INTERNAL REPORT 35

LAKE WASHINGTON THERMAL STUDY, JULY 1971

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FOR REVIEW ONLY

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ABSTRACT

The Washington Cooperative Fishery Unit at the College of Fisheries, University of Washington, is carrying on studies of fishes in Lake Washington as part of the International Biological Program sponsored by the National Science Foundation. One of our interests is in the effects of temperature on the movements of fishes within the lake. In addition, we are aware of the interest of Puget Sound Power and Light Company in the water temperatures of Lake Washington. The company provided financial support to our study so that we could purchase an electronic bathythermograph and hire students on an hourly basis to measure water temperatures in the lake.

Depth-temperature profiles were made at selected stations in the lake. Because of the potential source of heat from the Shuffleton generating plant, effort was concentrated in time and space at the south end of the lake, but data were collected over the entire lake. This report summarizes the data obtained for July 1971 and integrates pertinent results of previous reports by Fraser (1971) and Weaver (1971) for the periods of December 1970 and June 1971.

MATERIALS AND METHODS

Methods and equipment used were as described in the earlier reports by Fraser and by Weaver. The July sampling followed a similar pattern. The July sampling schedule increased the number of stations in the south end to provide a better picture of thermal variation at a time when adult sockeye salmon (*Oncorhynchus nerka*) were accumulating in the lake and extended sampling sites to include the entire lake (Table 1). A total of 106 stations were sampled in July. For convenience, stations were renumbered from earlier reports to go consecutively from south to north by transects. Transect numbers (in roman numerals) and the location of each station are shown in Figure 1. Stations sampled in previous months but not covered in the July sampling are included in the 112 station numbers.

RESULTS

Data presented in Figures 2, 3, and 4 show depth-temperature profiles for the stations sampled in July. From these profiles, temperature data were taken at 3-m (10-ft) intervals from the surface to 15 m (50 ft). Raw data were corrected to a platinum thermometer standard and are listed in Table 2. Figures 5, 6, and 7 show temperatures at 0-, 3-, and 6-m (0-, 10-, and 20-ft) depths throughout the length of Lake Washington and are coded in 0.5°C intervals to reveal temperature trends.

Lake Washington south of Mercer Island

Seventeen stations were sampled in July. The total number of stations was increased over previous sampling months and concentrated in the lower half of the area in the vicinity of the Shuffleton plant and the mouth of the Cedar River.

A marked thermocline was present at some, but not all, stations. Along transect II (Figure 2a) the thermocline was strong from the middle of the lake toward the western shore, but became noticeably weaker in stations of the eastern half of the transect. The eastern stations of transect II, approximately in front of the Shuffleton plant, were also cooler than surrounding stations, averaging about a degree lower.

The thermocline pattern at transect IV was generally similar but formed at about the 12-m (40-ft) level instead of at 6-9 m (20-30 ft) as seen in stations of transect II. Temperatures ranged from 16.3° to 18.3°C at the surface, 1.1° to 17.5°C at 3 m, and 15.4° to 17.7°C at 6 m (20 ft).

Where data were available for previous months, comparisons were made of depth-temperature profiles for the same station. These are seen for stations 8, 9, 10, 13, and 15, and show data for April, June, and July (Figure 2a). The increased temperatures up to about 10°C at the surface and the formation of a thermocline at most stations are apparent. The rapid increase in temperature and thermocline formation occurred mostly between June and July.

Lake Washington south of Evergreen Point Floating Bridge

A trend toward warmer water was exhibited from the southern end of Lake Washington northward to Evergreen Point Bridge, which also marks the location of the outlet. The trend was pronounced at the surface and 3-m (10-ft) levels (Figures 5 and 6) but was more variable at the 6-m (20-ft) depth (Figure 7). Surface temperatures ranged from 15.8° to 19.6°C at the surface, from 16.1° to 18.5°C at 3 m (10 ft), and from 15.4° to 17.7°C at the 6-m (20-ft) depth. These ranges include variations resulting from a seven-day disparity in the completion of all measurements; however, they are not believed to affect the trend. The greatest difference between surface and bottom temperatures near the Shuffleton plant was about 7.5°C at stations 9 and 10.

Waters to the east and west of Mercer Island differed in their respective temperature patterns. The eastern waters were generally cooler by about 2°C at 3 and 6 m (10 and 20 ft). Surface water temperatures differed to a smaller degree. Also, a more marked thermocline was seen at the stations east and north of Mercer Island (Figures 3 and 4). West of Mercer Island the temperature profile showed weak or nonexistent thermoclines with few exceptions. Thermoclines, where present, were generally at 12-15 m (40-50 ft) and began at temperatures of 13°-15°C.

Lake Washington north of Evergreen Point Floating Bridge

Water temperature generally warmed from the north end toward the Evergreen Point Bridge, just as was seen in the south end. It was evident at the 0-, 3-, and 6-m (0-, 10-, and 20-ft) depths (Figures 5, 6, and 7). Surface temperatures ranged from 18.6° to 22.2°C. The ranges for 3 and 6 m (10 and 20 ft) were 17.3°-21.1°C and 16.6°-19.6°C. Figures 4a and b show that a thermocline was not established at each station. There is no thermocline at the shallow northern end, but at transect XXIX, where depths of about 30 m (100 ft) are reached, a sharp thermocline is present (Figure 4b). Further south the thermocline is less marked or nonexistent. Where present, the thermocline begins at about 12 m (40 ft) at temperatures of 14°-17°C.

DISCUSSION

During the period of December 1970 to July 1971, preliminary investigations of the temperature patterns in Lake Washington were carried out. Temperatures were found to be low and quite evenly mixed, vertically and horizontally, during the period of December through March, ranging from 5.1° to 7.7°C. A warming trend began in April and continued through July. Temperatures at the south end of the lake ranged from 5.4° to 8.5°C in April, from 6.0° to 10.7°C in May, from 8.3° to 11.8°C in June, and from 8.4° to 17.9°C in July. The beginnings of thermal stratification were seen in late May and June, and by the July sampling a strong thermocline was found, though not at all stations. In July the water generally warmed as sampling moved from south to north as far as the Evergreen Point Bridge. Similarly, the north end of the lake was coolest near the Sammamish Slough and warmed toward the Evergreen Point Bridge. A cooler area existed in the southeastern corner of the lake that was particularly apparent at the surface and at 6 m (20 ft). The thermocline was less marked at these sites. Local wind conditions may contribute to these findings, and it is not known if they are persistent features of the temperature pattern. The lack of a thermocline at a number of stations indicates some mixing of waters still occurs in July at the south end of the lake.

The potential impact of a heated water discharge on the fish life of the lake will depend upon the frequency and timing of plant operation, the species of fish, and the stage of their life when they come in contact with the warmed water. In the past, the Shuffleton plant has operated infrequently, only 44 days since October 1966 (Table 3). Operating months have been October, November, and January. The outflow during these times has been 11.36 m^3 sec^{-1} (180,000 gpm, or about 400 cfs) and the usual rise in temperature between inflow and outfall water has been 8.3°C. This outflow is compared with the Cedar River outflow for 1967, 1968, and 1969 in Table 4. Since this power plant is used when certain power shortages occur, the possibility exists that it could operate at any time of the year.

There are several species of fish that are known to occur in some abundance at the south end of Lake Washington. These fish might experience deleterious effects from the operations of the plant. During summer and early fall, large numbers of adult sockeye salmon remain in the lower end of the lake ripening their sex products and waiting for appropriate water conditions to ascend the Cedar River to spawn. These fish generally stay at 15 m (50 ft) or below in July to escape the warmer upper waters. The Lake Washington sockeye support an important and well-publicized commercial fishery in Puget Sound, an equally well-known recreational fishery in Lake Washington, and an Indian fishery. Puget Power would be well advised to proceed carefully here because of the public relations aspects of the situation. On one day in July, as many as 400 boats and an estimated 1000 people were seen fishing for sockeye in the lake near and below Mercer Island. During the fall and winter seasons, populations of coho salmon, steelhead and cutthroat trout, and lake smelt spend some time in the water of the south end of Lake Washington prior to their spawning run up the river and its tributaries. In late winter and spring, young longfin smelt, large numbers of sockeye fingerlings, and coho, steelhead, and cutthroat smolts enter the lake from the Cedar River and remain in the lower part of the lake for an undefined period of time. It is known that various predatory fish may feed on these fish at this time, and that a warmer environment may increase the predation rate (Sylvester 1971).

In considering the release of heated water into Lake Washington, the water quality regulations of the Washington State Pollution Control Commission, dated 8 January 1970, are pertinent. According to the regulations, all intrastate lakes are placed in a category where "no measurable change from natural conditions" is to take place in temperature. A discharge of heated water into Lake Washington from the Shuffleton plant would violate these specifications. Therefore the question of possible harmful effects on fishes and other life in the lake is academic at this point in time. There are several approaches Puget Power might follow:

1. Abandon the Shuffleton plant.
2. Cool the water before it is released into Lake Washington.
3. Divert the outfall to the Cedar River. The plant could then operate without raising the water temperature above 18.3°C, according to the regulation. The outfall would also have to be placed far enough upstream so that the heat would be dissipated by the time the water reached Lake Washington, where the regulations permit no measurable changes in temperature from natural conditions.
4. Appeal enforcement of the regulation.

Should Puget Power feel that it ought to appeal, or that it does now have the right to discharge heated water into Lake Washington, the company will need to defend its position. Studies will be required to establish:

(1) the patterns and extent of warming of the epilimnion, determined by trial run of the Shuffleton plant at various times of the year (dye marker experiments would be most effective);

(2) the distribution in time and space of important sport fishes (including known species and salmonids, longfin smelt, bass, and sunfish) in the area where temperatures would be increased;

(3) continual monitoring of temperature patterns if the plant is to run more than a few days;

(4) determination of whether young fish are sucked into intake orifices; and

(5) from these, the determination of whether "safe" times of the year exist for the operation of the power plant and the discharge of warmed water.

REFERENCES

FRASER, J. 1971. Lake Washington temperature studies. Unpubl. report to Wash. Coop. Fish. Unit as Fish. 499 project.

SYLVESTER, J. R. 1971. Some effects of thermal stress on the predator-prey interaction of two salmonids. Ph.D. theses, Univ. Washington.

WEAVER, D. 1971. Lake Washington temperature studies for spring 1971. Unpubl. MS (Fish. 499 report), Coll. Fish., Univ. Wash., Seattle. 48 p. (Typewritten)

Table 1. Sampling dates and transects for Lake Washington thermal survey.

Date	Area	Transects
December	South of Mercer Island	IV through VII
January		
February		
March		II, IV through VII
30 April		I, II, IV through VII
18 May		IV through VII
2 June		I, II, IV through VII
7 July		I through V (number of stations increased and concentrated at lower end)
12 July	West side of Mercer Island	VII through XX
14 July	East side of Mercer Island and north to Evergreen Pt. Floating Bridge	VIII through XXIII
18 July	North of Evergreen Pt. Floating Bridge	XXIV through XXXII

Table 2. Selected depths and recorded temperatures in Lake Washington, July 1971.

Date (July)	Transect	Station	Max. depth(m)	Temperature at various depths (°C)						
				Surf.	3 m	6 m	9 m	12 m	15 m	Min. temp.
7	I	1	8.5	16.3	16.4	16.2	16.0			16.0
		2	12.5	17.1	16.5	16.3	16.1	13.9		13.7
		3	18.3	16.0	16.1	15.4	14.3	13.7	12.8	11.5
7	II	4	6.7	16.6	16.3	16.0				16.0
		5	26.5	17.4	16.6	16.3	15.8	13.7	13.0	8.7
		6	17.1							
		7	24.4	16.4	16.0	15.8	15.6	13.6	11.9	9.1
		8	24.1	15.8	16.1	15.8	14.7	13.5	12.6	9.0
		9	23.2	16.6	16.5	15.9	14.6	14.0	13.0	9.3
		10	22.3	16.3	16.3	15.6	14.0	13.7	12.8	9.5
7	III	11	14.3	18.0	17.1	16.9	16.6	16.1		13.3
		12	29.0	17.8	16.8	16.5	15.9	13.9	12.9	8.5
7	IV	13	29.6	17.9	17.1	16.8	16.5	16.1	13.6	8.8
		14	28.3	17.1	16.3	16.1	15.6	13.6	11.9	8.4
		15	25.0	18.3	17.5	16.7	16.4	15.5	13.9	9.8
		16	25.3	17.4	16.8	16.4	15.7	14.8	14.0	9.7
		17	24.4	17.8	16.6	16.4	15.5	15.2	14.6	10.0
12	VII	24	29.9	17.4	17.1	16.6	15.4	13.9	13.0	8.9
		25	32.0	17.3	16.5	16.1	15.4	14.6	12.2	7.7
		26	32.9	17.3	16.8	16.0	15.4	13.7	12.0	17.3
		27	32.6	17.7	17.5	16.3	15.0	14.4	12.3	8.0
12	VIII	28	24.7	17.8	17.3	17.0	13.7	11.9	10.7	8.2
		29	16.5	17.2	16.7	16.3	13.4	11.5	10.3	8.6
12	IX	30	29.9	17.7	17.5	16.4	15.5	15.0	13.9	9.6
		31	38.4	17.5	17.1	16.1	15.7	14.8	13.7	8.4
		32	36.6	17.4	16.3	15.8	14.5	13.8	12.5	8.0
		33	36.6	17.0	16.6	15.3	14.7	12.7	12.5	8.4
12	X	34	9.1	17.9	17.5	16.8	14.4			14.4
		35	19.5	17.5	17.5	17.3	15.3	14.7	11.3	9.7
12	XI	36	19.5	17.1	16.8	15.6	15.0	14.7	14.5	12.6
		37	43.6	17.5	16.5	15.8	15.6	14.4	13.7	8.4
		38	20.7	17.5	17.5	16.3	15.5	14.9	12.9	11.2
12	XII	39	11.3	17.5	17.1	16.6	13.8			12.9
		40	20.7	17.5	17.2	16.7	15.4	12.7	10.3	9.4
12	XIII	41	6.1	18.3	18.0	17.0				17.0
		42	6.7	17.7	17.2					16.6
		43	5.5	18.4	17.6					16.9
12	XIV	44	8.2	17.8	16.9	16.6				16.1
		45	10.7	17.2	16.8	16.4	15.9			15.6

Table 2. (cont.)

Date (July)	Transect	Station	Max. depth (m)	Temperature at various depths (°C)						
				Surf.	3 m	6 m	9 m	12 m	15 m	Min. tem
12	XV	46	8.2	17.5	16.8	16.1				15.6
		47	22.3	17.5	16.5	16.2	15.3	14.7	12.8	10.1
		48	13.7	17.2	16.4	15.9	15.5	15.1		14.3
		49	15.2	17.8	16.4	15.8	15.1	14.2	13.0	13.0
		50	50.9	17.7	16.9	16.0	14.9	13.8	12.9	6.7
5		51	43.6	17.6	17.1	16.3	15.3	13.8	12.3	10.8
12	XVI	52	14.3	17.8	17.5	16.8	14.4	13.3		12.1
		53	13.7	17.8	17.6	16.9	14.7	13.0		12.3
		54	11.3	17.9	17.6	17.4	15.2			14.7
12	XVII	55	13.4	18.5	17.6	17.3	15.5	14.8		13.7
12	XVIII	56	4.0	18.4	17.4					16.5
		57	52.4	18.3	17.1	16.6	15.6	15.4	13.5	8.0
		58	47.2	18.0	17.5	16.6	15.6	13.5	12.7	8.6
		59	16.2	17.5	16.9	15.8	15.1	13.4	12.4	12.4
14	XIX	60	25.3	18.4	17.8	16.4	15.6	14.4	12.7	10.2
		61	23.5	18.8	17.8	17.0	15.6	14.2	12.9	11.2
		62	19.8	18.7	17.8	17.1	15.7	14.3	12.8	12.0
14	XX	63	25.9	18.2	17.8	16.7	16.4	14.7	12.9	9.5
		64	57.9	18.6	17.5	16.8	16.4	15.8	13.2	7.8
		65	41.8	18.4	17.4	16.6	15.9	14.2	12.6	8.7
		66	20.4	18.3	16.3	15.5	14.1	12.5	11.9	11.3
14	XXI	67	12.2	20.2	17.3	16.5	15.7	15.1		15.1
		68	11.6	19.5	17.2	16.7	15.7			14.1
		69	45.1	18.7	17.6	17.2	16.2	14.5	13.3	8.6
		70	25.3	18.6	18.1	17.3	15.6	14.2	13.3	10.6
14	XXII	71	42.7	19.6	18.0	17.3	16.5	14.5	11.9	8.4
		72	40.2	19.8	17.1	16.5	15.9	13.7	12.5	8.4
		73	50.0	19.5	17.5	16.7	15.7	14.4	12.5	7.9
		74	12.2	18.6	17.7	17.6	16.4	14.1		14.1
		75	28.7	19.3	18.0	17.0	15.7	13.9	12.9	9.6
14	XXIII	76	14.6	20.2	18.5	17.5	17.3	14.2		12.3
		77	57.9	18.8	17.9	17.5	16.7	13.9	11.3	7.5
		78	57.9	18.4	17.0	16.2	15.9	13.9	12.1	7.6
		79	57.9	17.8	16.6	15.8	15.4	14.1	12.2	7.3
		80	10.1	21.6	20.7	19.3	16.5			16.3
18	XXIV	81	10.1	22.2	21.1	19.6	16.5			15.6
		82	8.8	22.2	21.2	19.3				15.8
		83	57.9	21.8	20.6	19.2	16.5	14.5	12.8	7.4
		84	57.9	21.4	19.7	18.5	17.2	14.8	13.6	7.4
		85	16.8	21.3	19.2	18.4	17.5	14.6	13.0	12.3

Table 2. (cont.)

Date (July)	Transect	Station	Max. depth(m)	Temperature at various depths (°C)						
				Surf.	3 m	6 m	9 m	12 m	15 m	Min. temp.
18	XXV	86	48.8	21.2	20.2	17.9	15.9	14.7	12.8	7.4
		87	55.5	21.4	19.3	18.1	16.5	15.5	13.1	7.2
		88	50.1	22.2	19.5	18.4	17.3	15.9	13.6	8.4
18	XXVI	89	46.3	21.4	19.6	18.1	16.1	14.8	13.8	7.6
		90	47.9	20.6	19.5	17.6	15.9	13.9	12.7	7.4
		91	25.6	21.0	19.4	18.5	16.5	15.6	13.2	9.2
18	XXVII	92	20.4	20.2	19.0	16.7	15.6	15.5	13.7	11.2
		93	39.3	20.3	18.8	17.3	15.6	14.8		7.8
		94	31.1	20.5	19.2	17.6	16.3	15.6	13.1	8.5
18	XXVIII	95	38.1	20.6	19.2	17.5	16.3	14.9	13.8	8.7
		96	40.2	20.3	18.8	17.5	15.6	15.0	12.7	8.2
		97	32.9	20.2	19.1	17.2	15.9	14.7	12.3	8.7
18	XXIX	98	32.0	20.2	19.0	16.9	15.8	15.4	11.5	8.4
		99	31.7	18.6	18.1	16.6	15.8	15.0	11.9	8.6
		100	30.5	18.8	17.9	16.6	16.0	14.9	12.5	8.7
18	XXX	101	7.6	20.3	17.5	16.8				16.6
		102	10.1	19.7	17.9	16.8	16.5			16.4
		103	11.9	19.3	17.9	17.0	16.2			14.9
		104	20.4	18.2	17.5					17.1
18	XXXI	105	4.9	20.3	17.6					17.3
		106	6.1	19.5	17.6	16.7				16.7
		107	7.3	19.6	17.5	16.9				16.5
		108	5.5	20.2	17.5					17.0
18	XXXII	109	3.4	19.0	17.3					17.1
		110	3.0	19.2	17.4					17.5
		111	3.0	19.7	17.3					17.4

Table 3. Inflow-outflow water temperatures recorded at Shuffleton plant of Puget Sound Power and Light Company[a].

Date	Inflow Temp. (°C)	Outflow Temp. (°C)	Temp. (°C)
October 1966			
12	17.2	25.0	7.8
13	17.8	22.2	4.4
14	16.7	22.2	5.5
15	16.7	22.2	5.5
16	16.7	21.7	5.0
17	16.1	21.7	5.6
18	15.6	22.2	6.6
19	15.6	23.3	7.7
20	13.3	21.1	7.8
21	11.7	18.9	7.8
22	11.7	18.3	6.6
23	13.3	20.6	7.2
24	12.8	20.6	7.8
25	13.3	21.7	8.4
26	12.2	20.6	8.4
27	13.9	22.2	8.3
28	13.9	22.2	8.3
29	13.3	21.7	8.4
30	13.9	22.2	8.3
31	13.9	22.2	8.3
November 1966			
1	13.3	21.7	8.4
2	13.9	22.2	8.3
3	13.3	21.7	8.4
4	13.3	21.7	8.4
5	12.8	21.1	8.3
6	12.8	21.1	8.3
7	12.8	21.1	8.3
8	12.8	21.1	8.3
9	12.8	21.1	8.3
10	12.8	21.1	8.3
11	12.2	20.6	8.4
12	12.2	20.0	7.8
13	10.0	18.3	8.3
14	11.1	18.9	7.8
15	11.1	18.9	7.8
January 1969			
1	7.8	8.9	1.1
2	5.6	10.0	4.4
22	5.6	8.9	3.3
23	6.7	12.2	5.5
24	4.4	11.1	6.7
27	6.1	12.2	6.1
28	6.1	8.9	2.8
29	5.6	11.7	6.1
30	5.6	12.2	6.6

[a]From Fraser (1971).

Table 4. Monthly mean discharge (cubic meters per second) of the Cedar River at Renton in 1967, 1968, and 1969.[a,b]

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1967	7.2	12.8	32.8	48.7	38.8	24.0	15.6	18.0	12.2	3.9	2.6	3.2
1968	5.9	8.3	27.8	38.2	40.6	27.1	25.0	19.4	12.0	8.1	5.2	10.6
1969	15.1	26.7	32.8	37.7	17.3	14.1	30.3	27.9	21.5	10.7	6.7	6.2
	28.2			124.6	96.7					22.8	8.5	20.0
	9.4			41.5	32.2						2.9	6.7
				(3-year average)								

[a]Data from U.S. Geological Survey Northwest Water Resources Center, Portland, Oregon.

[b]Discharge from plant = 11.36 m^3 sec^{-1} (400 cfs). Six months of year (June-November) stream inflow ≈ or < cooling water little as ~ 1/4 in July and Sept. Maximum river flow Jan. and Feb. ~ 3X (1 1/2 to 4 1/2).

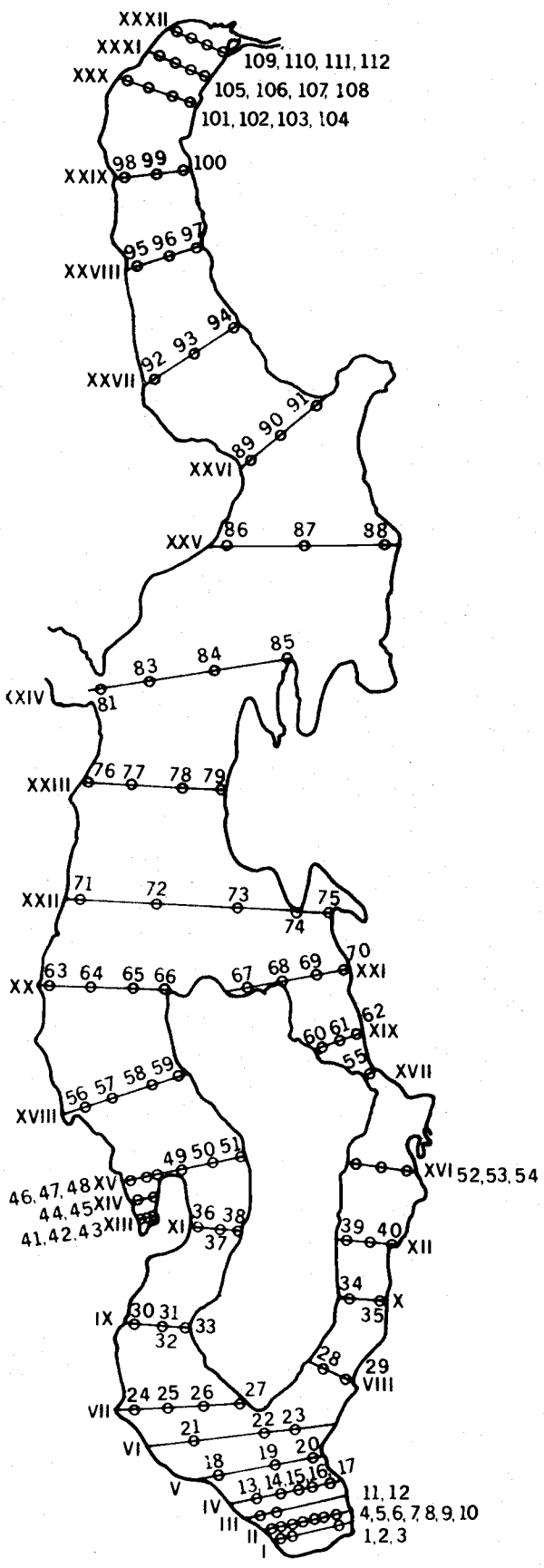

Figure 1. Sampling stations in Lake Washington. Numbers 1-112 = station numbers; I-XXXII = transect numbers.

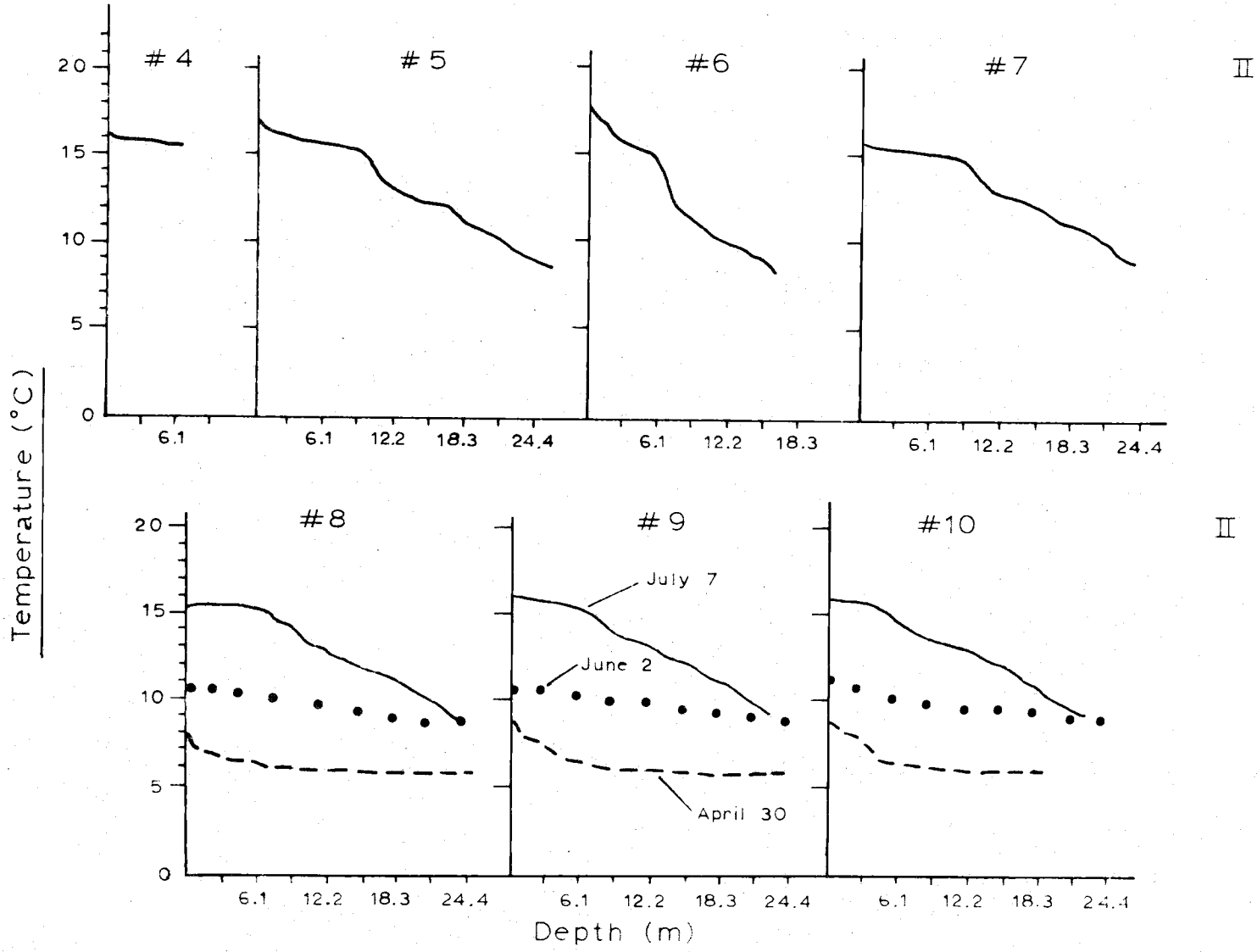

Figure 2a. Depth-temperature profiles of Lake Washington south of Mercer Island, transect II.

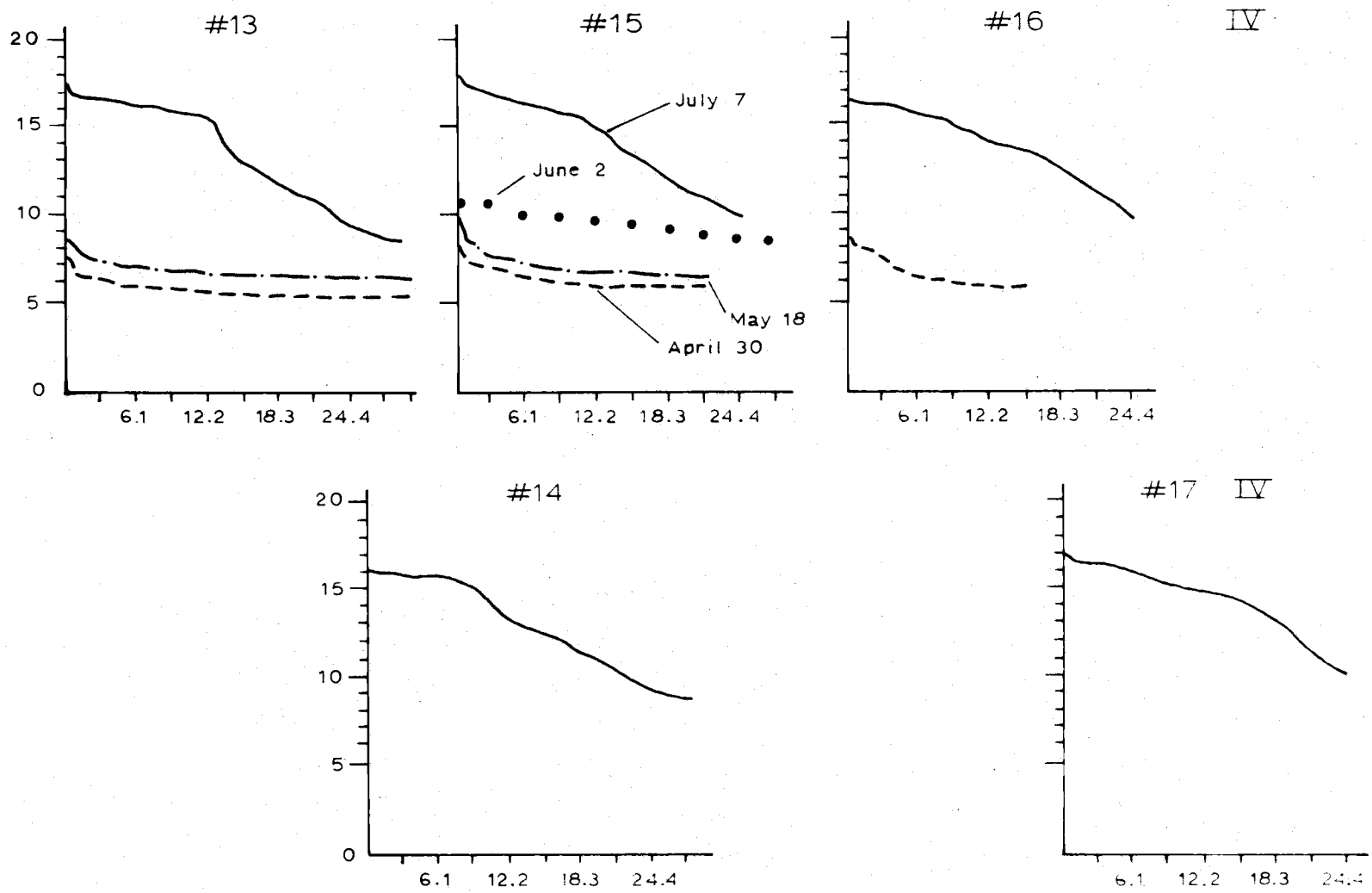

Figure 2b. Depth-temperature profiles of Lake Washington south of Mercer Island, transect IV.

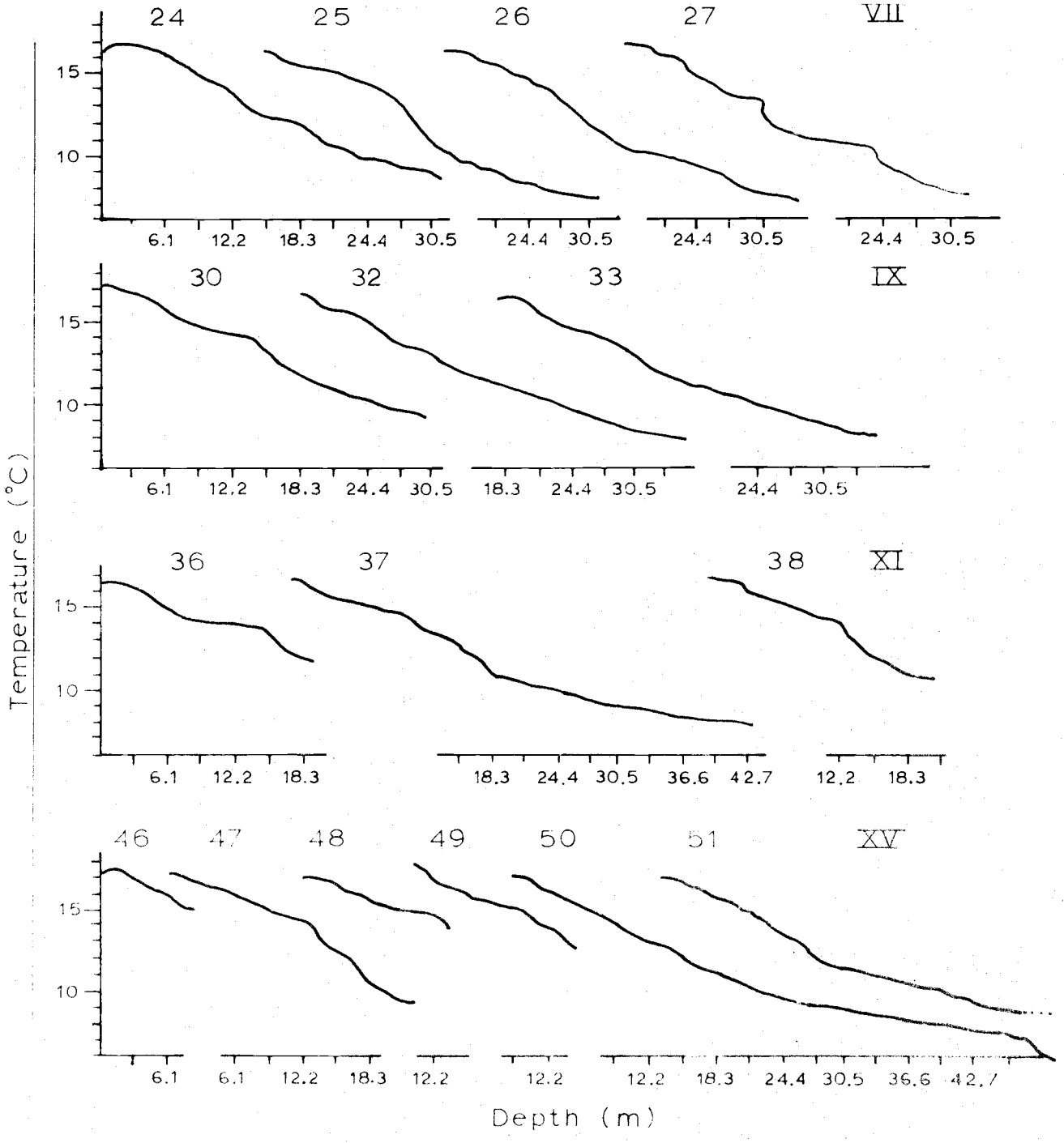

Figure 3a. Depth-temperature profiles of Lake Washington south of Evergreen Point Bridge and west of Mercer Island.

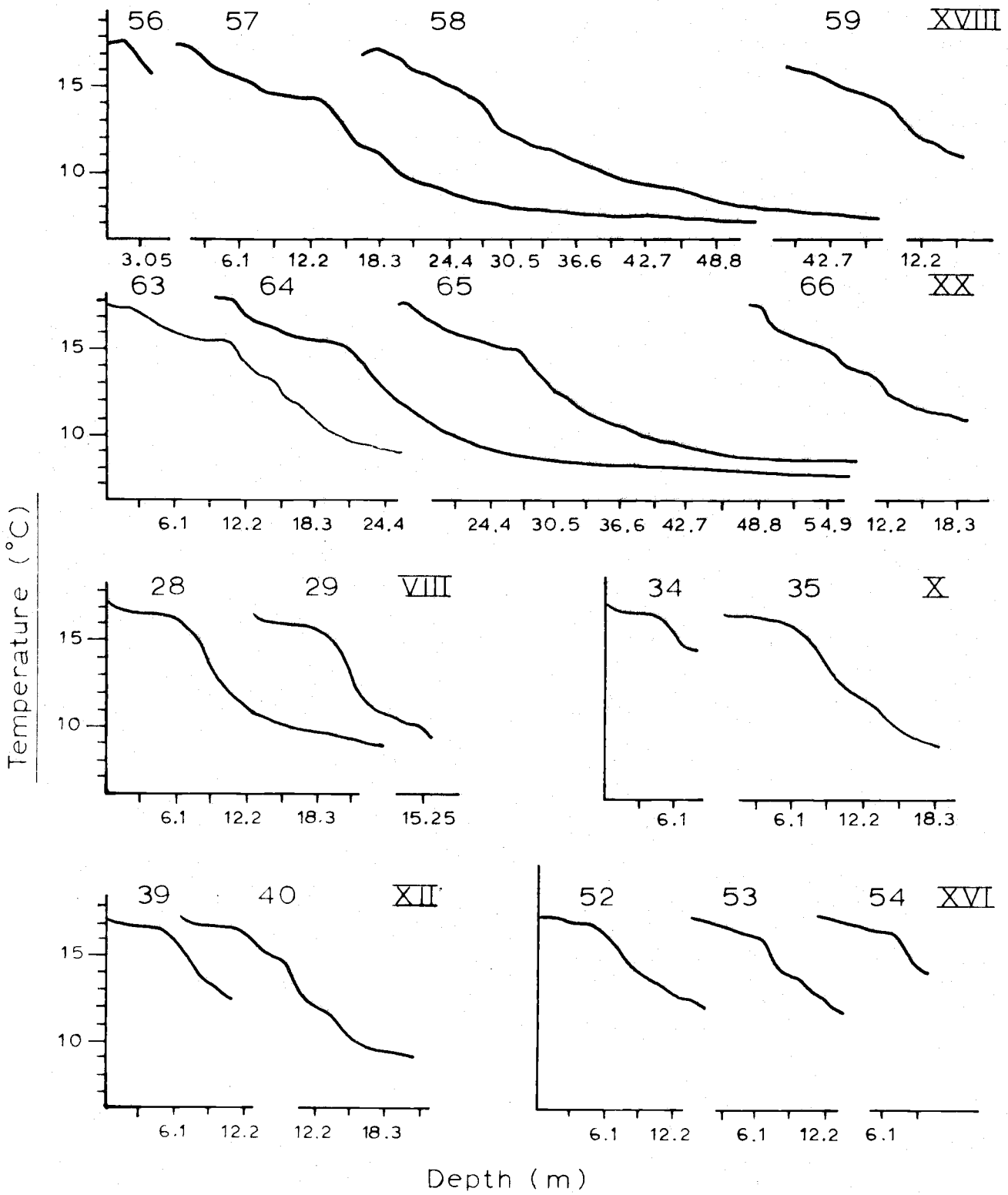

Figure 3b. Depth-temperature profiles of Lake Washington south of Evergreen Point Bridge. Transects XVIII and II are west and VIII, X, XII and XVI are east of Mercer Island.

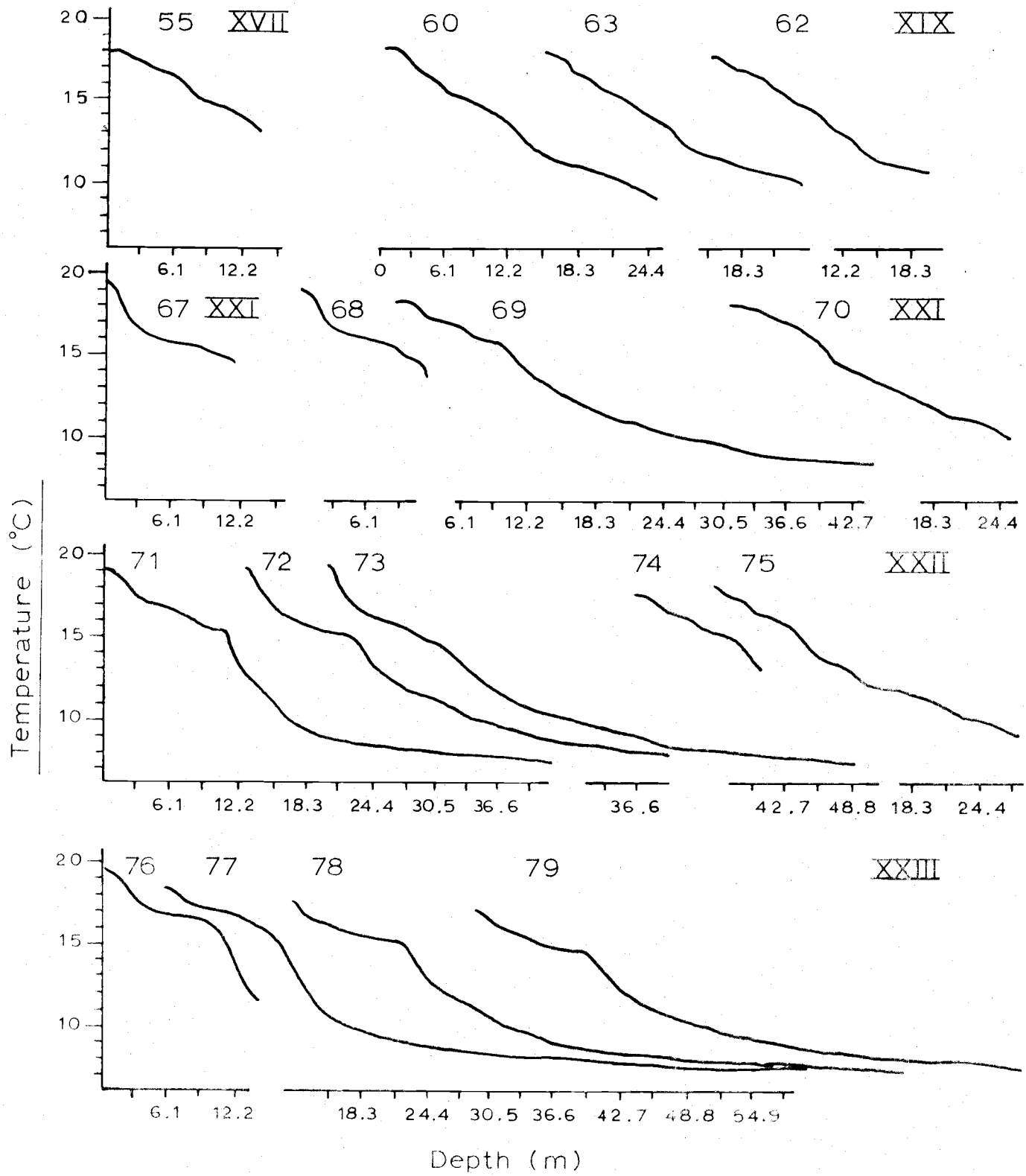

Figure 3c. Depth-temperature profiles of Lake Washington south of Evergreen Point Bridge. Transects XIX and XXI are east of Mercer Island; XXII and XXIII are north of Mercer Island.

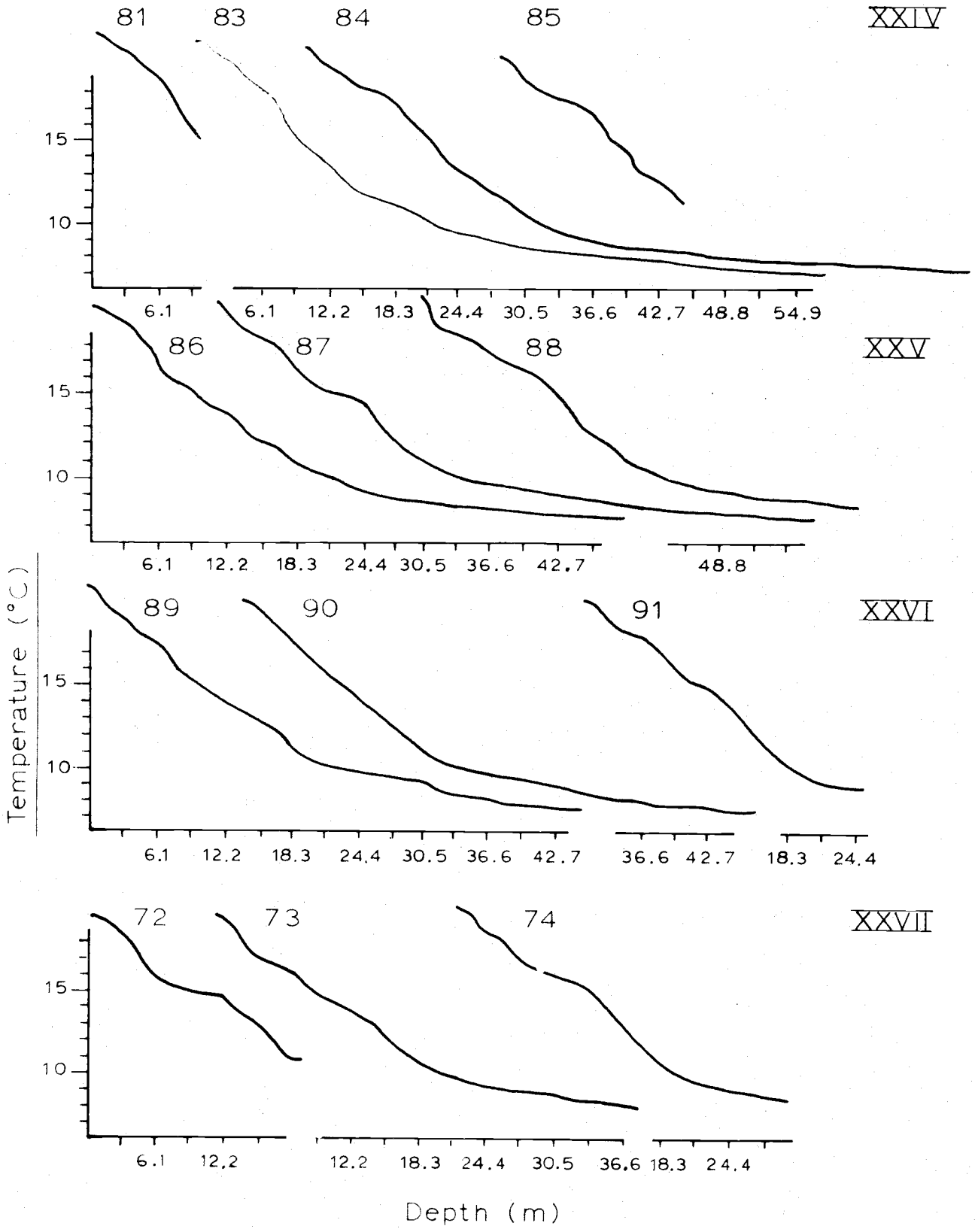

Figure 4a. Depth-temperature profiles of Lake Washington north of Evergreen Point Bridge, transects XXIV-XXVII.

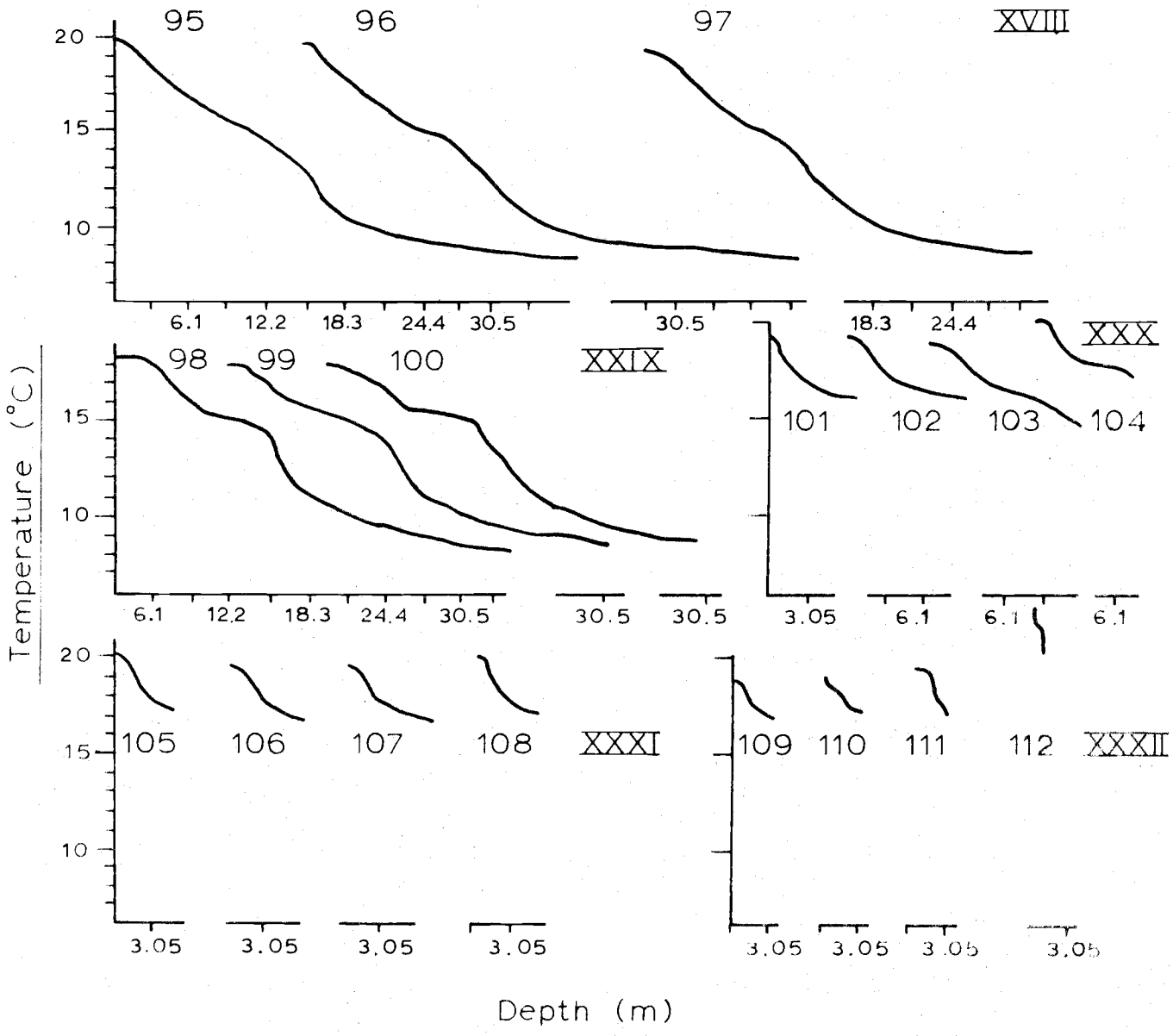

Figure 4b. Depth-temperature profiles of Lake Washington north of Evergreen Point Bridge, transects XVIII, XXX, XXXII.

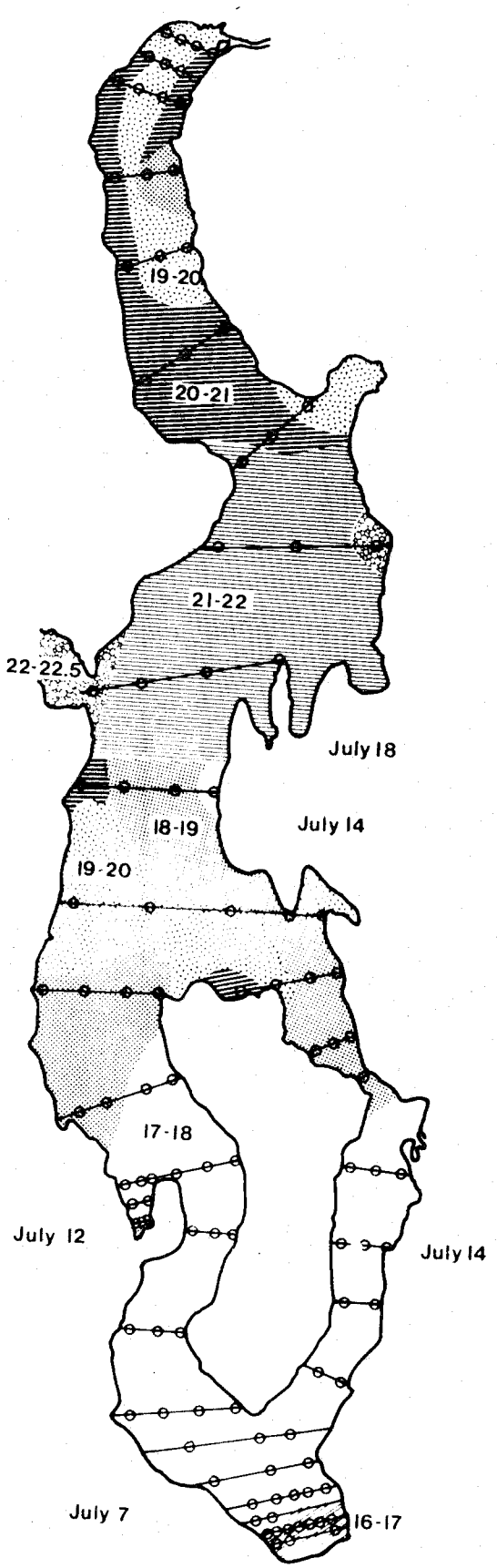

Figure 5. Surface water temperatures in Lake Washington, July 1971.

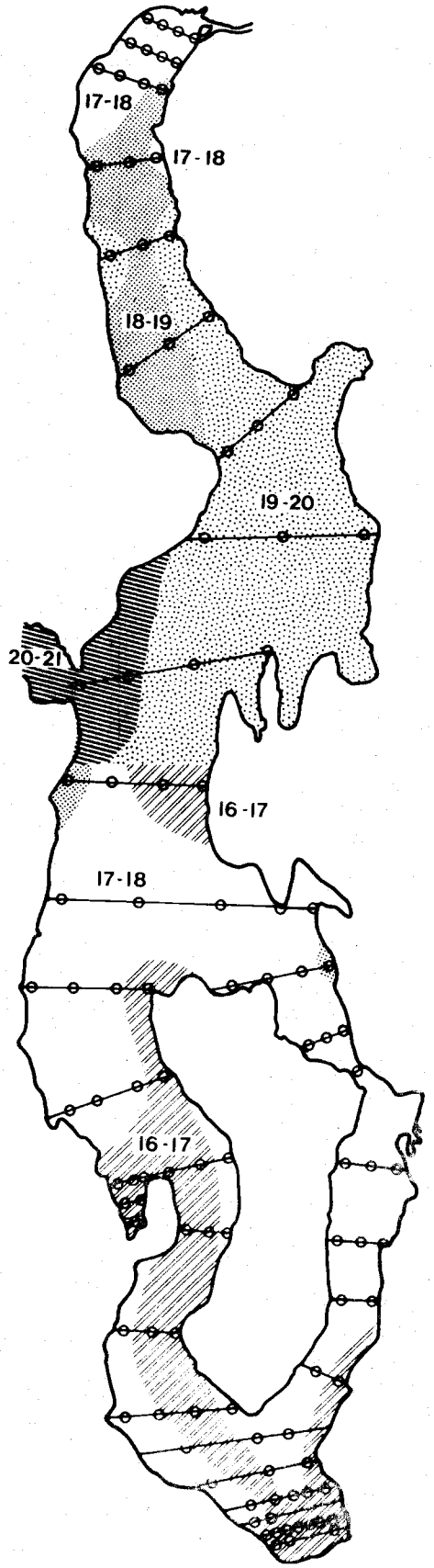

Figure 6. Temperature trends at 3 m depth in Lake Washington, July 1971.

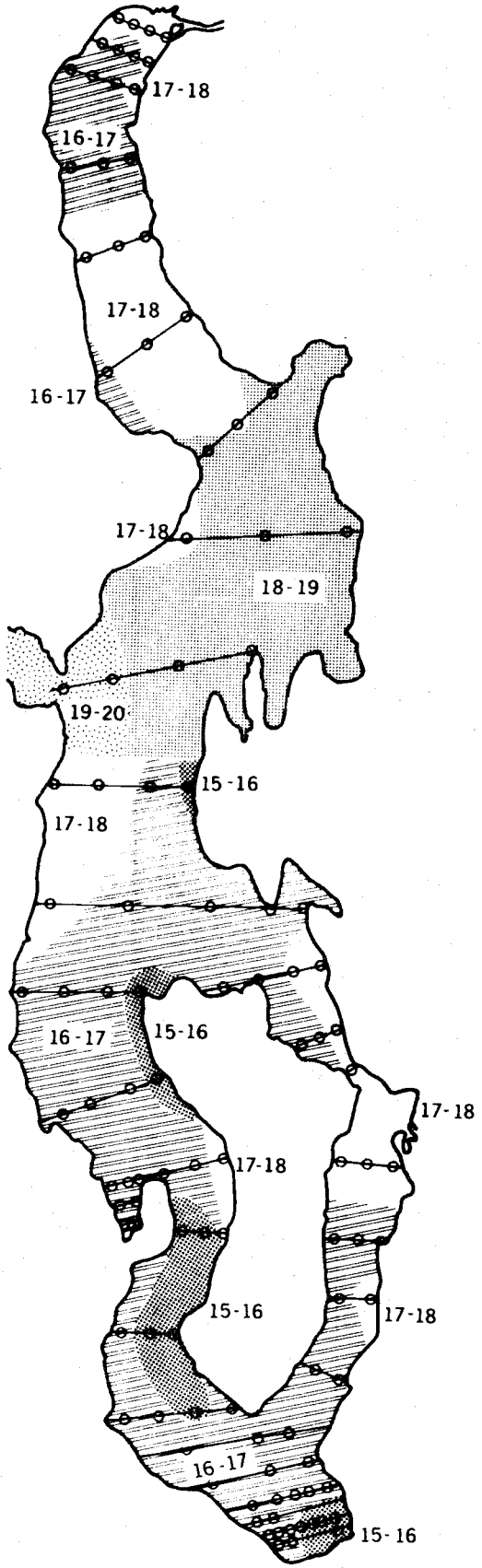

Figure 7. Temperature trends at 6 m depth in Lake Washington, July 1971.