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LAKE WASHINGTON SOCKEYE SALMON PRESMOLT STUDIES 1980

by

James J. Dawson

and

Richard E. Thorne

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1.0 INTRODUCTION

The Cedar River watershed is managed by the City of Seattle Water Department as the primary source of municipal and industrial water for the metropolitan Seattle area. The river is also the primary spawning ground for the Lake Washington sockeye salmon. The size of this run was inconsequential prior to 1964, when the escapement from the 1960 brood year was over 100,000 fish. All subsequent escapements have been greater than this value. Recent riverine studies have indicated that one of the primary factors controlling freshwater production of the Lake Washington sockeye salmon is management of river discharge by the City of Seattle. Due to biological requirements of the fish, demands have been placed on the system that often conflict with the domestic and industrial water needs.

As the economic value of the sockeye run continues to increase, the ability to forecast run size becomes more essential. Population studies on the juvenile sockeye salmon in Lake Washington have been conducted for the past several years with the objective of developing an accurate and timely forecasting tool. This report represents the hydroacoustic estimate of the 1978 brood year and interpretation of midwater trawl data. Support for this study has been provided by the Washington State Department of Fisheries (WDF).

1.1 Objectives

The primary objective of this study was to estimate the size of the 1978 brood year of sockeye salmon using hydroacoustic survey techniques. Supplementary trawl data were gathered to provide species composition data as well as an additional estimator of population size. Secondary objectives included examinations of trawl efficiency and of potential sources of bias in the acoustic estimation technique.

2.0 DESCRIPTION AND HISTORY OF THE STUDY AREA

Lake Washington is a lowland sockeye-producing lake that has been studied intensively, due in part to its proximity to the University of Washington. The lake is bordered on the west by the City of Seattle and is surrounded by intensive urbanization. Stretching 29.6 km along a north-south axis, the lake has a mean width of 2.4 km and a mean depth of 33 m. The outlet, located midway along the western shore, reaches Puget Sound by way of Lake Union, Portage and Union bays, 6.4 km of canals, and the H. S. Chittenden Locks. Major tributaries include the Cedar River flowing into the south end and the Sammamish River flowing into the north end.

Lake Washington was used as a disposal basin for sewage from Seattle and surrounding suburbs since the early 1900's. The progressive eutrophication reached nuisance proportions by 1955. Diversion of the sewage input began in 1963 and was essentially completed by 1967. The enrichment and later rapid recovery following diversion are discussed by Edmondson (1969, 1970).

The sockeye population spawning in the Cedar River is an introduced stock, originating from plantings of fry, fingerlings, and yearlings from the sockeye stocks in Baker Lake, Washington during 1935 through 1945 (Woodey 1966; Kolb 1971). Substantial increases in escapements began with the 1960 brood year and have continued since.

Life history of the Lake Washington sockeye has been described by Woodey (1972). Utilization of the lake by juveniles has been described by Woodey (1972) and Dawson (1972). Effects of river discharge on spawning area utilization and presmolt production are presented by Stober and Graybill (1974) and Miller (1976), while biological production of the Lake Washington run was modeled by Miller (1976) and Bryant (1976). Investigations of control of fry production by density-dependent mortality (Stober et al. 1978) and fry emigration and enumeration studies (Stober and Hamalainen 1979 and 1980) have also been reported. Eggers et al. (1978) discuss implications of juvenile sockeye salmon as prey in the Lake Washington ecosystem.

3.0 DATA COLLECTION AND ANALYTICAL METHODS

3.1 Hydroacoustic Surveys

3.1.1 Description of Acoustic Equipment

The acoustic system consisted of a production model of echo sounder designed specifically for fisheries acoustic research by Biosonics, Inc., of Seattle, Washington. The specifics of the equipment are described by Wirtz and Acker (1979). The system, operating at 105 kHz, transmitted 500 watts of power through a 10^o full angle transducer. Bandwidth of the receiver was 5 kHz, pulse length was 0.6 millisecond, and the time-varied gain was $20 \log R + 2 \alpha R$. The α value selected was $\alpha = 0$, which represents essentially no absorption of 105 kHz energy by freshwater. The high frequency echo returns were converted to 8 kHz and recorded on a Sony TC 377 tape recorder at 7 1/2 I.P.S. tape speed. Tape type was Maxell UDXL 35-90B, a high output, extended range magnetic tape. Signals were monitored during data collection by a Tektronix oscilloscope. Power for all electronic equipment was provided by a 12 V DC to 115 VAC Nova inverter coupled to 12 volt automotive batteries.

The benefits of using a research quality echo sounder include electronic stability of the transmitting and receiving sections relative to time, temperature, humidity, and power supply fluctuations, reducing errors within and between surveys caused by electonic drift. The digitally controlled TVG (time varied gain) circuit which corrects depth-induced biases (sound spreading and absorption), the ability of the receiving section of the echo sounder to amplify signals from the transducer in a linear fashion, and accurate calibration capabilities built into the receiver are additional features that are usually deficient in commercial fathometers.

3.1.2 Acoustic Acquisition Techniques

Acoustic data were collected from the R/V MALKA, a 40-foot Kodiak seiner modified as a research vessel. The transducer was mounted on the hull, approximately amidship. Transecting speed as determined from runs along a measured course was 7.9 knots. The transect pattern of 16 diagonal transects used in previous years (Drew and Thorne 1979) was followed this year. Transects were run during 2 nights. On 13 March, all transects south of the Evergreen Point Floating Bridge (transects 7-16) were surveyed. Due to weather and time constraints and the failure of the power converter, transects 1-6 north of the bridge were not run this first night. On 15 March a complete series of 16 transects was completed. Data were collected only at night to take advantage of maximum dispersal of the fish (Woodey 1972).

3.1.3 Processing of Acoustic Returns

The acoustic data were analyzed by digital echo integration techniques (Thorne et al. 1975). The integration results were scaled by counts and sample volume estimates obtained from the oscilloscope. To minimize errors and reduce processing fatigue, counts were collected from each 2-min time block along a transect and from each depth interval. Depth intervals, as in previous years, were chosen with a given trawl depth at the center. Intervals used were 4-11, 11-18, 18-25, 25-32, 32-39, and 39-53 m. The transects that were selected for counting were those that ran through or were closest to the trawl station. Sample volume estimates were also made for each transect that was counted. This was done to eliminate potential volume estimation errors due to horizontal changes in the size distribution of fish in the lake. The counts in each 2-min time cell divided by the volume estimate for that cell were used to scale the digital integrator's estimate of density in that cell. The slopes of the regression of oscilloscope densities on computer densities were pooled for all transects and all depths above 18 m. The data below 18 m indicated significant differences in the regression slope from different sections of the lake, and therefore were not pooled.

After scaling, computer densities were multiplied by the percent by number of sockeye in the catch at that stratum. These sockeye densities were then extrapolated over the appropriate lake volumes to estimate population size.

3.2 Trawl Sampling

3.2.1 Description of Sampling Methods and Gear

Midwater trawl samples were collected using a 3 m Isaacs-Kidd midwater trawl (Isaacs and Kidd 1953). This has been the standard sampling gear for juvenile sockeye in Lake Washington for over 11 years. At a tow speed of 5.4 knots, the net is assumed to filter 1,000 m^3 of water per min. Last year the trawl speed was inadvertently reduced to 4-4.5 knots, resulting in an apparent drop in catching efficiency for all but larval fish. This year the net was fished off the R/V MALKA with a resulting maximum tow speed of 4.5 knots. Estimated swept volume was reduced to 833 m^3 per min. Depths of 15, 22, 28, 35, and 50 m were sampled when possible in each of the five standard sampling areas used in previous years (Drew and Thorne 1979). The net was fished for 10 min at depth. Duplications of tows with large sockeye catches was completed as often as possible. A total of 29 tows were made on the nights of March 13-15.

3.2.2 Preservation and Processing of Samples

In general, all samples were retained for future analysis. Sockeye from the March tows were put on ice and taken by WDF personnel for racial studies using electrophoretic techniques. All other species were preserved in 10% formalin solution. Data logged at time of catch included date, time of day, length of tow, depth, lake area, and number of each species and yearclass captured. For one tow only, a large catch of peamouth chubs was returned to the lake.

3.2.3 Estimation of Population Size from Trawl Catch

In addition to the hydroacoustic estimate, an independent estimate of the population is obtained from the net catches by assuming a particular swept volume per 10-min tow. A form (Fig. 1) is used to summarize catch per unit volume by area and depth. Numbers in the lower right corner of each square represent lake volume in $10^6 m^3$. Average catch of one yearclass of sockeye salmon per unit of swept volume is written in the upper left corner. The product in each cell is written in the center and summed for each area.

4.0 RESULTS AND DISCUSSION

4.1 Acoustic Surveys

4.1.1 Population Estimates

The results of the two acoustic estimates of the 1978 brood year of sockeye salmon as itemized in Table 1 are 6.6 and 7.0 million pre-smolts. This is the highest number of fish just prior to outmigration since the first acoustic estimate was completed in February, 1969.

4.1.2 Sources of Error in the Acoustic Technique

The primary source of error in the hydroacoustic estimate is associated with the high variability in the regression of computer density on oscilloscope density. This variability is predominantly a result of changes in mean target strength by area and depth. In area 2, larger peamouth chubs were caught in the deeper tows. In general, the smaller stickleback were caught in the upper tows. These species and size variations necessitated use of separate regression constants to scale

Trip Lk. WA Date 13-15 Mar, 1980

Gear 3 m. IKMWTS Speed 4.5 kts. Duration 10 min. VPUE 8.333 $m^3 \times 10^3$

Species Sockeye salmon Year class 1978

Limnetic Area

Depth Fished (m)	1	2	3	4B	4
15	1 9.72E3 81.0*	11 2.65E5 200.7	9 2.36E5 218.5	27 2.95E5 91.0	21 3.05E5 120.9
22	0 0 48.6	12.5 1.83E5 122.2	13 2.11E5 135.5	35 2.31E5 55.1	43 3.73E5 72.3
28	1 9.71E3 80.9	11.5 1.35E5 97.8	7.5 9.85E4 109.4	87.5 4.54E5 43.2	63.5 5.27E5 69.2
35		10.5 1.85E5 146.9	10 1.90E5 158.7	75.5 1.32E6 146.0	
50		9.5 1.76E5 154.2	14 3.13E5 186.4		
Area Total	1.943E4	9.44E5	1.05E6	2.30E6	1.21E6

Lake Total 5.52 million

*Volumes are $m^3 \times 10^6$

Total volume = 2.34×10^9

Fig. 1. Lake Washington limnetic fish population estimate.

Table 1. Population estimates by lake area.

Area	Acoustic				Trawl	
	13 Mar	%	15 Mar	%	13-15 Mar	%
1 (north)	(79,400)	1.2	79,400	1.1	19,428	0.4
2	(941,000)	14.3	941,000	13.4	944,070	17.1
3 (central)	2,116,000	32.2	2,172,000	30.95	1,049,352	19.0
4	1,743,000	26.5	1,963,000	27.97	2,302,620	41.7
5 (south)	1,698,000	25.8	1,863,000	26.54	1,205,040	21.8
Totals	6.58 million		7.03 million		5.52 million	

computer output from different trawl areas. The data analysis techniques do incorporate this variability without bias, but the variability and smaller sample sizes which result from the need to stratify by area and depth do add uncertainty to the final result. The degree of uncertainty is very difficult to quantify due to the complexity of the estimator. However, most of the variability was associated with the shallower depths where the densities were lower, so the effect on the sockeye estimate is probably minor.

Sources of bias in the technique for measuring the volume sampled have been investigated by Nunnallee (1980). His results indicate that the bias associated with the data collection procedures on Lake Washington is less than 5% in the worst case.

The largest source of errors is usually associated with the distributional characteristics of the fish. The good agreement between the two nights suggests that sampling effort was adequate. Several past estimates on Lake Washington have been adversely affected by anomalous distributional characteristics, which usually lead to underestimation. There was no indication of major distributional problems in this year's results.

4.2 Midwater Trawling

4.2.1 Midwater Trawl Catch Data

Table 2 contains the number of each species of fish caught in each tow. The average catch of 1978 yearclass sockeye was 23.25 fish per tow compared to 4.04 1977 yearclass sockeye and 18.67 fish in the 1976 yearclass. The 1976 value is not directly comparable to those of the last two yearclasses due to differing trawling speeds, the consequences of which will be discussed later.

Table 2. Raw catch data.

Area	Depth (m)	Sockeye 79 Y.C.	Sockeye 78 Y.C.	Sockeye % of total	CATCH Age 0	CATCH Age 1	CATCH Stickle-back	CATCH Cottid	CATCH Pea-mouth	CATCH Other
1	15	0	1	25	0	0	0	3	0	0
	22	0	0	0	0	0	0	1	0	0
	28	0	0	0	0	1	0	0	6	1
	35	0	2	4	0	0	0	2	43	0
2	15	0	11	65	0	1	1	2	2	0
	22	0	14	82	1	0	2	0	0	0
	22	1	11	46	1	2	8	1	0	0
	35	0	11	65	1	1	0	1	3	0
	35	0	10	63	2	1	2	0	1	0
	50	0	10	8	0	4	2	112	3	1
	50	0	9	82	0	2	0	0	0	0
3	15	0	9	90	1	0	0	1	0	0
	22	0	13	59	0	1	6	0	2	0
	28	0	8	44	1	0	2	4	3	0
	28	0	7	54	0	1	1	0	4	0
	35	1	10	83	0	1	0	0	0	0
	50	0	21	50	0	4	0	17	0	0
	50	1	7	64	0	1	2	0	0	0
4	15	0	27	68	0	5	8	0	0	0
	22	0	35	63	2	2	8	2	7	0
	28	1	74	81	0	3	2	1	10	0
	28	0	101	85	1	0	0	0	14	3
	35	0	78	76	1	2	0	0	17	5
	35	0	73	76	1	4	0	1	15	2
5	15	1	21	62	1	0	11	0	0	0
	22	1	43	77	2	0	7	0	3	0
	28	0	98	71	1	0	4	7	27	1
	28	0	29	28	2	0	2	13	33	25 (perch)

4.2.2 Population Estimate Based on Trawl Catches

Figure 1 and Table 1 show the estimate of population size based on density of sockeye in the catch. The assumed swept volume per 10-min tow is 8,330 m^3, resulting in an estimate of 5.5 million sockeye based on 100% net efficiency. Table 3 lists acoustic and trawl estimates for the 1967 through 1978 yearclasses, including trawl speed and a ratio of trawl to acoustic estimates. For a trawl speed of 5.4 knots, the mean ratio of trawl to acoustic estimates excluding invalid data points is 1.15 to 1.0, or 115% net efficiency assuming 10,000 m^3 swept volume. The mean ratio for the slower trawling speeds the past 2 years is only .625 to 1, or net efficiency reduced by a factor of nearly 2. A more accurate estimate of trawl efficiency will evolve as the data base at the slower trawling speed increases.

An additional but quite coarse technique of estimating population size from trawl catch is to multiply mean catch per tow by total lake volume. The resulting estimate corrected for trawl speed is 6.53 million fish, agreeing closely with one acoustic estimate. A comparison of last year's data using this technique reveals the acoustic estimate of 2.93 million is higher than both the stratified trawl estimate (1.28 million) and the unstratified estimate from average catch (1.22 million assuming 4.2 knots trawl speed). The two techniques for extrapolation of catch results are similar due to the uniform distribution of pre-smolts in the lake last year.

4.2.3 Sources of Error in the Catch Results

The main source of error in using the catch data either to modify acoustic data or to estimate population size directly is in the degree of extrapolation required. Each net tow samples only 0.0004% of the lake and the total net sampling effort was only 0.01% of the lake volume. The effects of this extrapolation can be seen by comparing the percent of the population within each area as estimated by the two

Table 3. Acoustic and trawl estimates. Brood years 1967-1978.

Year class	Survey date	10^6 Acoustic est.	10^6 Trawl est.	Trawl/AC ratio	Knots estimated Trawl spd.
1967	Feb 69	* 8.92	7.50	0.84	5.2-5.4
1968	Nov 69	* 6.18	9.10	1.47	"
	Feb 70	* 3.19	6.60	2.07	"
1969	Mar 71	3.80	3.30	0.87	"
	Apr 71	3.60	4.60	1.28	"
1970	Aug 71	3.60	3.80	1.06	"
	Oct 71	3.30	3.30	1.00	"
	Mar 72	2.00	3.00	1.50	"
	Apr 72	1.00	1.30	1.30	"
1971	Aug 72	1.99	2.06	1.04	"
	Oct 72	2.10	3.11	1.48	"
	Dec 72	2.58	2.44	0.95	"
	Feb 73	1.70	1.66	0.98	"
	Apr 73	1.78	1.22	0.69	"
1972	Oct 73	2.00	2.20	1.10	"
	Nov 73	4.41	4.30	0.98	"
	Jan 74	5.22	**1.50	0.29	"
	Mar 74	3.58	**1.60	0.45	"
1973	Nov 74	4.06	4.23	1.04	"
	Mar 75	1.94	2.53	1.30	"
1974	Feb 76	.76	.85	1.12	"
1975	Mar 77	1.14	1.61	1.41	"
1976	Nov 77	5.76	8.85	1.54	"
	Feb 78	3.96	4.75	1.20	"
1977	Feb 79	2.93	1.28	0.45	4-4.5
1978	Mar 80	6.80	5.52	0.81	4.5

* Acoustic estimates calibrated by net hauls.
** Population distributed sparsely in trawl sampling area.

techniques. These differences would be minimal during periods of relatively uniform distribution by the juveniles. The choice of only five sampling areas and standardized depths is a compromise made necessary by boat time (funding) restrictions. Other sources of error include ability to duplicate tow speed and depth accurately. These sources will be reduced by better shipboard instrumentation.

4.2.4 Length-Frequency Results From the 1979 Yearclass

All sockeye caught in the 1980 trawl series were given to WDF personnel for racial determination studies as mentioned above. Length-frequency data from these catches were not available at the time of this writing; however, the length-frequency distribution of the previous year's catch are incorporated into this report (Table 4). These data are a summary of the samples collected during February 1979. It can be seen that 3 yearclasses of sockeye salmon were sampled. The 1978 yearclass showed a mean length of 26.3 mm, while the 1977 yearclass averaged 98.3 mm and the 1976 yearclass, 205.3 mm.

5.0 RELATION OF RESULTS TO OTHER LAKE POPULATION ESTIMATES

The size of the parent stock of the 1978 yearclass smolts was estimated at 305,000 fish, including 263,000 spawners in the Cedar River, 15,000 Cedar River fish taken for enhancement, and 27,000 beach and other tributary spawners. To calculate presmolt to spawner ratio (P/S), we took the mean of the two acoustic estimates and the stratified trawl estimate and decreased it by 10% for non-Cedar River sockeye. The resulting estimate of presmolt production from the Cedar River is 5.74 million sockeye resulting in a P/S ratio of 20.65. This value compares favorably with the ratio of 20.1 for the 1976 brood year which experienced similar discharge conditions (Miller 1976). It is significantly higher than the ratio of 7.7 calculated by Stober and Hamalainen (1979) for the 1978 yearclass. Their estimated ratio is based on a presmolt estimate calculated by applying a mortality rate to their estimate of

Table 4. Sockeye Tow Net Samples Collected February 1979.

Interval (mm)	Length Frequency Data Frequency
21-25	18
26-30	17
31-35	3
36-40	1
41-45	0
46-50	0
51-55	0
56-60	0
61-65	1
66-70	0
71-75	2
76-80	5
81-85	5
86-90	17
91-95	13
96-100	20
101-105	17
106-110	12
111-115	7
116-120	2
121-125	1
126-130	2
131-135	0
136-140	0
141-145	1
146-150	1
161-155	0
156-160	0
161-165	0
166-170	0
171-175	0
176-180	0
181-185	0
186-190	0
191-195	1
196-200	0
201-205	0
206-210	1
211-215	0
210-220	1

fry production from the Cedar River. The 1976 yearclass sockeye had a parent stock of abou. 140,000 fish, producing an estimated 22.8 x 10^6 fry into the lake (Stober et al. 1978). The 1978 yearclass had a parent stock of 278,000 fish (including the 15,000 taken for enhancement) producing an estimated 25.5 x 10^6 fry. The 1978 yearclass presmolt estimate of 2.1 x 10^6 fish based on extrapolation from the fry estimate (Stober and Hamalainen 1979) is much lower than our estimate of 5.74 x 10^6 Cedar River presmolts, possibly indicating either variable lake survival or inaccuracy in the fry production estimates. The difference between the two estimates has important implications concerning optimal escapement levels, since the P/S ratio from Stober and Hamalainen indicates less relative production from the higher escapement.

Although river discharge conditions apparently play a predominant role in controlling fry production, some yearclasses may be affected to a greater degree than others by some factor in the lake. Surveys during early summer indicated that the 1969 yearclass produced over 30 million fry, but the presmolt production was only 3.6 million (Thorne et al. 1973).

If the fry estimates for the 1976 and 1978 yearclasses are correct, then differential lake survival occurred for these two years.

6.0 SUMMARY

Acoustic estimates on the 1978 year class carried out in March of 1980 indicate that 6.6 to 7.0 million presmolt sockeye were in the lake. Data from trawl catches were used to estimate the population size at 5.5 to 6.5 million fish. The mean of these estimates is 6.4 million. The nominal value for ocean survival of sockeye is 10%; however, this has varied considerably for the Lake Washington stock. Assuming 10% survival, a run of 640,000 adults would be expected back in the summer of 1980.

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