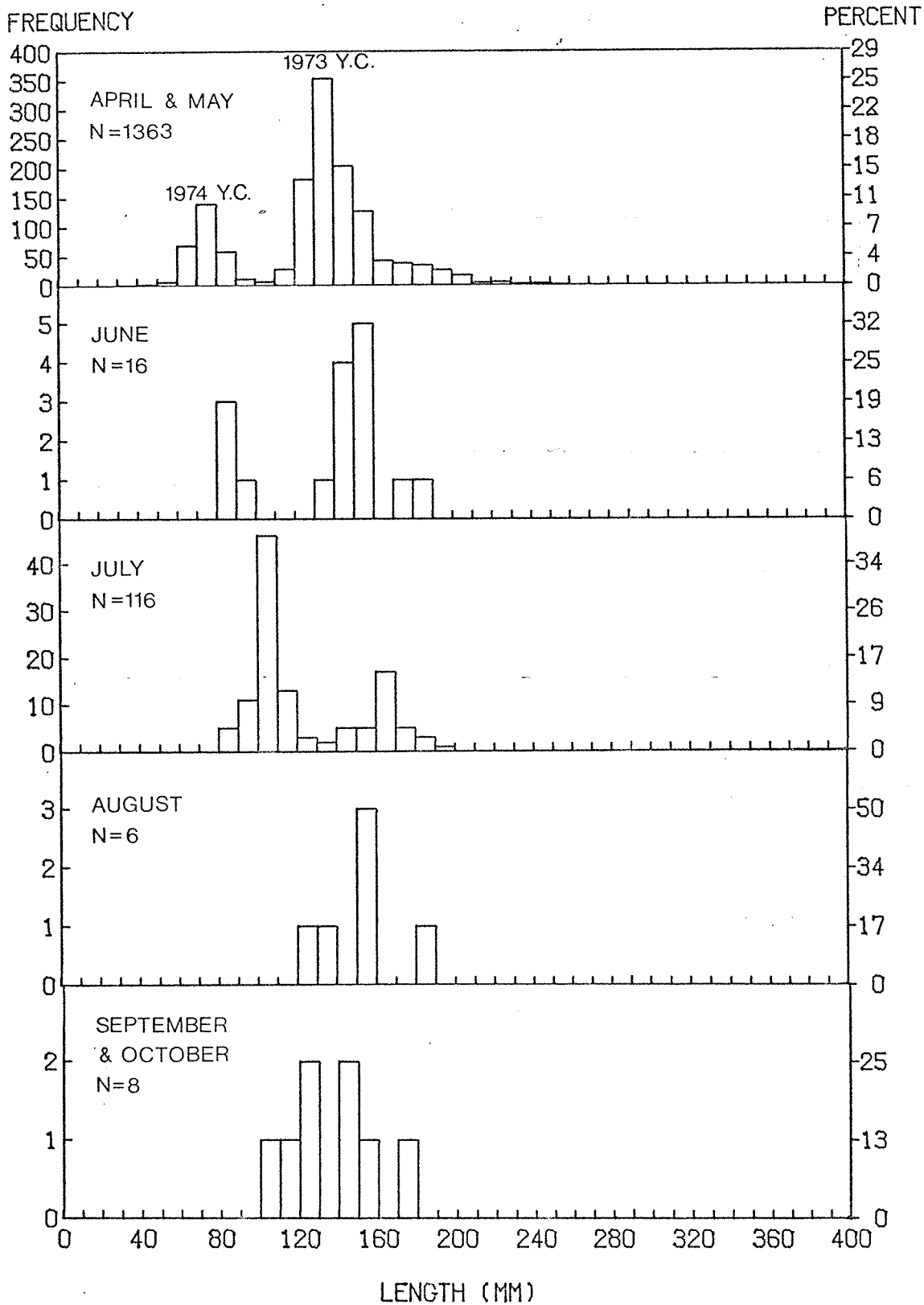


Fig. 8.9 Monthly length frequency and year class of yellow perch caught in irrigation canal entrainment samples in 1975.

YELLOW PERCH LENGTH FREQUENCY 1976

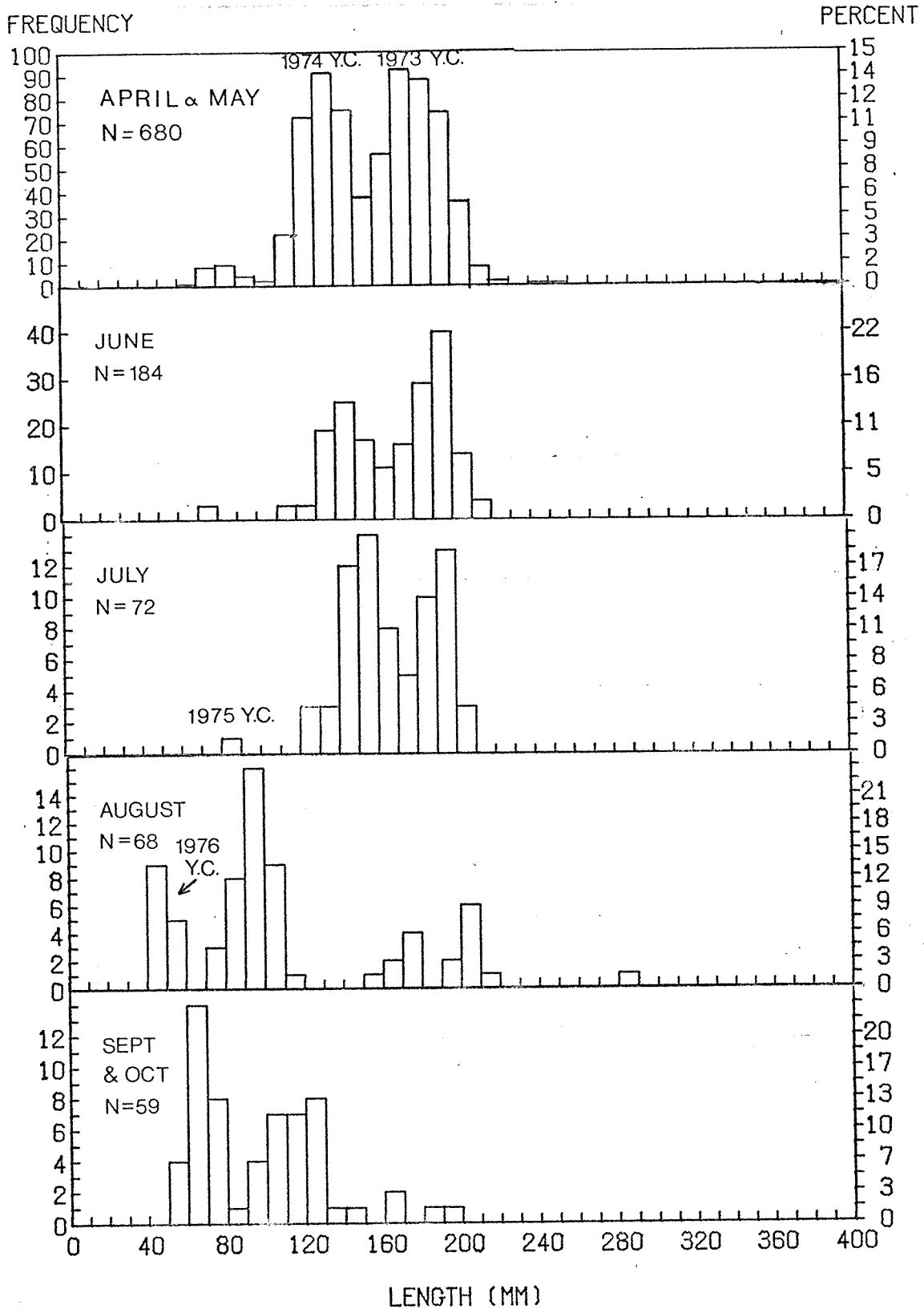


Fig. 8.10 Monthly length frequency and year class of yellow perch caught in irrigation canal entrainment samples in 1976.

juveniles in 1976 would have accounted for delayed occurrence in the canal nets. This late timing may have been caused by the presence of large numbers of ages II- and III-year-old perch which are predaceous on the juveniles.

8.4.3 Kokanee (*Oncorhynchus nerka*)

An estimated 50,007 kokanee were entrained during the 1976 season as compared to 128,397 in 1975. This was a decrease of 61 percent from 1975 to 1976. Estimated biomass entrained for 1976 was 22,556 kg as compared to 59,210 kg for 1975.

Kokanee entrainment in the irrigation canal began in early May in both years (Fig. 8.7). In 1975, estimated numbers entrained remained below 5,000 per week until late July when an estimated 19,000 kokanee were entrained in 1 week. Numbers entrained per week generally remained above 6,000 until the end of the season. In 1976, kokanee entrainment was consistently lower throughout the season. Numbers reached a peak in mid-August and remained at about 4,000 per week until the end of the season (Fig. 8.7).

The age composition of kokanee entrained in 1976 was fairly similar to that observed in 1975 based on comparison of length-frequency distributions (Figs. 8.11 and 8.12). Although no age analysis was made in 1976, the similarity of the distributions indicates that age composition and length at age were nearly identical between years. In 1975, the age composition through July was 3 percent age I; 39 percent age II; 54 percent age III; 4 percent age IV. After July, the number of immatures decreased and the age composition shifted to 1 percent age I, 8 percent age II, 75 percent age III, 18 percent age IV, and < 1 percent age V.

KOKANEE 1975

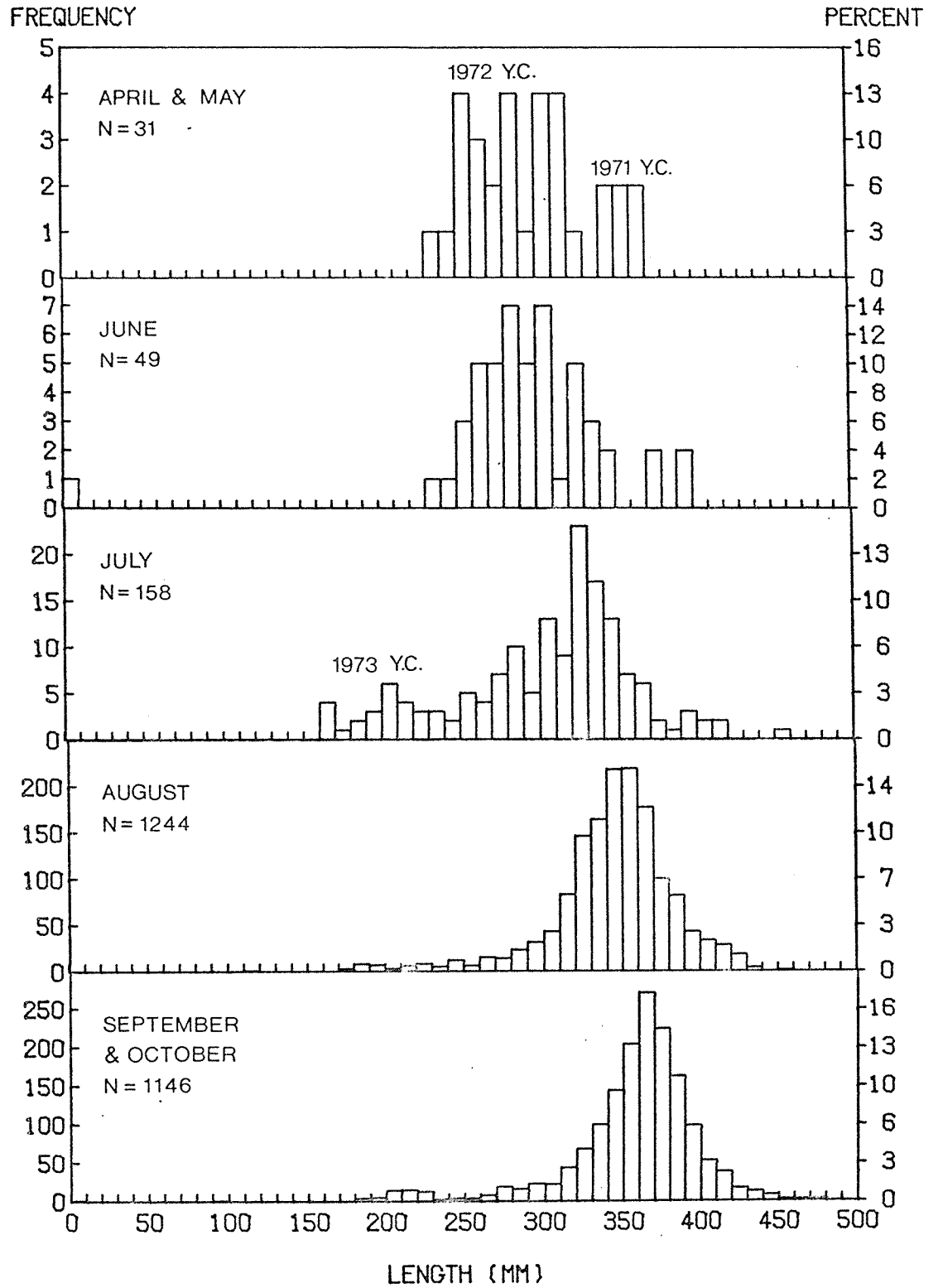


Fig. 8.11 Monthly length frequency and year class of kokanee caught in irrigation canal entrainment samples in 1975.

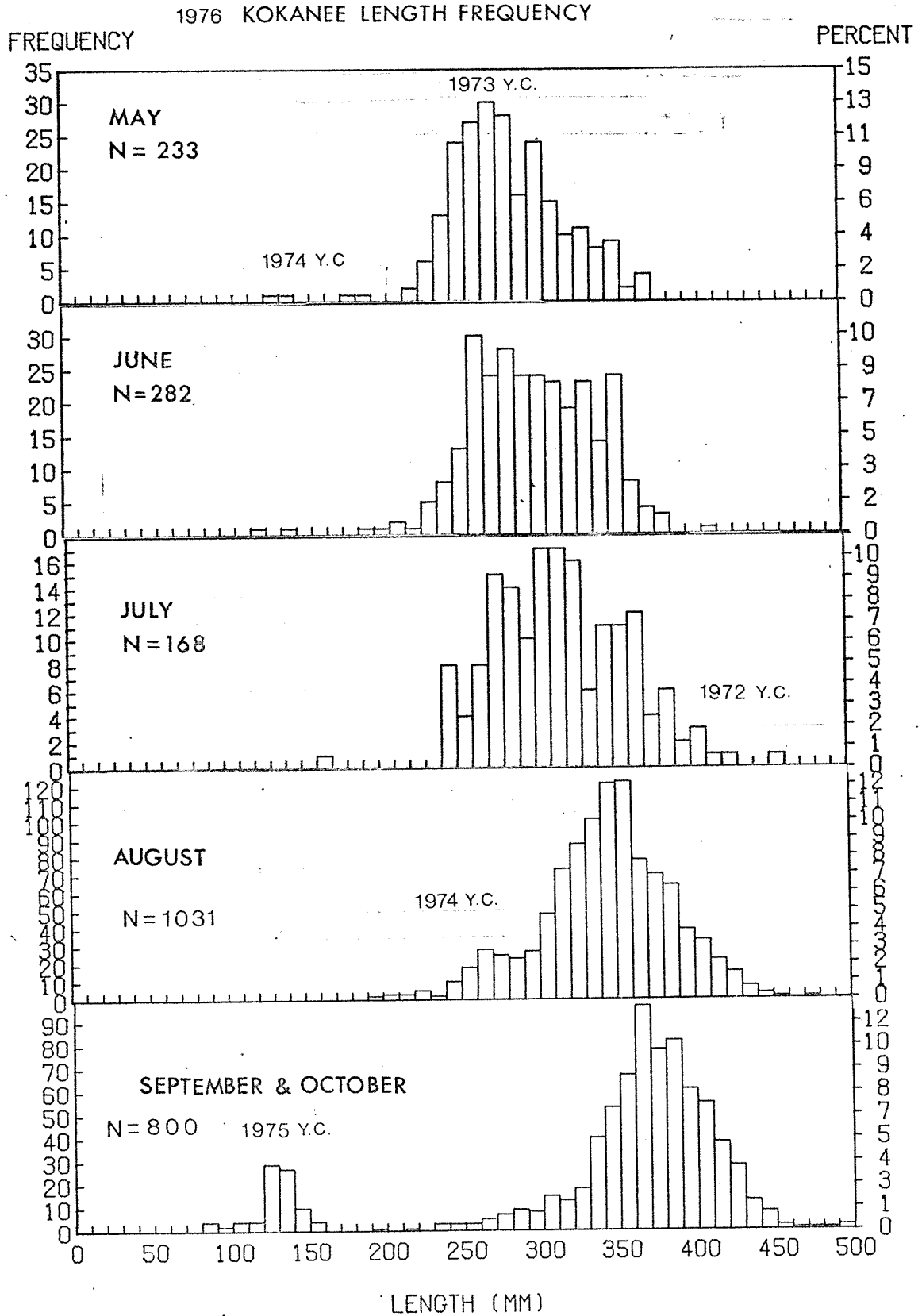


Fig. 8.12 Monthly length frequency and year class of kokanee caught in irrigation canal entrainment samples in 1976.

Two minor dissimilarities between years were noted. In 1975, the July-to-October entrainment included moderate numbers of age I immature kokanee of the 1973 year class. These averaged 205 mm standard length. In 1976, the August-to-October entrainment of age I immatures was numerically similar but the lengths averaged 255 mm, or 50 mm greater. In October 1976, a relatively large entrainment of age 0 kokanee of the 1975 year class occurred in the irrigation canal.

The relative abundances of maturing kokanee entrained in the irrigation canal and of maturing kokanee caught by gillnets in Banks Lake have been similar and are probably closely correlated. However, little is known about the abundance of ages 0 and I immature kokanee in Banks Lake because no method of sampling them has been found. The gillnets do not effectively catch ages 0 and I kokanee. It is likely that the entrainment of immature kokanee accurately reflects their relative abundance in Banks Lake and therefore may be used to predict the abundance of maturing kokanee 2 years in advance. To the extent that this is true, the large canal catch of age 0 kokanee in October 1976 indicates good production from the 1974 spawning. This year class will mature principally in 1978.

The large size of age I kokanee, as was noted in the 1976 canal catches, indicates that kokanee maturing in 1977 (principally contributors to the sports creel) will be large fish.

8.4.4 Lake Whitefish (*Coregonus clupeaformis*)

An estimated 23,731 lake whitefish weighing 15,850 kg were entrained in 1976 as compared to 19,326 weighing 12,272 kg in 1975 (Table 8.1). The lake whitefish was one of the few species to increase in numbers

(23 percent) and biomass during the 1976 irrigation season. This was due both to lower entrainment of other species in 1976 and to high survival of the 1974 year class.

The temporal pattern of entrainment for lake whitefish in 1976 was reversed from that seen in 1975 (Fig. 8.7). In 1976, peak entrainment rates were reached in early May through the middle of June, followed by a rapid decline to less than 1,000 per week through the remainder of the season. In 1975, lake whitefish exhibited low entrainment throughout the first 5 months of sampling and reached a peak from mid-September to mid-October (Fig. 8.7).

No diel differences in the entrainment of lake whitefish were observed in 1975 or 1976.

The entrainment of large, maturing lake whitefish decreased during mid-summer both years because of their intolerance to warmer water temperature. As elaborated in section 5.0, large lake whitefish avoided warm water by descending 23 m subsurface. This placed them well below the level of the irrigation outlet, concentrating these fish in the Devils Hole area of the lake, and greatly reduced their entrainment rate during July and August. The effect was particularly noticeable during July 1975, when none was entrained (Fig. 8.13).

Length frequency plots (Figs. 8.13 and 8.14) show a difference in the age classes being entrained during the 2 years. Table 8.2 presents mode lengths for both years. Entrainment in 1975 consisted of 1-year-olds (275 mm) and of 4-year-olds and greater (455 mm). Few 2- and 3-year-olds were entrained. In 1976, age II and III+ were entrained with a few age I during April and May 1976.

LAKE WHITEFISH LENGTH FREQUENCY 1975

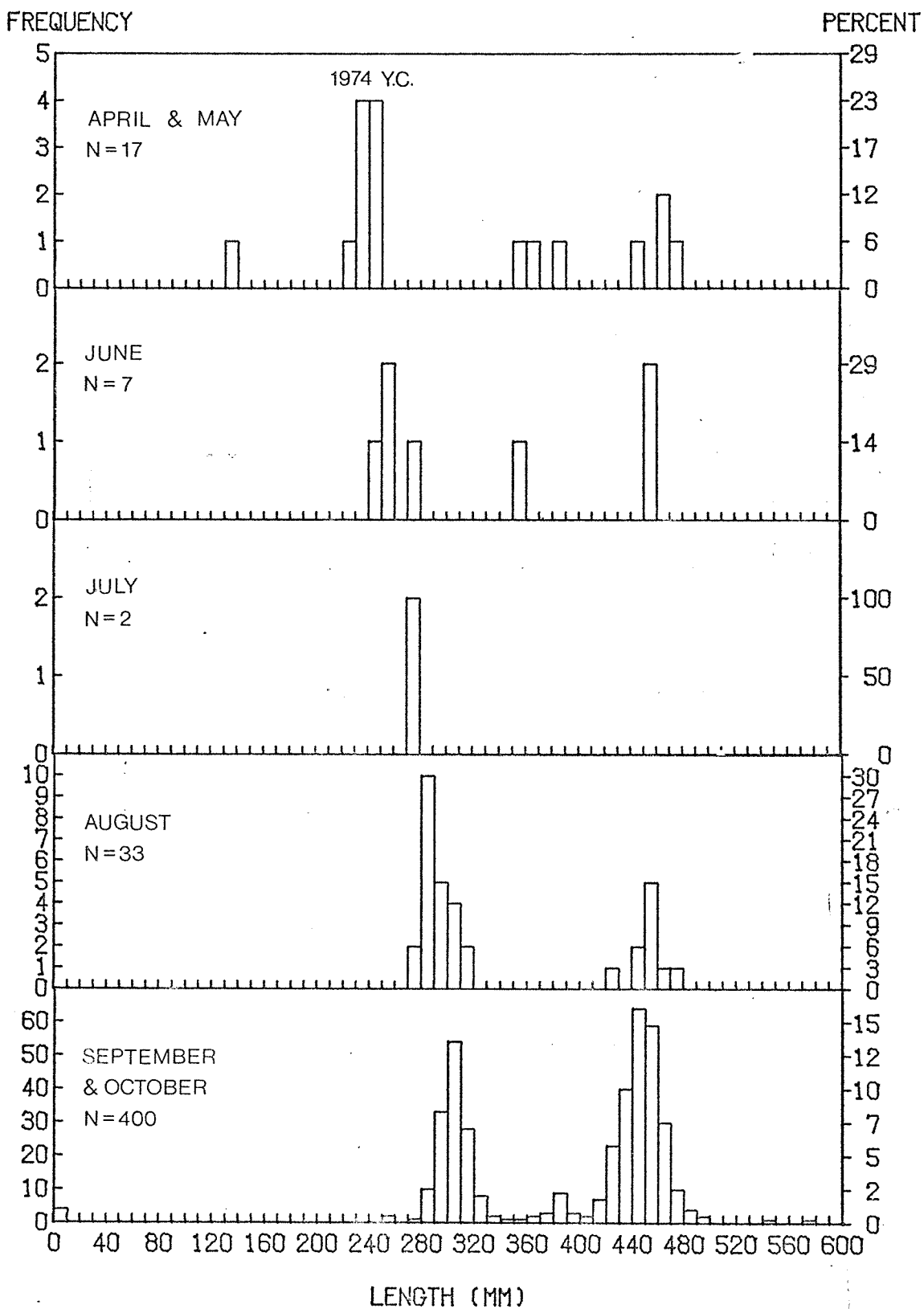


Fig. 8.13 Monthly length frequency and year class lake whitefish caught in irrigation canal entrainment samples in 1975.

LAKE WHITEFISH LENGTH FREQUENCY

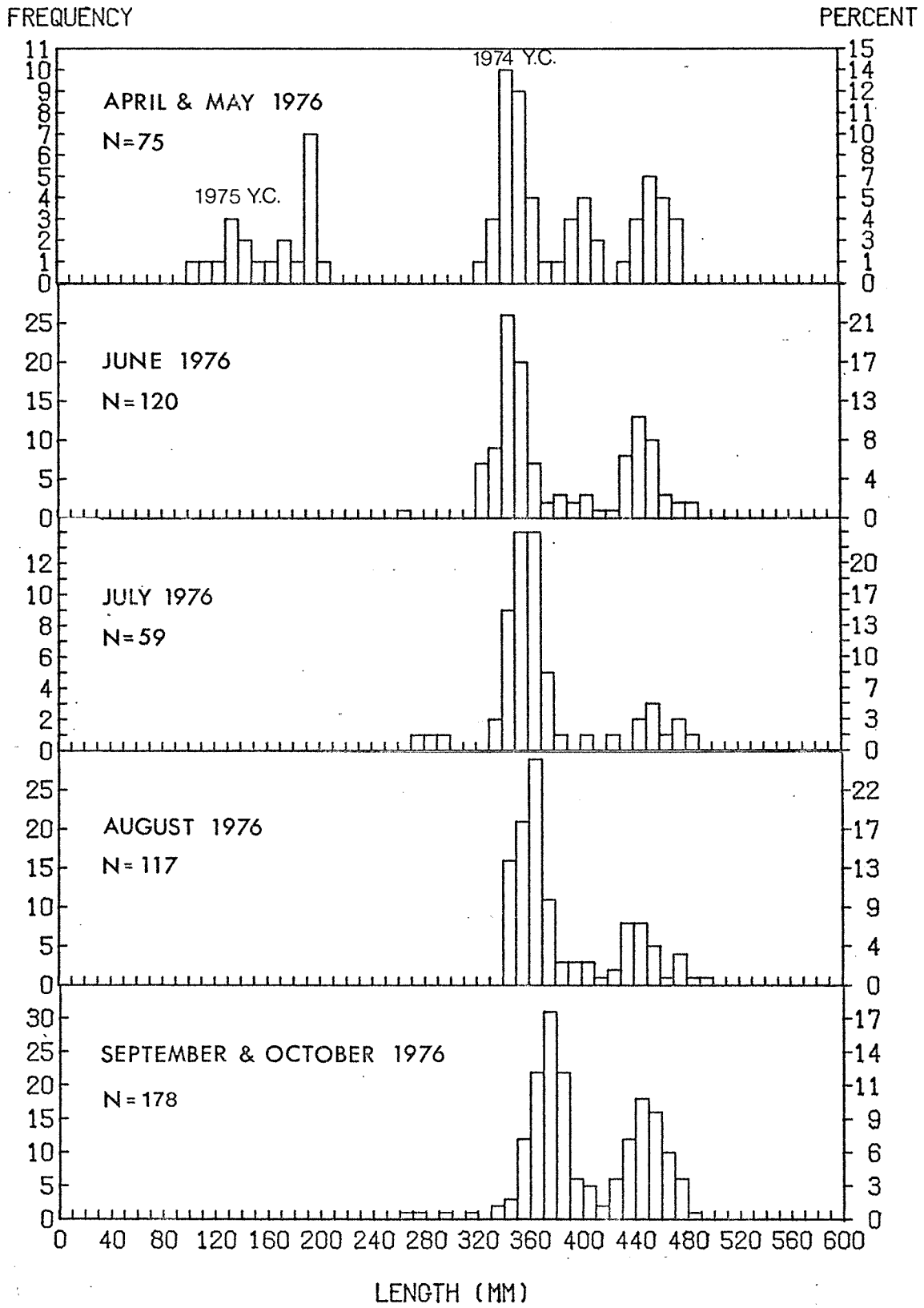


Fig. 8.14 Monthly length frequency and year class lake whitefish caught in irrigation canal entrainment samples in 1976.

Table 8.2 Mode length (mm) of lake whitefish entrained in the irrigation canal in 1975 and 1976.

	1975		1976		
April, May	240	465	185	345	455
June	255	455			455
July	275				455
August	285	455			440
September, October	305	445			445

8.4.5 Longnose Sucker (*Catostomus catostomus*)

An estimated 14,399 longnose suckers were entrained in 1976 as compared to 9,895 entrained in 1975 (Table 8.1). This was an increase of 45 percent. Biomass entrained was 7,940 kg in 1976 as compared with 5,937 kg in 1975.

Longnose sucker was one of the few fish which showed a similar entrainment pattern both years (Fig. 8.7). This species first appeared in the catch in mid-May and reached peak entrainment rates in early June followed by a decline to a relatively low and uniform rate for the remainder of the season. In 1975, 100 percent of the fish entrained were mature during the first part of the season. Longnose suckers showed no diel variation in the rate of entrainment.

8.4.6 Carp (*Cyprinus carpio*)

An estimated 2,921 carp were entrained in 1976 as compared to 8,495 in 1975 (Table 8.1). In 1976, 5,255 kg were entrained in the canal as compared to 9,845 kg in 1975. Carp first appeared in the irrigation canal catch in mid-May during both years (Fig. 8.15). Carp entrainment in 1976 remained below 400 per week throughout the season until early September when it dropped below 100 per week. Length frequency analysis for both years (Fig. 8.16) showed carp had a roughly trimodal distribution. The second mode which represents age I fish comprised 11 percent of the catch for 1976 and 14 percent of the 1975 catch. Daytime and nighttime catches were about equal and no consistent diel entrainment patterns were observed.

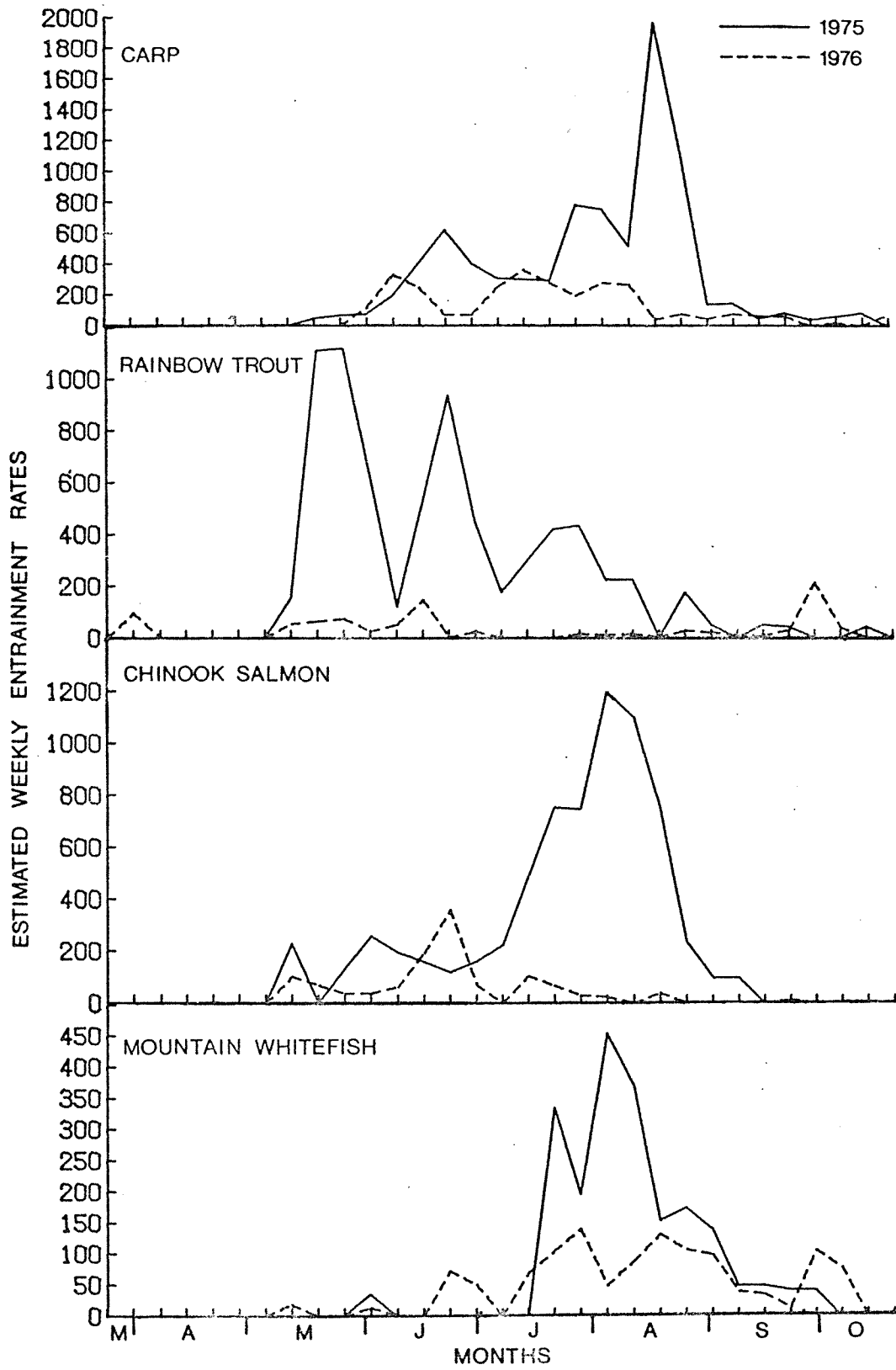


Fig. 8.15 Total estimated weekly entrainment rated for carp, rainbow trout, chinook salmon and mountain whitefish through the irrigation canal in 1975 (solid) and 1976 (dashed).

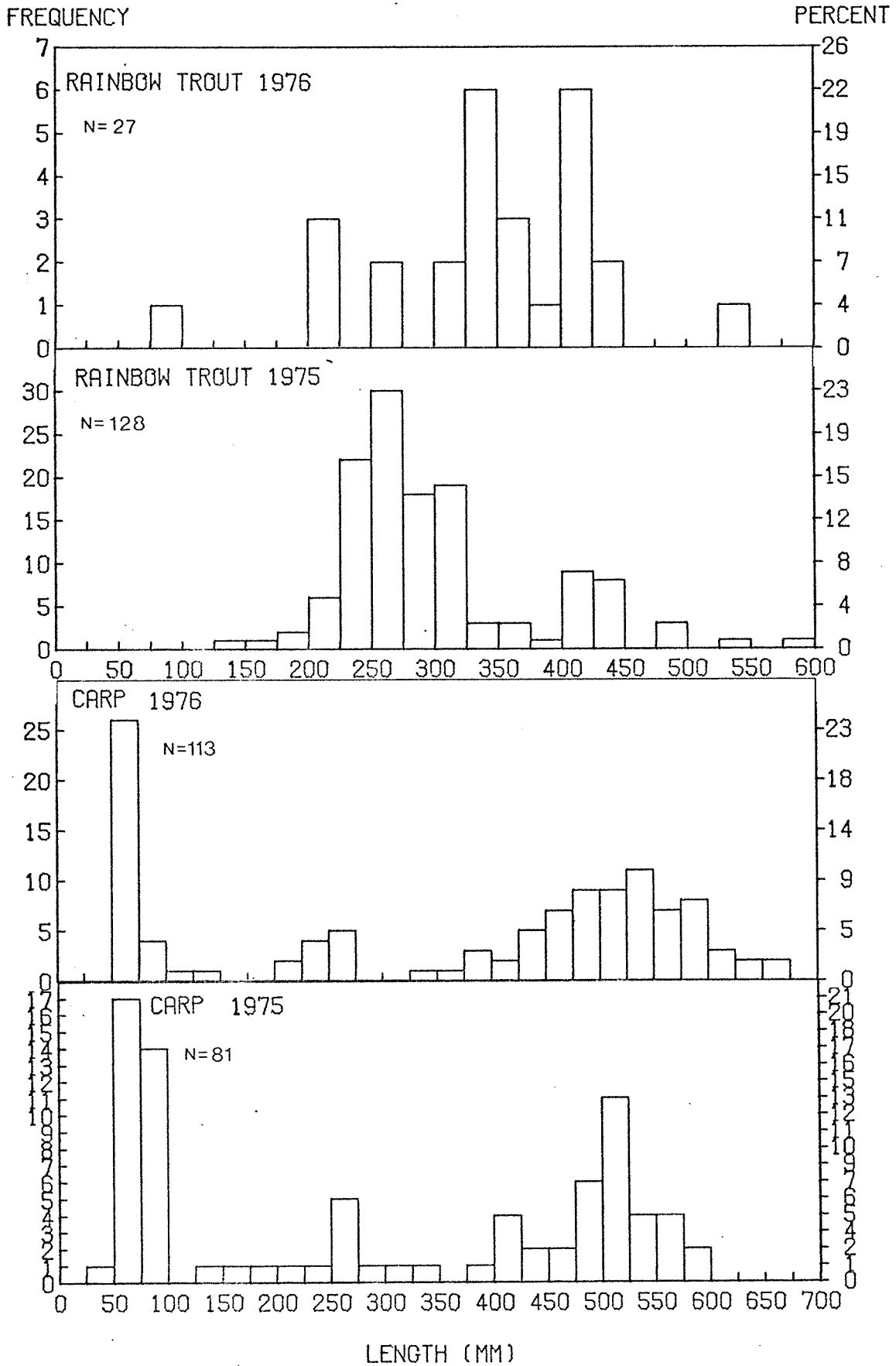


Fig. 8.16 Composite length frequency analysis of rainbow trout and carp caught in irrigation canal entrainment samples in 1975 and 1976.

8.4.7 Rainbow Trout (*Salmo gairdneri*)

An estimated 916 rainbow trout were entrained in 1976 as compared to 7,183 in 1975 (Table 8.1). An estimated 544 kg were entrained in 1976, and 2,694 kg were entrained in 1975. Rainbow trout entrainment varied from 0 to 200 per week throughout 1976 (Fig. 8.15). In 1975 the entrainment rate peaked during May and June and then decreased throughout the rest of the irrigation season. The length frequencies plotted monthly for 1975 indicated that two length modes of 250 and 410 mm were being entrained (Fig. 8.16). In 1976, length modes were not discernible due to the small sample size (Fig. 8.16). The majority of the fish, however, were between 300 and 450 mm.

Appendix Table A.8.1 shows the history of rainbow trout planting programs in Banks Lake.

8.4.8 Chinook Salmon (*Oncorhynchus tshawytscha*)

An estimated 1,212 chinook salmon were entrained in 1976 as compared to 6,976 in 1975 resulting in an 83 percent decline (Table 8.1). Estimated biomass was 337 kg and 1,150 kg in 1976 and 1975, respectively. In 1975 they comprised 1.6 percent of the total catch but accounted for only 0.6 percent in 1976.

A plant of 40,000 age 0 chinook was made in August 1974 from holding pens at the north end of the lake. Another group of 19,000 chinook was released from the same location during June 1975. A third release was made on October 19, 1975 after the 1975 canal sampling had terminated.

The 1974 plants began to appear in the irrigation canal catches in early May 1975 (Fig. 8.15). All were immature females. In early July 1975, moderate numbers of the 1975 chinook salmon plants began to appear.

By August, the 1974 plants had nearly disappeared. The chinook appearing in the irrigation canal catches of 1976 were from the 1975 plant. A total of 36 chinook salmon from this plant was caught.

A composite of length frequency data taken throughout the 1975 season shows the relative abundance of the two year classes in the catch (Fig. 8.17). The entrainment of the 1974 plants was estimated at 1,550 or 3.9 percent of the 40,000 planted. These fish averaged 297 mm in length and 316 g in weight. The entrainment of the 1975 plants was estimated at 5,850 or 30.8 percent of the 19,000 planted. These fish averaged 223 mm in length and 125 g in weight. Length frequency data for 1976 (Fig. 8.17) indicated that these fish were all from the 1975 plant, including the ones planted in October. These fish averaged 299 mm in length and 374 g in weight.

8.4.9 Prickly Sculpin (*Cottus asper*)

An estimated 5,657 prickly sculpin were entrained in 1976 as compared to 4,174 in 1975 (Table 8.1).

This small inshore fish (average entrained weight = 6 g) was of no direct importance to the Banks Lake sport fishery, but it is a potentially important forage fish and a possible predator on kokanee eggs and larvae. Because of its small girth, which approximates the mesh openings of the sampling nets, the entrainment was underestimated. One or two individuals appeared in most of the catches.

8.4.10 Mountain Whitefish (*Prosopium williamsoni*)

An estimated 1,211 mountain whitefish were entrained in 1976, as compared to 2,044 in 1975 (Table 8.1). From length frequency analysis,

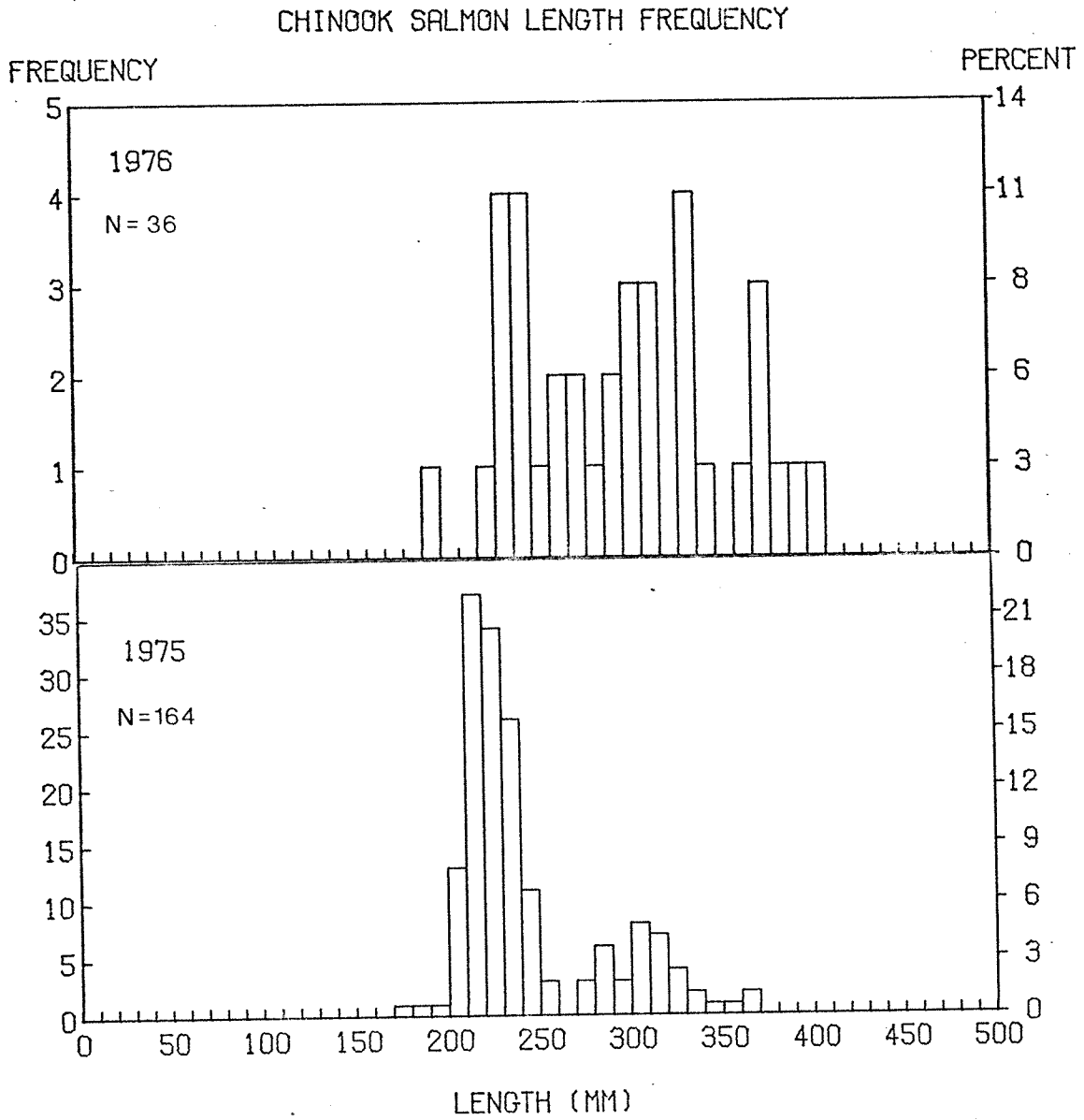


Fig. 8.17 Composite length frequency analysis of planted chinook salmon caught in irrigation canal entrainment samples in 1975 and 1976.

6 percent of these entrained were 1-year-old fish (Fig. 8.18). The remainder ranged from 200 mm to 400 mm. Their appearance in the catch for both years was sporadic (Fig. 8.15). In 1975 up to 500 per week were entrained. In 1976 the peak entrainment rate did not exceed 150 per week. No consistent diel differences in entrainment rates were observed.

8.4.11 Peamouth (*Mylocheilus caurinus*)

An estimated 1,692 and 2,048 peamouth were entrained in 1976 and 1975, respectively. They comprised less than 1 percent of both the total number and total estimated biomass for 1975 and 1976. Entrainment rates were sporadic for both years (Fig. 8.19). No noticeable differences between daytime and nighttime entrainment rates were observed.

8.4.12 Pumpkinseed sunfish (*Lepomis gibbosus*)

An estimated 730 sunfish were entrained in 1976. In 1975, 1,148 sunfish were entrained. They comprised less than 1 percent of the numbers and biomass entrained. Entrainment was sporadic throughout the season (Fig. 8.19). The individuals caught were largely immature.

8.4.13 Black Crappie (*Pomoxis nigromaculatus*)

The estimated entrainment for black crappie was 218 for 1976 and 1,059 for 1975. The entrainment was sporadic throughout the season.

8.4.14 Other Species

The estimated entrainment rates of the remaining six species which appeared in the irrigation canal sampling nets were relatively low. One burbot was caught in 1975, and none was caught in 1976. Totals of 11

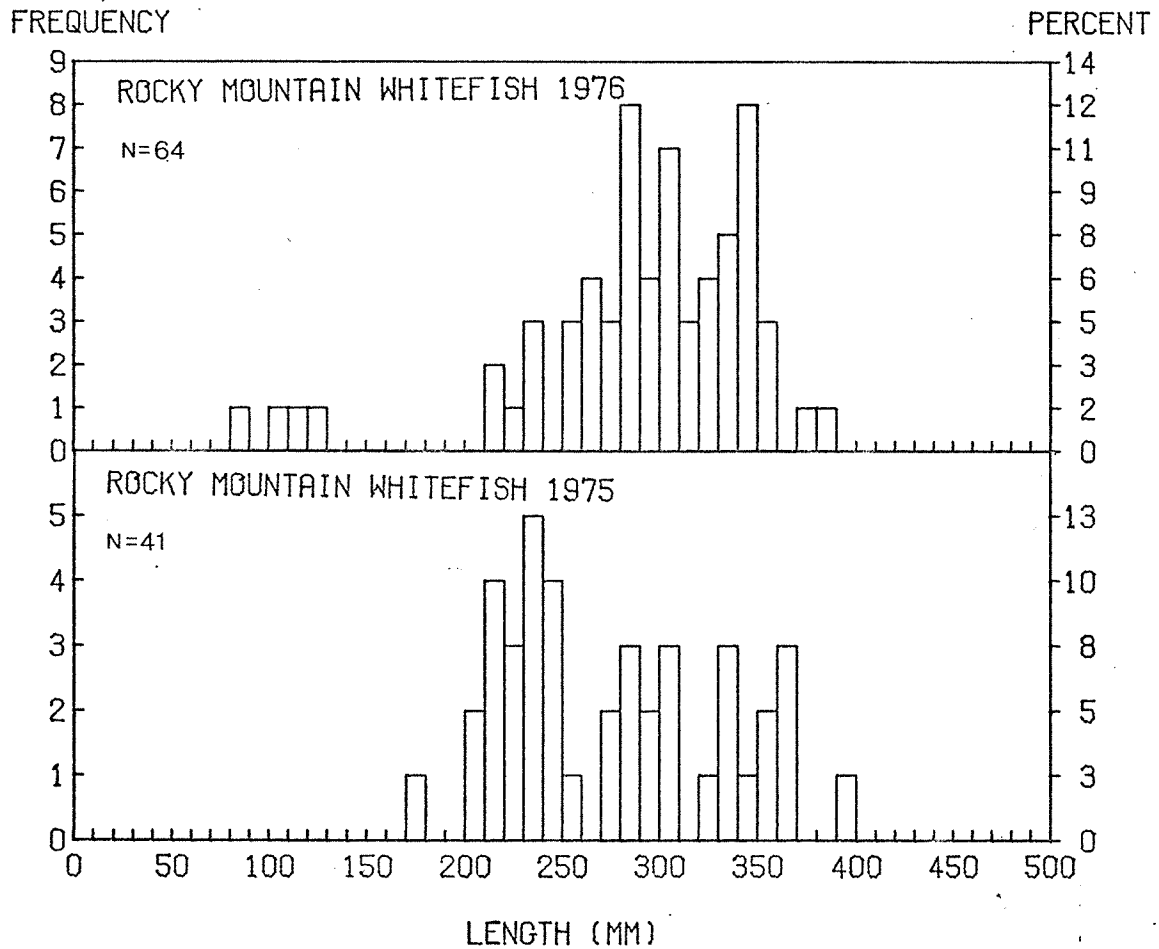


Fig. 8.18 Composite length-frequency analysis of rocky mountain whitefish caught in irrigation canal entrainment samples in 1975 and 1976.

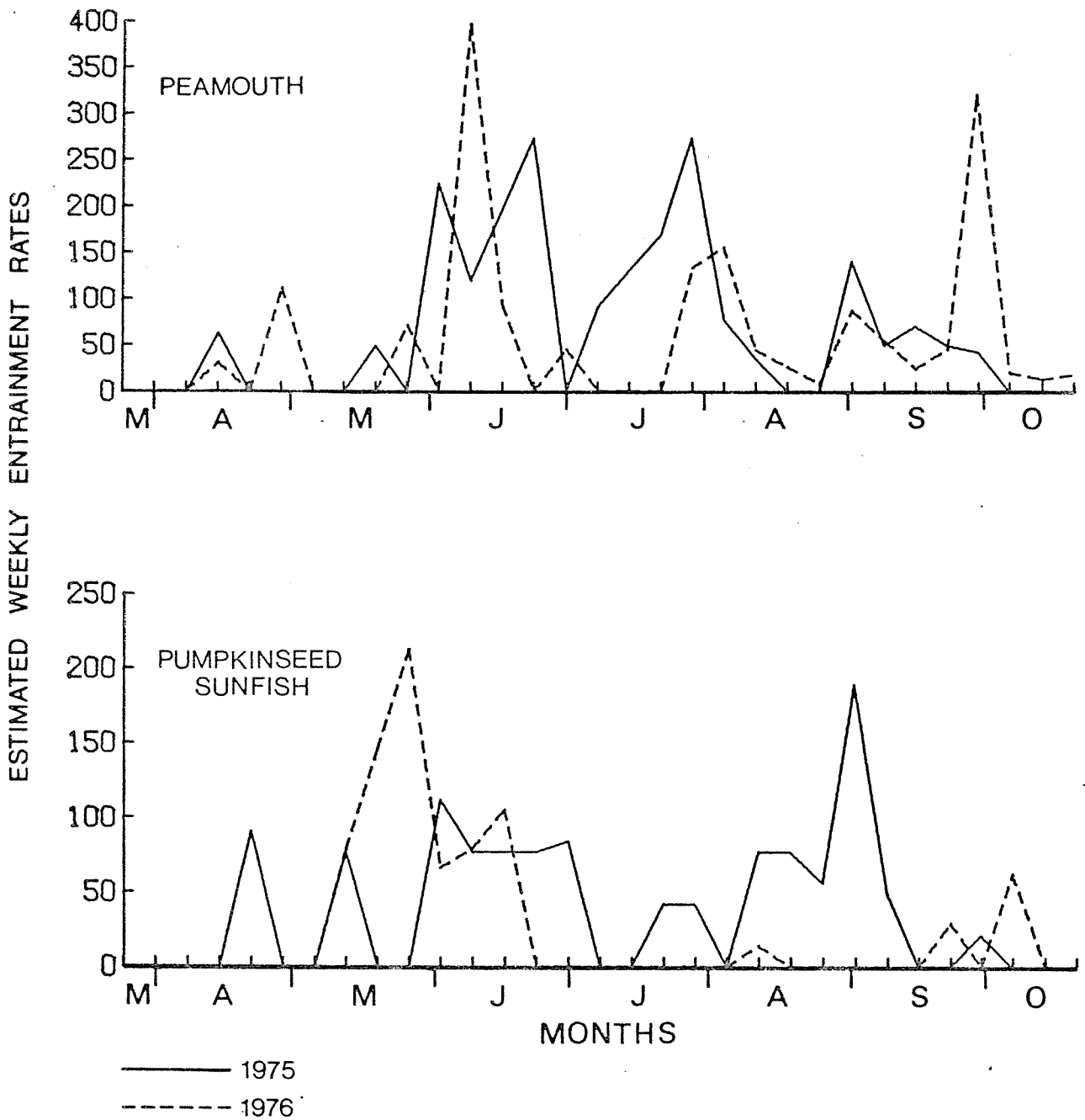


Fig. 8.19 Total estimated weekly entrainment rates for peamouth and pumpkinseed sunfish through the irrigation canal in 1975 (solid) and 1976 (dashed).

walleye in 1975 and six in 1976 were caught. Three largemouth bass were caught in both 1975 and 1976 and three brown bullhead were caught in 1975 as well as in 1976. One Dolly Varden trout was caught in May 1976.

A single specimen of white sturgeon, *Acipenser transmontanus*, heretofore unknown in Banks Lake, was caught in an irrigation canal net in August 1977. The fish measured 570 mm and weighed 750 g.

8.5 Discussion

8.5.1 Gear

Factors considered in the selection of the net in order of importance were: 1) current velocity; 2) range of fish sizes; 3) swimming capabilities of fish species; and 4) volume of the catch anticipated during a 12-hr sampling period. These factors dictated selection of three sampling locations in the canal, a 25.4-mm (1-inch) stretch mesh size of #252 fine-thread knotless nylon, and net openings of 6 x 8 ft (downstream net) and 12 ft² (upstream net).

The principal consideration was whether the net strength was adequate to withstand the relatively high velocity of the water surges (5 fps) in the turbulent flow below the canal headworks. Stress was increased as catches accumulated during the 12-hr sampling periods, at times weighing up to 136 kg (300 lb). Net material was selected for high tensile strength (test 34 kg, 75 lb) and resistance to abrasion.

Mesh size was of secondary importance. This selection necessarily was a compromise between the benefits and deficits of small and large mesh sizes. Small mesh reduced the bias against catching small fish, but increased drag by decreasing the ventilation rate, and thereby slowed the current and allowed larger fish to escape. Large mesh,

conversely, increased the bias against catching small fish, but reduced drag, promoted higher current velocity through the net and more effectively sampled the larger fish. A mesh size of 1 inch was selected as the best compromise for sampling the aggregation of species present in Banks Lake.

The sampling location of the downstream net influenced catch selectivity. Downstream nets were fished in turbulent white-water of highest velocity consistent with the strength of the net and supporting gear. This reduced the visibility of the net and consequently the rate of avoidance. Comparison of results obtained by concurrently fishing a net from the tunnel faces (upstream location) and from the end of the concrete apron (downstream location) indicated that the larger, faster swimming salmonids (rainbow, kokanee) may have been able to escape from and avoid the downstream net.

The size of the net opening influenced the degree of selectivity for larger fish at the downstream site. As the net opening increased, the selectivity against larger fish decreased. However, because the downstream net was handled manually, the size of the opening was limited for practical reasons to the 6- x 8-ft dimensions used. The upstream sampling nets were nearly as wide as the outlet tunnels and thus the opportunity for avoidance was greatly reduced. Because the upstream nets were positioned in turbulent white-water immediately below the outlets of the darkened tunnels, the opportunity for avoidance was negligible, even for the largest salmonids.

8.5.2 Factors Affecting Entrainment

Two modes of entrainment were observed: Active and passive. Fish may actively seek an outlet from the lake for spawning, feeding, or smolting purposes, and may be guided by the direction and magnitude of water currents. Fish may be passively entrained as a result of their position in the water column and proximity to the outlet. This entrainment is most likely to occur at night when the fish are resting and when they are unable to maintain visual orientation to the bottom.

Behavioral factors which influenced the entrainment of Banks Lake fishes were those which affected distribution and activity related to foraging, temperature tolerance, spawning, or smolting behavior. Influencing environmental factors were water temperature, availability of food, photoperiod, and rate of irrigation withdrawal. Rate of irrigation withdrawal was the single overriding factor which influenced the entrainment rates of all species.

The entrainment of perch was influenced primarily by nearshore spawning activity, which took place during April and May; secondarily by foraging activity, which peaked in July commensurate with maximum water temperatures; and thirdly, by the timing of offshore movement of juveniles. The entrainment rate of ages II and III perch dropped sharply from August through the remainder of the season due to the normal offshore movements of yellow perch. In 1975, age I fish comprised a substantial portion of the catch throughout the irrigation season, whereas in 1976, they were absent until August. Reasons for this behavior are speculative. Obviously, yellow perch responded to additional factors not monitored by this study.

The peak entrainment rate of kokanee during the third and fourth weeks of July 1975 coincided with peak abundance at Station 6 and with highest levels of pumping and irrigation water withdrawal. Of these fish, 58 percent were maturing age 3- and 4-year-olds.

The drastic drop of kokanee in the 1976 entrainment was due to the low abundance of kokanee in the lake. These were the spawners from the small 1973 year class.

One puzzling difference between the July and August entrainment maxima was the diel difference in entrainment rates. During July, the majority of entrainment occurred during the day, while during August, most entrainment occurred at night. During neither of these time periods did the catch length-frequency composition vary significantly from day to night. The decreasing rate of entrainment during September and October was related to decreasing irrigation withdrawal.

Kokanee were entrained differentially through the six outlet tunnels. The two outside tunnels had consistently higher entrainment rates and were about equal; while entrainment through the four inside tunnels was consistently lower and approximately equal. During June and August 1975, gillnets were set along the shoreline adjacent to the irrigation canal headworks. Kokanee catches were very small in relation to the canal net catches. This suggests that kokanee were not following the shoreline formed by Dry Falls Dam but were entering the irrigation canal headworks via the 16-m deep drainage channel which leads into the headworks from a point north of the center of Dry Falls Dam.

The entrainment of lake whitefish in 1975 was influenced by temperature and by spawning activity. Catches were reduced during July and

August in response to warm surface water temperatures which lake whitefish tended to avoid. During midsummer, the lake whitefish were concentrated in the deep, cool water of the hypolimnion which placed them below the level of the discharge flow. Until the second week in September, the entrained lake whitefish were predominantly immature. From September until the end of irrigation in mid-October, the majority was mature.

In 1976, the early peak entrainment of lake whitefish was due to a large catch of age I fishes. The reduced numbers later in the season cannot be readily explained.

The entrainment of longnose suckers was largely influenced by spawning behavior. The spawning period was relatively short. Spawning individuals were observed in the catch only during a 2-week period from May 11 to May 25 during 1975. Spawning individuals were also observed during this term in 1976.

Carp were entrained in small numbers during the peak of spawning which occurred in June. This low rate may have resulted from the preference by spawning carp for shoreline habitat with abundant aquatic vegetation. The outlet of the irrigation canal was probably avoided by spawning carp because it lacked aquatic vegetation. Entrainment rates peaked when foraging schools of age 0 juveniles were entrained during mid- and late August in 1975.

The marked decline after June in the canal catch of 1974 planted age I chinook probably reflects decreasing abundance of that year class in the lake. The age 0 chinook which were planted in June 1975 appeared in the irrigation canal for the first time on July 3, nearly 30 days after the date of first release. The peak entrainment of chinook occurred

during the next 4 weeks and consisted almost entirely of the June 1975 plants. An estimated 30.8 percent of the 19,000 chinooks planted in June 1975 were entrained during the 1975 irrigation season. This represents a rather substantial loss, particularly since normal mortality and sport catch had already reduced the population. The high entrainment rate was probably due to the combined factors of foraging and smolting behavior, with the latter being the principal factor involved.

The low occurrence of chinook in the 1976 catch was due to the total loss of the 1974 plants and the apparent loss in 1975 of the 1975 plants. In 1976, the chinook planting was delayed until September 23 when 45,840 were planted at Station 1. This planting strategy minimized the immediate loss through entrainment in the irrigation canal.

The timing of the appearance of mountain whitefish in the irrigation canal catch was dissimilar to that of the lake whitefish. The mountain whitefish has a more southerly zoogeographic distribution than the lake whitefish and tolerates much warmer water. This may, in part, explain the correspondence of the mid-July to mid-August entrainment maximum with peak yearly temperature at Station 6.

The entrainment of peamouth was influenced by spawning activity during June and possibly by temperature-induced activity during mid- and late July 1975.

The prickly sculpin is a small benthic fish which exists in large numbers along the rocky shorelines of Banks Lake. Because of its small size, it seems likely that individuals of this species were able to pass through the sample net and the entrainment estimates were substantially biased.

Pumpkinseed, black crappie, largemouth bass, and walleye are found only infrequently at Station 6 near Dry Falls Dam, but are relatively abundant elsewhere in the lake. The entrainment rates for these four species were consistently low. No entrainment occurred during the spawning period of these fishes which suggests that they spawn elsewhere in Banks Lake.

The burbot is now rare in Banks Lake. A single 250-mm immature individual was captured, indicating that a remnant population remains.

In 1976, the entrainment of nearly all species decreased during September and October. Although water temperature was still relatively high during this period, and most species were active, the rate of flow through the irrigation canal had sharply decreased. Therefore, it seems likely that the decrease in entrainment was related to the decreased rate of water withdrawal.

9.0 FISH ENTRAINMENT (FEEDER CANAL)

9.1 Introduction

The entrainment of fish through the feeder canal is bidirectional and dependent on season and operational mode. The feeder canal conducts irrigation water from FDR Reservoir to Banks Lake during the irrigation season, which normally begins in March, and ends in October each year. During the winter months from November to March, the feeder canal conducts water into Banks Lake during the pumping mode and out of Banks Lake during the generation of electrical energy in the pumped/storage power-plant. This fisheries investigation began in June 1973 to determine the amount of fish entrainment which would occur with P/G operation. Operation of P/G 7 and 8 was conducted on a test basis during 1974 and 1975, however, mechanical difficulties with the pump turbines prevented routine winter operation during the course of this study. Data obtained from the test operation periods of P/G 7 and 8 and during the 1976 irrigation pumping season are reported.

9.2 Description of Feeder Canal

The feeder canal (Fig. 4.1) is a 1.6-mi long, concrete-lined structure leading from the pumphouse conduits in Grand Coulee Dam into Banks Lake. This canal receives water which is pumped up 365 ft from FDR Reservoir at a present maximum rate of 13,100 cfs (eight pumps). During periods of peak power demand, water is siphoned from Banks Lake through the feeder canal to the pumphouse in the left forebay of Grand Coulee Dam, and back into Roosevelt Lake where the two pump/generation units now in operation produce 50,000 kw each of peaking power. Future plans call for the installation of four additional pump/generation units and

consequent modifications of the feeder canal to handle increased flows to 14,400 cfs in the generation mode and 20,100 cfs in the pumping mode. These modifications are planned for the November to May periods of 1978, 1979 and 1980.

The headworks of the feeder canal is a concrete structure with 12 tunnels 15 ft high x 12 ft wide, which empty into the canal. The original six irrigation pumps were installed to operate in tunnels 1 to 6 and pump/generation (P/G) units presently operate in tunnels 7 and 8. The remaining four tunnels will eventually connect with future pump/generation units. The depth of the canal at the headworks is approximately 30 ft. P/G operation will occur during the months from November through March and will not occur simultaneously with irrigation withdrawal.

9.3 Materials and Methods

9.3.1 Sampling Gear

Attempts to develop a sampling capability to measure the entrainment of fishes through the feeder canal met with several formidable obstacles which stymied the work initially in 1975, but which were gradually overcome later in the season and employed during the 1976 season. The development of fixed-net sampling was complicated by: 1) Bidirectional flow over a range of velocities from 1 to 6 fps in the canal and approximately 12 fps at the stop-log slots of the headworks; 2) the presence of a variety of fish species encompassing a broad range of sizes, swimming capabilities, and behavioral responses to water velocity; 3) the occasionally large resident fish population in the feeder canal to be excluded from the pump mode entrainment samples.

The sampling problem in the feeder canal was solved by employing two types of gear. A downstream net similar to the one used in the irrigation canal was used in the stop-log slots of pump units 1 to 6 to monitor entrainment during pumping. A closed-circuit television (CCTV) camera installed and operated by the USBR Engineering and Maintenance Division at Grand Coulee Dam was used to monitor the pump and generation modes of P/G units 7 and 8 (Fig. 9.1). The CCTV system was the only sampling method found to monitor P/G operation since the use of net gear was precluded by the trash racks installed at the feeder canal headworks.

Monitoring of the feeder canal by means of closed-circuit television was planned for the winter of 1976-77 to obtain information which was lacking in full-scale, simultaneous operation of both P/G units. Of particular interest was the entrainment rate during the early and late portions of the P/G season, i.e., November, December, and March. However, a breakdown of P/G 8 precluded following this schedule until January, by which time the most important part of the season was past. The remaining schedule was cancelled because of the discontinuity and high turbidity of the water pumped from FDR Reservoir which reduced the visibility.

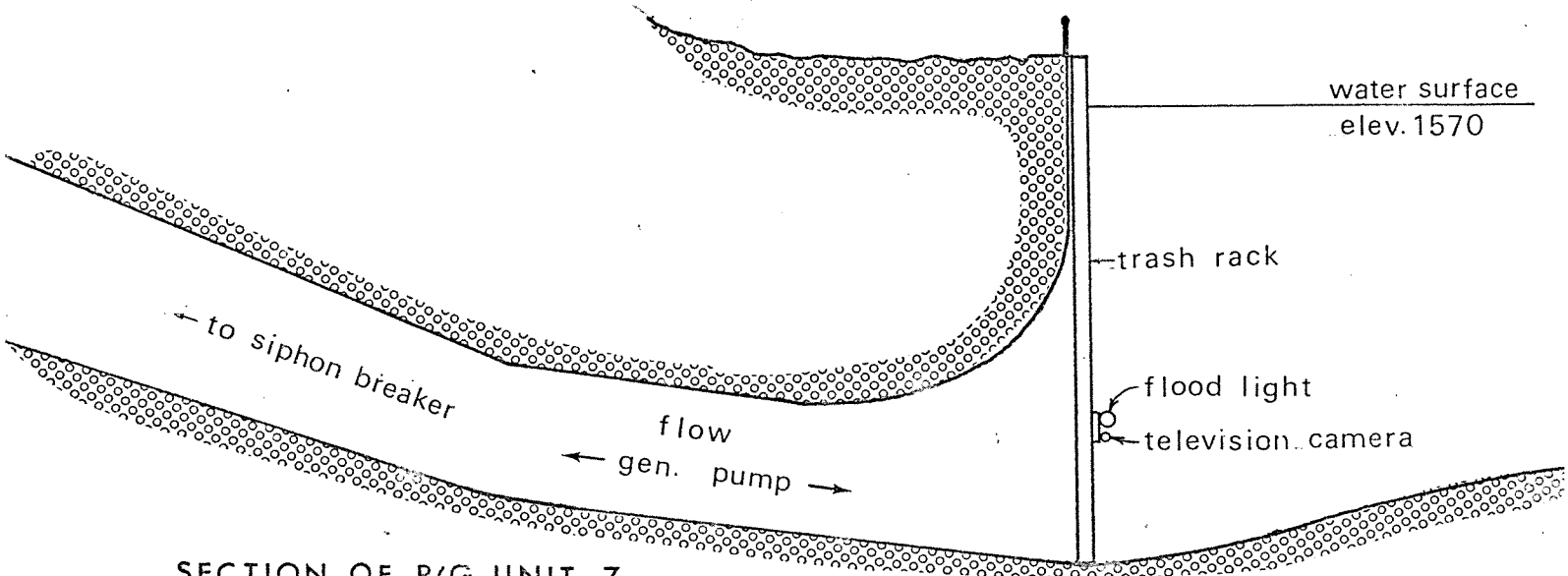
9.3.2 Generation Mode

The television camera was mounted to a vertical bar on the outer edge of the trash rack by means of a specially constructed bracket which held both the television camera (Edo Western) and floodlamp (150-w thalium iodide) (Fig. 9.1). A team of USBR divers installed the bracket with the camera and floodlamp aimed horizontally across the opening of the P/G unit. The power supply-video cable was led to a video unit and tape recorder (Sony AV650) housed in the siphon-breaker house 150 ft

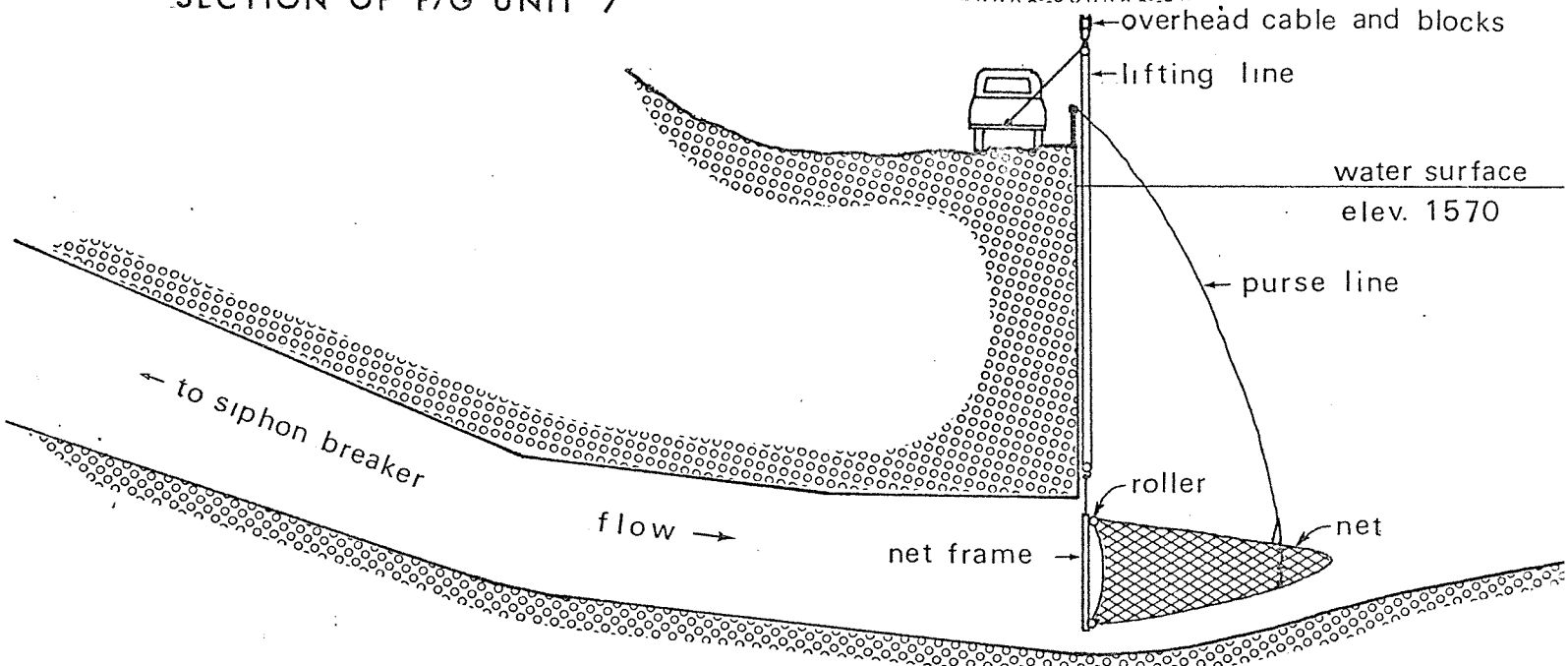
Location of Section P/G Unit 7

Location of Section Pump Unit 6

VIEW OF PUMP UNIT 6 AND P/G UNIT 7



SECTION OF P/G UNIT 7



SECTION OF PUMP UNIT 6

Fig. 9.1 Position of sampling apparatus in the flows during pump/generation and pump units at feeder canal headworks.

away from the trash racks. The camera angle was 48 degrees, which enabled viewing of approximately one-fourth of the entire area of the trash rack during conditions of low turbidity which included a 54-ft² area. The viewed area during turbid water conditions was determined by counting the number of vertical bars visible across the face of the trash rack.

The high current velocity through the trash rack (12 fps) made positive identification of most fish difficult even during stop-action and slow-motion playback of the videotape; however, rainbow, chinook, and lake whitefish were positively identified.

9.3.3 Irrigation and Pumpback Mode

A quantitative net sampling capability was developed in the feeder canal during the spring and summer of 1975. This gear underwent considerable revision during the 1975 irrigation season to develop a net and frame to withstand the high water velocities encountered. Sampling was not standardized until late summer. Gear development precluded quantitative assessment of the 1975 entrainment, but the method was determined to be valid and used during the 1976 irrigation season.

The sampling gear consisted of a cableway directly over the trash rack slots of the feeder canal headworks from which a 14-ft x 14-ft net frame was suspended. The frame was equipped with casters on the downstream side at each corner, which allowed the frame to roll up and down in the slots while under tension from the drag of the net. The net was raised and lowered from the cable way by a lift line through two double blocks. Lifting was accomplished by securing the lift line to a vehicle which was driven away slowly.

Three types of nets were employed during the season. A large net 12 ft² similar to that used in the irrigation canal was used during the first part of the season. A problem occurred with this net in that it would not gravitate to the bottom where the highest velocity laminar flow occurred. During times of reduced canal flow larger fish were able to swim upstream in the feeder canal to the headworks. Many attempted to negotiate passage down the siphon tunnels and were swept into the net. These constituted a source of error in estimating the entrainment from Roosevelt Lake. To minimize this effect, a smaller 6-ft x 8-ft net which could be positioned completely within the laminar flow near the bottom of the tunnels was employed for the remainder of the season. The fact that this net fished well within the laminar flow greatly reduced the opportunity for upstream migrating salmonids to enter the net. A third net was also fished. This net was designed to assess the entrainment of juvenile fish into Banks Lake. The net measured 6 x 6 ft at the entrance, was constructed of 1/4-inch stretch mesh of thread size #147, and was fished on 15-ft warps from the frame in water of reduced velocity in order to reduce the pressure on the small mesh. The net fished well within the laminar flow and was presumed to sample effectively those fish which were not capable of swimming against the water velocities found in the feeder canal (juvenile fishes and cottids). Estimates of the number of fish entrained were calculated by the same method as was used on the irrigation canal data.

9.4 Results

9.4.1 Irrigation and Pumpback Mode

A total of 15 species numbering 152,895 fish was entrained in the feeder canal during the 1976 season. Of the total, 141,013 were sculpins (*Cottus asper*) (Table 9.1). The actual catch by gear type used in the feeder canal in 1976 is shown in Table 9.2.

No burbot (*Lota lota*) were entrained during 1976, but three species not observed in 1975 were caught; bridgelip sucker (*Castostomus columbianus*); black crappie (*Pomoxis nigromaculatus*); longnose sucker (*Catostomus catostomus*).

9.4.2 Kokanee

An estimated 3,073 kokanee were entrained during 1976. Kokanee ranked second in abundance during both years of the study. Excluding prickly sculpin, kokanee constituted 26 percent of the catch in 1976. Kokanee were entrained regularly during the early part of June and sporadically throughout the rest of the season (Fig. 9.2). Of the kokanee entrained, 16 percent were age 0, with an average length of 67 mm; 13 percent were age I, with an average length of 178 mm; and the remaining 71 percent were greater than age I, with an average length of 384 mm (Fig. 9.2). Analysis of maturity showed that 21 percent of the kokanee entrained were immature, 60 percent were mature males, 17 percent were mature females, and 2 percent were spent females.

Data obtained during the FDR Reservoir study (Stober et al. 1977) showed the kokanee age composition in the reservoir to be 49 percent age I, 49 percent age II, and 2 percent age IV. Individuals in all stages of

Table 9.1 Total estimated entrainment through the feeder canal for each species during the 1976 irrigation pumping season (March to October). Pumping was stopped for a 2-week period in April.

Species	1975 Relative Order of Abundance	Scientific Name	Estimated Number Entrained	Interval Estimate $\alpha = .05$	Relative Number (%)**	Estimated Weight Entrained (kg)	Relative Weight (%)
Prickly sculpin	1	<i>Cottus asper</i>	141,013* \pm 1,077,151		-----	70.6	.005
Kokanee	2	<i>Oncorhynchus nerka</i>	3,073 \pm	1,726	.259	964.1	.083
Carp	6	<i>Cyprinus carpio</i>	2,784 \pm	1,239	.234	366.4	.630
Largescale sucker	3	<i>Catostomus macrocheilus</i>	1,704 \pm	1,064	.143	2,067.8	.156
Walleye	11	<i>Stizostedion vitreum</i>	1,226 \pm	276	.103	745.7	.056
Yellow perch	10	<i>Perca flavescens</i>	1,092 \pm	690	.092	10.6	.001
Lake whitefish	4	<i>Coregonus clupeaformis</i>	519 \pm	210	.044	432.7	.033
Northern squawfish	9	<i>Ptychocheilus oregonensis</i>	464 \pm	210	.039	247.2	.019
Rainbow trout	7	<i>Salmo gairdneri</i>	245 \pm	233	.021	58.8	.004
Longnose sucker		<i>Catostomus catostomus</i>	189 \pm	217	.016	102.7	.008
Black crappie		<i>Pomoxis nigromaculatus</i>	179	-----	.015	-----	.001
Peamouth	5	<i>Mylocheilus caurinus</i>	174 \pm	318	.015	18.6	.001
Chinook salmon	12	<i>Oncorhynchus tshawytscha</i>	167 \pm	224	.014	146.5	.011
Mountain whitefish	8	<i>Prosopium williamsoni</i>	44 \pm	127	.004	12.9	.001
Bridgeliip sucker		<i>Catostomus columbianus</i>	22 \pm	62	.001	31.4	.002
Total			152,895			13,290.3	

* one-week catch was 122,103. Total without sculpin: 11,882

** calculated without sculpins which comprised 88% of the total numbers entrained.

Table 9.2. Catch of fishes in the feeder canal during irrigation pumping in 1976.

Species	Total	12x12' net	6x8' net	4x4' net (1/4 inch mesh)
Yellow perch	19	7	12	0
Lake whitefish	5	2	1	2
Peamouth	3	1	2	0
Longnose sucker	7	6	1	0
Carp	82	53	29	0
Black crappie	1	0	1	0
Walleye	16	8	8	0
Rainbow	3	1	2	0
Prickly sculpin	429	48	11	370
Kokanee	123	117	2	4
Largescale sucker	48	33	15	0
Mountain whitefish	2	2	0	0
Squawfish	12	10	1	1
Chinook	11	11	0	0
Bridgelip sucker	2	2	0	0
	<u>763</u>	<u>301</u>	<u>85</u>	<u>377</u>

Total No. Catches = 110, or 123 diel periods

97 12-hr catches, 13 24-hr catches

Gear 8 -- 67 catches, 7 24-hr catches; 74 diel periods fished

Gear 9 -- 28 catches, 4 24-hr catches; 32 diel periods fished

Gear 10 -- 15 catches, 2 24-hr catches; 17 diel periods fished

FEEDER CANAL KOKANEE LENGTH FREQUENCY

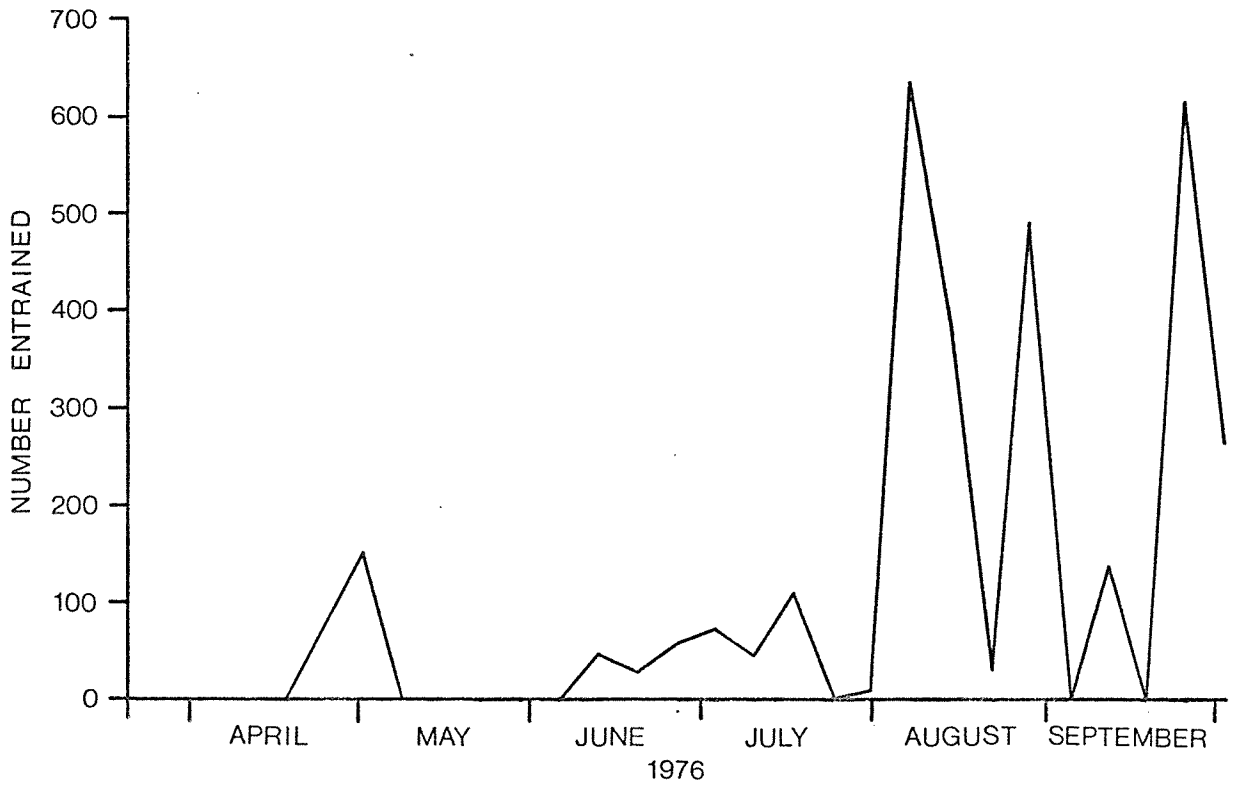
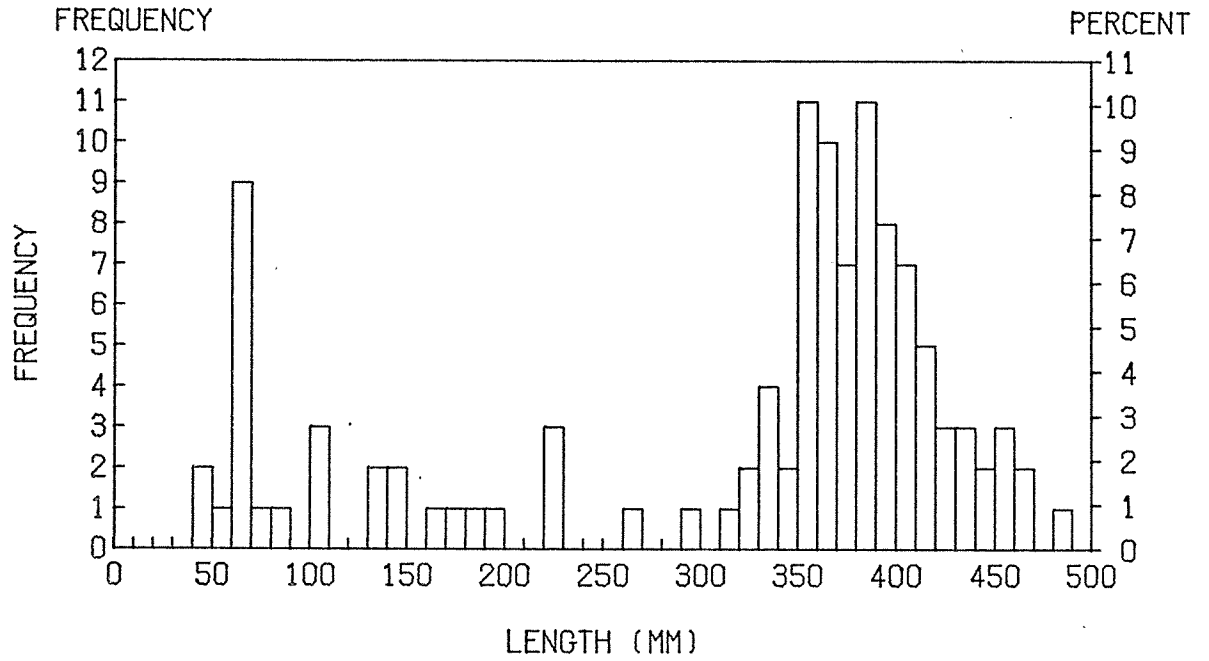


Fig. 9.2 Length frequency and seasonal entrainment rate of kokanee in the feeder canal during irrigation pumping, 1976.

maturity were collected in that study. About 25 percent of the catch was immature and the rest were in various stages of prespawning development.

9.4.3 Carp

An estimated 2,784 carp were entrained during the 1976 season. Carp ranked third in 1976 in numbers and sixth in 1975. Due to their large average size (573 mm in length, and 3,345 g weight) they comprised 63 percent of the biomass entrained.

Carp were entrained sporadically throughout the season; however, the majority was caught during June and July.

9.4.4 Prickly Sculpin

An estimated 141,013 prickly sculpin were entrained in the feeder canal during 1976. Of 429 sculpins actually caught, 370 were caught in the 4 x 4-ft fry net which was fished for only 17 diel periods, as compared with 59 sculpins caught in the 12 x 12-ft net which was fished for 106 diel periods. One diel fry net catch of 294 sculpins was the basis for an estimated 1-week entrainment of 122,103. In general, the estimated number of sculpins entrained was low due to the bias against them by the larger mesh net.

Due to their small average size (59 mm) sculpins accounted for only 0.005 percent of the biomass entrained.

9.4.5 Other Game Fish

Other game fish entrained in the feeder canal included an estimated 1,226 walleye, which ranked fifth in abundance. Of those entrained, 38 percent were age 0, with an average length of 91.6 mm; 38 percent

were age I, with an average length of 283 mm; the remaining 24 percent were age > I. One specimen of undetermined age measured 637 mm.

An estimated 1,092 yellow perch were entrained. Yellow perch ranked sixth in abundance and comprised 9 percent of the total catch. The average length of yellow perch was 88.4 mm.

An estimated 519 lake whitefish were entrained in 1976. Average length at age was 382.6 mm for age III (75 percent of catch) and 450.0 mm for age IV (25 percent of catch). Lake whitefish comprised 4.4 percent of the total catch.

An estimated 245 rainbow trout were entrained, comprising 2.1 percent of the catch.

Other fish entrained were 179 black crappie, 167 chinook salmon, and 44 mountain whitefish. All comprised less than 2 percent of the total catch.

9.4.6 Other Nongame Fish

An estimated 1,704 largescale suckers were entrained during 1976. Due to their large average size (443 mm, 1,199 g), they comprised 16 percent of the total biomass.

Other nongame fish entrained included 464 northern squawfish, 189 longnose suckers, 174 peamouth, and 22 bridgelip sucker.

9.4.7 Generation Mode

The operating schedule of P/G units 7 and 8 since November 1974 is summarized by week in Table 9.3. During the winter of 1974-75, P/G units 7 and 8 were run primarily for performance testing on a sporadic schedule for relatively short time periods. The units were operated on

Table 9.3. Summary of operating times, discharge volumes, and weeks sampled for P/G units 7 and 8.

Date	P/G 7 & 8 - Pumping		P-1 - P-6 Pumping	P/G 7 & 8 Generating		Weeks Sampled
	Run Time (hrs)	Acre-ft	Acre-ft	Run Time (hrs)	Acre-ft	
1974 12/01-07	00:45	119.01	0	15:56	3,242.97	
12/08-14	10:41	1,709.75	0	06:11*	1,243.64	
12/15-21	01:03	166.61	0	00:63	186.45	
12/22-28	00:11	27.77	0	03:43	704.13	
1975 12/29-1/04	00:00	0	0	00:45	107.11	
1/26-2/01	00:00	0	3,584.13	44:18	7,352.72	X
2/02-08	16:05	2,513.06	0	00:00	0	
2/09-15	31:03	4,851.57	0	08:48	1,315.04	X
2/16-22	00:00	0	0	20:58	3,544.46	
2/23-3/01	40:49	6,253.88	0	38:38	5,162.97	
3/02-08	38:55	5,918.68	0	07:57	1,311.07	X
1976 1/18-24	00:52	140.83	0	23:56	3,574.21	
1/25-31	13:54	2,207.60	5,875.04	29:31	5,063.80	
2/01-07	64:12	10,195.04	0	53:29	9,911.40	
2/08-14	53:17	8,467.43	0	36:32	6,585.12	X
2/15-21	31:58	4,982.48	49.50	36:44	6,884.62	
2/22-28	65:48	9,822.14	0	37:40	7,429.16	
2/29-3/06	35:33	6,436.36	0	69:40	12,846.94	
3/07-13	60:30	8,495.20	6,390.74	39:27	7,207.93	
3/14-20	46:56	6,083.30	12,751.73	15:32	2,723.30	
3/21-27	22:56	2,624.13	21,235.03	25:41	4,308.10	
3/28-4/03	48:59	5,246.28	29,722.30	00:00	0	
4/04-30	00:00	0	89,177.22	00:00	0	
5/01-18	09:57	1,229.58	268,284.06	00:00	0	
5/19-31	00:00	0	0	00:00	0	
6/01-30	695:08	109,309.00	353,873.00	01:39	105.00	
7/01-31	744:00	118,911.00	350,747.00	00:00	0	
8/01-29	685:09	109,950.00	208,254.42	00:00	0	
8/29-9/03	00:00	0	31,743.36	00:00	0	
9/04-30	636:30	101,845.00	160,661.00	00:00	0	
10/01-06	144:00	24,542.10	21,358.00	00:00	0	

* Estimated value.

request of the Fisheries Research Institute once each month during January, February, and March 1975, during which times observations of entrainment rates were made using closed-circuit television (Third Annual Report op cit).

During the winter of 1975-76, P/G 7 was operated solely because P/G 8 was disassembled for mechanical repair. A minimal operation schedule, similar to that of 1974-75, was forecast by Grand Coulee Operations until late January, at which time a relatively full operating schedule was begun in response to increased power demand. The entrainment of fishes was observed by means of closed-circuit television during 2 weekly periods--January 20 to 23 and February 9 to 11. The results are summarized in Table 9.4. The visibility was greatly reduced during the February sampling. A third sample period scheduled for March 5 to 7 was cancelled because of high turbidity caused by spring runoff and by drawdown of FDR Reservoir.

The portion of the total flow which was observed was determined by counting the number of bars visible across the trash rack on which the camera was mounted. During good visibility in January, approximately one-fourth of the 12-ft x 12-ft opening was visible, but during turbid conditions in February, only one-eighth of the area was visible.

The estimated entrainment rate for P/G 7 was 1.58 fish/hr during generation and 0.00 fish/hr during pumping in 1976. Of the eight fish actually observed, five were identified as rainbow, one as a whitefish, and two were unidentified. The entrainment rate was less than that observed during a similar period in 1975 when 4.7 fish/hr/P/G unit were estimated.

Table 9.4 Summary of observations of entrained fishes of the feeder canal headworks during P/G operation, 1975 and 1976.

Date	Gear	Time		Hours	Mode	Fish Viewed (Identified)	Entrainment		Adjusted ¹ Entrainment Rate/hr
							Observed Entrainment Rate/hr	Rate/hr	
1/30/75	TV	0800 to 1130		3.7	G	6 (2 rainbow)	1.62	6.49	
		1600 to 2000		4.0	G	8 (1 lake whitefish)	2.00	8.00	
1/31/75	TV	0800 to 1200		4.0	G	5 (1 chinook, 3 perch)	1.25	4.00	
		1600 to 2000		4.0	G	1	0.25	1.00	
2/01/75	TV	0800 to 1200		4.0	G	2 (1 rainbow)	0.50	2.00	
		1600 to 2000		4.0	G	1	0.25	1.00	
2/10/75	TV	1030 to 1330		3.0	G	2	0.67	2.67	
		1600 to 2000		4.0	G	2	0.50	2.00	
3/02/75	TV	1500 to 2000		5.0	P	0	0.00	0.00	
3/03/75	TV	0800 to 1200		4.0	G	1	0.25	1.00	
				4.0	G	2	0.50	2.00	
				40.5		30			
1/20/76	TV	1705 to 2040		2.0	G	1 (rainbow)	0.50	2.00	
1/21/76	TV	0700 to 1000		3.0	G	3 (2 rainbow)	1.00	4.00	
1/23/76	TV	0655 to 1100		4.0	G	0	0.00	0.00	
		1700 to 2000		3.0	G	2 (rainbow)	1.00	4.00	
1/25/76	net	0800 to 1700		9.0	P	0	0.00	0.00	
2/09/76	TV	1750 to 2005		2.0	G	1 (whitefish)	0.50	1.80	
2/10/76	TV	0405 to 0605		2.0	P	0	0.00	0.00	
		0700 to 0900		2.0	G	1	0.50	2.80	
		1700 to 2000		3.0	G	0	0.00	0.00	
2/11/76	TV	0400 to 0600		2.0	P	0	0.00	0.00	
		0700 to 0900		2.0	G	0	0.00	0.00	

¹ counts are adjusted for portion of opening sampled.

9.5 Discussion

The development of a standard net to sample fishes entrained in the feeder canal was complicated by high water velocity (10 fps) and the presence of a variety of fish species encompassing a broad range of sizes, swimming capabilities, and behavioral responses to water current. This range of requirements could not be met by any single net. The standard sampling net was necessarily a compromise which enabled quantitative sampling on all but the smallest fishes. Thus, the estimates of small fish (sculpins and fry of all species) were undoubtedly low. Periodic use of the fry net provided some information on the entrainment of small fishes but it was impossible to fish the fry net at all times of the season. A second source of error concerned those fish which were capable of swimming against the current such as larger kokanee, carp, and chinook. Some of these are assumed to have swum into the tunnel opening and then been swept downstream into the net. One example of this was the catch on August 29, 1975 of a chinook salmon measuring 87 cm and weighing 2,270 g. This fish probably originated from a plant of approximately 1.8 million chinook fry into FDR Reservoir in 1972 and was mature at the time of its capture. Because of its excellent growth, it is believed the individual was entrained soon after its release and reared in Banks Lake. This capture coincided with the reported sport catch of several other large chinooks during the summer.

The rate of fish entrainment into Banks Lake was largely influenced by the seasonal vertical distribution and abundance of fish in Lake Roosevelt assuming that most entrainment was passive. The water in Lake Roosevelt began to stratify about mid-June, with the thermocline at

between 4 and 20 m subsurface (Fig. 9.3). The thermocline remained about the pump intake openings during the irrigation season. From mid-June until mid-September, 95 percent of all fish found in FDR Reservoir were located above the thermocline and therefore above the pump intakes (Fig. 9.4). Examination of fish abundance and distribution in FDR Reservoir (Stober et al. 1977) for the 1976 feeder canal season showed that the highest CPUE's occurred in surface gillnet catches. This explains why fishes such as squawfish, peamouth, suckers, and carp, which prefer the warmer surface waters, were not entrained into Banks Lake at higher rates during the summer, while kokanee, which reside below the thermocline, were entrained in greatest abundance excluding the prickly sculpin during both years. It was found, however, that during the 1976 season, FDR Reservoir had a very low abundance of kokanee. Walleye entrainment was also controlled by seasonal movements in FDR Reservoir. Walleye were absent during most of the year in the forebay but began to show up in gillnet catches in late summer and fall. Although walleye entrainment was sporadic and small, the appearance in the forebay and entrainment in the canal generally coincided. Squawfish and walleye were the most abundant species found in FDR Reservoir and their minor importance in the feeder canal entrainment samples was a fortunate result of thermal stratification and depth (30 m) of the pump intakes. Pumping during P/G operation from November-March, when stratification is lacking in FDR Reservoir, may entrain a larger number of squawfish and other nongame fishes which at that time may range to greater depth in FDR Reservoir. Verification will require sampling once the P/G units begin routine operation.

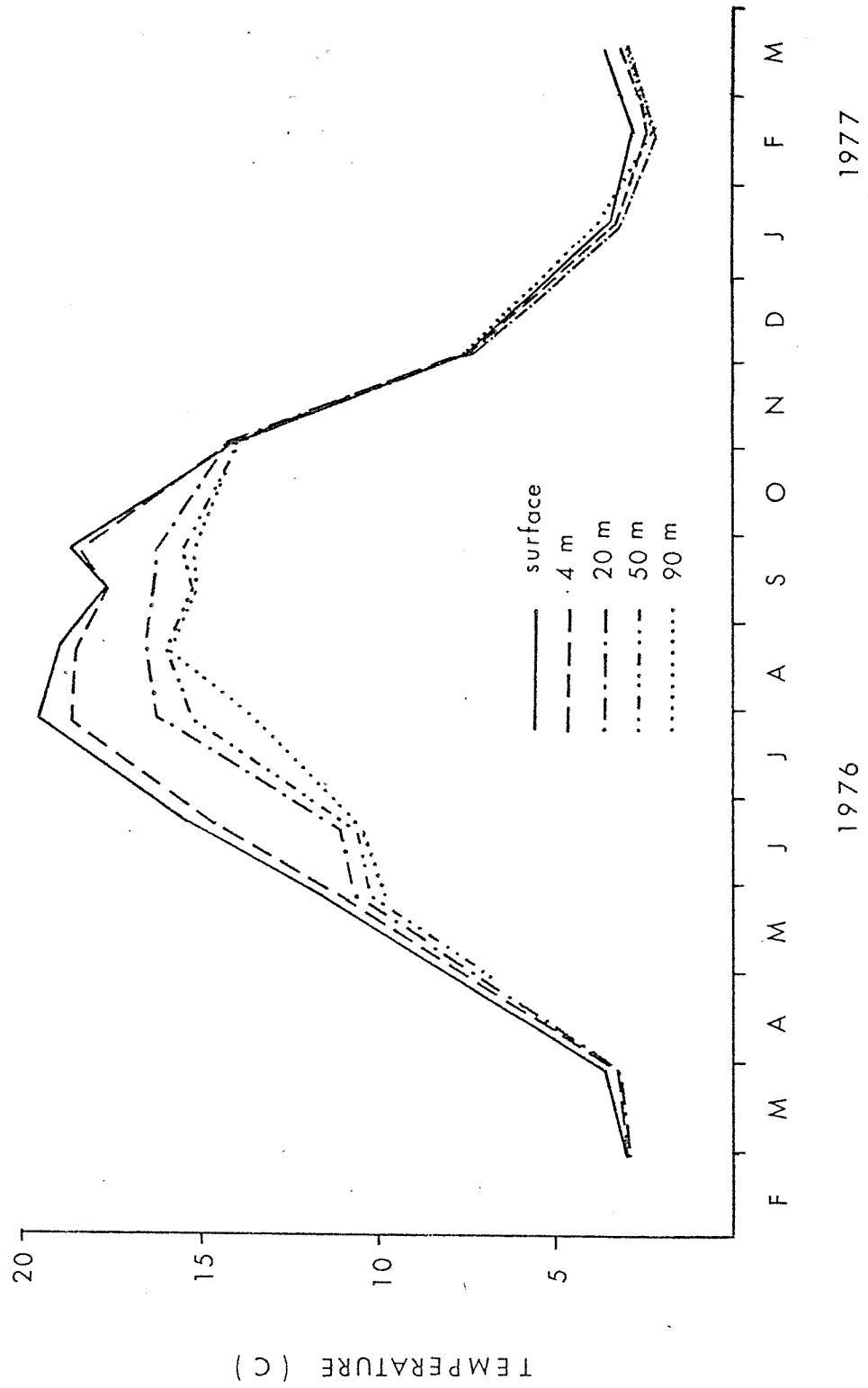


Fig. 9.3 Monthly water temperature at 5 depth strata in FDR forebay (Stober et al. 1977).

1976

1977

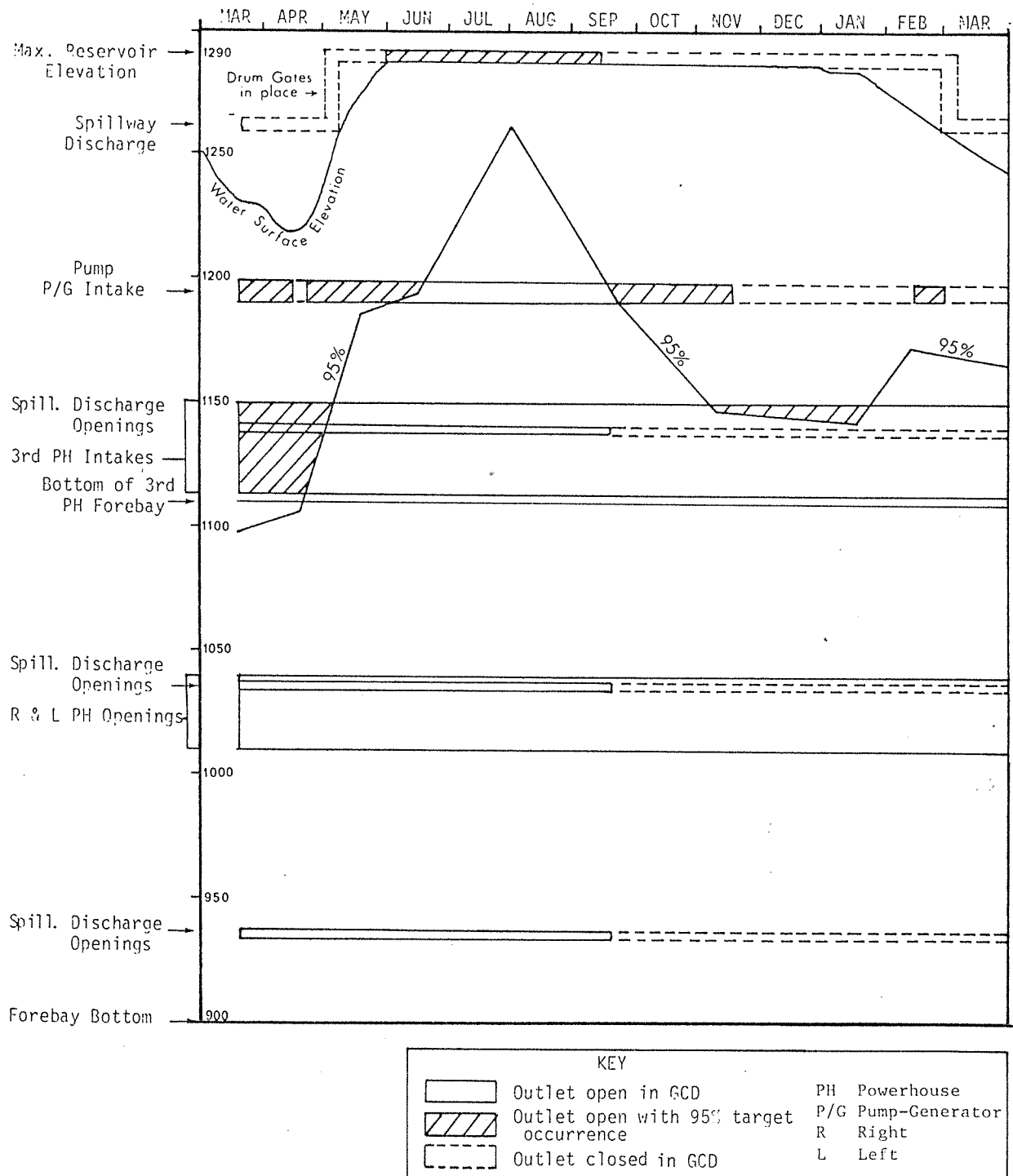


Fig. 9.4 Comparison between elevation of penstocks, spillway, and spill-discharge openings in Grand Coulee Dam and the monthly 95% level of fish target occurrence in FDR forebay, 1976-1977.

10.0 SUMMARY AND DISCUSSION

10.1 Aquatic Environment

The physical, chemical, and biological limnology of Banks Lake was examined in relation to irrigation pumping and drafting and pump-storage power generation. These parameters indicated a two-pool system emphasized by a morphometric constriction and shoaling of the lake basin. The northern pool which received the water pumped from FDR Reservoir was approximately 10 percent of the total lake volume. During peak irrigation withdrawal rates ($223.7 \text{ m}^3/\text{sec}$; 7,900 cfs), the average retention time ranged from 2.1 to 6.8 days in the north pool and 32 to 69 days in the south pool.

The pumped inflow maintained warmer temperatures in the winter and cooler temperatures in the summer in the north pool relative to the south pool. The turbulent inflow of cooler water to the north pool during the summer eliminated stratification in the north pool and resulted in a convergence zone where the cooler water from the north pool flowed under a warm epilimnetic layer of the stratified south pool. The temperature regime was one of modified dimixis possessing properties of both a stratified lake and a river-run reservoir.

The dynamics of the nutrient supply to Banks Lake are complex and directly influenced by the pumped input of water from FDR Reservoir. The input of plant nutrients (N and P) due to pumping resulted in higher primary production and phytoplankton biomass in the north pool. Nutrient levels were found to become depleted in the lake from north to south, particularly during the production season. Nutrient limitation due to a lower N:P ratio and low nitrate concentrations reduced primary production

in the south pool. The entire lake indicated nitrate limitation after pumping and drafting had ceased for a period of time.

Zooplankton input to the north pool from FDR Reservoir was mainly composed of *Cyclops* and to a lesser degree *Diaptomus* but their abundance was generally lower than in the south pool. *Daphnia* occasionally peaked in the north pool and occurred at consistently low levels throughout the south pool. The average zooplankton biomass for the entire lake was composed of 43.6 percent *Daphnia*, 22.6 percent *Diaptomus*, 20.1 percent *Cyclops*, 8.4 percent nauplii, and 5.4 percent *Bosmina* during the May to October period. Higher lake levels such as occurred in 1976 caused longer water retention in the north pool allowing greater zooplankton abundance to accumulate.

The two-pool basin and hydrology of this system make the classification of trophic type difficult. The winter mean nitrate concentration, nitrogen loading rate, and the level of chlorophyll a in the south pool are oligotrophic criteria, but chlorophyll a levels and ^{14}C primary production rates in the north pool indicated mesotrophic conditions. Phosphate levels indicated a eutrophic state while the zooplankton biomass estimates indicated a lake approaching mesotrophy. It appears that available nitrate is the major controlling factor and any additional nitrates added to the system should cause a corresponding increase in phytoplankton biomass. If this nitrogen loading rate were to increase in the future, the entire system may shift to a meso/eutrophic condition. It presently can be generally classified as a nitrate limited oligotrophic system.

A preliminary study of the benthic littoral zone indicated organisms were affected by reservoir drawdown. Chironomids and oligochaetes dominated the benthos and showed increased numbers from the north pool to the south pool. Recovery of the dessicated benthic areas appeared quite rapid when water levels remained stable for several months.

10.2 Fish Population Ecology

Twenty-two species of fish were identified in Banks Lake. These stocks originated from several sources including FDR Reservoir, small lakes which existed in the upper Grand Coulee prior to inundation, artificial stocking programs carried out by state and federal agencies, and possible release by sport fishermen. Yellow perch, lake whitefish, and kokanee salmon were the three dominant species in the lake which were selected for detailed analysis.

Analysis of gillnet sampling data over 45 months indicated the numerically dominant species in the lake was yellow perch. This species was found consistently in the lower 4 m of the water column, except during the summer when surface temperatures reached maximum levels. Yellow perch moved inshore during spring for spawning and offshore in the fall as temperatures decreased. Juvenile perch were reared inshore for protection to take advantage of a diverse food supply. A partial avoidance of the north pool was observed during irrigation pumping. Those perch which were resident in the north pool exhibited reduced growth rates and body condition. Food habits indicated nearly complete dependence on zooplankton of the genus *Daphnia*. Excellent growth rates for yellow perch up through age V were found in the south pool where

Daphnia were abundant. The gillnet catches indicated a decline in the abundance of yellow perch in 1976 and 1977.

Yellow perch spawning occurred during March and April in shallow shoreline areas. Depth distribution of spawners ranged from 0 to 60 ft, with maximum abundance at 6 ft. Incubation required from 3 to 4 weeks. Major drawdown of Banks Lake occurred during the spring-summer spawning, incubation, and rearing period of yellow perch. Water level declines of 24.9 ft, 23.6 ft, 8 ft, and 3.0 ft in 1973, 1974, 1975, and 1976, respectively, affected the reproductive habitat of perch in varying amounts; however, absolute estimates of population level effects could not be determined. During 1973 and 1974 the lake volume was reduced by about 50 percent during drawdown; however, the amount of shoreline habitat increased by about 25 percent. The abundance of yellow perch larger than 200 mm has continued to decline since 1974. This resulted in a smaller population of large perch available to the sport fishery. The actual mechanisms leading to the decline in abundance of larger perch are not known.

The lake whitefish was found to be a dominant species by numbers and biomass in the 1974 year class. Lake whitefish were found throughout the water column except during the summer when they were restricted primarily to the bottom strata. This distribution resulted from intolerance to warmer surface water temperatures during the summer. Juvenile and adult whitefish were captured inshore during the spring while temperatures remained cool. Adult lake whitefish moved inshore during December and January to spawn along the shoreline. A nearly complete avoidance of the north pool was observed during irrigation pumping. Maximum

abundance was found in the northern area of the south pool. This location may be a compromise between the preferred lower temperature of the north pool and higher food abundance of the south pool. The preferred food type was the cladoceran zooplankton *Daphnia*.

Differential behavior between size groups occurred during July, September, and December. Juveniles remained active during the summer and did not exhibit spawning behavior in December. Large nonfeeding adults greater than 350 mm in length estivated in a dense concentration in Devils Hole at depths ranging from 22 to 32 m over an area of about 82 acres. These fish dispersed in October as the temperature of the epilimnion decreased.

Growth rates could not be compared between pools due to general avoidance of the north pool. The growth between ages I and III was similar to that reported in other systems; however, growth appeared to stop at a length of about 435 mm. Age V appeared to be the maximum age obtained. Limited longevity and growth probably resulted from water temperatures which exceeded the preferred range for lake whitefish and from an almost exclusive dependence on zooplankton as compared to benthic diets in other systems. Recruitment of juvenile lake whitefish indicated a dominant year class age structure typical of a species with a pelagic larval stage. The mechanism controlling year class strength does not now appear to be affected by operational characteristics on the lake; however, these interactions are not presently understood. Large numbers of pelagic lake whitefish larvae were entrained through the irrigation canal during the spring; the effects on the population are unknown.

Spawning, incubation, and emergence did not appear to be affected since lake level fluctuation was held to a minimum during the winter and early spring. However, spawning occurred during December at depths ranging from 0 to 60 ft, with maximum abundance at 6 ft. Therefore, potential harm to recruitment exists, should the lake level be lowered more than 3 ft, during the period December to April. Lake whitefish fry emergence began March 29 and ended May 3, 1977, with a peak the third week of April. Reduction in lake volume during the extreme 1973 and 1974 summer drawdowns did not appear to significantly affect the population of lake whitefish.

The kokanee salmon is indigenous to the upper Columbia River system and occurs in FDR Reservoir where it was once abundant but presently occurs in small numbers. These fish represent one source of the Banks Lake stock. The kokanee were found to be one of the dominant fishes by number and biomass in Banks Lake. Kokanee were pelagic throughout the year, but showed a preference for cooler hypolimnetic waters during maximum summer water temperatures. They preferred the pelagic offshore areas except during the fall when spawners were concentrated inshore. Avoidance of the north pool was evident during irrigation pumping at which time maximum abundance occurred in the southern portion of the south pool. *Daphnia* was the preferred food type and occurred consistently in the south pool.

The kokanee has a thermal tolerance which is intermediate between lake whitefish and yellow perch as demonstrated by increase in the CPUE up to 19° C. This tolerance enabled kokanee to forage in the southern portion of the south pool where food abundance was greatest.

Comparison of growth rates between pools was not possible due to avoidance of the north pool; however, rapid growth rates were indicated in the south pool. Maturity was reached primarily at age III and spawning occurred during October and November.

Estimates of year class size were based on the abundances of age II and III kokanee because effective methods of sampling age 0 and I kokanee were lacking. The abundance of age II kokanee in 1977 appeared to be comparable with that observed in 1974 suggesting that recruitment of age III into the sport fishery in 1978 should be similar to the relatively large numbers which provided a good sport fishery in 1975. The abundance of age III kokanee in 1977 is expected to remain low similar to the low level observed in 1976 and to result in a second year of poor sport fishing.

Indirect evidence indicated strongly that the abundance of the kokanee age class maturing in 1976 had been reduced by the large drawdown in the lake level which had occurred in the spring of 1973. The survival of the eggs spawned in lakeshore gravel in the fall of 1972 was reduced by stranding during the spring drawdown. The small size of the year class which survived to emergence in spring 1973 has been documented by several independent methods including the small recruitment of age II kokanee into the gillnet catches in 1974, the small catch of kokanee by the sport fishery during the summer of 1976, the greatly reduced entrainment of kokanee into the irrigation canal in 1976, and the extremely small population of spawners in the lake in 1976. A length frequency analysis of the gillnet catches taken from June 1973 to December 1976 indicated 1971 and 1972 year classes were numerous, and 1970, 1973, and

1974 year classes were small in number (year class identified by year of fry emergence). The 1974 year class was very sparsely represented in the catches and at this time appears to be smaller numerically than the 1973 year class.

10.3 Kokanee Fry Study

A detailed study of the kokanee spawning, egg incubation, and fry emergence was conducted in 1976-77 to further elucidate the effects of the magnitude and timing of reservoir drawdown on kokanee survival and production in lakeshore spawning areas. Spawning was observed in several shoreline areas where the substrate ranged in size from 2 to 150 mm diameter. The largest concentration of spawners was found along the steep talus slopes of the southwest shore of the lake during surveys in both 1975 and 1976. In 1975, spawners were utilizing wavebuilt benches which were 3 to 10 ft wide and from 3 to 25 ft deep. In major spawning areas benches were found at two depths, 6 ft and 18 ft, resulting in two maximum spawning densities in 1975. Spawners were concentrated at a depth of about 16 ft during 1976, but ranged from 10 to 27 ft. A difference in shoreline spawning distributions between years was due to a shift in the level of the wavebuilt benches and a reduction in the estimated maximum number of spawners from about 10,000 in 1975 to about 150 in 1976.

Live developing kokanee eggs were recovered from the gravel as late as May 14, 1976, suggesting that emergence may not be concluded until late May or early June. Three plants of green eggs were made in the fall of 1976 to determine the development rates to hatching and emergence. Egg plants made on October 27, November 11 and 23 had mean respective

hatching dates on March 1, March 16, and April 15, and mean respective emergence dates of April 14, May 10, and May 17. Eggs took approximately 5 months to hatch after accumulating about 790 temperature units (TU) and an additional month before the fry emerged after a total accumulation of 1,200 TU. This study verified the long time required for kokanee egg incubation prior to fry emergence.

Conical emergent fry traps constructed of sheet metal and durable plastic were developed to sample wild kokanee fry production in the shoreline spawning areas of the lake. The traps proved effective, surviving rock slides, burial, and severe wave action. Wild fry were captured during the period from March 29 to May 31, 1977. Peak emergence occurred midway in this period during the last week of April. The estimated egg deposition in the lake in 1976 was 56,419. The estimated survival rate of wild kokanee fry from deposition to emergence was 18.6 percent. The lake was drawn down 10 ft in late April 1977, coincident with the peak emergence; however, little incubation habitat was exposed and drawdown had little effect on the survival of kokanee fry. However, a complicating factor was observed due to the extensive amounts of shoreline gravels which were excavated and redeposited by wave action. This material covered the primary spawning area to a variable depth up to 7 ft and may have resulted in egg destruction due to gravel movement, smothering, or entrapment of the alevins or fry. Therefore, fluctuation of the lake level not only cause egg and fry losses due to desiccation but it also causes instability in the shoreline spawning and incubation substrate.

10.4 Sport Fishery

A 12-month creel census of the Banks Lake sport fishery from April 1975 to March 1976 indicated that 350,866 angler hr were spent in catching 173,695 fish, or about 0.5 fish per angler hr. The principal species and estimated catch were: Kokanee (75,035), perch (59,798), rainbow (19,358), chinook (8,133), crappie (6,501), sunfish (3,529), and bass (1,036). A comparison of these data with two previous censuses indicated that a shift in the creel from spiny-rayed to salmonid fishes is continuing as the result of salmonid stocking by the game and fisheries management agencies and of decreased average size of the spiny-rayed fishes.

The boat fishery was active from April to October and concentrated mainly on kokanee and bass. The bank fishery was most active from January through May and concentrated mainly on perch, crappie, and rainbow trout. The present census indicated a 21 percent increase in effort since 1971-72. Since termination of this systematic creel census in March 1976, the sport fishery was observed to decline substantially and had not recovered to the 1975-76 levels by September 1977.

An estimated sport catch of 8,133 chinook salmon constituted 20 percent of the entire 1974 plant of 40,000 chinooks. This was considered a very high rate of return in view of losses due to entrainment and natural mortality which occurred. The timing and location of the chinook catch approximated that of the rainbow catch which indicated similar habitat and feeding preferences for the two species.

In 1971-72 the Washington Department of Game estimated the annual direct expenditure by anglers utilizing Banks Lake at \$1.6 million.

Based on the 1975-76 creel census of 77,970 angler days at a revised 1976 cost of \$24 per angler day, the estimated annual expenditure increased to \$1.8 million. More recent data by other economic analysts have estimated the angler day at \$40.83 in 1976 which would result in an estimated annual expenditure of \$3.2 million. Regardless of the economic criteria applied, the Banks Lake sport fishery is increasingly important to the residents of the state.

10.5 Fish Entrainment (Irrigation Canal)

Fish entrained through the irrigation canal outlet were sampled with nets during the 1975 and 1976 irrigation seasons. Nineteen of the 22 species known to occur in Banks Lake were caught. The total estimated entrainment was 432,608 and 218,178 in 1975 and 1976, respectively. Total fish biomass was 103,215 and 59,235 kg in 1975 and 1976, respectively. Point estimates in 1975 and 1976 for the three most abundant species were: Yellow perch, 241,528 and 115,146; kokanee, 128,397 and 50,007; and lake whitefish, 19,326 and 23,731. From 1975 to 1976, yellow perch and kokanee declined 52 percent and 61 percent, respectively, while lake whitefish increased by 23 percent. The entrainment timing of most species was associated with such factors as sexual maturity, spawning activity, seasonal water temperature extremes, and feeding activity.

Length frequency analysis of the yellow perch entrained indicated the 1973 and 1974 year classes were predominant in the catch during 1975 and from April to July 1976. The 1975 and 1976 age classes were predominant during August-October 1976. Entrainment of kokanee through the irrigation canal during 1975 was predominantly composed of the 1972 year class and during the 1976 season the 1973 year class was predominant.

The entrainment of mature kokanee in 1976 resulted in a severe reduction of the brood stock remaining in the lake to extremely low numbers (150). The entrainment of age 0 and age I kokanee was low throughout both irrigation seasons except during September-October 1976 when the 1975 year class appeared in the samples. It is likely that the entrainment of immature kokanee reflects their relative abundance and may indicate a strong year class will mature in 1978. Entrainment of lake whitefish was composed predominantly of the 1974 year class during both irrigation seasons.

The northern squawfish and bridgelip sucker have not been captured in the irrigation canal. This is notable because both species were entrained through the feeder canal from FDR Reservoir and have not successfully invaded the entire lake.

Chinook salmon were planted in Banks Lake in 1974 and 1975. Entrainment of the 40,000 planted in 1974 amounted to 3.9 percent while 30.8 percent of the 19,000 planted in 1975 were lost. These data indicated that large numbers of artificially introduced fish were rapidly removed from the lake through the irrigation canal soon after release.

10.6 Fish Entrainment (Feeder Canal)

The entrainment of fishes through the feeder canal during the 1976 irrigation season was systematically sampled with net gear similar to that used in the irrigation canal. A total of 15 species numbering 152,895 fish was entrained. The most numerous species in order of decreasing abundance were prickly sculpin, kokanee, carp, and largescale sucker. Kokanee also ranked second in 1975. The total biomass of all species was 13,290 kg. An estimated 3,073 kokanee were entrained during

1976 which constituted 26 percent of the catch excluding sculpins. Over 70 percent of the kokanee were age II+ and a combined 29 percent were age 0 and I.

Of the other species entrained, northern squawfish and walleye were notable for their low rates of entrainment since these species ranked first and second in FDR Reservoir. This occurred due to thermal stratification in FDR Reservoir which predominated throughout the irrigation pumping season. These species were segregated above the pump intakes while kokanee remained in the hypolimnetic waters and thus were more readily entrained. The entrainment of fishes into Banks Lake through the feeder canal was relatively minor compared to the losses observed through the irrigation canal.

The pump-generation flow during testing of P/G 7 and 8 in 1975 and 1976 resulted in a relatively minor loss of fish from Banks Lake by comparison with the fish loss during irrigation drafting. Preliminary fish entrainment rates based on small samples indicated mean rates per P/G unit per hour during the generation mode of 4.7 in 1975 and 1.58 in 1976. Rainbow trout was the species most commonly entrained from Banks Lake through the feeder canal. Other species observed were lake whitefish, chinook salmon, and yellow perch. The entrainment of fish into Banks Lake during the pumping mode was negligible during the winter.

Since rainbow trout are maintained in the lake by an artificial stocking program, the movements, distribution, and entrainment rates were studied by mark-recapture of a known population. Mark-recoveries suggested that fish released in either the north or south pools tended to be recaptured in the same pool. Releases made closest to the canals

in either end indicated higher loss due to entrainment, particularly during the summer irrigation season in the irrigation canal and through the feeder canal in winter. Plants during these seasons should be made at alternate ends of the lake to minimize entrainment losses.

10.7 Management Implications

The primary purpose of Banks Lake is to function as the equalizing reservoir for the Columbia Basin Irrigation Project. The operational changes imposed on the lake by irrigation result in dramatic effects on the water quality which are exemplified in the aquatic ecosystem and the important sport fish populations. Some of the changes imposed on the lake are beneficial, such as nutrient addition and mixing which stimulate production. Other changes such as frequent, major water level fluctuations as well as entrainment and flushing can impose strict limitations on the ability of the system to produce and sustain aquatic life and fish. Although the full range of interaction has not been determined completely, the extreme drawdown imposed on the lake due to third powerhouse construction at Grand Coulee Dam in 1973 and 1974 created some undesired reductions of the sport fish species. The development of pumped storage power generation on the lake will impose changes which will occur during the winter. The operational use of the lake for water supply and production of electric energy will occur throughout the year once full development is reached.

In spite of the operational effects imposed on Banks Lake throughout its history, a popular sport fishery developed due to the production of relatively large populations of kokanee and other species. The fishery developed along with a maximum annual drawdown of about 15 ft, suggesting

that some operational fluctuation of the lake level can be tolerated. However, based on the information obtained in this study the magnitude, timing and rate of water level change could be managed in the future to achieve a larger and more consistent standing crop of sport fishes. The occasional severe reduction of a key sport fish year class due to construction or unusual reservoir operation may also be minimized.

The entrainment of kokanee through the irrigation canal is an annual loss which has been imposed on every year class to date. There is little doubt, however, that the entrainment loss constitutes a substantial reduction of the population of mature age III and IV kokanee. Entrainment of adult kokanee through the irrigation canal has been found to seriously deplete the spawning population remaining in the lake where natural reproduction must take place to sustain the species. This loss of large mature kokanee is especially acute on a year class which has previously been reduced by lake drawdown. This loss of brood stock in 1976 resulted in insufficient egg deposition needed to produce an adequate number of fry the following year. The entrainment loss of adult kokanee also removed large numbers of fish from the concentrated sport troll fishery active on Banks Lake. Therefore, management of the lake level to sustain the natural reproductive potential of kokanee and retention of the adult kokanee by selective screening of the irrigation outlet would help to insure continuation of a viable sport fishery on Banks Lake.

The future impacts to be imposed on the lake due to the development of pumped storage have not yet been fully evaluated. This activity will largely be restricted to the winter period when aquatic production

reaches an annual minimum and therefore changes imposed may be less pronounced than those already occurring due to irrigation. Some effects have been indicated by research conducted to date while other impacts remain to be tested. 1) Winter temperatures in the north pool will increase, thereby reducing ice covers; 2) nutrient input to the north pool will probably increase, thereby stimulating further primary production; 3) flushing rates of the north pool will increase; 4) entrainment of fish through the feeder canal (generation mode) may increase above the minimal rates presently observed after full development is reached. The significance of this loss presently is considered small relative to the loss through the irrigation canal; however, it remains to be adequately tested; 5) increased movement of water in two directions between Roosevelt Lake and Banks Lake may increase the numbers of nongame fish in the north pool because P/G operation will occur during a time when FDR Reservoir is homothermous allowing nongame fish to reach the pump intakes; 6) fluctuation in water level during winter due to P/G operation will increase to a potential seasonal maximum of about 7 ft, which can further impact reproduction of shore spawning species such as kokanee and lake whitefish; however, this may be avoided by water level management during the spawning season; 7) modifications to the feeder canal, planned for 1978, 1979, and 1980, will prohibit filling of the lake until mid-May each year, even though irrigation drafting will begin in March. Impacts on the fishes due to major drawdowns such as those experienced in 1973 and 1974 may reoccur during these years and cause stranding of yellow perch and kokanee eggs and alevins. Since the majority of kokanee in the lake mature in 3 years this could virtually eliminate the natural

kokanee population in the lake, however, these impacts also may be minimized by intentional drawdown during the spawning season; 8) the eventual installation of six P/G units will provide a larger capacity pumpback capability than previously available and will allow a means of maintaining a more constant lake level and provide greater water management flexibility. This management capability could be utilized to minimize drawdown impacts on the fishery if integrated into the irrigation and power programs for the lake.

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APPENDIX A.8.1

Appendix Table A.8.1 Known fish introductions to Banks Lake¹

Date	Number	Species	Common Name	Size	Origin
2/53	4,000	<i>Salmo gairdneri</i>	Rainbow trout (Kamloops)	30/lb	-
4/56	10,010	<i>Salmo gairdneri</i>	rainbow trout	11/lb	-
5/56	1,504,000	<i>Oncorhynchus nerka</i>	kokanee salmon	fry	Leavenworth
10/56	14,190	<i>Salmo gairdneri</i>	rainbow trout	11/lb	-
6/57	1,533,000	<i>Oncorhynchus nerka</i>	kokanee salmon	fry	-
9/57	12,250	<i>Salmo gairdneri</i>	rainbow trout	12.5/lb	-
10/4-8/57	28,000	<i>Salmo gairdneri</i>	rainbow trout	14/lb	-
4/4/58	10,035	<i>Salmo gairdneri</i>	rainbow trout	9/lb	-
6/5/58	39,500	<i>Salmo gairdneri</i>	rainbow trout	59/lb	-
6/13/58	39,600	<i>Salmo gairdneri</i>	rainbow trout	66/lb	-
7/2/58	53,000	<i>Salmo gairdneri</i>	rainbow trout	45/lb	-
8/5/58	18,000	<i>Salmo gairdneri</i>	rainbow trout	30/lb	-
9/3-16/58	97,300	<i>Salmo gairdneri</i>	rainbow trout	20/lb	-
5/23/58	1,298,800	<i>Oncorhynchus nerka</i>	kokanee salmon	1,640/lb	Leavenworth
6/10/59	89,060	<i>Salmo gairdneri</i>	rainbow trout	20-22/lb	-
6/3-9/59	59,980	<i>Salmo gairdneri</i>	rainbow trout	9-18/lb	-
7/14/59	28,270	<i>Salmo gairdneri</i>	rainbow trout	22/lb	-
7/23/59	24,988	<i>Salmo gairdneri</i>	rainbow trout	30-45/lb	Tucannon
3/23/60	949,560	<i>Oncorhynchus nerka</i>	kokanee salmon	5,790/lb	Leavenworth
4/27/60	946,400	<i>Oncorhynchus nerka</i>	kokanee salmon	5,200/lb	Leavenworth
6/28/60	14,400	<i>Salmo gairdneri</i>	rainbow trout	18/lb	-
7/1-17/60	72,000	<i>Salmo gairdneri</i>	rainbow trout	17-20/lb	-
8/16/60	50,100	<i>Salmo gairdneri</i>	rainbow trout	14-19/lb	-
9/28/60	12,000	<i>Salmo gairdneri</i>	rainbow trout	15/lb	-
1961	NO RECORDS				
6/13/62	31,430	<i>Salmo gairdneri</i>	rainbow trout	14/lb	Columbia Basin
6/15/62	14,300	<i>Salmo gairdneri</i>	rainbow trout	13/lb	Columbia Basin
7/13/62	14,980	<i>Salmo gairdneri</i>	rainbow trout	14/lb	Columbia Basin
9/20/63	65,680	<i>Salmo gairdneri</i>	rainbow trout	8.5-12/lb	Columbia Basin
8/20/63	10,000	<i>Salmo gairdneri</i>	rainbow trout	8/lb	Columbia Basin

¹Unpublished information obtained from Washington State Departments of Game and Fisheries.

Appendix Table A.8.1 Known fish introductions to Banks Lake (cont'd.)

Date	Number	Species	Common Name	Size	Origin
7/1-2/63	47,340	<i>Salmo gairdneri</i>	rainbow trout	10-12/lb	Columbia Basin
6/17-24/63	44,040	<i>Salmo gairdneri</i>	rainbow trout	11-12/lb	Columbia Basin
4/25/63	506,000	<i>Oncorhynchus nerka</i>	kokanee salmon	6,175/lb	Leavenworth
5/8/64	954,000	<i>Oncorhynchus nerka</i>	kokanee salmon	5,600/lb	Leavenworth
5/6/64	56,000			125/lb	Spokane
5/20-26/65	1,000,000	<i>Oncorhynchus nerka</i>	kokanee salmon	fry	Leavenworth
9/65	25,000	<i>Oncorhynchus nerka</i>	kokanee salmon	9/lb	Leavenworth
10/65	85,000	<i>Oncorhynchus nerka</i>	kokanee salmon	7-12/lb	Leavenworth
9/22/65	24,000	<i>Oncorhynchus nerka</i>	kokanee salmon	25/lb	Leavenworth
	26,300			20/lb	Leavenworth
5/13/66	1,000,000	<i>Oncorhynchus nerka</i>	kokanee salmon	fry	Leavenworth
4/27-29/66	50,400			9/lb	Columbia Basin
5/6/66	9,000			9/lb	Columbia Basin
7/7/66	8,500			12/lb	Columbia Basin
6/21/66	17,550	<i>Salmo gairdneri</i>	rainbow trout		
			(Kamloops)	15/lb	Columbia Basin
8/25-31/66	39,120	<i>Salmo gairdneri</i>	rainbow trout	10-12/lb	Columbia Basin
6/13/67	46,000	<i>Salmo gairdneri</i>	rainbow trout	10/lb	Columbia Basin
7/19/67	32,300	<i>Salmo gairdneri</i>	rainbow trout	9-10/lb	Columbia Basin
8/8/67	11,600	<i>Salmo gairdneri</i>	rainbow trout	10/lb	Columbia Basin
	5,400	<i>Salmo gairdneri</i>	rainbow trout	-	-
10/31/67	6,500	<i>Salmo gairdneri</i>	rainbow trout	19/lb	Chelan
11/21/67	15,000	<i>Salmo gairdneri</i>	rainbow trout	10/lb	Columbia Basin
10/3/68	20,000	<i>Salmo gairdneri</i>	rainbow trout	20/lb	Columbia Basin
10/3/68	21,150	<i>Salmo gairdneri</i>	rainbow trout	9/lb	Columbia Basin
10/30/68	11,250	<i>Salmo gairdneri</i>	rainbow trout	10/lb	Columbia Basin
11/6/68	32,600	<i>Salmo gairdneri</i>	rainbow trout	10/lb	Columbia Basin
11/7/68	28,525	<i>Salmo gairdneri</i>	rainbow trout	10/lb	Columbia Basin
11/8/68	16,500	<i>Salmo gairdneri</i>	rainbow trout	10/lb	Columbia Basin
6/11/69	8,500	<i>Salmo gairdneri</i>	rainbow trout	5/lb	Columbia Basin
5/23/69	12,000	<i>Salmo gairdneri</i>	rainbow trout	10/lb	Columbia Basin
9/25/69	12,000	<i>Salmo gairdneri</i>	rainbow trout	10/lb	Columbia Basin

Appendix Table A.8.1 Known fish introductions to Banks Lake (cont'd.)

Date	Number	Species	Common Name	Size	Origin
9/30/69	26,100	<i>Salmo gairdneri</i>	rainbow trout	10/1b	Columbia Basin
10/1/69	24,000	<i>Salmo gairdneri</i>	rainbow trout	10/1b	Columbia Basin
10/6/69	11,500	<i>Salmo gairdneri</i>	rainbow trout	9-10/1b	Columbia Basin
10/15/69	12,300	<i>Salmo gairdneri</i>	rainbow trout (Kamloops)	12/1b	Chelan
10/8/69	11,160	<i>Salmo gairdneri</i>	rainbow trout	9/1b	Columbia Basin
11/20/69	19,575	<i>Salmo gairdneri</i>	rainbow trout	13/1b	Tucannon
9/2/70	50,883	<i>Salmo gairdneri</i>	rainbow trout	21/1b	Chelan
9/4/70	20,265	<i>Salmo gairdneri</i>	rainbow trout	21/1b	Columbia Basin
10/8/70	20,230	<i>Salmo gairdneri</i>	rainbow trout	7/1b	Columbia Basin
10/13/70	12,500	<i>Salmo gairdneri</i>	rainbow trout	10/1b	Columbia Basin
10/21/70	26,200	<i>Salmo gairdneri</i>	rainbow trout	10/1b	Columbia Basin
10/22/70	13,000	<i>Salmo gairdneri</i>	rainbow trout	10/1b	Columbia Basin
10/29/70	10,350	<i>Salmo gairdneri</i>	rainbow trout	10/1b	Columbia Basin
11/10/70	10,950	<i>Salmo gairdneri</i>	rainbow trout	4/1b	Columbia Basin
11/18/70	7,600	<i>Salmo gairdneri</i>	rainbow trout	8/1b	Columbia Basin
11/18/70	11,825	<i>Salmo gairdneri</i>	rainbow trout	11/1b	Columbia Basin
3/30/71	20,000	<i>Salmo gairdneri</i>	rainbow trout	16/1b	Columbia Basin
3/30/71	9,000	<i>Salmo gairdneri</i>	rainbow trout	18/1b	Columbia Basin
3/30/71	42,000	<i>Salmo gairdneri</i>	rainbow trout	25/1b	Columbia Basin
4/5/71	21,750	<i>Salmo gairdneri</i>	rainbow trout	25/1b	Columbia Basin
4/19/71	20,116	<i>Salmo gairdneri</i>	rainbow trout	18/1b	Columbia Basin
5/10/71	150,000	<i>Oncorhynchus nerka</i>	kokanee salmon	fry	Leavenworth
5/12/71	12,000	<i>Salmo gairdneri</i>	rainbow trout	10/1b	Columbia Basin
4/27/71	8,850	<i>Salmo gairdneri</i>	rainbow trout	10/1b	Columbia Basin
4/30/71	32,000	<i>Oncorhynchus kisutch</i>	coho salmon	160/1b	Columbia Basin
4/30/71	69,750	<i>Oncorhynchus kisutch</i>	coho salmon	150/1b	Columbia Basin
10/29/71	18,000	<i>Salmo gairdneri</i>	rainbow trout	9/1b	Columbia Basin
11/1/71	16,515	<i>Salmo gairdneri</i>	rainbow trout	9/1b	Columbia Basin
11/2/71	8,820	<i>Salmo gairdneri</i>	rainbow trout	9/1b	Columbia Basin
11/2/71	7,850	<i>Salmo gairdneri</i>	rainbow trout	10/1b	Columbia Basin
5/5/72	11,475	<i>Salmo gairdneri</i>	rainbow trout	9/1b	Columbia Basin

Appendix Table A.8.1 Known fish introductions to Banks Lake (cont'd.)

Date	Number	Species	Common Name	Size	Origin
5/5/72	8,550	<i>Salmo gairdneri</i>	rainbow trout	10/lb	Columbia Basin
5/30/72	15,000	<i>Salmo gairdneri</i>	rainbow trout	10/lb	Columbia Basin
5/31/72	11,280	<i>Salmo gairdneri</i>	rainbow trout	19/lb	Columbia Basin
6/6/72	1,800	<i>Salmo gairdneri</i>	rainbow trout	9/lb	Columbia Basin
6/6/72	10,400	<i>Salmo gairdneri</i>	rainbow trout	8/lb	Columbia Basin
6/28/72	11,050	<i>Salmo gairdneri</i>	rainbow trout	13/lb	Columbia Basin
6/28/72	3,500	<i>Salmo gairdneri</i>	rainbow trout	8/lb	Columbia Basin
6/28/72	10,800	<i>Salmo gairdneri</i>	rainbow trout	8/lb	Columbia Basin
6/29/72	7,600	<i>Salmo gairdneri</i>	rainbow trout	8/lb	Columbia Basin
6/29/72	4,950	<i>Salmo gairdneri</i>	rainbow trout	11/lb	Columbia Basin
10/2/72	16,335	<i>Salmo gairdneri</i>	rainbow trout	11/lb	Columbia Basin
10/3/72	15,500	<i>Salmo gairdneri</i>	rainbow trout	10/lb	Columbia Basin
10/3/72	6,215	<i>Salmo gairdneri</i>	rainbow trout	11/lb	Columbia Basin
10/26/72	25,542	<i>Salmo gairdneri</i>	rainbow trout	8.6/lb	Columbia Basin
11/8/72	3,120	<i>Salmo gairdneri</i>	rainbow trout	8/lb	Columbia Basin
11/8/72	3,300	<i>Salmo gairdneri</i>	rainbow trout	8/lb	Columbia Basin
5/1/73	37,290	<i>Salmo gairdneri</i>	rainbow trout	12/lb	Columbia Basin
8/73	110,660	<i>Salmo gairdneri</i>	rainbow trout	22/lb	Winthrop
5/28/74	16,445	<i>Salmo gairdneri</i>	rainbow trout	13/lb	Columbia Basin
8/11/74	40,000	<i>Oncorhynchus tshawytscha</i>	chinook salmon	3/lb	Ringo
10/23/74	23,202	<i>Salmo gairdneri</i>	rainbow trout	9/lb	Columbia Basin
10/24/74	12,615	<i>Salmo gairdneri</i>	rainbow trout	10.7/lb	Columbia Basin
10/24/74	110,000	<i>Oncorhynchus nerka</i>	kokanee salmon	50/lb	Leavenworth
10/24/74	11,748	<i>Salmo gairdneri</i>	rainbow trout	11/lb	Columbia Basin
10/31/74	21,004	<i>Salmo gairdneri</i>	rainbow trout	8/lb	Columbia Basin
10/31/74	22,375	<i>Salmo gairdneri</i>	rainbow trout	12.5/lb	Columbia Basin
11/6/74	15,750	<i>Salmo gairdneri</i>	rainbow trout	12.5/lb	Columbia Basin
11/13/74	1,350	<i>Salmo gairdneri</i>	rainbow trout	13.5/lb	Columbia Basin
11/13/74	11,024	<i>Salmo gairdneri</i>	rainbow trout	10.6/lb	Columbia Basin

Appendix Table A.8.1 Known fish introductions to Banks Lake (cont'd.)

Date	Number	Species	Common Name	Size	Origin
4/23/75	18,810	<i>Salmo gairdneri</i>	rainbow trout	19/lb	Columbia Basin
4/23/75	250	<i>Salmo gairdneri</i>	rainbow trout	25/lb	Columbia Basin
4/24/75	1,500	<i>Salmo gairdneri</i>	rainbow trout	25/lb	Columbia Basin
4/24/75	7,820	<i>Salmo gairdneri</i>	rainbow trout	17/lb	Columbia Basin
4/25/75	13,753	<i>Salmo gairdneri</i>	rainbow trout	17/lb	Columbia Basin
4/25/75	9,800	<i>Salmo gairdneri</i>	rainbow trout	24/lb	Columbia Basin
4/27/75	10,735	<i>Salmo gairdneri</i>	rainbow trout	19/lb	Columbia Basin
4/27/75	15,950	<i>Salmo gairdneri</i>	rainbow trout	25/lb	Columbia Basin
4/29/75	11,320	<i>Salmo gairdneri</i>	rainbow trout	22/lb	Columbia Basin
4/29/75	6,825	<i>Salmo gairdneri</i>	rainbow trout	21/lb	Columbia Basin
6/3/75	11,030	<i>Salmo gairdneri</i>	rainbow trout	13.5/lb	Columbia Basin
6/3/75	10,050	<i>Salmo gairdneri</i>	rainbow trout	13/lb	Columbia Basin
6/3/75	11,264	<i>Salmo gairdneri</i>	rainbow trout	10.5/lb	Columbia Basin
6/3/75	8,997	<i>Salmo gairdneri</i>	rainbow trout	10/lb	Columbia Basin
3/21/75	30,696	<i>Salmo gairdneri</i>	rainbow trout	24/lb	Columbia Basin
3/21/75	25,168	<i>Salmo gairdneri</i>	rainbow trout	26/lb	Columbia Basin
3/22/75	44,640	<i>Salmo gairdneri</i>	rainbow trout	32/lb	Columbia Basin
6/75	19,000	<i>Oncorhynchus tshawytscha</i>	chinook salmon	8/lb	Green River
10/75	35,000	<i>Oncorhynchus tshawytscha</i>	chinook salmon	17/lb	Deschute River
3/21/76	30,696	<i>Salmo gairdneri</i>	rainbow trout	24/lb	Columbia Basin
3/21/76	25,168	<i>Salmo gairdneri</i>	rainbow trout	26/lb	Columbia Basin
3/22/76	44,640	<i>Salmo gairdneri</i>	rainbow trout	32/lb	Columbia Basin
9/23/76*	23,000	<i>Oncorhynchus tshawytscha</i>	chinook salmon	24/lb	Skykomish River
9/24/76*	22,840	<i>Oncorhynchus tshawytscha</i>	chinook salmon	24/lb	Skykomish River
10/27/76	12,045	<i>Salmo gairdneri</i>	rainbow trout	16.5/lb	Columbia Basin

* Reared 112 days at Rocky Reach.

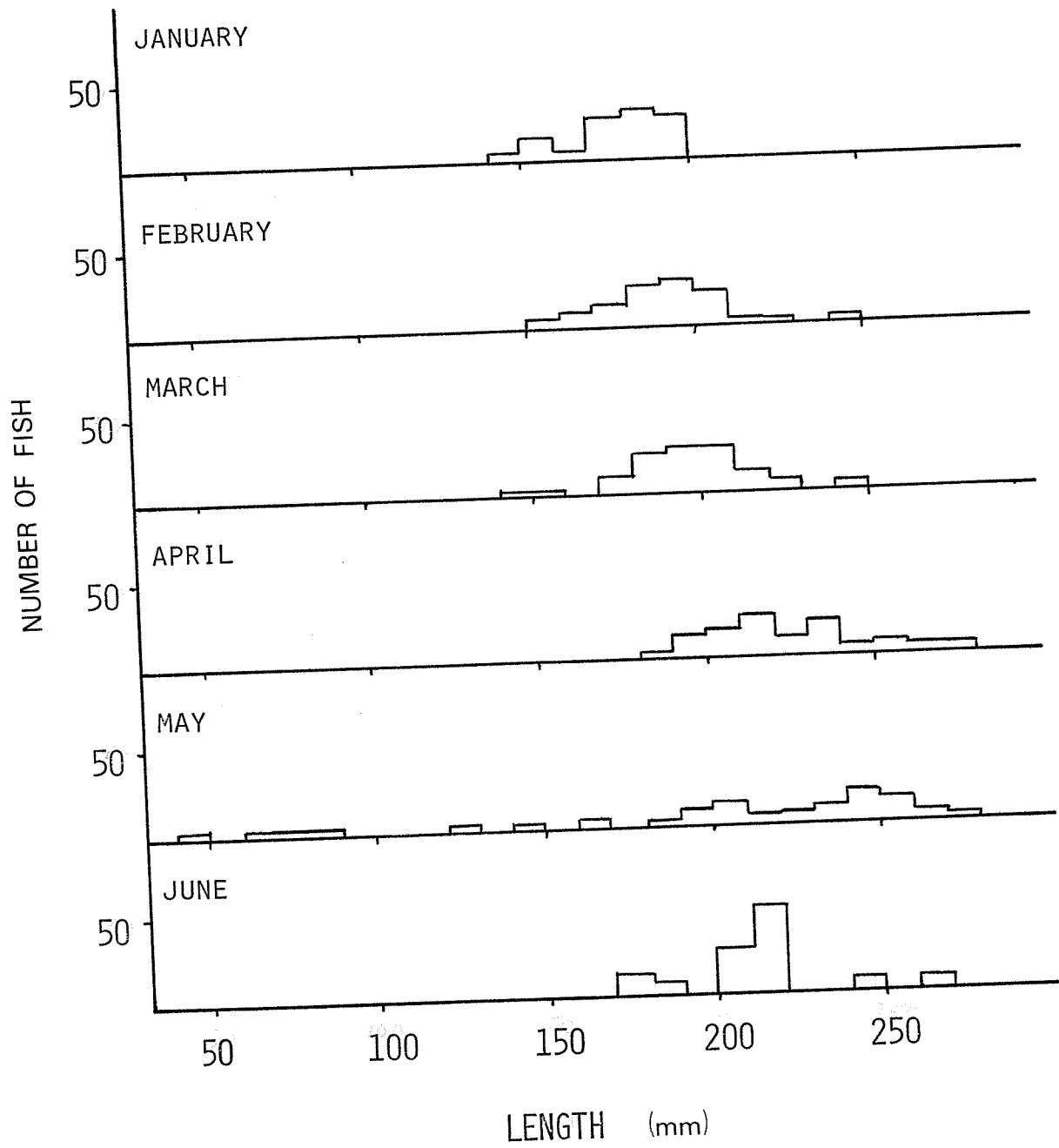


Figure 7.1 Monthly variation in the length frequency of yellow perch in the creel, 1975-76.