SEX RATIOS AND SURVIVAL ESTIMATES AMONG SALMON POPULATIONS

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Abstract: The effects of sex ratios other than one-to-one on survival estimates produced by Murphy's method of estimating third-year survival of silver (coho) salmon (*Oncorhynchus kisutch*) are discussed.

Techniques are described for determining sex of fingerling king (chinook) salmon (*O. tshawytscha*) over 40 mm in total length by gross gonad examination. Sex composition of 970 fingerling king salmon at the Coleman National Fish Hatchery was 490 males and 480 females.

Evidence is presented which suggests that fish cultural practices may alter the initial sex ratio among propagated silver salmon stocks.

INTRODUCTION

Sex ratios among spawning populations of salmon common to California almost always demonstrate a preponderance of males. Spawning runs of king salmon (*Oncorhynchus tshawytscha*) and silver salmon (*O. kisutch*) contain numbers of mature two-year-old males referred to as grilse or jacks. Very few females of either species spawn as two-year-olds. King salmon females spawn primarily as three- and four-year-olds and spawning silver salmon females are, with few exceptions, three-year-olds. Males of each species which do not spawn as grilse return to spawn at ages similar to female spawners; that is, mostly three- and four-year-old king salmon and three-year-old silvers.

California's commercial salmon fishery routinely takes well over three-quarters of the State's annual ocean salmon landings (Jensen, 1964 and Jensen and Swartzell, 1967). Size restrictions in this fishery limit the landings to king salmon 26 inches or greater in total length and silvers 25 inches or greater. Because king and silver salmon rarely reach these sizes prior to the conclusion of fishing during their second year of life, grilse of neither species undergo significant fishing mortality resulting from commercial fishing effort.

Size limits in the sport fishery allow one fish of either species 20 inches or greater in total length and two of either species 22 inches or greater in the three-fish daily bag. A portion of the population of each species is recruited to the sport fishery toward the end of their second year. However, most salmon in their second year of life escape the ocean fisheries.

The fisheries are, therefore, operating more efficiently on females than males. If a one-to-one or near one-to-one sex ratio exists in the ocean population prior to the end of year two, females should predominate in fishery landings and males in spawning escapements.

Murphy (1952) has developed a method for determining survival of silver salmon during their ultimate year of life. Murphy's method requires only counts of grilse and adult males and females from successive spawning runs. It postulates that the number by which three-year-old females exceed three-year-old males represents the number of two-year-old males which would have returned as threes had they been exposed to an additional year's mortality. Third-year survival is then obtained by subtracting three-year-old males from three-year-old females in year *n* and dividing the difference by grilse escapement in year *n*-1.

Murphy applied his scheme to 13 years of silver salmon counts at Benbow Dam Counting Station on the South Fork of the Eel River in northern California and arrived at a mean value for third-year survival of 0.356. Yearly values ranged from 0.158 to 0.569.

During the developmental work at Nimbus Hatchery, histological methods were used to confirm results. The final technique, as used at Coleman Hatchery, employed gross organ detection and a dissecting microscope for organ determination.

In general, the king salmon egg taking season at Coleman National Hatchery extends from October through January. As a result, juvenile fish are growing into the easily sexable size range (i.e., > 40 mm) throughout the spring and summer months. Sampling for sex determination occurred on three occasions: June 6 and 7, July 9 and 10, and August 8, 1968.

Samples were examined in groups of ten fish each and were obtained by dipnetting. An attempt was made to examine at least one ten-fish sample for every 100,000 fish. At least one sample of ten fish was taken from the head and one from the tail end of each 8 x 80-foot concrete raceway pond, and additional samples of ten fish were taken alternately from pond heads or tails when a pond contained more than 200,000 fish. During June sampling, six ten-fish samples were taken from near the middle of the raceways.

The ten-fish samples were placed in a solution of MS222 (Tricain-Methane-sulfonate) and left there until they expired. Total length of each fish was measured prior to dissection. One author obtained length measurements and recorded sex, while the other performed dissections and made sex determinations. Tasks were alternated between authors every few samples.

RESULTS

Sex composition of 97 ten-fish samples was determined. Examination of mean lengths and standard errors reveals no significant difference with regard to sex within sample groups (Table 1). Of the 970 fish examined, 490 were males and 480 females.

Repeated observation is the only way by which the actual sex ratio can be measured; statistical tests provide little assistance. For example, the instant data certainly provide no basis for rejecting the hypothesis that the actual ratio was one-to-one. Indeed, grounds for rejection at $\underline{P}$ = .95 would have been provided only if the number of males had fallen outside the range 454-516 of 970 fish examined. Based on the evidence at hand, the best estimate of the sex ratio among fingerling king salmon in the Sacramento River is 490 males to 480 females, or 1.02:1.

DISCUSSION

Murphy estimated third-year ocean survival by solving

$$\underline{s} = \frac{\text{♀}\,\underline{n} - \text{♂}\,\underline{n}}{\text{♂}\,(\underline{n}-1)} \qquad (1)$$

where $\underline{n}$ = year of counting

For estimates where the sex ratio is other than 1:1, his formula can be modified to:

$$\underline{s} = \frac{\frac{\text{♀}\,\underline{n}}{\underline{p}} - (\text{♀}\,\underline{n} + \text{♂}\,\underline{n})}{\text{♂}\,(\underline{n} - 1)} \qquad (2)$$

where $\underline{p}$ = the proportion of females in the initial population

The term "initial population" refers to the population of fish immediately prior to the time that grilse migrate. If sex specific mortality occurs after that time, the rates must be determined so that appropriate corrections can be made to estimates of survival.

Estimates of survival derived by Murphy's method are quite sensitive to minor changes in initial sex ratio. For example, using equation (2) on Murphy's Benbow data, a change in the assumed proportion of females from 0.500 to 0.495 results in an increase in mean annual third-year survival of from 0.356 to 0.399.

TABLE 1.

Sex and Mean Length of 970 Fingerling Chinook Salmon from Coleman National Fish Hatchery June, July and August 1968

Pond area sampled	Month	Male				Female			
		Number	Length			Number	Length		
			Mean	Range	S.E.		Mean	Range	S.E.
Head	June	39	75.28	57-101	2.57	31	74.71	56-100	2.61
Middle	"	27	72.67	54-100	3.06	33	72.23	49-106	3.52
Tail	"	29	64.10	45-85	3.26	31	65.87	44-92	3.45
Head	July	81	68.38	52-110	1.61	79	68.77	51-86	1.33
Tail	"	69	64.55	49-80	1.50	81	64.47	46-82	1.43
Head	August	137	67.91	48-99	1.17	93	67.57	45-87	1.28
Tail	"	108	67.81	49-91	1.30	122	67.54	50-90	1.03
TOTALS		490				480			

TABLE 2

Release and Recovery Data from Marked 1962 Brood Year Coho Released from Washougal Hatchery 1/

	Mark		
	Ad RV	Ad LV	Ad LV LM
Number released	111,588	61,400	50,120
Fishery returns	4,665	2,761	638
Escapement			
Grilse	1,115	134	19
Adult males	1,222	597	151
Adult females	801	351	68

1/ From Senn and Noble (1967). Estimates of sex composition of escapement obtained from Senn (personal communication).

The Benbow data for the 1946-47 spawning year produced an estimate of third-year survival of 33.3 percent, almost identical to the average estimate for the 12-year period. Acceptable values of s (i.e., $0 < s < 1$) for this year are produced only when the initial proportion of females ranges between 0.435 and 0.540.

Senn and Noble (1967) describe the return rates, to fisheries and to spawning stocks, of three groups of marked coho released as yearlings in 1963 from the Washougal Hatchery in Washington (Table 2). Values of s obtained with equation (2) using the sex ratio observed among Sacramento River chinook fingerlings (proportion of females, p, = 0.495) are unreasonable ($s < 0$) in all three instances (Table 3).

Maximum possible survival among these marked groups would have been achieved if the only mortality had resulted from fishing. Since catch estimates are available from fisheries operating on the marked populations, maximum possible third-year survival can be estimated by dividing adult spawning escapement of marked groups by fishery landings plus adult spawning escapement. These values are 0.302, 0.259 and 0.256 for the Ad RV, Ad LV and Ad LV LM groups respectively (Table 3).

The relationship between s and p is inverse; solving equation (2) for p using maximum values of s produces minimum values of p, and maximum values of p can be estimated by taking limits of p as s approaches 0. The actual lower possible limit of s for each group can be approximated because the total number of marked fish released is known.

Values of p, throughout the three marked groups, which produce acceptable values of s, range from 0.304 in the Ad LV LM marks to 0.392 in the Ad RV marked group (Table 3). Assuming that fishery landing and escapement estimates are valid, the proportion of females among coho produced at the Washougal Hatchery is between 0.3 and 0.4.

Evidence is available to substantiate the premise that troll catches of both chinook and coho salmon contain more females than males. Mr. Bertel Christiensen, skipper of the troller M/V Silverside, has provided sex and species composition of his annual salmon catch for the seven-year period 1961 through 1967 (Table 4). Although Mr. Christiensen's catches were taken off central California and consisted primarily of chinook salmon, females of each species consistently outnumbered males. This situation was the rule among adult spawners at Benbow, and was also the case during the first seven or eight years of operation at Minter Creek. However, in six of the final seven years at Minter Creek discussed by Salo and Bayliff, and among the three marked groups of 1962 brood coho at Washougal Hatchery, the situation reversed itself, adult males outnumbering females.

Acceptable ranges of p can be approximated from the Minter Creek data by solving equation 2 for $s = 0.01$ and $s = 0.99$ (Table 5). No single value of p exists which produces values of s between 0.01 and 0.99 in every year. An examination of the ranges indicates that the proportion of females among coho produced at Minter Creek was reduced in the late 1940's and early 1950's from what it was in the early 1940's immediately after the station was opened. Survival estimates, assuming a 1:1 sex ratio ($p = .5$) become generally unreasonable after 1947.

Application of Murphy's method to wild coho populations (e.g., South Fork Eel River) yields acceptable survival estimates, while application to cultured stocks (e.g., propagation either alters the sex ratio among the propagated stock, or artificially-produced coho females are much more vulnerable to some mortality factor than are the males.

If fish cultural techniques alter sex ratios among juvenile populations, the ratio can be measured prior to release, and Murphy's method can be used to estimate third-year survival. Such estimates obtained by Murphy's method are quite sensitive to subtle changes in the sex ratio. Depending on the size of the population under study, it may prove necessary to actually measure the ratio rather than estimate it by sampling. This would require a very rapid sexing method which did not injure the fish. Techniques for such a procedure have yet to be developed.

TABLE 3

Maximum and Minimum Values of p and s for Marked Washougal Hatchery Coho

	Mark		
	Ad RV	Ad LV	Ad LV LM
s (p = 0.495)	- 0.0138	- 0.5097	- 2.5565
s maximum	0.302	0.259	0.256
s minimum	0.018	0.015	0.004
p maximum	0.392	0.369	0.311
p minimum	0.339	0.357	0.304

TABLE 4

Sex Composition of the Catch 1/ of the Troller M/V Silverside 1961 through 1967

Year	Chinook			Coho		
	Males	Females	Proportion Females	Males	Females	Proportion Females
1961	464	620	.572	12	19	.613
1962	396	493	.555	18	35	.660
1963	485	671	.580	52	79	.600
1964	464	551	.543	98	143	.593
1965	507	672	.570	41	49	.544
1966	246	322	.567	75	107	.588
1967	161	203	.558	159	198	.555
TOTAL	2,723	3,532	.565	455	630	.581

1/ Fish taken off Central California Coast between Half Moon Bay and Cape Mendocino

D. H. Fry, Jr. (personal communication) applied Murphy's method to silver salmon spawning counts obtained at the Washington Department of Fisheries' Minter Creek Station (Salo and Bayliff, 1958). Minter Creek data yielded unreasonable results, $\underline{s}$ 0 or $\underline{s}$ 1, in seven of 14 years, even though a basic requirement of the method is probably better met here than at Benbow. That requirement is accurate fish counts. Conditions at the Benbow Station did not always provide counts of unquestionable accuracy. This is a technical problem, however, which in no way affects the validity of the method.

Murphy's method, developed to estimate ocean survival of silver salmon, is also applicable to king salmon, although complicated by adult males and females of the same brood appearing in two or three successive spawning escapements. Furthermore, as Murphy points out, it provides a means of separating fishing mortality from total mortality when applied to groups of marked salmon when estimates of fishery contribution of marked fish are available.

In theory, the method requires two basic assumptions. First, that a one-to-one sex ratio exists in the population prior to year three; and second, that total mortality (other than spawning mortality) with respect to sex is equal. The first of these assumptions readily lends itself to testing.

A review of the literature on sex ratios of juvenile salmonids produced little information. Ricker (1958) in a description of Murphy's technique, states that sex ratios other than one-to-one have been observed in juvenile sockeye smolts. In any event, if no differential mortality occurs with regard to sex, the method will work with any sex ratio so long as the ratio is known.

Because of the potential value of Murphy's method in providing information regarding fishing, hooking and natural mortality in ocean salmon populations, we undertook to measure the sex ratio of hatchery-produced juvenile king salmon at Coleman National Fish Hatchery on the upper Sacramento River.

METHODS

The subject of sex determination is fundamental in comparative anatomy texts, yet the literature was almost barren of publications specific to sexing immature salmonids. Wiesel (1943), Robertson (1958), and Robertson and Rinfret (1957) provided information which aided in the development of a technique.

Initial work was accomplished at the Nimbus Salmon and Steelhead Hatchery on the American River near Sacramento to determine the minimum size at which sex could be readily determined. King salmon fry in the size range from 30 to 40 mm total length were isolated in circular tanks and sampled periodically to determine stage of gonadal dimorphism.

The fish were opened ventrally by an incision started at the gill isthmus and continued posteriorly to the vent. A second incision was made from immediately posterior to the pectoral fin into the dorsal musculature. The flap thus formed was lifted for entry into the body cavity. Care must be used to maintain an intact air bladder, as it is extremely difficult to detect the gonads once the air bladder has been deflated. They are held in contour with the air bladder from its most anterior ventral surface.

Tissue preparation was not required for sex determination once specimens had reached 42 to 44 mm in total length. At this size, gonads can be distinguished by shape as well as texture and surface appearance. Ovaries are relatively enlarged in the anterior portion and taper to become undistinguishable from the mesenteries in the area below the origin of the dorsal fin. They are mushy in texture and exhibit a tapioca-like appearance under a dissecting microscope. Testis are smooth, narrow bands of tissue, uniform in cross section and extend to a point well beyond the insertion of the dorsal fin. Testis respond elastically to teasing with forceps and if pulled away will coil upon breaking.

Microscopic examination was necessary to determine sex of the smallest fish (i.e., 40 mm or less). Phase microscopy was employed for squashed preparations and also for frozen cross sections that were manually cut and mounted in glycerol. Developing ova were observed in ovaries of the smallest fish.

TABLE 5

Coho Salmon Counts at Minter Creek [1] and
Estimates of Survival (s) and Proportion Females (p)

Year	♂	♀	Jacks Year-1	s, when p = .5	p, when s = 0.01	p, when s = 0.35	p, when s = 0.99
1939	673	915	679	0.356	0.574	0.501	0.405
1940	1,314	1,574	433	0.600	0.544	0.518	0.474
1941	921	1,160	860	0.278	0.555	0.487	0.396
1942	759	821	502	0.124	0.518	0.468	0.395
1943	978	1,015	662	0.056	0.507	0.456	0.383
1944	1,787	1,959	349	0.493	0.522	0.506	0.749
1945 [2]			166				
1946	719	1,034	134	2.351	0.589	0.574	0.548
1947 [2]			179				
1948	357	291	39	-1.692	0.448	0.440	0.424
1949	1,181	1,140	44	-0.932	0.491	0.488	0.482
1950	964	807	178	-0.882	0.455	0.440	0.414
1951	637	598	68	-0.574	0.484	0.475	0.459
1952	1,282	1,536	290	0.876	0.544	0.526	0.495
1953	943	737	55	-3.745	0.439	0.434	0.425
1954	593	441	75	-2.027	0.426	0.416	0.398

[1] From Salo and Bayliff (1958)

[2] Counts incomplete

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