METHOD USED TO DISTINGUISH BETWEEN IMMATURE AND MATURING SOCKEYE AND CHUM SALMON TAKEN BY CANADIAN EXPLORATORY FISHING VESSELS IN THE GULF OF ALASKA

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ABSTRACT

Immature and maturing sockeye and chum salmon were distinguished on the basis of an index of maturity, which was the ratio of the weight of the gonads to the total body weight. Among fish classified as "immature" the index remained low and relatively constant throughout the fishing season (May-August). Among "maturing" fish the index increased sharply during the same period. Arbitrary limits of the index were proposed to separate the two kinds of fish. The method does not permit positive identification of maturity in the case of "immature" fish taken very early in the season that might have begun to mature at a later date had they not been caught.

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INTRODUCTION

In accordance with commitments to the International North Pacific Fisheries Commission, two Canadian vessels have fished for salmon in the Gulf of Alaska each summer since 1956. The periods of operation have extended from about mid-May through August, and the vessels have gone as far west as 160° West Longitude, and as far south as 42° North Latitude. The purpose has been to provide information on the distributions and migrations of the salmon.

Salmon were frozen on board at the time of capture and were brought back for examination. A method was sought to distinguish between maturing fish that would have spawned in the year they were caught and immature fish that would have remained in the ocean one or more years longer.

This paper describes how the 1957 catch data were used to identify the two kinds of fish among sockeye (*Oncorhynchus nerka*) and chum (*O. keta*) salmon. The information obtained is being used by INPFC in describing the distribution of salmon in the North Pacific, and in relating their distribution to oceanographic features and areas of origin.

The data collected from the 1957 operations have been distributed in multilithed form (Manzer and Neave, 1958).

The "Index of Maturity" used herein (which will be referred to hereinafter as the Index) is the ratio of the weight of both gonads to the total body weight expressed as a percentage—that is, gonad weight $\times 100$/body weight. The Index is used to distinguish between fish, irrespective of their size, in which the gonads had begun to enlarge and mature, and those in which they remained undeveloped. Fish were thawed before weighing, and in 1957 body weight was determined by weighing in pounds and ounces to the nearest ounce (later converting to grams), and gonad weight in grams by weighing to the nearest tenth of a gram.

METHOD

The method of using the Index to distinguish between maturing and immature fish was to arrange frequency distributions of the Index in chronological order, according to period of capture. When this was done, it was noted that for one group the magnitude of the Index remained low and showed little or no seasonal change, whereas among the remainder the value of the Index increased as the season progressed. Arbitrary limits of the Index were then

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applied, defining fish of the first group as the " immature " and those of the second as the " maturing ".

Pink salmon (*O. gorbuscha*) in their second year of life (i.e., in their second year of ocean residence) were used first in order to test the method, by noting the the seasonal shift in the Index from a low to an increasingly greater value, among fish that would definitely have matured and spawned in the year they were caught (known exceptions to this age at maturity being extremely rare among pink salmon).

The results for pink salmon are shown in Figure 1 for males, and in Figure 2 for females. In Figure 1, it can be seen that, as the season progressed, there was a shift of the Index to the right, or, in other words, an increase in its average value. After mid-June, all Indices had a value greater than 0.1, and all values of less than 0.1 had occurred in the early mid-May to mid-June period. Of course, even the earliest pinks with the lowest Index values might actually have been in the first stages of maturing at the time of their capture, but arbitrarily, Indices of less than 0.1 and greater than 0.1 are applied to distinguish between the " immature " and " maturing ", respectively. This would place only 5 fish in the former category, all of which had been caught early in the season. It should also be noted that in some fish the gonads had begun to increase in weight considerably as early as mid-June, giving high Indices of between 2.0 and 3.0.

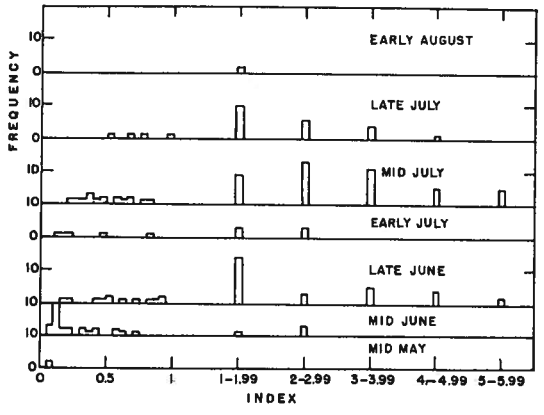

FIGURE 1. Frequency distributions of the Index of Maturity for 2-*year-old male pink salmon*, by seasonal periods.

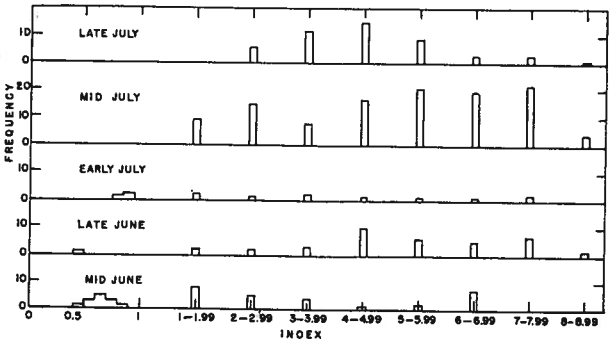

FIGURE 2. Frequency distributions of the Index of Maturity for 2-*year-old female pink salmon*, by seasonal periods.

The smallest gonads occurring were taken from the first male caught, in mid-May. Its body and gonad weight were 709 g. and 0.3 g., respectively, which gave the lowest Index value of 0.04.

In the case of the female pink salmon (Figure 2), there was already as early as mid-June a wide range in Index values, from less than 0.5 to almost 7.0. Indices of less than 1.0 were present during mid- and late June and in early July, but not thereafter. Arbitrary values of the Index for separating the " immature " and the " maturing " females are set at <1.0 and >1.0.

The smallest ovaries found weighed 4.8 g., and came from a fish that weighed 794 g., taken in mid-June (Index of 0.6, approximately).

RESULTS

SOCKEYE SALMON

3_2 Male Sockeye

Among 3_2 male sockeye (as also among the 4_2 and 5_2 fish, which are discussed below), there might be fish that would have spawned in the year they were captured, and others that would not until one or more years later.

As shown in Figure 3, two groups of fish are distinguishable on the basis of body weights, gonad weights and Index values (the logarithms of the gonad weights have been used to accommodate the great range in values).

By body weight, 51 fish are identified as immature, being under 1,000 g., and 31 as maturing, being over 1,200 g. The single exception, a fish of 1,077 g., was probably immature, since its gonad weight was only 0.2 g., giving it a very low Index of 0.02.

By gonad weight, there were 56 immature fish having gonad weights ranging from 0.1 to 3.4 g. The gonad weight of the 27 maturing fish ranged from 6.5 to 43.5 g.

According to the Index, there were 50 immature fish having values of 0.2 or less, and 33 maturing fish having values greater than 0.2.

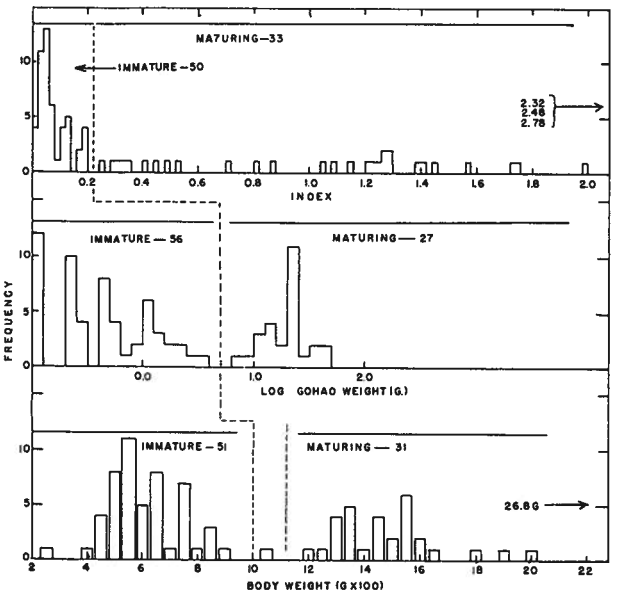

FIGURE 3. Frequency distributions of body weights, $\log_{10}$ gonad weights, and the Index of Maturity for 3-*year-old male sockeye salmon.*

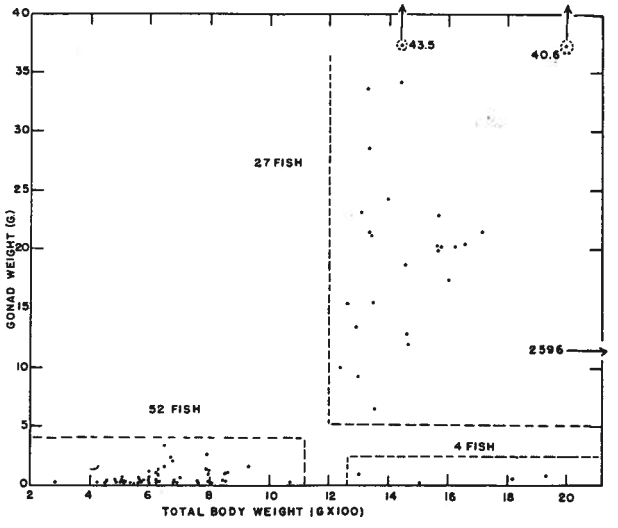

FIGURE 4. Plot of gonad weight vs. total body weight, for 3-*year-old male sockeye salmon.*

The two groups of fish may also be discerned in Figure 4, where the gonad weights are plotted against the total body weights. This figure also shows that, beyond a certain minimum body weight, the weights of the gonads vary greatly, irrespective of the size of the fish, depending upon their degree of maturation.

The actual identification of individual fish can be improved by considering all three properties of body weight, gonad weight and Index. Thus, several of the fish with body weights greater than 1,000 g. were undoubtedly immature at the time of their capture, since they had very small gonads. The fish of 1,077 g. noted above is one example, and others are the four large fish with very small gonads that are shown in Figure 4. Conversely, there were also a few small fish that had relatively large gonads, that may have been maturing. By considering the three properties, it is estimated that there were altogether 51 immature and 32 maturing fish in the sample.

The seasonal increase in the Index among the maturing fish, and the presence throughout the season of immature fish with Indices of less than 0.2, may be seen in Figure 5.

At this point, it should be noted that the method does not allow for certainty in identification in the case of fish classified as " immature " that might have begun to mature at a later date had they not been

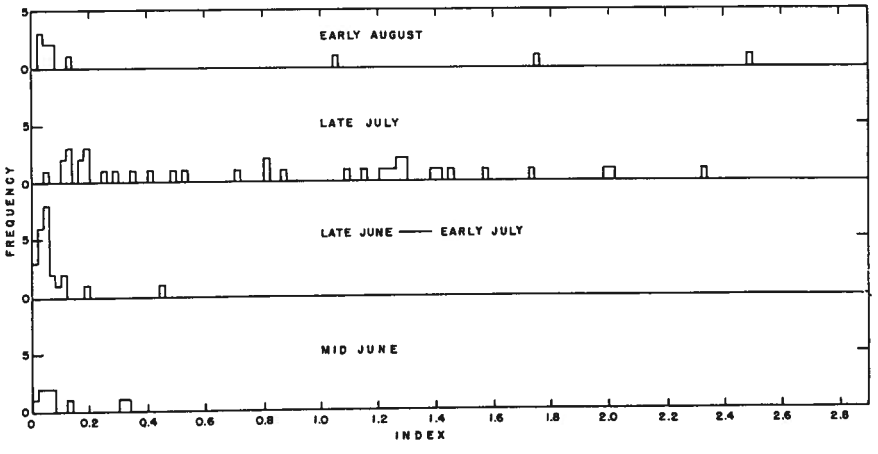

FIGURE 5. Frequency distributions of the Index of Maturity for 3-*year-old male sockeye salmon*, by seasonal periods.

caught. This applies particularly to fish taken early in the season (and, of course, to other ages and species also).

3_2 Female Sockeye

Since extremely few female sockeye salmon mature in their third year of life this age-group needs here only a cursory examination. According to Figure 6, there appears to have been a slight seasonal increase in the relative weights of the gonads, but this is not too certain. The largest Index obtained was 0.55 (body weight 652 g., gonad weight 3.6 g.), which was still much below the 1.0 upper limit for immature 4_2 female sockeye, as determined below.

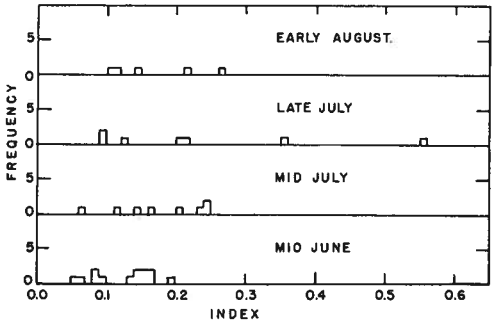

FIGURE 6. Frequency distributions of the Index of Maturity for 3-*year-old female sockeye salmon*, by seasonal periods.

4_2 Male Sockeye

The Indices are shown in Figure 7, where it may be seen that throughout the season there were present fish with Indices of less than 0.1, and that progressively through the season the average value of the Index among fish with Indices greater than 0.1 increased. The former group is therefore identified as the immature, and the latter as the maturing.

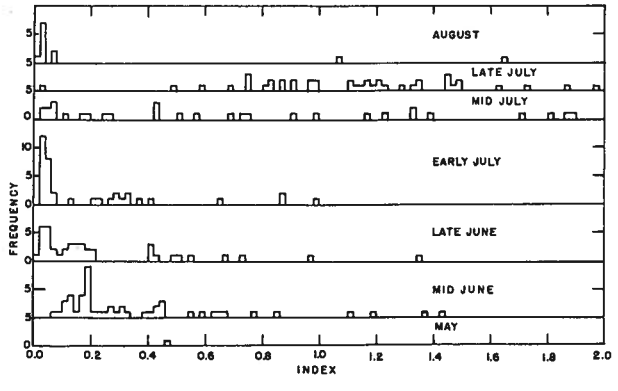

FIGURE 7. Frequency distributions of the Index of Maturity for 4-*year-old male sockeye salmon*, by seasonal periods.

Histograms of gonad weights by period of capture are shown in Figure 8. Here, a group with gonad weights of less than 2 g. was present all season, while the average value for those with gonads weighing more than 2 g. increased. Thus, gonad weights of more than 2 g. separate the maturing from the immature fish.

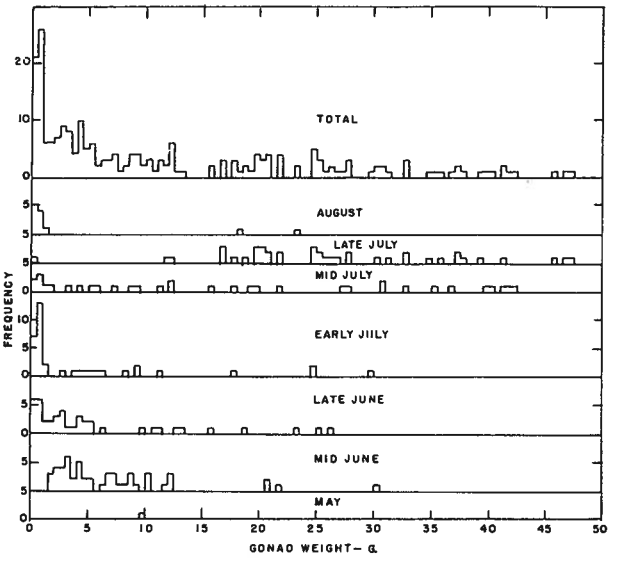

FIGURE 8. Frequency distributions of the gonad weights of 4-*year-old male sockeye salmon*, by seasonal periods.

Of the fish that were described as maturing by Index value of more than 0.1, all but one had testes weighing more than 2 g., and the exception weighed just 2 g. No fish with testes weighing more than 2 g. had an Index lower than 0.1.

4_2 Female Sockeye

Histograms of the Index are shown in Figure 9. Throughout the season, from mid-June to August, fish having Indices of less than 1.0 were present. The average value of the Index for the remainder increased progressively during the season. Thus, Index values of less or more than 1.0 are used to distinguish between the two kinds of fish.

Gonad weights are shown in Figure 10, and limits of less and more than 10 g. appear to separate the immature from the maturing fish, respectively.

With the exception of a few fish taken early in the season, whose Indices were only slightly below 1.0, all fish with an Index of less than 1.0 had gonads weighing less than 10 g. Furthermore, only three fish with gonad weights greater than 10 g. had Indices less than 1.0. Two of these were taken in early July and might have matured later, but it is unlikely that the third

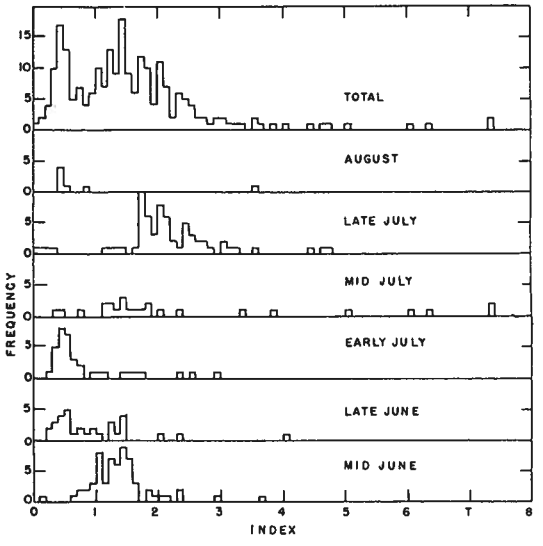

FIGURE 9. Frequency distributions of the Index of Maturity for 4-*year-old female sockeye salmon*, by seasonal periods.

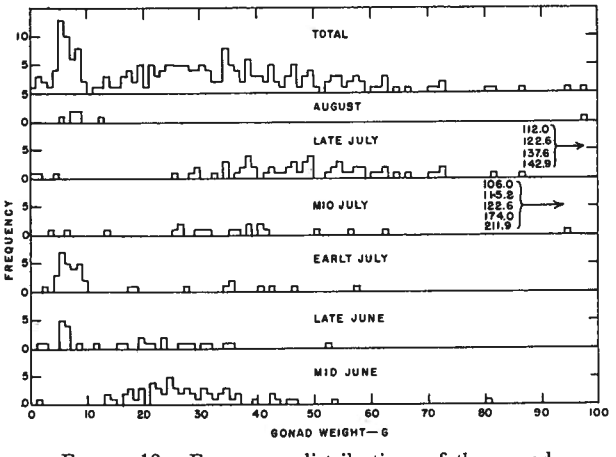

FIGURE 10. Frequency distributions of the gonad weights of 4-*year-old female sockeye salmon*, by seasonal periods.

would have done so, since it was taken as late as mid-August. Again, it is possible that some of the "immature" fish that were caught early might have begun to mature at a later date had they not been caught.

5_2 and 5_3 Male and Female Sockeye

In the 1957 catches, fish of these age groups were too few for adequate recording of seasonal changes in the relative weights of the gonads. However, examination of data from later years indicates that Index limits for separating the immature from the maturing among these age groups must be approximately the same as for the 4_2 fish. The frequency distributions of the Index and the gonad weights for 5_2 males and females are shown in Figure 11.

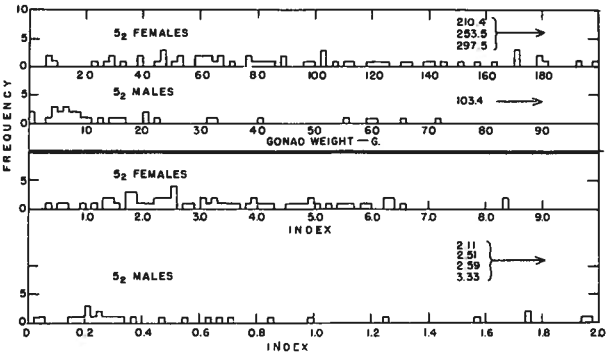

FIGURE 11. Frequency distributions of the Index of Maturity and the gonad weights of 5-*year-old male and female sockeye salmon.*

CHUM SALMON

2-Year-Old Male and Female Chum Salmon

The 2-year-old chum salmon provided an opportunity of observing seasonal changes in the ratio of gonad weight to body weight among fish that would have remained immature one or more years longer. Figure 12 shows the seasonal distribution of the Indices for both sexes.

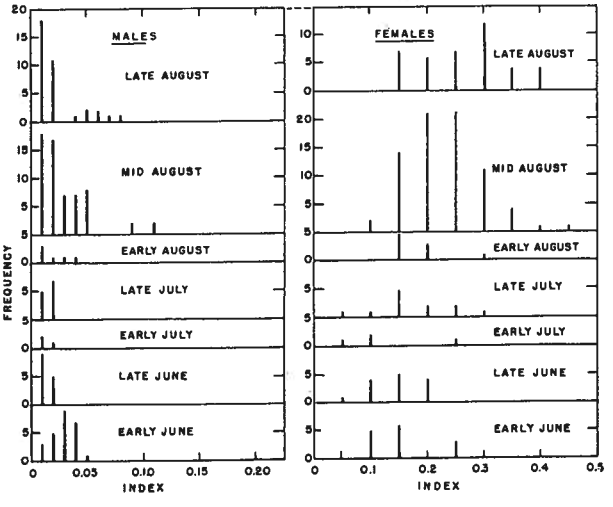

FIGURE 12. Frequency distributions of the Index of Maturity for 2-*year-old male and female chum salmon*, by seasonal periods.

Among the females, there was a slight seasonal increase in the average value of the Index (roughly, from 0.15 to 0.30). Had this increase continued during the ensuing months, Indices for some females would have reached or even exceeded a value of 1.0 by the time of first fishing operations in the next year. These would then be regarded as the maturing fish, since, as is discussed below, the identification of maturing 3-year-old female chum salmon is based upon

their having an Index value greater than 1.0.

Partly because of the very small range in values, a seasonal increase in the Index for males was less noticeable than for the females, but probably did occur. All values remained below 0.1, with the great majority lying within the 0.01–0.05 range. Again, it could be expected that by the following spring the Index for some of the fish would have reached or exceeded the 0.1 level, which, as discussed below, is taken as the upper limit for immature 3-year-old male chum salmon.

3-Year-Old Male Chum Salmon

The histograms of Figure 13 indicate that the upper limit of the Index for immature male chum salmon is about 0.1, and that higher values identify the maturing fish.

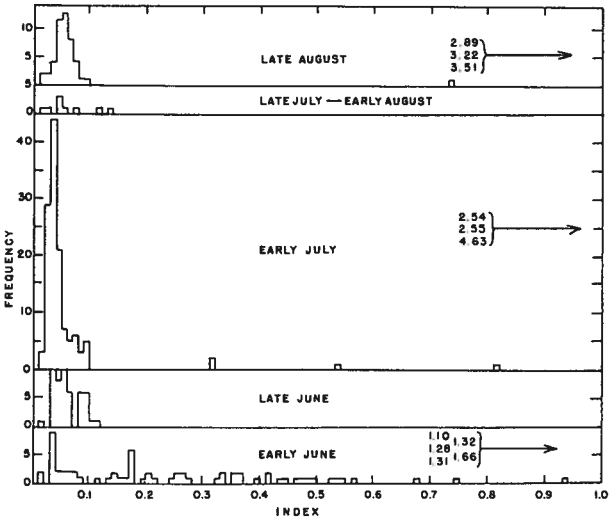

FIGURE 13. Frequency distributions of the Index of Maturity for 3-*year-old male chum salmon*, by seasonal periods.

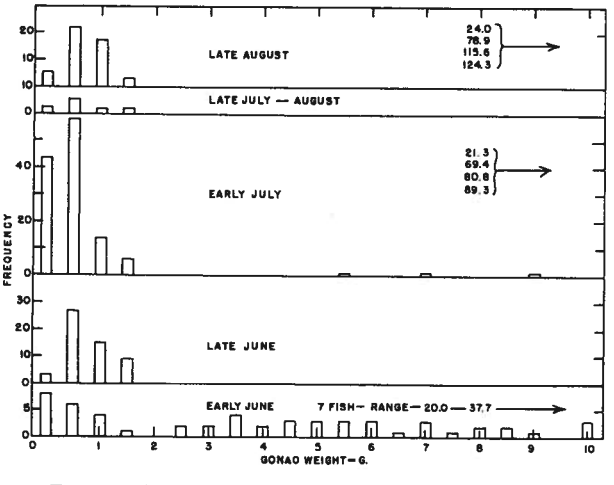

FIGURE 14. Frequency distributions of the gonad weights of 3-*year-old male chum salmon*, by seasonal periods.

The seasonal distributions of the gonad weights are shown in Figure 14, and an upper limit of 2 g. would appear to separate the immature from the maturing fish, on this basis.

There was good agreement between the two methods. By both Index and gonad weight, about 80 per cent of the 3-year-old male chum salmon were identified as immature fish.

Maturing male chums with high Indices were found in the earliest period (early June).

3-Year-Old Female Chum Salmon

According to Figure 15, the upper limit for immature 3-year-old female chum salmon was an Index of about 1.0. Maturing female chums were also present in early June.

By gonad weight (Figure 16), an upper limit of about 15 g. separated the immature from the maturing females, although the value may have increased some-

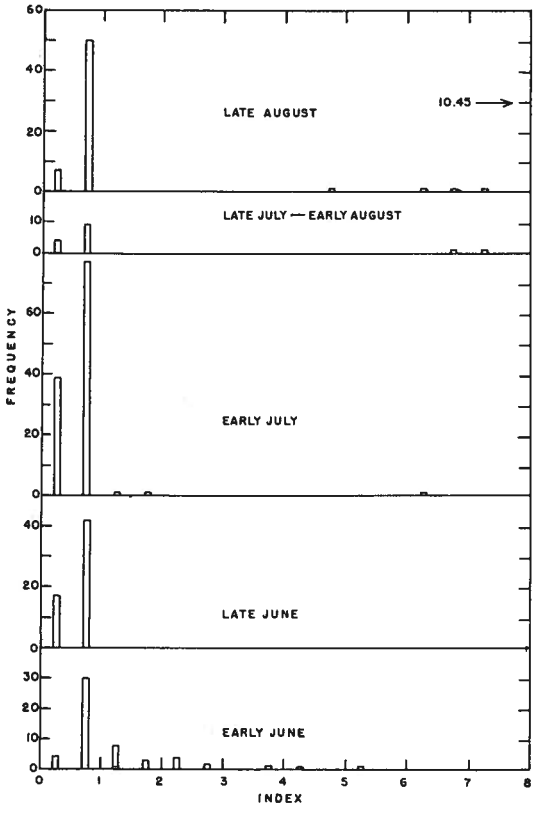

FIGURE 15. Frequency distributions of the Index of Maturity for 3-*year-old female chum salmon*, by seasonal periods.

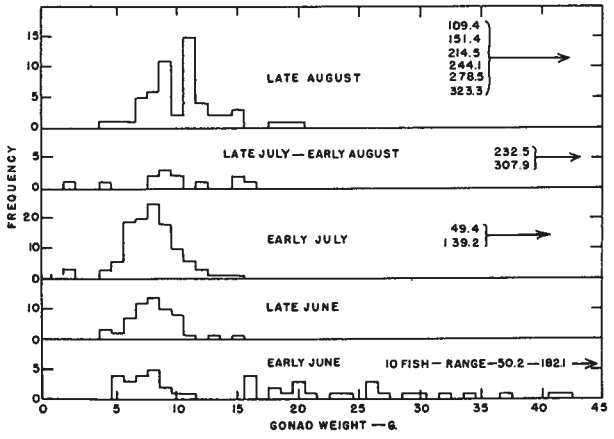

FIGURE 16. Frequency distributions of the gonad weights of 3-*year-old female chum salmon*, by seasonal periods.

what during the season. By both Index and gonad weight, about 90 per cent of the female 3-year-old chum salmon were immature.

4-Year-Old Male Chum Salmon

Using Index and gonad weight (Figures 17 and 18) in the same manner as above, upper limits for immature 4-year-old male chum salmon were set at 0.1 Index, and 2.0 g. gonad weight. By both methods about 34 per cent of these fish were found to be immature.

4-Year-Old Female Chum Salmon

According to Figures 19 and 20, upper limits of Index and gonad weight for immature 4-year-old female chum salmon appear to be about 1.0 and 20 g., respectively. This was the same Index limit that was applied to the immature 4_2 female sockeye, but the gonad limit for the sockeye was only 10 g. This could be expected, since the average body weight

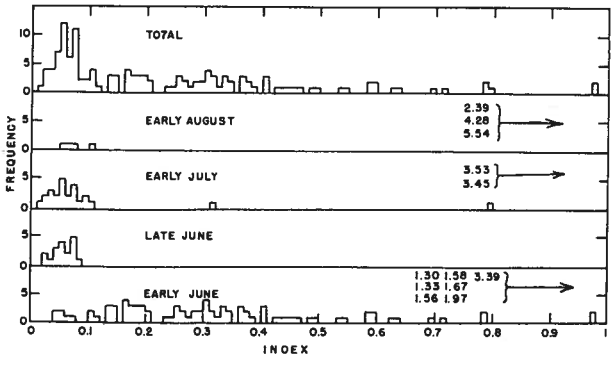

FIGURE 17. Frequency distributions of the Index of Maturity for 4-*year-old male chum salmon*, by seasonal periods.

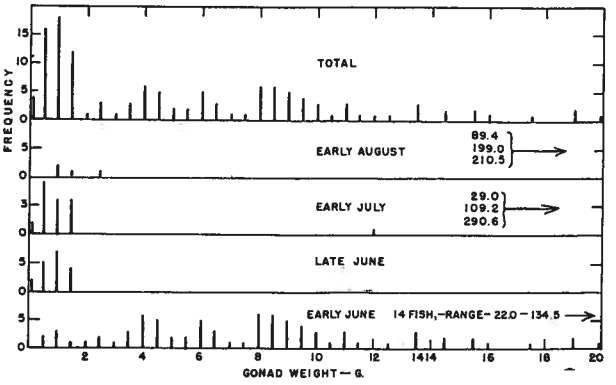

FIGURE 18. Frequency distributions of the gonad weights of 4-*year-old female chum salmon*, by seasonal periods.

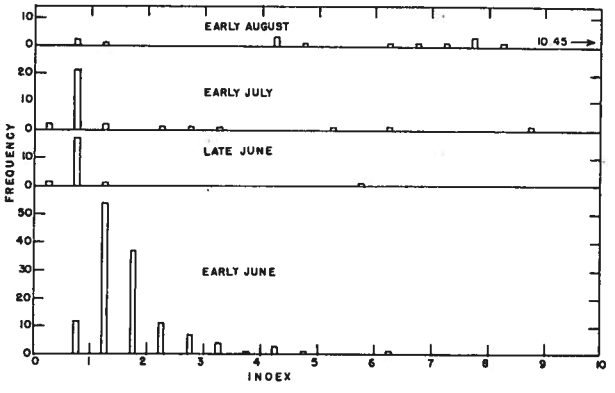

FIGURE 19. Frequency distributions of the Index of Maturity for 4-*year-old female chum salmon*, by seasonal periods.

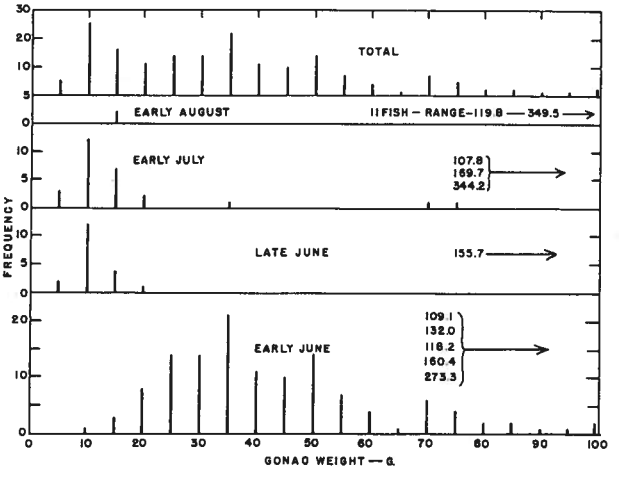

FIGURE 20. Frequency distributions of the gonad weights of 4-*year-old female chum salmon*, by seasonal periods.

(and doubtlessly gonad weight also) of 4-year-old female chum salmon is appreciably greater than that of 4_2 female sockeye salmon.

Also, the 20 g. gonad weight limit for the 4-year-old chum females is greater than the 15 g. limit for the 3-year-old chum females. Again, this is reasonable, because of the greater average size of the 4-year-old fish. The Index limits for both ages were the same. (There may have been similar differences between the 3- and 4-year-old male chums, and between the 4-year-old male chums and male sockeye salmon, but the very small range in weights of the male testes up to 2 g. made such differences less readily discernible.)

season. Thus, the former fish were designated as the " immature " and the latter as the " maturing ", and Index limits were noted which identified the two kinds.

There was some evidence, particularly among the females, that even among the non-maturing fish the relative weight of the gonads increased slightly over the season.

The differences between immature and maturing fish, in Index value and in actual gonad weight, were sufficiently distinct to permit their separation according to the following limits:

Fish	*Immature*		*Maturing*	
	Index	*Gonad weight*	*Index*	*Gonad weight*
3_2 male sockeye	<0.2	< 3.5 g.	>0.2	> 6.5 g.
(Also, in 1957, immature fish had body weights of <1,000 g.; maturing fish of >1,200 g.)				
3_2 female sockeye—Probably none would have matured in the year of their capture, and the highest Index obtained was about 0.6.				
4_2 male sockeye	<0.1	< 2 g.	>0.1	> 2 g.
4_2 female sockeye	<1.0	<10 g.	>1.0	>10 g.
5_2 and 5_3 male & female sockeye—The sample numbers were small but Index limits appeared to be similar to those of 4_2 fish.				
2-year male & female chums—None would have matured in the year of their capture. The Index did not exceed 0.05 for the males and 0.3 for the females.				
3-year male chums	<0.1	< 2 g.	>0.1	> 2 g.
3-year female chums	<1.0	<15 g.	>1.0	>15 g.
4-year male chums	<0.1	< 2 g.	>0.1	> 2 g.
4-year female chums	<1.0	<20 g.	>1.0	>20 g.

By both Index and gonad weight about 26 per cent of the 4-year-old female chum salmon were immature.

SUMMARY AND DISCUSSION

The weight of the gonads expressed as a percentage of the total body weight (the Index of Maturity) has been used to distinguish between maturing and immature sockeye and chum salmon taken in the Gulf of Alaska in 1957. In some instances, also, the actual body weights and gonad weights were used for the same purpose. However, whereas the Index limits employed to separate the two kinds of fish might be expected to remain fairly constant from year to year, body weights and gonad weights could be expected to vary considerably according to annual changes in rates of growth.

The use of the Index for the purpose indicated depended upon the fact that among some fish the Index remained low and fairly constant throughout the fishing season. Among the remainder the average value of the Index increased progressively over the

Use of the Index did not permit certainty of maturity identification in the case of " immature " fish that were caught very early in the season, which might have begun to mature at a later date had they not been caught.

In 1956 and 1957, Japanese biologists sampled sockeye, pink and chum salmon taken by the high-seas commercial fishery in the northwestern Pacific and in the Okhotsk Sea, and observed the seasonal variation in the weights of the gonads (Ishida and Miyaguchi, 1958). Using the actual gonad weight (not the ratio of gonad weight to body weight) they concluded that both sockeye and chum female salmon with ovaries weighing more than 20 g., and both sockeye and chum male salmon with testes weighing more than 2 g., were maturing fish. They also stated that fish with smaller gonads than the above " would wait another year before spawning ", although it might have been better to have noted merely that they were " immature " fish, since some, particularly those taken early in the season, might have begun to mature at a later date.

The present results are in general agreement with those of Ishida and Miyaguchi (1958), but the use of the Index has made it possible to improve the differentiation between the two kinds of fish. This was because the Index indicated the maturation of the fish irrespective of differences in the actual sizes of fish. Thus: (a) for 4_2 female sockeye the upper limit for gonad weight in immature fish was 10 g. (Index 1.0) rather than 20 g.; (b) the upper limit for gonad weight in 3-year-old immature female chum salmon was only 15 g. (Index 1.0); (c) the upper limit for immature 4-year-old female chums was 20 g. (Index 1.0), which was higher than that for the 3-year-old fish. These differences appear reasonable, since in the 4-year age class chum salmon are heavier fish than sockeye salmon, and 4-year-old chums are heavier than 3-year-old chums.

Sexual maturation in animals is a complex phenomenon and, in the case of salmon at sea, is one which would be most difficult to study throughout its course. The data used here were acquired in the process of sampling salmon for racial studies, and they do not lend themselves well to attempting more precise definitions of the stages of maturation. It is hoped that they have been useful in separating with reasonable accuracy the maturing from the non-maturing fish, which is, apparently, an urgent need in several fields of INPFC investigations.

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