FLUCTUATIONS IN THE SUPPLY OF HERRING, *CLUPEA PALLASII*, IN PRINCE WILLIAM SOUND, ALASKA

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INTRODUCTION [1]

The herring fishery of Prince William Sound has been marked by fluctuations in the abundance, size, and quality of fish. The effect on the industry has been widespread and harmful. Companies have lost large sums owing to temporary fluctuations in abundance or to changes in the proportions of large herring suitable for pickling. The stabilization of the yield of this fishery constitutes an important economic problem for solution.

The main causes for these fluctuations in abundance are twofold: First, inequality in the numerical strength of the annual increments to the population proceeding from each year class; and second, insufficient numbers of older fish, caused by a too intensive fishery. The first cause of fluctuations can not well be controlled, as the success or failure of a spawning appears to depend chiefly on the surface temperature of the ocean. Knowing that such fluctuations in the annual increments to the population are bound to occur, it is obvious that the fishery can not be stabilized unless it draws chiefly upon the older fish, which should form a reservoir of sufficient size to be able to bridge gaps of a few years with very small increments to the population, without causing too large or too sudden a decrease in the yield of the fishery. This paper deals chiefly with the problem of securing this optimum yield.

The methods of collecting and analyzing the data are similar to those given in a previous report by the senior author (Rounsefell, 1930).

[1] The authors wish to acknowledge the criticism of Dr. Frederick A. Davidson on the section on local populations. Submitted for publication, Oct. 14, 1931.

THE FISHERY

EARLY HISTORY AND DEVELOPMENT

Although the Prince William Sound herring fishery originated at a comparatively recent date, only a few scattered references indicate when it had its inception. In 1913 the Prince William Sound Fish Co. reported to the United States Bureau of Fisheries pickling 20,000 pounds of herring, and selling 1,600 pounds as halibut bait at Kiniklik. In 1914 the Pacific Fishermen credits this company with 42,800 pounds of pickled herring, and also refers to a company in Valdez handling herring exclusively. In 1915 the only reference in the Pacific Fishermen is of a shipment of 2,400 pounds of herring from Seward. In 1916 the same journal mentions the establishment of a herring saltery by J. A. Linseth at Kiniklik.

In 1917, to offset the shortage of imported herring caused by the World War, the United States Bureau of Fisheries sent Aug. H. D. Klie and several assistants to Alaska to introduce the Scotch method of curing herring, hoping thereby to prepare a commodity acceptable to the general trade. Clarence L. Anderson was assigned to the Prince William Sound region. In that year 137,400 pounds of pickled herring (229,458 raw) were recorded from Cordova, Kiniklik, and Evans Bay. In addition, a cold storage plant was built at Seward that sold 125,000 pounds of herring as halibut bait.

The Prince William Sound fishery can really be said to date from 1918. Owing to the World War, prices of foodstuffs were high. As a consequence, in that year, plants were built at Thumb Bay, Latouche, and Evans Bay. For the first time operations were begun in the early summer instead of waiting until the fish schooled near the spawning grounds in the late fall and winter, at which time, although the fish are more easily caught, they are too thin to be of much value.

The 1918 pack was, in general, poorly prepared. As a result the operators had difficulty in marketing, and prices were low. However, the larger fish taken in Prince William Sound gave the packers in this district an advantage over those in southeastern Alaska, as the buyers would not accept the smaller selections. Thus in southeastern Alaska the quantities of herring used for pickling fell from 21,000,000 pounds in 1918 to 5,400,000 pounds in 1919, while in Prince William Sound 7,200,000 and 7,100,000 pounds were used in the two years.

The canning of kippered herring was initiated in 1916 in southeastern Alaska, reaching a peak in 1919 of 5,000,000 pounds in southeastern Alaska and 2,600,000 pounds in Prince William Sound. All efforts to find a satisfactory market failed, however, and this project was abandoned.

In 1920 two reduction plants were installed to handle the waste from the pickling operations (Table 1), utilizing 10,400,000 pounds of herring.

TABLE 1.—*Capacity of Prince William Sound reduction plants in tons of fish used per hour*

Location of plant	Years operated										
	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
Thumb Bay	2	-------	2	2	2	2	2	2	2	2	2
Port Ashton	4	4	4	4	4	4	4	4	4	-------	-------
Port Benny	-------	-------	-------	2	2	2	2	2	-------	-------	-------
Crab Bay	-------	-------	-------	-------	2	2	2	2	2	2	10
Sawmill Bay	-------	-------	-------	-------	2	2	2	2	2	2½	2½
Drier Bay	-------	-------	-------	-------	2	2	2	[1] 2	-------	-------	-------
Port Benny	-------	-------	-------	-------	-------	4	4	4	-------	[2] 4	4
All plants	6	4	6	8	14	18	18	[1] 17	10	[2] 8½	18½

[1] Drier Bay plant operated for only few days early in season, so rated at one-half capacity in the total for all plants.
[2] Port Benny plant used only one seine boat, so rated at one-half capacity in the total for all plants.

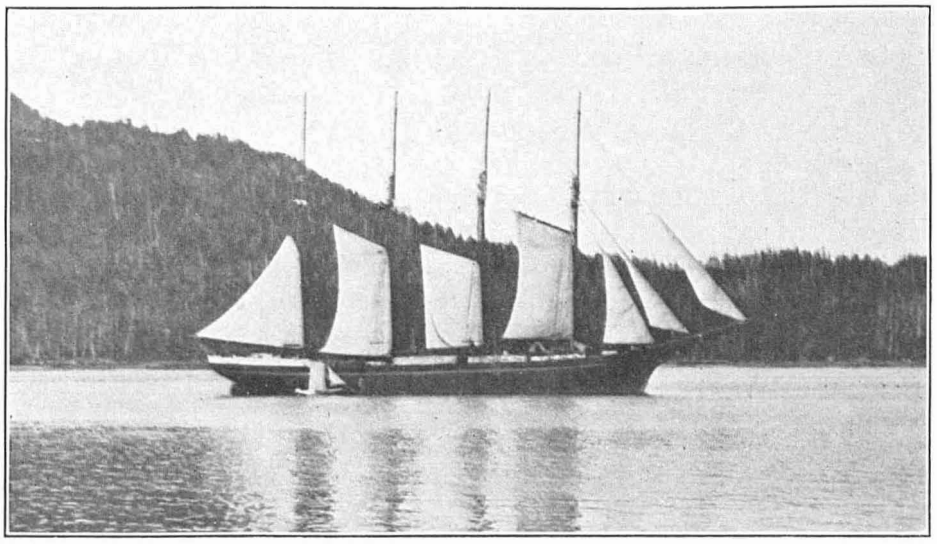

FIGURE 1.—Schooner *Alice Cooke*, a typical floating herring saltery in Evans Bay in June, 1928. Later in the season she operated in the Kodiak-Afognak and Aleutian Islands districts

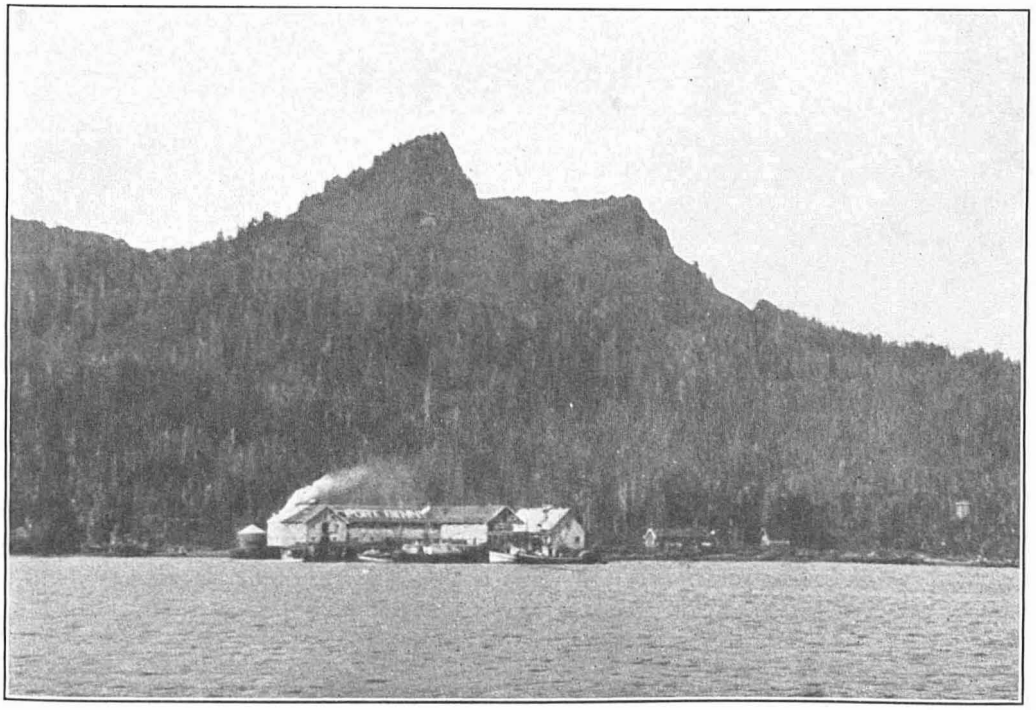

FIGURE 2.—Saltery and reduction plants at Port Benny, Evans Bay. Built in 1921 as a saltery, a 2-ton reduction unit was added in 1923 and a 4-ton reduction unit in 1925. Taken in July, 1926

In 1921 the prices of fish oil and fish meal were so low that the Thumb Bay plant did not operate the reduction unit, and the Port Ashton plant utilized but 1,900,000 pounds in this manner. The amounts used for pickling increased, however, from

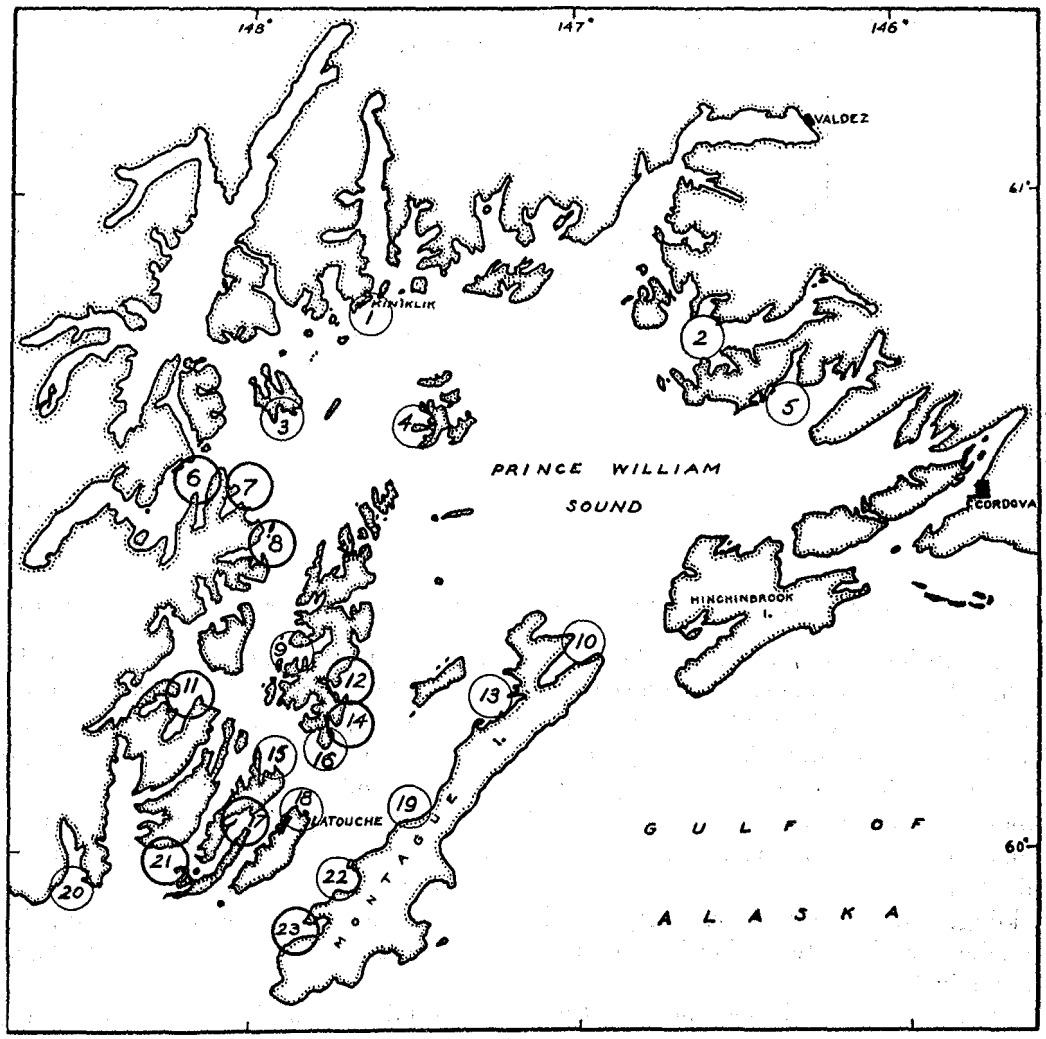

FIGURE 3.—Past and present fishing grounds of Prince William Sound. The more important grounds are indicated by heavier circles. 1, Kiniklik; 2, Port Fidalgo; 3, Perry Island; 4, Naked Island; 5, Port Gravina; 6, McClure Bay; 7, Main Bay; 8, Eshamy Bay; 9, Drier Bay; 10, Zaikoff Bay; 11, Whale Bay; 12, Snug Harbor; 13, Port Chalmers; 14, Hogan Bay; 15, Shelter Bay; 16, Point Helen; 17, Evans Bay; 18, Sleepy Bay; 19, Glacier Bay; 20, Puget Bay; 21, Elrington and Prince of Wales Passages; 22, Hanning Bay; and 23, Macleod Harbor

9,200,000 pounds in 1920 to 16,700,000 pounds in 1921, in spite of the loss by fire of the W. J. Imlach plant at Port Benny in Evans Bay.

The success met with in marketing the 1921 pickled herring pack resulted in more operators establishing plants in this district in 1922. The number of plants increased from 5 in 1921 to 9 in 1922 (a very small amount was also pickled at Cordova), and the number of purse seine boats employed increased from 9 to 18. (Table 2.) The prices of fish oil and fish meal had not wholly recovered from their 1921 slump, and only 6,800,000 pounds of herring were diverted for this purpose.

This amount must be considered as waste incidental to pickling operations. The companies were all attempting to make as large a pack as possible of pickled herring, 37,100,000 pounds being so utilized.

TABLE 2.—*Number of boats fishing in Prince William Sound weighted according to per cent of season's catch taken during portion of season they fished in the sound*

Year	Actual number of boats						Number of boats weighted by per cent of total average seasonal catch taken during period each boat fished in Prince William Sound [1]
	Fishing only in Prince William Sound	Fishing in Prince William Sound until opening of season at Kodiak-Afognak district	Fishing in Prince William Sound until opening of season at Kodiak-Afognak district and returning about Sept. 3	Fishing in Prince William Sound until leaving for Cook Inlet about Aug. 4	Fishing in Prince William Sound until leaving for Dutch Harbor about Aug. 4	Fishing in Prince William Sound until leaving for Dutch Harbor about Aug. 4 and returning about Sept. 12	
1918	10						10
1919	7						7
1920	8						8
1921	9						9
1922	18						18
1923	20						20
1924	13	4	1	7			18.29
1925	12	6	2	6			13.20
1926	10	8	1	2			10.48
1927	7	7		7			12.31
1928	6	15		2	1	2	12.59
1929	10						7.23
1930	8						5.78

[1] Per cent taken during each part of the season was computed from the table of the average catch per boat per 10-day period.

A considerable quantity of the large 1922 pack still remained on the market in 1923. As a consequence, less effort was made to pickle herring, the amount so used decreasing from 37,100,000 pounds in 1922 to 19,700,000 pounds in 1923. The decline in the amount pickled may be ascribed partially to scarcity of large pickling fish during the late summer, as by this time a demand for 1923 fish had become apparent and the packers made belated efforts to obtain a pack. A small reduction plant was installed in 1923 at Port Benny, increasing the total capacity of all of the reduction units from 6 to 8 tons of raw fish per hour. Owing also to less interest in pickling, and to complete recovery of oil and meal prices from the 1921 slump, the poundage used for reduction increased from 6,800,000 pounds in 1922 to 13,900,000 pounds in 1923.

Since 1924 the development of the Prince William Sound herring fishery has been closely linked with that of the Kodiak-Afognak and Cook Inlet districts. In 1922 the three largest operators in Prince William Sound sought for pickling herring farther to the westward. The W. J. Imlach Packing Co. established a saltery in the town of Uzinki, near Kodiak. The San Juan Fishing & Packing Co. located a saltery in Uganik Bay on the Shelikof Strait side of Kodiak Island. The Franklin Packing Co. salted herring aboard the schooner *Henry Wilson*, and built a saltery ashore at Port McKinley in Izhut Bay, Afognak Island. These ventures were not very successful in 1922. In 1923, W. J. Imlach discovered herring in large quantities in Red Fox Bay on Afognak Island, and the Fidalgo Island Packing Co. at Port Graham met with success in using purse seines in Cook Inlet during the summer months, while formerly all of the fine, large Cook Inlet fish had been taken with gill nets late in the fall when the fish were not sufficiently fat to be suitable for the Scotch cure.

In 1924 several of the packers in Prince William Sound prepared to fish on a large scale in Red Fox Bay and in Cook Inlet. From 1924 until 1928, inclusive, many of the seine boats did a great deal of moving about during the season, fishing in Prince William Sound, Cook Inlet, the Kodiak-Afognak district, and, in 1928, at Unalaska in the Aleutian Islands. This renders it rather difficult to understand the fluctuations that occurred in the catch during the period from 1924 to 1928, inclusive. These changes are treated more fully in the section on the condition of the supply.

FISHING GROUNDS

Prior to 1923 accurate records of the fishing grounds are lacking. Some knowledge of the grounds fished and amounts and sizes of fish taken has been gathered from various sources, and, although fragmentary, it is presented for what it is worth. (See fig. 4.)

Most of the 1918 herring were seined in Evans Bay (Evans Island area). In 1919 a large share of the pack was caught in the Evans Island area during July, some small herring were taken in the southern Knight Island area during June, and a quantity of large fat herring were caught in Whale Bay from mid-September through October.

During 1920 the southern Knight Island and Evans Island areas produced large quantities of summer herring. From mid-September through October large quantities of herring were taken in Whale Bay (two companies took 7,000 barrels). These were mostly small and used for reduction. One packer reports that herring were also plentiful in Main Bay, but he considered it too distant for profitable fishing.

Only a few thin fish were taken during June in 1921. From about the 4th of July until the 1st of August herring were taken off Procession Rocks in the Evans Island area. Herring were scarce during August and until the last of September. From then on through October large quantities of herring of mixed sizes were taken in both Whale Bay and Main Bay. Very late in the fall several loads of herring were caught in McClure Bay (Main Bay area).

For 1922 we have accurate locality records of a company that caught about 8.7 per cent of the total catch. This company took 50.7 per cent of its catch from the Evans Island area, 3.9 per cent from southern Knight Island, 5.5 per cent from the southwest Montague Island area, and 39.9 per cent from the Main Bay area. Other operators, however, fished but little in the vicinity of Evans Island, taking about 50 per cent of their catch from Macleod Harbor and Hanning Bay on the southwest end of Montague Island. All packers agree that the 1922 herring were the largest ever taken in the sound, rivalling the large Kodiak-Afognak district herring taken in Red Fox Bay from 1923 to 1927.

For 1923 and succeeding years accurate locality records are available on a sufficient portion of the catch to permit allocation of the whole catch to various localities with a high degree of confidence. (Table 3.) The most striking feature of Table 3 is the large percentage of the catch taken in the vicinity of Evans Island. It is at once apparent from the table and from the foregoing discussion that this area never failed to contribute a share of the catch. The next largest producing areas, southern Knight Island and southwestern Montague Island have, on the contrary, been extremely erratic.

In framing any regulations to govern these fisheries it is imperative that the relative importance of each fishing ground be kept clearly in mind.

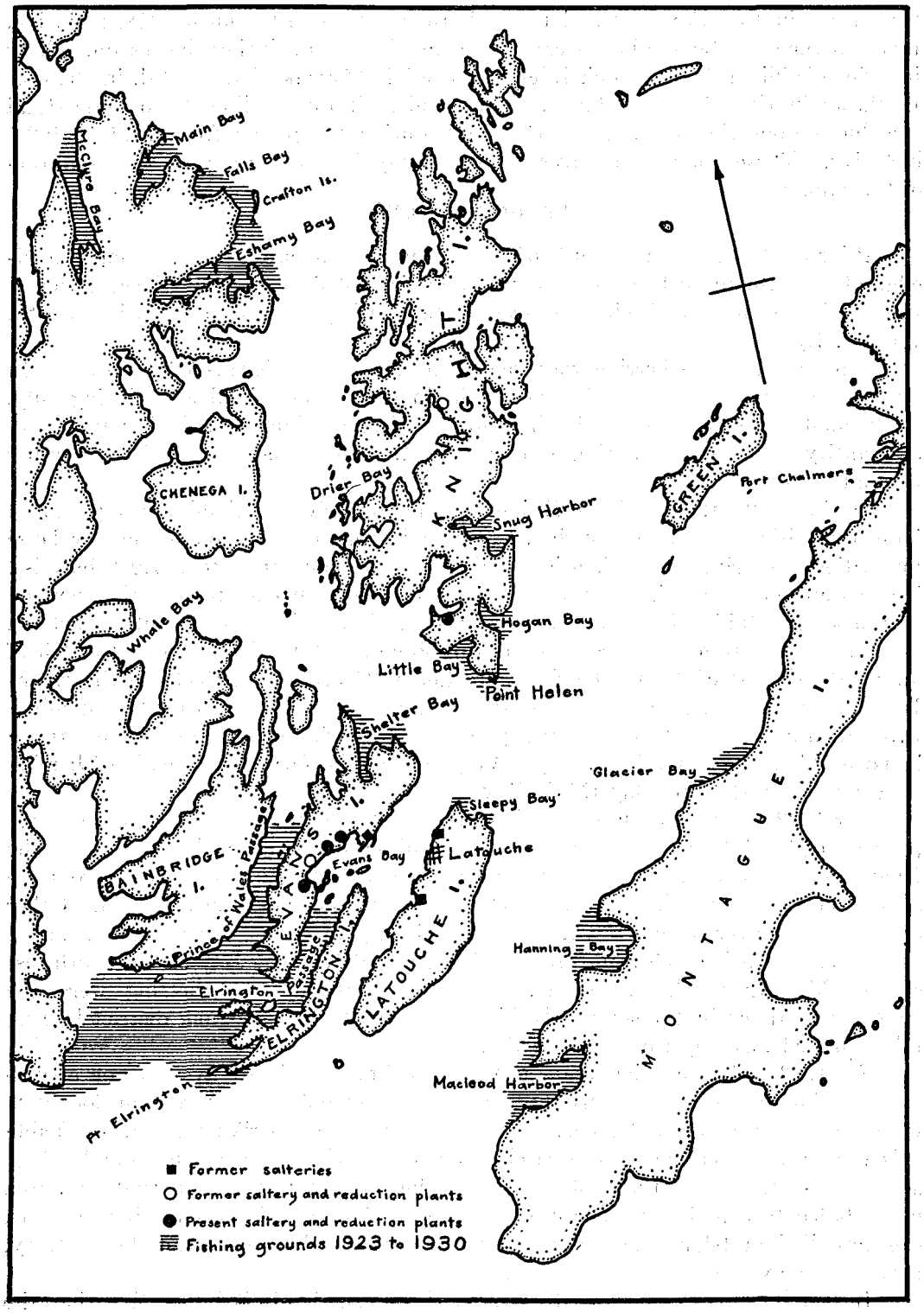

FIGURE 4.—Western portion of Prince William Sound, showing the herring plants and the present fishing grounds

TABLE 3.—*Catch in various localities in Prince William Sound*

[In thousands of pounds]

Area fished	Year								Area totals	Average per cent in each area
	1923	1924	1925	1926	1927	1928	1929	1930		
Evans Island	26,803	11,931	14,364	7,373	7,197	1,832	3,104	8,985	81,589	50.7
Southwestern Montague Island	175			1,247	209	12,533	7,151	20,496	41,811	26.0
Southern Knight Island	4,134	5,199	8,896	619		711	2,270	104	21,933	13.6
Main Bay	3,293	921	3,564	1,539	2,026				11,343	7.0
Northeastern Montague Island							1,149	1,704	2,853	1.8
Whale Bay	631					61			692	.4
Naked Island			381		60				441	.3
Perry Island								326	326	.2
Annual total	35,036	18,051	27,205	10,778	9,492	15,137	13,674	31,615	160,988	
Per cent of catch for which localities are known	30	30	15	20	70	50	65	100		

LOCAL POPULATIONS

In making a detailed study of the fluctuations in abundance, it is of great advantage to know whether the catch is being drawn from one or from several populations since the commercial catch may not be drawing proportionately on each population and each population may not be securing proportional annual increments. Owing to the difficulty of securing sufficient numbers of accurate counts of the fin rays and gill rakers, and to the great variability in the body proportions (which is especially noticeable in purse-seined material), the analysis has been based wholly on vertebral counts.

Before comparing the vertebral counts from the various localities it is interesting to know what the causes are for variability in this character, whether they are genetic or environmental. For this purpose the counts from all localities in Prince William Sound for each year class (fish spawned the same year) from 1919 to 1927, inclusive, were treated as a single distribution and the mean computed. These means (Table 5) were correlated with the average air temperatures for March, April, May, and June from Seward, Cordova, and Latouche. (Table 4.)

TABLE 4.—*Mean annual air temperatures of the combined months of March, April, May, and June from Seward, Cordova, and Latouche*

Year	U. S. Weather Bureau data				U. S. Coast and Geodetic Survey data [1]
	Seward	Cordova	Latouche	Average	Seward
1908	41.40			41.40	
1909	39.88			39.88	
1910	38.43	40.55		39.49	
1911	38.80	37.70		38.25	
1912	42.35	43.15		42.75	
1913	41.73	43.38		42.56	
1914	41.88	43.50		42.69	
1915	46.70			46.70	
1916	40.30			40.30	
1917	44.25		39.83	42.04	
1918	40.45		40.07	40.26	
1919	40.63	39.50		40.07	
1920	38.35	38.95	39.63	38.98	
1921	41.43	42.23		41.83	
1922	38.98	38.18		38.58	
1923	44.33	40.13		42.23	
1924	42.23	42.43	42.10	42.25	
1925		40.53	40.15	40.34	
1926		46.23	46.18	46.20	45.90
1927		40.20	41.05	40.63	40.26
1928		40.90	41.62	41.26	41.94
1929					40.06
1930					41.31

[1] 5.40° have been subtracted from the U. S. Coast and Geodetic Survey temperatures to make them comparable to Weather Bureau data. This allowance has been made for the difference in the time of day at which the temperatures were taken. The correction was empirically determined by taking the average difference between the two series for 1926, 1927, and 1928.

Two sources were available for air (and water) temperatures: The Climatological Data, published by the United States Weather Bureau since 1908, and daily air and water temperatures (unpublished) taken at Seward by the United States Coast and Geodetic Survey since June, 1925.

Since only air temperatures are available for these months previous to 1926, a correlation was made between the air and surface water temperatures which were taken daily at the same hour at Seward, to determine the degree of relationship existing between the two. These data, covering a period of 5 years, gave a coefficient of correlation of 0.93; to test the significance of this relationship t was computed, and was found to be 11.017, when a t of only 2.878 was equivalent to a probability of 0.01, proving the correlation to be highly significant. This shows that air temperatures give an accurate index to surface-water temperatures, and that the use of air temperatures as an index to conditions on the spawning beds is justified.

Unfortunately the series of air temperatures for Cordova, Latouche, and Seward are not complete. (Table 4.) Figure 5 shows, however, that the temperatures for these points are comparable from year to year. The temperatures for the Prince William Sound area, as given in the following discussion, are averaged from those which are available for each year from these three localities. The dotted line in Figure 5 shows the air temperatures for Seward, taken from unpublished United States Coast and Geodetic Survey data (from which 5.40 degrees have been subtracted to make them comparable to the United States Weather Bureau statistics).

The means of the vertebral counts of the various year classes were therefore correlated with the average air temperatures for March, April, May, and June from Seward, Cordova, and Latouche by the formula:

$$r = \frac{S(xy)}{\sqrt{S(x^2) \cdot S(y^2)}} \qquad \text{(Fisher, 1930)}$$

giving a coefficient of correlation of -0.85. The significance of this coefficient was tested by the method of Fisher for small samples (1930, p. 159) if n′ be the number of pairs of observations:

$$t = \frac{r}{\sqrt{1-r^2}} \cdot \sqrt{n'-2}$$

giving a t of 5.807 which has a probability much less than 0.01 (Fisher's tables) showing that the coefficient of correlation -0.85 is definitely significant.

TABLE 5.—*Correlation of air temperature and average number of vertebræ in Prince William Sound*

Year	1919	1920	1921	1922	1923	1924	1925	1926	1927
Air temperature [1]	40.07	38.98	41.83	38.58	42.23	42.25	40.34	46.20	40.63
Mean of vertebræ	52.870	53.150	52.836	52.963	52.869	52.719	52.821	52.456	52.784
Number of specimens:									
Elrington Passage	12	11	107	73	58	70	9	343	6
Naked Island	4	3	45	16	3	3	2	-------	-------
McClure Bay	7	1	74	27	32	29	2	-------	-------
Eshamy Bay	-------	5	56	14	8	1	-------	-------	-------
Macleod Harbor	-------	-------	4	5	28	142	50	599	34
Snug Harbor	-------	-------	-------	-------	1	6	16	350	7
Port Chalmers	-------	-------	-------	-------	-------	1	2	94	3
Zaikoff Bay	-------	-------	-------	-------	-------	2	-------	35	7
Port Fidalgo	-------	-------	-------	-------	-------	4	5	54	-------
Glacier Bay	-------	-------	-------	-------	-------	5	5	168	19
Shelter Bay	-------	-------	-------	-------	-------	-------	1	86	9
Point Helen	-------	-------	-------	-------	-------	-------	1	70	2
Sleepy Bay	-------	-------	-------	-------	-------	-------	2	173	24
Total	23	20	286	135	130	263	95	1,972	111

[1] Average for March, April, May, and June from Seward, Cordova, and Latouche.

As the herring in Prince William Sound spawn and the eggs develop during the months from March to June, inclusive, the inference to be drawn is obvious. The differences in the vertebral count found between different year classes are probably due entirely to environment. Also any significant differences found between herring of the same year class taken in different localities in Prince William Sound may be, and probably are, simply an expression of environmental differences on the spawning grounds.

From the foregoing it is clear that comparisons between the vertebral counts of different localities are valid for showing population differences (in the absence of exact knowledge as to the conditions on the spawning grounds) only when the com-

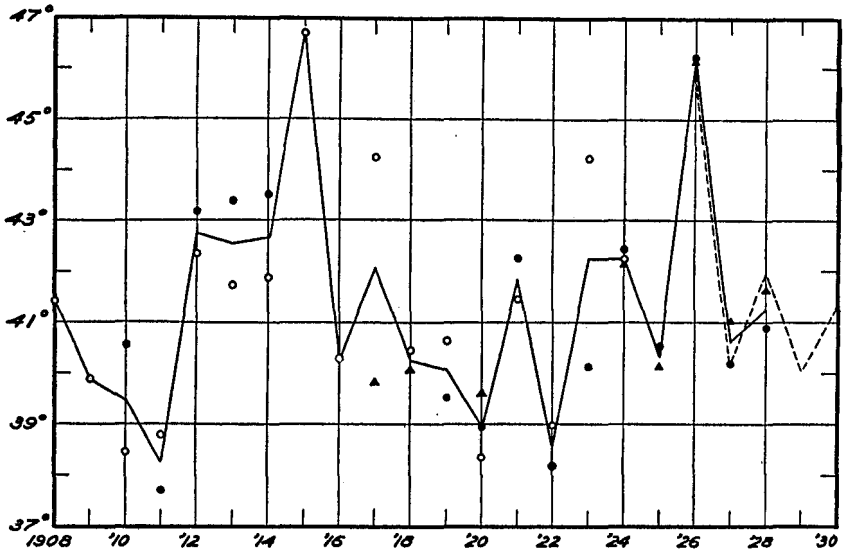

FIGURE 5.—Average mean annual air temperatures for the combined months of March, April, May, and June for Seward, Cordova, and Latouche. Solid line is from "Climatological Data" of the U. S. Weather Bureau. Dotted line (see text) from unpublished data taken by the U. S. Coast and Geodetic Survey at Seward only. Circles indicate Seward temperatures; dots, Cordova temperatures; triangles, Latouche temperatures taken by Weather Bureau

parisons are between fish of the same year class. It is also clear that the absence of significant differences in the vertebral count between samples of the same year class does not necessarily indicate that the populations of any two localities are identical. Similarity of conditions on the spawning grounds may cause the lack of a significant difference between fish from two localities.

Comparisons of vertebral count distributions of fish of the same year class from neighboring localities are given in Table 6. Any two means are compared by dividing their difference by the standard error estimated by the formula

$$\sigma = \sqrt{\frac{S(x-\bar{x})^2 + S(x'-\bar{x}')^2}{n_1+n_2}\left(\frac{1}{n_1+1}+\frac{1}{n_2+1}\right)}$$

if $x_1, x_2 \ldots, x_{n_1+1}$ and $x'_1, x'_2 \ldots x'_{n_2+1}$ be two samples, and

$$\bar{x} = \frac{1}{n_1+1} S(x), \quad \bar{x}' = \frac{1}{n_2+1} S(x')$$

TABLE 6.—*Comparisons of the means of the vertebral counts of each year class in Prince William Sound*

Localities compared	Year class	Difference between means	Summation of populations	Standard error of difference between means	Difference between means divided by standard error
McClure Bay and Naked Island	1921	0.322	119	0.1010	3.19
Do	1922	.060	33	.1949	.31
McClure Bay and Eshamy Bay	1921	.232	130	.0990	2.34
Do	1922	.328	41	.1811	1.81
Naked Island and Eshamy Bay	1921	.090	101	.1233	.73
Do	1922	.268	30	.2341	1.14
Naked Island and Elrington Passage	1921	.154	152	.1183	1.30
Do	1922	.221	89	.2010	1.10
Snug Harbor and Point Helen	1926	.020	420	.0959	.21
Snug Harbor and Port Chalmers	1926	.094	444	.0869	1.08
Snug Harbor and Glacier Bay	1926	.052	518	.0685	.76
Snug Harbor and Port Fidalgo	1926	.016	404	.1086	.15
Zaikoff Bay and Port Fidalgo	1926	.032	89	.1649	.19
Zaikoff Bay and Port Chalmers	1926	.142	129	.1520	.93
Glacier Bay and Port Chalmers	1926	.146	262	.0917	1.59
Glacier Bay and Sleepy Bay	1926	.061	341	.0782	.78
Do	1927	.053	43	.1975	.27
Glacier Bay and Macleod Harbor	1926	.076	767	.0620	1.23
Do	1927	.465	53	.2311	2.01
Glacier Bay and Point Helen	1926	.032	238	.0969	.33
Macleod Harbor and Sleepy Bay	1926	.015	772	.0624	.24
Do	1927	.412	58	.2260	1.82
Macleod Harbor and Elrington Passage	1923	.276	86	.1694	1.63
Do	1924	.061	212	.0997	.61
Do	1926	.024	942	.0502	.48
Sleepy Bay and Elrington Passage	1926	.009	516	.0721	.12
Sleepy Bay and Shelter Bay	1926	.073	259	.0957	.76
Sleepy Bay and Point Helen	1926	.029	243	.1025	.28
Shelter Bay and Elrington Passage	1926	.082	429	.0922	.89
Shelter Bay and Point Helen	1926	.102	156	.1068	.96
Port Chalmers and Point Helen	1926	.114	164	.1118	1.02

The desirability of calculating the standard error of the difference by a pooled estimate of the variance is explained by Fisher (1930, p. 108), who says:

> It may be noted in connexion with this method, and with later developments, which also involve a pooled estimate of the variance, that a difference in variance between the populations from which the samples are drawn will tend somewhat to enhance the value of t [difference between means divided by its standard error] obtained. The test, therefore, is decisive, if the value of t is significant, in showing that the samples could not have been drawn from the same population; but it might conceivably be claimed that the difference indicated lay in the variances and not in the means. The theoretical possibility, that a significant value of t should be produced by a difference between the variances only, seems to be unimportant in the application of the method to experimental data; as a supplementary test, however, the significance of the difference between the variances may be tested directly by the method of paragraph 41.

These comparisons give two statistically significant differences between neighboring localities which might be construed as indicating the independence of the stocks of herring of the localities between which these significant differences occur. However, these differences can not be accepted as valid without a knowledge of the homogeneity of the material. To this end Table 7 is presented showing the means of the 12 samples of vertebral counts from herring of the 1926 year class caught at Macleod Harbor. These samples do not show any statistically significant differences between each other.

TABLE 7.—*Vertebral count samples of the 1926-year class from Macleod Harbor*

Date taken	Mean	Number of specimens	Sum of squares of deviations from mean	Standard error of mean	Date taken	Mean	Number of specimens	Sum of squares of deviations from mean	Standard error of mean
June 28, 1928	52.545	33	20.182	0.136	July 18, 1930	52.548	42	20.405	0.107
July 5, 1928	52.333	12	4.667	.180	July 19, 1930	52.553	47	41.617	.137
July 8, 1929	52.406	96	45.156	.070	Do	52.349	43	19.767	.103
July 9, 1929	52.380	71	40.732	.090	July 21, 1930	52.350	40	13.100	.090
July 19, 1929	52.477	88	37.955	.070	July 22, 1930	52.415	41	19.951	.109
July 20, 1929	52.600	45	14.800	.085					
July 22, 1929	52.366	41	17.512	.102	Total	52.442	599	305.763	.029

Since the material is apparently homogeneous McClure Bay, which differs by 3.19 standard errors from Naked Island and 2.34 standard errors from Eshamy Bay, giving probabilities of 0.002 and 0.02, respectively, may have an independent stock of herring, but can not be definitely said to differ without further data.

CONDITIONS OF THE SUPPLY

FACTORS INFLUENCING THE DETERMINATION OF ABUNDANCE

The principal aim of this investigation has been to determine the trend of abundance as influenced by the present intensive fishery. Our determinations of this trend are, and must be, imperfect, as the only index to the abundance of the herring is contained in the records of the commercial fishery. Even supposing this fishery obtained a representative sample of the total population (which it does not, due to selective schooling and the selective action of the gear used) there would still be some doubt as to the adequacy of our sampling of this commercial catch. Even if the size and age composition of the population were accurately known, there would still be the question of its abundance. The only available unit of fishing effort—the seine boat—is not standardized; and, if it were, we would still be confronted with changes in the availability of the fish at different seasons, and in fluctuations of this availability at the same period in different years owing to factors not yet understood. In spite of these handicaps the following analysis has been made, using the available data, and a few important facts have been discovered.

As aforementioned, the changes in the abundance of the supply of fish may be caused by natural conditions such as the presence of dominant year classes, or they may be caused by the artificial conditions brought about by an intensive fishery. The availability of the fish, apart from their abundance, may be subject to seasonal variations, and is influenced by regulations restricting the length of the season or limiting the areas to be fished. The intensity of the fishery depends not only on the number, size, and efficiency of the fishing boats, but also indirectly on the size and type of shore plants, inasmuch as the quantity, size, and condition of the fish on delivery to the plant is dependent on the purpose for which the fish are to be used, and governs the effort expended in securing them. Considerable difficulty is met with in showing the relation existing between these various factors and the total catch from year to year, on account of the data being insufficient, especially for the earlier years of the fishery, to give a proper measure of the effects of each factor.

SEASONAL CHANGES IN AVAILABILITY

Among the causes for fluctuations in the yield of the fishery is a seasonal variation in the availability of the supply of fish. Figure 6 shows the average catch per boat per 10-day period, computed for data from 1923 to 1930, inclusive. The first and highest mode of 938 barrels occurs during July, after which there is a steady decline until about the 20th of September, when a second rise becomes apparent, reaching a

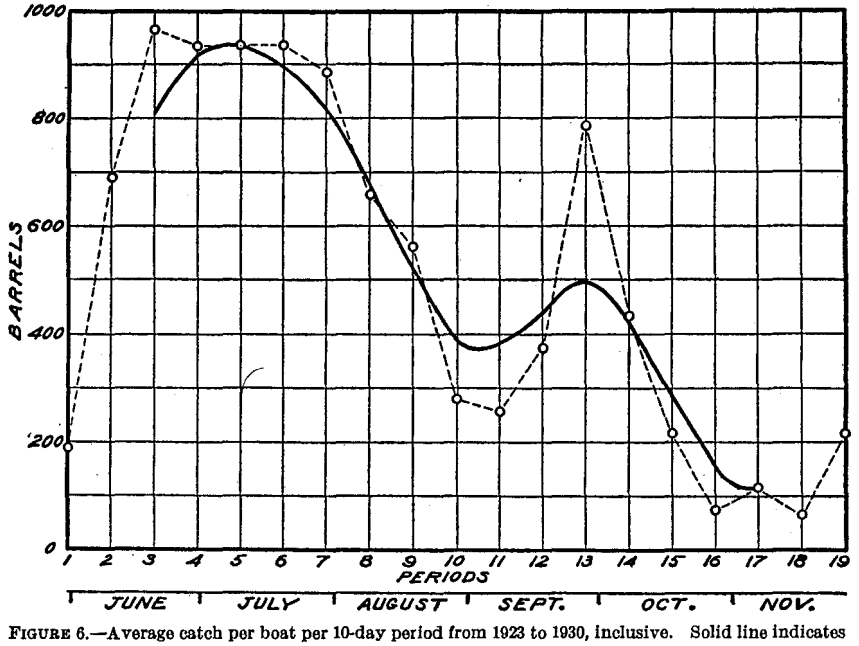

FIGURE 6.—Average catch per boat per 10-day period from 1923 to 1930, inclusive. Solid line indicates the average smoothed twice by threes

mode of 787 barrels during the period September 23 to October 2. Following this second peak the catch declines sharply, fluctuating at a low level until the end of the season.

TABLE 8.—*Catch per boat in Prince William Sound from 1923 to 1930, inclusive, by 10-day periods*

Period No.	Date	1923	1924	1925	1926	1927	1928	1929	1930	Average	Per cent of total	Cumulative percentage	Average smoothed twice by 3's
1	May 26–June 4	(1)	190	(1)	(1)	(1)	(1)	(1)	(1)	190	2.0	2.0	
2	June 5–June 14	438	941	(1)	(1)	(1)	(1)	(1)	(1)	690	7.2	9.2	
3	June 15–June 24	1,413	1,741	(1)	(1)	323	382	(1)	(1)	965	10.1	19.3	808
4	June 25–July 4	1,469	1,221	1,168	611	274	308	[2]1,230	[2]1,199	935	9.7	29.0	915
5	July 5–July 14	1,350	1,205	1,295	352	308	344	902	1,738	937	9.8	38.8	934
6	July 15–July 24	1,513	392	1,102	336	99	862	965	2,232	938	9.8	48.6	894
7	July 25–Aug. 3	1,031	767	468	195	139	702	1,212	2,559	884	9.3	57.9	816
8	Aug. 4–Aug. 13	1,025	17	57	86	513	633	1,090	1,837	657	6.8	64.7	676
9	Aug. 14–Aug. 23	1,413	50	79	90	46	782	483	1,554	562	5.9	70.6	522
10	Aug. 24–Sept. 2	338	0	348	0	6	174	427	950	280	2.9	73.5	390
11	Sept. 3–Sept. 12	0	0	417	708	0	255	511	167	257	2.7	76.2	381
12	Sept. 13–Sept. 22	130	0	83	44	93	772	216	1,655	374	3.9	80.1	436
13	Sept. 23–Oct. 2	888	333	550	16	482	601	0	3,428	787	8.2	88.3	494
14	Oct. 3–Oct. 12	69	0	75	87	492	679	213	1,844	432	4.6	92.9	416
15	Oct. 13–Oct. 22	122	30	0	312	159	504	28	564	215	2.2	95.1	284
16	Oct. 23–Nov. 1	0	0	0	0	280	234	0	(1)	73	.8	95.9	153
17	Nov. 2–Nov. 11	21	0	0	0	[3]300	0	500	(1)	117	1.2	97.1	117
18	Nov. 12–Nov. 21	6	0	(4)	(4)	(1)	(4)	250	(1)	[5]64	.7	97.8	
19	Nov. 22–Dec. 1	336	83	(1)	(1)	(1)	(1)	225	(1)	215	2.2	100.0	

[1] No fishing.
[2] Four days fishing weighted to equal 10 days.
[3] Three days fishing weighted to equal 10 days.
[4] Four days fishing.
[5] When computed, the three 4-day open periods of 1925, 1926, and 1929 (totaling 12 days) during which time no fish were taken, were considered as one period.

Graphing these seasonal variations in yield in a different way, Figure 7 shows the cumulative per cent curve of the average daily catch per boat computed by 10-day periods. During the first 6 of the 19 periods (from May 26 to July 24), 49 per cent of the season's catch is taken; during the last 6 periods (from Oct. 3 to Dec. 1) only 7 per cent. Approximately 75 per cent of the seasonal catch is taken before the 1st of September.

The histogram of Figure 7 shows the first differential of the cumulative percentage curve, giving the percentage increments occurring during each period. The largest increments occur from the third through the seventh periods, remaining

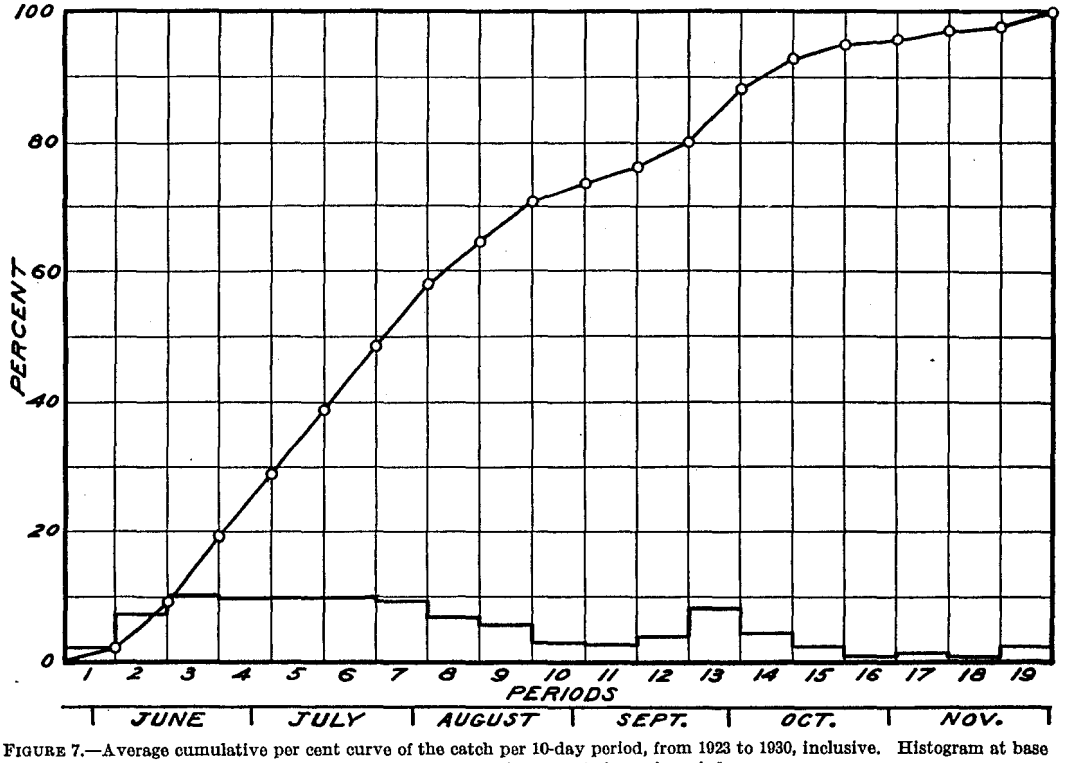

FIGURE 7.—Average cumulative per cent curve of the catch per 10-day period, from 1923 to 1930, inclusive. Histogram at base shows the percentage increments for each period

almost constant at about 10 per cent of the seasonal catch. Therefore, regulations prohibiting fishing during any portion of these periods would curtail the catch more than a proportional cut in time during any other part of the season.

During the late summer and early fall, the runs of herring have proven to be erratic, varying widely from year to year from the norm established over the period of eight years for which data are available. (Table 8.) The autumn run, which is evidently a normal condition in the fishery, was unusually abundant in 1930, being one of the chief factors in the increase in total production of 1930 over 1929. In 1929 the fall run did not appear, even though both years depended almost entirely on the same year class. This would indicate that the magnitude of the autumn run depends to a very large extent on some factor or factors other than the abundance of herring.

ANNUAL VARIATIONS IN WEIGHT OF THE INDIVIDUAL HERRING

In addition to the availability of the fish, another factor that influences the yield of the fishery is the variation in the average weight of the fish caught each season, since a smaller number of older fish may yield the same poundage as will a larger number of younger ones. If the relative abundance of the age classes were to remain constant, this factor would not need to be taken into consideration, because as each annual age increment would have approximately the same numerical strength a uniform distribution of age and size classes would be maintained from year to year from which the fishery would draw its supply. If such were the case, the average weight of the fish taken would approach a norm. However, the presence of dominant year classes causes the average size and weight to fluctuate to a marked degree, as shown by Table 9.

This table shows clearly the effect produced by the growth of dominant year classes. Thus in 1928, when the 1926 year class first entered the catch, the number of fish taken exceeded the average, but owing to their small size the catch was below normal. In 1930, after two years of growth, the size of the catch exceeded its mean more than did the number of fish.

It is thus plain that the increase in weight of the individual fish, especially during the earlier part of their existence, aids in minimizing the effects of fishing and of natural mortality.

TABLE 9.—*Showing the annual changes in the average weight of individual herring from 1924 to 1930, inclusive, and comparing the total catch with the number of fish*

Year	Average[1] weight of fish (grams)	Total catch[2]		Number of fish caught	
		Actual (pounds)	As per cent of average	Actual	As per cent of average
1924	86.86	17,130,000	102.4	89,454,000	129.6
1925	106.98	23,260,000	138.5	98,621,000	142.9
1926	147.03	9,239,000	55.2	28,502,000	41.3
1927	130.02	7,406,000	44.3	25,837,000	37.4
1928	92.28	15,076,000	90.1	74,104,000	107.4
1929	113.18	13,673,000	81.8	54,797,000	79.4
1930	126.97	31,288,000	187.1	111,774,000	162.0
Average	109.92	16,725,000	100.0	69,013,000	100.0

[1] Computed by weighting the per cent of fish at each length (smoothed twice by 3's) by the weight at that length from the formula $W = \frac{L^{3.18}}{K}$ (Rounsefell, 1930).

[2] Includes the Evans Island, southern Knight Island, and Montague Island areas.

SIZE AND AGE COMPOSITION OF THE CATCH

The presence of dominant year classes has been the largest factor in causing the fluctuations in abundance which have taken place. (Rounsefell, 1930.) Since this last report additional data, covering 1928, 1929, and 1930 have been secured. These body length measurements were taken from samples caught in the vicinity of Latouche (including the Evans Island area, Montague Island, and southern Knight Island) during June and July, and are fairly representative of the entire Prince William Sound district since 90 per cent of the total catch is taken in the area included, and 50 per cent of the total seasonal catch is taken during these months. Lacking definite evidence of racial differences these data may be used to represent the fishery of the entire district, with the possible exception of the Main Bay area, in which the age

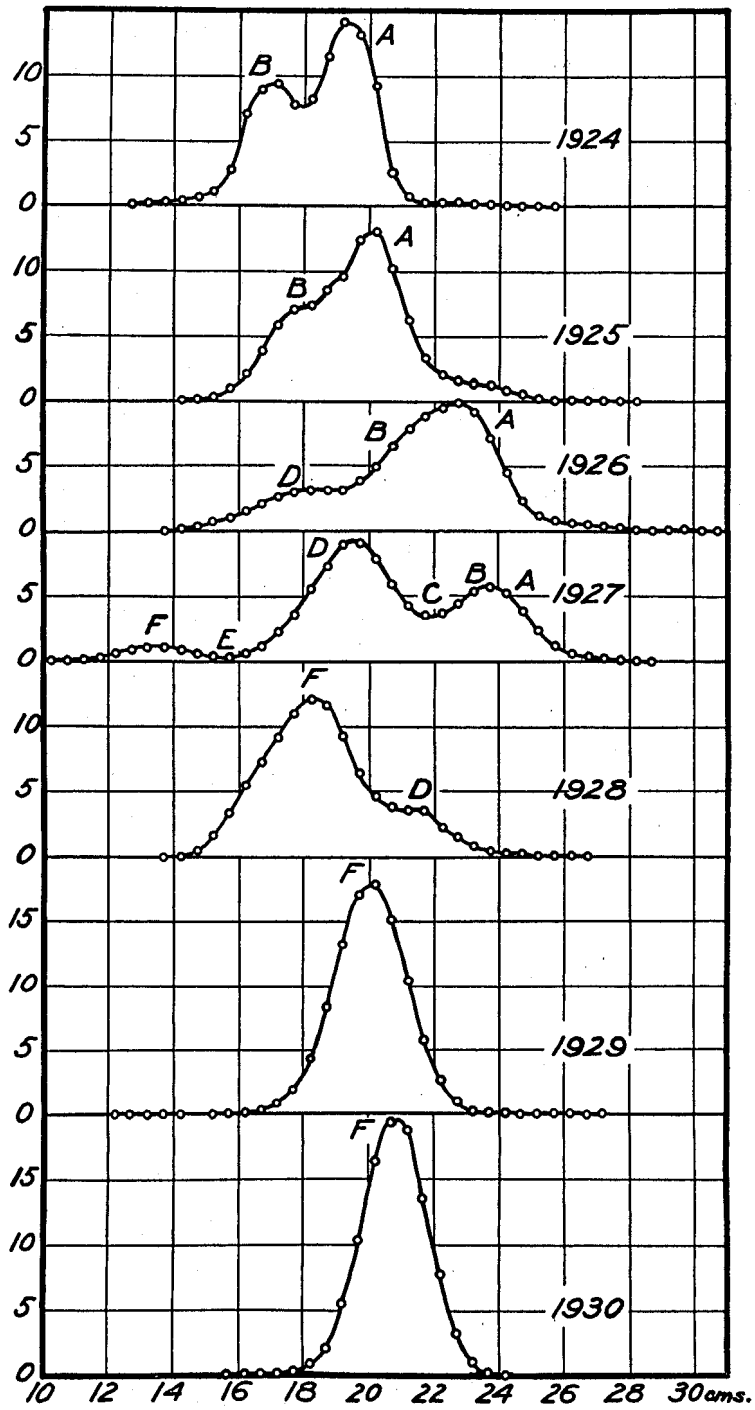

FIGURE 8.—Body length frequencies from the Evans Island, southern Knight Island, and Montague Island areas, for June and July, shown as percentages of each distribution (smoothed twice by threes)

and size distributions from Eshamy and McClure Bays differ considerably from those of the area under consideration (Rounsefell, 1930, pp. 299–301). However, the age distributions from four localities for 1929, given in Table 10, show a close agreement, justifying our disregard of possible racial differences in studying dominant year classes in these areas.

TABLE 10.—*Age distributions from four different localities in Prince William Sound for 1929*

Age	MacLeod Harbor		Evans Island Area		Southern Knight Island area		Port Chalmers	
	Actual	Percentage	Actual	Percentage	Actual	Percentage	Actual	Percentage
3	12	3.3	15	3.2	6	2.8	3	3
4	342	93.4	434	93.1	197	92.9	94	94
5	8	2.2	7	1.5	7	3.3	2	2
6	3	.8	7	1.5	2	.9	1	1
7	1	.3	3	.6				

The body lengths used in this analysis of size fluctuations were measured to the nearest millimeter. (Rounsefell, 1930, p. 239.) The lengths were grouped in 5-millimeter categories, and then smoothed twice by threes in order to remove minor modes due to chance sampling. These length distributions (fig. 8) show the progression from year to year of four distinct modes through the catch. The two modes (*A* and *B*), present in 1924, are plainly discernible in 1925, but in 1926 and 1927 they have become fused into a common mode, due, probably, to a decreasing difference in growth rate; the small mode (*D*) which first appears in 1926 may be traced through 1927 and 1928. The most prominent mode (*F*) appears in 1927 and advances through 1928, 1929, and 1930. During these two latter years this mode dominates the field, there being no minor modes. The troughs at *C* and *E* are best explained in the following paragraphs.

TABLE 11.—*Percentage length frequencies for June and July from the vicinity of Latouche smoothed twice by threes*

Body lengths (millimeters)	Percentage							Average percentage
	1924	1925	1926	1927	1928	1929	1930	
90–94				0.01				
95–99				.03				
100–104				.04				
105–109				.05				
110–114				.11				0.02
115–119				.32				.05
120–124				.61		0.01		.09
125–129	0.03			.92		.01		.14
130–134	.16			1.09		.02		.18
135–139	.32		0.02	1.09	0.02	.01		.21
140–144	.46	0.02	.10	.93	.11	.01		.23
145–149	.66	.19	.27	.59	.56			.32
150–154	1.15	.36	.58	.38	1.64	.01		.59
155–159	2.81	1.00	.97	.30	3.43	.05	0.01	1.22
160–164	7.05	2.06	1.50	.64	5.49	.14	.04	2.41
165–169	8.99	3.96	2.03	1.21	7.41	.36	.10	3.43
170–174	9.46	5.87	2.60	2.29	9.23	.79	.21	4.34
175–179	7.84	7.03	3.02	3.62	11.02	1.95	.40	4.97
180–184	8.22	7.46	3.16	5.50	12.19	4.42	.95	5.98
185–189	11.55	8.51	3.21	7.36	11.63	8.48	2.15	7.54
190–194	14.20	9.67	3.22	8.86	9.29	13.34	5.46	9.13
195–199	13.13	12.46	3.85	9.03	6.49	17.04	10.34	10.32
200–204	9.21	13.07	4.98	7.84	4.63	17.86	16.37	10.55
205–209	2.58	10.20	6.60	5.93	3.94	15.18	19.38	9.10
210–214	.69	6.30	7.91	4.26	3.58	10.48	18.66	7.40
215–219	.37	3.41	8.92	3.51	3.11	5.77	13.57	5.51
220–224	.35	2.05	9.57	3.68	2.31	2.56	7.84	4.04

TABLE 11.—*Percentage length frequencies for June and July from the vicinity of Latouche smoothed twice by threes*—Continued

Body lengths (millimeters)	Percentage							Average percentage
	1924	1925	1926	1927	1928	1929	1930	
225–229	0.29	1.65	9.99	4.45	1.54	0.95	3.24	3.15
230–234	.21	1.43	9.21	5.30	.87	.33	1.02	2.62
235–239	.14	1.26	7.24	5.66	.51	.12	.21	2.16
240–244	.06	.91	4.52	5.17	.33	.04	.04	1.58
245–249	.03	.55	2.39	3.86	.27	.01		1.01
250–254	.01	.23	1.24	2.32	.18	.01		.57
255–259	.01	.15	.83	1.23	.14	.01		.34
260–264		.15	.67	.66	.09	.02		.23
265–269		.11	.52	.45	.04	.01		.16
270–274		.06	.39	.32		.01		.11
275–279		.01	.29	.21				.07
280–284		.01	.16	.11				.04
285–289			.06	.04				.01
290–294			.11					.02
295–299			.22					.05
300–304			.33					.05
305–309			.22					.05
310–314			.11					.02
Number of specimens	2,000	6,889	1,041	785	615	1,585	782	13,697
Number of samples	10	70	17	14	14	20	14	159

By plotting the deviations of the curves for each year from the average curve for the seven years, the relative lack of certain size groups becomes apparent, not only as compared to the other sizes for the same year, but also as compared to the average of the same sizes over the entire period of seven years. (Fig. 9.) The top curve shows the average for the seven years, computed by summing the weighted (percentage) frequencies of each of the seven annual curves, and dividing by seven to obtain the mean at each ordinate. From this standard curve the deviations of each of the seven years were plotted, those above the line (solid black) indicating a frequency greater than the average, those below the line (diagonally barred) indicating a frequency less than average. Here we find the same condition of certain abundant size-groups progressing through the catch from year to year as is shown by Figure 8. Figure 9 also shows, however, that certain size-classes are present in less than normal proportions. (*C* and *E*, fig. 8.) Those size-classes which are not present in normal proportions, likewise progress through the catch from year to year.

Evidence that the progression of size-modes is due to growth from year to year, is furnished by the age analysis. Figure 10 shows the age frequency distributions on a percentage basis. Although there may be some error in the age readings, they are of great value in interpreting the significance of the size-modes, and the consistency of the results obtained by the two methods is further proof of their validity.

TABLE 12.—*Percentage age distributions from the vicinity of Latouche, Prince William Sound* [1]

Age	1925		1926		1927		1928		1929		1930	
	Actual	Percentage	Actual	Percentage	Actual	Percentage	Actual	Percentage	Actual	Percentage	Actual	Percentage
2					25	4.0						
3	13	7.9	35	9.0	38	6.1	330	78.2	36	3.1	7	0.9
4	42	25.4	137	35.4	343	55.2	39	9.2	1,067	93.3	82	10.8
5	59	35.8	82	21.1	69	11.1	37	8.8	24	2.1	662	87.5
6	11	6.7	120	31.0	43	6.9	15	3.6	13	1.1	5	.7
7	11	6.7	3	.8	82	13.2	1	.2	4	.4	1	.1
8	6	3.6	3	.8	2	.3						
9	4	2.4	1	.3	9	1.4						
10	9	5.4	1	.3	5	.8						
11	10	6.1	3	.8	4	.6						
12			2	.5	1	.2						
Number	165		387		621		422		1,144		757	

[1] Inclusive of Evans Island, southern Knight Island, and Montague Island during the months of June and July.

The existence and the progression through the catch of dominant year classes is more clearly shown by the age distributions than by those of length. The 1921 year class (cross hatched) is dominant over that of 1922 (solid black) for the three years in which it enters the catch. The 1923 year class (vertically barred) is also slightly dominant over that of 1922. The 1924 year class (stippled) appears to be much more numerous than those of 1923 and 1922, but is dwarfed in 1928 by the overwhelming

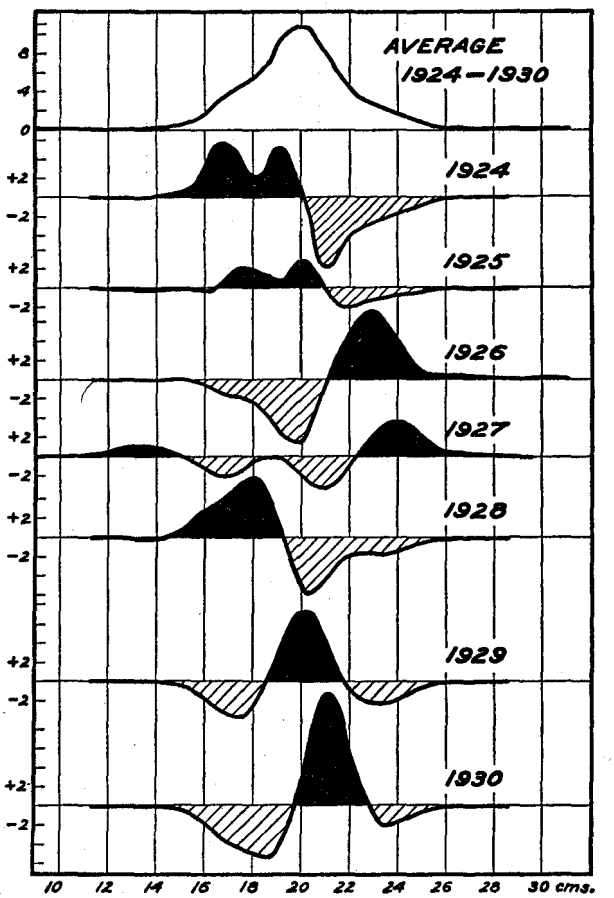

FIGURE 9.—Showing the percentage deviations of each of the annual length-frequency curves (fig. 8) from the 7-year average

abundance of the 1926 year class (horizontally barred), which maintains its dominant position through 1930.

The 3-year-olds of 1925 and the 3-year-olds of 1926 make a sharp rise in percentage taken between their third and fourth years and the same would have been true of the 3-year-olds of 1927, but for the great abundance of the 1926 year class. These fish do not enter the catch in true proportion to their actual abundance as 3-year-olds partly on account of differential schooling and partly on account of selection of sizes by the fishing gear. The 2-year-olds of 1927 made a sharp rise in the percentage taken between their second and third years. In fact, this year class is the only one which entered the catch as 2-year-olds. This difference in their availability to the fishermen as compared to the other year classes may have been caused by the unusual abundance of the 1926 year class inducing these young fish to school with the older and more

mature fish, or to the unusually high rate of growth causing the larger fish of this year class to attain a size suitable for schooling with the older fish at an earlier age. That the 1926 year class actually did grow at a faster than normal rate is shown by comparing the positions (fig. 8) of mode *F* in 1928 with mode *B* in 1924 and mode *F* in 1929 with mode *D* in 1927.

The effect of dominant year classes on the catch is expressed in the following quotation (Rounsefell, 1930):

> The presence of dominant age groups may have a far-reaching effect; at times a race may be exceedingly abundant and at other times exceedingly scarce, for there may be periods of several

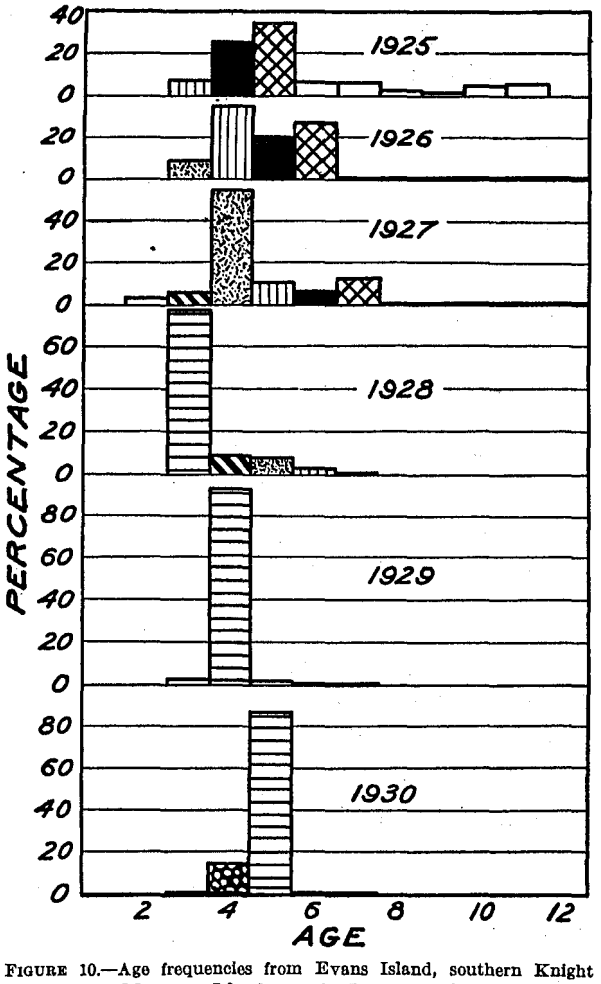

FIGURE 10.—Age frequencies from Evans Island, southern Knight Island, and Montague Island areas for June and July, shown as percentages of each distribution

years between dominant year classes, the population becoming much reduced before another dominant year class appears in the catch. The appearance of such a year class may cause excessive abundance for a time. When a very dominant year class first enters the commercial catch its members will be small, lowering the average size of the fish in the whole catch. Later, as the fish of this year class grow older, the average size of the fish in the commercial catch will be gradually raised, until another dominant year class appears and temporarily lowers it.

The fluctuations in the catch caused by these dominant year classes are of great importance to the fishery. During the intervals when no abundant year classes of

young fish are present, the fishery must be supported by a reserve of the older age groups. Depletion of these older age groups by a too intensive fishery has caused the variations in the yield which have characterized the fishery during the past few years. Unless protection is adequate to insure a sufficient quantity of older age groups at all times the fishery can not be maintained without such undersirable fluctuations.

REGULATIONS

In 1924, acting under the authority vested in the Secretary of Commerce by the White law which was enacted by Congress in that year, the Department of Commerce promulgated regulations for the herring fishery. Prior to that time, no restrictions had been imposed. The regulations are as follows:

Under date of June 21, 1924:

1. Fishing for herring is prohibited during the period from January 1 to June 24, both dates inclusive, and from November 1 to December 31, both dates inclusive, of each calendar year, except for bait or for local food purposes.

2. Gill nets used in catching herring shall not be of smaller mesh than 3 inches, stretched measure.

3. No one shall place, or cause to be placed, across the entrance of any lagoon or bay any net or other device which will prevent the free passage at all times of herring in and out of said lagoon or bay.

Under date of October 13, 1924:

Commercial fishing for herring in the waters of the Prince William Sound area will be permitted with gill nets of mesh not smaller than 3 inches, stretched measure, from November 1 to November 30, 1924, inclusive.

Under date of October 25, 1924:

The regulation of October 13, 1924, permitting commercial fishing for herring in the waters of the Prince William Sound area with gill nets of mesh not smaller than 3 inches, stretched measure, from November 1 to November 30, 1924, inclusive, is hereby modified to permit the use of gill nets of mesh not smaller than 2¼ inches, stretched measure, in the Prince William Sound area from November 1 to November 30, 1924.

Under date of November 24, 1924:

Commercial fishing for herring with purse seines in the waters of the Prince William Sound area will be permitted through December 15, 1924.

Under date of December 2, 1924:

1. Commercial fishing for herring is prohibited during the period from January 1 to June 24, both dates inclusive, and from November 1 to December 31, both dates inclusive, of each calendar year.

2. The closed seasons herein specified for herring fishing shall not apply to any boat taking not to exceed 60 barrels of herring in any calendar week in waters open to fishing.

3. Commercial fishing for herring is prohibited in all waters closed throughout the year to salmon fishing.

4. Gill nets used in catching herring shall not be of smaller mesh than 2¼ inches, stretched measure.

Under date of January 28, 1925:

Regulation No. 1 is amended to read as follows: Commercial fishing for herring is prohibited during the period from January 1 to June 24, both dates inclusive, and from November 16 to December 31, both dates inclusive, of each calendar year.

Regulation No. 3 is amended to read as follows: In the period from June 1 to October 1, both dates inclusive, commercial fishing for herring is prohibited in all waters closed throughout the year to salmon fishing.

Under date of December 5, 1925:

3. During the period from June 25 to October 1, both dates inclusive, commercial fishing for herring is prohibited in all waters closed throughout the year to salmon fishing.

Under date of July 1, 1926:

Regulation No. 2 is amended to read as follows: The closed seasons herein specified for commercial herring fishing shall not apply to the taking of herring for bait purposes in waters otherwise open to fishing.

Under date of December 22, 1926:

1. Commercial fishing for herring is prohibited during the period from January 1 to June 9, both dates inclusive, and from November 1 to December 31, both dates inclusive, of each calendar year.

2. The closed seasons herein specified shall not apply to the taking of herring for bait purposes in waters otherwise open to fishing.

3. Commercial fishing for herring, except for bait purposes, is prohibited from 6 o'clock postmeridan of Saturday of each week until 6 o'clock antemeridian of the Monday following.

Under date of July 26, 1927:

Regulation No. 1 is amended so as to prohibit commercial fishing for herring from October 15 to December 31, 1927, both dates inclusive.

Regulation No. 3 is amended so as to permit commercial fishing for herring from 6 o'clock postmeridian of Saturday of each week until 6 o'clock antemeridian of the Monday following.

Under date of October 11, 1927:

Regulation No. 1 is further amended so as to permit commercial fishing for herring with purse seines from October 15 to November 5, 1927, both dates inclusive, and with gill nets of not less than 2½ inches stretched measure between knots from October 15 to December 15, 1927, both dates inclusive.

Under date of December 12, 1927:

1. Commercial fishing for herring is prohibited during the period from January 1 to June 26, both dates inclusive, and from November 1 to December 31, both dates inclusive, except that gill nets of not less than 2½ inches stretched measure between knots may be used from November 1 to December 15, both dates inclusive.

4. Gill nets used in catching herring shall not be of smaller mesh than 2¼ inches stretched measure.

Under date of April 16, 1928:

Regulation No. 1 is amended to read as follows: Commercial fishing for herring is prohibited during the period from January 1 to June 15, both dates inclusive, and from November 1 to December 31, both dates inclusive, except that gill nets of not less than 2½ inches stretched measure between knots may be used from November 1 to December 15, both dates inclusive.

Under date of October 31, 1928:

Regulation No. 1 is amended to read as follows: Commercial fishing for herring is prohibited during the period from January 1 to June 15, both dates inclusive, and from November 16 to December 31, both dates inclusive, except that gill nets of not less than 2½ inches stretched measure between knots may be used from November 16 to December 15, both dates inclusive.

Under date of December 18, 1928:

1. Commercial fishing for herring, except for bait purposes, is prohibited from January 1 to June 30, both dates inclusive, and from November 16 to December 31, both dates inclusive, except that gill nets with mesh of not less than 2½ inches stretched measure between knots may be used from November 16 to December 15, both dates inclusive.

2. During the period from July 1 to October 1, both dates inclusive, commercial fishing for herring, including bait fishing, is prohibited in all waters closed throughout the year to salmon fishing.

4. Commercial fishing for herring, including bait fishing, by means of any trap is prohibited.

5. Commercial fishing for herring, including bait fishing, by means of any purse seine more than 1,400 meshes in depth, more than 180 fathoms in length, or of mesh less than 1½ inches stretched measure between knots is prohibited.

CATCH STATISTICS

The total production figures have been derived from the following sources: (1) Sworn annual reports, which the Bureau of Fisheries has required of every operator since 1904. (2) Daily catch records kept on books issued to the companies by the Bureau of Fisheries and filled in by the operators each time a load of fish is delivered to the plant. (3) Field notes. (4) Company records. Most of these records do not give the poundage taken (except in the case of halibut bait), but give the amounts of the various products which were prepared. In analyzing the statistics, it was necessary for purposes of comparison, that all amounts be put on a common basis, the unit selected being the pound of raw herring as delivered to the plant. (Rounsefell, 1930, pp. 303–305.)

The installation in 1930 of a 10-ton reduction plant in Evans Bay similar to those used in southeastern Alaska, and more efficient than the smaller type hitherto used in Prince William Sound, necessitated the use of the same conversion factors as were used in southeastern Alaska for this one plant; that is, 6.5 pounds of raw fish per pound of meal and 50 pounds of fish per gallon of oil. As a check on these figures, it was found that the actual weight, computed at 250 pounds to the barrel (the unit of measure which is used in buying the fish), was 21,000,000 pounds; the estimated weight (using the above-noted conversion factors for the meal and oil) was 21,631,706 pounds. The discrepancy between these figures may be partially accounted for by taking into consideration the fact that the unit of measure (a barrel containing 31.5 gallons) may hold more or less than its estimated 250 pounds, depending on the size and condition of the fish. Also the conversion factors are influenced by the fatness of the fish, a condition which can not be closely estimated since it varies greatly within the season as well as between seasons.

The converted products are listed in Table 13, and plotted in Figure 11. This figure shows a rapid increase in the catch from 1918 until 1922, a steady decline from then until 1927 (except for a minor rise in 1925), followed by a rise continuing through 1930. However, the total catch figures are of no significance as far as giving an index to the actual abundance of fish is concerned, unless some measures of the intensity of the fishery and of the changes in the size or age composition of the herring populations are considered.

TABLE 13.—*Pounds of raw herring caught in Prince William Sound, 1917 to 1930*

Year	Used for reduction	Pickled	Used for bait	Canned	Total
1917		229,458	270,482		499,940
1918		7,230,900	691,800		7,922,700
1919		7,104,848	411,126	2,565,300	10,081,274
1920	10,355,700	9,185,591	20,000	375	19,561,666
1921	1,914,000	16,709,239	12,000		18,635,239
1922	6,784,757	37,145,225	524,600		44,454,582
1923	13,854,488	19,730,903	1,451,759		35,037,150
1924	12,446,879	4,216,023	1,387,750		18,050,652
1925	17,117,594	10,073,336	14,250		27,205,180
1926	7,479,322	2,586,779	712,550		10,778,651
1927	4,771,314	4,379,418	341,750		9,492,482
1928	13,863,218	933,427	340,000		15,136,645
1929	13,470,718	157,188	45,400		13,673,306
1930	29,486,145	1,988,994	139,100		31,614,239
Total	131,544,135	121,671,329	6,362,567	2,565,675	262,143,706

These factors are shown in Figure 12 giving the total catch, the number of vessels engaged in the fishery (weighted by the length of time spent in Prince William Sound and the relative productivity of that time, estimated from the catch per 10-day period), the portion of the catch used for pickling, and the reduction plant capacities, plotted on a logarithmic scale to show comparative rates of change. Before entering

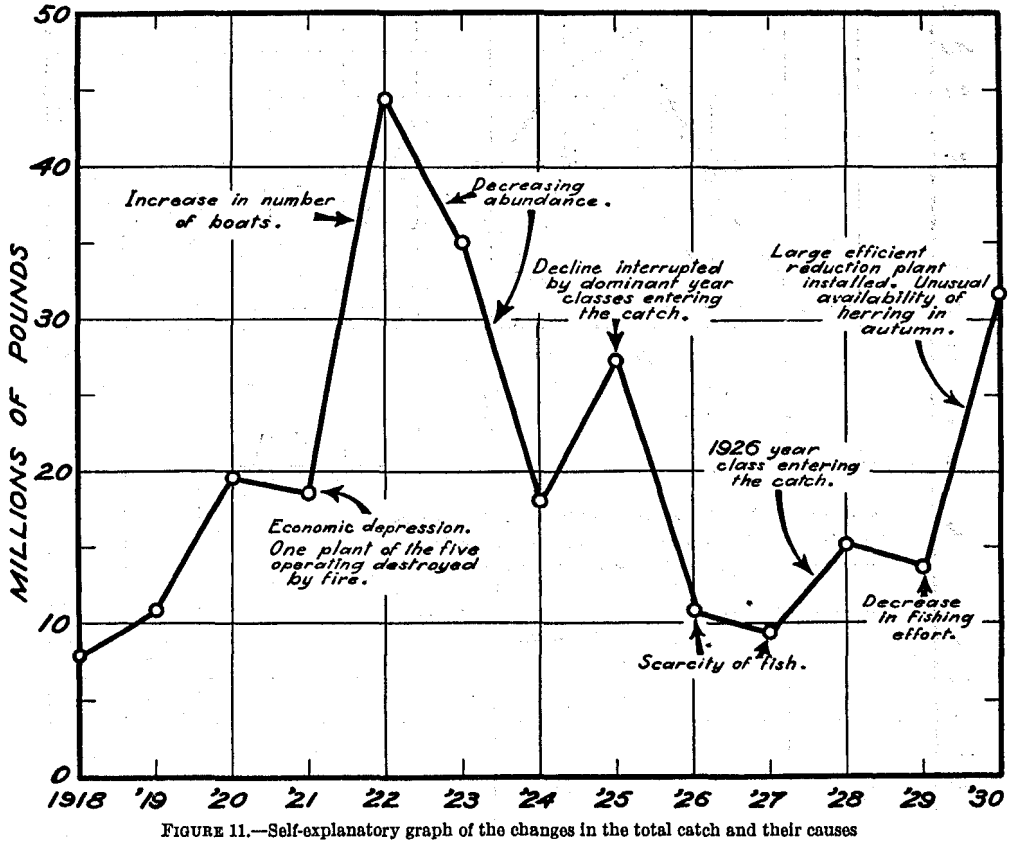

FIGURE 11.—Self-explanatory graph of the changes in the total catch and their causes

further discussion, however, the regulations governing the fishery should first be considered.

Figure 13 shows the opening and closing dates which have been in force in Prince William Sound. The regulations governing the opening dates of the seasons are the only ones which have measurably affected the catch, the closing dates having had little influence. (Fig. 7.) The effect which the shortening of the season has had on the total catch is difficult to measure because no accurate records were kept of the dates on which herring were taken prior to 1923, but the conclusions from the available data are given in Table 14.

TABLE 14.—*Effect of closed seasons on the catch in Prince William Sound*

Year	1924 [1]	1925	1926	1927	1928	1929	1930
Per cent reduction of catch by closed seasons [2]	0.0	22.9	22.9	8.9	11.8	27.7	27.7

[1] Closed seasons were not effective until 1925.

[2] Computed from catch per boat per 10-day period.

For those years which the data cover, the fact that many of the same companies and boats which operated in Prince William Sound also operated in the Kodiak-Afognak district, in Cook Inlet, and (in 1928) at Unalaska influences the proportions of fish taken from this area before, compared with that taken after, the date upon which fishing is permitted in these other localities. The season has usually opened

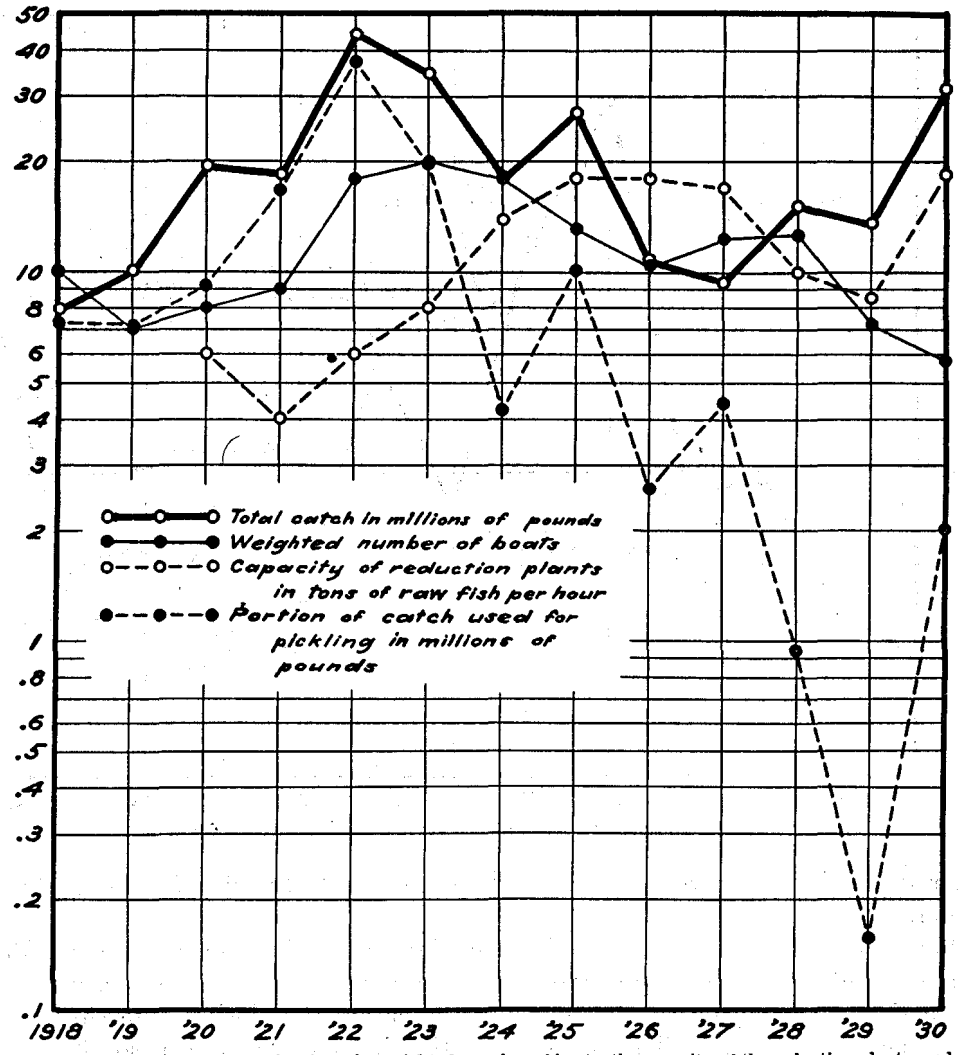

FIGURE 12.—The catch of raw herring, the weighted number of boats, the capacity of the reduction plants, and the portion of the catch used for pickling, plotted on a logarithmic scale to show the comparative rates of change

about three weeks earlier in Prince William Sound than in the aforementioned districts. These other areas usually have produced larger fish than has Prince William Sound, so that while good runs of herring occur there, the operations in Prince William Sound are curtailed in favor of these more profitable fisheries.

No weighting to allow for tonnages of the boats operated has been made. Table 15 shows the number of boats used and the average net tonnages of those vessels of which the capacities are known. Although there has been an increase in tonnage per boat since 1918, the changes since 1922 have been small and erratic. The efficiency

of the boats, and the effectiveness of their gear have also been disregarded in this analysis, because no measure of these is available. For instance, the introduction of the power seine roller was a great advancement over the former method of pulling

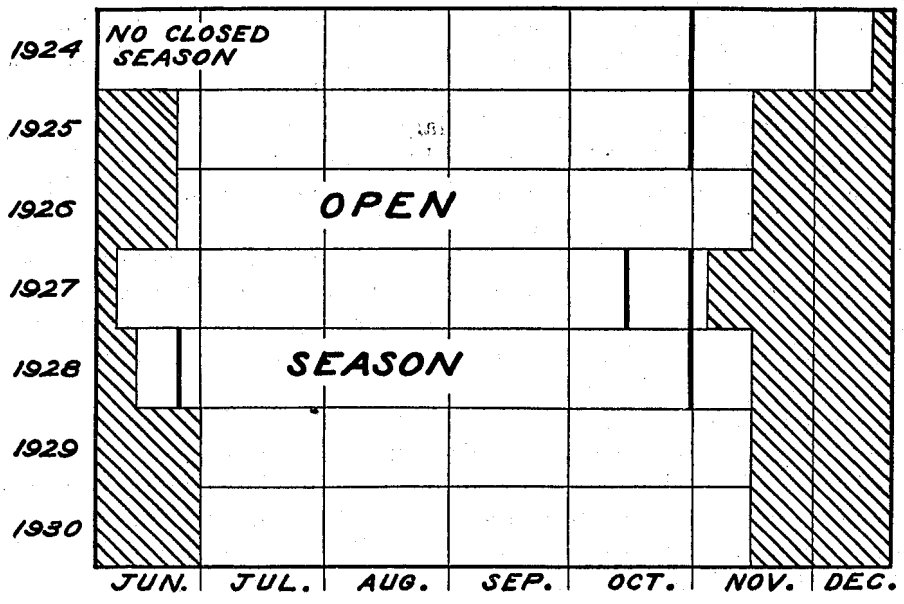

FIGURE 13.—Legal fishing seasons in Prince William Sound. The first closed period became effective in December, 1924. Unshaded portions indicate open seasons. The heavy vertical lines in 1924, 1925, 1927, and 1928 indicate opening and closing dates changed, before becoming effective, by supplementary regulations

seines by hand, but we have no records of when it was first introduced, and no method of determining the effect which it has had on the catch.

TABLE 15.—*Purse seine fleet of Prince William Sound*

Year	Number of boats	Number with tonnages known		Average net tonnage	Year	Number of boats	Number with tonnages known		Average net tonnage
		Actual	Per cent				Actual	Per cent	
1918	10	8	80.0	17.25	1925	26	22	84.6	23.73
1919	7	6	85.7	16.50	1926	21	20	95.2	22.65
1920	8	5	62.5	16.60	1927	21	20	95.2	25.20
1921	9	7	77.8	18.71	1928	26	25	96.2	25.60
1922	18	15	83.3	21.93	1929	10	10	100.0	21.70
1923	20	20	100.0	19.25	1930	8	7	87.5	23.14
1924	25	17	68.0	21.53					

The fishery of Prince William Sound was developed primarily for the pickled product. The fish were superior in quality to those taken in southeastern Alaska, and a market was readily found for them (p. 264). The first reduction units (Table 1) were introduced chiefly to utilize the waste which accompanies the curing process. Large fish predominated in the catch, and the mild-curing of herring was a thriving business.

The curing industry requires a supply of large fish, which must be brought to the saltery in good condition. The fishermen, therefore, made special efforts to take only the larger fish, usually disregarding the schools of smaller individuals. Their

seasonal catch, consequently, was smaller than it would have been had the plants been able to utilize any fish which they could have taken, and at the same time the younger age classes were afforded protection. Furthermore, the curing of herring requires much hand labor, and the daily capacity of a saltery was limited to the amount of fresh fish which could be handled. Much fishing time was lost impounding "feedy" loads of herring to allow them time to cleanse their intestinal tracts of food material (for description of impounding, see Rounsefell, 1930, pp. 231–232).

The introduction of the reduction units largely removed these limitations placed on the amount and size of the fish which could be utilized by the plants. The change from a fishery for salting to one for reduction has been gradual, and culminated in 1928 when the relative proportions of pickling fish in the catch became unusually low. This was due partly to the tremendous abundance of the 1926 year class which was then entering the catch as 3-year-olds and partly to earlier overfishing, which had caused the practical disappearance of the older age groups. The size of these 3-year-olds made them unsuitable for packing, but their abundance was sufficient to maintain a fishery for reduction products.

The change of interest from pickled herring to fish oil and meal has caused some change in the conduct of the fishery. Precious fishing time is no longer wasted while small loads of "feedy" fish are impounded. Now impounding is resorted to only at times of unusual abundance so as to keep the reduction plants busy during a period of scarcity or of weather too stormy for fishing. No size limit for the fish to be taken is observed, and fishermen seldom spend much time searching for schools of large herring. In operating a reduction plant without salting, the machinery can be kept operating constantly without having to wait upon the limitations that are necessarily imposed when all of the larger fish must be sorted out for pickling.[2]

Referring again to Figure 12 we find the curve showing the number of boats corrected to allow for the factors of regulations restricting the fishing season and time spent by the boats during the season at grounds other than Prince William Sound. From 1918, when the exploitation of this region began on a large scale, until 1922, the total catch and the weighted number of boats increased in about relative proportions. From 1922 until 1928 there was a decrease in total catch in proportion to the weighted number of boats fishing (except in 1925). During 1929 and 1930, however, a decreased number of boats caught an increased poundage. Apparently, then, although there was a decline in abundance beginning in 1923 and continuing through 1927, the 1926 year class was sufficiently abundant to cause the fishery to approach the abundance of earlier years. Since the fishery is drawing almost entirely from this year class, however, a decline to former low levels of abundance may be expected shortly unless the intensity of the fishery is reduced, or a new abundant year class appears.

CONCLUSIONS

1. The fishery is highly localized. Over a period of 8 years, 51 per cent of the catch was taken in the waters adjacent to Evans Island, 26 per cent in Macleod Harbor and Hanning Bay on Montague Island, 14 per cent in a few small bays on the southern end of Knight Island, and 7 per cent in the small area from McClure Bay to Eshamy Bay (including Main Bay). The whole of the remainder of Prince William Sound produced less than 3 per cent of the catch during this period.

[2] During 1929, however, at least one of the plants operated its two boats only on alternate days, since the limited capacity of the 2-ton reduction unit would not handle all of the fish which could have been taken. Had the plant sufficient capacity, its production could have been doubled during part of the season.

FIGURE 14.—Pickled herring on the wharf at Port Benny, Evans Bay, receiving fresh brine before being shipped to Seattle. Taken in 1927

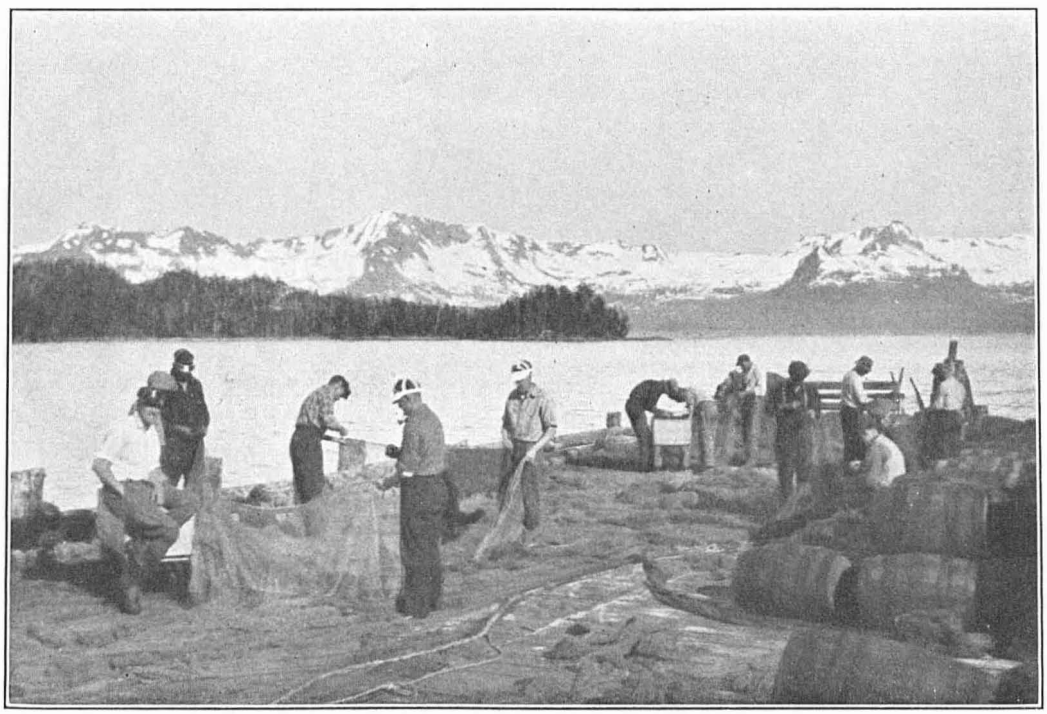

FIGURE 15.—Repairing a torn purse seine on the dock at the Crab Bay plant in Evans Bay. Taken in 1928

2. The means of the vertebral counts of each year class of herring in Prince William Sound showed a very high negative correlation, —0.85, with the temperatures during the period in which the eggs and larvæ of each year class were spawned and developed, showing that the differences in the means of the vertebral counts within Prince William Sound are chiefly, if not wholly, due to environmental conditions and not to genetic differences.

3. Comparisons of the means of the vertebral count distributions of fish of the same year class from neighboring localities suggest that McClure Bay has a stock of herring independent of those caught elsewhere in Prince William Sound but can not be definitely said to differ without further data.

4. The availability of the herring schools to the fishermen varies widely during different portions of the fishing season, as shown by the catch per boat per 10-day period, being highest during July, reaching a low point about September 20, rising to a second peak during the period from September 23 to October 2, and then fluctuating at a low level until the end of the season.

5. The herring normally enter the commercial catch in true proportion to their relative abundance during their fourth summer, although exceptionally rapid growth may cause the fish to enter the catch in large numbers during their third summer.

6. The great fluctuations in abundance that have occurred in Prince William Sound have been due largely to the growth and passage through the commercial catch of fish of dominant year classes.

7. In order to avoid violent fluctuations in the yield of the fishery a reserve of older age classes must be maintained.

8. The only regulations that have had a limiting effect on the fishery are those defining the fishing season.

9. In the period from 1925 to 1930, inclusive, the closed periods for fishing have probably decreased the total catch from about 9 to 28 per cent in the various years.

10. The present fishery is losing much profit by taking large quantities of young herring for reduction, that should be permitted to reach an age of 6 years and over before being caught.

RECOMMENDATIONS

FUNDAMENTAL CONSIDERATIONS

In order to prevent a recurrence of a scarcity of herring as in 1926 and 1927, or of the lack of fish of pickling size that characterized 1928, 1929, and to a large extent 1930, it will be necessary to protect the 1926 year class (now composing the bulk of the catch) until sufficient numbers of herring of another or other year classes also reach pickling size. As mentioned elsewhere the 1927 year class was poor. From the great scarcity of 3-year-olds in the 1930 age distributions it is extremely probable that the 1928 year class was a practical failure. In applying protection to this fishery one must not be mislead by the present abundance (due wholly to the 1926 year class), as year classes as abundant as that of 1926 are the exception, so that adequate protection must be given during periods of abundance if the fishery is to avoid periods of great scarcity.

The catch may be limited by restrictions on gear, fishing season, localities fished, or the size of fish taken. However, each type of regulation has its own peculiar advantages and disadvantages. Regulating the size of fish to be taken, for instance, is not very practicable in a purse seine fishery, as the gear catches all sizes

of fish that are in the school. Limitations on the length of the fishing season are often of great benefit and have the advantage of being easily enforced. The closing of certain localities is often feasible, especially if various localities are frequented by schools of herring of different sizes. Also, some localities may be better adapted to certain types of gear. Restrictions on the type or size of the unit of gear may be quite effective if it is desired to protect certain sizes of fish, or if it is feared that a shorter fishing season will merely result in the use of more gear, with a consequent loss to the operators, without a corresponding reduction in the catch.

It seems desirable in the present case to combine these methods. The season in Prince William Sound is unnecessarily long for a district in which reduction plants are operating. In southeastern Alaska the present season is only four months minus a weekly closed season of 36 hours, while in Prince William Sound the present season covers 4½ months. The question, of course, arises as to whether it would be best to shorten the present season at either end, or to impose a weekly closed season. Of the two, the weekly closed season is preferable in that it would cut off practically the same proportion of the catch each season. It would have the added advantage of allowing the saltery crews a period in which to repack the "seasticks" that had accumulated, instead of having to do this during the time fish were available for salting. A weekly closed season would therefore tend to increase the proportion of fish used for salting, allowing the companies to make a larger proportionate return on the fish caught.

The gear also needs regulation. The purse seine boats used range in size from 12 to about 40 net tons, and the purse seines from 150 to 180 fathoms in length. In this district where the distances are short and practically all of the seining is done in comparatively sheltered waters the sole advantage of a large seine boat is in its carrying capacity. The carrying capacity of these larger boats is a disadvantage, however, in so far as the most economical use of the resource is concerned, as the crushing weight of such loads renders quantities of otherwise suitable herring unfit for pickling. Also, it is these larger boats that render possible the operation of reduction plants independently of the supply of pickling fish. This criticism is not aimed at the use of herring for reduction, but at the exploitation by the reduction plants of immense quantities of small herring that in one to three years' time would be of a size suitable for salting. Since taking only large fish would tend to stabilize production, as explained above, and as the use of large boats increases the possibilities of profit from the small fish, it seems desirable to limit the size of the boats. This we believe can best be accomplished by limiting the size of the purse seine. With the shorter seine the large boats would have difficulty in securing full loads. However, this would be fairer than limiting the size of boats, as some operators might still wish to use large boats, and their use would not be objectionable when not carrying full loads.

SPECIFIC RECOMMENDATIONS

1. That commercial fishing for herring with seines, except for bait purposes, be prohibited from 12 o'clock noon on Saturday of each week until 12 o'clock noon on the Monday following.

2. That commercial fishing for herring, including bait fishing, by means of any purse seine more than 1,200 meshes in depth, more than 150 fathoms in length, or of mesh less than 1½ inches stretched measure between knots be prohibited.

3. That commercial fishing for herring, including bait fishing, by means of set and drift gill nets of mesh not less than 2½ inches stretched measure between knots be permitted until December 15 of each calendar year.

4. That the use of herring of over 10½ inches in total length, measured from the tip of the snout to the end of the tail fin, for reduction purposes be regarded as wanton waste under section 8 of the act of June 26, 1906. Any willful use or changes of gear, machinery, or handling so as to depreciate the value of herring as food shall be considered as an infringement of this regulation.

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