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DEVELOPMENT OF MEROMIXIS IN TWO SMALL LAKES IN MICHIGAN [1]

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Two small lakes in the Pigeon River State Forest, Michigan, apparently have become meromictic in recent years. Lost Lake (T. 32 N., R. 1 W., Sec. 2, 3, Otsego County) has an area of 3.7 acres and a maximum depth of 51 feet. Hemlock Lake (T. 33 N., R. 1 W., Sec. 34, 35, Cheboygan County), which lies one-half mile north of Lost Lake, has an area of 4.9 acres and a maximum depth of 59 feet. These lakes are two of a group of seven lakes in the area that have been described by geologists as limestone sinks; i.e., they were formed through the solution of underlying limestone by ground water, accompanied by a settling of the surface layer of sand and gravel, producing a cone-shaped pothole. As a result, the water surface for most of the lakes is 40 to 60 feet below the surrounding land surface (Tanner, 1960). Hemlock is an exception in that the surrounding bank is about 20 feet high on the southeast side and is very low on the north side of the lake. Eschmeyer (1938) in providing general descriptions of all the lakes, indicated an

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[1] Contribution from Dingell-Johnson Project F-27-R, Michigan.

intermittent outlet for Hemlock Lake in 1932. However, since 1948 the lake has been considered landlocked.

The objectives of the following report are: (1) to establish that the lakes are (or have been) meromictic and (2) to demonstrate that the lakes have become meromictic since the original lake surveys in the early 1930's.

A lake in which some water remains partly or wholly unmixed with the main water mass at the circulation periods is classified as meromictic (Hutchinson, 1957). The perennially stagnant, deep layer is called the monimolimnion. Meromictic lakes are uncommon. Sodon Lake in Oakland County (T. 2 N., R. 10 E., Sec. 20) and Canyon Lake in Marquette County (T. 51 N., R. 29 W., Sec. 12) are the only ones known in Michigan (Newcombe and Slater, 1950; Smith, 1941).

In 1965 and early 1966, for selected months, temperature profiles and chemical descriptions were obtained from the waters of the two lakes. Temperatures were measured with a resistance thermometer at 3-foot intervals from surface to bottom. Water samples were taken at 9-foot intervals and dissolved oxygen, carbon dioxide and methyl orange alkalinity concentrations in parts per million were determined by routine titrimetric methods. Conductivity was recorded in micromhos per cubic centimeter at 18 C.

Chemical profiles of the waters of Hemlock and Lost lakes on June 26 and July 13, 1965, respectively, are given in Figure 1. In both lakes, below a depth of 36 feet the amount of carbon dioxide,

alkalinity, and conductivity increased rapidly to exceedingly high levels. The hydrogen ion concentration decreased. Dissolved oxygen was essentially zero below 36 feet, and the odor of hydrogen sulfide was present in most samples. These mid-summer conditions of carbon dioxide, alkalinity, pH and oxygen still prevailed during February 1965 (Fig. 2).

Temperature profiles of these lakes taken in July 1965, indicated they were both slightly dichothermic, i.e., the minimum temperature occurred somewhat above the bottom and there was a warming trend from this minimum point to the bottom (Fig. 3). In Hemlock Lake, the temperature increased from a minimum of 40.2 F at 39 feet to 42.2 F at the bottom at 59 feet. In Lost Lake the temperature increased from 42.3 F at 45 feet to 42.6 F at 51 feet. Dichothermy is usually associated with meromixis.

The bottom waters of Hemlock and Lost lakes retained the same chemical characteristics throughout the year through both the spring and fall mixing or overturn. The monimolimnion consisted of the bottom 23 feet in Hemlock and 15 feet in Lost Lake. The chemical characteristics of Hemlock and Lost lakes from January 1965 through February 1966 are given in Tables 1 and 2, respectively. The concentrations of carbon dioxide and alkaline salts remained high throughout the year. There did not appear to be any seasonal peaks or trends. Much of the variation observed probably can be attributed to the difficulties of measuring exactly the high concentrations. Similar

values for alkalinity were observed for Hemlock and Lost lakes on August 18, 1967.

The first survey of Hemlock Lake was made July 28, 1932 by a crew from the Institute for Fisheries Research, University of Michigan. Temperature for each meter of depth was recorded as well as dissolved oxygen, carbon dioxide, alkalinity and hydrogen ion concentrations at surface, mid-depth and bottom (Table 3). In 1932, there was oxygen at the bottom of Hemlock Lake (2.3 ppm) and carbon dioxide and alkalinity were only 39 and 198 ppm, respectively.

Lost Lake was surveyed on August 1, 1931 also by a group from the Institute for Fisheries Research. Again there was oxygen at the bottom (0.8 ppm) and carbon dioxide and alkalinity were 6 and 193 ppm, respectively (Table 4).

On the basis of these two surveys made in 1931 and 1932, it appears that Hemlock and Lost lakes were not meromictic at that time.

In 1948, Tanner began an experiment on the effects of adding fertilizer to five of the sink lakes (Tanner, 1960). In 1948, pre-fertilization data were collected, and fertilizer was applied in 1949. Both Hemlock and Lost lakes were fertilized. Unfortunately neither Tanner's thesis (1952) nor the published paper (1960) provide detailed descriptions of the bottom waters of these lakes. However Dr. Tanner kindly allowed me to review his field notes (those still available) for those years and lakes. A compilation of observations made by Tanner in 1948 leads me to conclude that at that time Lost Lake was not

meromictic but that Hemlock was. Most of Tanner's observations were for the upper, and not for the bottom waters. However, the recording in early June, shortly after stratification, of a lack of oxygen, the presence of hydrogen sulfide, and concentrations greater than 200 ppm of carbon dioxide and alkalinity in the bottom waters of Hemlock, suggests that the lake was meromictic. The records for Lost Lake did not indicate higher concentrations.

Following 1948, the next records for the lakes are for July 13 and 14, 1960, when two temperature profiles indicated that Hemlock Lake was dichothermic. Further temperature and chemical observations in 1964 suggested that both lakes were meromictic, and this was verified in 1965 as demonstrated above.

Fast (1971) indicated that Hemlock was still meromictic in 1969, before he started to aerate the hypolimnion. In 1970, he successfully accomplished a mid-summer aeration in which he increased the oxygen in the hypolimnion from zero to more than 10 ppm, while still maintaining the thermal stratification. The lake was then no longer meromictic.

As to the cause for development of meromixis in Hemlock Lake between 1932 and 1948, one can only speculate. It appears that it was not caused by Tanner's fertilization experiments. In Lost Lake the meromixis developed between 1931 and 1964. It could have developed as a result of the fertilization, but the other sink lakes in the area that also were fertilized are not meromictic. Undoubtedly, in the

sink lakes the small surface areas, the relatively deep basins, and the high surrounding banks lessen the mixing of the lake waters by the wind. Presumably the increase in salts in the monimolimnion is the result of biochemical reaction rather than a physical introduction, but more information is needed before any conclusions can be drawn.

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Table 1.--Chemical description of the waters at a depth of 54 feet in Hemlock Lake from January 1965 to February 1966

Year and date	Carbon dioxide (ppm)	Hydrogen ion (pH)	Alkalinity (Methyl orange, ppm)	Conductivity [b] (μmhos 18° C)
1965				
Jan 21	-	6.4[a]	496[a]	-
Feb 15	274	6.6	469	-
May 13	316	6.4	471	-
June 26	243	6.1	532	-
Sep 21	285	6.6	467	804
Oct 28	-	6.8	470	905
1966				
Feb 14	263	6.4	515	-

[a] Sample taken at a depth of 56 feet.

[b] Sample taken on July 12, 1965, had a conductivity of 862 μmhos.

Table 2.--Chemical description of the waters at a depth of 48 feet in Lost Lake from January 1965 to February 1966

Year and date	Carbon dioxide (ppm)	Hydrogen ion (pH)	Alkalinity (Methyl orange, ppm)	Conductivity (μmhos, 18° C)
1965				
Jan 21	-	7.0	290	-
Feb 16	50	6.8	286	-
May 14	60	6.8	274	-
July 13	78	7.0	328	551
Oct 1	65	7.0	311	—
Oct 29	84	7.0	320	579
1966				
Feb 15	67	6.8	288	-

Table 3.--Physical and chemical description of the waters of Hemlock Lake on July 28, 1932

Depth (meters)	Temperature (°F)	Oxygen (ppm)	Carbon dioxide (ppm)	Alkalinity (Methyl orange, ppm)	Hydrogen ion (pH)
0	70	8.7	10	160	8.1
1	69				
2	69				
3	68				
4	67				
5	58				
6	56				
7	50				
8	44				
9	44				
10	43	6.0	12	156	8.0
11	43				
12	43				
13	43				
14	43				
15	42				
16	42				
17	42				
18	42				
19	42	2.3	39	198	7.4

Table 4.--Physical and chemical description of the waters of Lost Lake on August 1, 1931

Depth (meters)	Temperature (°F)	Oxygen (ppm)	Carbon dioxide (ppm)	Alkalinity (Methyl orange, ppm)	Hydrogen ion (pH)
0	74	8.4	0	144	7.9
1	74				
2	74				
3	72				
4	70				
5	66	7.7	0	145	7.9
6	55				
7	51				
8	49				
9	48				
10	48	11.0	0	183	7.6
11	46				
12	46				
13	46				
14	46				
14.5	46	0.8	6	193	7.4

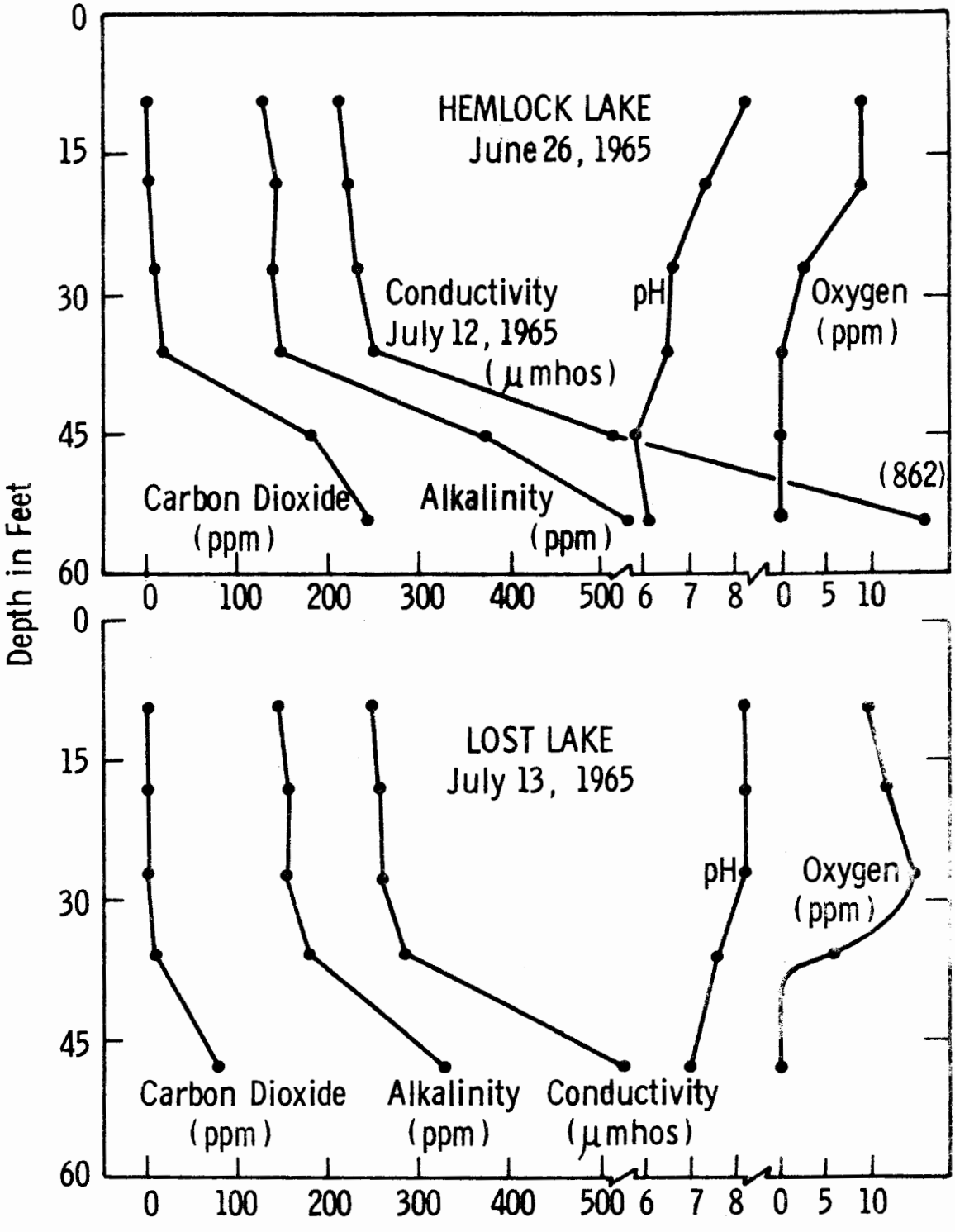

Figure 1. --Chemical profiles of the waters of Hemlock and Lost lakes in June and July, 1965, respectively.

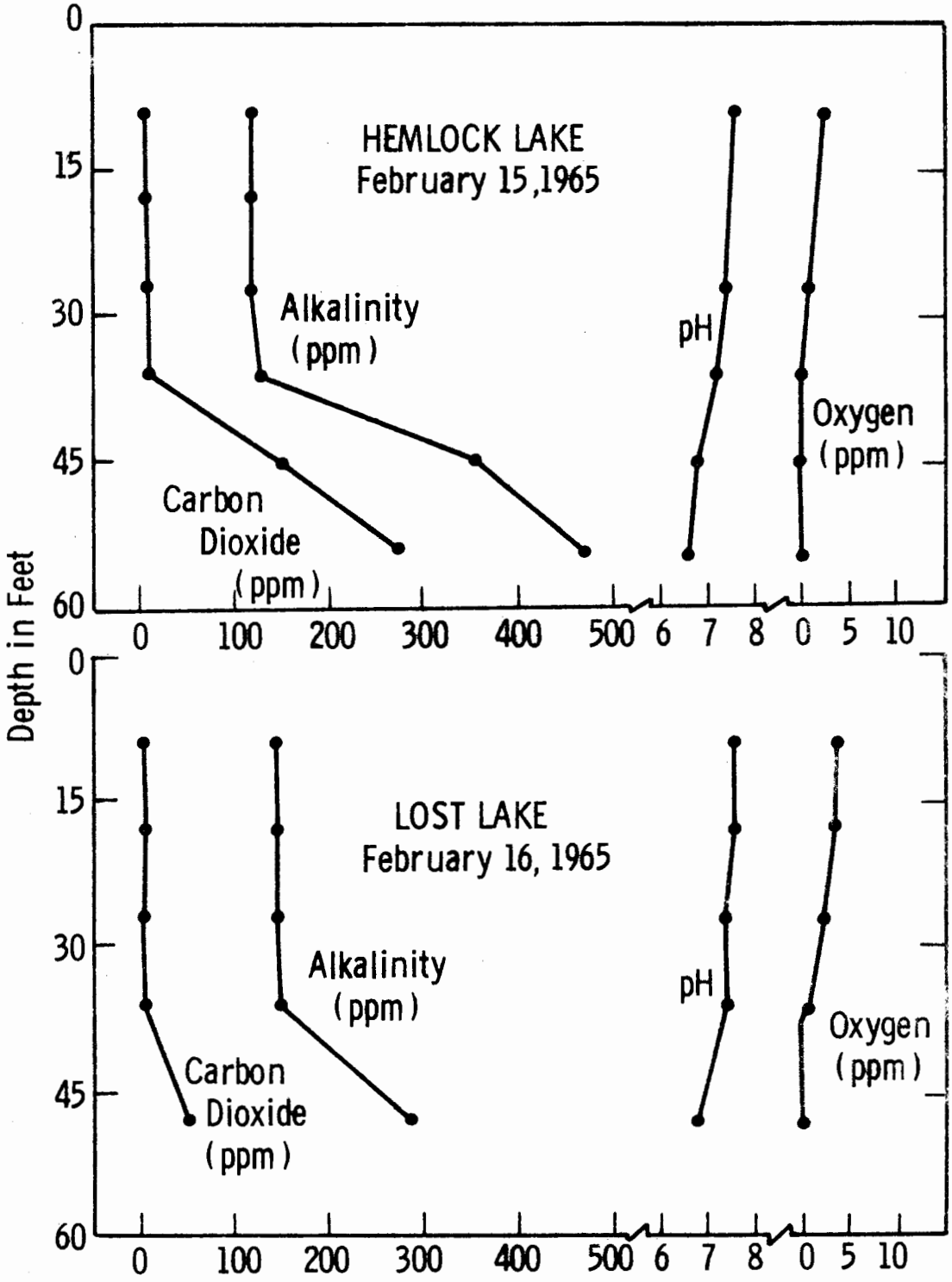

Figure 2. --Chemical profiles of the waters of Hemlock and Lost lakes in February, 1965.

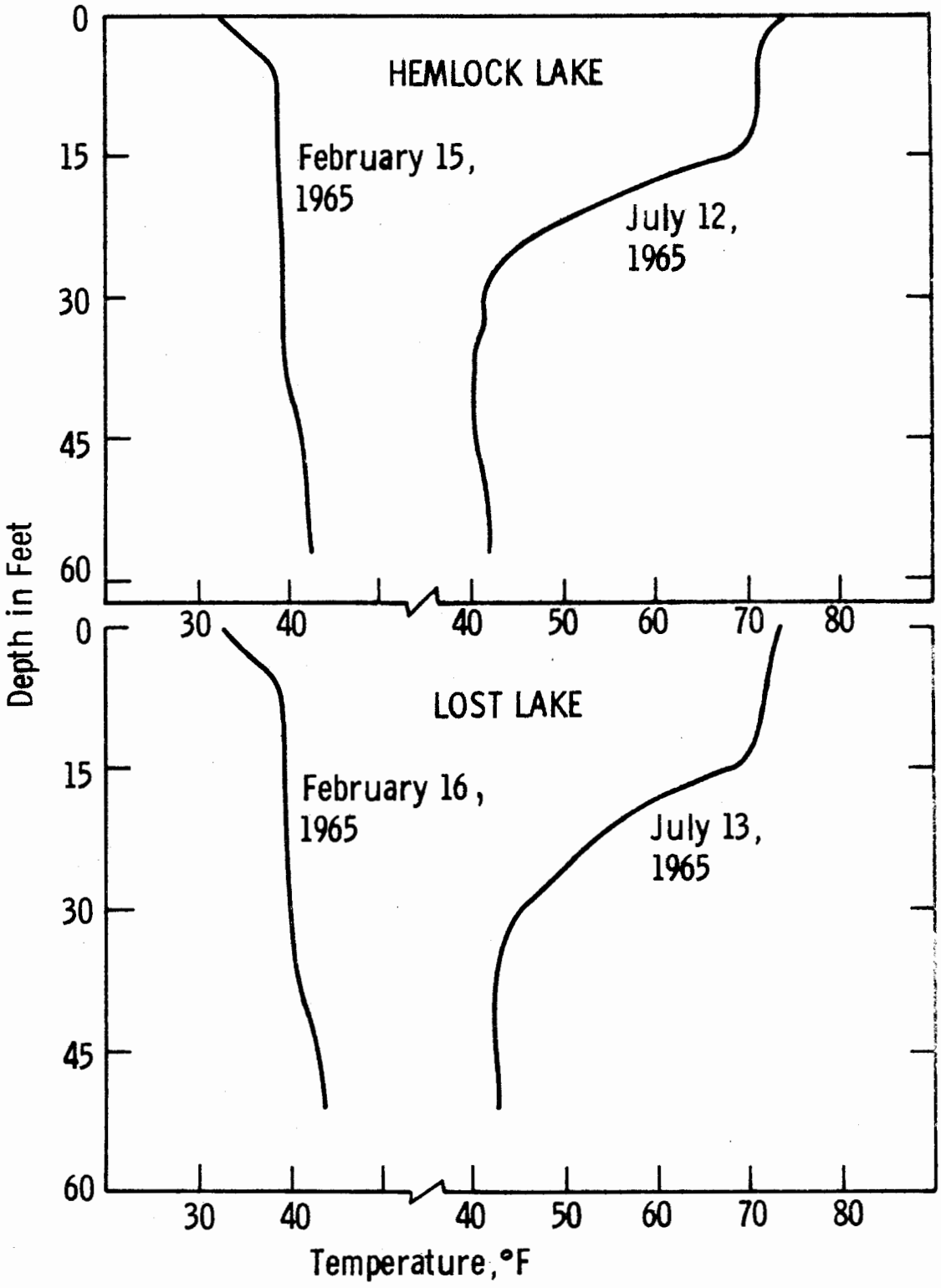

Figure 3.--Temperature profiles in February and July, 1965, for Hemlock and Lost lakes.