KVICHAK RIVER SIDE-LOOKING SONAR SMOLT ABUNDANCE ESTIMATION

By

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and

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TABLE OF CONTENTS

	Page
LIST OF TABLES	iv
LIST OF FIGURES	iv
LIST OF APPENDICES	v
ABSTRACT	viii
INTRODUCTION	1
METHODS	2
Hydroacoustic Equipment	2
Sounding Parameters	3
Data Analysis	4
Echo Integration	4
Dual Beam	5
RESULTS	5
Dual Beam	6
Abundance Estimation	6
DISCUSSION	7
LITERATURE CITED	10
APPENDICES	20

LIST OF TABLES

Table | Page

1. Paired hourly side-looking and upward-looking abundance estimates of sockeye salmon smolt migrating down the Kvichak River from 2 June through 14 June 1991 12

2. Total abundance and cumulative percent of sockeye salmon smolt outmigrating in the Kvichak River by 2 m interval in 1991 14

LIST OF FIGURES

Figure | Page

1. Map of the upper Kvichak River showing the location of the 1991 sockeye salmon smolt sonar sampling activities 15

2. Kvichak River Bottom profile on 15 June 1991, showing side-looking and upward-looking cross-sectional area insonified 16

3. Upward and side-looking hourly abundance estimates of sockeye salmon smolt outmigrating in the Kvichak River in 1991 17

4. Side-looking vs upward-looking hourly abundance estimates of sockeye salmon smolt outmigrating in the Kvichak River in 1991 18

5. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking and upward-looking sonar data from 2 June through 14 June 1991 19

LIST OF APPENDICES

APPENDIX		Page
A.1	Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking and upward-looking sonar data from 00:15 h to 04:00 h on 2 June 1991	21
A.2	Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking and upward-looking sonar data from 03:08 h to 06:44 h on 3 June 1991	22
A.3	Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking and upward-looking sonar data from 15:13 h to 19:15 h on 4 June 1991	23
A.4	Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking and upward-looking sonar data from 19:45 h to 23:45 h on 4 June 1991	24
A.5	Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking and upward-looking sonar data from 23:57 h on 4 June to 04:00 h on 5 June 1991	25
A.6	Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking and upward-looking sonar data from 01:38 h to 05:30 h on 6 June 1991	26
A.7	Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking and upward-looking sonar data from 22:15 h on 6 June to 02:00 h on 7 June 1991	27
A.8	Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking and upward-looking sonar data from 02:30 h to 06:30 h on 7 June 1991	28
A.9	Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking and upward-looking sonar data from 23:29 h on 7 June to 03:25 h on 8 June 1991	29

LIST OF APPENDICES (Continued)

APPENDIX | Page

A.10 Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking and upward-looking sonar data from 22:58 h on 8 June to 02:58 h on 9 June 1991 30

A.11 Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking and upward-looking sonar data from 23:50 h on 9 June to 02:00 h on 10 June 1991 31

A.12 Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking and upward-looking sonar data from 02:00 h to 03:45 h on 10 June 1991 32

A.13 Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking and upward-looking sonar data from 04:04 h to 06:45 h on 10 June 1991 33

A.14 Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (dots) and upward-looking (bars) sonar data from 00:25 h to 03:00 h on 11 June 1991 34

A.15 Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (dots) and upward-looking (bars) sonar data from 03:00 h to 06:30 h on 11 June 1991 35

A.16 Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (dots) and upward-looking (bars) sonar data from 00:18 h to 03:00 h on 12 June 1991 36

A.17 Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (dots) and upward-looking (bars) sonar data from 03:00 h to 07:00 h on 12 June 1991 37

A.18 Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (dots) and upward-looking (bars) sonar data from 19:44 h to 23:11 h on 12 June 1991 38

LIST OF APPENDICES (Continued)

APPENDIX		Page
A.19	Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (dots) and upward-looking (bars) sonar data from 23:44 h on June 12 to 03:31 h on 13 June 1991	39
A.20	Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (dots) and upward-looking (bars) sonar data from 01:14 h to 06:14 h on 14 June 1991	40

ABSTRACT

Side-looking, single-beam hydroacoustic equipment was deployed on the Kvichak River of western Alaska at night from 26 May through 14 June 1991 to collect echo integration data on the abundance of out-migrating sockeye salmon smolt. A total 44,972,863 smolt were estimated to have passed the site during side-looking sonar operations. The cumulative peak distribution occurred at 98 m from the right bank. Nightly spatial distributions varied markedly throughout the course of data collection. Distributions peaked at ranges as close as 64 m on 12 June and as far as 118 m on 7 June from the right bank.

KEY WORDS: sockeye salmon, smolt, hydroacoustic, echo integration, Bristol Bay

INTRODUCTION

The Bristol Bay area of western Alaska boasts the largest sockeye salmon (*Oncorhynchus nerka*) fishery in the world (Groot and Margolis, 1991). Researchers and managers have been keenly interested in quickly assessing annual production by estimating the freshwater abundance of these anadromous stocks prior to their dispersal in marine waters. Early attempts to estimate the number of out-migrating juvenile sockeye salmon were based on spatially expanded riverine fyke net catch per unit effort information (Kerns, 1961). The resulting estimates were unrealistically conservative, and were used primarily as measures of relative abundance. Therefore, in 1969 the Alaska Department of Fish and Game (ADF&G) embarked on a program to develop smolt abundance estimates based on acoustic data (McCurdy and Paulus, 1972).

Sonar was first used to estimate the number of outmigrating sockeye salmon smolt in the Kvichak River in 1971 (Paulus and Parker, 1974). Acoustic data were collected from three banks or arrays of upward-facing transducers placed on the river bottom approximately five km downstream from the outlet of Lake Iliamna (Figure 1). Each array contained either seven or 14 transducers and ensonified roughly 3.3 m (11 ft) of river cross section. The arrays were positioned on the bottom so that essentially all smolt passing over the array could be detected, since smolt normally migrate very close to the surface.

In the Kvichak River, all arrays were used to acquire data 24 h per day. Total abundance is estimated by expanding adjusted counts within ensonified areas to the remaining portions of the river used by actively migrating smolt. To synopsize, counts in areas between arrays were estimated by linear interpolation between average counts per meter over each array. Counts in areas beyond the outside arrays were linearly interpolated between the average counts per meter over the outside arrays and zero at the respective edges of smolt distribution. Side-looking sonar was used to describe the horizontal boundaries of smolt distribution.

In 1989, the Kvichak River sonar project was relocated approximately 1 km downstream from the historic location. We conducted an investigation during the 1990 field season which described the lateral limits of migrating smolt distribution at the new location using side-looking sonar (Huttunen and Skvorc, 1991). Catalyzed by the results of that study, this report summarizes our efforts to estimate smolt abundance by applying echo-integration techniques in a side-looking orientation.

METHODS

We acquired all data during peak migration times at night using available sonar equipment. Each evening, one hour of dual-beam data was collected immediately preceding the nightly echo-integration data collection. Separate transducers were used to acquire dual-beam and echo-integration data because our narrowest dual-beam transducer was range-limited by water depth. All side-looking data were collected from the right bank during upward-listening operations. The side-looking transducers were aimed perpendicular to the river exactly over the existing upward-listening arrays which were located 56 m, 78 m, and 97 m from the right bank (Figure 2). The total river width at the sonar site was 134 m in 1991.

Acoustic data were simultaneously recorded in three formats: 1) electronically, written to file; 2) hard-copy on a paper chart recorder; and 3) on magnetic Digital Audio Tape (DAT) storage media.

Hydroacoustic Equipment

We used a 420 kHz-configured Biosonics Model 102 Scientific Echo Sounder to generate and interrogate electronic pulses. Separate single-beam and dual-beam transducers were used to emit and receive sound pulses during this study to maximize the river cross-section sampled during echo-integration data collection. A single-element Acoustic Transducers International (ATI) transducer with measured half-power beamwidth angles of 1.75° in the vertical plane and 3.75° in the horizontal plane was used to acquire echo-integration data. A two-element International Transducer Corporation (ITC) transducer with measured narrow-beam and wide-beam half-power beamwidth angles of 3.75° and 7.5° in the vertical plane and 10.0° and 21.0° in the horizontal plane was used to acquire dual-beam data.

Echo-integration and dual-beam signal processing was conducted on a Biosonics Model 221/281 Echo Signal Processor (ESP) on-board a Compaq 386-20E microcomputer. Processed data were written directly to file from the ESP and backed up on 3.5 in floppy disks. Detected echoes were simultaneously recorded in hard-copy form on a Biosonics Model 115 portable chart recorder and in analog (DAT) form on a Victor Model XD-Z700 DAT recorder.

We used a Remote Ocean Systems Model PT-25 pan and tilt dual-axis rotator and PTC-1 control unit to aim the transducer. This device allowed us to move the transducer in increments as small as 0.3 degrees in both the vertical and horizontal axes. We conducted range calculations and real-time aiming feedback directly on a Nicolet Model 310 digital storage oscilloscope display. The entire sounding, taping, and aiming systems were powered by a Honda Model EM-3500SX portable generator.

Sounding Parameters

User-defined acoustic sounding parameters on the transceiver remained unchanged throughout the periods of echo-integration and dual-beam data collection. Settings common to both types of data collection were: 1) Pulse Width = 0.4 ms; 2) Attenuation Coefficient = Freshwater (0 dB); 3) Pulse repetition rate = 5 Hz; 4) Bandwidth = 5 kHz; 5) Transmit Power = -3 dB; 6) Receiver Gain = 0 dB; 7) Blanking Range = 3.0 m; and 8) Total listening range = 120 m. Time Varied Gain (TVG) was set to 20 log R for echo-integration and 40 log R for dual-beam data collection. Minimum detection thresholds varied from 50 mv to 500 mv in user-defined range strata. Chart recorder detection threshold was set at 135 mv, and the machine paper speed was set at level three (16 mm/min).

Data Analysis

Echo Integration:

Electronic raw data files written by the Model 221 Echo Signal Processor were imported into Quattro-Pro spreadsheet format where all processing was accomplished. Raw data included summed squared voltage, number of processed pings, and number of machine samples possessing valid echoes. All data were written to file in 2 to 10 m (user-defined) range intervals each minute. Relative density (RD) was calculated for each range interval (i) and minute (j) following Burczynski (1979) as:

$$RD_{ij}=\frac{(\sum V^2)_{ij}(m)}{(pp)_{ij}(S)_{ij}} \tag{1}$$

where $\sum v_{ij}^2$ = summed squared voltage in range interval i and minute j,

m = multiplier for imperfect machine TVG,

pp_{ij} = processed pings; and

S_{ij} = the number of machine samples possessing valid echoes.

Absolute density (AD), expressed as fish/m^3, was calculated from RD using the integrator scaling factor (A) described by Burzcynski and Johnson (1986) as:

$$AD_{ij}=(RD_{ij})\cdot(A) \tag{3}$$

where

$$A=\frac{1}{(\pi\cdot\tau\cdot c\cdot\sigma_{bs}\cdot p_0^2\cdot g_x^2\cdot b^2(\theta))} \tag{4}$$

and π = 3.14,

τ = 0.0044 sec (pulse width),

c = 1465 m/sec (speed of sound in 5° C water),

σ_{bs} = 0.00002 m^2/fish (mean back-scattering cross section),

p_0^2 = 1.3 e+22 μPa (Root Mean Squared transmitted pressure 1m from the transducer),

g_x^2 = 1.41 e-16 v/ μPa (through system gain); and

$b^2(\theta)$ = 0.000147 (average squared beam pattern factor).

The speed of sound was calculated following Urick (1983) for 5° C freshwater and zero depth. Mean backscattering cross-section (σ_{bs}) was calculated from the 1991 seasonal average fork length of Kvichak River smolt samples using Love's equation (Love, 1969). The average squared beam pattern factor ($b^2(\theta)$) was calculated from a digitized polar plot of the single beam transducer used to acquire echo- integration data during this investigation (ATI s/n 830016).

Dual Beam:

Returning electronic signals were filtered for minimum narrow-beam peak voltage, half-power pulse duration, beam pattern factor, and number of valid echoes. Peak voltage thresholds were established in 2 m to 10 m user-defined range intervals at roughly three times greater than the background noise. Acceptable half-power pulse durations were limited to those between 333 μsec and 467 μsec. Beam pattern factors were rejected if they resulted in negative values or if they were greater than 3 decibels (dB) off axis. A minimum of 3 valid echoes was required per individual fish tracked.

RESULTS

Data acquisition was first attempted at 2300 hours on 26 May but ice passage prevented meaningful data collection until 0000 hours on 2 June. Between 2 and 14 June we collected 81 h of horizontal-aspect echo-integration data on the abundance-at- range of sockeye salmon smolt migrating down the Kvichak River. During that time, an additional 11 h of potential sampling time (12% of the total) was lost to weather-induced acoustic noise, mainly caused by strong winds.

The maximum single-beam listening range varied from 118 m to 120 m, which means that 88%-90% of the total (134 m) river cross section was insonified (Figure 2). And based on results obtained during a 1990 study, we were able to insonify 92%-94% of the portion of the river used by migrating smolt (Huttunen and Skvorc 1991). However, acoustic noise originating from nearly continuous boat operations within 20 m of the transducer prevented abundance estimation within that range.

Dual Beam

Also during that time, we collected approximately 14 h of dual-beam data during periods of low abundance. Unfortunately, we were not able to calculate target strengths because we were only able to acquire a limited number of echoes from individual fish. Water velocity (1.5 m/s) and listening range restrictions (45 m maximum) limited fish residence time in the beam, and as a result, limited the number of echoes returned.

Abundance Estimation

In all, some 44,972,864 smolt were estimated to have passed the sonar site during side-looking data collection (Table 1). Of those, approximately 57% were estimated to have passed within the area bracketed by the upward-looking gear between 56 m and 98 m range (Table 2). During the same hours of operation, the upward-looking sonar program provided an estimate of 43,525,980 smolt. The patterns of hourly abundance from both upward- and side-looking data were similar, normally peaking during the darkest part of the night (Figure 3). While the patterns of daily abundance were similar, there was no significant relationship ($r^2 = 0.0$) between the hourly estimates generated by the two acoustic systems (Figure 4).

The cumulative horizontal distribution of smolt detected by the side-looking gear peaked at 96 m from the right bank, and declined quickly beyond that range (Figure 5). This contrasted with cumulative results from the upward-looking gear where the peak estimate came from the inshore array located at 56 m from the right bank.

Nightly spatial distributions were highly dynamic; side-looking estimates peaked at ranges from 64 m on 12 June to 118 m on 7 June (Appendices A.1 - A.20). The distribution of upward-looking estimates also varied between nights, but the largest estimates were usually from the inshore array located at 56 m from the right bank.

DISCUSSION

The objective of this project was to estimate abundance of out-migrating sockeye salmon smolt using echo-integration techniques on data acquired in a horizontal aspect. The incentive to apply proven technology in this unorthodox manner was to increase our acoustic sampling power from the roughly 7.5% of the river insonified by the historic upward-looking sonar program. Using a very narrow-beam transducer and precise positioning equipment, we were able to insonify passing smolt schools across 90% of the river from the right bank at the existing sonar site. It is important to remember however that echo-integration techniques were developed primarily as a tool for use in mobile surveys where the transducer orientation is vertical. The question of transducer orientation is critical since the intensity of an echo reflected by a target is heavily influenced by the target's angular distance from the maximum response axis (its position in the beam). In a mobile survey it is assumed that targets pass through the beam randomly. Given random positioning in the beam, it is reasonable to use an average (edge-to-edge) beam energy or beam pattern factor ($b^2(\theta)$) to correct all returning echo intensities for position off-axis. From a side-looking frame of reference, the depth distribution of targets becomes an angular off-axis distribution acoustically. While the exact vertical distribution of smolt in the Kvichak River is not precisely known, various researchers have reported that smolt generally tend to migrate near the surface (Mesiar 1985), and therefore, close to the (half-power) edge of the side-looking beam. Without knowing the true vertical distribution of passing smolt schools, we were forced to use the average beam pattern factor without further adjustment. This means that the estimates we produced are probably conservative. However, the absolute magnitude of that error is likely to be small since true $b^2(\theta)$ for this situation lies somewhere between the calculated value and the "edge" of the beam at the half-power (-3dB) level. Additionally, $b^2(\theta)$ is a relatively minor component of the integrator scaling factor (see Equation 3).

In addition to the true beam pattern factor, another basic piece of information required to calculate absolute abundance using echo-integration is an accurate estimate of the mean backscattering cross-section (σ_{bs}), calculated from target strength in terms of squared volts per fish. Without an acoustic estimate of mean target strength, we were forced to rely on Love's (1969) generalized equation which relates target strength to body length in a number of teleosts. If side-looking echo-integration technology were to be implemented in future full-scale smolt abundance estimation projects, narrow beam, dual-beam or split-beam transducers designed for each particular situation would be necessary to allow estimation of mean beam pattern factors and unbiased target strengths of passing smolt. Still, corroborating estimates of fish size at age would be required from physical samples to accurately describe target strength as a function of age (to estimate age composition from acoustic samples).

It is important to reiterate that acoustic noise, usually in the form of air bubbles entrained by rain and/or wind events, is cumulative over the entire listening range. Therefore, horizontal-aspect sonar is more likely to be sensitive to noise than the upward-facing system simply due to the much longer operating ranges. However, it wasn't possible to carefully test the actual abilities of either system to provide accurate abundance estimates during weather events. One means of minimizing the effect of noise on side-looking data acquisition would be to deploy transducers on both banks of the river, reducing by nearly one-half the range insonified by each.

One especially important finding is that the within-day and between-day spatial distributions observed during both years of the side-looking echo-integration study were highly dynamic. The distribution modes regularly occurred in waters unensonified by the upward facing arrays, and periodically occurred between the 'outside' arrays and shore. From these studies, it appears that the observed variability in spatial distribution may be generally characteristic of the smolt migration in the Kvichak River. Thus, increased sampling, by whatever means, will significantly improve the accuracy and precision of abundance estimates.

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Table 1. Paired hourly side-looking and upward-looking abundance estimates of sockeye salmon smolt migrating down the Kvichak River from 2 June through 14 June 1991.

Date	Time	Side-looking Abundance Est.[a]	Upward-looking Abundance Est.[b]
2 June	0000	177,950	251,990
	0100	112,479	973,590
	0200	57,113	1,111,924
	0300	47,539	1,660,815
	0400	151,597	708,893
3 June	0300	33,416	1,001,652
	0400	198,935	896,573
	0500	23,383	376,700
	0600	8,482	119,158
4 June	1500	226,542	604,524
	1600	230,981	1,195,037
	1700	374,382	1,909,600
	1800	347,806	1,436,582
	1900	255,892	1,077,242
	2000	280,363	865,282
	2100	267,706	857,343
	2200	373,072	1,819,352
	2300	371,145	2,503,328
5 June	0000	363,995	432,407
	0100	347,869	859,400
	0200	437,356	521,960
	0300	442,428	397,430
	0400	471,664	995,997
6 June	0100	888,129	424,400
	0200	1,026,818	330,679
	0300	1,139,419	579,099
	0400	685,564	1,260,955
	0500	286,787	437,863
	2200	466,643	384,037
	2300	1,143,548	1,164,366
7 June	0000	1,554,599	783,640
	0100	1,509,439	379,070
	0200	1,654,748	510,907
	0300	1,612,034	546,304
	0400	1,138,077	558,569
	0500	620,830	421,860
	0600	196,485	70,357
	2300	705,485	1,313,999
8 June	0000	1,217,162	394,761
	0100	1,262,412	205,296
	0200	1,232,979	1,184,884
	0300	1,334,547	1,066,230
	2300	413,459	327,525

-- Continued --

Table 1. (page 2 of 2)

Date	Time	Side-looking Abundance [a]	Upward-looking Abundance [b]
9 June	0000	411,462	122,307
	0100	430,159	120,675
	0200	338,492	47,379
	2300	375,528	124,306
10 June	0000	320,812	48,893
	0100	363,470	79,204
	0200	629,740	309,297
	0300	698,230	342,655
	0400	534,534	270,997
	0500	444,164	125,513
	0600	134,437	116,060
11 June	0000	936,361	151,536
	0100	933,579	341,310
	0200	846,069	450,279
	0300	782,832	188,367
	0400	474,011	131,388
	0500	174,453	53,164
	0600	106,560	69,658
12 June	0000	415,845	74,730
	0100	729,789	223,454
	0200	789,348	271,858
	0300	945,170	434,373
	0400	855,041	800,146
	0500	359,209	688,415
	0600	196,417	134,842
	1900	157,211	259,228
	2000	194,760	274,103
	2100	454,911	176,216
	2200	427,783	171,866
	2300	386,476	109,330
13 June	0000	584,266	303,139
	0100	1,111,328	528,128
	0200	943,262	626,279
	0300	705,420	324,921
14 June	0300	371,505	26,381
	0400	309,124	41,216
	0500	201,876	26,830
	0600	207,971	15,957
Total Estimated Passage		44,972,864	43,525,980

[a] Based on backscattering cross-section (σ_{bs}) value of 0.00002 m^2/fish
[b] Based on 10 fish per count, and expanded geometrically across the river to estimate total hourly passage.

Table 2. **Total abundance** and cumulative percent of sockeye salmon smolt **outmigration** in the Kvichak River by 2m range interval in 1991.

Range (m)	Total Abundance	Cumulative Percent	Range (m)	Total Abundance	Cumulative Percent
2	0	0.00	62	620097	20.26
4	0	0.00	64	1259775	23.09
6	0	0.00	66	1305700	26.03
8	0	0.00	68	396962	26.92
10	0	0.00	70	1426948	30.12
12	0	0.00	72	811374	31.95
14	0	0.00	74	1075901	34.37
16	0	0.00	76	777040	36.11
18	0	0.00	78	1333424	39.11
20	75771	0.17	80	1735278	43.01
22	144522	0.50	82	1535742	46.46
24	149338	0.83	84	1375562	49.55
26	98739	1.05	86	1215381	52.29
28	48140	1.16	88	1343271	55.30
30	109673	1.41	90	2044451	59.90
32	301842	2.09	92	841356	61.79
34	234948	2.61	94	1014748	64.07
36	176358	3.01	96	2849498	70.48
38	117769	3.27	98	1899080	74.74
40	239944	3.81	100	2538494	80.45
42	514897	4.97	102	707672	82.04
44	422158	5.92	104	505939	83.18
46	458643	6.95	106	1583809	86.74
48	495128	8.06	108	3312202	94.18
50	702839	9.64	110	184565	94.60
52	1230166	12.41	112	898426	96.62
54	939038	14.52	114	459180	97.65
56	1135967	17.07	116	229582	98.16
58	396351	17.96	118	816994	100.00
60	401384	18.87			

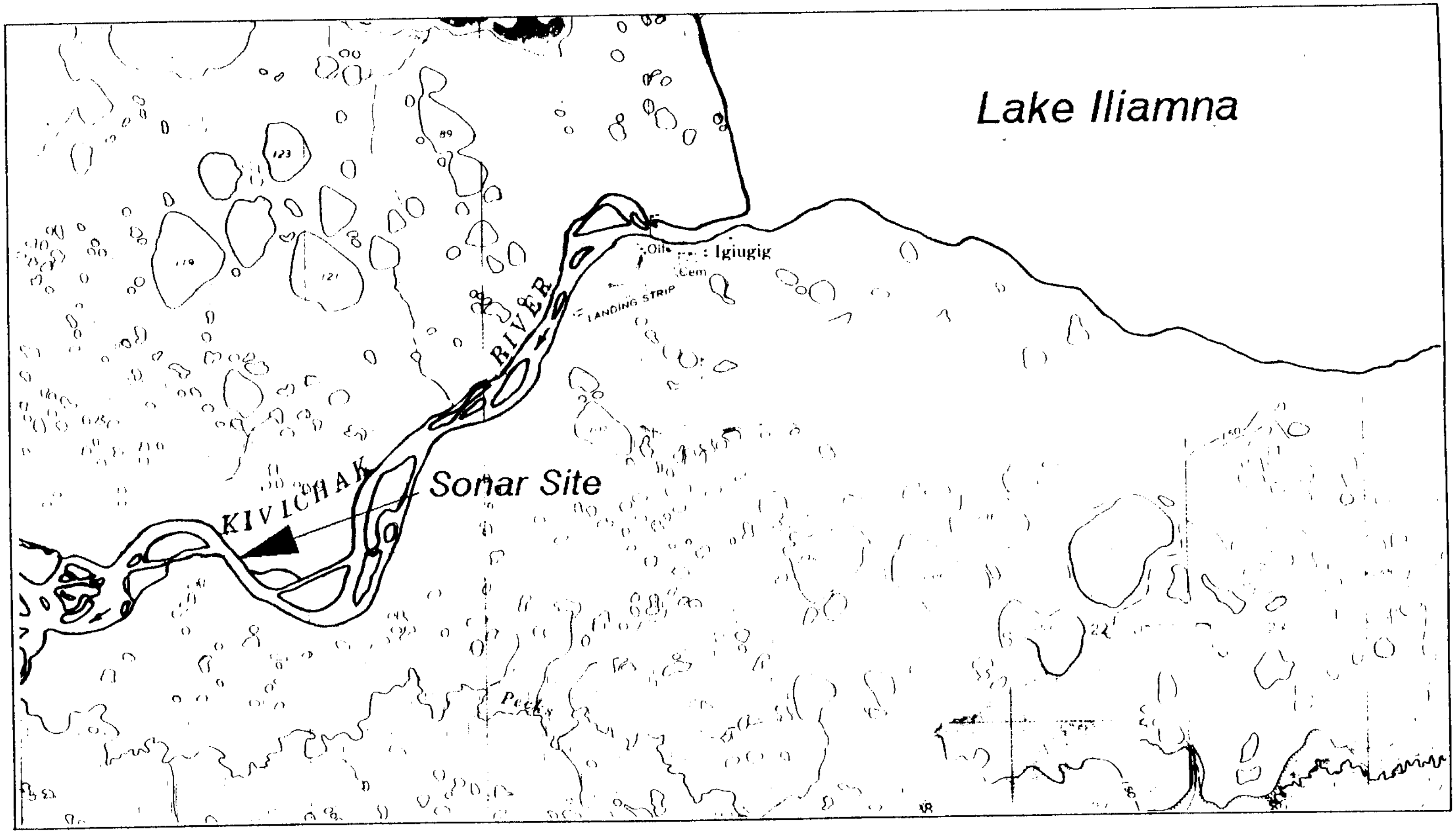


Figure 1. Map of the upper Kvichak River showing the location of the 1991 sockeye salmon smolt sonar sampling activities.

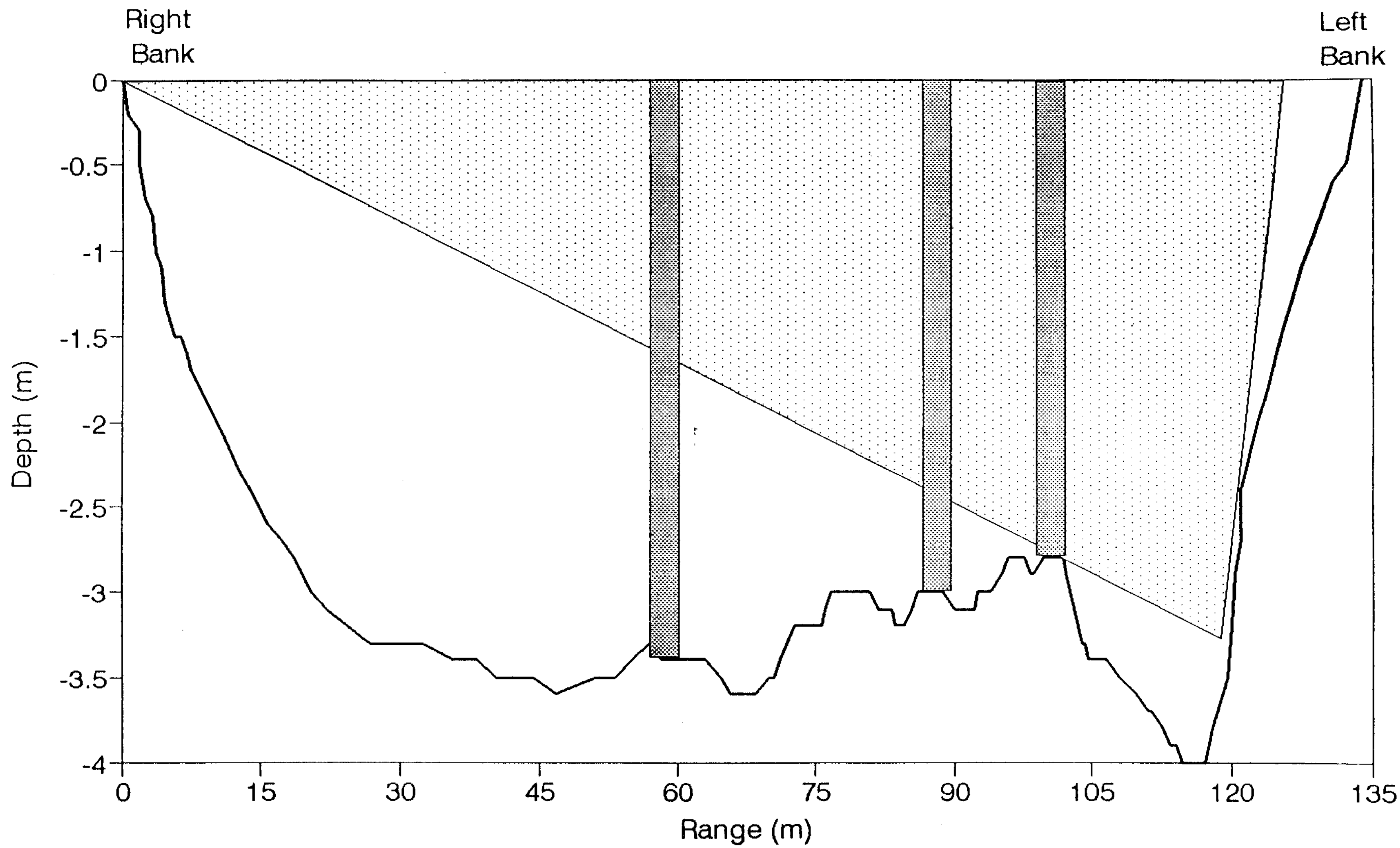


Figure 2. Kvichak River bottom profile on 15 June 1991, showing side-looking and upward-looking cross-sectional area insonified (drawn to horizontal scale).

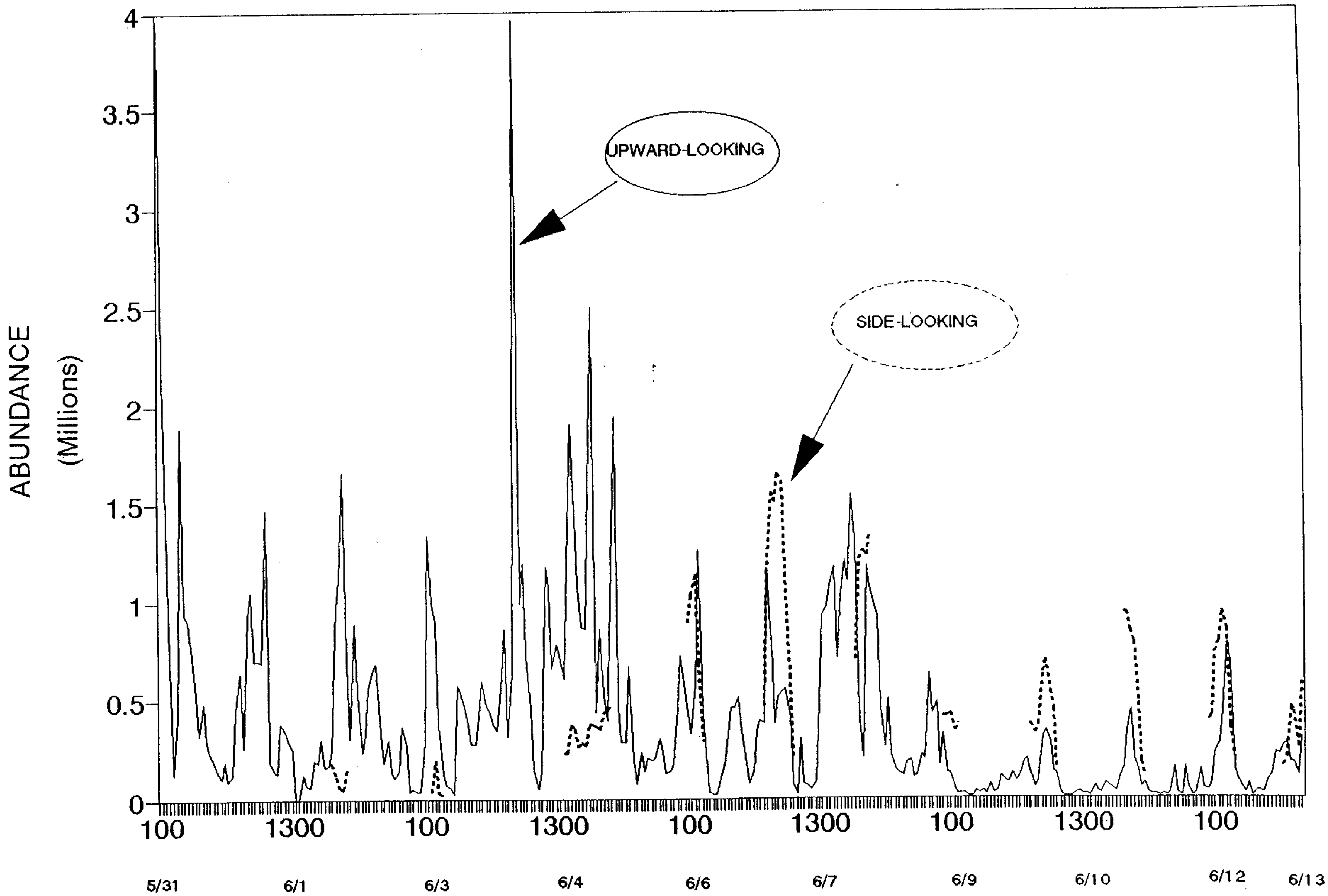


Figure 3. Upward and side-looking hourly abundance estimates of sockeye salmon smolt outmigrating in the Kvichak River in 1991.

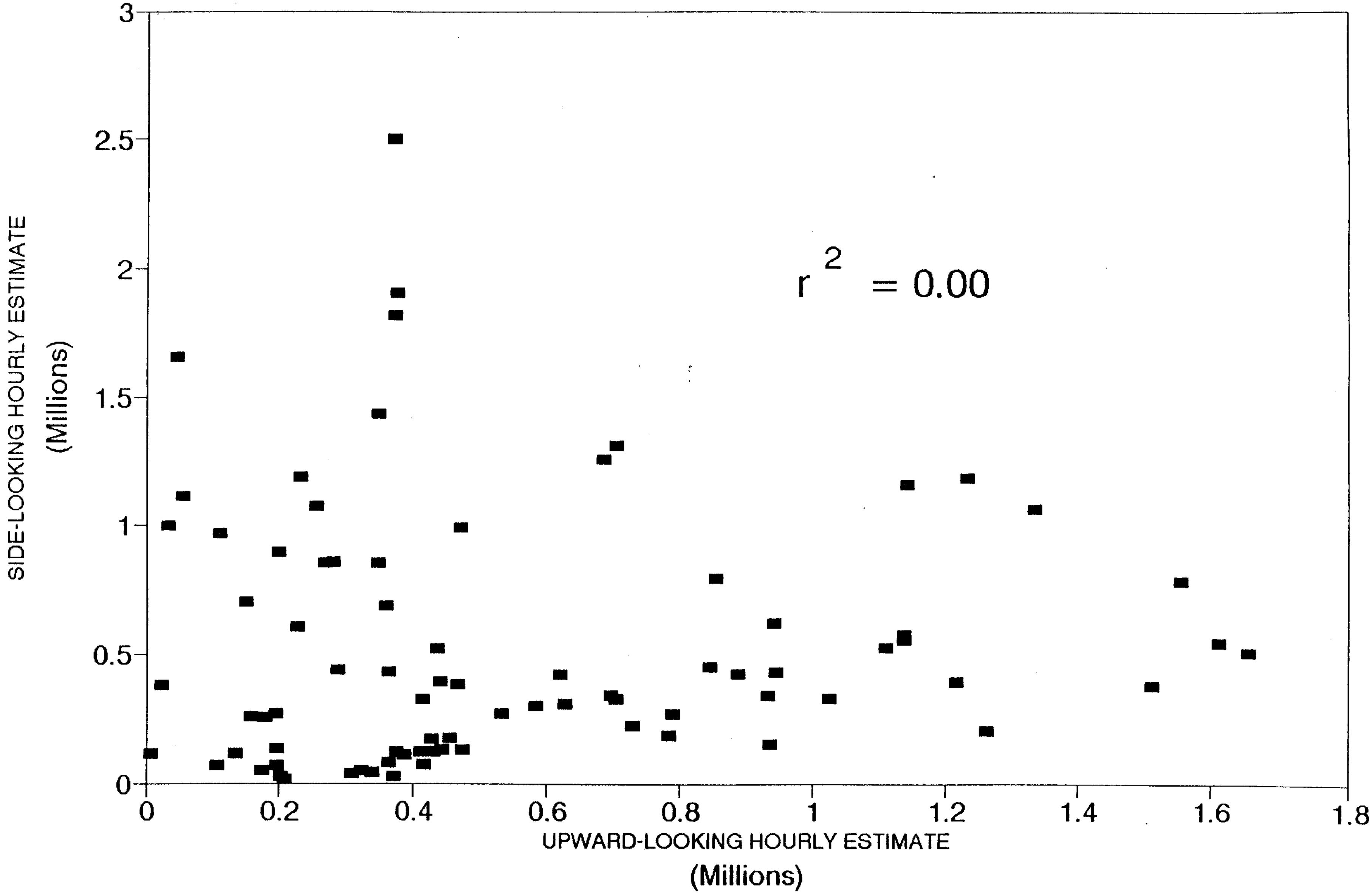


Figure 4. Side-looking vs upward-looking hourly abundance estimates of scokeye salmon smolt outmiigrating in the Kvichak River in 1991.

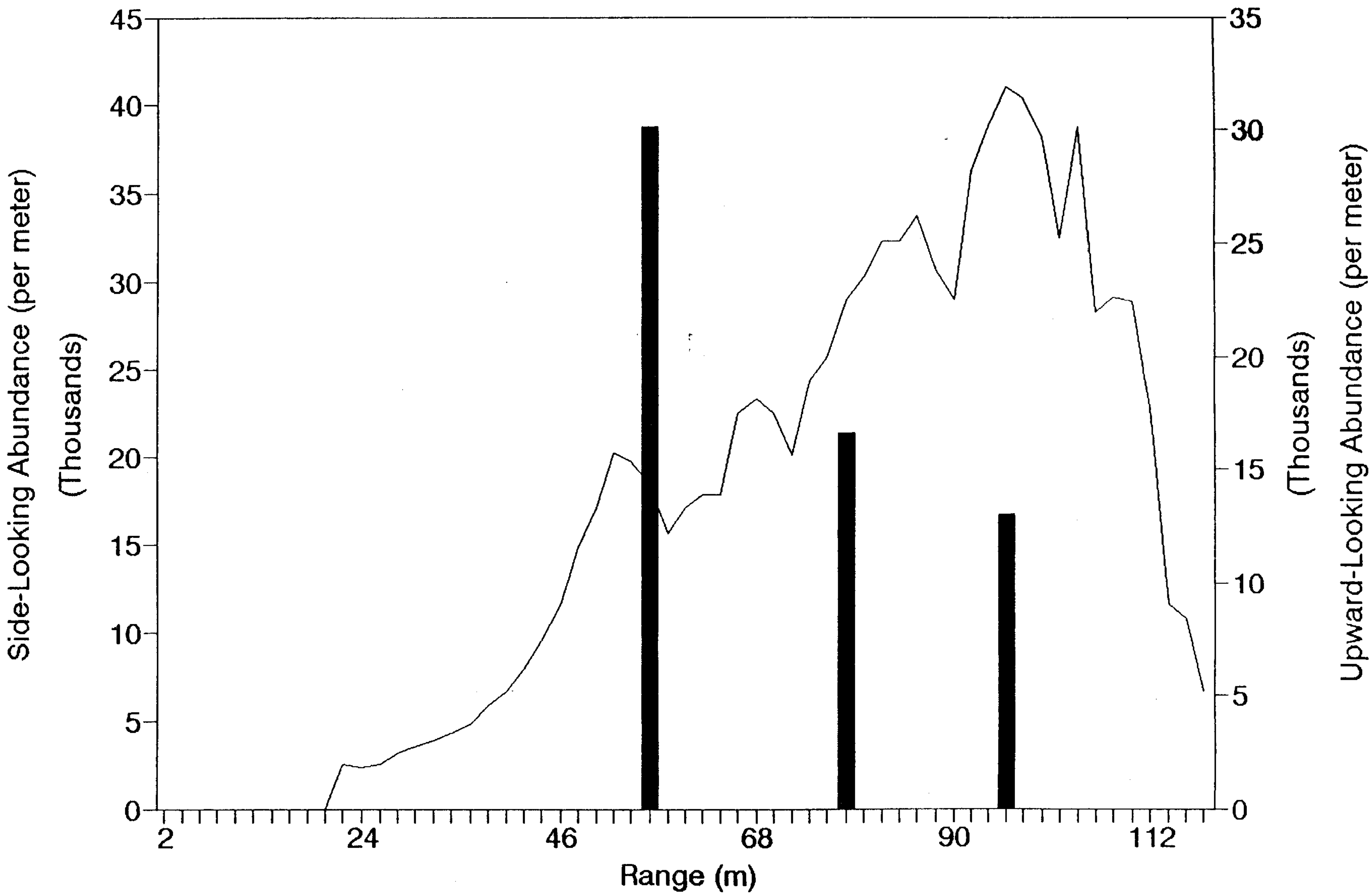
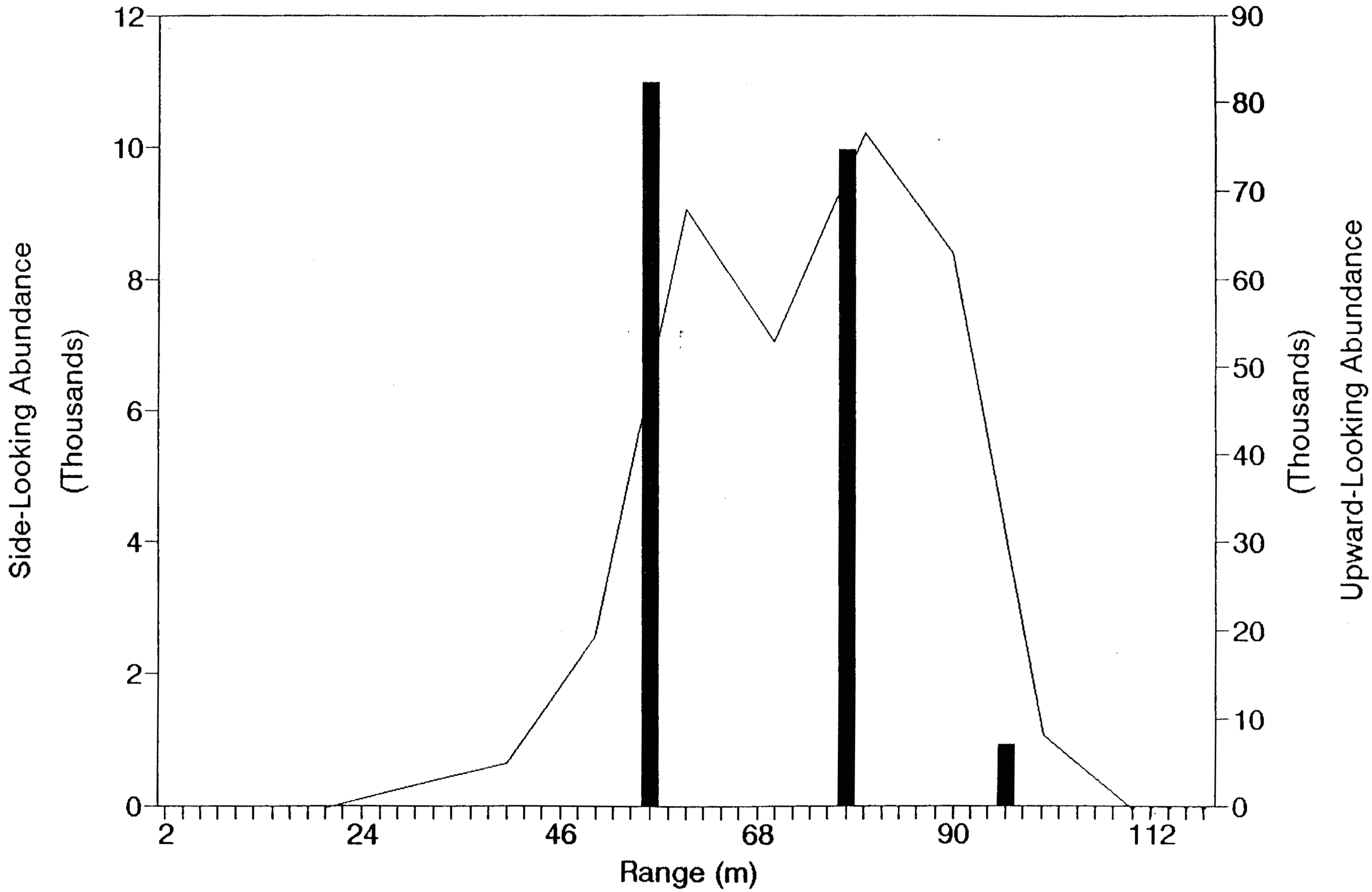
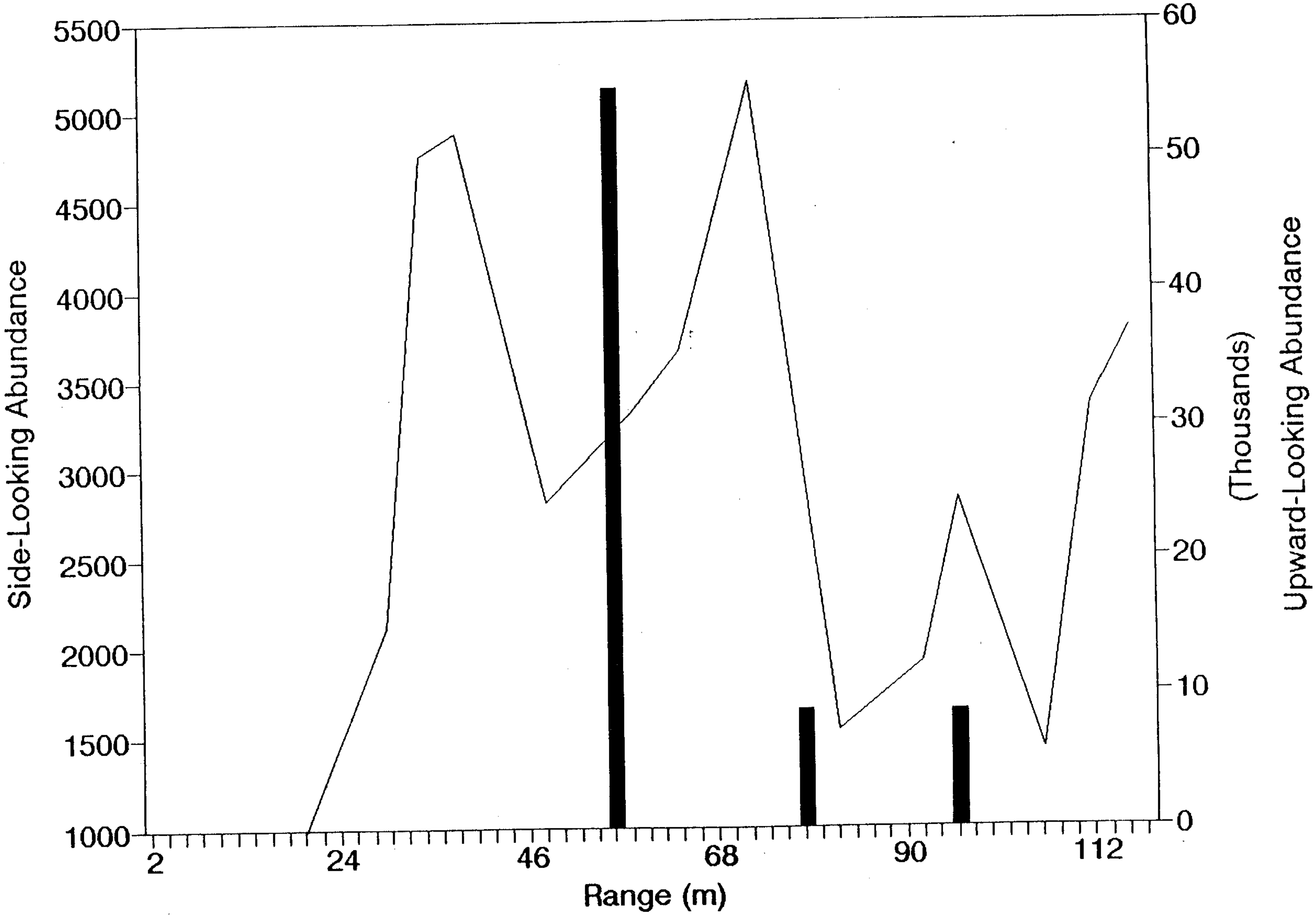


Figure 5. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 2 June through 14 June1991. Side-looking data are smoothed.

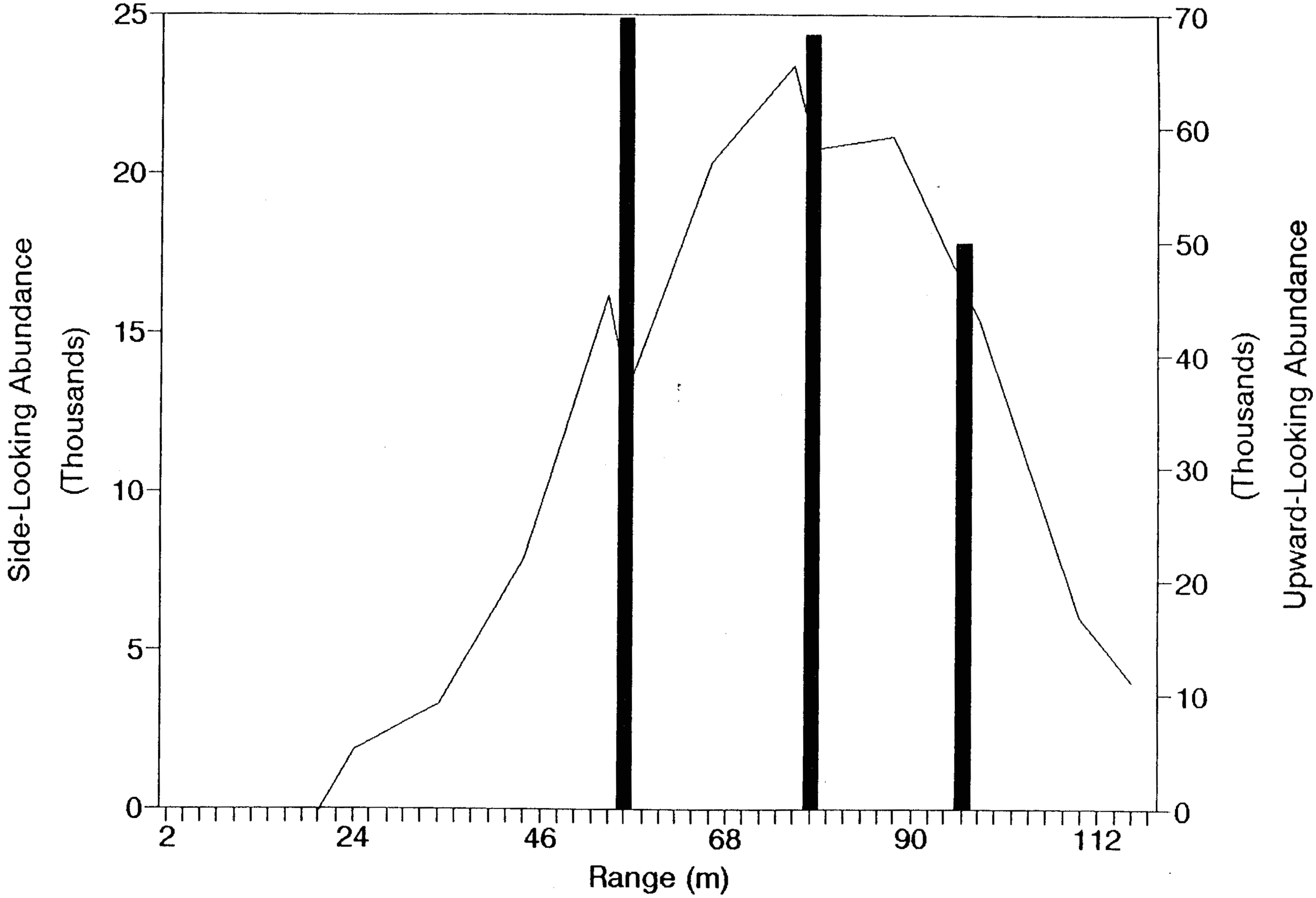
APPENDICES



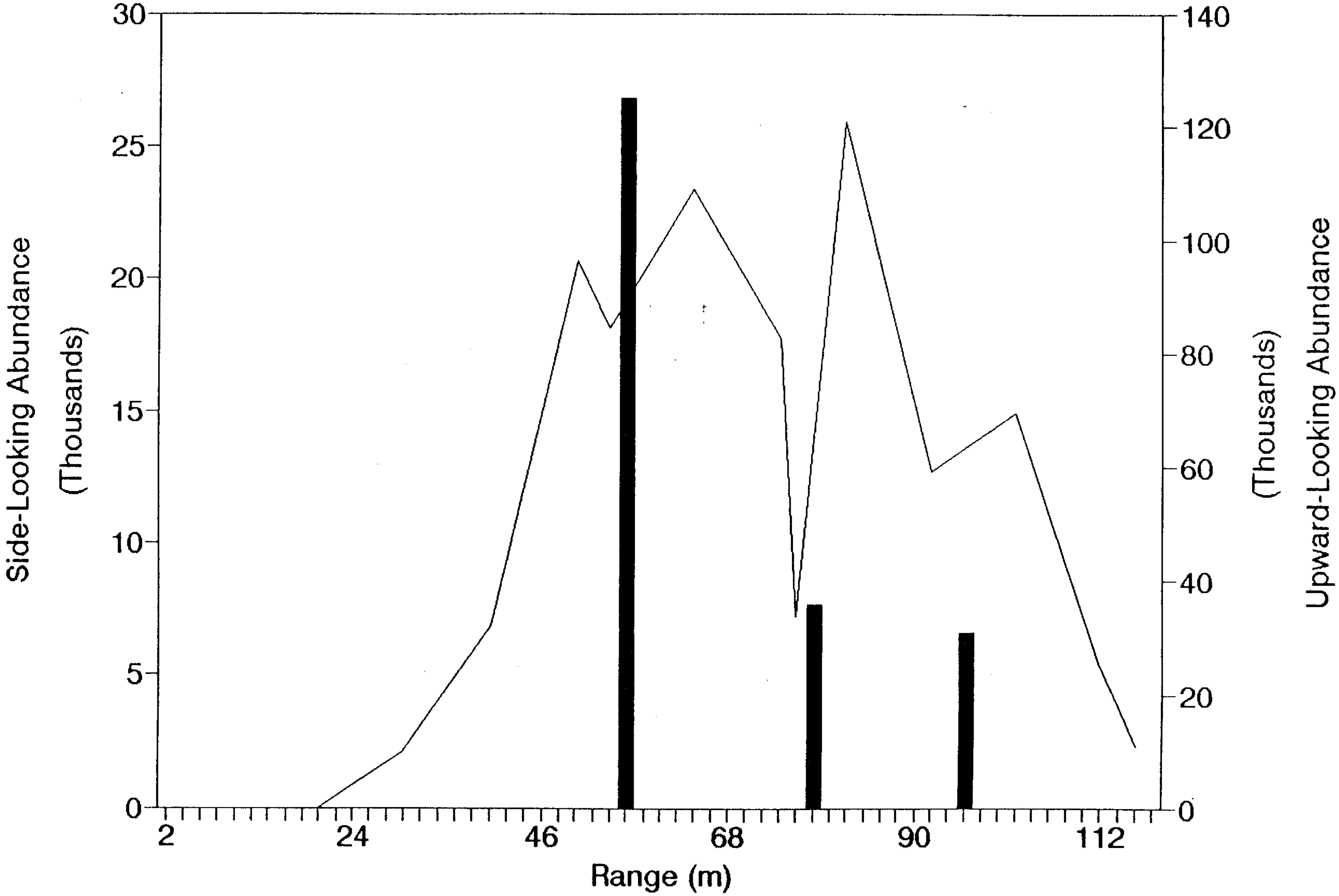
Appendix A.1. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 00:15h to 04:00h on 2 June 1991.



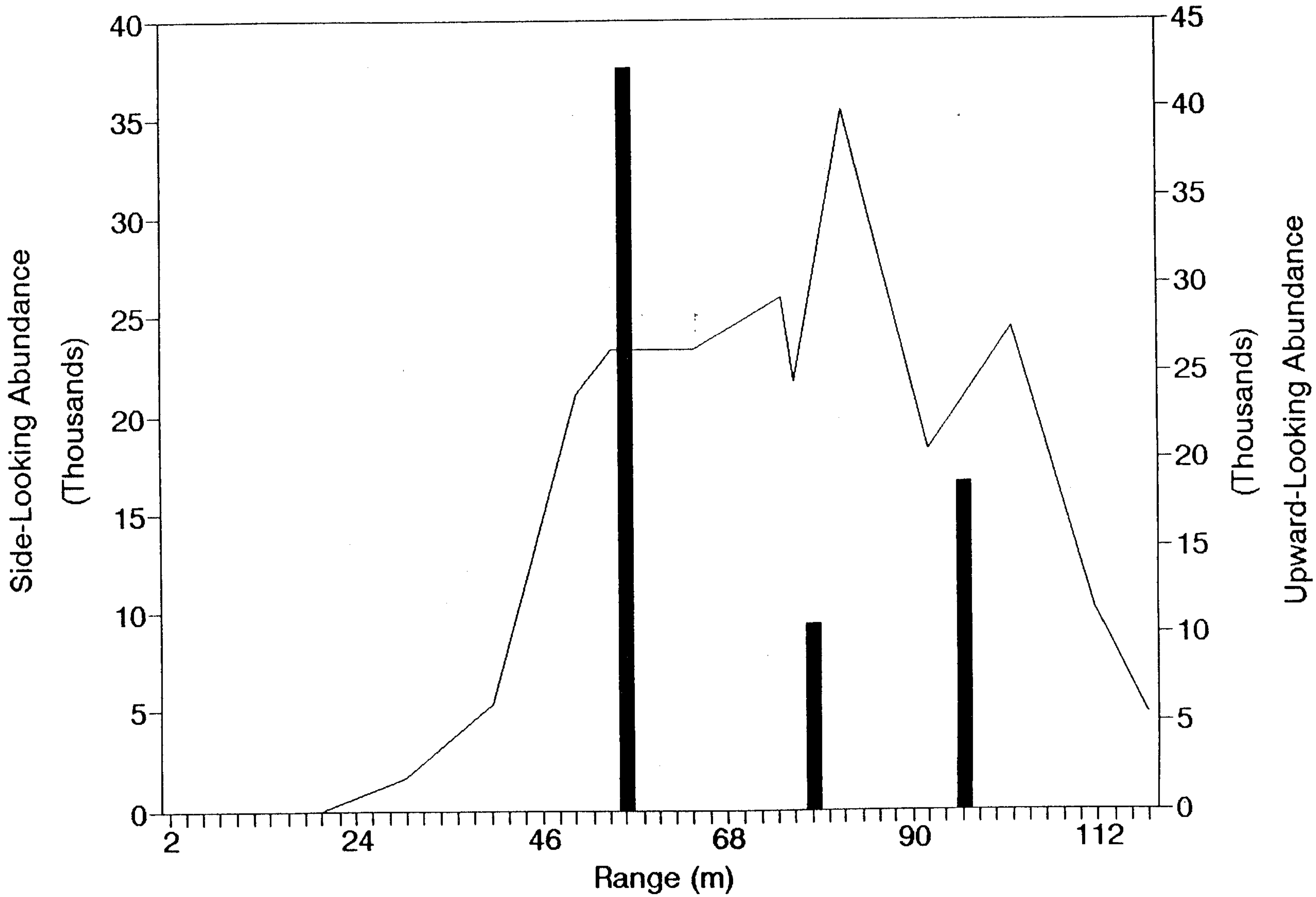
Appendix A.2. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 02:08h to 06:44h on 3 June 1991.



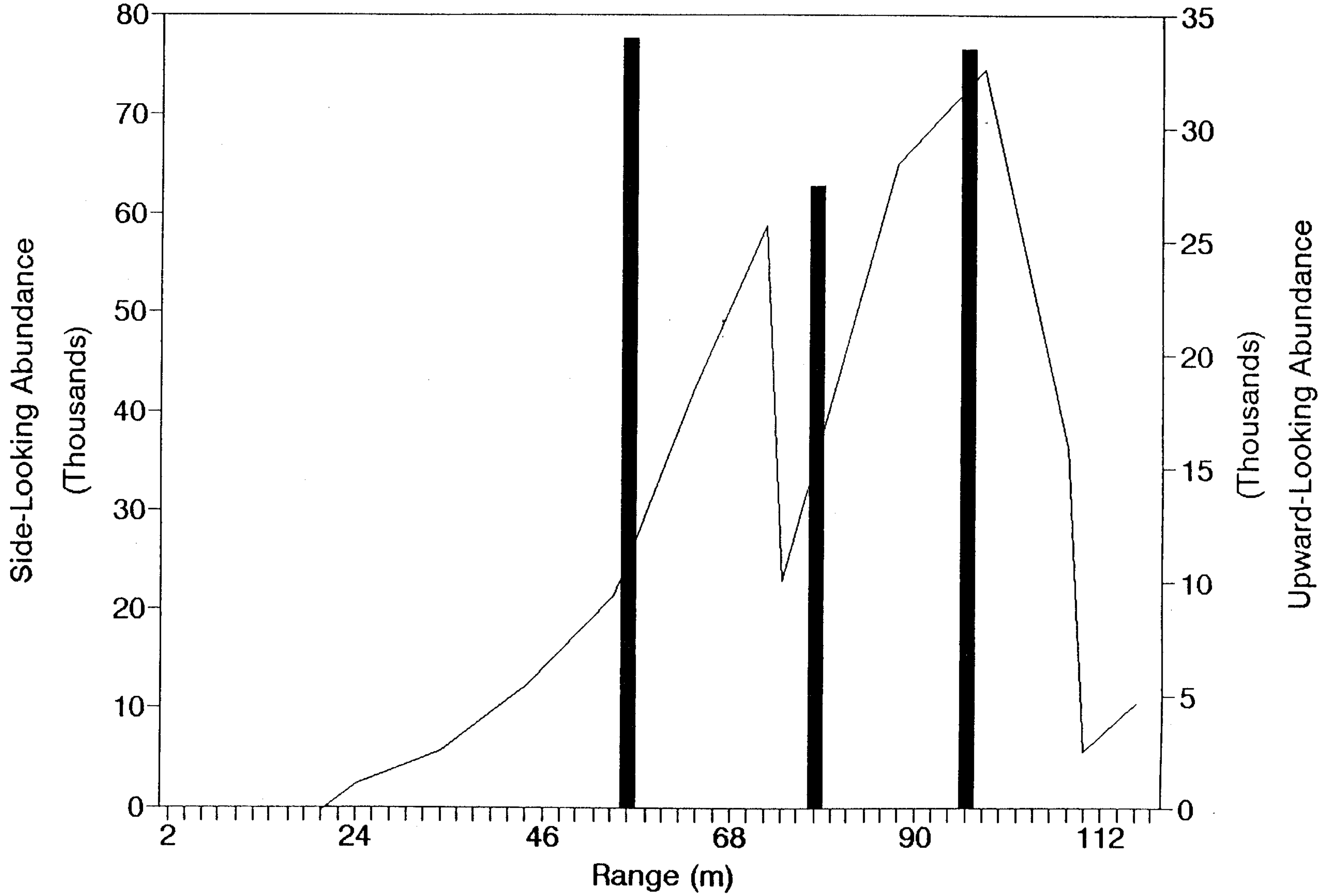
Appendix A.3. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 15:13h to 19:15h on 4 June 1991.



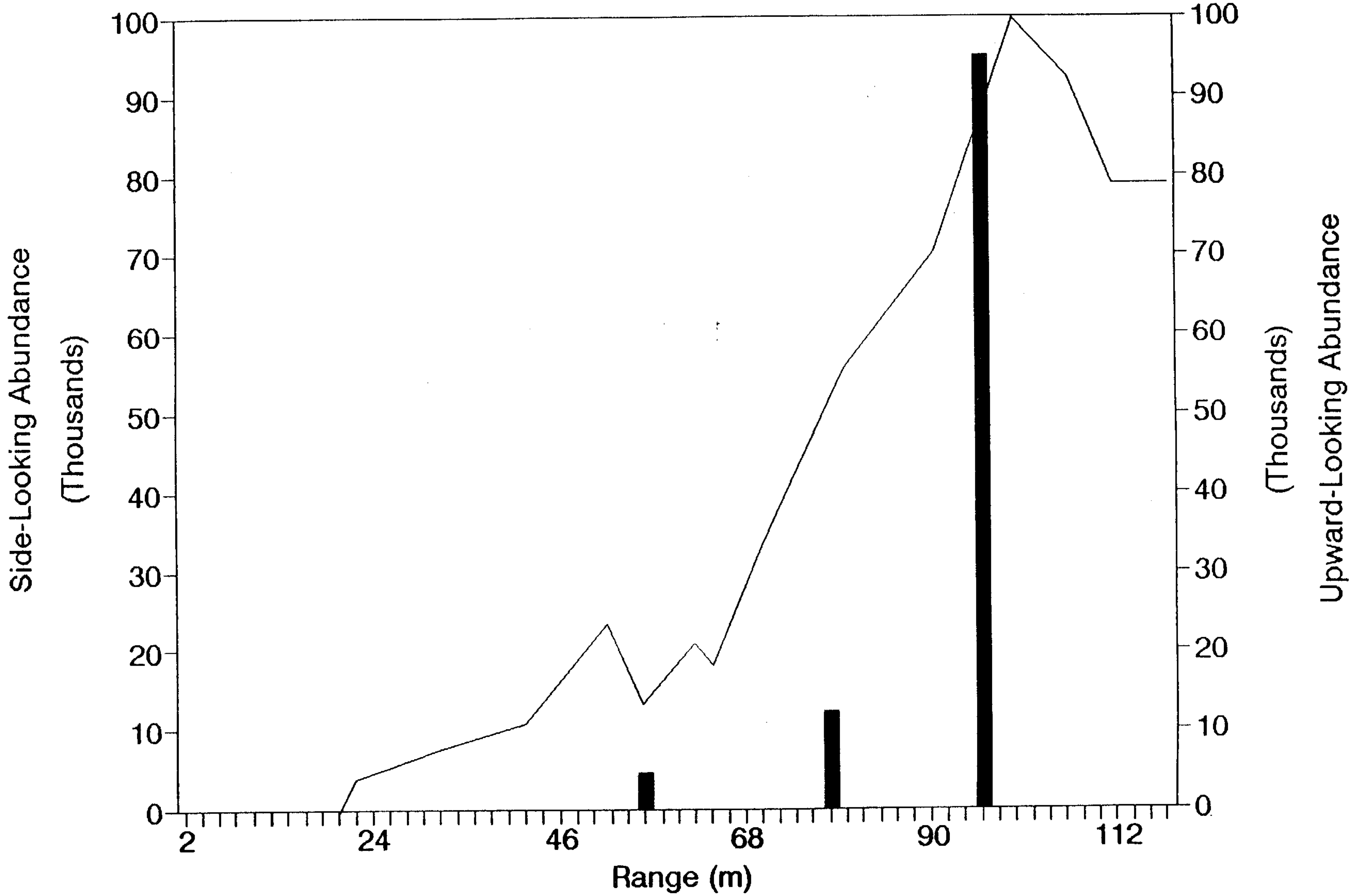
Appendix A.4. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 19:45h to 23:45h on 4 June 1991.



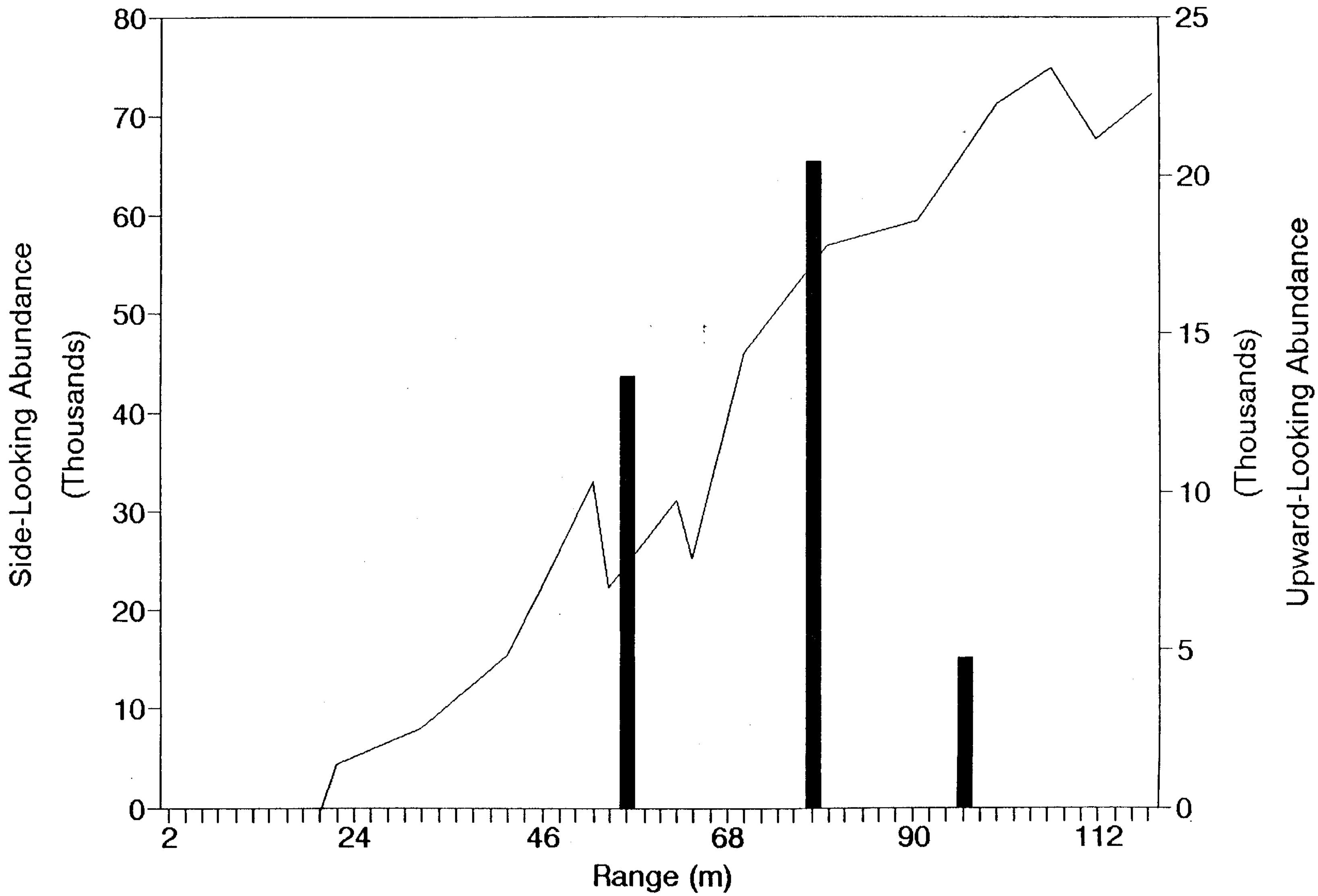
Appendix A.5. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 23:57h on 4 June to 04:00h on 5 June 1991.



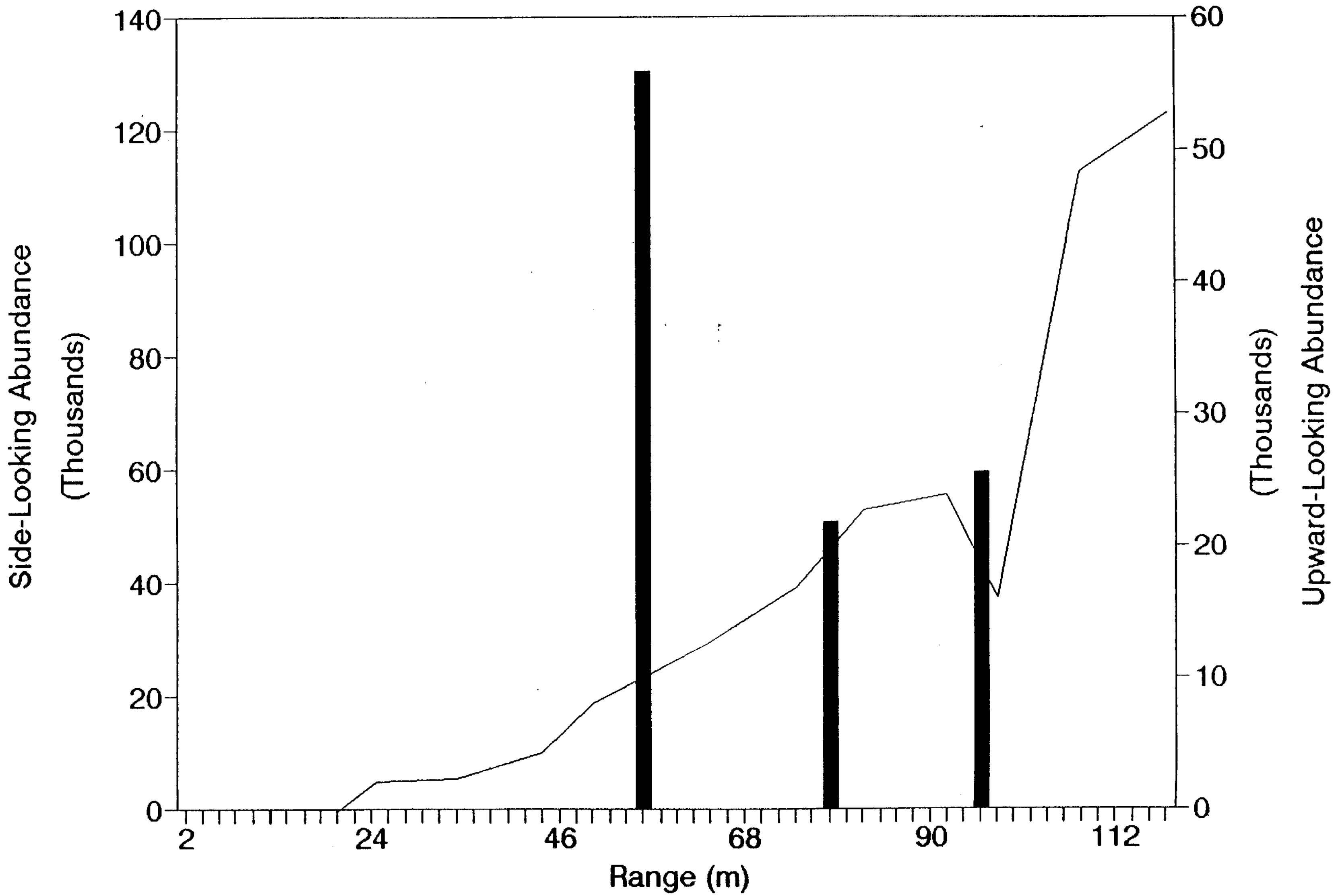
Appendix A.6. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 01:38h to 05:30h on 6 June 1991.



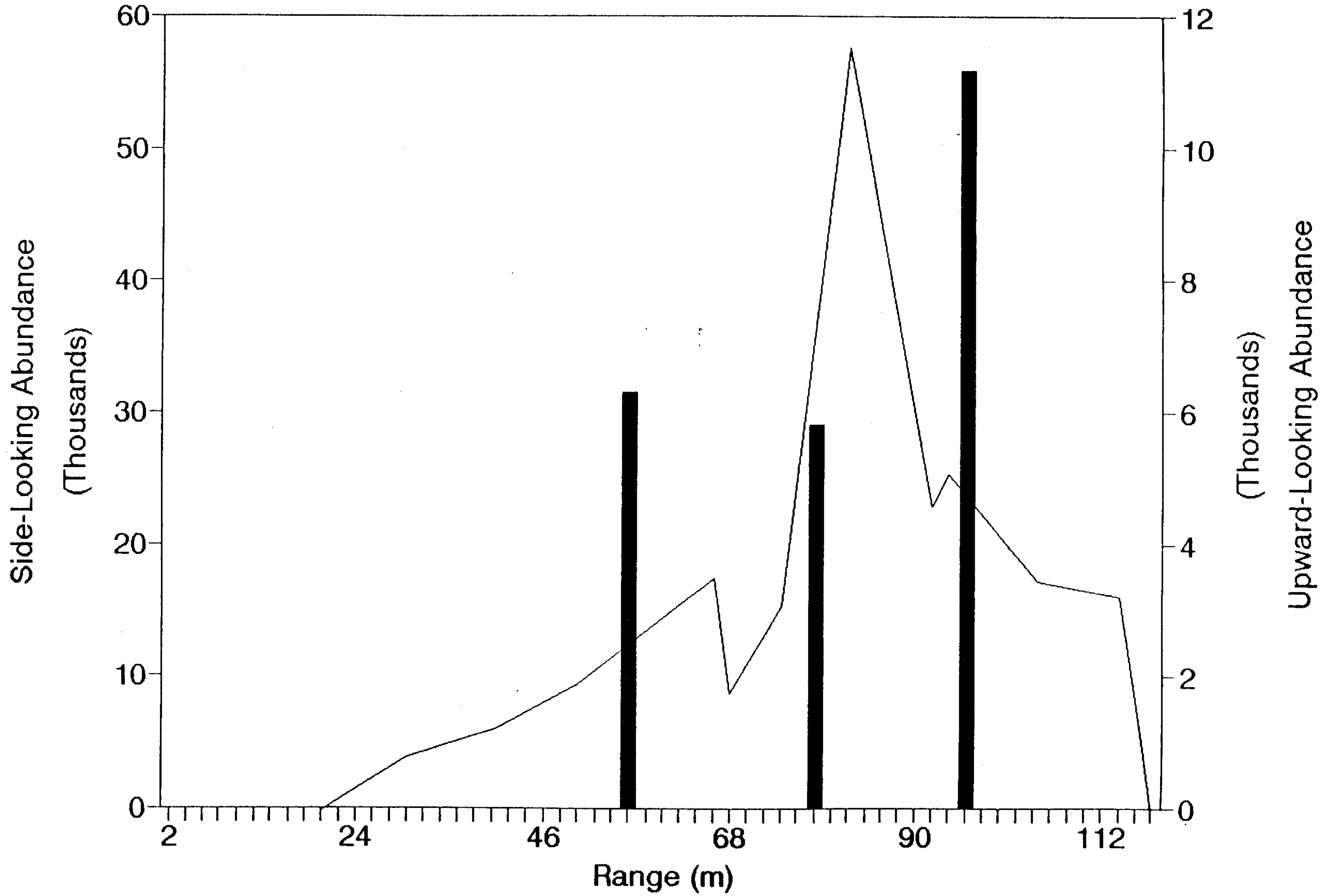
Appendix A.7. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 22:15h on 6 June to 02:00h on 7 June 1991.



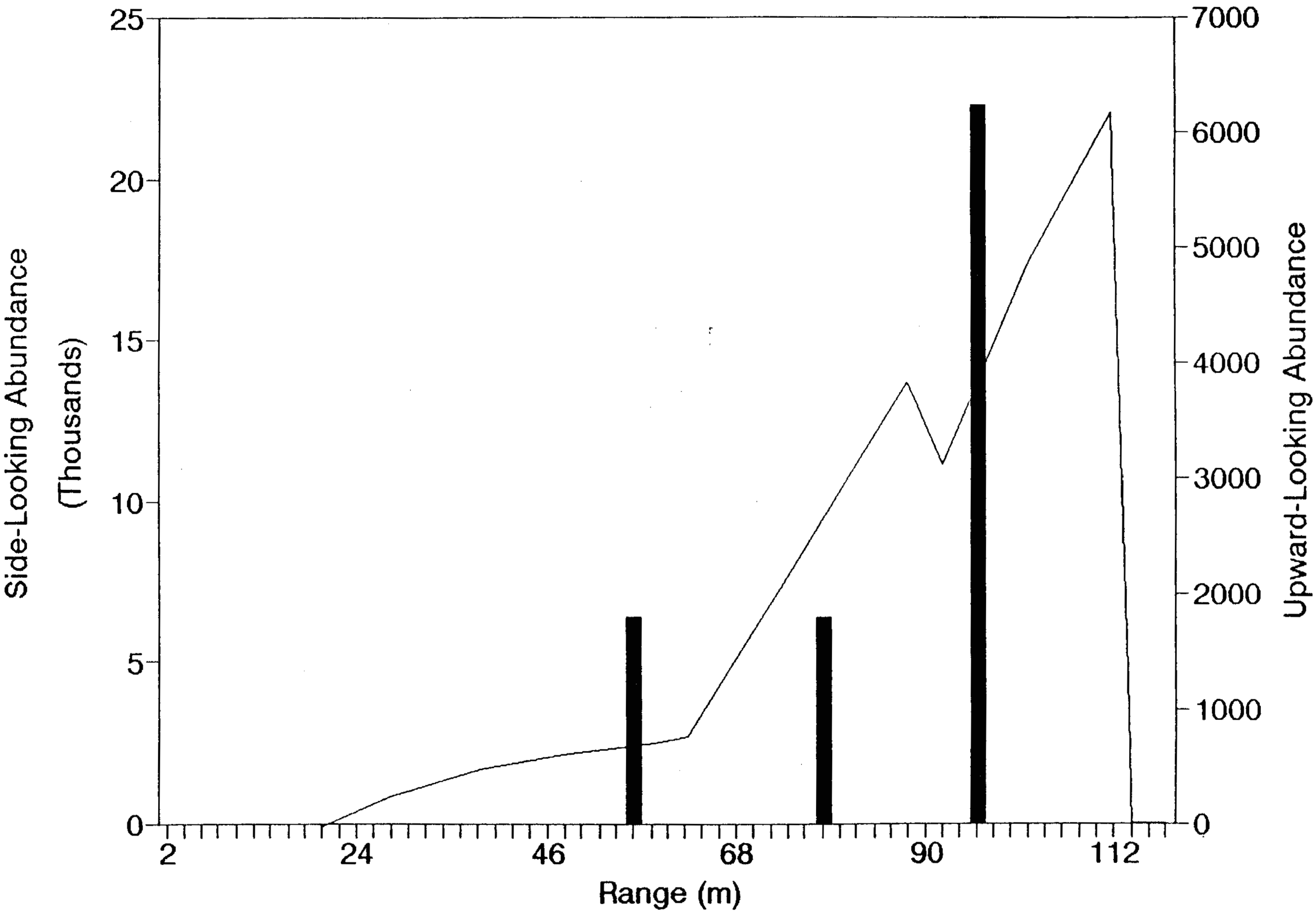
Appendix A.8. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 02:30h to 06:30h on 7 June 1991.



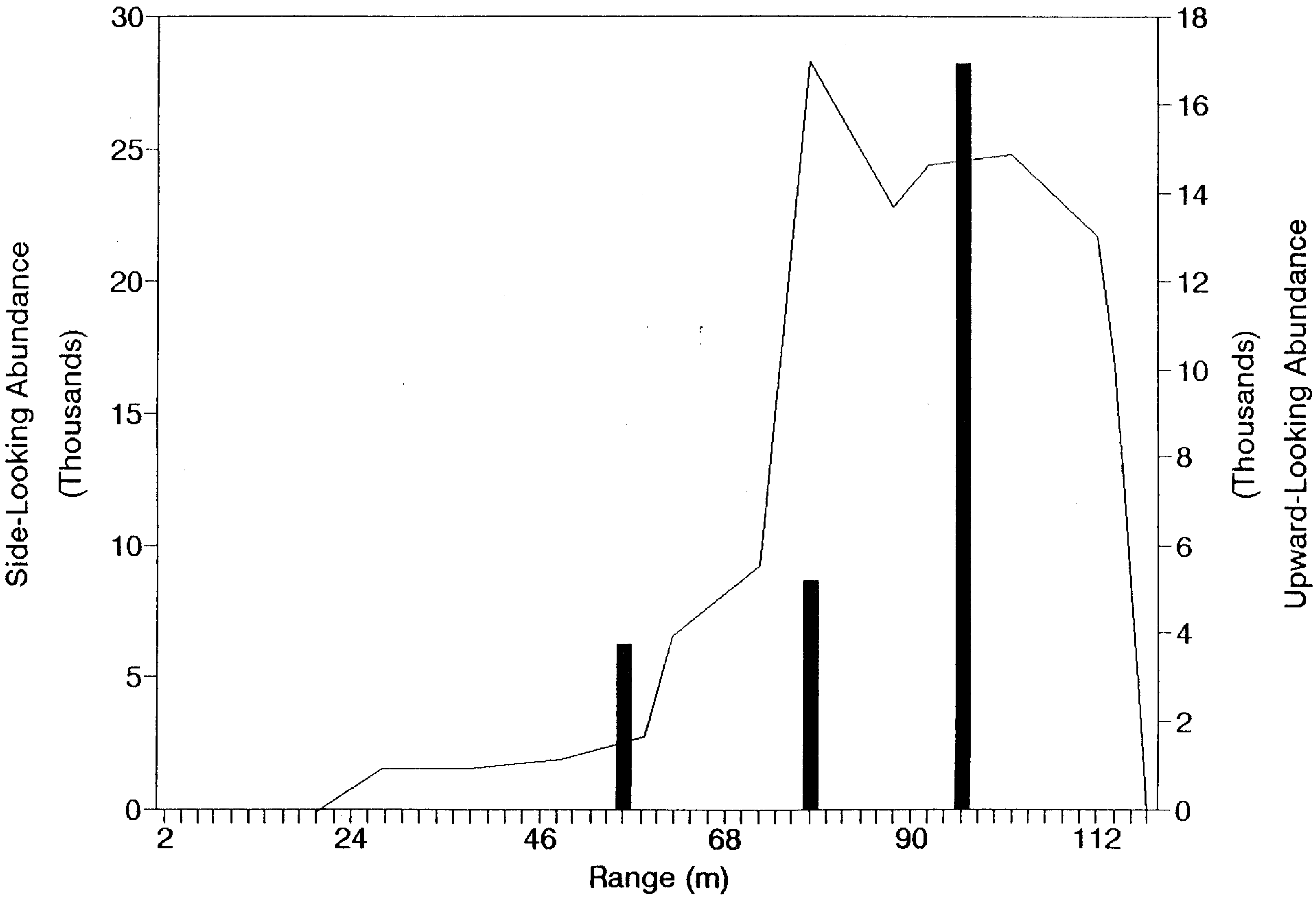
Appendix A.9. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 23:29h on 7 June to 03:25h on 8 June 1991.



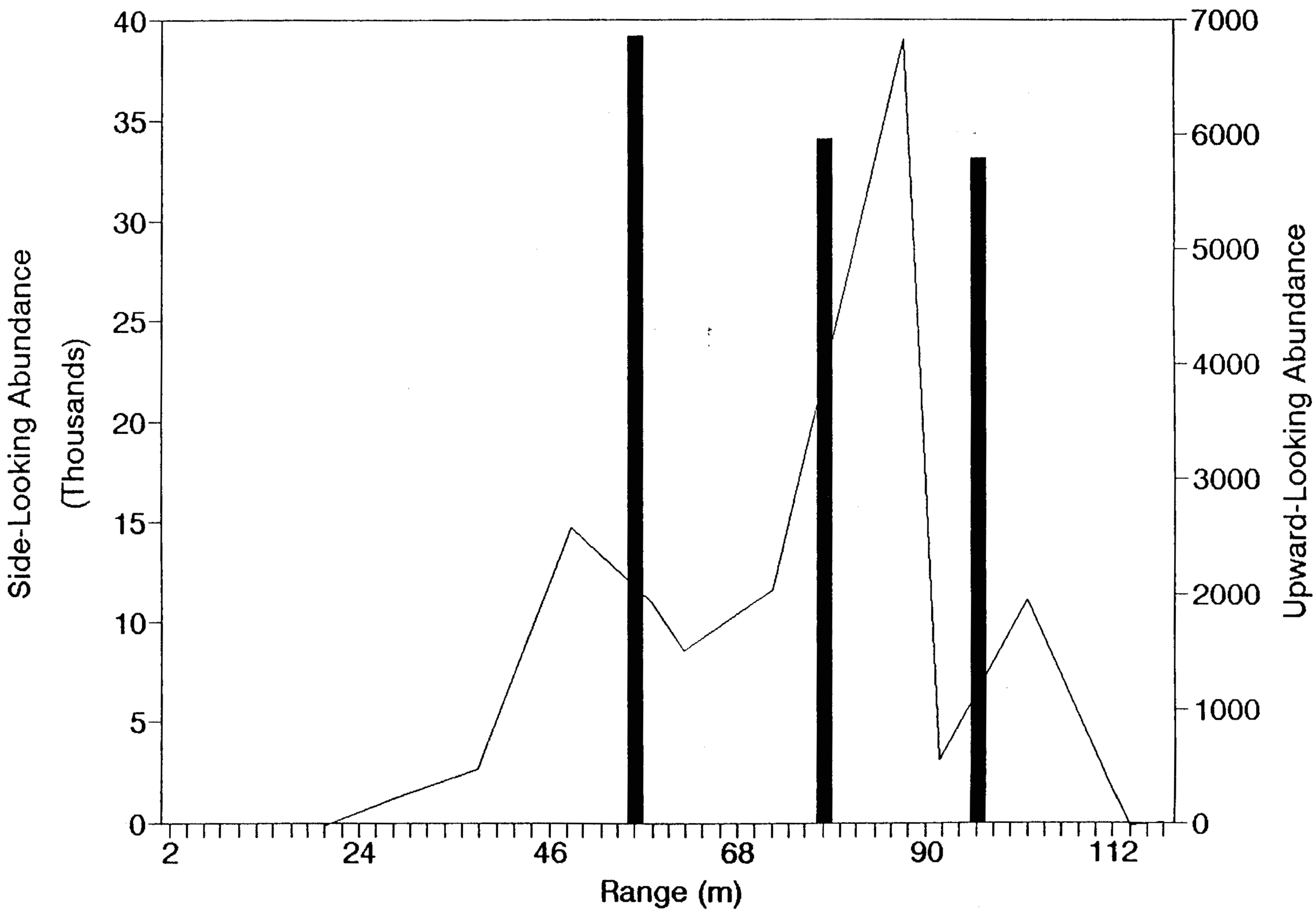
Appendix A.10. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 22:58h on 8 June to 02:58h on 9 June 1991.



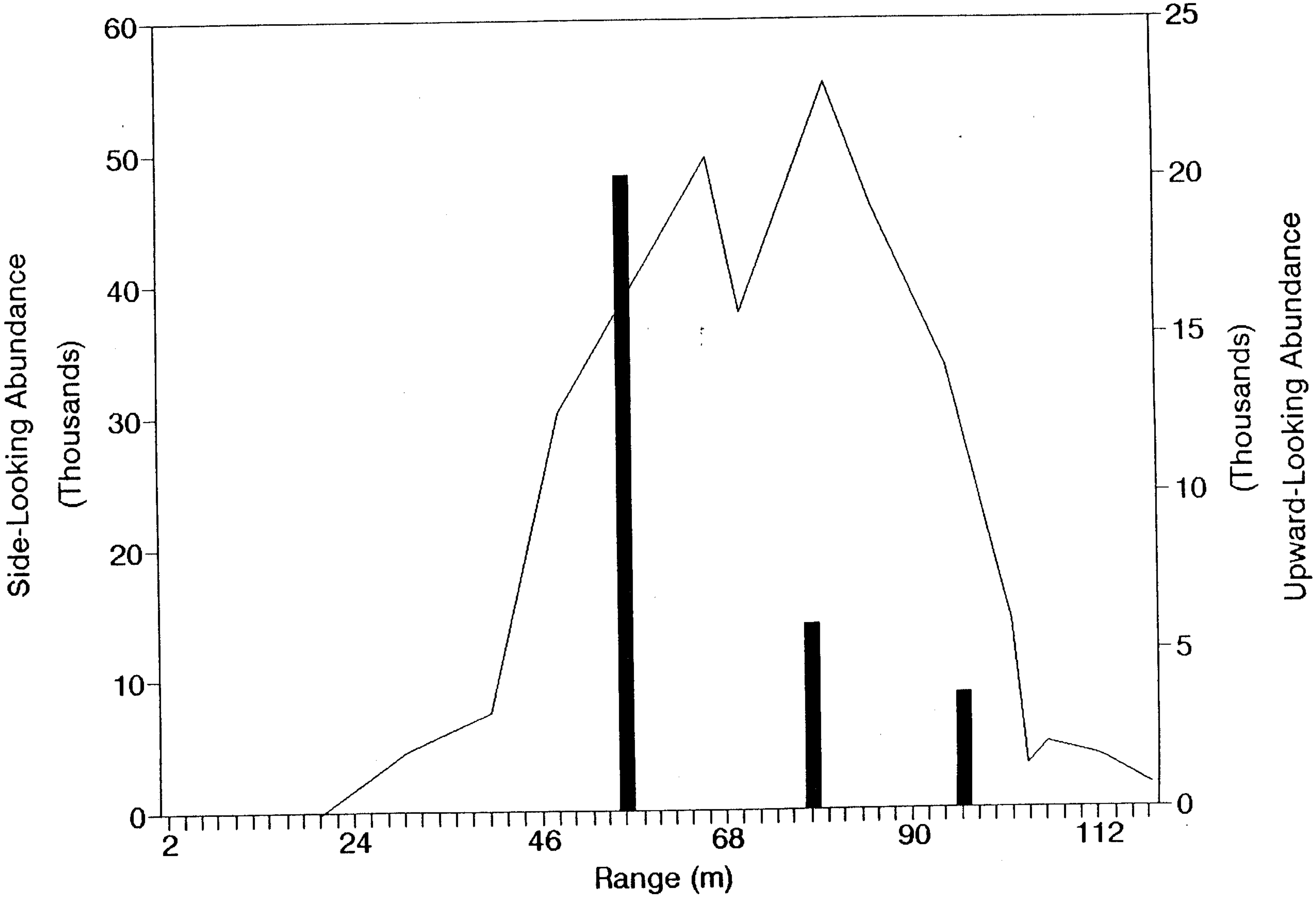
Appendix A.11. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 23:50h on 9 June to 02:00h on 10 June 1991.



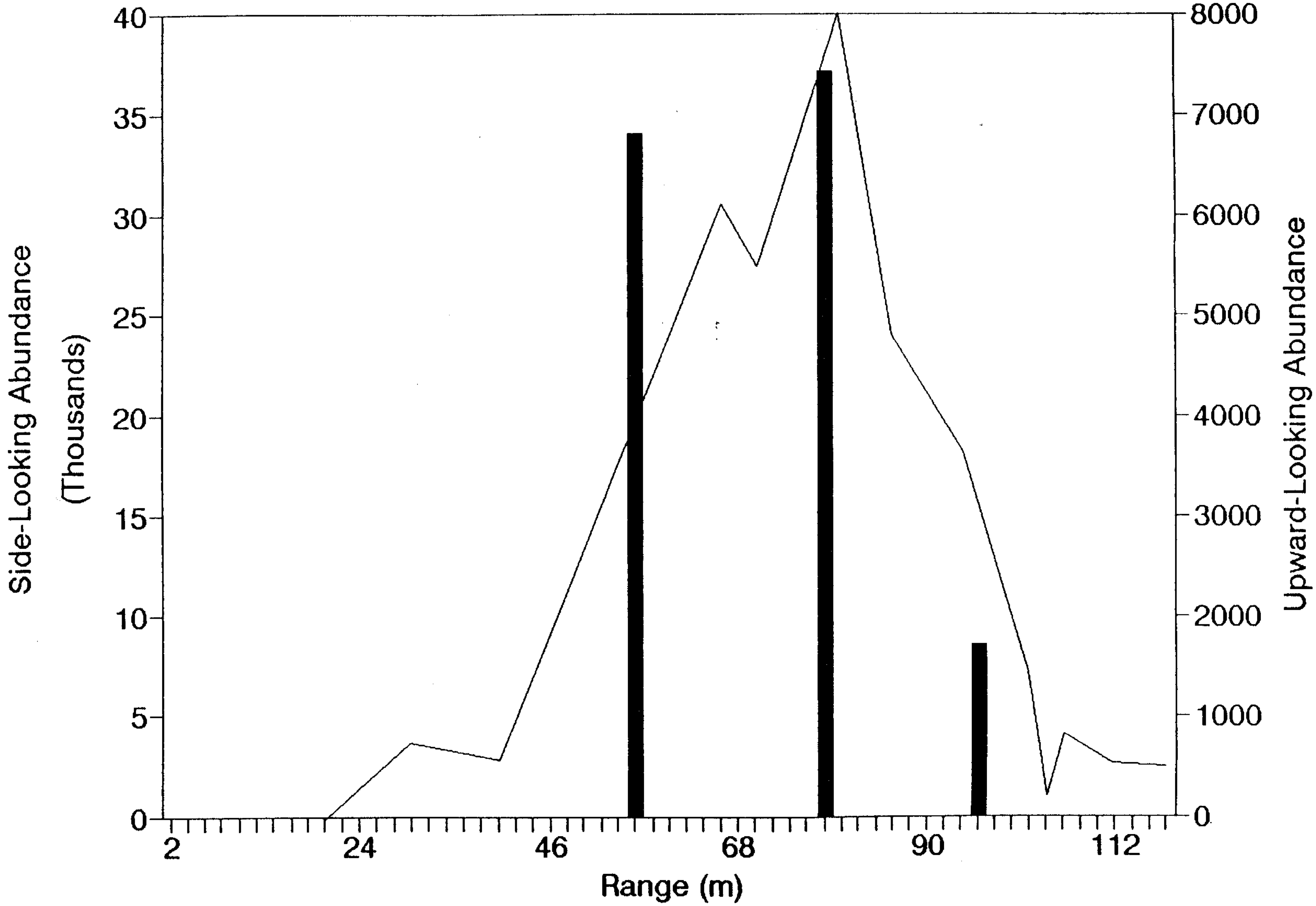
Appendix A.12. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 02:00h to 03:45h on 10 June 1991.



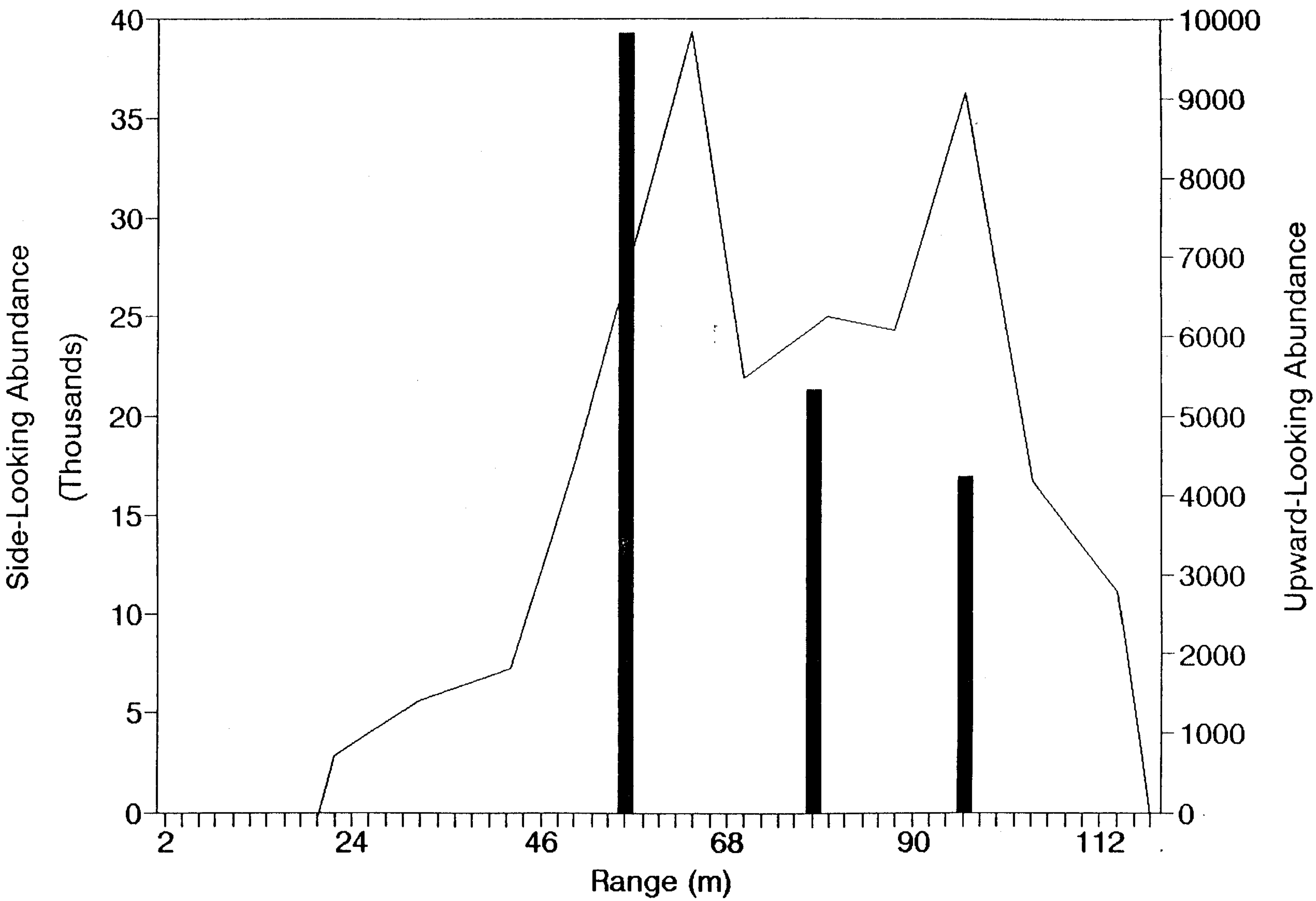
Apendix A.13. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 04:04h to 06:45h on 10 June 1991.



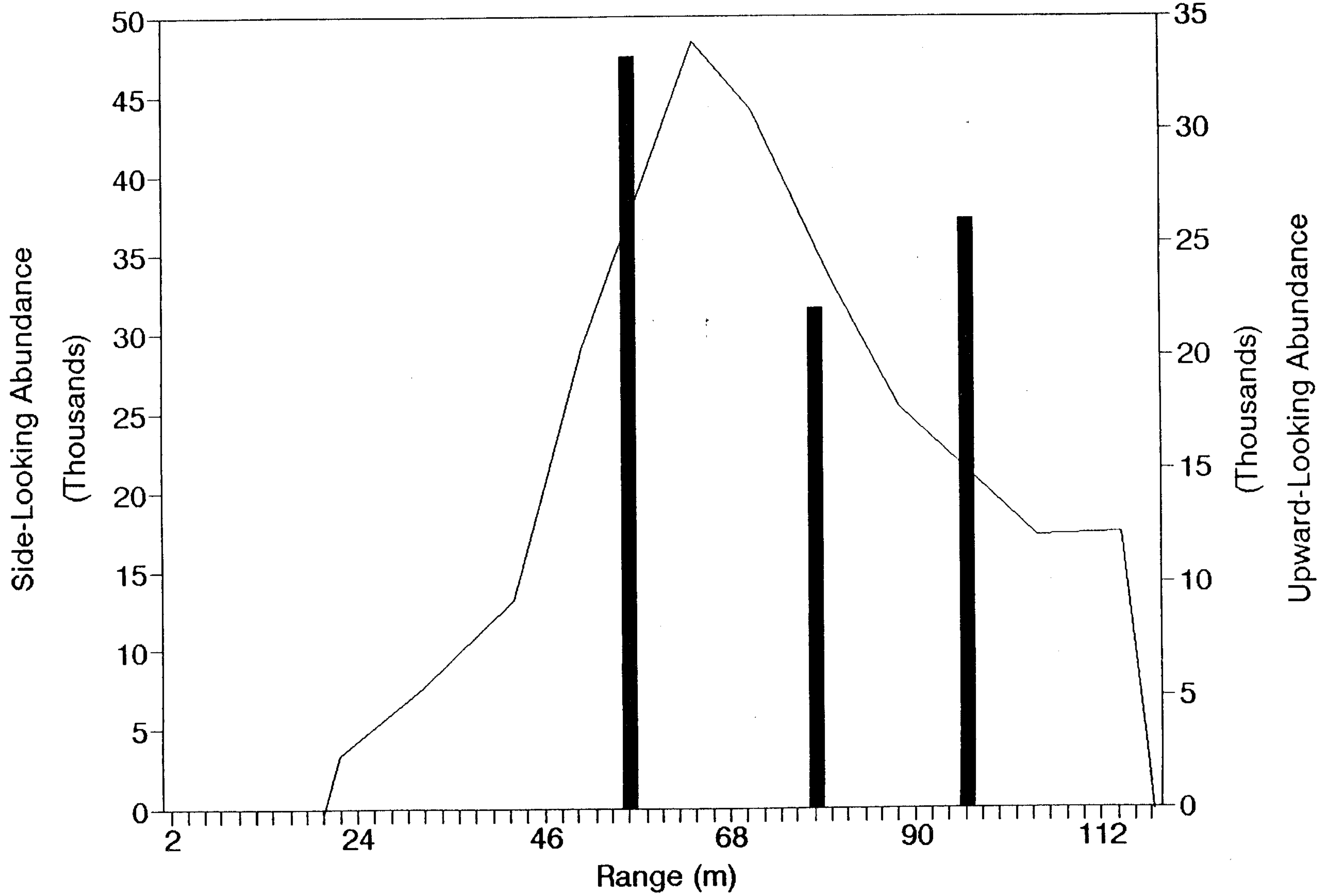
Appendix A.14. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 00:12h to 03:00h on 11 June 1991.



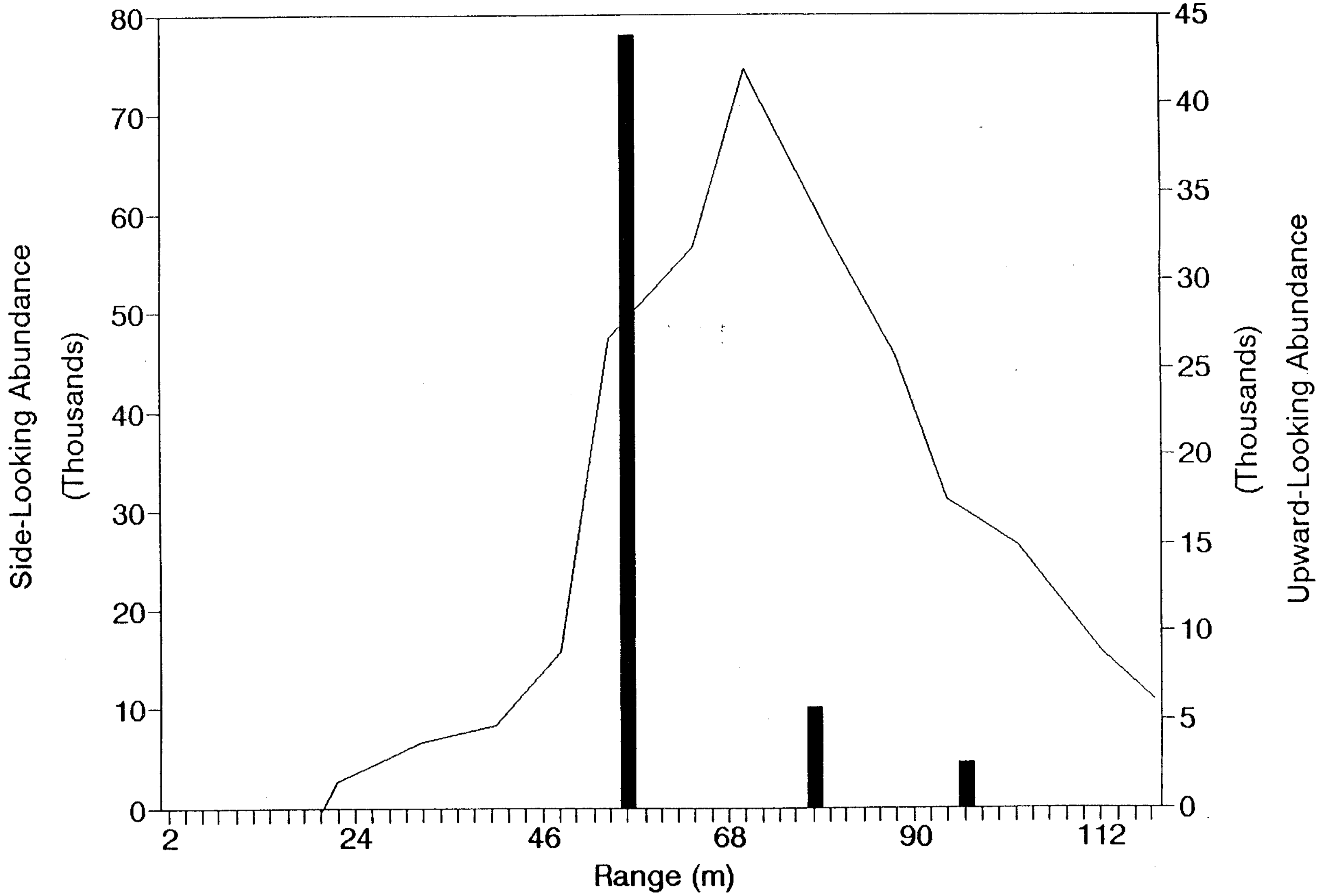
Appendiix A.15. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 03:00h to 06:30h on 11 June 1991.



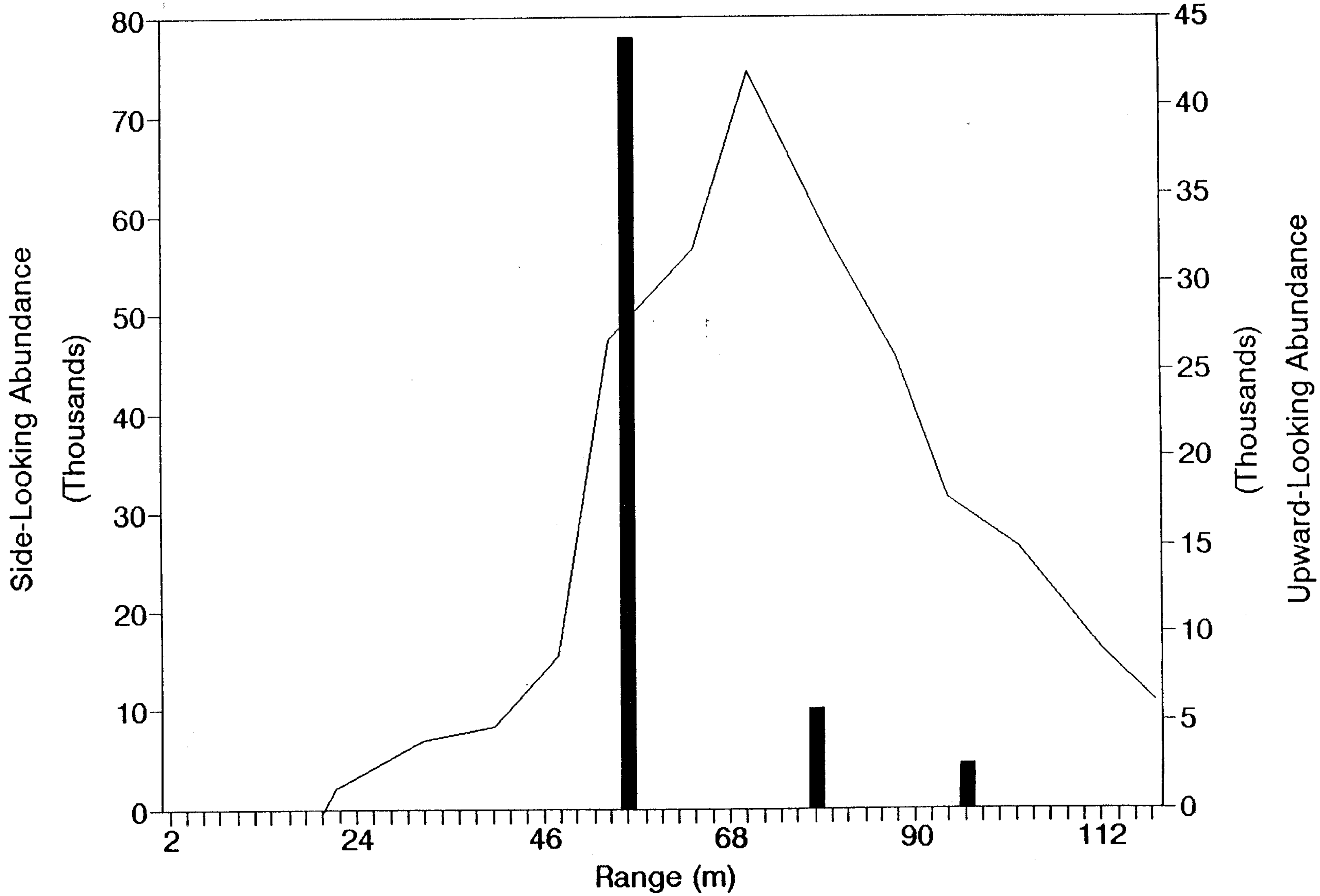
Appendix A.16. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 00:18h to 03:00h on 12 June 1991.



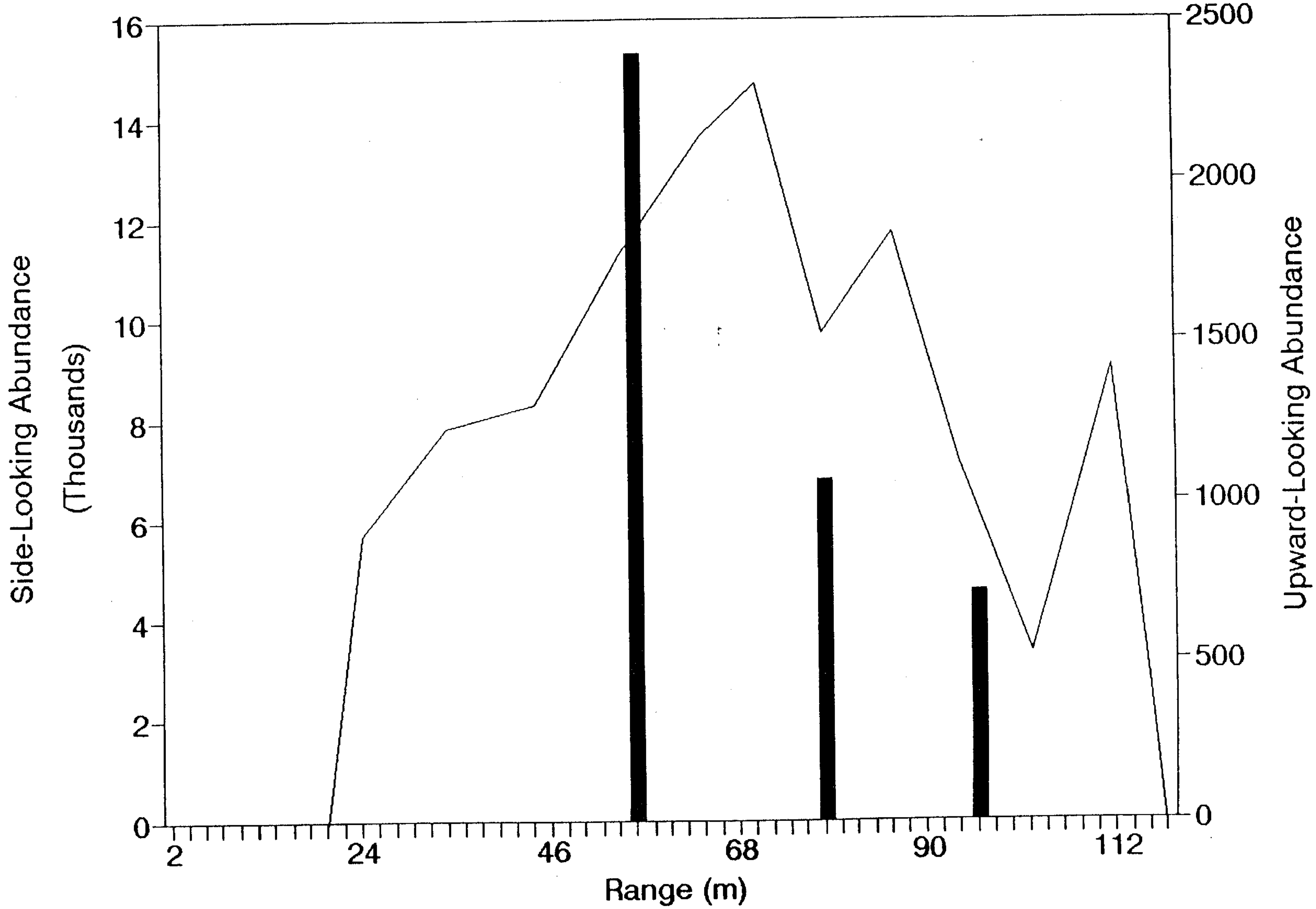
Appendix A.17. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 03:00h to 07:00h on 12 June 1991.



Appendix A.18. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 19:44h to 23:11h on 12 June 1991.



Appendix A.19. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 23:44h on 12 June to 03:31h on 13 June 1991.



Appendix A.20. Kvichak River sockeye salmon smolt mean per-meter abundance estimates at range based on side-looking (line) and upward-looking (bars) sonar data from 03:14h to 06:14h on 14 June 1991.