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ESTIMATING RED SALMON ESCAPEMENTS BY SAMPLE COUNTS FROM OBSERVATION TOWERS

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ABSTRACT

The method of estimating red-salmon escapements used from 1955 to 1959 on the Kvichak River (Alaska) involved taking visually systematic sample counts as the fish passed observation towers beside the paths of migration. The counts followed a sampling design which fluctuated in extent of coverage with the intensity of the run. This report describes in detail the method of sampling and calculating the escapement estimates, summarizes the counts for each year, and discusses the accuracy of the estimates.

ESTIMATING RED SALMON ESCAPEMENTS BY SAMPLE COUNTS FROM OBSERVATION TOWERS

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The Kvichak River system of western Alaska is the foremost producer of red or sockeye salmon, *Oncorhynchus nerka* (Walbaum), for the Bristol Bay commercial fishery. Since 1955, a series of biological investigations on the red salmon of this system has been conducted by the Fisheries Research Institute of the University of Washington. A major aspect of the investigation has been to estimate the numbers of adult red salmon which compose the annual spawning escapement.

The method of estimation developed by the Institute involves systematic visual sample counts of the transient bands of migrants, taken in the main river after the fish have passed through the fishery and before they have dispersed throughout the spawning grounds. When the numbers of fish in the commercial catch are added, the total return can be determined. In addition, when the data are coupled with age analysis of scale samples from both the catch and the escapement, accurate estimates can be made of the number of adults in each age group returning from a given year of spawning and from a given year of seaward migration.

It is the purpose of this report to: (1) describe in detail the counting method, (2) summarize the counts from the years 1955 to 1959, and (3) discuss the factors influencing the estimation. The techniques discussed are the results of 5 years of research on the Kvichak.

This method of estimating a salmon escapement from tower counts made from observation towers in Bristol Bay, Alaska, was proposed by W. F. Thompson in the spring of 1953, and he organized the initial experiment on the Wood River in that same summer (Fisheries Research Institute, 1955; Thompson and Clancy, 1959). The success of this method prompted repetition the following year, with expansion to the Kvichak River system in 1955. In 1956 and 1957, the Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, compared estimates from tower counts with those from the weirs on the Egegik River and found insignificant differences in total numbers of fish (Bureau of Commercial Fisheries, 1956 and 1957). In 1957, for the first time the escapements to all major red salmon streams in Bristol Bay were assessed from intermittent visual counts made from towers along the river banks.

The Kvichak River is about 57 miles long, draining from Iliamna Lake and following a twisting course through flat tundra country before flowing into Kvichak Bay (fig. 1). Its lower 43 miles is influenced by tides and the river has a mean depth of about 10 feet. From the head of tidewater, a broad area of numerous shallow channels called the Kaskanak Flats extends upriver 8 miles. From the flats to the outlet of Iliamna Lake, a distance of 4 miles, the river is restricted to a deeper channel that contains a few islands and gravel bars.

The system drains a watershed of 7,700 square miles, which includes a profusion of lakes and connecting or tributary streams. Iliamna Lake alone is 77 miles long and from 8 to 20 miles wide. Clark Lake, connected to Iliamna Lake by the Newhalen River, is 52 miles long and from 1 to 4 miles wide (U.S. Army Corps of Engineers, 1957). Extensive red salmon spawning grounds are distributed in streams, in spring ponds, and on beaches throughout the area.

As the Kvichak River empties into the ocean it is joined by first the Alagnak and then the Naknek River. These streams each sustain their own populations of red salmon, which mix as they arrive from ocean feeding grounds and encounter the commercial fishery in the Kvichak-Naknek district.

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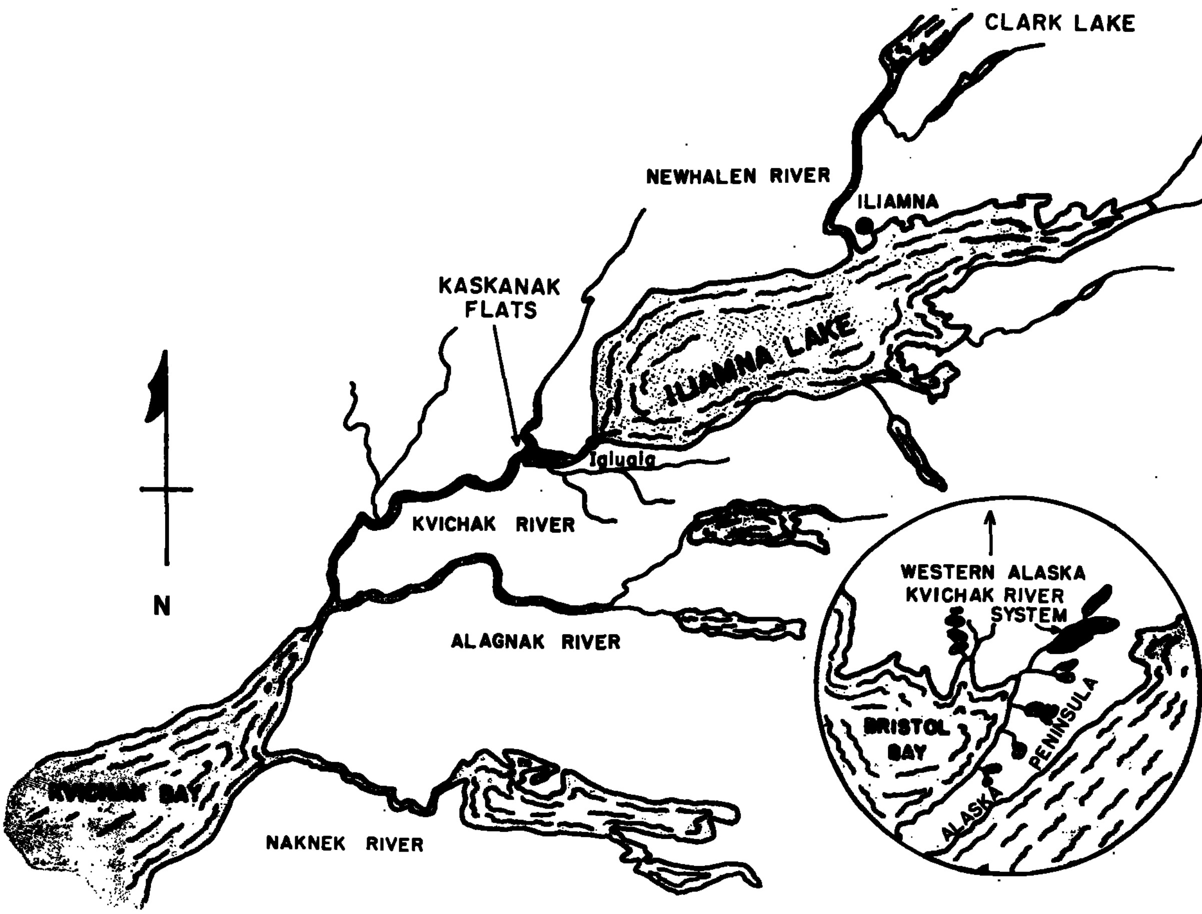

FIGURE 1.—Kvichak River system: one of the principal spawning areas for red salmon in the Bristol Bay region of western Alaska.

The Kvichak-Naknek district is one of several areas in Bristol Bay in which commerical fishing is permitted. The fishery came into large production at the turn of the century. Continuous catch and pack records since that time show tremendous fluctuations in abundance of red salmon from year to year. These fluctuations have formed a cyclic pattern with peak catches usually occurring every 4 or 5 years. From 1910 to 1958, the average annual catch was 9 million fish. The peak catch was taken in 1938 when 21 million red salmon were supplied to local canneries. Since 1938, however, the cycles tended to decline, and the catch reached a 60-year low of 923,000 fish in 1958.

Accurate estimates of escapements into the Kvichak River system are lacking for the years prior to 1955. In only one year was the entire escapement counted: in 1932, when the Bureau of Fisheries passed 5,065,000 salmon through a weir on the upper river (U.S. Bureau of Fisheries, 1933). Continued enumeration by weirs proved impractical because of excessive costs of construction and maintenance, hence, their use was discontinued.

Catches have been used in some areas as indices to escapements. But catches in the Kvichak-Naknek district include fish destined for the Kvichak, Naknek, and Alagnak Rivers, and to a lesser extent, the Egegik River. In addition, yearly changes in the distribution of gear, the intensity of the fishery, and contributions of the various runs, all vary the relation between catch and escapement. For these reasons, the catches are poor indices to red salmon escapements up the Kvichak River.

Estimates of the numbers of salmon on the spawning grounds, obtained from aerial surveys, have also been used as means of determining the escapements. However, detailed surveys of the numerous and widely distributed spawning areas of Iliamna Lake in the past 5 years have failed to reveal more than 20 percent of the estimated total Kvichak migration as determined from observation-tower counts. This percentage has varied from year to year; also the relative number of total spawners in each major spawning area has varied from year to year, irrespective of the size of the escapement. Hence, indices based on counts of spawning fish in the Kvichak River system appear to be highly unreliable.

METHOD OF OBSERVATION

The sample-count method of estimating escapements is based on the migratory habits of red salmon as they move up the river toward the area in which they originated. Salmon first appear in the Kvichak River the latter part of June and continue to pass upriver throughout July, with a migration peak occurring near the middle of the month. Once in the river the fish seek places where currents are reduced. Since areas of low currents are usually found near the bottom and next to the banks, the migrants follow restricted paths close to the shore where they can be readily observed. This habit is quite consistent in sections above tidewater where the river is confined to a single channel and where there are swift midstream currents.

It has been found that current velocities 6 inches from the bottom at the sites where the counts are taken range from 1.55 to 2.13 ft. a second, while those 6 inches from the surface range from 2.34 to 3.34 ft. a second. In 1959, the migrants passed upriver at an average relative speed of 1.52 ft. a second against the bottom currents.

Varying water levels influence the paths taken by the fish. Red salmon generally follow the banks more closely when the water level is high because of the relatively greater area of deep and quiet water close to shore. Kvichak water levels at the first of July have varied more than 2 feet from year to year, and usually rise from 8 to 14 inches during that month.

Fish appear in small separate schools when the size of the run is low. As the magnitude increases, the schools become larger and extend until the fish are passing in continuous bands. The separate schools behave somewhat erratically, but when the migration intensity is high the fish are less wary and follow the banks more closely. The direction of migration is usually continuously upriver. Only a few fish return downstream at the Kvichak counting site, and these occur invariably near the end of the migration. Slack water areas and sloughs are utilized by some individuals to rest. These fish commonly bear injuries from gill nets and predators in the ocean.

From extensive beach seining the Kvichak River escapements have been found to consist almost entirely of red salmon. Other species of salmon occur in the seine samples largely near the end of the migration, and make up less than 0.5 percent of the total escapements. The other species are omitted from the counts when identified from the towers, and therefore the possible error caused by including species other than red salmon is very small.

The visual counts are taken from towers erected at suitable locations, aided by use of background panels to silhouette the fish, turbulence reducers to smooth the surface, and other special counting aids. Once all migration paths can be observed clearly, it is relatively simple to count during sampling periods of predetermined length and to estimate the total escapement with a high degree of accuracy.

Tower Locations

The migratory habits of the fish and the physical characteristics of the Kvichak River limit the number of suitable sites for observation towers. The river below Kaskanak Flats is turbid and subject to tides that periodically reverse current flow. Migrants filter through the channels of the flats in numerous locations. Consequently, the most practical counting sites are limited to the area above the flats. The counting sites selected are near the outlet of Iliamna Lake close to the village of Igiugig and more than 50 miles upriver (fig. 1).

For peak efficiency, towers should be located where the moving bands of fish are constricted in width and pass without deviating from near the base of the structures. Since the river near Igiugig is split by an island, three towers are required (fig. 2). Towers No. 1 and No. 2 provide for sampling of the two primary paths in the main channel, which has a width of 380 feet and a maximum depth of about 16 feet. Tower No. 3

covers a shallow secondary channel through which the fish migrate when the water level is high. No fish passed through this secondary channel in 1957 and 1959 because of low water levels. The heaviest runs generally pass at tower No. 1 where a steep gradient and swift midstream currents tend to hold the salmon inshore where they pass in a narrow band. At tower No. 2, the gradient is more moderate and currents are reduced. Consequently, the fish spread over a broader area, particularly after the tower has been erected.

Tower No. 1 was constructed from spruce timbers on the right (west) bank of the river. Tower No. 2 was afloat, constructed of aluminum scaffolding and assembled on two skiffs which were lashed together and anchored off the right side of an island and on the left (east) side of the river (fig. 3). Tower No. 3 was also of aluminum scaffolding, and was located on the left (east) bank where the entire secondary channel could be observed.

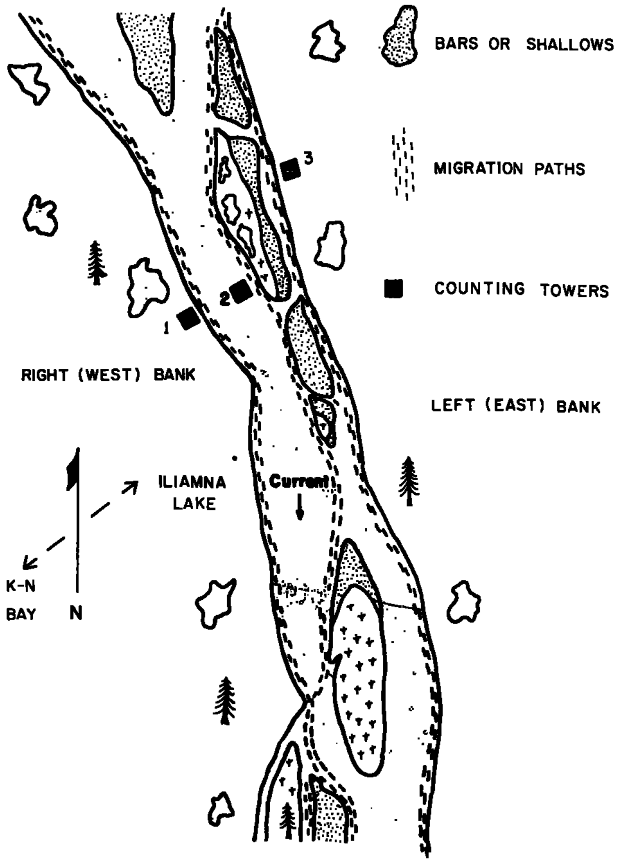

FIGURE 2.—Tower sites and paths of migrating fish on the Kvichak River, near Igiugig.

During sunny, calm days when the water is clear, salmon can be seen at any point in the river between towers No. 1 and No. 2. Only occasionally have they been seen near the middle and then never in a migrating band. Hence, we are confident that the salmon seen near the towers represent closely the entire migration passing at a given time.

Background Panels

Since fish blend with bottom contours making accurate counting difficult, panels were installed on the river bottom at the towers to silhouette the salmon passing. The blending is particularly camouflaging under conditions of semiturbid waters, overcast skies, and distorted river surfaces. The panels were painted a light gray to make the salmon visible under all but the most adverse conditions. As a rule, the fish will pass readily over any panel of dark or dull tones in preference to panels of bright tones. Such panels are particularly important for counting fish at night when artificial lights must be used.

In addition to revealing fish, panels must not startle the migrants, must be easy to install, and must resist deterioration in the current. Panels of 16-gage woven-wire screen of ¼-inch mesh have proved satisfactory. These panels are 3 feet wide, 10 feet long, and reinforced along the edges by 1-inch iron pipe (fig. 4). When placed in position, the panels extend out and downstream across the migration paths. Stakes of ¼-inch iron pipe, 18 inches long, are driven through metal loops to hold the panels in position.

Turbulence Reducers

Surface distortions resulting from rain, wind, waves, and bottom contours detract from accuracy of counting by reducing visibility. Turbulence reducers, an arrangement of boards and logs utilized to eliminate surging currents and wave action (fig. 5), are used to smooth the surface of the water over the panels so that the migrants can be readily seen. The wooden float is on the surface of the river immediately upstream from the panels and should not startle the fish by bobbing in the current or with vibrating anchor lines. Normally 4 feet of water is necessary before fish pass underneath undisturbed.

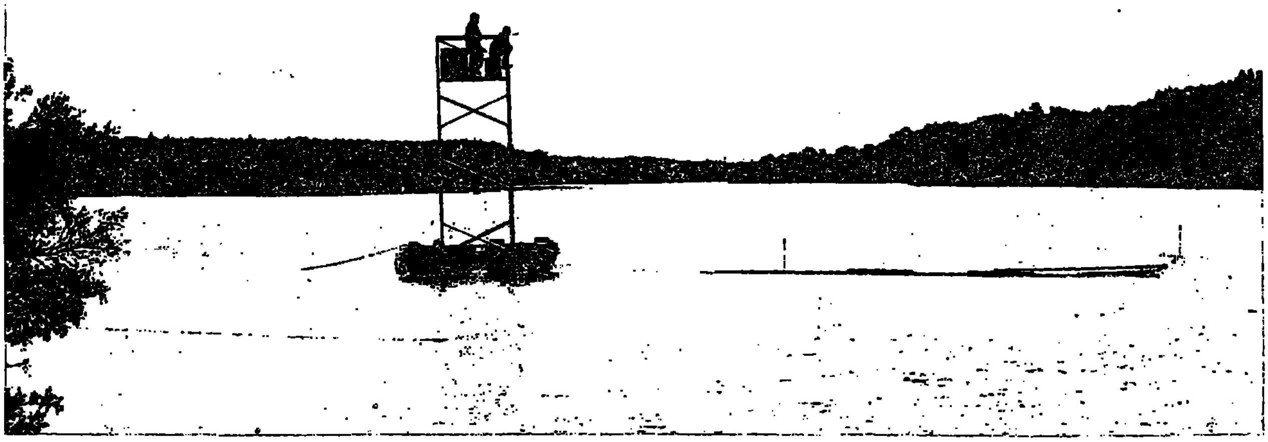

FIGURE 3.—Tower No. 2, the floating tower from which migrating red salmon were counted on the Kvichak River.

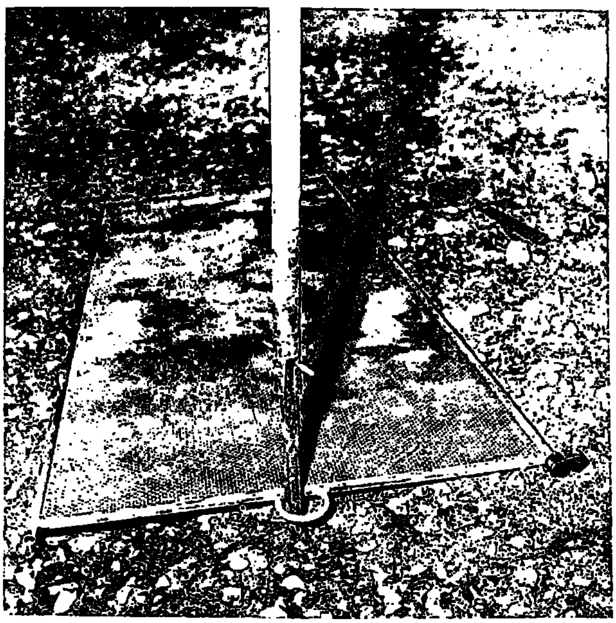

FIGURE 4.—Background panel used on river bottom to silhouette passing fish. Pin and driving rod in foreground. (Photograph by E. F. Marten.)

Three types of turbulence reducers have been used. The simplest was a log placed diagonally across the current. The second was a large V-frame, constructed from two or more timbers and placed with the apex upstream. The third and most efficient was a modification of the second, in which the effectiveness was increased by adding vertical pickets about 18 inches long and 3 inches apart to straighten subsurface currents. The latter type was originally developed and tested by the Fish and Wildlife Service on the Naknek River in 1957.

Experiments to improve visibility have also been conducted with a transparent plastic sheet which trailed on the surface of the water. The sheet smoothed the surface and did not disturb the migrants under moderate weather conditions, but rain, winds, and waves destroyed its effectiveness.

Counting Aids

Accuracy of counts was further increased by the use of (1) Polaroid glasses to reduce sun glare and surface reflection, (2) hand tallies to record

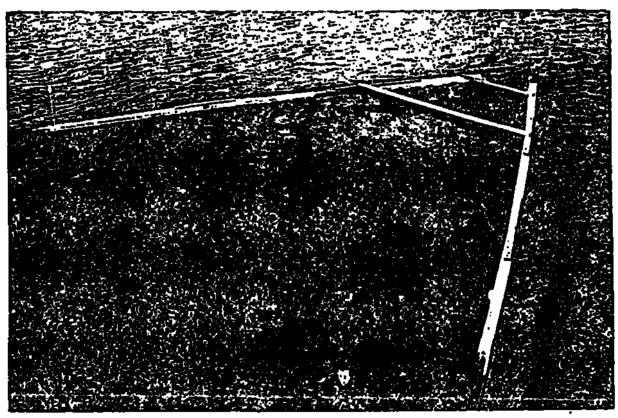

FIGURE 5.—A large turbulence reducer without vertical pickets smoothing an area 40 feet wide.

the migrants quickly and efficiently, (3) audible timers to limit the counting periods precisely and eliminate the need of watching a clock, (4) guiding devices to lead the migrants over the panels, and (5) spotlights to assist in night counts.

ESTIMATION OF THE RUNS

The sampling procedure was designed to obtain a reasonably accurate estimate of the total escapement while staying within the limits of both manpower and budget. Most of the information on which the initial sampling plan was formulated was known from previous observations of red salmon moving upriver and through weirs. Usually the major peak of the migration occurred in a day or two, although it was often preceded or followed by minor peaks. There were usually marked variations in numbers of fish from day to day and throughout a given day. In some locations near the fishery there were also marked changes in the numbers with the opening and closing of the fishing periods or with changing tides. It has since been noted at Igiugig on the Kvichak River that the heaviest runs usually appear along one bank at a time, with comparatively small numbers of fish passing along the opposite shore. The major path of the run changes erratically during the season and from year to year, but once a heavy run develops along one bank, it is usually maintained for several days.

A typical migration up the Kvichak River was counted continuously on July 16, 1955, in front of tower No. 1 (fig. 6). The fluctuations during daylight ranged from about two-thirds of the mean of 507 fish each 10 minutes to about one and one-half times the mean. With such variations, it is desirable to sample every day and within each day to use a large number of short counting periods equally spaced in a systematic fashion.

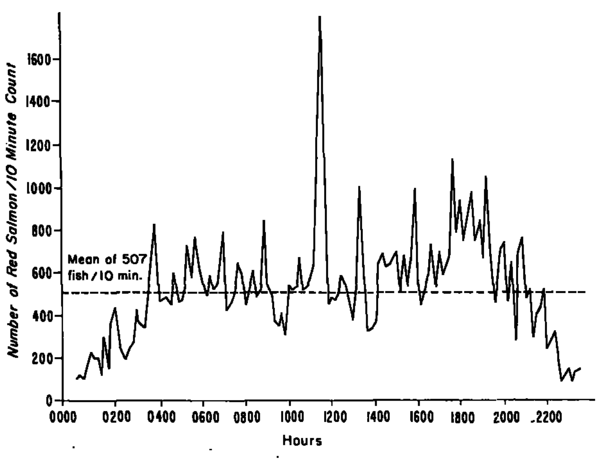

FIGURE 6.—Numerical fluctuations in migrating red salmon, from 10-minute continuous counts taken on July 16, 1955, at tower No. 1.

Since the magnitude of the escapement fluctuates greatly, even in successive 10-minute counts, the estimates calculated from the samples are basically point estimates. A single count depicts accurately only the number of fish that happens to be passing at the time. Frequent counts depict accurately only the number of fish passing when the counts were taken, yet they are closely related to the total numbers in the fluctuating population. As a result, the daily estimates obtained from the counts approximate the numbers of migrating salmon, with the accuracy depending on the magnitude and frequency of the fluctuations and the frequency and duration of the sample counts.

Method of Sampling

The basic sample unit used in 1957, 1958, and 1959 consisted of 10-minute counts taken systematically each hour from each tower. The initial sample counts in 1955 were of 2 hours' duration and taken every 4 hours. In 1956, counts were eventually reduced to 40 minutes and were taken every 3 hours. But the 10-minute counts were found most practical to obtain and to use in calculating the estimate. Any sampling procedure will be improved if it is flexible enough to permit increases or decreases in the degree of coverage with the intensity of the migration. Consequently, at the beginning and end of the migration the counts were taken every 2, 3, or 4 hours. Also, at the peak of the migration or if a heavy run commenced along one bank, counts were increased to 15 or 20 minutes. This flexibility placed emphasis on increasing the accuracy of the total estimates by concentrating the counts on the periods with the heaviest escapements.

Counts were taken by natural light as early in the morning and as late at night as possible. The hours of darkness normally extend from 2300 to 0200, but often vary from day to day depending on the extent of sky overcast and the season. Accurate night counts depend on seeing the fish by means of artificial light from spotlamps. The intensity of these lamps was controlled by a rheostat; however, when the lights were sufficiently dimmed so that the salmon passed without hesitation, the counts were not so accurate as desired. Consequently, night counts were taken from only one tower in 1957 and not at all in 1958. In 1959, night counts were successfully obtained throughout the season by using a single, bright spotlight focused outside of the panels from the top of the towers. The fish passed in the dim area inshore from the spotlight and could be seen satisfactorily when crossing the background panels. Amber and red lenses were used experimentally in 1957 to determine whether the salmon would tolerate high illumination intensities when the lights were colored. The colored lights caused stronger avoidance reactions than dimmed white lights, and also were less penetrating in waters that were moderately turbid.

The tallying procedure varied with the intensity of the migration. Fish can be tallied separately when the number passing is fewer than 250 per minute. After the run exceeds this quantity, fish must be tallied by estimating groups of 10. Heavy runs requiring such grouped counts occurred only near the peaks of the larger escapements, such as the ones that occurred in 1956 and 1957.

Method of Calculation

The calculating procedure for estimating numbers of red salmon utilized the sample count as an estimator of the number of fish passing in a given unit of time. Therefore, with 10-minute counts taken hourly, the estimate of numbers of fish passing a tower is the product of multiplying the count by six. Daily estimates are the sum of calculated hourly estimates for all towers, and the seasonal estimate is the sum of all daily estimates.

Whenever systematic counts ceased at night or when the waters were turbid with sediment, the number of fish passing has been determined by averaging the counts preceding and following the periods with no counts. The estimate has been calculated by multiplying this average by the appropriate time factor.

Results

Estimates for Kvichak River escapements have varied widely from year to year, as would be expected from the cyclic nature of the runs and the changing intensities of the commercial fishery.

TABLE 1.—*Kvichak daily estimates of red salmon escapements, 1955 through 1959*

Date	1955	1956	1957	1958	1959
June 21	----------	----------	----------	----------	308
22	----------	----------	----------	----------	623
23	120	8	----------	0	307
24	256	38	----------	0	99
25	509	32	----------	0	212
26	166	30	7,337	24	914
27	211	88	4,987	29	416
28	38	263	2,922	58	1,133
29	90	229	9,305	515	440
30	112	343	55,827	582	1,098
July 1	186	311	51,797	174	588
2	148	311	62,332	1,485	384
3	102	373	82,789	960	1,152
4	151	11,280	60,394	153	7,872
5	3,426	10,256	70,371	129	49,612
6	24,364	63,065	48,245	48	51,288
7	9,125	75,851	45,703	29,328	48,780
8	657	134,163	83,275	161,109	30,758
9	893	221,055	56,435	148,760	12,524
10	918	268,179	133,815	44,945	19,097
11	12,766	268,048	269,310	24,802	32,627
12	11,351	375,393	358,194	3,575	21,285
13	6,937	498,944	461,961	2,241	52,818
14	5,458	583,882	371,154	3,966	88,226
15	21,578	694,874	147,430	43,458	90,994
16	73,304	923,007	88,426	47,559	55,343
17	31,822	1,053,583	56,012	5,946	23,398
18	13,398	910,574	30,330	1,530	16,093
19	5,726	711,050	49,258	879	17,357
20	4,146	650,430	72,705	1,017	13,225
21	4,781	606,643	37,966	2,673	9,140
22	4,537	440,420	26,820	834	5,637
23	3,972	288,795	23,152	2,130	5,631
24	2,245	212,571	25,612	2,274	3,801
25	2,187	154,609	14,537	999	1,514
26	1,073	98,495		357	2,119
27	962	66,923	[1] 34,409	543	2,189
28	785	37,516		938	2,592
29	797	25,100	----------	384	1,800
30	545	20,353	----------	381	390
31	409	15,999	----------	----------	[2] 6,216
Aug. 1	213	14,558	----------	----------	----------
2	82	5,676	----------	----------	----------
Total	250,546	9,443,318	2,842,810	534,785	680,000

[1] Estimate for July 26, 27, and 28 based on irregular daytime samples.
[2] Estimated late season migration.

These totals for the past 5 years were: 250,546 in 1955; 9,443,318 in 1956; 2,842,810 in 1957; 534,785 in 1958; and 680,000 in 1959.

Daily estimates for these years are listed in table 1, and a graphic comparison of the daily escapements thus obtained is presented in figure 7. The escapement of 1956 was the largest red salmon run ever counted moving upriver in Alaska. The escapement of 1955 undoubtedly was one of the smallest noted in the history of the Kvichak River system.

The significant part of the Kvichak River escapement has always passed the Igiugig towers within approximately 3 weeks (table 2). The peak varied from July 8–9 in 1958 to as late as July 17 in 1956. The end of the runs, defined as the points where the daily escapements are less than 1 percent of the final total, are relatively unimportant to the total estimates. Small numbers of fish usually continue upriver even after the counts are terminated. Earlier, before the counts commence in the

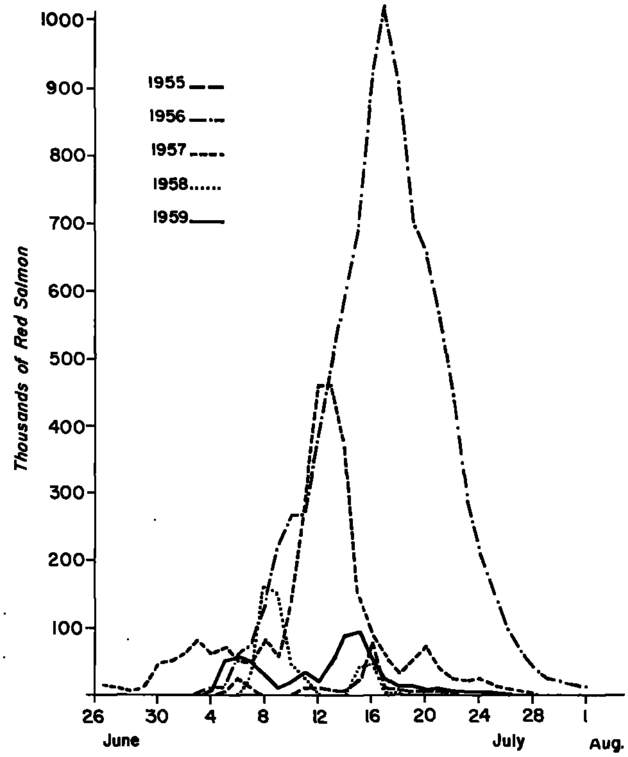

FIGURE 7.—Daily escapements of red salmon up the Kvichak River, 1955 through 1959.

spring, a few fish migrate upriver; adult red salmon have been reported taken in gill nets on upper Iliamna Lake as early as June 6.

There has been no apparent correlation between the duration and the size of the escapements. The main part of the small 1955 and the large 1956 escapements each passed in 19 days, and neither the start nor the end of the migration in the 2 years was more than 3 days apart.

FACTORS INFLUENCING VISUAL COUNTS

To a large extent, the accuracy of the basic sample counts depends on (1) individual counters, (2) migration intensity, (3) weather conditions, and (4) disrupted migration patterns. Once the relationships of these factors to the counts are recognized and understood, they can be taken into consideration in improving the counting method.

Errors Introduced by Individual Counters

Counting errors are known to result from individual differences in seeing, counting, and recording numbers of passing salmon. In 1957, 32 counts

TABLE 2.—*Size and timing of Kvichak red salmon escapements at Igiugig, 1955 through 1959*

Year	Size of escapement	Timing of 95 percent of the escapement			
		Start	Peak	Stop	Range (days)
1955	250,546	July 5	July 16	July 23	19
1956	9,443,318	July 8	July 16-18	July 26	19
1957	2,842,810	June 30	July 12-14	July 21	22
1958	534,785	July 7	July 8-9	July 17	11
1959	680,000	July 4	July 14-15	July 23	20

of 5 minutes' duration were taken by 2 observers counting simultaneously from the same tower. One counter (A) participated in all counts, while the other counter was taken from a group of three men designated XYZ. The data obtained are listed in table 3, where the difference in numbers of fish counted by XYZ is expressed as a plus or minus percentage of variation from A's count.

The range of variations between the 5-minute counts of A and one of the other three counters extends from −22.1 to +17.9 percent. By combining two consecutive counts to form standard 10-minute counts, the range is shortened from −7.8 to +10.7 percent. Further reductions occur when the counts are totaled and the differences calculated. For the two groups of 5-minute counts, the total differences are but +3.5 and −5.3 percent, respectively. The totals of all 32 counts differ by only −1.0 percent. Consequently, errors occurring in counts between paired observers, operating under a variety of observation conditions, tended to cancel out. Such counting errors, therefore, apparently occurred randomly and probably did not bias estimates of the escapement.

Errors Associated With Migration Intensity

As intensity of the migration increases, fish must be tallied more rapidly. An increase in migration intensity might indicate an increase in counting errors. The comparative data (fig. 8), however, show only a slight correlation between migration intensity and percentage of counting variation, even though greater variations in total numbers of fish counted did occur. This indicates that counts taken during increasingly heavy runs do not necessarily inject an increasing number of errors into the calculations.

The five comparative counts with extreme variations exceeding a plus or minus 10 percent ap-

TABLE 3.—*Comparison of counts during the same period by different observers*

1957	Tower No.	Time	Number of fish counted						Percentage variation		
			Counter A			Counters XYZ			5 min.	5 min.	10 min. (total)
			5 min.	5 min.	10 min. (total)	5 min.	5 min.	10 min. (total)			
July 9	1	----------	63	9	72	66	9	75	+4.8	0.0	+4.2
11	1	1900	----------	228	228	----------	212	212	----------	−7.0	−7.0
	2	1915	1,020	860	1,880	1,100	880	1,980	+7.8	+2.3	+5.3
12	1	1500	631	680	1,311	720	700	1,420	+14.0	+2.9	+8.3
	2	1515	700	600	1,300	650	620	1,270	−7.1	+3.3	−2.3
	1	0715	306	659	965	327	574	901	+6.9	−12.9	−6.6
13	2	1020	960	950	1,910	1,020	740	1,760	+6.3	−22.1	−7.8
14	1	0900	688	745	1,433	658	703	1,361	−4.4	−5.6	−5.1
	2	0915	487	510	997	574	530	1,104	+17.9	+3.9	+10.7
	1	1700	760	653	1,413	755	560	1,315	−0.7	−14.2	−6.9
	2	1715	413	440	853	395	443	838	−4.4	−0.7	−1.7
15	1	1900	93	76	169	92	75	167	−1.1	−1.3	−1.2
	2	1915	280	285	565	276	285	561	−1.4	0.0	−0.7
16	1	1700	----------	70	70	----------	67	67	----------	−4.3	−4.3
	2	1715	190	94	284	190	96	288	0.0	+4.3	+1.4
17	1	1700	36	50	86	34	48	82	−5.6	−4.0	−4.7
	2	1715	18	106	124	18	99	117	0.0	−6.6	−5.6
Total	----------	----------	6,645	7,015	13,660	6,875	6,643	13,518	+3.5	−5.3	−1.0

peared when the migration passed 450 fish per 5-minute interval, but even these errors followed a random pattern and tended to average out. However, because of the greater magnitude and importance of these errors, it is imperative to increase the number of samples taken with an increase in intensity of the run. This greatly increases the reliability of the calculated estimates.

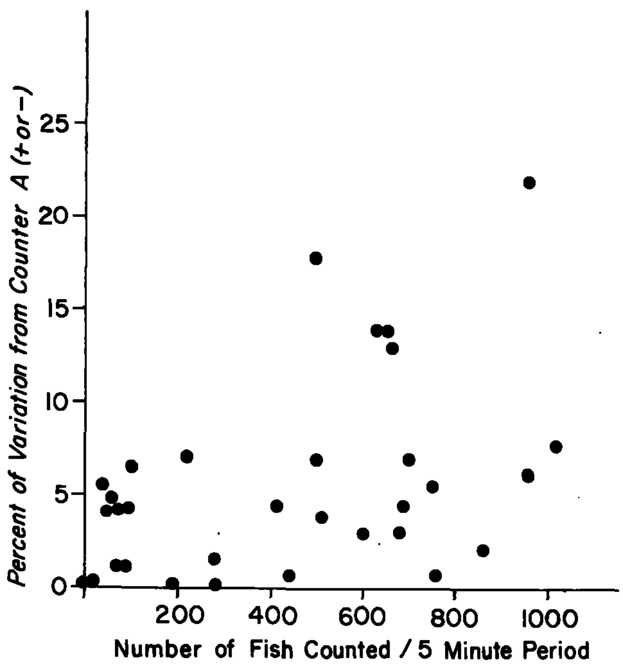

FIGURE. 8.—Relation between migration intensity and variations between counters.

When extremely heavy runs occur and samples must be obtained by estimating groups of 10 fish, counting errors are undoubtedly greater than when individual fish can be tallied. Heavy runs requiring such counting procedures are infrequent and usually occur past one tower at a time. On the Kvichak River, such runs appeared only during the intense 1956 escapement (July 11–21) and briefly in 1957 (July 12–14).

Effect of Weather Conditions

Sun glare, overcast skies, wind, and rain lower visibility and increase the difficulties of obtaining accurate sample counts. Glare may be troublesome during a 4-hour period daily when the sun is bright and low over the water. Overcast skies impart a dull appearance to the surface of the water, while upriver winds and rain disturb the surface and thereby distort the outlines of objects under the surface. The effects of these adverse conditions, combined with the normally turbulent water surface, make turbulence reducers essential. Then, with the aid of Polaroid glasses, the observers can count the passing fish accurately at almost any part of a given day.

Moderately turbid water, which occurs irregularly throughout the season, is the most important factor affecting the accuracy of the counts. This turbidity is the result of heavy breakers against the beach at the outlet of Iliamna Lake, which occur with strong east winds. The pounding causes excessive amounts of silt to be suspended in the water which then flows downriver and reduces visibility at the tower sites. Occasionally the point is reached where counts are not possible. This is discussed as high turbidity, under the section on "Accuracy of the Estimates."

When the water is moderately turbid, the variation between comparative counts might be expected to increase. Yet the data presented in table 4 show that the variation between comparative counts taken in moderately turbid water was less (+1.7 percent) than those obtained in clear water (−3.0 percent). This suggests that moderately turbid water did not increase the counting variation between two counters. It does not indicate that both counts were as accurate in turbid water as in clear water, especially on the fringe areas of the migration paths.

Effect of Disrupted Migration Pattern

Migration past a tower is momentarily disrupted as the fish scatter into deep water when the skiff bearing the counter arrives. While the fish soon re-form their ranks and resume an apparently normal migration pattern, it is possible that commencing the counts as soon as the counter is ready would inject directional errors.

A test of the timing of the counts to the time of the counter's arrival was made in 1957 by comparing the first and second 5-minute counts of 841 samples (table 5). In most instances these counts were started as soon as the counter had tied the skiff, climbed the tower, and readied his equipment, a period of 1 or 2 minutes. Since the first count was higher than the second almost one-half the time, i.e., neither consistently higher nor lower, the counts were probably not biased. The time required in preparation to commence the counts, therefore, is evidently sufficient for the migration to assume a normal pattern.

TABLE 4.—*Effect of turbid water on count variation*

Counter	Number of fish counted in—					
	Clear water			Moderately turbid water		
	1st 5 minutes	2d 5 minutes	Total	1st 5 minutes	2d 5 minutes	Total
A	3,988	3,988	7,976	2,657	3,027	5,684
XYZ	4,078	3,658	7,735	2,797	2,986	5,783
Percent variation	+1.3	−8.1	−3.0	+5.3	−1.4	+1.7

ACCURACY OF ESTIMATES

Estimates of the total migration are subject to statistical error because of periods when the continuity of the sample counts is interrupted, and because of fluctuations in abundance of fish from one counting period to another. At present we can only guess at possible bias that may accrue because of interruptions in the counts, but we can estimate precisely the possible statistical error for fluctuations of abundance. For example, it is possible to calculate confidence limits for each annual escapement to determine the reliability of the sampling program. In addition, various mathematical tests can be applied to determine the effects of changes in the length of the samples and the interspacing periods.

Effect of Interruptions in the Counts

Interruptions in counting have occurred because of high turbidity when no fish can be seen, also because of darkness, especially before satisfactory lighting was developed.

Highly turbid water occurred 10.9, 3.7, 3.1, 6.2, and 5.5 percent of the time in the years from 1955 to 1959, respectively. Once the river becomes turbid it normally remains in that condition for at least 24 hours, because the water takes about 8 hours to clear after the east wind ceases. The periods when high turbidity prevailed, in relation to the magnitude of the escapement each year, are shown in figure 9. Only in 1957 did the water turn highly turbid when a heavy migration of red salmon was passing the towers.

Beach seine hauls have been obtained occasionally to provide relative indications of migration intensity in turbid waters. These hauls are probably more effective in turbid than in clear water because of inability of the fish to see the net. Yet, catches were low, indicating a low migration intensity. A systematic comparison of hauls in clear and in turbid water was made in 1958, where the average catch per haul along the right bank was compared with the estimated number of fish migrating past tower No. 1 (fig. 10). The curve formed by this relationship indicated that few fish were migrating in the highly turbid water. Therefore, calculations of the migration for the period of turbid water, based on an average of low counts immediately preceding and following the turbid period, were basically correct.

TABLE 5.—*Relation of 1st 5-minute counts to 2d 5-minute counts, Kvichak River, 1957*

Category	Counter									Total
	A	B	C	D	E	F	G	H	I	
1st count (high)	56	83	54	88	42	57	6	5	26	417
2d count (high)	43	82	46	89	49	61	8	10	36	424
Number times counted	99	165	100	177	91	118	14	15	62	841
Percent 1st count high	56.6	50.3	54.0	49.7	46.2	48.3	42.9	33.3	41.9	49.6

Night counts were not taken in 1958 because of difficulty in counting the fish and the questionable accuracy of counts made under floodlights. Instead, estimates were made on the assumption that the migration was constant between the last evening count and the first morning count. The total time lost to sampling by omitting night counts each day was 4 hours, 2300—0200. Estimates of the escapements based on systematic night counts in 1957 and 1959 from tower No. 1 were compared with those calculated by averaging the 2200 and 0300 samples (table 6). In both instances the escapements test-calculated by omitting night counts were high, 6.8 percent for the

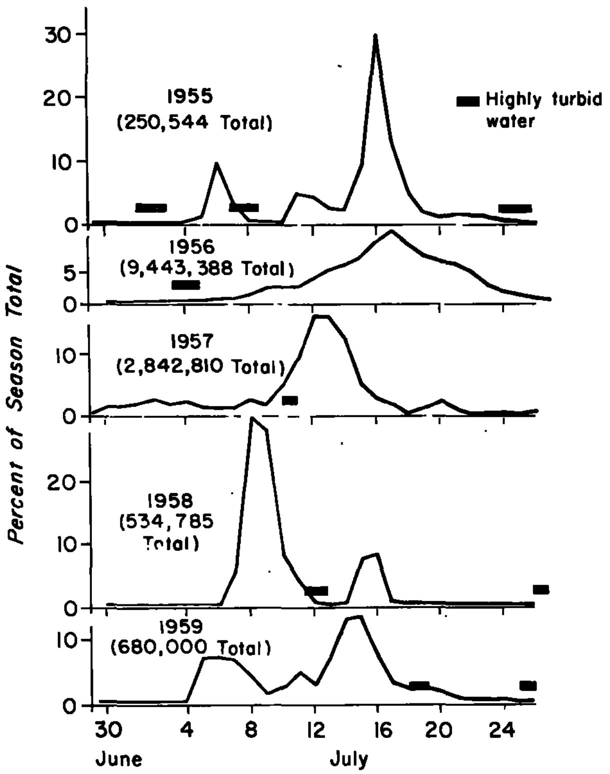

FIGURE 9.—Relationship of periods of high turbidity to red salmon escapements, Kvichak River, 1955 through 1959.

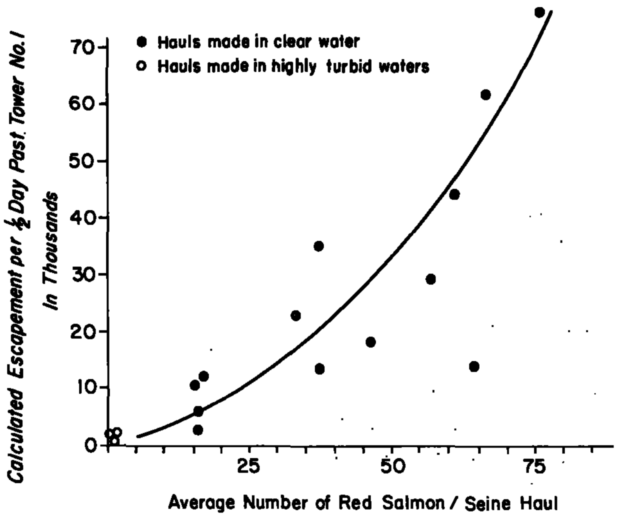

FIGURE 10.—Relation between average numbers of red salmon caught per seine haul and the calculated number of fish passing tower No. 1. Data computed on a ½-day basis, Kvichak River, July 7–17, 1958.

larger 1957 run and 34.6 percent for the smaller 1959 run. Consequently, it is necessary to obtain night counts whenever possible to maintain a high degree of accuracy in the estimates.

Population Fluctuations

Fluctuations in numbers of migrating fish from season to season, from day to day, and from hour to hour, are characteristic of Kvichak River salmon runs. Seasonally, the fluctuations have ranged from ¼ to 9½ million fish. Daily fluctuations were clearly defined in small escapements, less defined in large runs.

However, fluctuations taking place between counts are of the greatest importance to the estimates of the escapement. The greater the frequency and magnitude of fluctuations from one sample to the next, the more the calculated estimates are likely to deviate from the true population passing upriver. Fluctuations from sample to sample and between samples are the result, to a large extent, of the schooling habits of the fish. These schools are particularly noticeable when the migration intensity is low, but even during a heavy run wide fluctuations in numbers continue to occur.

TABLE 6.—*Determination of possible error from omitting all night counts from tower No. 1, 1957 and 1959*

Year	Night estimate		Percentage error by method B	Percentage error in daily estimates
	A. By expanding hourly samples (used)	B. By averaging 2200 and 0300 samples (tested)		
1957	198,441	211,944	+6.8	+1.4
1959	51,454	69,240	+34.6	+6.9
Total	249,895	281,184	+12.5	+2.5

The width of the confidence intervals associated with a point estimate is influenced directly by the fluctuations in numbers of fish. The width of such intervals can be decreased by an increase in sampling time, especially by increasing the number of samples but also by expanding the length of the sample unit.

Confidence Limits of the 1959 Escapement

Confidence limits were determined for point estimates of the annual red salmon escapements.[1] The method was applied to the 1959 counts to illustrate the procedures and to point out the accuracy achieved by the present sampling methods. The counts were of 15 minutes' duration and were taken every 4 hours early in the season. A change to 10-minute counts taken hourly was made on June 29 as the migration increased. Daytime counts were increased to 15 minutes, some to 30 minutes or more each hour, near the peaks of the escapement. Then all counts were reduced to 10 minutes and taken every 4 hours near the end of the run.

Before confidence limits can be calculated, the season must first be stratified, since the variance in the counts is associated with the mean numbers of fish for each segment of the escapement (table 7). The total migration season from which the four strata were drawn extended from noon, June 21 to August 1, a total of 39.5 days. This is equivalent to 79 days of total counting for the two towers. As intended by the sampling plan, an increase in the percentage of sampling time occurred with each strata in proportion to its numerical importance; 7.8, 14.1, 22.1, and 24.8 percent with strata I to IV, respectively.

It is assumed that the sample counts were taken randomly throughout each stratum regardless of some extended counts or occasional gaps and were, therefore, representative of the stratum from which they were taken. The preliminary calculations for the determination of the confidence limits are summarized in tables 7 and 8, where—

N=total number of sampling units (10-minute counts).

P=total fish passage (population).

N_i=total number of sampling units in the i^th^ stratum.

n=total number of samples (10-minute counts) obtained.

n_i=total number of samples obtained in i^th^ stratum.

X_{ij}=number of fish in j^th^ sample in i^th^ stratum.

$\overline{X}_i$=mean number of fish per sample in i^th^ stratum from—

$$\overline{X}_i=\frac{\sum_j X_{ij}}{n_i}$$

S_i^2=variance of the samples in i^th^ stratum from—

$$S_i^2=\frac{\sum_j X_{ij}^2-\frac{\left(\sum_j X_{ij}\right)^2}{n_i}}{n_i-1}$$

Each stratum is weighted by $W_i=\frac{N_i}{N}$. The weighted mean ($\overline{\overline{X}}$) and the associated variance ($S^2_{\overline{\overline{X}}}$) are then calculated from—

$$\overline{\overline{X}}=\sum_{i=1}^{4}\overline{X}_i\cdot W_i=60.62, \text{ also}$$

$$S^2_{\overline{X}_i}=\frac{S_i^2}{n_i}\cdot\frac{N_i-n_i}{N_i},\ S^2_{\overline{\overline{X}}}=\sum W_i^2\cdot S^2_{\overline{X}_i}$$

[1] The principal procedures have been used previously by O. A. Mathisen in analysis of Wood River escapement estimates: A Stratified Sampling Program for Visual Tower Counting. 1957. University of Washington, Fisheries Research Institute, Seattle (Wash.). Manuscript. Modifications in this procedure for application to Kvichak River data were made with the assistance of C. O. Junge, Jr., of the Fisheries Research Institute.

TABLE 7.—*Stratification of the Kvichak escapement in 1959*

Strata	Average number fish counted[1]	Date and site of escapement in stratum	Number sampling units (N_i)	Number samples obtained (n_i)	Percent n_i
I	0-20	All units from June 21 to July 30 other than noted.	6,912	540	7.8
II	20-80	Tower No. 1: July 4, 8, 10, 12, 18, 19, 20, 21, 22. Tower No. 2: July 12, 17, 18, 21, 22.	1,872	264	14.1
III	80-220	Tower No. 1: July 6, 7, 11, 17. Tower No. 2: July 5, 6, 7, 8, 9, 10, 14, 16.	1,728	382	22.1
IV	260-500	Tower No. 1: July 5, 13, 14, 15, 16. Tower No. 2: July 15	864	214	24.8
			N=11,376	n=1,400	--------

[1] Determined as 10-minute counts for uniformity of calculation.

The final calculations of the confidence limits, with the level of significance set at 95 percent (t=1.96), are made from—

$$(\overline{P}, \underline{P})=N\left[\overline{\overline{X}}\pm t_{.05}\sqrt{\sum(W_i^2)\left(\frac{S_i^2}{n_i}\right)\left(\frac{N_i-n_i}{N_i}\right)}\right]$$

$$=11{,}376\left[60.62\pm1.96\sqrt{S^2_{\overline{\overline{X}}}}\right]$$

$$=689{,}613\pm(11{,}376)(1.96)(\sqrt{1.5213})$$

$$=689{,}613\pm(22{,}297)(1.233)$$

$$=689{,}613\pm27{,}492$$

As calculated, the 95-percent confidence limits for the 1959 Kvichak River escapement are equivalent to ±3.99 percent (±27,492) of the 689,613 estimated total fish passage (P). Such narrow limits point to the effectiveness of the sample-count estimation program in current use.

The sum of the daily estimates given in table 1 (680,000) differs slightly from the estimate calculated from the stratified data. The tabulated value is considered the best estimate, and is well within the calculated confidence limits.

Effect of Changing the Sampling Design

The length of the counting period and the frequency of the samples are the two main variables to be considered in formulating a sampling program. Increasing or decreasing either one influences the reliability of the calculated estimates.

To analyze these variables, systematic test samples were drawn from a continuous 48-hour count obtained in 1955. The lengths of the counting period of the samples tested were 10, 20, 30, 40, and 60 minutes, while the sampling frequencies were 1, 2, 3, and 4 hours. Generally, four different tests were made with each relationship: sample period length to sample frequency. Totals of the calculated estimates were then compared with the actual total for the 48-hour period, and the percentage deviation plotted in figure 11.

The percentage of error tends to drop with an increase in the length of the samples and with an increase in the frequency of the samples. Short counts, under 40 minutes in length, provide reliable calculations when taken every 1 or 2 hours, usually ranging within a plus or minus 6 percent. These counts show a much wider range of error when taken every 3 or 4 hours. This indicates that, for a specific reduction in counting time, the most consistent results would be obtained with short samples taken frequently. The 1955 and 1956 estimates, based on infrequent larger samples, may have been less accurate than those in recent years. However, in 1955, 73 percent of the escape-

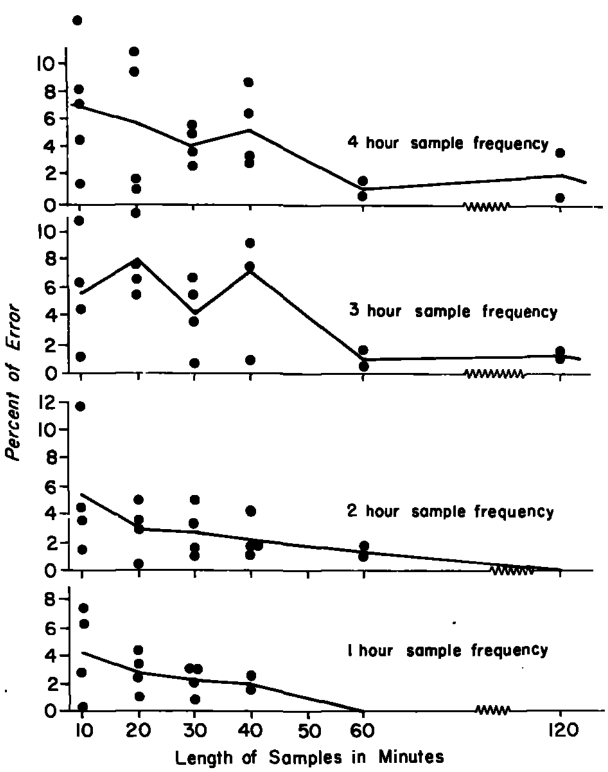

FIGURE 11.—Distribution of sampling errors with various sample period lengths and frequencies.

TABLE 8.—*Preliminary calculations for the determination of confidence limits for the 1959 Kvichak escapement*

Strata (i)	Weights		$_j\Sigma X_{ij}^2$	$_j\Sigma X_{ij}$	$\bar{X}_i$	S_i^2	$\frac{N_i-n_i}{N_i}$	n_i	$W_i^2 S_{\bar{x}_i}^2$
	W_i	W_i^2							
I	0.6076	0.369,178	84,686	3,160	5.9	122.8	0.922	540	0.0774
II	.1646	.027,093	1,385,368	13.995	53.0	2,446.7	.859	264	.2157
III	.1519	.023,074	12,684,729	56.027	146.7	11,725.4	.779	382	.5524
IV	.0760	.005,776	32,187,143	73,290	342.5	33,272.4	.752	214	.6758
Total	1.0001								$S_{\bar{x}}^2=1.5213$

ment was enumerated in a continuous count. In 1956, the variation in number of fish from sample to sample was low, evidently because of the greater magnitude of the run. The basic sampling design of 10-minute counts taken hourly and supplemented by longer counts during a heavy run, therefore, appears to be highly efficient.

It is difficult to determine with any degree of precision the most efficient sampling design, since the size and nature of the migration vary from year to year. Such factors as the proper distribution of time, manpower, and equipment in obtaining accurate counts must also be considered. On the Kvichak River, short frequent counts have proved practical to obtain adequate estimates under all operating conditions.

SUMMARY

1. A method of estimating red salmon escapements by using systematic sample counts was developed and used on the Kvichak River, Alaska, from 1955 to 1959 by the Fisheries Research Institute.

2. The method was based on the fact that migrating red salmon avoid swift midstream currents and pass upriver in narrow bands close to the shores, where observation towers, background panels, turbulence reducers, and other counting aids could be used to obtain accurate counts.

3. Statistically, migrating red salmon were considered as a fluctuating finite population. The design of the sampling procedure was aimed at obtaining a reasonably accurate estimate of the total run from properly distributed visual counts throughout the migration season.

4. The basic sample unit consisted of 10-minute counts taken systematically each hour from each tower. This design was varied to provide increased or decreased coverage with the corresponding variations in the intensity of migration.

5. Estimates for a given period of time were obtained by multiplying the sample count by the appropriate factor. For longer periods when no samples were obtained, the estimates were interpolated by averaging the counts preceding and following the gap and multiplying by the appropriate time factor.

6. Daily estimates were calculated as the sum of all estimates for all towers each day, and the final escapement estimate was the sum of all daily estimates.

7. Kvichak River escapements, as estimated by the sample count method, amounted to 250,546 fish in 1955; 9,443,318 fish in 1956; 2,842,810 fish in 1957; 534,785 fish in 1958; and 680,000 fish in 1959.

8. The accuracy of each sample count was affected by different counters, migration intensities, weather conditions, and disrupted migration patterns. However, the factors were not found to inject significant directional errors but showed definite tendencies to cancel out.

9. The accuracy of the calculated estimates was affected by interruptions in the continuity of the counts from highly turbid waters and darkness and by fluctuations in numbers of fish between samples.

10. A method of determining confidence limits was illustrated. Applied to the 1959 Kvichak River escapement, the confidence limits were established at a plus or minus 3.99 percent at a 95 percent level of significance.

11. The calculated estimates were influenced by varying the lengths and frequencies of the samples. The percentage of error tended to drop with an increase in the length of the samples, and with an increase in the frequencies of the samples. Samples less than 40 minutes in length were found to provide estimates usually within a plus or minus 6 percent of error when taken every 1 or 2 hours.

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