AN ATTEMPT TO DETERMINE ABUNDANCE AND DISTRIBUTION OF MIGRATING SKEENA RIVER SALMON STOCKS BY ACOUSTICAL MEANS

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by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Since it is rarely possible to make a complete count of all individuals in a given area, some indirect method of estimating population size is generally applied. Three main categories of indirect population estimates are: capture - re-capture methods, incomplete count methods and incomplete counts in which indices of abundance are utilized. Each indirect method depends, naturally, on certain working assumptions. This paper deals specifically with an applied example of the third indirect method, in this case referred to as echo surveying.

Echo surveying is one of the newer techniques for estimating the abundance and distributional patterns of fish stocks and its potential seems promising as it is a convenient, economical and effective way of collecting information on underwater objects. Stock assessment by acoustical means was initiated locally by Tester (1943). More recent studies, Richardson et al (1959) and Cushing (1968) have shown that accurate indices of abundance and distributional patterns can be obtained with echo sounders. Most studies to date have dealt primarily with demersal and pelagic fish stocks. The present paper deals with migrating fish, ascending a shallow river, which are potentially more difficult to enumerate by acoustical means.

Optimum escapement of Skeena River salmon stocks, which spawn in a multitude of streams located primarily as tributaries to Babine Lake, has been the primary objective of the

Skeena River Salmon Management Committee. Stock enumeration of Skeena salmon, has since 1956, been calculated on the basis of a catch per unit effort of a standardized gillnet. During the period 1956 to 1963 inclusive, test-fishing indices provided annual estimates of escapement which were within 15 percent of the actual escapement in most years. From 1964 to 1968 the error associated with test-fishing increased and approached deviations of up to 40 percent from the actual escapement figure in some years. Such large errors are not conducive to precise regulation of a gantlet fishery, especially in view of a continuing increase in the relative efficiency of the fishing fleet.

Prior to 1965 two skippers participated in the annual test-fishing operation, but because the efficiency of one skipper seemed lower and more erratic than that of the other skipper, his services were terminated following the 1965 fishing season.

Immediately following the release of one skipper, errors associated with escapement estimates became more erratic and errors became both positive and negative, i.e. both under-estimates and over-estimates of actual escapements. It was for this reason that a yearly echo sounding program was initiated in 1968. The program objectives are:

(1) To determine whether systematic changes in availability of salmon are occurring with tide or time.

(2) To formulate an acoustic index of stock abundance which can be used in conjunction with test-fishing or separately, to estimate stock size.

(3) To evaluate echo sounding as a management tool for regulation of a commercial fishery.

II. MATERIALS AND METHODS

A Ross model 200A (101 kHz) fine line recorder was used exclusively during the 1969 and 1970 surveys except for a few periods during 1970 when, due to sounder breakdowns, a Ross model 100/25 dual sounder (sounder used in 1968) was used as a replacement. The fine line recorder seemed suitable for fish detection in shallow water, because of its narrow keel line (2 feet), short pulse width (min. 0.4 msec), fast paper speed (max. 60 inches/hr.) and large sounder paper scale (1.25 inches = 10 feet). At a gain setting of 7.0 the detection volume was observed to be nearly cylindrical in shape and no volumetric correction factors were applied to the data.

The sounder transducer in 1968 and 1969 was mounted on the bottom of an aluminum pipe which was hinged to the mid-port side of the 18 foot sounding boat. In 1970 the transducer was mounted on the bottom of the sounding boat, about two-thirds the distance back from the bow. Due to the roundness of the boat's hull, a flaring block was installed to level the transducer to within 5 degrees of the vertical. Moving the transducer to a thru hull mounting position reduced its below surface depth from 14 inches to approximately 6 inches. During rough weather water surface disturbance extended the keel line from 2 to 5 feet.

Electrical power was supplied to the sounder by a portable gas powered charging unit which was connected to the sounder through a heavy duty twelve volt battery. A 13.5 volt power output was maintained by regulating the charger.

In 1968 both river transect crossing and passes of the test-fishing net were made during each sounding period at a site below the test-fishing area (Fig. 1). Sounding was also conducted below the test-fishing site (lower transect, Fig. 1) in 1970, on several randomly selected days throughout the season. The relative availability of sockeye throughout individual tide periods was determined by recording the numbers of fish per time interval for the period before, during and after each gill-net set.

Echo sounding in 1969 and 1970 was conducted on two to three daylight slack tide periods per day, with an average of 6 river transect crossings, with an approximate total time of 1.5 hours. The sounding site utilized in 1969 and 1970 was located approximately 1.75 miles upstream from Aberdeen float (Fig. 1). Crossings of the river transect were started from the rock quarry on the north bank and Frizzell hotsprings on the south bank on alternate days. The length of this transect varied from 0.8 miles to 1.3 miles on low and high tides respectively. A cross section of the river at the transect site, for an average tide level (Fig. 2), shows the area of the transect sampled by the test-fishing gear. The downstream

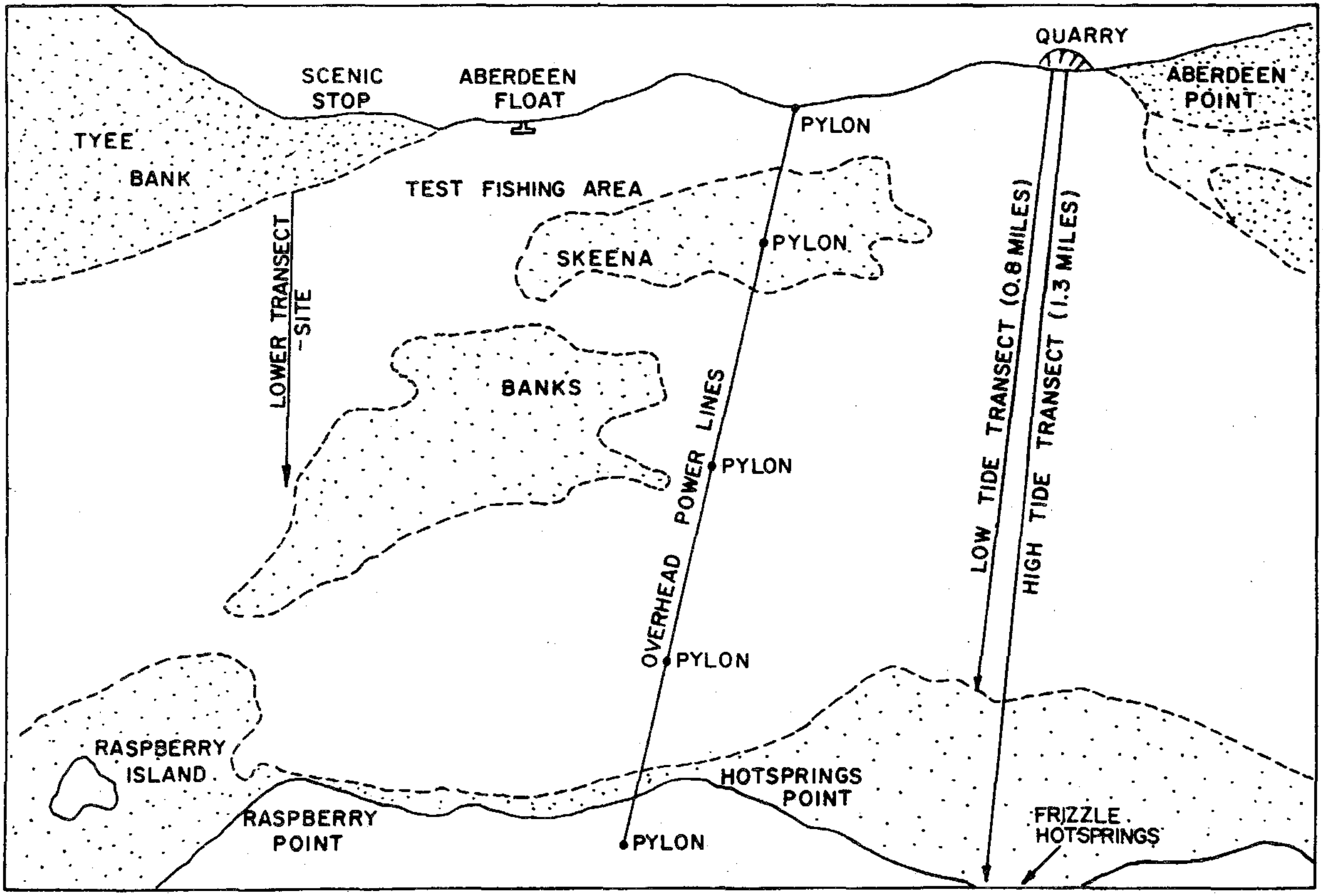

Figure 1. Locations of test-fishing and echo transect sites.

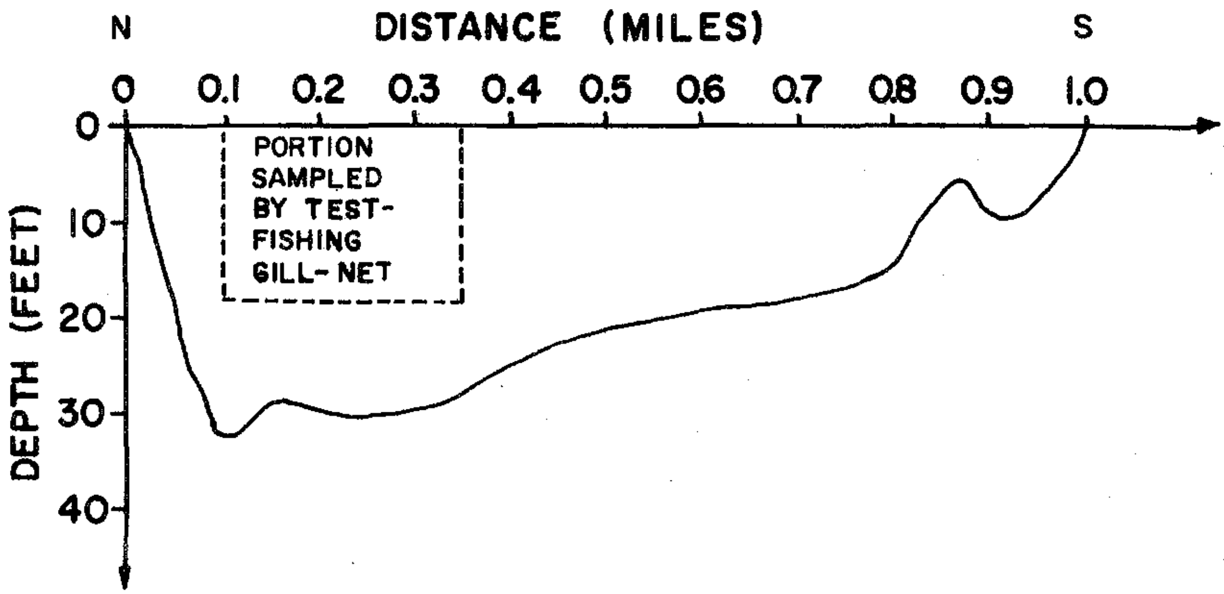

Figure 2. A transect cross section for a low high tide level (16 ft.).

transect utilized in 1970 ran from the scenic stop on the north bank of the Skeena to a position opposite the third pylon of the over head power cables. Data collected from crossings of this transect were not used in either the representation of spatial distribution or in estimates of stock abundance but were used in studies of abundance of fish with time during tide periods.

All sounding data was recorded on computer data forms by day and analyzed following each survey year. Echo sources were counted visually from echograms and recorded by depth interval and section number on the river transect. Echo targets were counted to a maximum and a minimum. Maximum counts included all possible fish targets; minimum counts included only those echo marks which the author felt were definitely derived from fish. Only minimum counts were used in fish abundance estimates and fish distribution patterns. It was felt that one of the major sources of error connected with this survey is attributable to the arbitrary decisions made when counting assumed fish targets.

On several occasions it was possible to accompany the test-fisherman on drifts. This was done to count the number of fish within 5 feet of the corkline. A record of downriver gilled fish was also kept to aid in the determination of suspected milling of sockeye in the test-fishing area. Sounding conducted in the lower regions of the Ecstall River and in the area of the commercial fishing boundary was also used to determine the relative extent of holding and milling of salmon between tides.

During the 1970 survey several sounder beam shape tests were made to determine whether the beam approximated the twenty-two degree conical shape claimed by the manufacturer. For these tests both a weighted light bulb and a weighted dead sockeye were used to simulate a fish target. Simulated fish targets were recorded on the echo sounder as inverted "V" shaped traces characteristic of real fish targets.

During several slack tide periods the simulated target was lowered vertically below the transducer in increments of five feet and then moved horizontally away from the transducer. The horizontal distance at which the trace first disappeared was recorded for each depth interval.

Correlation coefficients and regression equations based on echo sounding indices and Babine fence counts were calculated using standard linear regression analysis. A General Electric time-sharing computer program (FOSTR:)[1] was used for stepwise multiple regression analysis of factors influencing abundance estimates. Factors tested for their influence on abundance estimates were: tide, wind speed, cloud cover, water clarity, water temperature and net condition.

III. RESULTS

A. 1969 SURVEY:

(1) <u>Spatial Distribution</u>

A total of 1,904 targets were located during 106 sounding periods (562 river transect crossings).

[1]FOSTR: General Electric Mark I Marketing and Economic Forecasting Program. Catalog No. 906330

Distribution of fish across the river transect examined throughout the season for individual tide periods, statistical periods (weeks ending Sunday at 1700 hours) and for grouped tide periods; i.e. spring and neap tides are shown in Figures 3 through 5 respectively.

In Figure 3 a major change in the horizontal distribution of salmon is evident for different tide periods. The proportion available to the test-fishing gear is proportionately less on high tides. When tide periods are grouped, (Fig. 5) it can be seen that there is very little change in the portion available to the test-fishing gear. Only slight changes in horizontal distributions were disclosed for statistical periods (Fig. 4).

Vertical distributions for statistical periods throughout the season are shown in Figure 6. On the average, ninety-five percent of the targets located appeared in the surface to twenty foot depth interval. Slight changes in vertical distributions were apparent when individual high and low tides were examined but not to the extent that a change in the portion of the migrating stock available to the test-fishing net was altered. The following differences in vertical distribution by tide, were observed:

Tide	Depth Interval		
	0-10 ft.	10-20 ft.	>20 ft.
Low Low	88.3%	11.6%	0.1%
High Low	65.6%	28.0%	6.4%
Low High	79.1%	13.8%	7.2%
High High	89.8	7.6%	2.6%

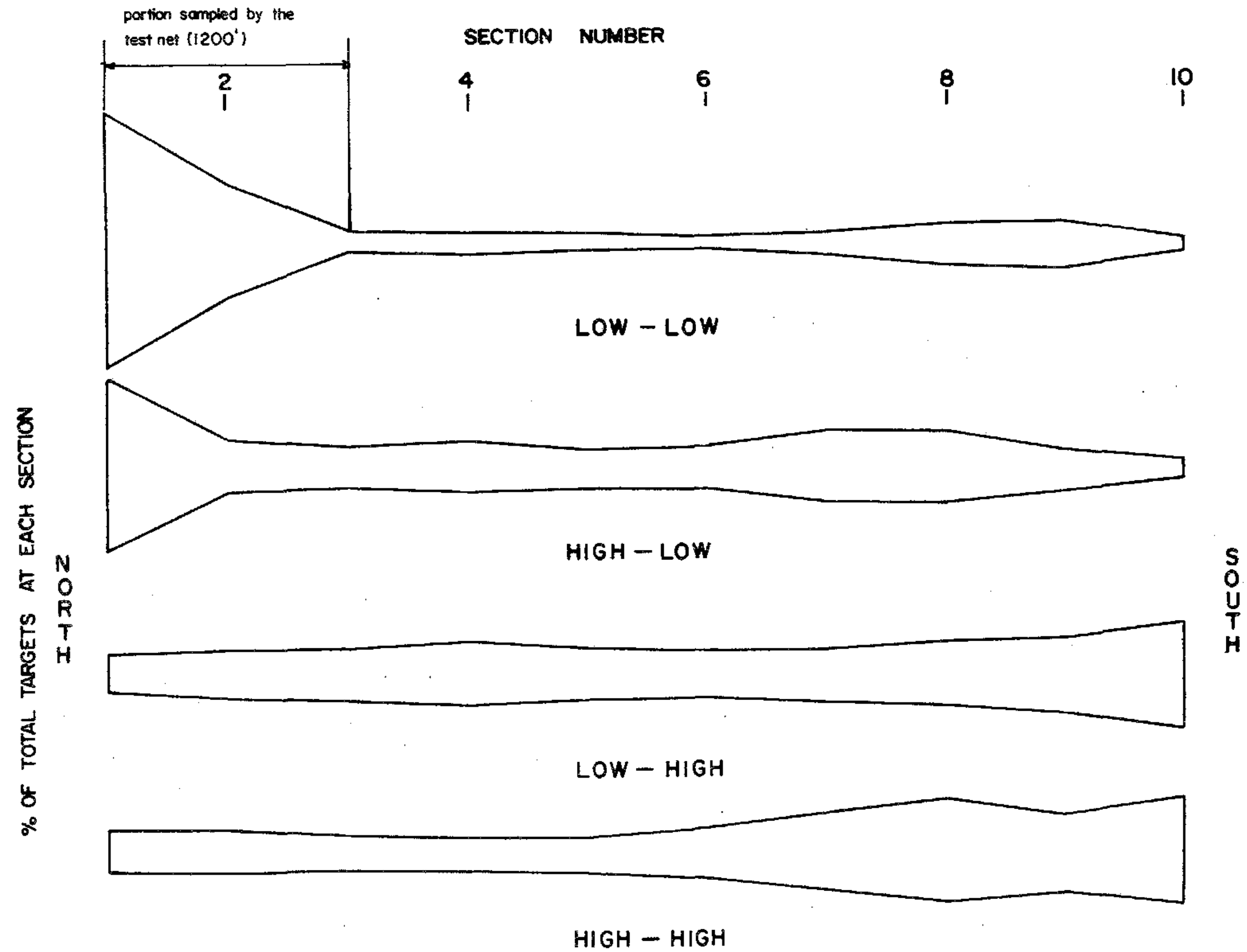

Figure 3. Horizontal distribution by tide period 1969.

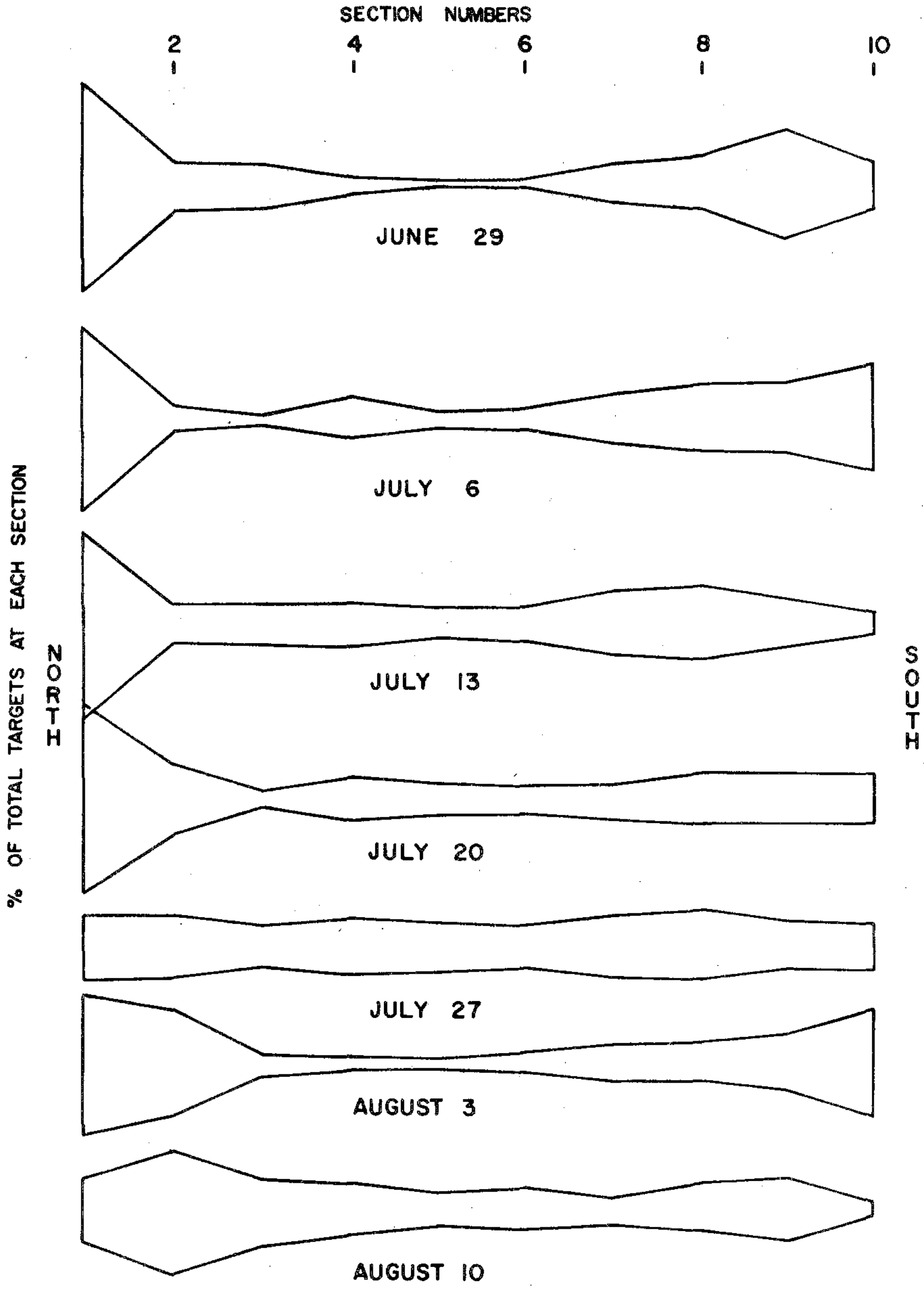

Figure 4. Relative abundance across transect 1969.

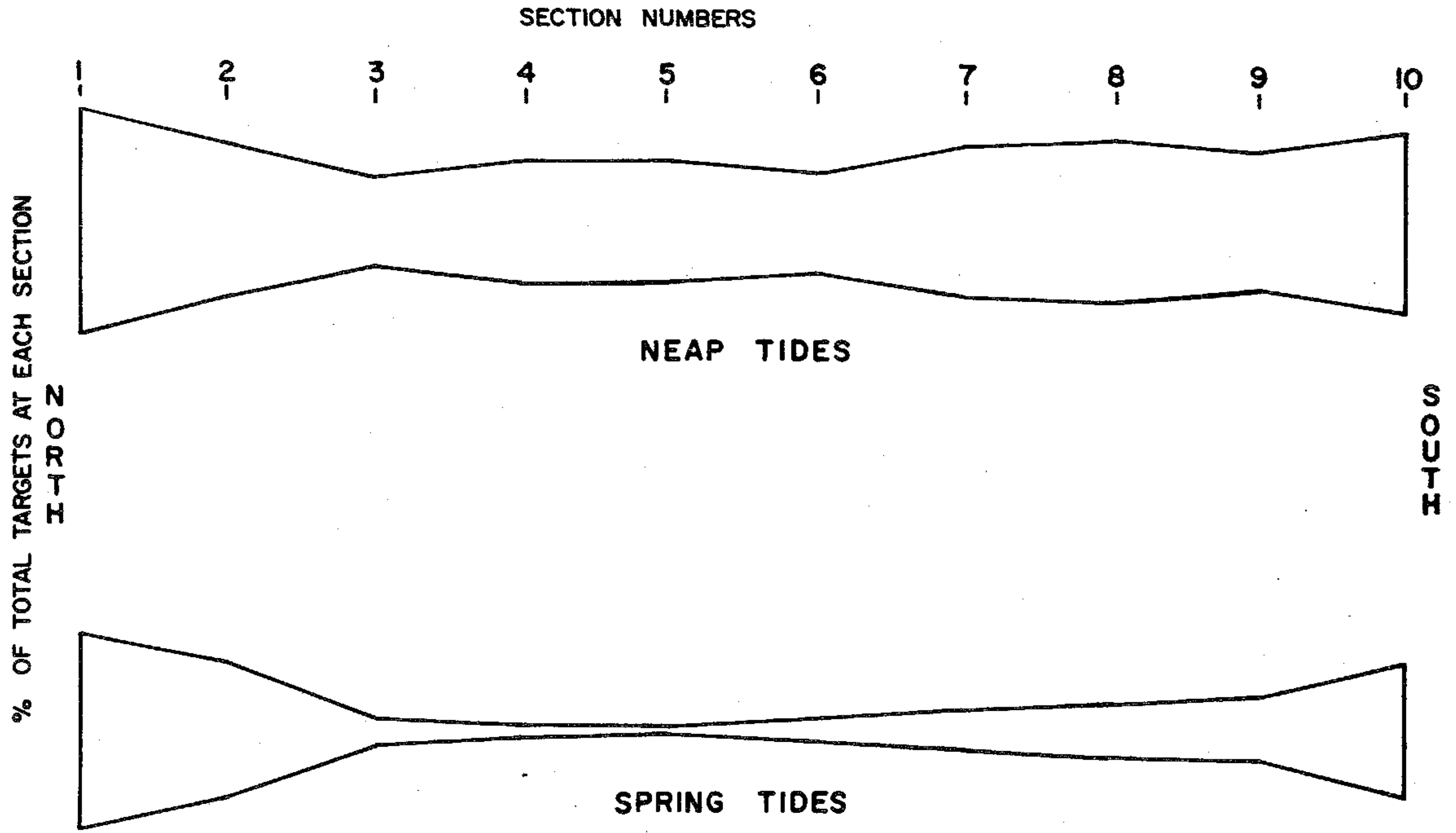

Figure 5. Horizontal distribution by grouped tides 1969.

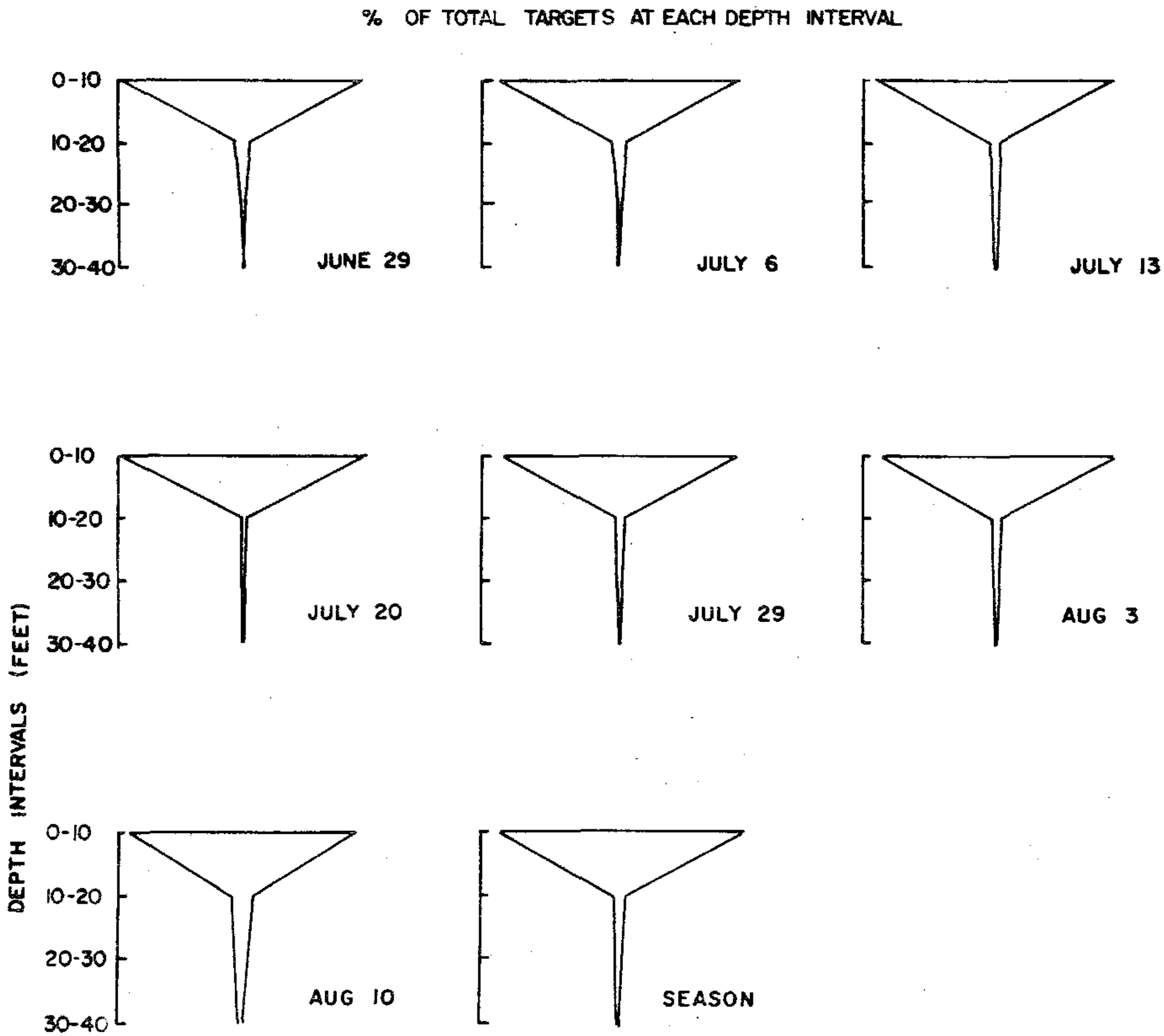

Figure 6. Vertical distribution by week 1969.

Vertical distributions derived from sounding data are corroborated by observations made during test-fishing gear pick-ups on several occasions. Approximately 80 percent of the fish, observed on 9 occasions, throughout the season on various tides, were within 10 feet of the corkline.

(2) Abundance Estimates: correlation between acoustically registered quantities of fish and the actual catch.

Sum daily test-fishing catch per hour and sum daily echo sources located per hour are tabulated in Table I. Statistically significant correlations ($P < .05$) for grouped and individual tides were observed as follows:

All tides: $r = 0.66541$ (d.f.= 37); $t = 5.34863$ (d.f.= 36)
High tides: $r = 0.45199$ (d.f.= 33); $t = 2.86643$ (d.f.= 32)
Low tides: $r = 0.3898$ (d.f.= 33); $t = 2.43138$ (d.f.= 32)

It is interesting to note that while there are significant correlations for data based on daily grouped high or low tides and for all tides combined, there is no significant correlation between test-fishing catches and numbers of echo targets on a "set by set" basis.

Since 1965 there has been a marked increase in the test catch on low tides. In 1969, 65.6 percent of the total test-fishing catch was made on low tides, whereas 52 percent of the total echo sources were located on high tides.

B. 1970 SURVEY:

(1) Spatial Distribution

A total of 1,530 targets were encountered during 84 regular sounding periods, (307 crossing of the transect).

Table I. Sum Daily Catch per hour and Sum Daily Echo Sources Located per hour, 1969

Date	Sum Daily Sources/hr.	Sum Daily Catch/hr.	Date	Sum Daily Sources/hr.	Sum Daily Catch/hr.
June 23	6.00	8.39	July 14	10.65	32.38
24	7.20	3.78	15	23.50	24.61
25	5.61	2.84	16	21.39	53.63
26	1.74	24.35	17	32.01	71.81
27	10.80	5.53	18	84.00	55.73
28	11.25	25.04	19	77.55	127.19
29	3.51	10.01	20	100.71	120.70
30	6.99	3.87	21	62.37	67.67
			22	14.49	45.90
July 1	6.75	11.13	23	13.23	41.02
3	7.14	15.34	24	4.2	10.56
4	13.35	20.68	26	23.76	112.40
5	11.25	31.57	27	12.45	85.08
6	23.25	15.03	28	68.09	73.77
7	4.50	15.40	30	79.65	78.56
8	3.99	11.52	31	2.25	19.38
9	23.79	30.57			
10	6.54	36.71	Aug. 1	17.55	38.60
11	19.89	84.81	2	8.38	91.64
12	19.08	77.72			
13	24.69	78.54			

Horizontal distributions are shown in Figures 7 and 8. There was no appreciable change in the horizontal distribution by tide, at least not to the extent that the portion available to the test-fishing gear changed, as it did in 1969. Fish were, however, more disperse on high tides, some utilizing the south bank channel. As in the two previous years (1968 and 1969) the south bank migration route was only utilized early in the season.

Figure 9 depicts vertical distributions of fish throughout the season for statistical periods. About ninety percent of the total echo sources, regardless of time or tide, are within the range of the test-fishing gear. However, during peaks of migration (late July - early August), there was a noticeable increase in the number of targets located below twenty feet (Fig. 9). Vertical distributions by individual tide varied significantly from patterns observed in previous years. The percent occurring in the surface to 20 foot interval remained nearly constant, but the percent of the total sources in the zero to ten foot interval was down from the percent of the total sources located in this interval in previous years. The following differences in vertical distribution by individual tides were observed:

Tide	Depth Interval		
	0-10 ft.	10-20 ft.	>20 ft.
Low Low	44.9%	50.7%	4.4%
High Low	63.3%	30.2%	6.5%
Low High	46.9%	38.5%	14.6%
High High	34.1%	42.2%	23.7%

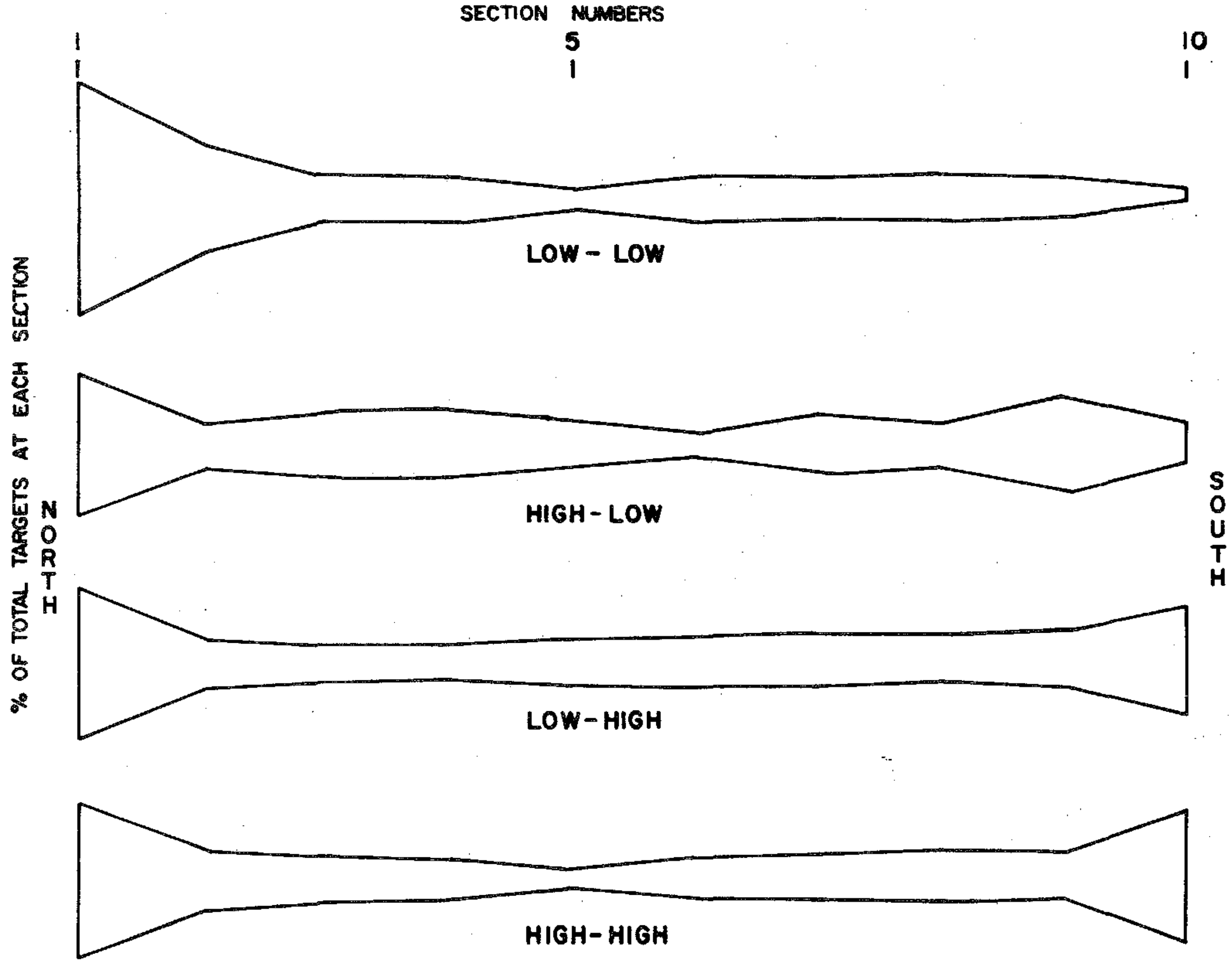

Figure 7. Horizontal distribution by ride period 1970.

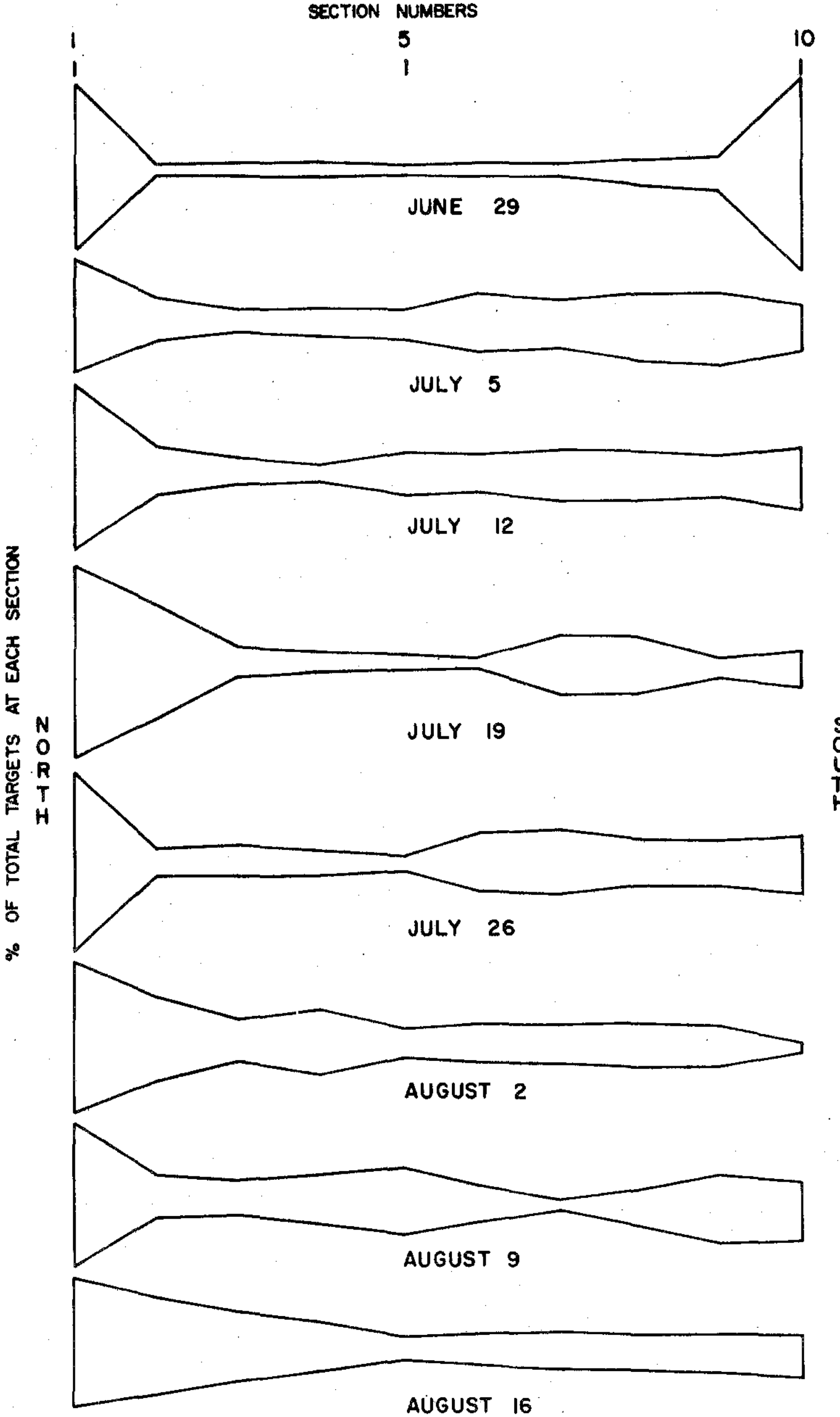

Figure 8. Relative abundance across transect 1970.

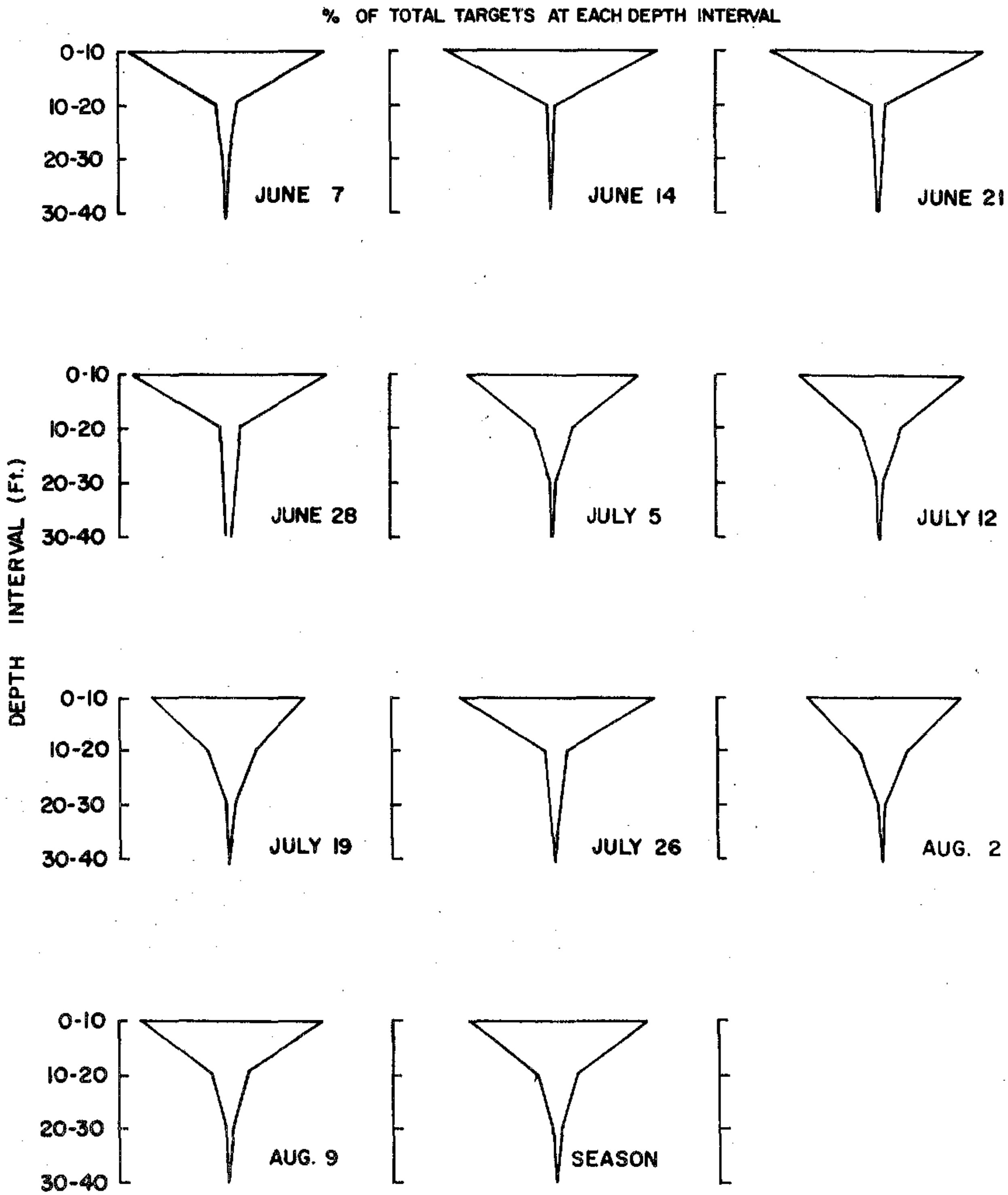

Figure 9. Vertical distribution by week 1970.

(2) Abundance Estimates:

a. Correlation between ocoustically registered quantities of fish and the actual catch.

The sum daily sources per hour and the sum daily catch per hour are tabulated in Table II. Statistically significant correlations ($P < .05$) were observed for data based on grouped and individual tides as follows:

All tides: $r = 0.3741$ (d.f.= 38); $t = 2.4546$ (d.f.= 37)
High tides: $r = 0.48125$ (d.f.= 37); $t = 3.2941$ (d.f.= 36)
Low tides: $r = 0.5033$ (d.f.= 38); $t = 3.5456$ (d.f.= 37)

As in 1968 and 1969 there was no significant correlation for data based on a "set by set" basis. Following the trend to larger catches on low tides, the catch on these tides in 1970 accounted for approximately 60 percent of the total catch, while more than 55 percent of the total echo sources were located on high tides.

b. Regression analysis between acoustic index, test-fishing index and actual escapement.

The regression line in Figure 10 is derived from a plot of the test-fishing index on the echo-sounding index for data from all tides. Values for either the echo index (x) or the test-fishing index (y) can be found by substituting the value of either of the dependent variables into the equation $y = 1.3x + 22.9$. The variance about the line is so great that the 95 percent confidence interval lines do not appear within the limits of this graph.

Two equations were derived from a regression analysis of

Table II. Sum Daily Catch per hour and Sum Daily Echo Sources Located per hour, 1970

Date	Sum Daily Sources/hr.	Sum Daily Catch/hr.	Date	Sum Daily Sources/hr.	Sum Daily Catch/hr.
June 20	0.86	10.15	July 11	16.15	78.94
22	2.20	11.46	12	26.95	134.32
23	29.70	0.85	13	20.26	34.29
24	4.70	12.07	18	10.40	25.22
25	1.76	16.55	19	20.70	21.94
26	0.36	13.88	20	3.60	10.10
27	3.342	25.79	21	21.00	28.41
28	4.65	51.49	22	50.80	19.80
29	5.39	9.25	23	17.20	11.99
30	3.53	4.65	28	17.00	10.08
July 1	8.47	15.68	29	19.02	80.26
2	17.70	63.89	30	7.50	132.81
3	5.66	52.36	31	20.66	63.05
4	4.20	10.99	Aug. 8	18.86	28.40
5	8.40	19.41	9	110.58	207.93
6	9.20	16.73	10	83.50	73.96
7	21.70	11.93	11	22.69	123.90
8	14.00	58.59	12	22.60	113.39
10	12.10	53.54	13	42.80	134.16
			14	15.00	55.10

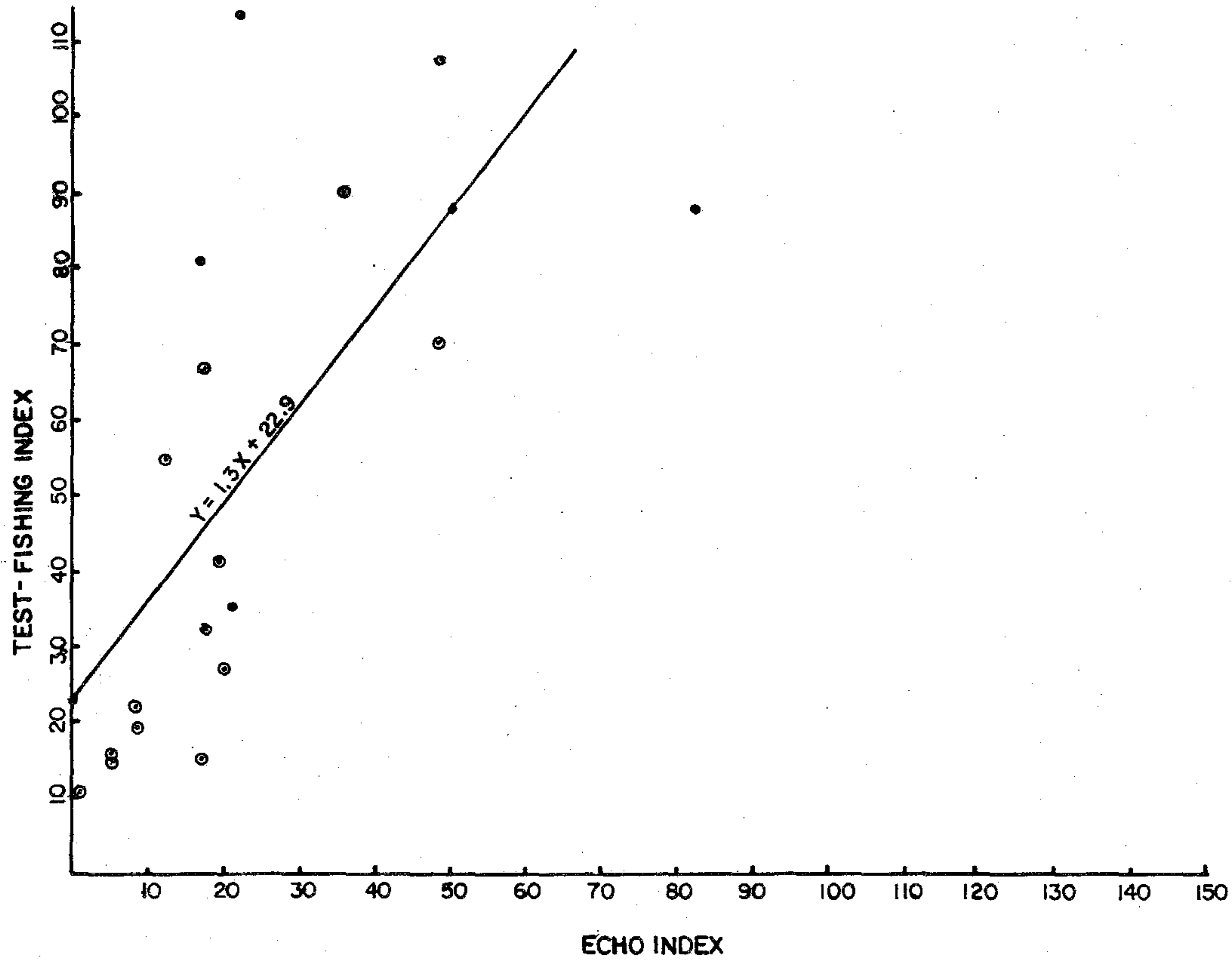

Figure 10. Regression of test-fishing index on echo index.

echo indices versus Babine fence counts for predicting daily and weekly escapements from echo indices using 1970 echo sounding data. The equations are:

(1) $\hat{y} = 248x + 147$ (daily)

$\hat{y} = 248x + 1031$ (weekly)

Where: x = echo index

$\hat{y}$ = predicted escapement to Babine

Figure 11 shows the regression of the echo index on Babine fence counts for 1970 data.

(3) Availability Studies

A plot of the average number of echo sources with time (Fig. 12) indicates that salmon are most abundant at the start of the high, slack tide period and that abundance drops off with time after set. Abundance on low tides remains nearly constant throughout the slack tide period. Sounding conducted within the lower test-fishing area one-half hour or more before the high slack set time located significant numbers of sources, especially in shallow water very close to the north bank shore.

Little evidence of suspected milling of sockeye in the test-fishing area was found. Only one downriver gilled fish was observed upon close observation of 9 test-fishing gear pick-ups throughout the 1970 survey. However, echo sounding conducted in the mouth of the Ecstall River located large numbers of targets (fish holding between tides) during the period of peak sockeye migration (weeks ending July 19, August 2 and August 9).

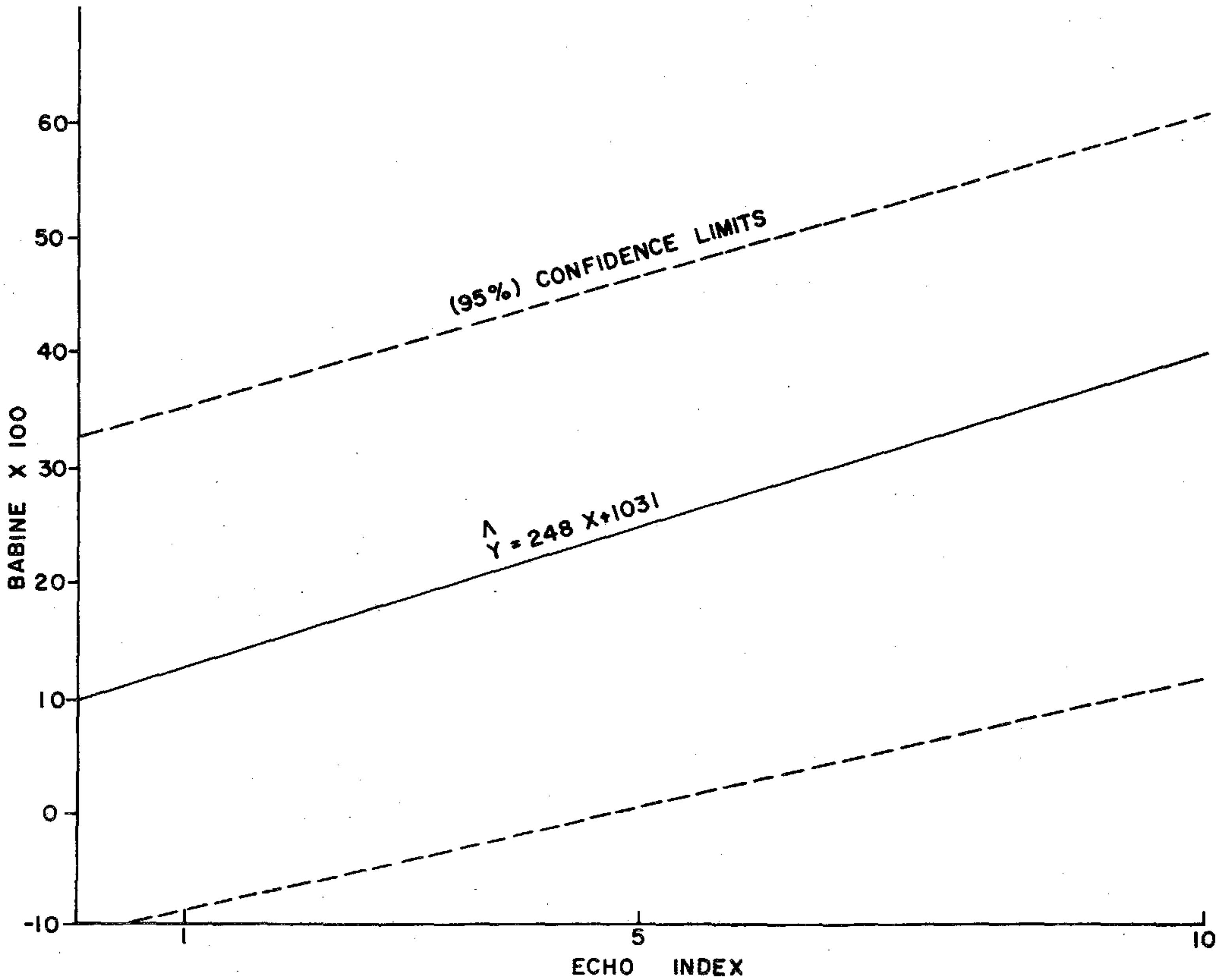

Figure 11. Regression of Babine escapement on echo index 1970.

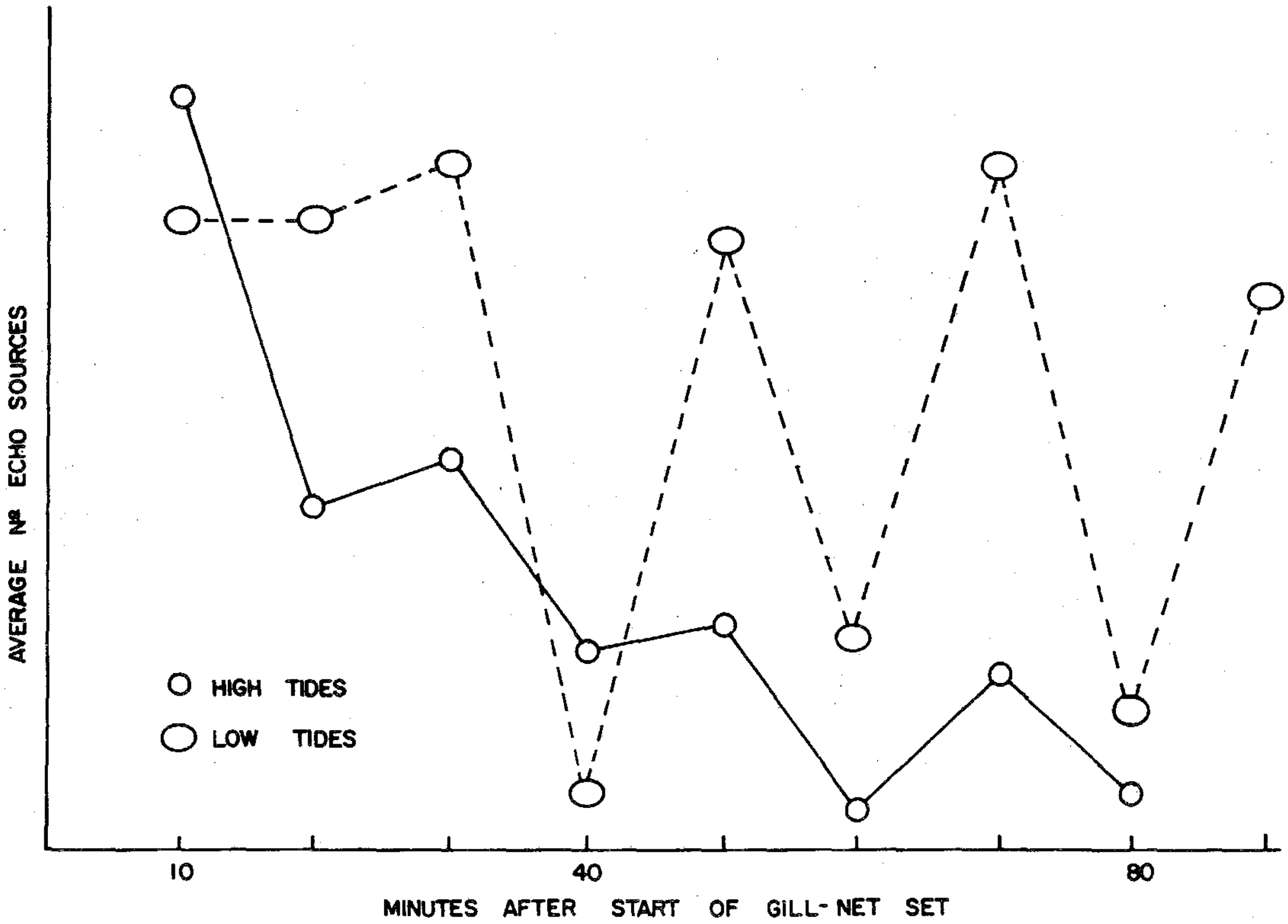

Figure 12. Abundance of fish with time after set.

(4) Factors Influencing Indices of Abundance

The results of a stepwise multiple regression between escapement estimates and a number of suspected influencing variables are shown in Tables III and IV. Equations derived iteratively by computer analysis for predicting the value of escapement indices are:

$$(3)\quad y_1 = (-35.3) + (-1.8)x_1 + (0.6)x_2 + (1.3)x_3 + (-0.2)x_4 + (1.1)x_4 + (6.3)x_6 + (5.6)x_7 + (-0.14)x_8$$

$$(4)\quad y_2 \quad (54.0) + (.048)x_1 + (1.4)x_2 + (-0.65)x_3 + (0.25)x_4 + (-1.3)x_5 + (4.4)x_6$$

Where: y_1 = estimate of test-fishing index

y_2 = estimate of echo sounding index

x_1 = tide level (ft.)	x_5 = temperature (^oF)
x_2 = cloud cover (tenths)	x_6 = tide chronology
x_3 = wind speed (m/hr.)	x_7 = tide period
x_4 = turbidity (secchi reading in cm.)	x_8 = net condition

Wind speed and tide level have the strongest effect on test-fishing indices while temperature, tide level and wind speed have the strongest effect on echo sounding indices. Increased wind speed increases the efficiency of test-fishing and decreases the efficiency of echo sounding.

(5) Beam Shape

Field tests made in 1970 indicate that the sounder detection volume was cylindrically shaped and considerably

Table III. Stepwise multiple regression analysis of factors influencing echo sounding

Correlation Matrix

Independent Variable	Dependent Variable	"r" Value
1 (tide)	8 (echo index)	.2433*
2 (cloud)	8 (echo index)	.2187*
3 (wind)	8 (echo index)	-.2251*
4 (turbidity)	8 (echo index)	.2246*
5 (temperature)	8 (echo index)	-.2749*
6 (tide chronology)	8 (echo index)	.2109*
7 (tide period)	8 (echo index)	.2433*

* denotes significance at the 0.05 level

Iterative Calculations

Constant 54.12

Independent Variable (X_1)	Coefficient	Coeff. Standard Error
1	.4764	.2841
2	1.1395	.8212
3	-.6484	.389
4	.2544	.1492
5	-1.3156	.9115
6	4.4377	2.2335

Equation:

$$\hat{y}_1 = (54.12) + (.47)x_1 + (1.14)x_2 + (-.65)x_3 + (.25)x_4 + (-1.32)x_5 + (4.44)x_6$$

Table IV: Stepwise multiple regression analysis of factors influencing test-fishing

Correlation Matrix

Independent Variable	Dependent Variable	"r" Value
1 (tide)	9 (t.f. index)	-.2826*
2 (cloud)	9 (t.f. index)	.1927
3 (wind)	9 (t.f. index)	.3136*
4 (turbidity)	9 (t.f. index)	.1333
5 (temperature)	9 (t.f. index)	.0363
6 (tide chronology)	9 (t.f. index)	.1522
7 (tide period)	9 (t.f. index)	-.1928
8 (net condition)	9 (t.f. index)	.0939

* denotes significance at the 0.05 level

Iterative Calculations

Constant -35.26

Variable (x)	Coefficient	Coeff. Standard Error
1	-1.7888	.8864
2	.6024	.6544
3	1.2685	.454
4	-.1977	.2892
5	1.1079	1.8964
6	6.2637	3.8723
7	5.6003	5.6144
8	-.1369	1.0376

Equation:

$$\hat{y} = (-35.3) + (-1.79)x_1 + (0.6)x_2 + (1.27)x_3 + (1.11)x_5 + (6.26)x_6 + (5.6)x_7 + (-0.14)x_8$$

narrower than the claimed twenty-two degree conical shape (Fig. 3). Side lobes appeared at gain settings greater than 5.0. At gain settings of 7.0 (settings used for all sounding periods), the side lobes (Fig. 13) produce a detection volume nearly cylindrical in shape, i.e., the volume of water sampled at each depth to 40 feet is approximately equal.

IV. SUMMARY AND CONCLUSIONS

Horinzontal distribution changes only slightly intra-seasonally, being skewed to the south bank early in the season. This pattern, repeated annually, should not effect the present escapement index. Horizontal distribution also shows interseasonal variability by individual tide periods. This variation may, in part, be due to differences in operational techniques applied during each survey year, and/or it may partially explain changes in the escapement/catch ratio between years. The fact that the portion of the migrating stock available to test-fishing dropped during high tides in 1969 may substantiate the latter statement. In 1969 there was also an above average catch on low tides (65 percent of the total catch). Vertical distributions showed no significant difference between weeks within a season. Vertical distribution by tide period was similar for the years 1968 and 1969, however, in 1970 a major change in the tidal vertical distribution was apparent; a smaller percent of fish targets were encountered in the zero to ten foot interval, especially on high tides. There is no explanation for this discrepancy.

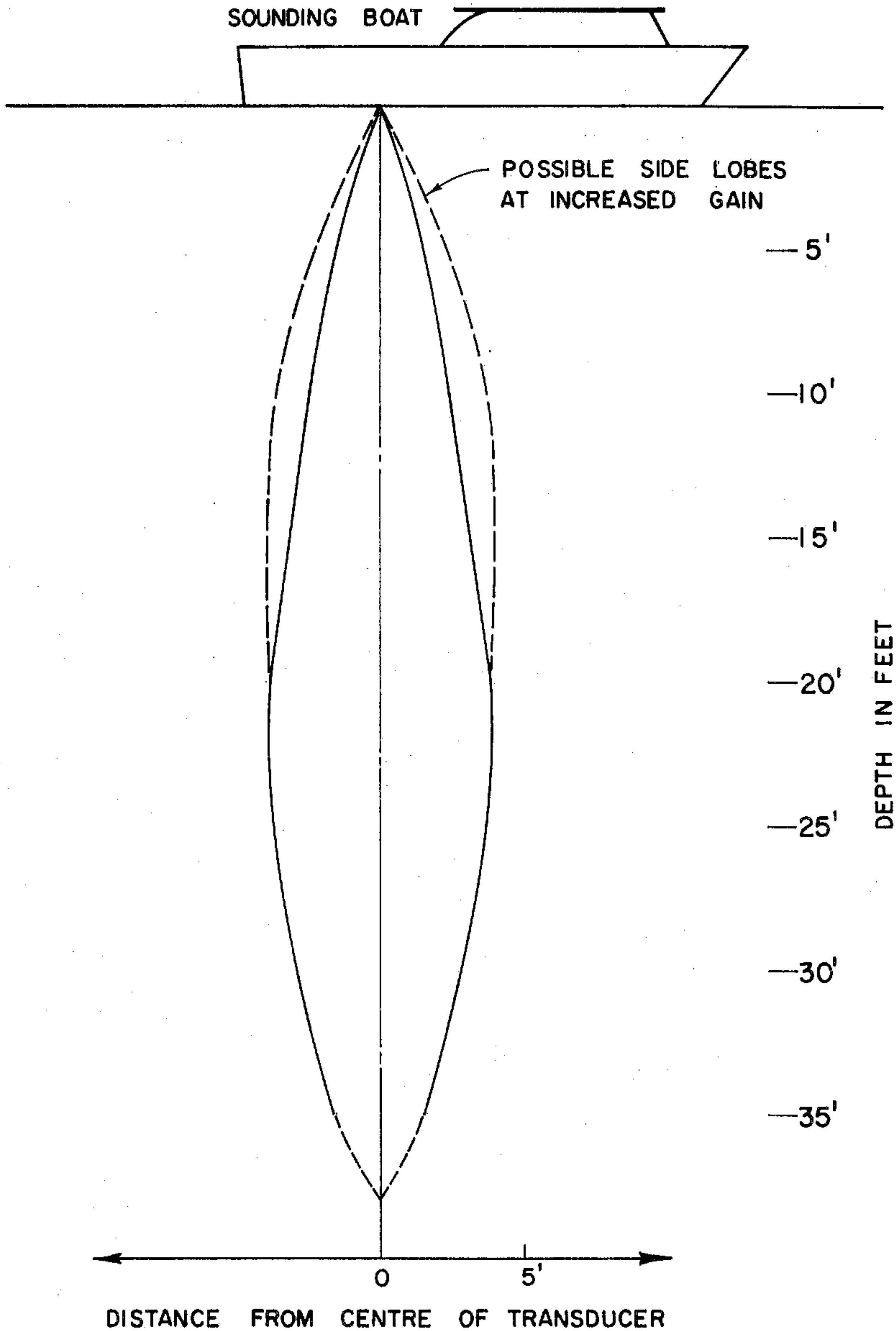

Figure 13. Transducer beam shape from 1970 tests.

Echo sounding and test-fishing indices are not correlated on a "set by set" basis, probably because there are too many independent variables affecting each abundance estimate. Correlations were, however, significant for data based on grouped tides. One of the major sources of variability inherent to the present test-fishing operation is the disproportionately large catch on low tides (average 61 percent). Observation of the test-fishing operation in situ revealed several reasons for this discrepancy. Test-fishing drifts on low tides are approximately twice the distance of drifts on high tides; net swimming velocities relative to fish movement are much greater on low tides than high tides; the test net on low tides covers a greater portion of the migration route and the net is closer to shore on low tides, therefore, it should catch greater numbers of fish. Salmon, particularly sockeye, seem to follow the shoreline, at least during daylight hours. It is also suggested that the peak in tidal migration may occur sometime before the beginning of the high slack tide.

Several variables affect the efficiency of both echo sounding and test-fishing. As expected, such factors as wind and tide were strongly correlated with operational efficiencies. A factor not accounted for in the stepwise multiple regression analysis is migration rate. Heavy migration may affect efficiencies of both indices. The efficiency of the test-fishing net may be reduced by gear saturation while echo sounding efficiency may be lowered by a similar saturation effect. The echo sounder cannot resolve individual targets which are very close together (targets closer than two feet). It is a personal opinion that gear saturation is the singly most important variable affecting present test-fishing efficiency.

Changes in the catch/escapement ratio can probably be narrowed down at present to two major causes:

(1) interseasonal changes in horizontal distribution

(2) varying intra- and interseasonal migration rates.

Echo surveying on the Skeena River has been useful in determining changes in spatial distribution of migrating salmon and to determine, to some extent, changes in migration rates. Escapement estimates may be adjusted on a intuitive basis based on relative changes of spatial distribution or migration rates detected from echo sounding. Alternatively, echo sounding may for economic or other reasons prove to be satisfactory in providing escapement estimates within the prescribed limits of accuracy as set by the management committee.

Echo surveying has proven to be a useful tool in management for determining the abundance and distribution of Skeena River salmon stocks. It is feasible that with minor changes to equipment and operational techniques, echo surveying could be as accurate or more accurate than other indirect methods of estimating the numbers of fish in migrating salmon stocks.

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