INFORMATIONAL LEAFLET NO. 225

MIGRATORY TIMING OF UPPER COPPER RIVER SOCKEYE SALMON (Oncorhynchus nerka) STOCKS, AND ITS MANAGEMENT IMPLICATIONS TO THE COMMERCIAL FISHERY

By

Margaret F. Merritt

and

Kenneth Roberson

STATE OF ALASKA
Bill Sheffield, Governor
DEPARTMENT OF FISH AND GAME
Don W. Collinsworth, Commissioner
P.O. Box 3-2000, Juneau 99802

October 1983

MIGRATORY TIMING OF UPPER COPPER RIVER SOCKEYE SALMON *(Oncorhynchus nerka)* STOCKS, AND ITS MANAGEMENT IMPLICATIONS TO THE COMMERCIAL FISHERY[1]

by

Margaret F. Merritt

and

Kenneth Roberson

Alaska Department of Fish and Game
Division of Commercial Fisheries
Glennallen, Alaska

October 1983

[1] The data collection for this investigation was partially financed by the Anadromous Fish Conservation Act (P.L. 89-304 as amended) under Project No. AFC-10 (1967-1970) and AFC-32 (1971-1972).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABSTRACT

Data from a tag and recapture project conducted between 1967 and 1972 were studied to estimate migratory timing of 15 upper Copper River sockeye salmon *(Oncorhynchus nerka)* stocks. Time density calculations were used to characterize mean date of migration, variation about the mean, form, and stability of these measures between years. Travel rates were used to estimate the mean calendar date of migration through the Copper River commercial fishery district of Prince William Sound.

River level showed significant negative correlation with travel rate and was a source of interannual variation in mean date of migration. Mean calendar dates of migration varied by stock and were grouped with a Student-Newman-Kuels test into six time spans which significantly differed from one another. Interannual variation in mean migration date increased over time, with earlier stocks demonstrating greater stability than later stocks. The majority of migratory time densities were positively skewed, platykurtic forms, which were relatively stable between years.

Due to the overlap of time density ranges, individual stock fishery management is not deemed feasible. Management of groups of stocks, according to clusters of time density means, is feasible. Identification of the upper Copper River stock composition within a commercial fishery time period will assist the manager in assessing stock abundance and the impact of the fishery on stocks.

KEY WORDS: migratory timing, salmon fishery stock composition, run timing, tag recovery analysis, mark and recapture analysis, migration time density, salmon travel rate

INTRODUCTION

When mixtures of stocks of unequal productivity are harvested together, the maximum yield will be less than if stocks were harvested separately (Ricker 1973). This is because different rates of exploitation are needed to attain each stock's best yield. To determine if the yield of a fishery can be increased through individual stock harvest management, stocks must be identified by objective criteria, such as migratory timing.

Migratory timing is described by Mundy (1979) as a predictable schedule of movement which is genetically transmitted. Killick (1955) observed that this pattern of movement maintains a chronological order over vast distances (1056 km). Therefore, migratory timing is a relatively reliable characteristic of a stock. Migratory timing is not directly dependent on date, but rather the maturation process, which in turn is influenced by environmental and biological factors (Sheridan 1962, Royal 1953). These factors contribute to variation in the mean date of migratory timing. Mundy (1979) found this variation to be conservative in Bristol Bay, and the interannual means to be normally distributed. Migratory timing has been used to segregate stocks in many systems, including the Fraser River (Killick 1955), Chignik River (Dahlberg 1968), and Yukon River (Buklis 1981).

When migratory timing is associated with a given time interval as measured from a fixed point, the proportion of a population within that time interval defines its probability of occurrence. Every migration has a probability density function, and this is referred to as its time density. Time densities have moments because they are probability densities, in particular, a mean (first order), variance (second order), symmetry or skewness (a function of the third moment) and kurtosis (a function of the fourth moment). Estimates of these moments allow comparisons within and between years, assuming time intervals remain unchanged (Mundy 1983). Time densities appear to be independent of the total abundance of a population (Mundy 1979).

Data from a tag and recapture project conducted between 1967 and 1972 for escapement estimates were examined by the authors for information on migratory timing. The observed time densities of 15 sockeye salmon *(Oncorhynchus nerka* Walbaum) stocks through Wood Canyon in the upper Copper River, Alaska, are exhibited in this paper. Form, mean date of migration, variation about the mean, and the consistency of these measures between years were studied for 15 stocks using yearly time densities. Calculated travel rates over time were used to estimate the mean date of migration through the Copper River commercial fishery district of the Prince William Sound management area. The objective was to determine the feasibility of individual or grouped-stock harvest management schemes for upper Copper River sockeye salmon.

Project Background

In 1966 the Branch of River Basin Studies of the U.S. Bureau of Commercial Fisheries (Alaska Region) initiated mark and recapture studies to estimate the number of salmon passing through Wood Canyon on the Copper River. The Alaska Department of Fish and Game, Commercial Fisheries Division, joined efforts with the federal studies in 1967 and assumed complete control of the mark and recapture work in 1969. A major program was continued through 1972 utilizing various sites at Wood Canyon as well as downstream at Baird Canyon and Miles Lake.

The mark and recapture studies conducted in 1966 used a combination of fin clips, so the data collected could only be used for population estimation. During the studies conducted from 1967 through 1972 numbered sequence tags were used, allowing not only population estimates but also evaluations of travel rate and distribution in time of various stocks. Previous to this paper, various reports discussed upper Copper River sockeye salmon stock enumeration and timing for the years 1967-72 (see Greenough 1971; Larson 1967; Larson and Fridgen 1968; Fridgen and Roberson 1969, 1971; Roberson and Fridgen 1972, 1974; Roberson et al. 1974), but quantitative evaluation of the data from all years combined has not been examined.

Study Area

Originating on the north slope of Mt. Wrangell, the Copper River flows through the Chugach Mountains into Prince William Sound, which forms the northern perimeter of the Gulf of Alaska (Figure 1). The Copper River is more than 530 km long, and, with its tributary waters, is the largest salmon river in central Alaska. Its relatively steep grade of 2.1 m/km is considered typical of glacial streams. Deposited glacial silt has created a delta which spreads along the Gulf of Alaska for a distance of 70 km (Thompson 1964).

At the mouth of the Copper River delta is the Copper River commercial fishery District, which includes waters lying between Hinchinbrook Island and Cape Martin. Sockeye, coho *(o. kisutch)*, and chinook salmon *(O. tshawytscha)* are the major commercial species, and lesser numbers of chum *(O. keta)* and pink salmon *(O. gorbuscha)* are taken incidentally. Each boat in this District is allowed to fish a maximum of 150 fathoms of drift gill net gear. Commercial fishing normally begins in mid-May and is regulated by field announcement. The commercial sockeye fishery is essentially complete by the end of July, with the majority of the catch taken between late May and mid June.

A subsistence fishery is located between Chitina and the confluence of the Slana River on the upper Copper River. Subsistence fishermen are issued dip net and fishwheel permits with catch allocations dependent on gross family income and family size.

METHODS AND MATERIALS

Salmon were captured with fishwheels from 1967 through mid-1972 and with a 91 m beach seine during the remainder of 1972. Fishwheels were located at: 1) Miles Lake (river km 48.3), a tag and release site, one wheel on each bank from 1970 to mid-1972, and 2) Wood Canyon (river km 152.9), a recovery and release site, two wheels on each bank from 1967 through 1972. The beach seine was used only at Miles Lake. Fishwheels were designed with wooden live-cars that allowed circulation of water, and fish captured with the beach seine were placed in a holding pen.

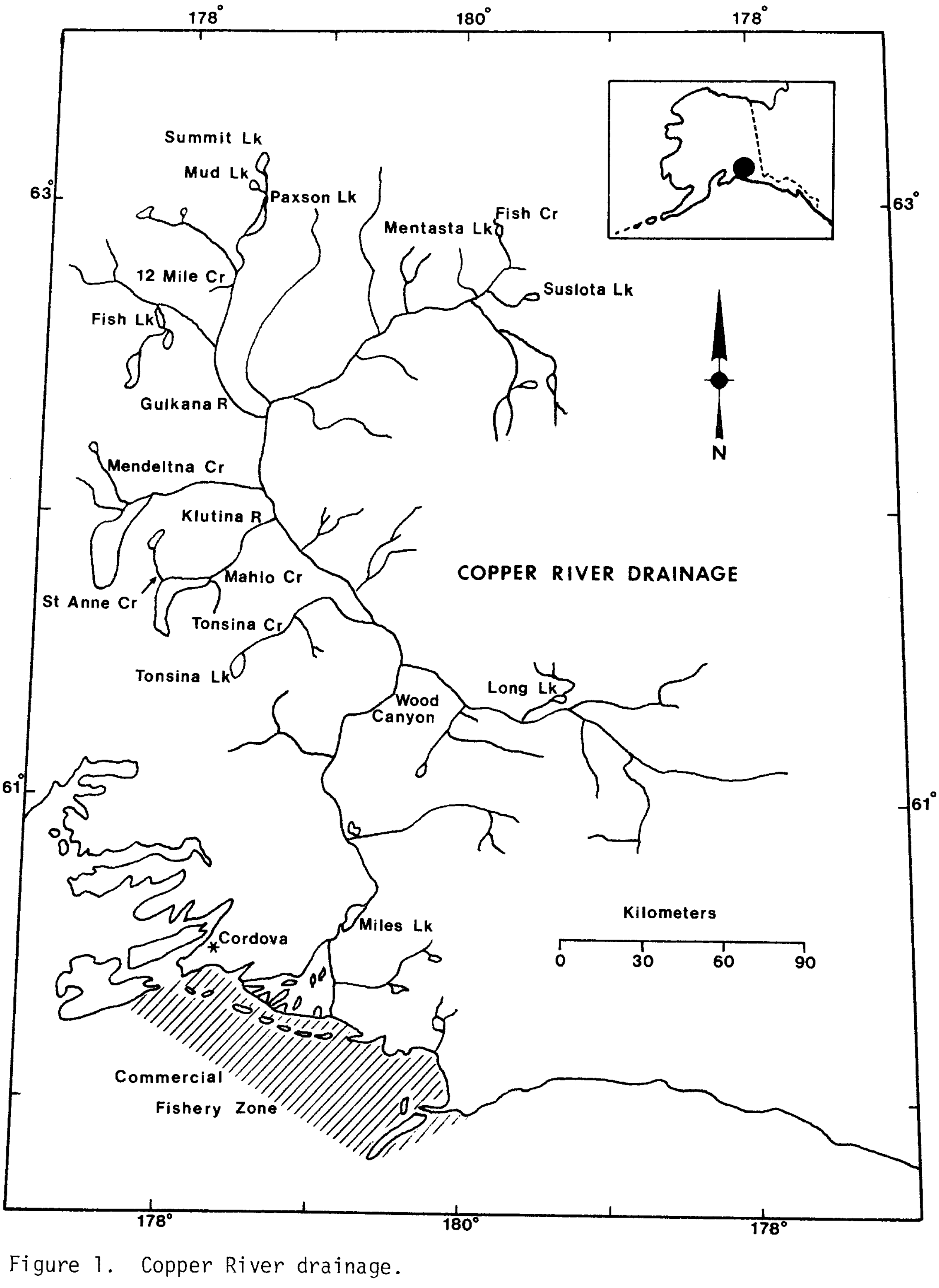

Figure 1. Copper River drainage.

Spaghetti tags were used in 1967, and from 1968 through 1972 various lengths and colors of Floy FD-67 internal anchor tags were used. Spaghetti tags were applied with a special tagging needle while internal anchor tags were applied with a Floy FD-67 tagging gun. The adipose fin was clipped from each tagged fish to serve as a secondary mark. From 1966 through 1968, the length and sex of every fish was determined and scale samples were collected from some fish. During the years 1969 through 1972 the sex of every fish was determined; however, only limited samples of lengths and scales were collected in order to minimize handling.

Tag recovery methods used on the spawning ground included SCUBA with spears, occasional shooting with rifles, snagging with rod and reel, dip-netting, spearing, and hand collection.

Tag recovery data were transferred to forms developed in 1978 and 1979 and keypunched. Computer treatment of the data included sorting by tag number, date, tag and recovery locations, and calculating the distance traveled per day by each tagged fish.

In 1970 and 1972 fish tagged at Miles Lake were recovered at Wood Canyon, a distance of 104.6 km. Travel rates were calculated by dividing the number of days elapsed between release and recovery, and tested with a one-way analysis of variance for differences between months. Travel rate data for 1970 and 1972 were combined and a linear regression by month was used to obtain an estimate of travel rate in the Copper River over time.

Migratory time density calculations were based on population estimates developed by Frohne (1982). An estimate of the number of fish from a given area j, passing the tagging site during a given period (three day interval) k, in year i, is

$$U_{ijk} = \frac{F_{ijk}}{P_{i.} S_{i.} R_{ij}} ,$$

where F is the number of tags recovered, P is the proportion of the escapement tagged, S is the survival and R is the porportion of a stock examined for tags. In calculating U_{ijk}, the following assumptions were applied:

1) the proportion of fish tagged is constant within year ($P_{ik} = P_{i.}$; see Table 1),

2) survival through the upriver subsistence fishery is constant within year ($S_{ik} = S_{i.}$; see Table 1), and

3) the proportion of tags examined (R_{ij}) varies by year and spawning area (see Table 2).

For example, six tags (F) were recovered from Mahlo Cr. (j) fish which had been tagged on 12, 13, or 14 June (k), 1967 (i). From Tables 1 and 2, the product $P_{i.} S_{i.} R_{ij}$ is determined to be 0.079. Thus, U_{ijk} = six tags divided by 0.079, or an estimated 76 fish from Mahlo Cr. passed the tagging site during the 3-day period surrounding 13 June 1967.

Table 1. Statistics from which the proportion of fish tagged ($P_{i.}$) and survival ($S_{i.}$) were estimated.

	1967	1968	1969	1970	1971	1972
Escapement[1]	151,467	233,280	499,037	303,232	486,641	282,851
Tags Applied	14,850	15,294	19,388	15,920	14,361	8,010
Estimated Escapement Tagged ($P_{i.}$)	0.0980	0.0656	0.0389	0.0525	0.0295	0.0283
Subsistence Fishery Tag Interception	1,618	2,399	1,860	1,649	712	457
Estimated Survival ($S_{i.}$)	0.8910	0.8431	0.9041	0.8964	0.9504	0.9429

[1] Calculated after Greenough (1971).

Table 2. Estimated proportion of the escapement examined (R_{ij}) and total number (n) of tags recovered by stock and year.

Stock	1967		1968		1969		1970		1971		1972		Total
	R_{ij}	n	R_{ij}	n	R_{ij}	n	R_{ij}	n	R_{ij}	n	R_{ij}	n	N
Fish Cr. - Mentasta	0.7	0	0.7	5	0.8	18	0.8	9	0.4	4	0.4	2	38
Fish Cr. & Lk.	0.1	1	0.9	150	0.7	68	0.8	14	0.8	10	0.8	2	245
Mentasta Lk.	0.1	2	0.5	26	0.2	5	0.2	2	0.3	6	0.3	3	44
St. Anne Cr.	0.8	23	0.8	108	0.8	66	0.6	120	0.8	61	0.8	4	382
Mahlo Cr.	0.9	43	0.9	74	0.9	39	0.9	29	0.9	25	0.6	4	214
Suslota Cr. & Lk.	0.1	1	0.9	156	0.2	17	0.2	31	0.2	12	0.8	22	239
12 Mile Cr.	0.1	3	0.1	1	0.4	34	0.3	7	0.1	0	0.1	1	46
Gulkana R.: Paxson-Mud Cr.	0.8	7	0.8	146	0.8	128	0.8	56	0.8	13	0.8	16	366
Mendeltna Cr.	0.8	38	0.8	146	0.9	54	0.5	20	0.3	6	0.8	1	265
Mud Cr. & Lk.	0.8	219	0.8	46	0.8	70	0.8	19	0.8	2	0.8	7	363
Upper Klutina R.	0.5	111	0.5	185	0.2	28	0.2	22	0.1	4	0.1	4	354
Lower Tonsina Cr.	0.3	2	0.3	1	0.3	5	0.3	3	0.3	0	0.5	0	11
Gulkana R: Mud Cr. - Summit	0.8	615	0.8	269	0.8	155	0.8	122	0.8	62	0.8	43	1266
Long Cr. & Lk.	0.8	150	0.8	200	0.8	239	0.8	136	0.8	28	0.8	35	788
Tonsina Lk.	0.2	1	0.2	2	0.5	12	0.2	3	0.2	0	0.3	5	23

Tagging effort between years was relatively constant, waning slightly in 1971 and 1972. Tag recovery by the upriver subsistence fishery was relatively constant between years. Tag recovery effort on the spawning grounds was relatively constant between years but differed between spawning areas, due to differences in accessibility.

Time density functions developed by Mundy (1979, 1983) possess moments as do an ordinary random variable, for example, the mean, variance, skewness, and kurtosis. Sample moments of time density functions were used to quantify sockeye salmon migratory behavior. The time span over which the migration occurs is denoted by T. A value within the range of T, t_i, is the arrival of an individual during the i-th time interval. The probability distribution of T is:

$$f(t_i) = \frac{x_i}{n}$$

where $f(t_i)$ is the time density of T, x_i is the number of salmon tagged per time interval, and n is the total number tagged. The mean is the first moment and is defined as:

$$\bar{t} = \sum_{i=1}^{n} t_i f(t_i).$$

The variance is the second moment about the mean and is defined as:

$$S^2 = \sum_{i=1}^{n} (t_i - \bar{t})^2 f(t_i).$$

An estimate of skewness, or asymmetry, is

$$\hat{\gamma}_1 = \frac{\sum_{i=1}^{n} (t_i - \bar{t})^3 f(t_i)}{S^3}$$

where S is the square root of S^2, the sample variance determined above. An estimate of kurtosis, or "peakedness", is:

$$\hat{\gamma}_2 = \frac{\sum_{i=1}^{n} (t_i - \bar{t})^4 f(t_i)}{S^4} - 3$$

RESULTS

Mean travel rate of tagged sockeye salmon was inversely correlated with river level in 1979 (r = -0.72; a 95% confidence interval extends from -0.83 to -0.58;

Figure 2 and 1972 [r = -0.59; a 95% confidence interval is (-0.76, -0.30); Figure 3]. The independent variable, river level, accounted for 52% and 35% of the variation in sockeye travel rate for the years 1970 and 1972, respectively. Mean monthly rate of tagged sockeye salmon in 1970 decreased from 10.25 km/day in June to 4.53 km/day in August. Data from tagged sockeye salmon in 1972 showed a similar trend, although mean travel rate per month was 20% less (Table 3). The slower travel rate observed in 1972 may have been caused by the higher water level (and associated higher water velocity) of the Copper River. During the dates 9 June to 30 July mean water level was 26% greater in 1972 than in 1970, a significant difference (t = 3.46, df = 62, $P < 0.001$). Travel rate data for 1970 and 1972 were combined and a linear regression was used to obtain an estimate of travel rate in the Copper River over time [r = -0.65; a 95% confidence interval is (-0.75, -0.53); Figure 4].

The mean date of migration at Wood Canyon differed between stocks. A Student-Newman-Keuls (SNK) test (Nie et al. 1975) was used to group the absolute mean dates into six time spans which significantly (α = 0.05) differed from one another (Table 4).

Interannual variation in mean migration date at Wood Canyon tended to increase over time [r = 0.73; a 95% confidence interval is (0.32, 0.88); Figure 5]. Thus, the mean migration date of early stocks tended to be more consistent year-to-year than the mean migration date of later stocks. No relationship was found between intra-annual variance of migration and mean date of migration. Thus, dispersion of the migration in a given year varies between stocks, regardless of mean migration date (Table 5).

Mean river distance to the spawning grounds was inversely correlated with the mean migration date at Wood Canyon for the six groups of stocks distinguished with the SNK test [r = -0.93; a 95% confidence interval is (-0.99, -0.47); Figure 6]. This observation agrees with the principle cited by Thompson (1951) that stocks which must migrate the farthest to spawn tend to be the first in the watershed.

Mean travel rate date for 1970 and 1972 were used to calculate the estimated mean date of migration at the Copper River commercial fishery district. Differential travel rates by month were incorporated into the calculations. Time density means for the majority of the 15 stocks occurred at the commercial fishery district prior to mid June (Table 6). Stocks whose calculated time density means occurred at the commercial fishery district after mid June include Gulkana River: Mud Creek to Summit Lake, and Long Creek and Lake. These stocks have the two greatest estimated spawning population sizes of the stocks examined in this study.

Yearly time densities of stocks were analyzed for form and stability of form between years (Table 7). The majority (73%) of combined-year time densities were positively skewed ($\hat{\gamma}_1 > 0$), with the remainder exhibiting negative skewness. A total of four stocks were consistently positively skewed, two stocks were consistently negatively skewed, and the remaining nine stocks exhibited both types of skewness between years. Platykurtosis ($\hat{\gamma}_1 > 0$) was observed in 67% of combined-year time density forms, with the remainder of forms exhibiting leptokurtosis. All stocks exhibited at least one platykurtic form. Thus, the majority of sockeye salmon stocks arrived at Wood Canyon in a positively skewed,

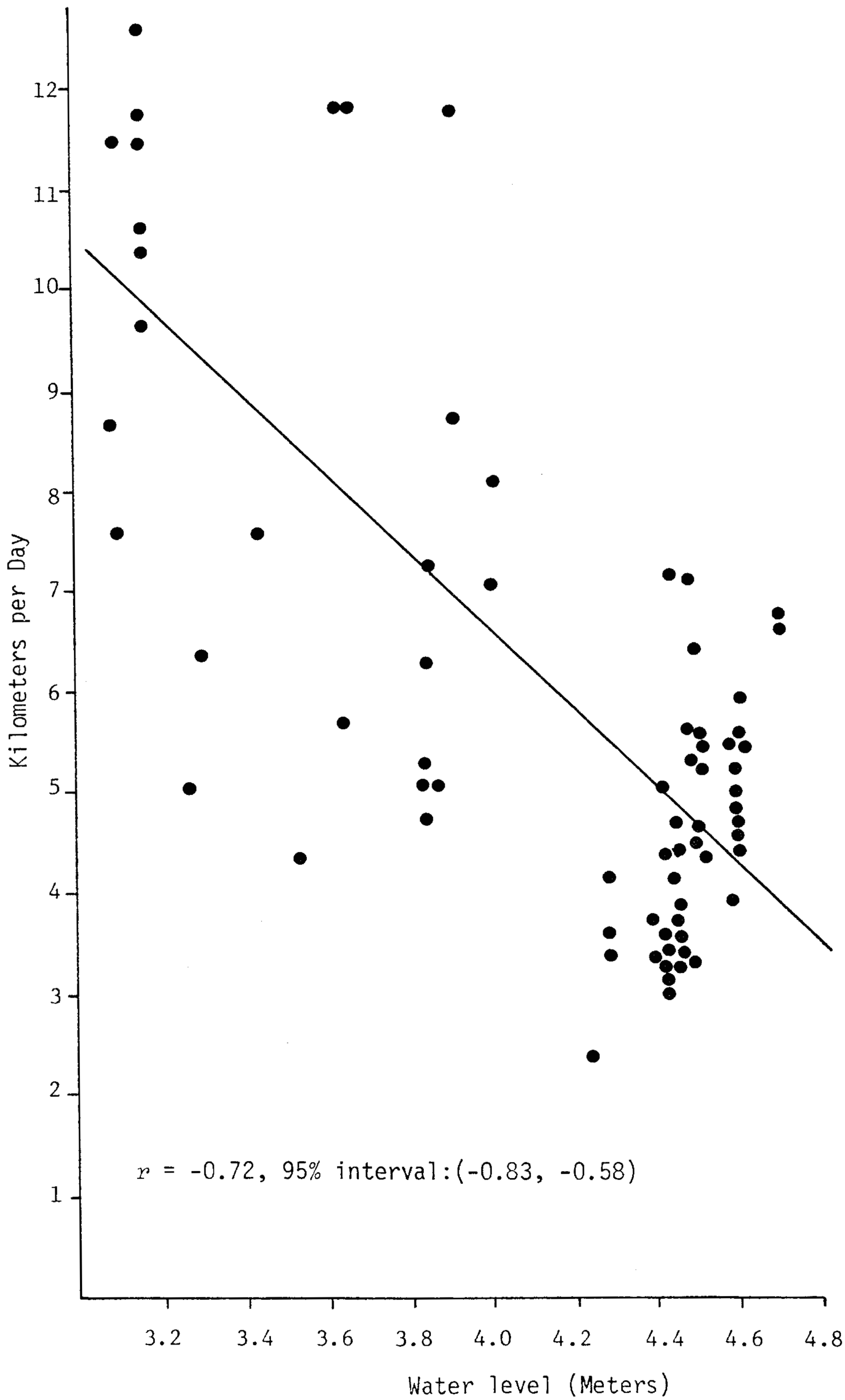

Figure 2. Mean travel rate of tagged sockeye salmon between Miles Lake and Wood Canyon versus mean water level measured at Wood Canyon, 1970.

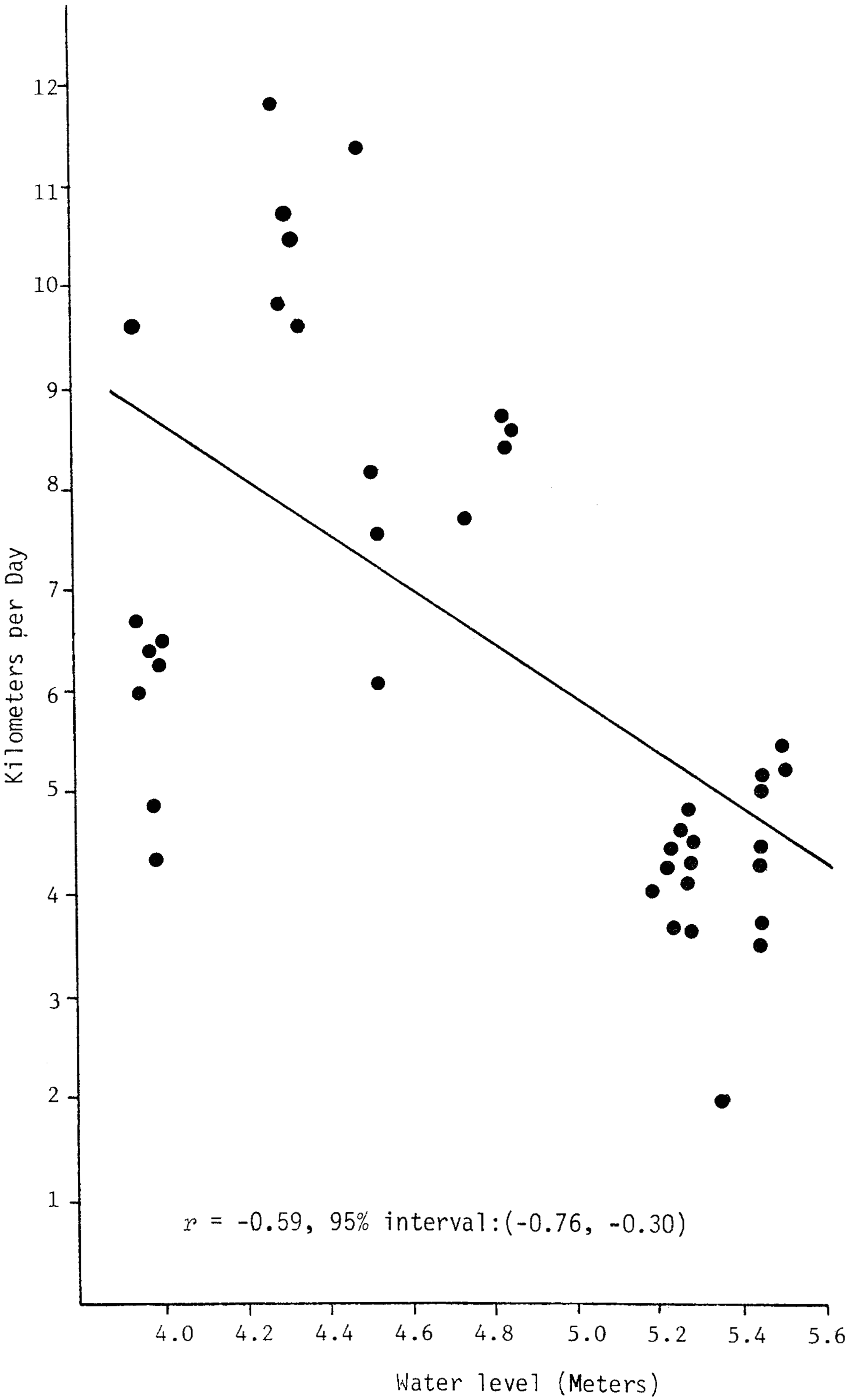

Figure 3. Mean travel rate of tagged sockeye salmon between Miles Lake and Wood Canyon versus mean water level measured at Wood Canyon, 1972.

Table 3. Analysis of variance for mean travel rate of tagged sockeye salmon from Miles Lake to Wood Canyon, by month and year.

Year: 1970	June	July	August
Mean km per day	10.25	7.35	4.53
Standard deviation	1.78	2.49	1.10
Sample number	10	16	46

	S.S	d.f.	M.S.	F
Months	308.90	2	154.45	60.57
Error	175.94	69	2.55	($P < 0.001$)
Total	484.85	71		

Year: 1972	June	July	August
Mean km per day	8.14	5.94	insufficient data
Standard deviation	2.32	2.25	
Sample number	9	30	

	S.S.	d.f.	M.S.	F
Months	33.64	1	33.64	6.57
Error	189.56	37	5.12	($0.01 < P < 0.025$)
Total	223.20	38		

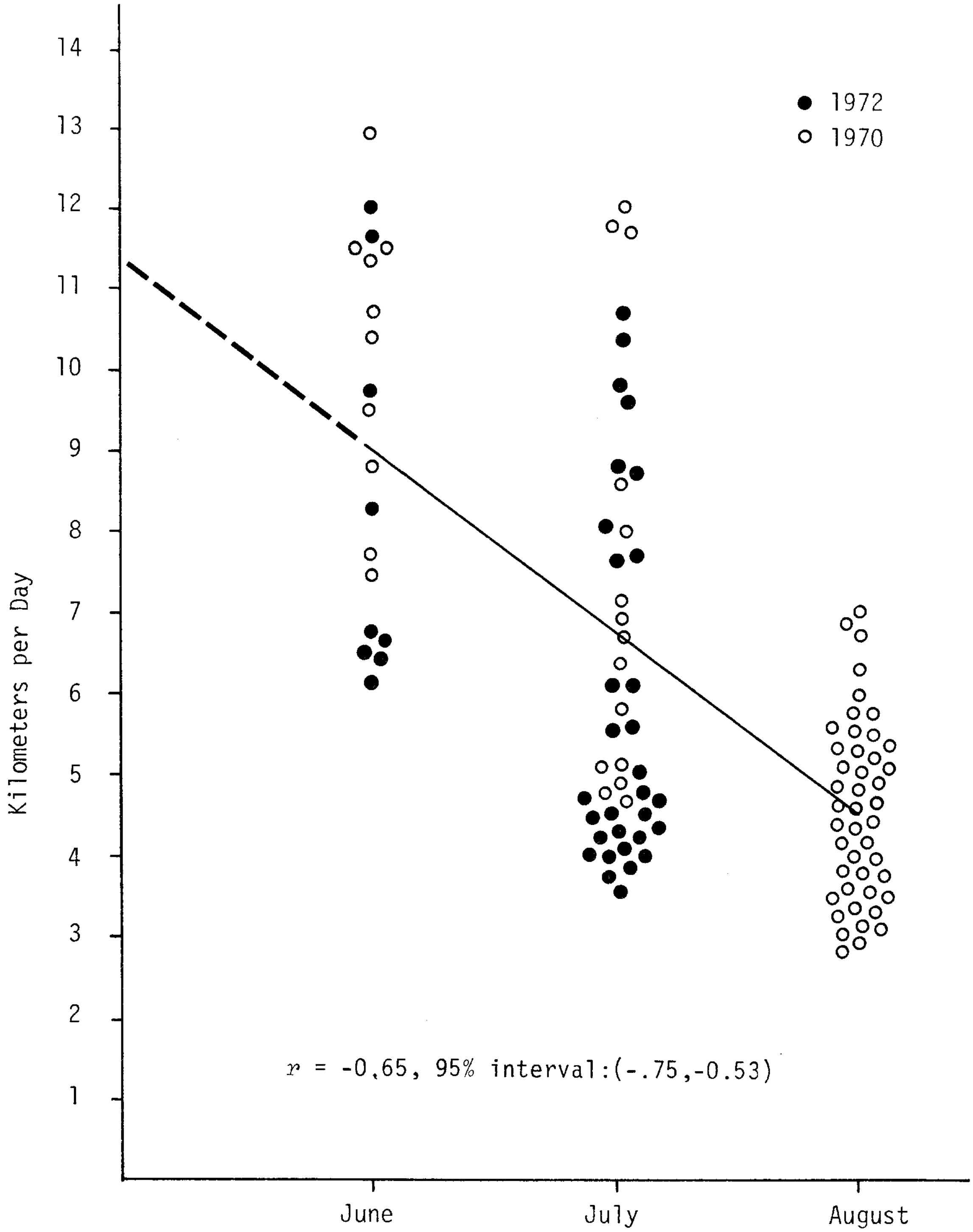

Figure 4. Mean travel rate of tagged Copper River sockeye salmon versus month, for 1970 and 1972.

Table 4. The mean passage date of upper Copper River sockeye salmon stocks at Wood Canyon, grouped into six significantly different time spans with the SNK test. River kilometers to the spawning grounds are given for each stock.

Mean Date: June (7, 17, 27), July (7, 17, 27), August (6)

Km	Stock	Group
459.2	Fish Cr - Mentasta	1
456.9	Fish Cr and Lk	1, 2
455.0	Mentasta Lk	1, 2, 3
305.2	St. Anne Cr	2, 3
292.5	Mahlo Cr	2, 3
419.4	Suslota Cr and Lk	3
417.1	12 Mile Cr	4
446.0	Gulkana R: Paxson - Mud Cr	4
357.6	Mendeltna Cr	4
446.5	Mud Cr and Lk	4
288.3	Upper Klutina R	4
197.6	Lower Tonsina Cr	4, 5
457.6	Gulkana R: Mud Cr - Summit	5
219.6	Long Cr and Lk	6
259.4	Tonsina Lk	6

* denotes mean passage date of combined years

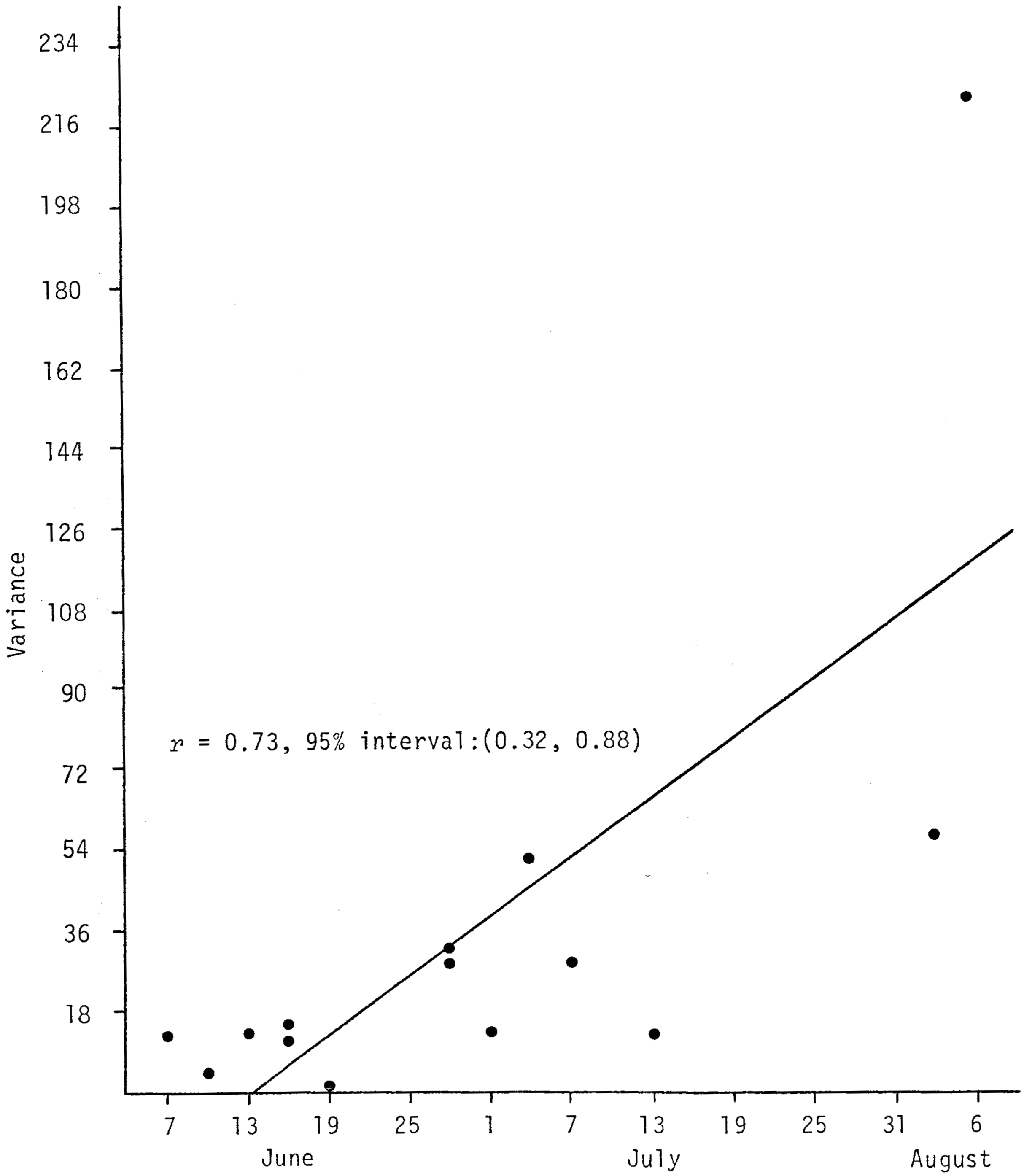

Figure 5. Interannual variance in mean migration date of stocks at Wood Canyon versus mean migration date.

Table 5. Estimated mean date and variance of migration (in days[2]) at Wood Canyon for upper Copper River sockeye salmon stocks by year. Based on an average of estimated numbers of sockeye salmon per three day interval, 1967-1972[1].

	1967		1968		1969		1970		1971		1972		All Years	
	Date	s^2	Date	s^2	Date	s^2	Date	s^2	Date	s^2	Date	s^2	Date	s^2
Fish Creek - Mentasta	--	--	6/ 7	5.76	6/ 1	11.16	6/10	11.52	--	--	--	--	6/ 7	19.53
Fish Creek & Lake	--	--	6/10	45.81	6/10	75.96	6/13	41.40	6/ 3	2.61	--	--	6/10	150.21
Mentasta Lake	--	--	6/10	62.46	6/16	440.64	--	--	6/10	8.01	--	--	6/13	125.91
St. Anne Creek	6/25	50.40	6/16	73.62	6/16	121.50	6/16	93.06	6/19	43.47	--	--	6/16	85.77
Mahlo Creek	6/25	93.42	6/16	62.37	6/16	80.73	6/16	111.42	6/19	79.92	--	--	6/16	85.68
Suslota Creek & Lake	--	--	6/19	82.89	6/22	82.62	6/19	37.71	6/19	63.72	6/22	30.87	6/19	62.10
12 Mile Creek	--	--	--	--	6/28	38.34	6/19	81.54	--	--	--	--	6/28	47.43
Gulkana River: Paxson - Mud Creek	7/ 7	224.82	6/25	120.78	7/ 1	119.07	6/25	96.57	7/ 1	121.32	6/25	85.50	6/28	129.69
Mendeltna Creek	7/ 1	44.37	7/ 4	71.64	7/ 4	53.91	7/ 4	56.25	6/25	23.04	--	--	7/ 1	66.33
Mud Creek & Lake	7/ 7	225.09	7/ 1	165.06	7/ 4	127.35	6/22	85.59	--	--	7/13	280.26	7/ 4	196.47
Upper Klutina River	7/13	111.06	7/10	41.94	7/10	52.74	7/ 1	134.91	--	--	--	--	7/ 7	120.87
Lower Tonsina Creek	--	--	--	--	7/10	38.16	--	--	--	--	--	--	7/10	108.54
Gulkana River: Mud Creek - Summit	7/16	318.06	7/10	245.88	7/13	210.06	7/10	191.79	7/19	471.51	7/16	312.48	7/13	290.07
Long Creek & Lake	8/ 9	184.05	8/ 3	161.73	7/28	52.74	7/31	142.11	8/18	16.92	8/ 6	33.93	8/ 3	136.26
Tonsina Lake	--	--	--	--	7/22	295.29	--	--	--	--	8/12	8.64	8/ 6	251.10

[1] For tag recoveries $\geq$ 5.

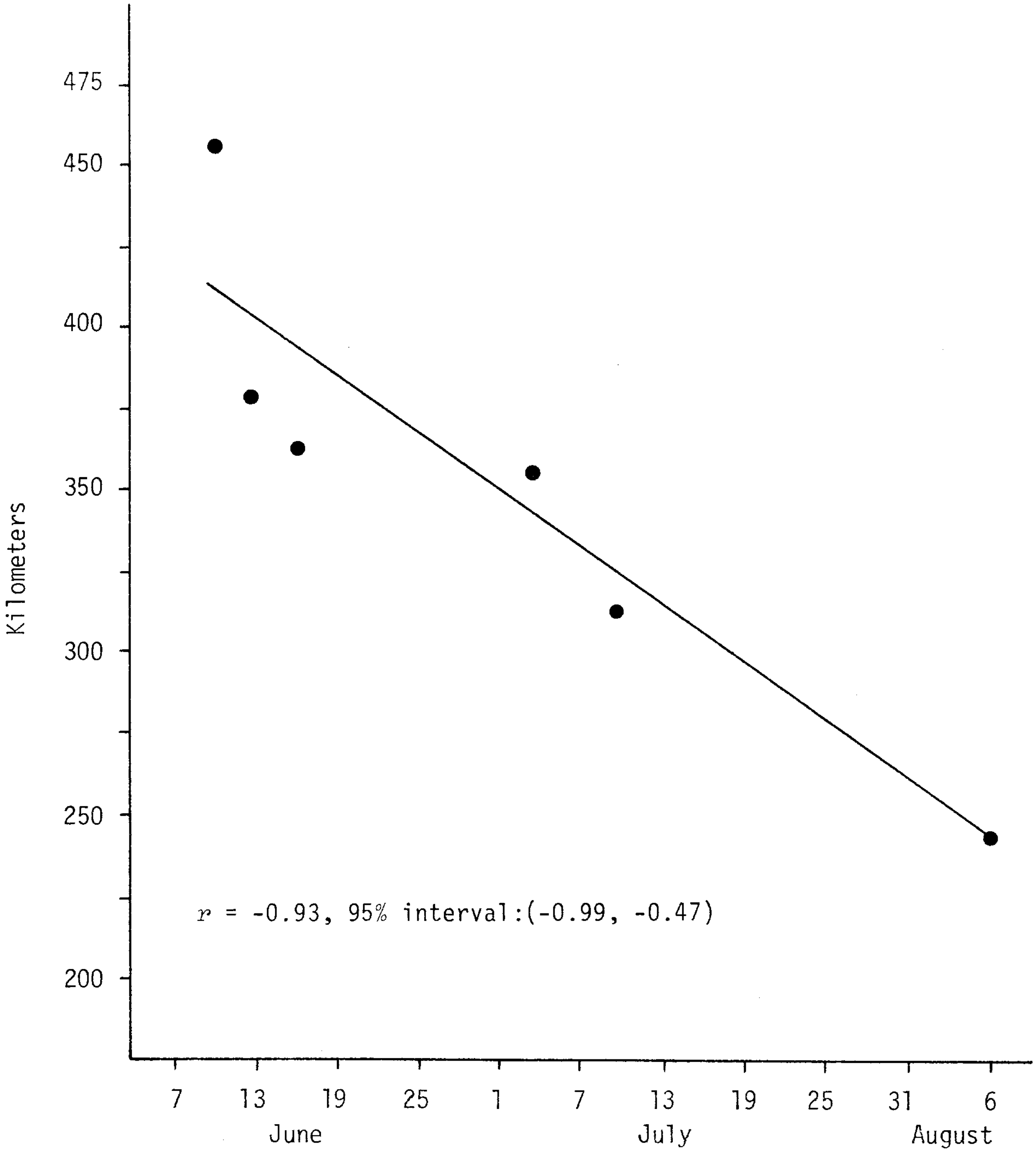

Figure 6. Mean migration date at Wood Canyon of six groups of stocks segregated with the SNK test, versus each group's mean river distance to the spawning grounds.

Table 6. Estimated mean date and range (80%) of migration at the commercial fishery district for upper Copper River sockeye salmon stocks, ranked by their estimated mean spawning population size.

Stock	Est. Pop. Size	Percent Contribution
Gulkana R.: Mud Cr. - Summit Lk.	28,412	19.8
Long Cr. & Lk.	21,662	15.1
Upper Klutina R.	18,476	12.9
Suslota Cr. & Lk.	12,313	8.6
St. Anne Cr.	12,285	8.6
Gulkana R.: Paxson - Mud Cr.	10,766	7.5
Mendeltna Cr.	7,659	5.4
Mud Cr. and Lk.	7,584	5.3
Fish Cr. and Lk.	6,916	4.8
Mahlo Cr.	5,442	3.8
12 Mile Cr.	3,911	2.7
Mentasta Lk.	3,398	2.4
Tonsina Lk.	1,989	1.4
Fish Cr. - Mentasta Lk.	1,552	1.1
Lower Tonsina Cr.	823	0.6
Total	143,188	100.0

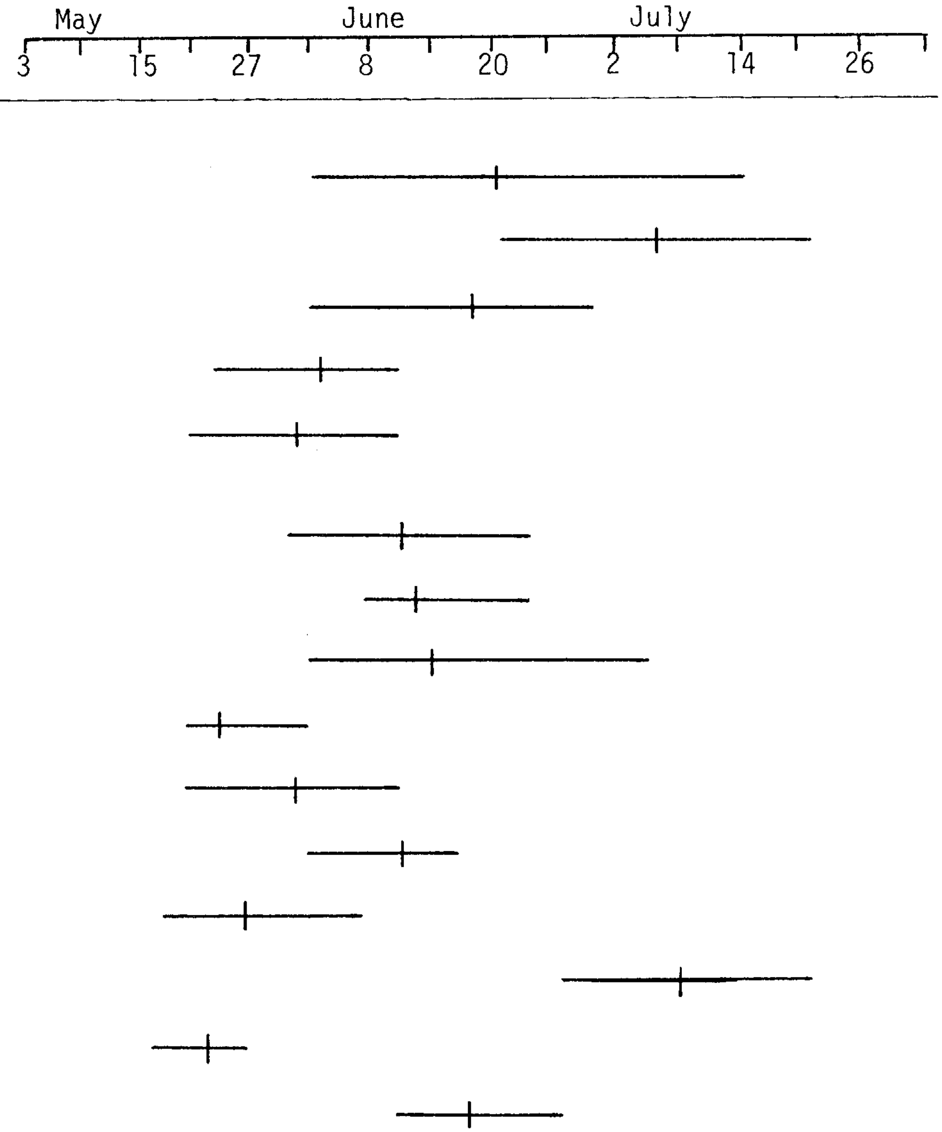

Table 7. Estimated skewness ($\hat{\gamma}_1$) and kurtosis ($\hat{\gamma}_2$) of migration at Wood Canyon for upper Copper River sockeye salmon stocks by year. Based on an average of estimated numbers of sockeye salmon per three-day interval, 1967-1972[1].

	1967		1968		1969		1970		1971		1972		All Years	
	$\hat{\gamma}_1$	$\hat{\gamma}_2$	$\hat{\gamma}_1$	$\hat{\gamma}_2$	$\hat{\gamma}_1$	$\hat{\gamma}_2$	$\hat{\gamma}_1$	$\hat{\gamma}_2$	$\hat{\gamma}_1$	$\hat{\gamma}_2$	$\hat{\gamma}_1$	$\hat{\gamma}_2$	$\hat{\gamma}_1$	$\hat{\gamma}_2$
Fish Cr. - Mentasta	--	--	0.8	-0.9	0.2	-1.3	-0.5	-1.2	--	--	--	--	-0.3	-0.8
Fish Cr. & Lk.	--	--	4.2	28.7	3.3	15.8	0.3	-1.2	0.1	0.3	--	--	3.2	11.0
Mentasta Lk.	--	--	1.1	-0.2	1.4	0.1	--	--	0.5	-0.7	--	--	2.8	8.5
St. Anne Cr.	-0.1	-1.3	0.8	0.0	0.6	0.2	0.6	-0.4	0.8	-0.2	--	--	0.5	-0.1
Mahlo Cr.	1.8	6.1	0.4	-1.0	0.2	-1.2	0.7	0.2	1.7	3.1	--	--	0.9	1.9
Suslota Cr. & Lk.	--	--	2.1	13.1	-0.3	-1.4	0.1	-0.1	1.4	0.5	-0.4	-0.8	1.0	5.4
12 Mile Cr.	-0.7	-1.5	--	--	-0.1	-0.4	-0.2	-0.6	--	--	--	--	-0.8	1.1
Gulkana R: Paxson - Mud Cr.	1.8	1.6	0.9	4.0	0.4	1.5	0.1	-0.3	1.1	0.3	1.8	4.3	0.6	1.8
Mendeltna Cr.	-1.7	1.9	1.3	6.6	0.1	2.1	-0.3	-0.9	-0.2	-0.9	--	--	0.7	4.3
Mud Cr. & Lk.	1.1	0.6	-0.1	-0.2	0.4	-0.1	0.1	-0.5	--	--	0.6	-1.1	0.8	0.8
Upper Klutina R.	1.1	-0.1	0.2	1.4	1.3	3.0	-0.1	-0.2	--	--	--	--	-0.1	0.4
Lower Tonsina Cr.	--	--	--	--	0.7	-1.3	--	--	--	--	--	--	2.1	5.4
Gulkana R: Mud Cr. - Summit	0.5	-0.9	0.2	0.3	-0.7	0.2	0.3	0.9	0.0	-1.4	0.0	-1.5	0.2	-0.4
Long Cr. & Lk.	-0.2	0.0	-0.1	-0.9	-1.3	8.9	0.0	-1.4	-1.3	0.2	-0.9	-0.1	0.1	0.3
Tonsina Lk.	--	--	--	--	-0.9	-0.4	--	--	--	--	0.9	-0.3	-1.5	2.4

[1] For tag recoveries > 5.

platykurtic time density form, and this form was relatively stable for some stocks between years.

DISCUSSION

Time density calculations allowed quantification of migratory behavior and examination of variability between stocks and years. Widely fluctuating measures of variance, skewness, and kurtosis may be due to inadequate data collection techniques, such as small sample size, or truncating the migration by sampling only a portion of the total run. Other sources of variability include genetic and environmental factors, and deviations in relative strengths of stocks (Mundy 1982). One cause of variability described in this paper was river level.

There was a significant negative correlation between river level and travel rate within a given year and between years. River level affects travel rate through the influence of river velocity and drag (Barber 1982). As river level increases, the percentage of the perimeter with respect to the cross sectional area decreases, producing rapid increases in velocity and consequent drag on salmon migrating upriver. Assuming decreased travel rates increases dispersion of the migration, increased river level contributes to intra- and interannual variations in the mean date of migration past the tagging site.

It was assumed that tagging did not contribute to variability. Killick (1955) determined that effects of the tag application are negligible over longer migrations (30 days). Since upper Copper River stocks required at least 10 and as much as 23 days to travel between tag and recovery sites, error due to tag application was assumed insignificant.

The SNK test provided an objective grouping of stock mean migration dates into six time spans. Assuming that the chronological order of migration is maintained from saline water to the spawning grounds, identified stocks may appear in six time spans in the commercial fishery district. Because of time density range overlap, identified stocks cannot be managed separately. Management of groups of stocks may be feasible.

The majority of time density means were calculated to occur in the commercial fishery district prior to mid June. This corresponds with commercial catch data, which indicates that the 10 year catch average to mid June is 82% of the total season's catch.

The majority of time density forms were positively skewed and platykurtic. Positive skewness has been observed in chinook salmon on Yukon River, and may be typical of salmon migrations (Mundy 1982). Platykurtosis indicates that migration is dispersed across time, rather than occurring within a short time interval.

Measures of skewness and kurtosis did not vary widely, but demonstrated relative preservation of the migratory time density form between years. Relative stability of time density measures suggests that sources of variability are not sufficient to significantly alter the migration form of sockeye salmon in the Copper River.

Observations of salmon migratory behavior on the Copper River differ from observations on other rivers. While Copper River stocks demonstrated a direct relationship between the mean migration date and variance, Waltemyer (1983) and Mundy (1982) observed inverse relationships between mean run dates and variance in Upper Cook Inlet rivers and the Yukon River, respectively. Upper Cook Inlet salmon travel time between the commercial fishery district and enumeration sites tended to decrease through the season, while Copper River travel time increased through the season. An inverse relationship between run timing and sea surface temperatures was suggested by both Waltemyer and Mundy. The differing patterns of migratory behavior suggests that sources of variability which determine run timing characteristics may vary by river system.

Ultimately, run timing is determined by the precision required for successful spawning. The evoluation of stock specific patterns is dependent on the average intragravel temperature regime during incubation, which determines peak fry abundance. Early spawning occurs in cooler temperature regimes, later spawning in warm regimes (Miller and Brannon 1982). Timing of arrival on the spawning grounds does not signify time of spawning. Some upper Copper River stocks (Fish, Mentasta, Suslota Lake stocks) arrive on the spawning grounds early, only to mill for several months before initiating spawning.

A general relationship between entry timing on the spawning grounds and spawning habitat is exhibited by the 15 stocks examined in this study. Assuming average intragravel temperatures are lowest in streams, higher in rivers and highest in lakes, early stocks tend to spawn in streams (coldest water) while late stocks tend to spawn in lakes (warmest water). The greatest number of "middle" stocks tend to spawn in rivers.

Identification of the stock composition within a commercial fishery district at a given time interval allows the manager to estimate the impact of fishery on individual stocks. The capacity of stocks to produce adult returns varies (Mundy 1979). For example, the two stocks with the greatest estimated spawning population size occur in the Copper River commercial fishery district after mid June, when harvest pressure is declining. Is the abundance of these stocks due to higher productivities, reduced harvest levels, or both? What are the productivities of the early stocks, which receive high harvest pressures? If the long-term harvest rates on the most productive stocks exceed optimum escapement levels, then combined yield will decline.

This paper has presented estimates of the time densities of 15 upper Copper River stocks. Little is known of the migratory time densities of other Copper River stocks, including those originating in the Copper River delta. Future research should be directed toward continued identification of stocks, their migratory time densities, and productivities.

ACKNOWLEDGMENTS

The authors are grateful to Dr. Phil Mundy and his graduate students Erik Barth, Howard Schaller, and John Clark of the Fisheries Research Center, Old Dominion University, for their guidance and data processing assistance. Dr. Mundy refined the initial concept of migratory timing and provided many hours of consultation.

Mr. Ivan Frohne provided statistical analysis guidance and constructive criticism of the manuscript. Mr. Fred Jamsen provided assistance with computer data analysis and graphics in a timely and helpful manner. Mr. Rich Randall reviewed the manuscript and provided critical comments with regards to management implications.

LITERATURE CITED

Barber, S. 1982. Hydrologist. Alaska Dept. of Transportation and Public Facilities, Juneau. Personal communication.

Buklis, L. 1981. Yukon River salmon studies. Anadromous Fish Conservation Act. Technical report for period July 1, 1980 - June 30, 1981. Alaska Dept. of Fish and Game. Draft in press.

Dahlberg, M. 1968. Analysis of the dynamics of sockeye salmon returns to the Chignik Lakes, Alaska. PhD. Dissertation, Univ. of Wash., Seattle. 337 pp.

Fridgen, P. and K. Roberson. 1969. Copper River sockeye salmon investigations. Annual Tech. Report, Project No. AFC-10-3. Alaska Dept. of Fish and Game, Juneau. 32 pp.

Fridgen, P. and K. Roberson. 1971. Copper River sockeye salmon investigations. Project No. AFC-32. Alaska Dept. of Fish and Game, Juneau. 35 pp.

Frohne, I. 1982. Problems in the use of tag recoveries to estimate calendar time salmon migration distributions (manuscript). Alaska Dept. of Fish and Game, Juneau. 10 pp.

Greenough, J. 1971. Estimation of sockeye, coho, and chinook salmon runs at Wood Canyon on the Copper River in 1966, 1967, and 1968. U.S. Dept. of the Int., Fish and Wildlife Service, Anchorage, AK. 109 pp.

Killick, S. 1955. The chronological order of Fraser River sockeye salmon during migration, spawning, and death. Int. Pac. Sal. Fish. Comm. Bulletin VII, New Westminster, Canada. 95 pp.

Larson, C. 1967. Copper River red salmon investigations. Annual Tech. Report, Project No. AFC-10-1, Alaska Dept. of Fish and Game, Juneau. 31 pp.

Larson, C. and P. Fridgen. 1968. Copper River sockeye salmon investigations. Annual Tech. Report, Project No. AFC-10-2. Alaska Dept. of Fish and Game, Juneau. 44 pp.

Miller, R. and E. Brannon. 1982. The origin and development of life history patterns in Pacific salmonids. In E. Brannon and E. Salo, eds. Proceedings of the salmon and trout migratory behavior symposium. Univ. of Wash., Seattle. Pp. 296-309.

Mundy, P. 1979. Quantitative measure of migratory timing illustrated by application to the management of commercial salmon fisheries. PhD., Univ. of Wash. 85 pp.

Mundy, P. 1982. Migratory timing of adult chinook salmon *(Oncorhynchus tshawytscha)* in the lower Yukon, Alaska with respect to fisheries management. Tech. Report No. 82-1. Dept. Oceanography. Old Dominion University, Norfolk, Virginia. 52 pp.

Mundy, P. 1983. Moments of migratory time densities. Draft document for the Alaska Dept. of Fish and Game, Glennallen. 4 pp.

Nie, N., C. Hull, J. Jenkins, K. Steinbrenner, and D. Bent. 1975. Statistical package for the social sciences. McGraw-Hill, N.Y., p. 428.

Ricker, W. 1973. Two mechanisms that make it impossible to maintain peak period yields from stocks of Pacific salmon and other fishes. J. Fish. Res. Bd. Canada. 30:1275-1286.

Robertson, K. and P. Fridgen. 1972. Identification and enumeration of Copper River sockeye salmon stocks. Annual Tech. Report, Project No. AFC-32. Alaska Dept. of Fish and Game, Juneau. 39 pp.

Roberson, K. and P. Fridgen. 1974. Identification and enumeration of Copper River sockeye salmon stocks. Annual Tech. Report, Project No. AFC-32. Alaska Dept. of Fish and Game. 76 pp.

Roberson, K., R. Zorich, and P. Fridgen. 1974. Copper River commercial fisheries management investigations. Annual Tech. Report, Proj. No. AFC-46. Alaska Dept. of Fish and Game, Juneau. 49 pp.

Royal, L. 1953. The effects of regulatory selectivity on the productivity of Fraser River sockeye. Can. Fish. Cult. 14:1-12.

Sheridan, W. 1962. Relation of stream temperatures to timing of pink salmon escapements in Southeast Alaska. Pgs. 87-102. In N. Wilimovsky, ed. Symposium on pink salmon. H. MacMillan Lectures in Fisheries. Univ. Brit. Columbia, Vancouver, Canada.

Thompson, S. 1964. The red salmon *(Oncorhynchus nerka)* of Copper River, Alaska. U.S. Dept. of the Interior, Bureau of Comm. Fish, Manuscript Report 64-12, Auke Bay, Alaska. 139 pp.

Thompson, W. 1951. An outline for salmon research in Alaska. Univ. Wash. Fish. Res. Inst., Circ. 18. Also ICES 10-1-51.

Waltemyer, D. 1983. Migratory timing and abundance estimation of the 1982 sockeye salmon return to Upper Cook Inlet based on a test fishing program. Cook Inlet Data Report No. 83-1, ADF&G.

APPENDICES

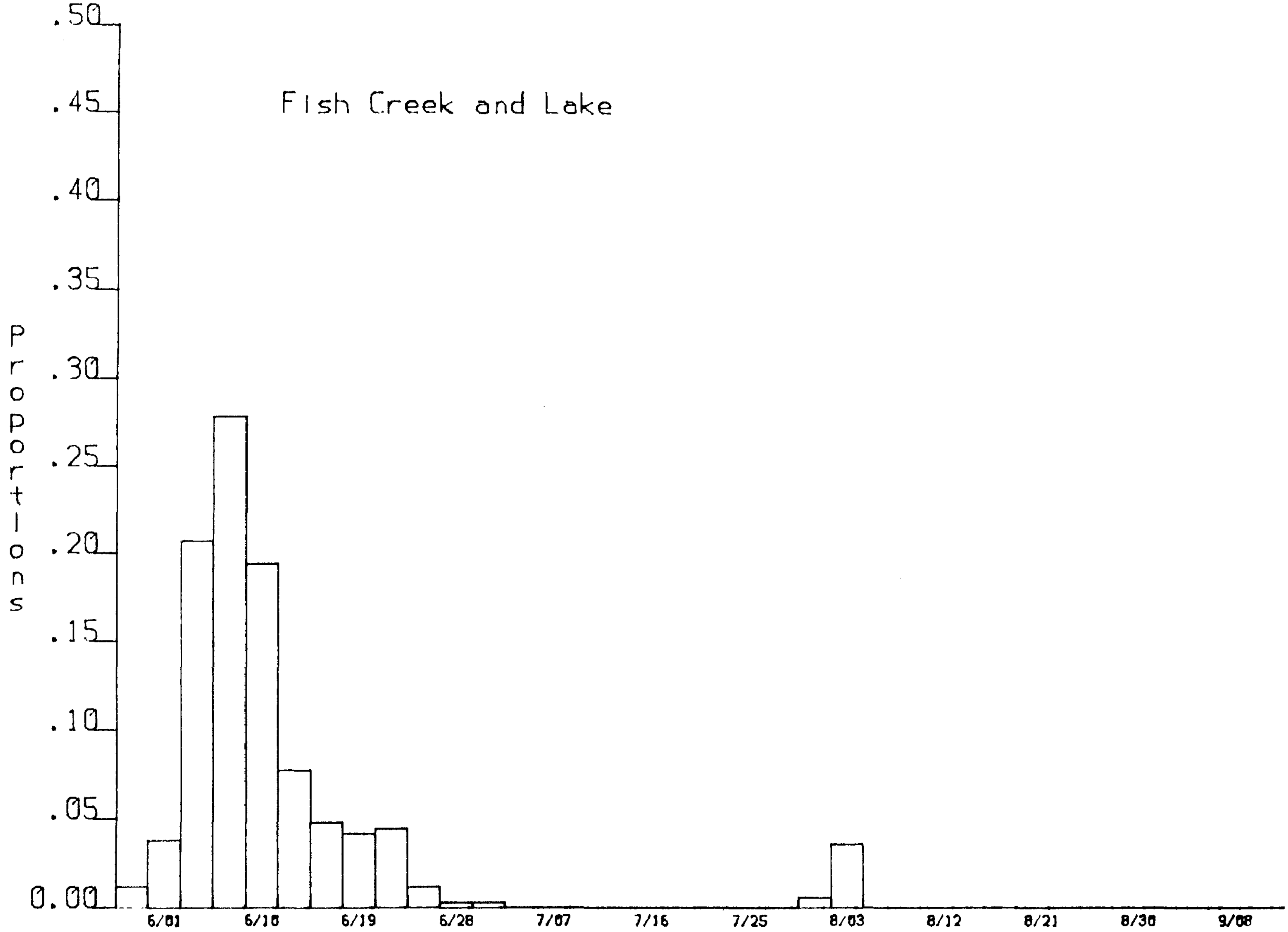

FIG.1 Proportion of Estimated Population Returning vs time(1967-1974)

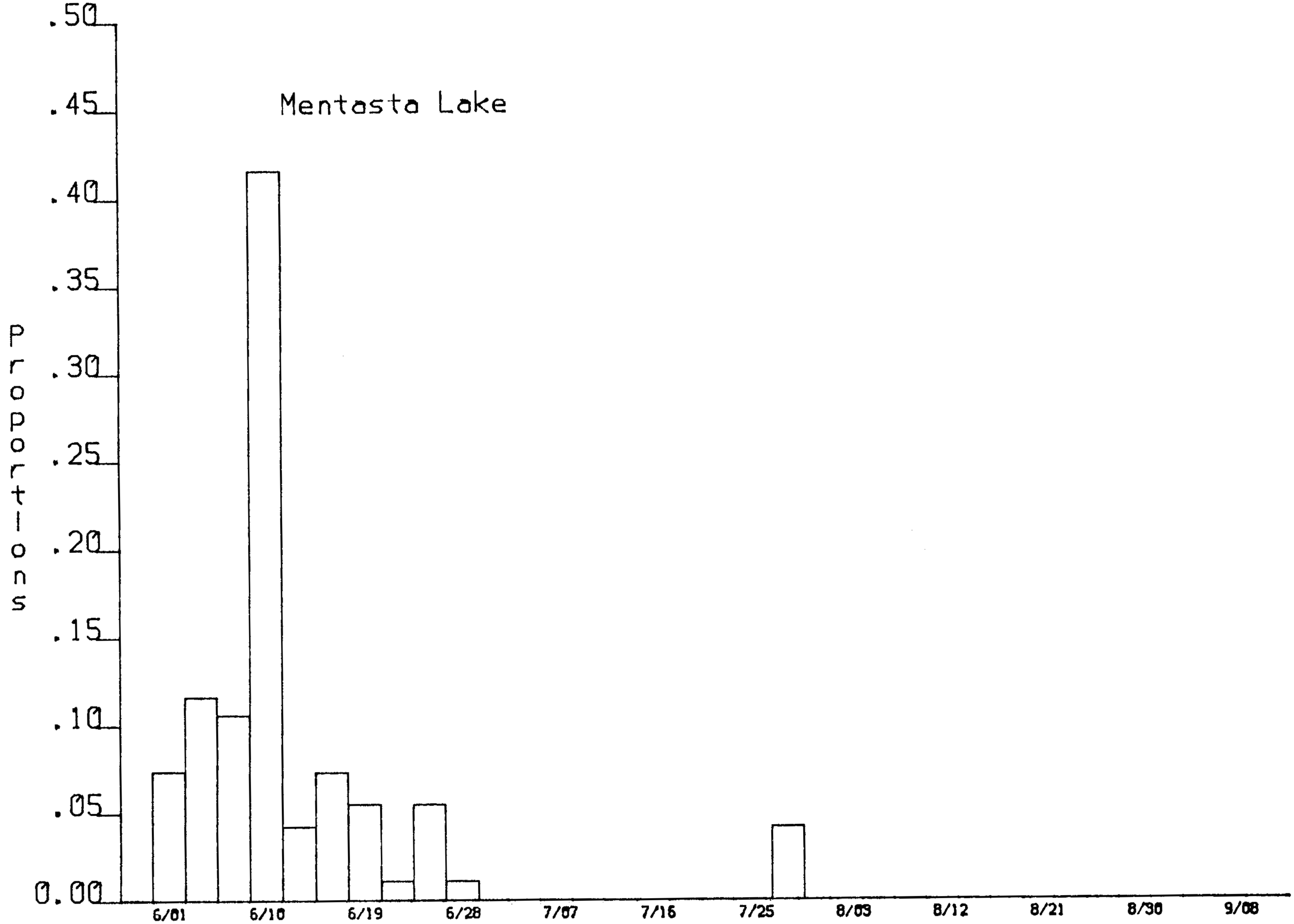

FIG.2 Proportion of Estimated Population Returning vs time(1967-1974)

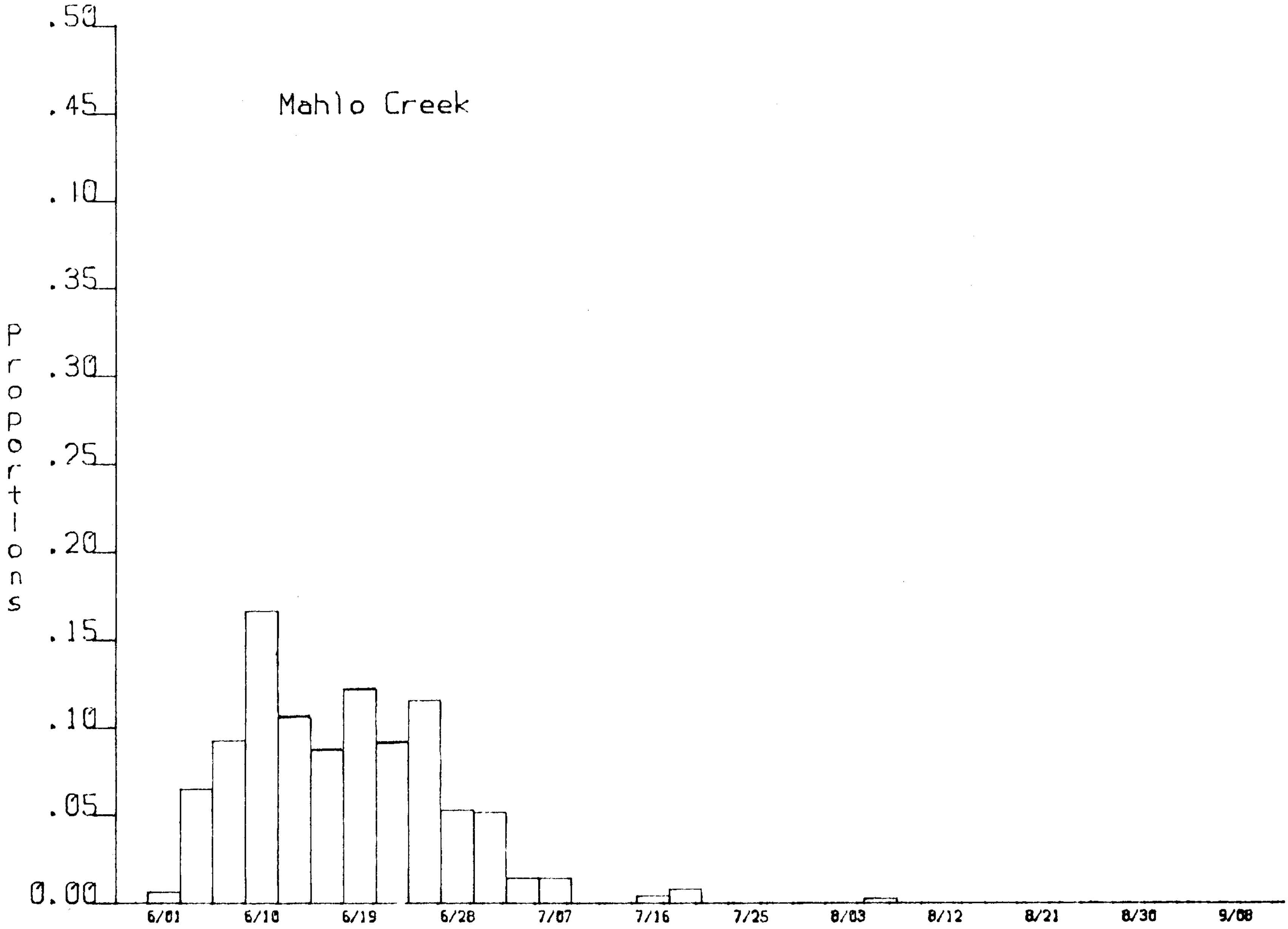

FIG.3 Proportion of Estimated Population Returning vs time(1967-1974)

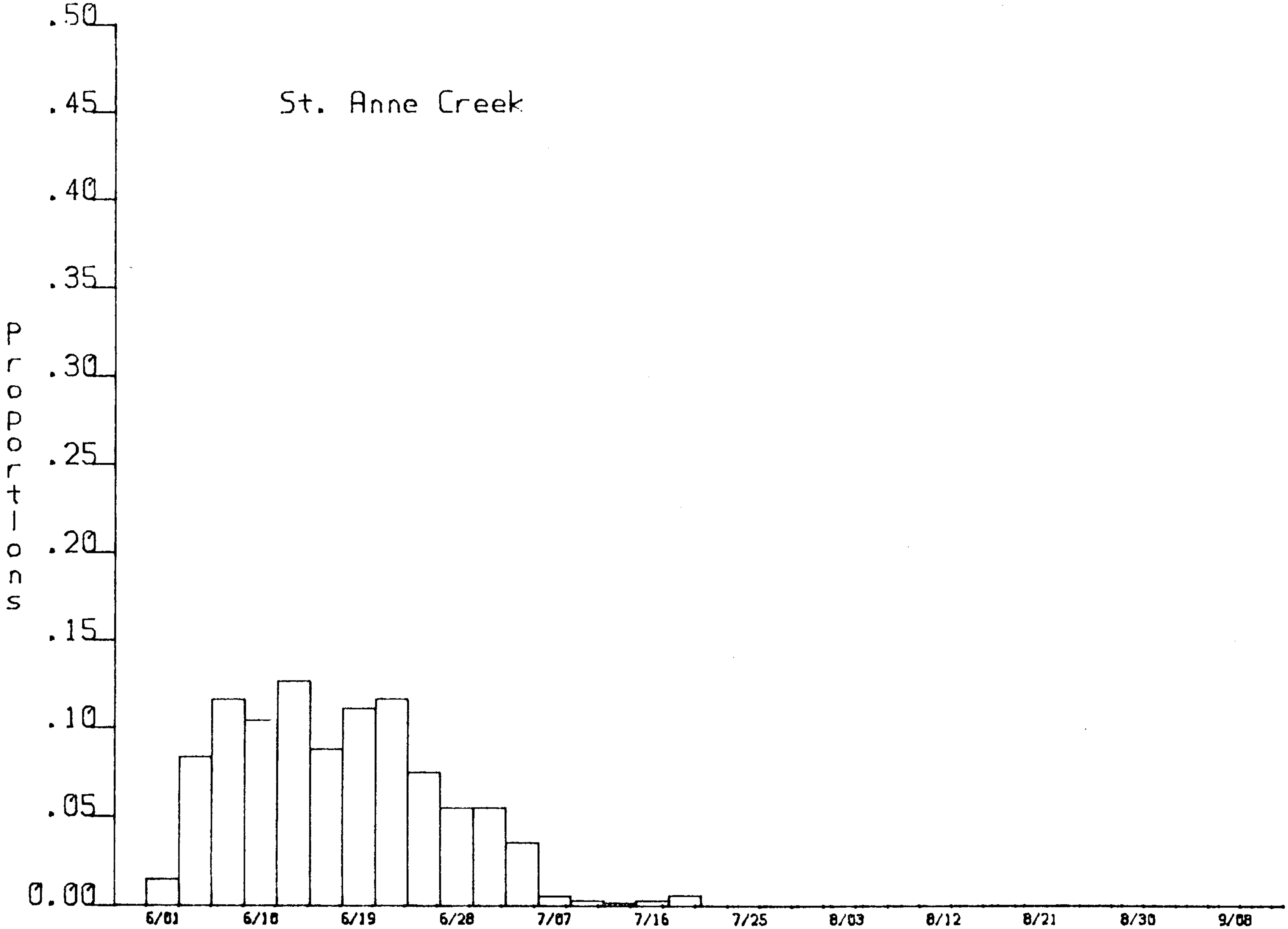

FIG.4 Proportion of Estimated Population Returning vs time(1967-1974)

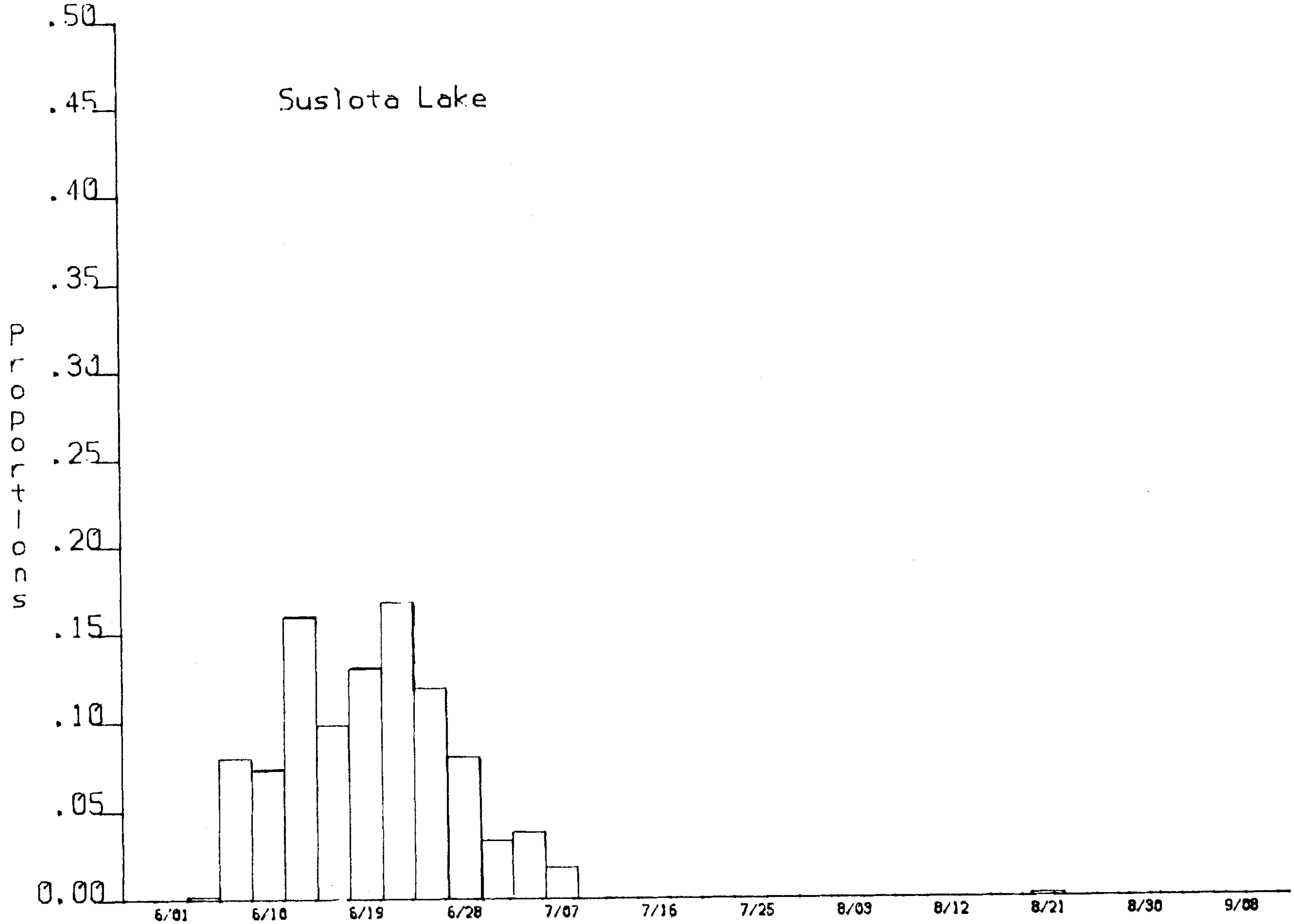

FIG.5 Proportion of Estimated Population Returning vs time(1967-1974)

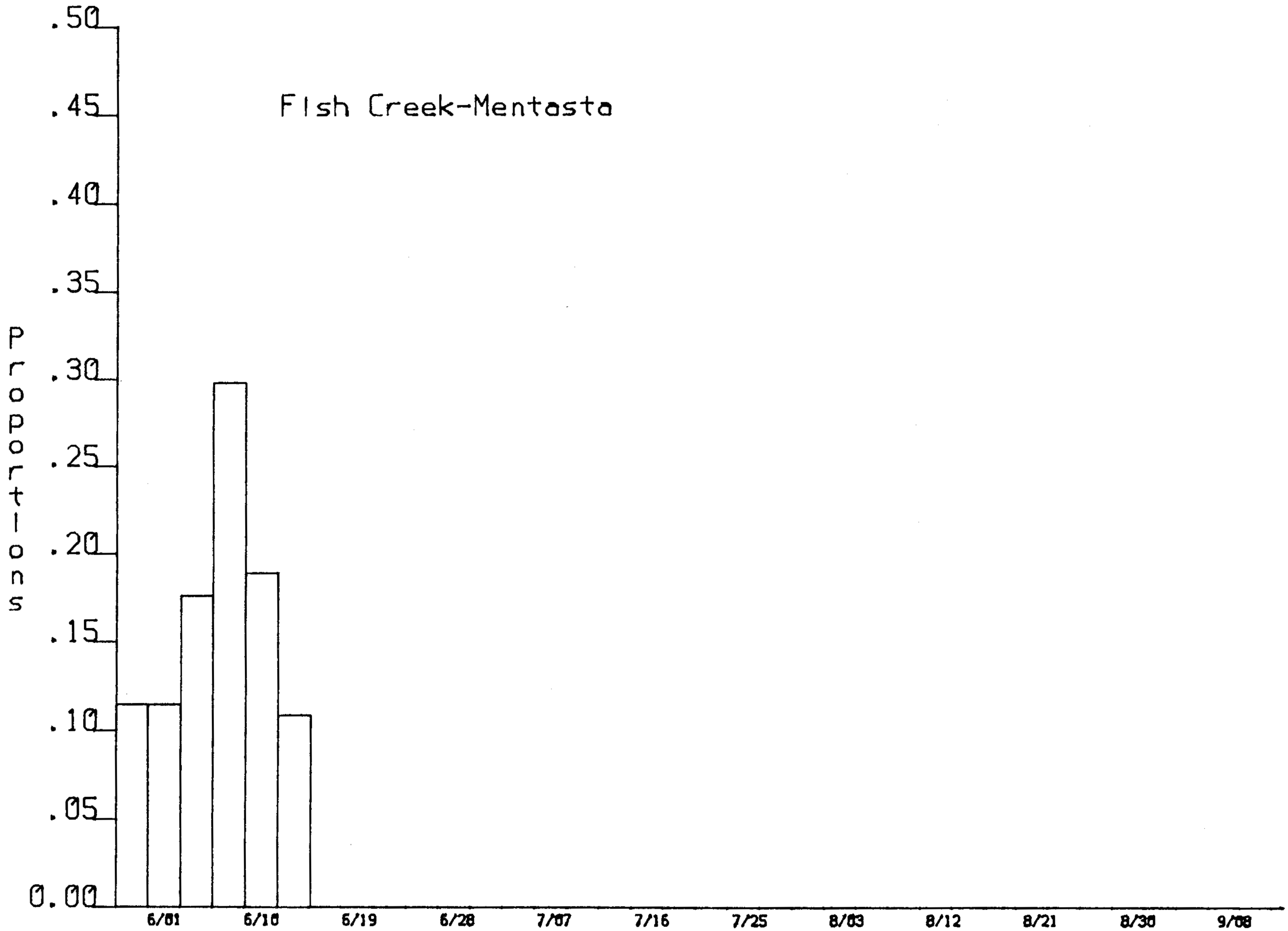

FIG.6 Proportion of Estimated Population Returning vs time(1967-1974)

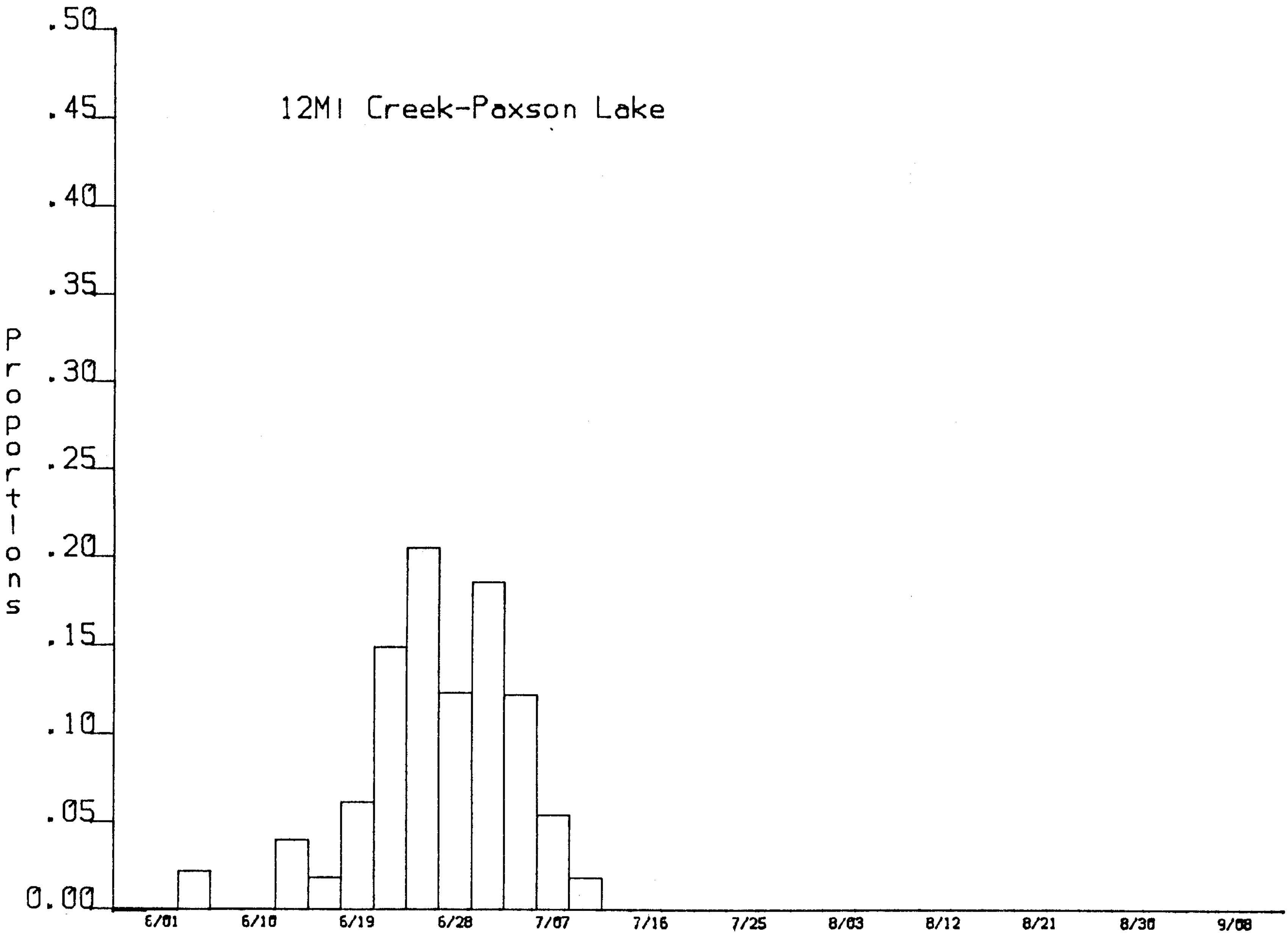

FIG.7 Proportion of Estimated Population Returning vs time(1967-1974)

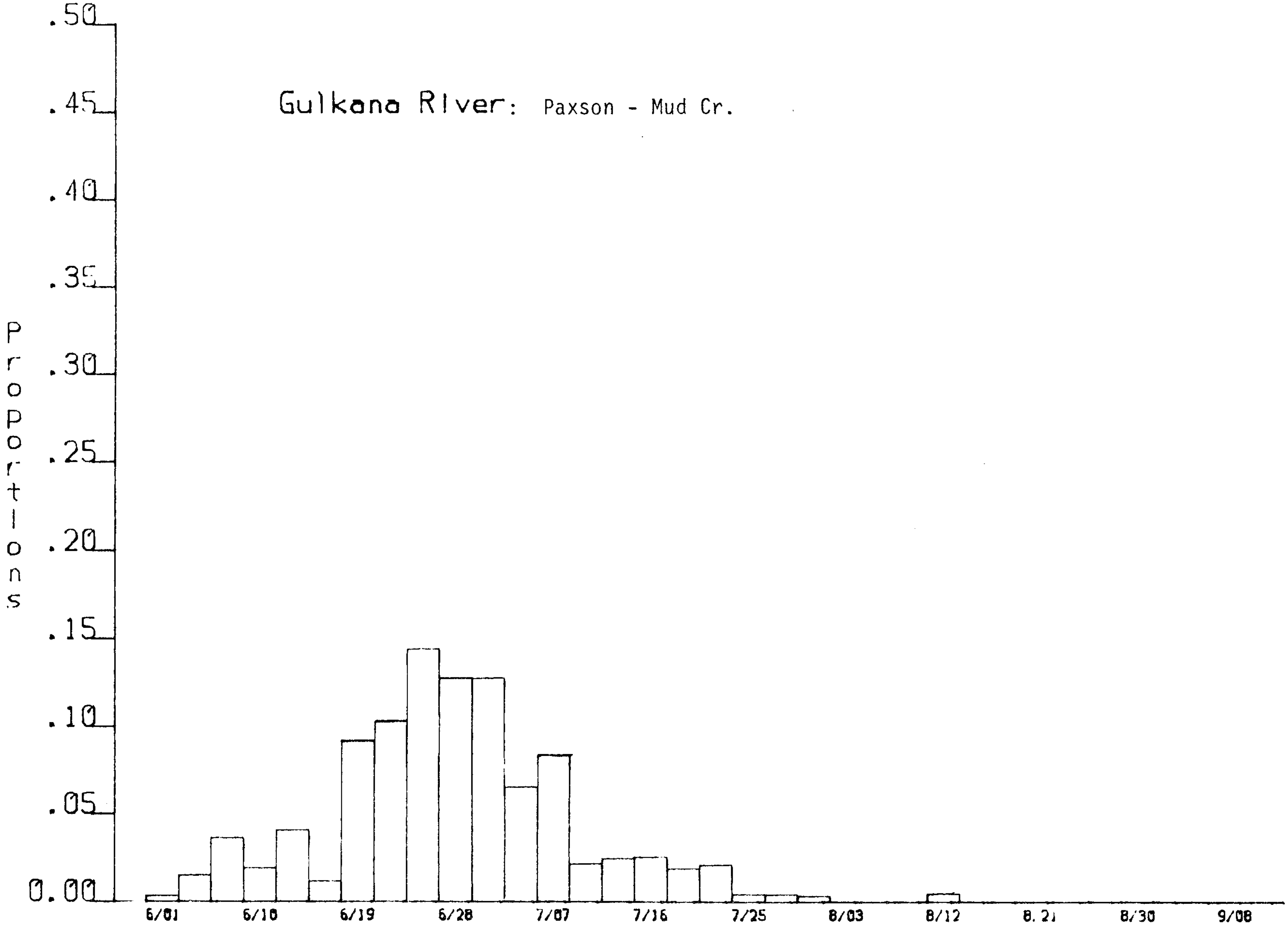

FIG.8 Proportion of Estimated Population Returning vs time(1967-1974)

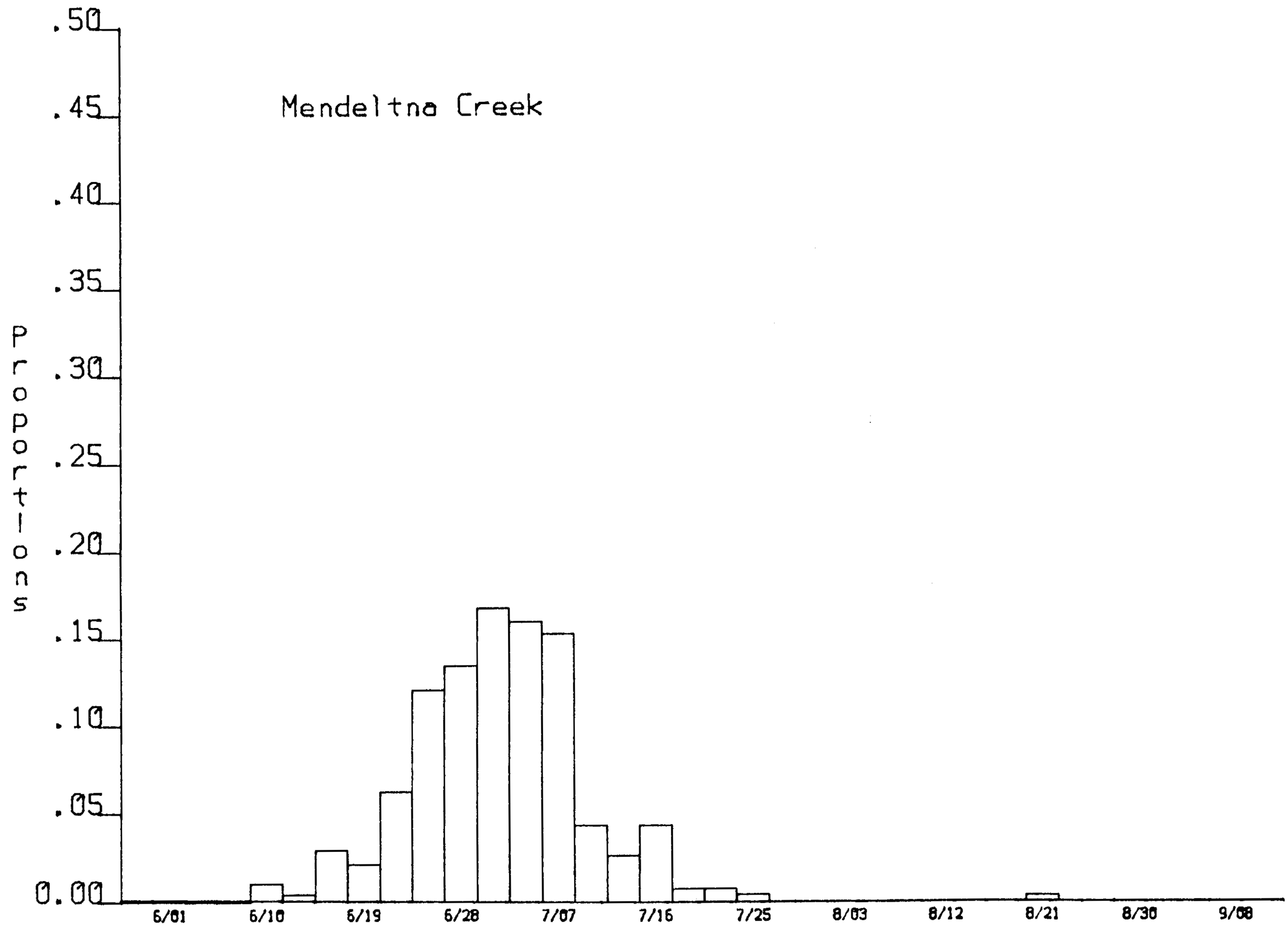

FIG.9 Proportion of Estimated Population Returning vs time(1967-1974)

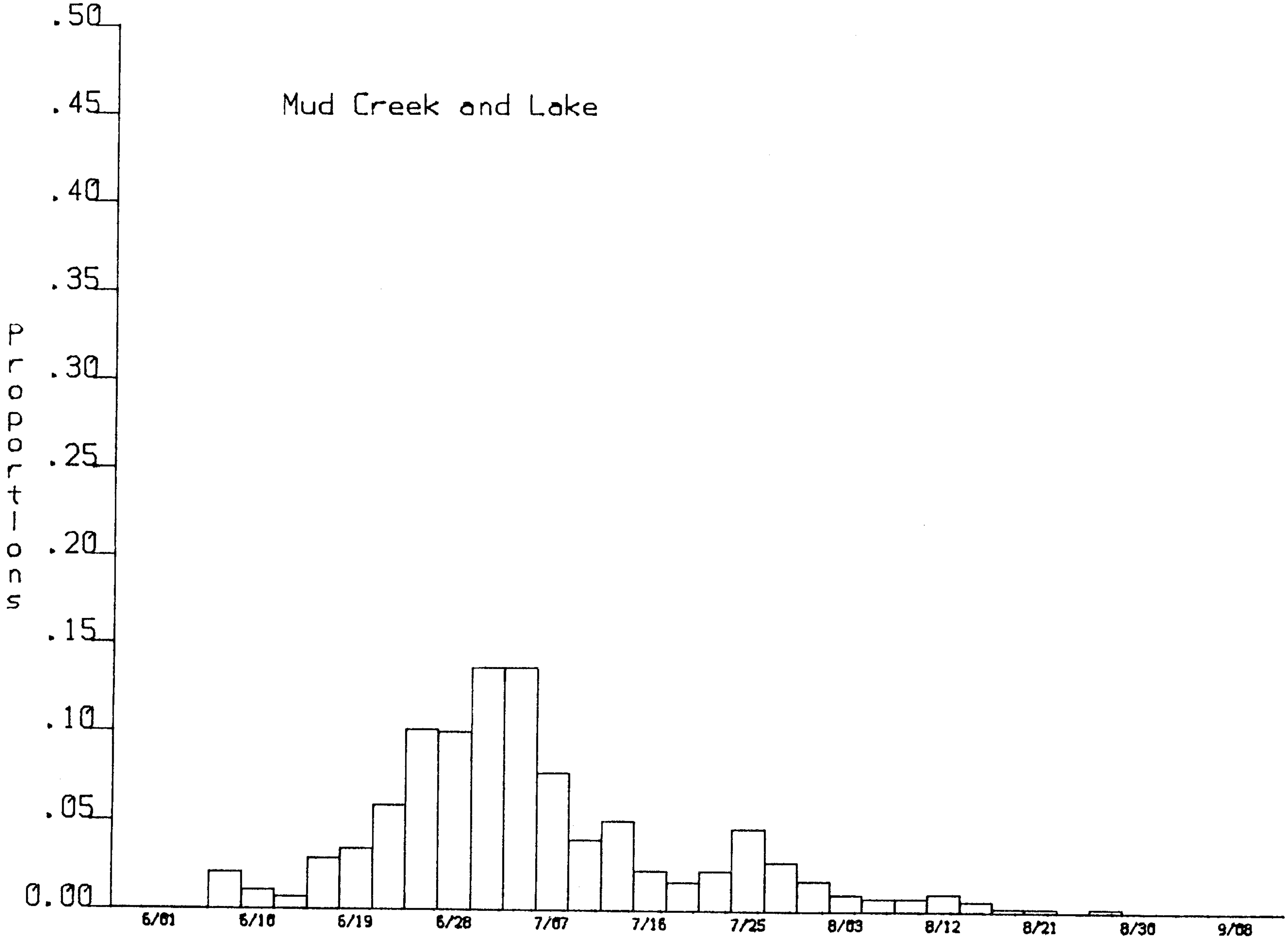

FIG.10 Proportion of Estimated Population Returning vs time(1967-1974)

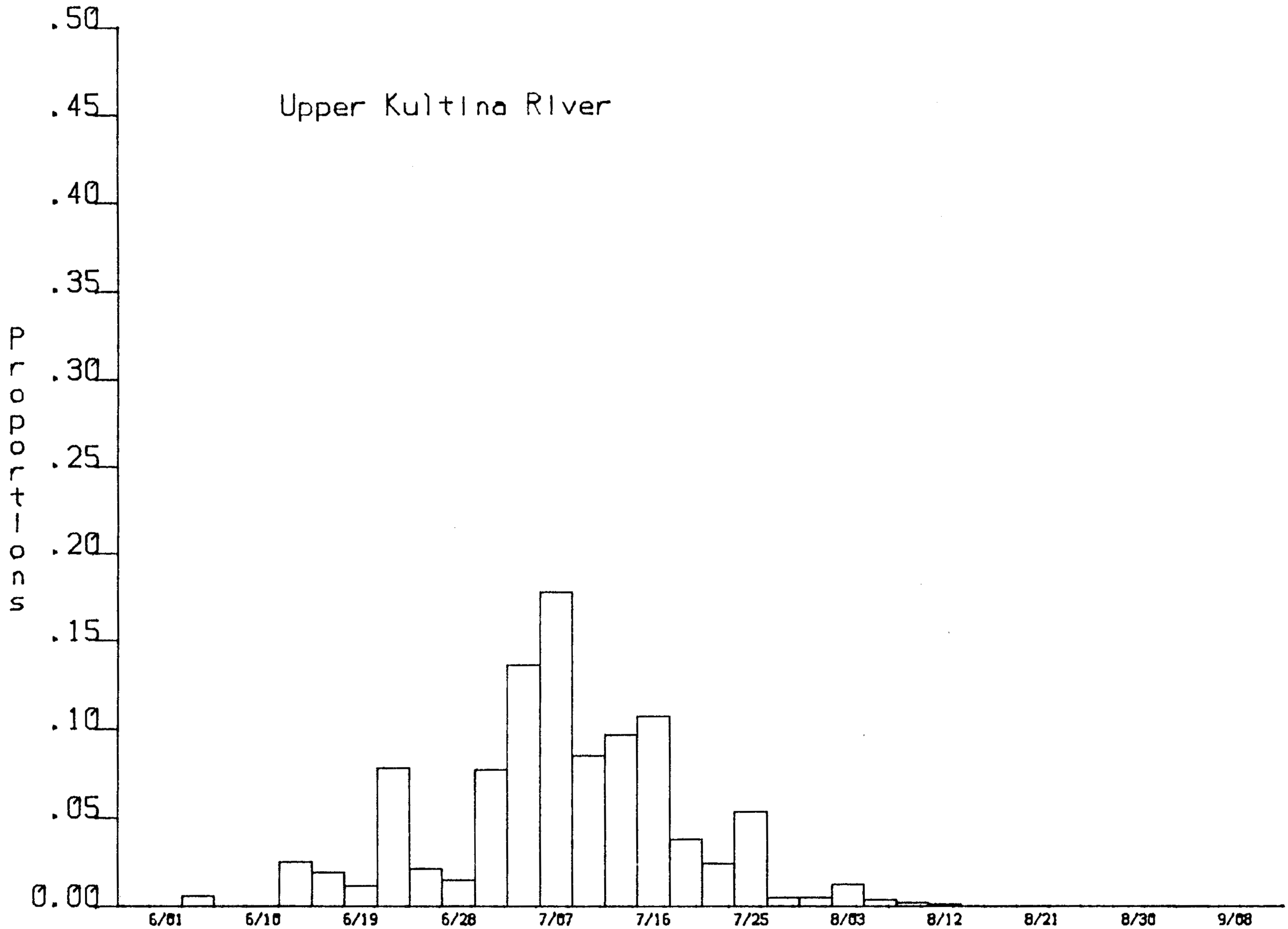

FIG.11 Proportion of Estimated Population Returning vs time(1967-1974)

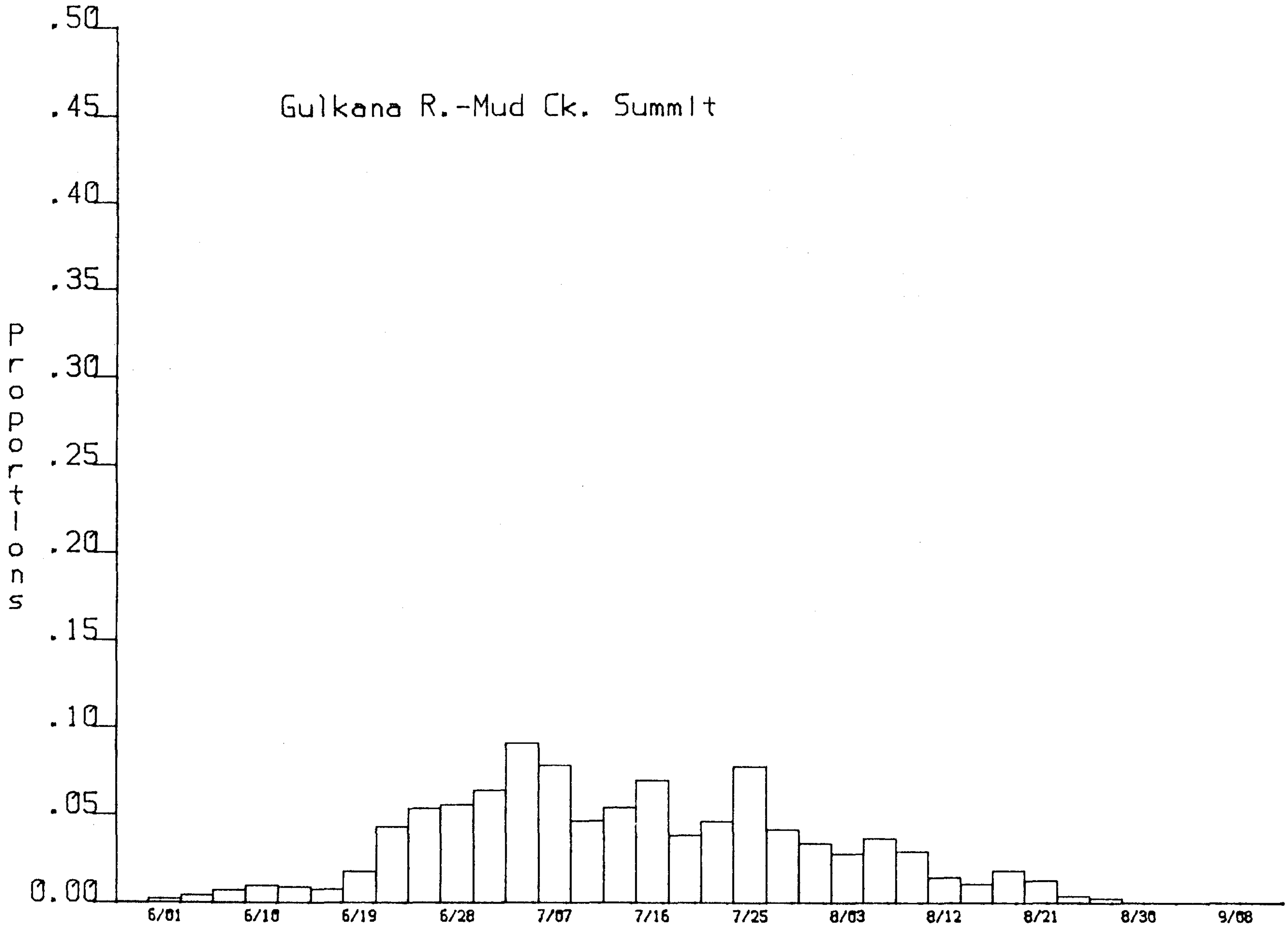

FIG. 12 Proportion of Estimated Population Returning vs time(1967-1974)

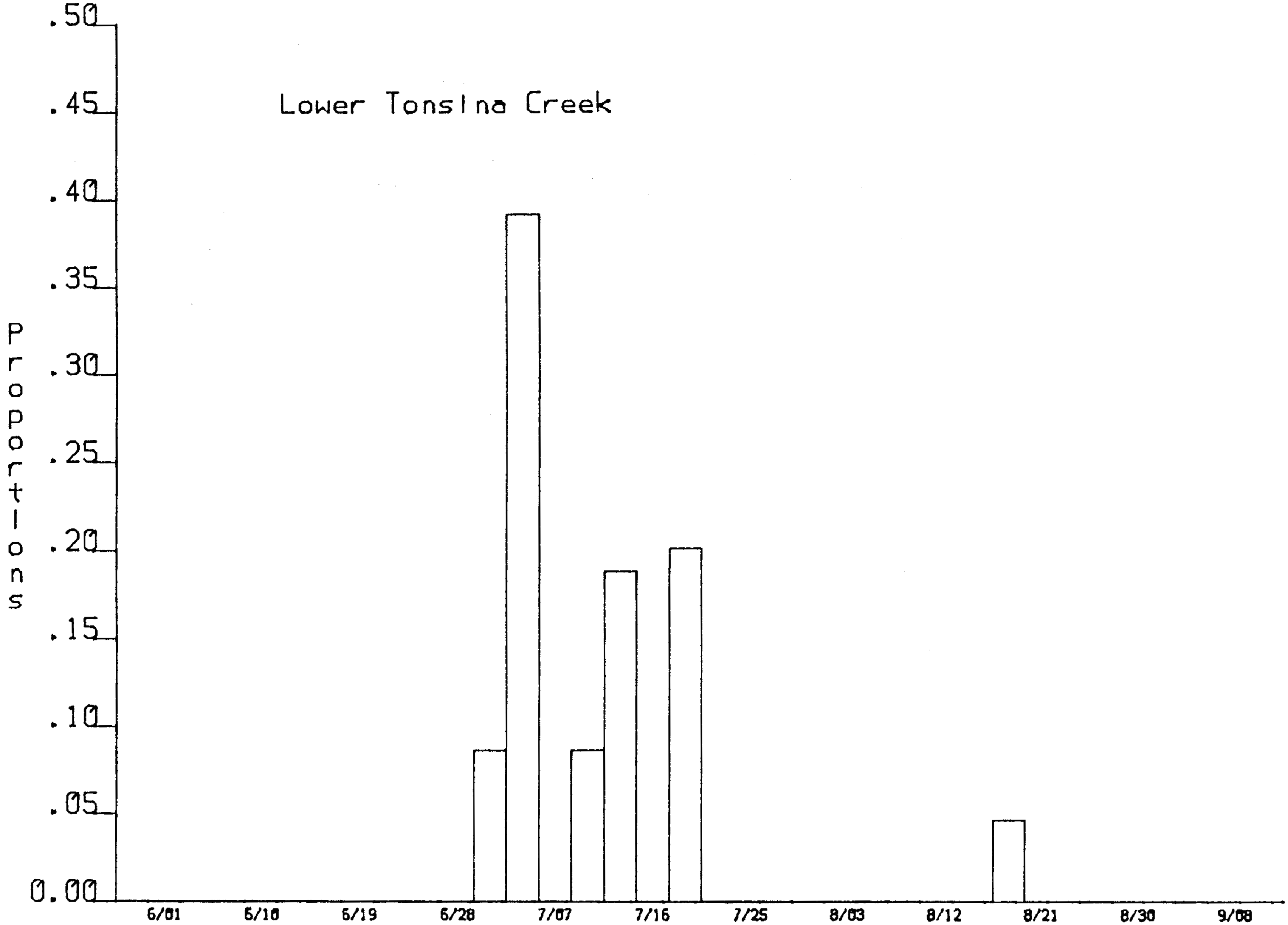

FIG. 13 Proportion of Estimated Population Returning vs time (1967-1974)

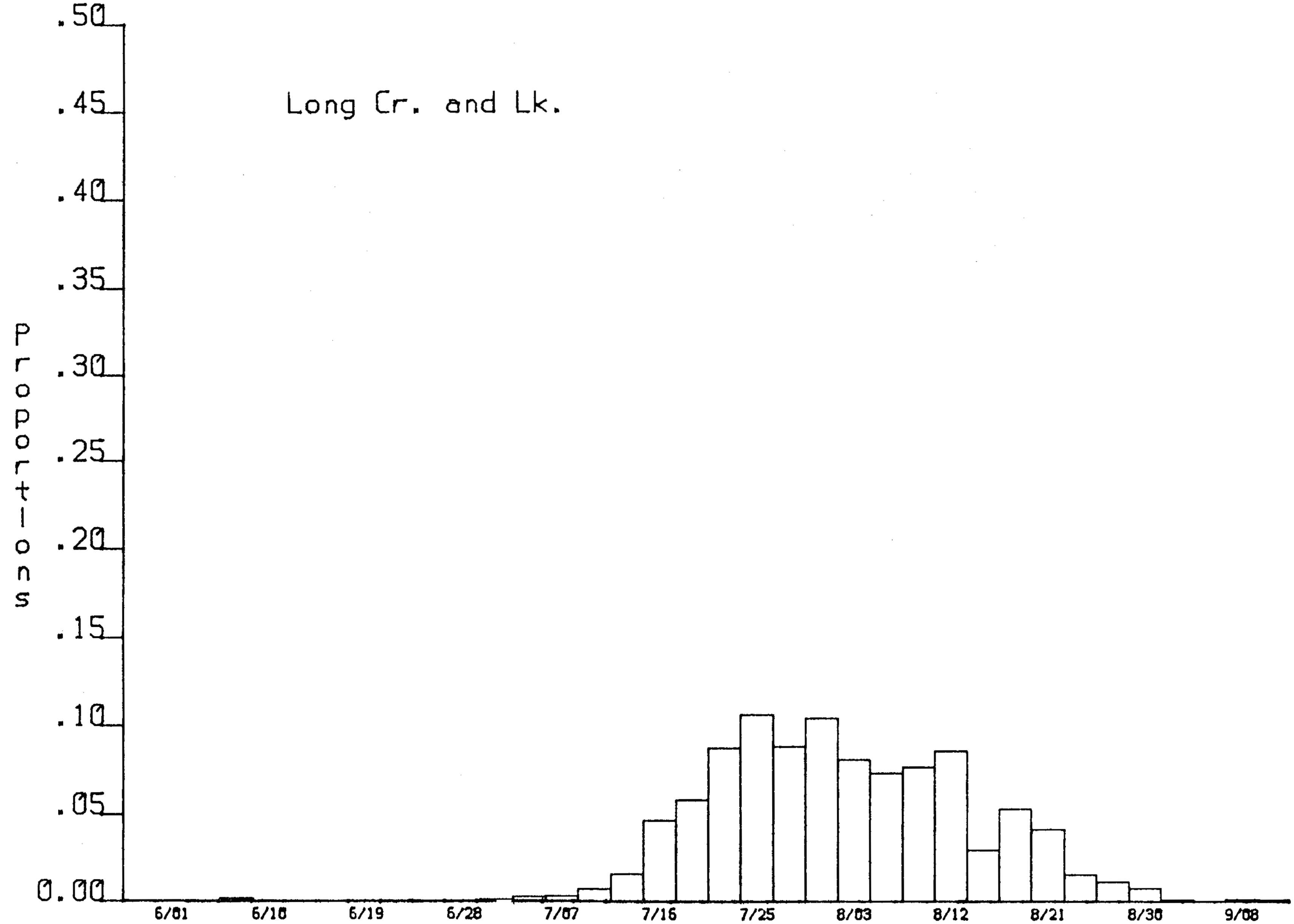

FIG. 14 Proportion of Estimated Population Returning vs time (1967-1974)

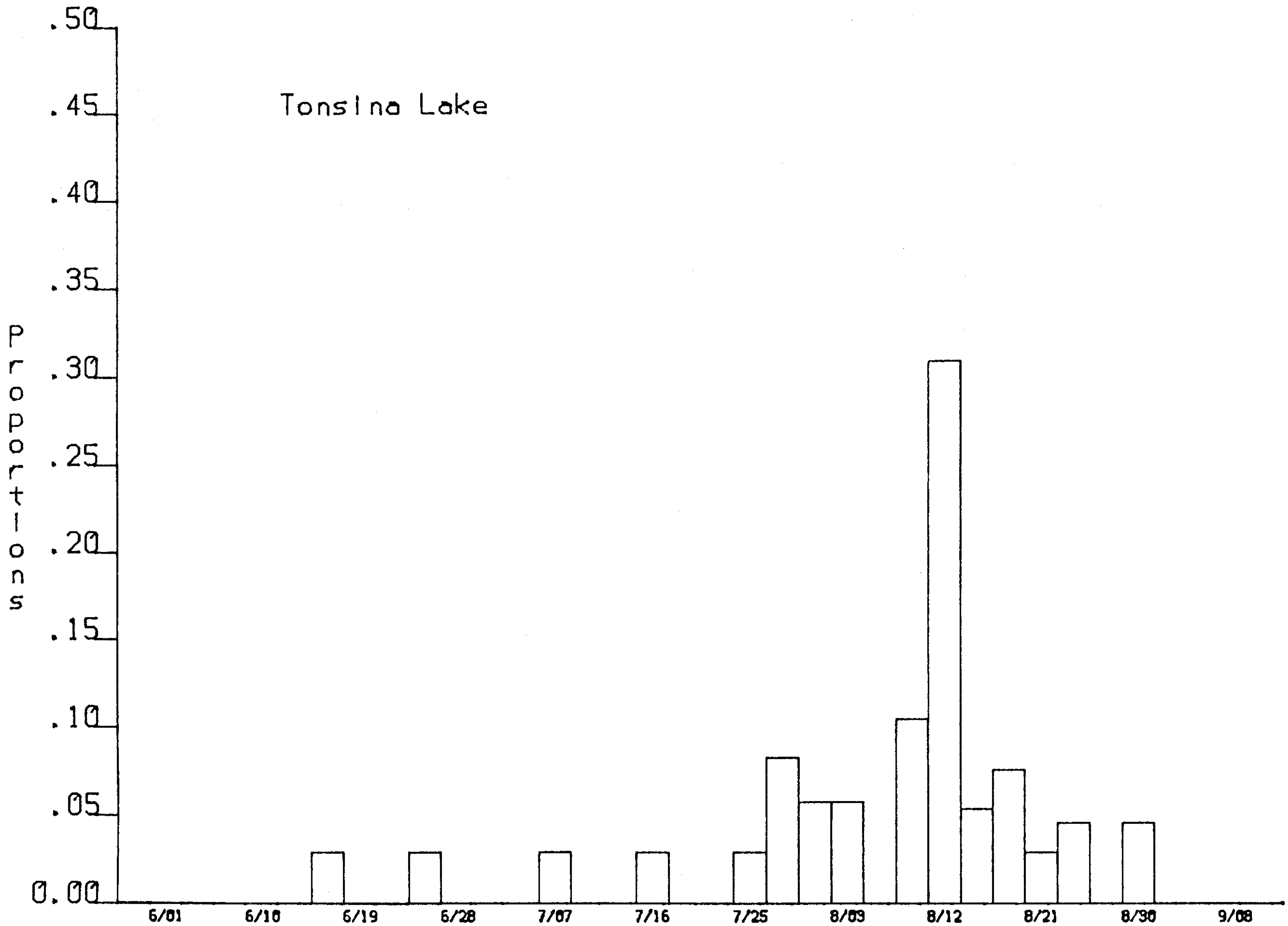

FIG.15 Proportion of Estimated Population Returning vs time(1967-1974)