LIMNOLOGY OF THE MIDDLE MISSISSIPPI RIVER. III. MAYFLY POPULATIONS IN RELATION TO NAVIGATION WATER-LEVEL CONTROL[1]

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ABSTRACT

Naiad populations of the mayfly *Hexagenia rigida* were studied in an isolated channel of the Mississippi River. Egg-laying by adult females was concentrated at the upper end of the channel. Numbers of naiads were greatest at the upstream end of the channel during most of each summer. The naiads moved downstream prior to emergence.

Following a winter in which the water level was drawn down about 4 ft for 6 weeks, the numbers of naiads were reduced at all stations. Populations near shore were reduced more than those in deeper water.

INTRODUCTION

The Corps of Engineers, U. S. Army, has constructed dams and other structures on the Mississippi River between Alton, Illinois, and Minneapolis, Minnesota, to maintain a channel depth of 9 ft. At each dam, a pool several miles in length is formed in which the water can be maintained at a uniform level. In the Iowa-Illinois-Missouri section of the river, Congress has authorized drawing down the water in the navigation pools during the winter months to provide water for navigation in the lower part of the river. The effect of the drawdown on the river biota has been the subject of much controversy.

Navigation Lock and Dam 21, located about 2 miles south of Quincy, Illinois, at mile 325 above the confluence of the Mississippi and Ohio Rivers, creates Navigation Pool 21 which extends 18.3 miles upstream to Canton, Missouri (Fig. 1). The navigation pool is formed by an earthen dam and concrete gates, with a concrete lock on the Illinois shore. Information of the morphometry of the pool has been made available by the U. S. Army Corps of Engineers (J. H. Peil, personal communication). The principal waterway through the dam is a 20-ft high movable gate with sills at 450 ft above sea level, 13 ft above the lowest point of the preconstruction stream bed. The gates are operated to maintain the navigation-channel depth, but pool elevation at the dam cannot exceed 470 ft. As water flow increases above the minimum, the gates are raised to allow more water to pass under, until the gates are entirely out of the water at a flow that would produce a tailwater elevation of 470 ft. The reservoir created by the dam is 18.3 miles long, with an average width of 0.8 mile, and a surface area of 9,380 acres. The watershed has a total drainage area of 135,000 square miles, with a length of 10,400 miles and an average width of 129.6 miles. The mean annual precipitation is 32.1 in., with a mean annual run-off of 6.88 in., or 49,500,000 acre-ft. Surveys conducted by the Corps of Engineers showed a reservoir capacity of 69,570 acre-ft in 1954.

The dam was put into operation 23 July, 1938. The range in pool elevation for each year to 1956 with the maximum and minimum elevations is shown in Figure 2. At no time did the water level fall as low as the minimum set by the gate sills. Since 1955, the range between maximum and minimum elevations in each year has been greatly reduced. This change was brought about by a decrease in rainfall, which reduced the maximum levels, and by the operation of the dams to raise the minimum levels (E. M. Fry, personal communication).

The periodic draining and drying of large areas of shallow water, which is characteristic of natural stream conditions, greatly

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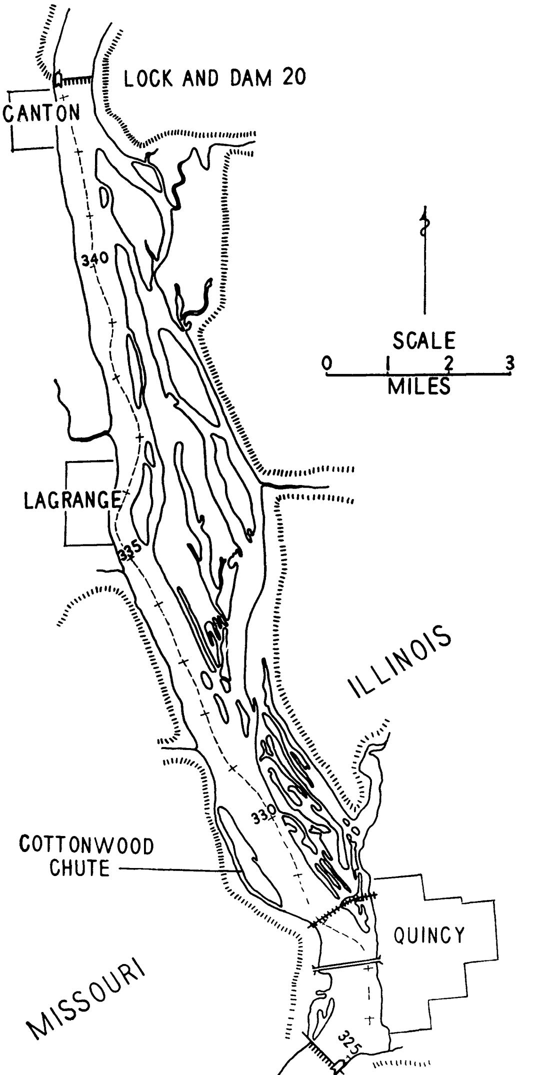

FIG. 1. Navigation pool 21, Mississippi River, between Quincy, Illinois, and Canton, Missouri.

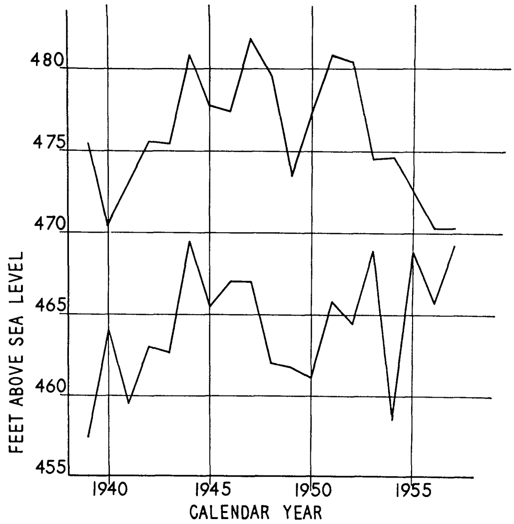

FIG. 2. Range in pool elevation, 1939–1956. Lower line is minimum elevation; upper line is maximum elevation for each year.

reduces the amount of bottom capable of supporting fish-food organisms. The effect of variations in stream discharge on water level was considerably modified by operation of the gates in the dam, so that differences between maximum and minimum surface levels were not as great as they would have been under natural conditions. As a result of the uniform water levels, a much larger area was continuously covered by water than would have been the case under natural conditions. Much of the area covered by higher water levels was located in isolated embayments where current characteristics were quite different from those areas nearer the main channel.

METHODS

Field studies were made at the lower end of the navigation pool near Cottonwood Island. This island is about 2 miles long, extending from about mile 328.5 to mile 330.5. Between the island and the Missouri mainland lies a narrow channel called Cottonwood Chute. This chute was chosen for study because of its accessibility and because of its similarity to many other isolated areas of reduced current within the navigation pool. The word "chute" is synonymous with the terms "bayou" and "slough" used to describe similar water bodies on other parts of the Mississippi River. The relationship of Cottonwood Chute to the main channel of the Mississippi River is shown in Figure 3, which was taken from an aerial photo map. Cottonwood Chute is about 11,880 ft long and 90 to 240 ft wide. The maximum depth is about 12 ft. Nineteen transects 600 ft apart were set up along the length of the chute, numbered from the

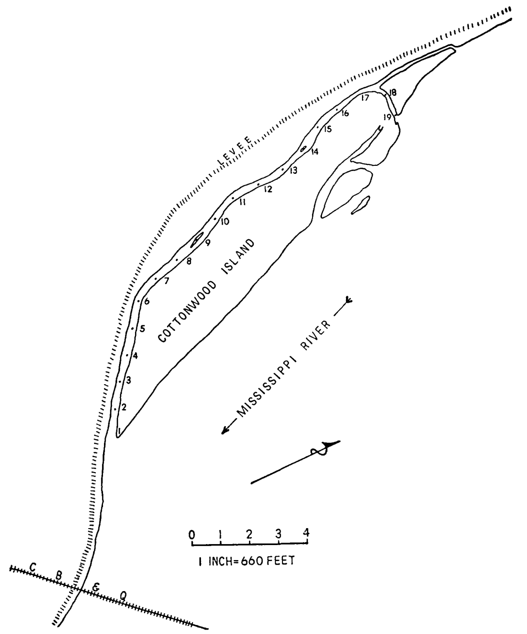

FIG. 3. West shore of Mississippi River, showing Cottonwood Island, with Cottonwood Chute lying between the island and the Missouri mainland. Sampling transects are numbered within the chute.

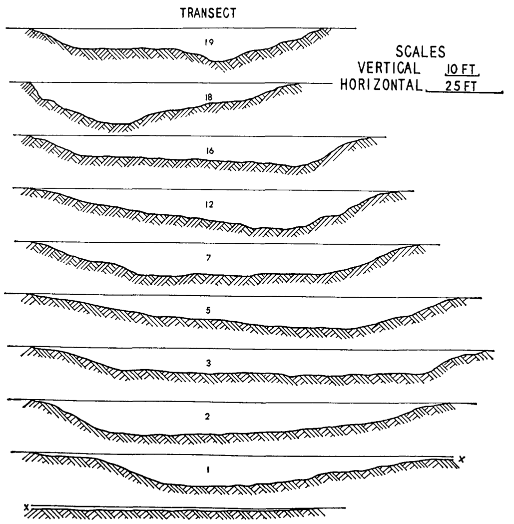

FIG. 4. Cross sections of Cottonwood Chute at selected transects.

lower end upstream. Soundings were made at 1-m intervals across the chute at 9 of these stations. The dimensions established at each of the nine stations are shown in Table 1. Cross-section diagrams are shown in Figure 4 for each station. In general, at each transect there was a narrow shelf with shallow water along each shore. From the bordering shelf, the bottom sloped away to a relatively broad expanse of fairly even configuration. A ridge-like barrier lay across the mouth of the chute at the upper end at a depth of 4 ft. This barrier probably had been placed by the Corps of Engineers to divert water from the chute into the river channel as a means of increasing channel flow and scouring action. The obstruction of the upper ends of isolated channels in this way has been a common practice. At the lower end of the chute the water expanse was quite broad, but almost half of this expanse consisted of water less than 1 ft deep. The main channel at the lower end was quite constricted, with the sides sloping steeply to create a narrow passage in the deeper water (see Fig. 5).

TABLE 1. *Dimensions of Cottonwood Chute at several transects*

Station	Distance from lower end		Width		Maximum depth	
	(ft)	(m)	(ft)	(m)	(ft)	(m)
1	0	0	239	73	9.8	2.99
2	660	201	138	42	10.3	3.15
3	1,980	403	151	46	7.6	2.32
5	3,300	806	141	43	9.3	2.84
7	4,620	1,209	128	39	10.0	3.05
12	7,920	2,217	121	37	11.6	3.54
16	10,560	3,023	111	34	9.0	2.75
18	11,880	3,426	88	27	12.3	3.76
19	12,540	3,627	95	29	10.0	3.05

Collections of bottom organisms were made with a Petersen square-foot bottom sampler at transects 2, 7, 12, and 16. Samples were taken during a 2-year period from October 1954 to November 1956. During the first year (1954–1955) the water level was held nearly constant, but during the second year (1955–1956) the water level was lowered 4 ft for a 6-week period during the winter so that repairs could be made on the dam.

Samples taken 1 April, 1 June, 1 July, and 15 August in 1955 and 1956 from transects 2, 12, and 16 were suitable for statistical analysis.

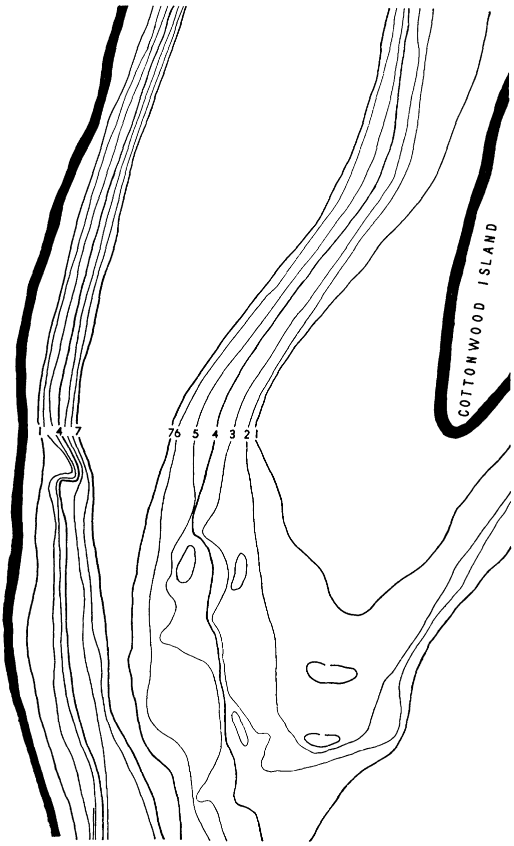

FIG. 5. Topographic detail of lower end of Cottonwood Chute, showing constriction of the channel at lower depths.

At each of the 3 sampling transects, 5 stations were established. One station was established on each shore just at the water's edge. One station was located in the deeper water, about midway between the shore and the center of the chute on each side. A single station was located in the center of the chute. On each collection date, 2 dredge hauls were taken with the Petersen dredge at each station except at the center of the chute where 4 dredge hauls were taken. These 4 hauls were arbitrarily divided 2 to each side. Thus, at each of 3 transects, 12 dredge hauls were taken, for a total of 36 at each collection date.

RESULTS

A factorial arrangement of data was used to investigate simultaneously the interaction

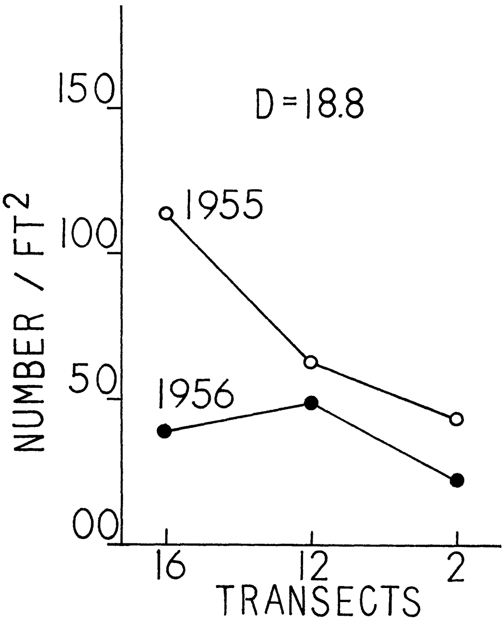

FIG. 6. Mean numbers of mayfly naiads at each transect in each year.

of transect location, year, month, station within a transect, and side of chute. The experimental layout is shown as follows:

	Side 1 stations			Side 2 stations		
Transect 16	1	2	3	3	2	1
Transect 12	1	2	3	3	2	1
Transect 2	1	2	3	3	2	1

The analysis of variance is shown in Table 2. The differences between transects, years, months, and stations, and all of the first and second order interactions between these factors (except for the interaction between stations, months, and years) are shown to be highly significant at the 5% level. The differences between sides were found not to be significant and interactions involving sides were not considered for the sake of brevity. The error term has not been broken down into all of the third and fourth order interactions since no interpretation can be made of those interactions. In a number of cases, one of the duplicate samples was lost, and the analysis of variance could not be applied to individual samples. As a result, the sample means were used in the analysis.

TABLE 2. *A. O. V. (factorial)—mean mayfly naiads/dredge haul*

Source	D/F	Sum of squares	Mean square	F Calculated	F Tabular (0.95)
Transect	2	45,691.0	22,846.0	47.2	3.18
Years	1	47,808.0	47,808.0	98.7	4.03
Interactions:					
Transect × years	2	25,761.0	12,881.0	26.6	3.18
Months	3	402,504.0	134,168.0	277.3	2.79
Interactions:					
Months × years	3	287,148.0	95,716.0	197.9	2.79
Months × transects	6	91,759.0	15,293.0	31.6	2.28
Months × years × transects	6	53,337.0	8,890.0	18.4	2.28
Stations	2	33,527.0	16,764.0	34.6	3.18
Interactions:					
Stations × years	2	6,073.0	3,037.0	6.3	3.18
Stations × months	6	13,790.0	2,298.0	4.7	2.28
Stations × transects	4	10,944.0	2,736.0	5.7	2.55
Stations × months × years	6	6,233.0	1,039.0	2.1	2.28
Stations × transects × years	4	7,863.0	1,966.0	4.1	2.55
Stations × transects × months	12	11,393.0	950.0	2.0	1.94
Sides*	32	5,987.0	187.0	0.4	1.68
Error (3rd and 4th order interactions)	52	25,182.0	484.0		
TOTAL	143	1,075,000.0			

* Tabulation of values for the interactions of side location with other factors is not shown, since none were significant.

Tukey's D was used for the test of comparisons among the factorial means with a 5% confidence interval set on the differences (Snedecor 1956). If the value obtained for Tukey's D was larger than the difference between two means, the difference was considered not to be significant. If the value of Tukey's D was smaller, the difference was considered to be significant. This test was used because of its sensitivity and its ease of application.

The present analysis is based upon the population of naiads of the mayfly *Hexagenia rigida* McDunnough. The characteristic mayfly species of large rivers in the United States is said (Burks 1953) to be *Hexagenia bilineata* (Say). However, naiads of this species were present in Cottonwood Chute in limited numbers only during the summer months. The anomalous distribution of species of mayfly naiads may have been the result of the influence of sewage effluents from two small towns upstream from Cottonwood Chute on the Missouri shore. La Grange, Missouri, is located

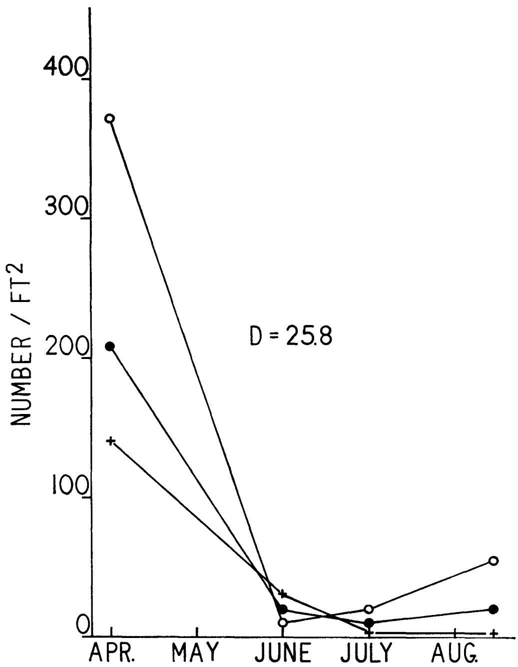

FIG. 7. Mean numbers of mayfly naiads at each transect in each month, 1955. ○ = transect 16, ● = transect 12, + = transect 2.

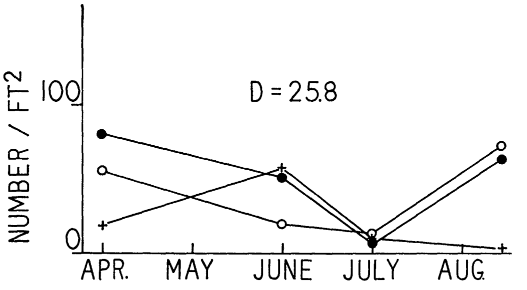

FIG. 8. Mean numbers of mayfly naiads at each transect in each month, 1956. ○ = transect 16, ● = transect 12, + = transect 2.

5 miles above the head of Cottonwood Chute, and discharges a sewage population equivalent of 240 to the river (U. S. Public Health Service 1954). Canton, Missouri, is located 10 miles above the head of Cottonwood Chute, and discharges a sewage population equivalent of 1,200 to the river. No information is available on the organic loading of the water entering Cottonwood Chute. Hoop nets placed in the chute were frequently fouled with debris of sewage origin. It may be that *Hexagenia rigida* was more tolerant of sewage pollution.

The mean numbers of mayfly naiads at each transect for each summer are shown in Figure 6. During 1955, following a winter of uniform water level, the mean numbers of mayfly naiads at all transects were higher than during 1956, after a winter when the water level was drawn down. The difference between the two summers at transect 12 was not significant. During 1955, mean numbers of naiads decreased progressively downstream from transect 16 to transect 2, but during 1956, transects 16 and 12 had populations of essentially the same size, and the population at transect 2 was smaller than either. Apparently, populations at the upper end of the chute declined most following the winter drawdown.

The mean numbers of mayfly naiads at each transect by months are shown for 1955 in Figure 7, and for 1956 in Figure 8. In April 1955 (Fig. 7), the largest numbers of naiads were located at the upper end of the chute at transect 16, and each transect downstream was populated by progressively smaller numbers of naiads. The adult mayflies apparently emerged earlier in 1955 than in 1956, since the numbers of naiads were much smaller in June 1955 than in June 1956 at transects 12 and 2. The water temperature in the river is shown for both years in Figure 9. Water temperature was much higher during April and the first part of May in 1955 than during the same period in 1956. The higher temperature in 1955 may have caused emergence to occur earlier than in 1956. The naiads seem to move downstream prior to emergence, since transect 2 has a larger number of naiads than either of the other two transects in June of both years. There was a much smaller number of naiads at transect 16 in April 1956 following the winter drawdown.

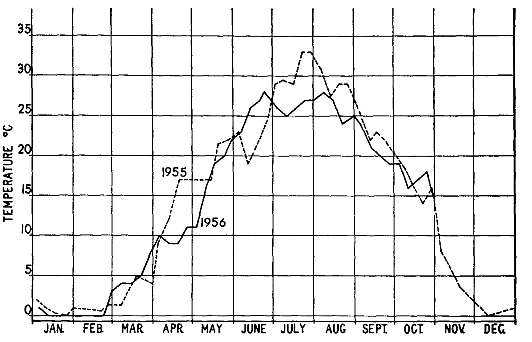

FIG. 9. River water temperature. Solid line = 1956; broken line = 1955.

Newly-hatched naiads were present in greater numbers in August at the upper end of the chute than at the lower end in both years (Figs. 7 and 8). Egg-laying by the adult females apparently occurred mostly at the upper end of the chute, and throughout the succeeding period of growth the upstream portions of the chute supported larger numbers of naiads.

The mean numbers of mayfly naiads at stations for the summer of each year are shown in Figure 10. In each year, the smallest numbers of naiads were present near shore at station 1 and numbers of naiads at the two stations in deeper water (stations 2 and 3) were larger and essentially alike. However, the numbers of naiads were reduced at all stations during the summer following the winter drawdown

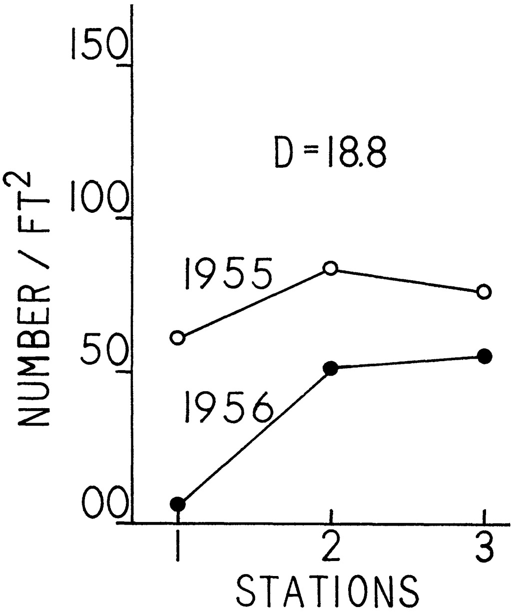

FIG. 10. Mean numbers of mayfly naiads at each station in each year.

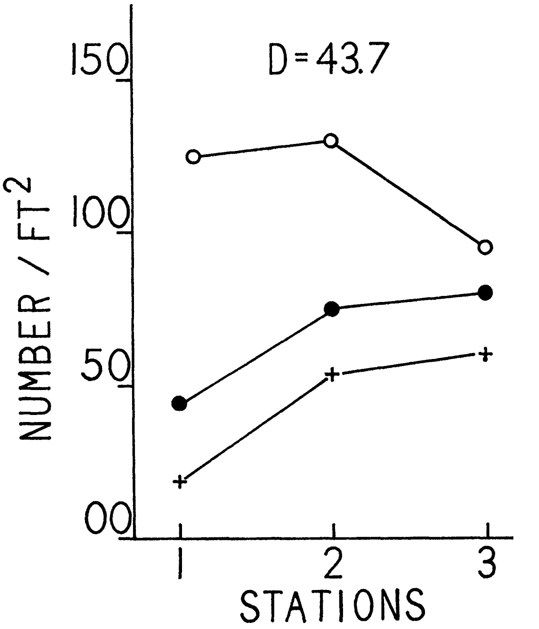

FIG. 11. Mean numbers of mayfly naiads at the stations on each transect, 1955. ○ = transect 16, ● = transect 12, + = transect 2.

with the greatest decrease in numbers occurring at the shore station.

The distribution of mayfly naiads at stations by transects for the summer of each year is shown in Figures 11 and 12. There was no significant difference between the two years at the stations at transects 12 and 2. The principal difference between the two years was in the greatly reduced numbers of naiads in 1956, at all stations at transect 16 where the water was most shallow.

The mean number of naiads by months in the entire chute for the summer of each year is shown in Figure 13. The populations present in June, July, and August were essentially alike in both years, although the numbers in 1956 were slightly higher than those in 1955. The population in April 1955 was much larger than that of April 1956. Large numbers of naiads were present during the spring months in 1955, following a winter of stable water level. Between April and June 1955, the numbers decreased greatly. At about the time of emergence, only about 15 naiads/ft^2 were present.

DISCUSSION

Under natural conditions, river levels fluctuate widely as water flows vary seasonally. Navigation dams tend to stabilize water levels and prevent exposure of the bottom. Populations of bottom-dwelling or-

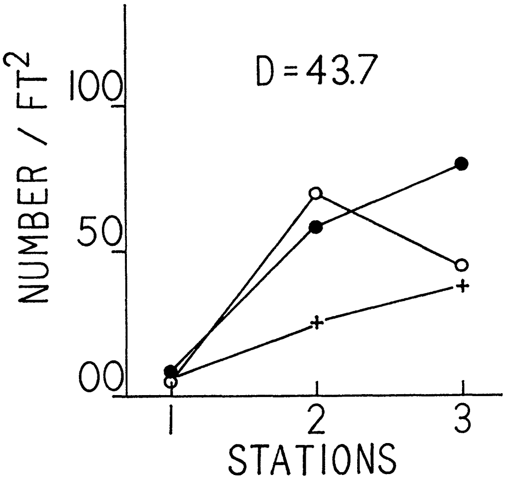

FIG. 12. Mean numbers of mayfly naiads at the stations on each transect, 1956. ○ = transect 16, ● = transect 12, + = transect 2.

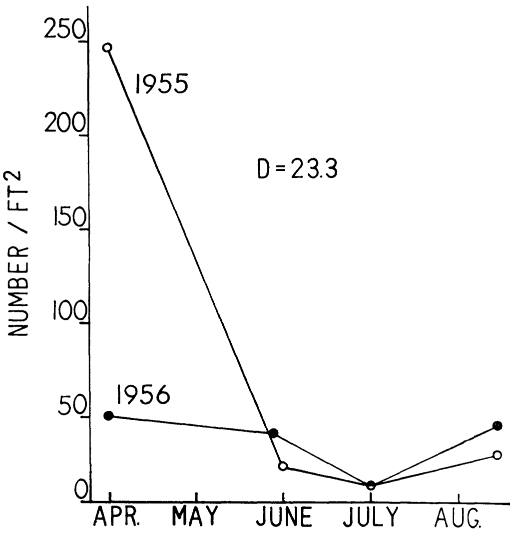

FIG. 13. Mean numbers of mayfly naiads in the entire chute in each month in each year.

ganisms are directly affected by water-level conditions. Stabilized water levels should result in maintenance of maximum numbers of organisms, and fluctuations in water level can be expected to result in reduction in numbers of bottom populations. In the present study, mean numbers of mayfly naiads were significantly smaller after a winter drawdown, as compared to a similar period following a winter period of stable water level. Upstream populations were more greatly reduced than those downstream. Under stable water-level conditions, naiad populations were greatest at the upstream end of the chute.

The naiads appeared to move downstream prior to emergence. Larger numbers of naiads were found in the deeper water than in the shallow water near shore, and their distribution was more uniform.

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