CONTRIBUTION TO THE BIOLOGY OF THE PACIFIC HERRING, *CLUPEA PALLASII*, AND THE CONDITION OF THE FISHERY IN ALASKA

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INTRODUCTION

NEED FOR INVESTIGATION

The herring fishery of Alaska has undergone a tremendous development in recent years. Gaining an impetus during the World War, it has increased until during the four years 1924 to 1927 an average of 160,000,000 pounds have been taken annually from the waters of Alaska. This ranks next to the take of salmon, the average annual catch of which during the same period was 358,000,000 pounds.

The rational use of this fishery and the desire to keep it at a point of maximum productivity without endangering the future supply demands a knowledge of two things: (1) We must know how the species is withstanding the strain of the fishery; (2) we must know what natural changes in abundance are occurring, so that they will not be confused with the effects of fishing, that they will be understood, and, if possible, foretold.

An investigation of the biology of the species was undertaken to understand and, if possible, to forecast these fluctuations in abundance, to discover whether they were due to natural causes or to depletion, and, if due to depletion, how this condition might best be remedied.[1] During the summer of 1925 the writer made a preliminary survey of the situation, visiting the important herring fisheries and collecting data for a general study of age and races. From an examination of these data it was decided that conditions were most favorable in central Alaska (Prince William Sound to Kodiak Island, inclusive) for working out the biology of the species, and so field work was confined to this part of Alaska in 1926.

PROBLEMS

Great natural fluctuations in abundance exist in the Atlantic herring (Hjort, 1914; Lea, 1919, 1924) and the California sardine (Higgins, 1926; Scofield, 1926). These two species, closely related to the Pacific herring, have been under observation for a number of years, and in both cases the fluctuations have been found to be due to the coming into the catch, or the departure therefrom, of fish produced in unusual numbers in some one year or years. Such an abundant year class may predominate in the catch for several years, during growth from young to adult, and as long as it is present it must increase the catch beyond that ordinarily taken. These "dominant" year groups may be one cause of the fluctuations in abundance of the Alaska herring, and if so, such fluctuations may be due largely to natural causes, not to overfishing.

To discover whether these fluctuations in abundance may be due to dominant year groups it is necessary to know the age or size composition of the herring population from year to year in order to connect any fluctuations in the catch with changes in the constitution of the population. Study of such age or size groups for a few years

[1] Many friends and associates have materially aided in the work with valuable advice and cooperation. William F. Thompson, director of investigations of the International Fisheries Commission of the United States and Canada, has aided the work in all its phases. Advice and valuable criticism have also been obtained from members of the scientific staff of the International Fisheries Commission: Henry A. Dunlop, William C. Herrington, and F. Heward Bell. I wish to thank Dr. Wilbert A. Clemens, director of the Pacific biological station of the Biological Board of Canada, for reviewing the manuscript on the section dealing with the independence of areas. To Lois F. Rounsefell I am indebted for aid in the making of counts and the tabulating and statistical analysis of data. Clarence L. Anderson, a former technologist of the United States Bureau of Fisheries, placed at my disposal several thousand length measurements. For special aid in the field work I wish to acknowledge my indebtedness to many of the herring operators, especially to Haakon Sundsby, of Halibut Cove, Wakefield Fisheries, North American Fisheries, Utopian Fisheries, S. Sklaroff & Sons, and others.

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might make it possible to foretell coming years of scarcity or abundance. Moreover, the value of such information to the industry in indicating the extent of preparations needed for the coming season would be very great. To determine this age or size composition we have sought to make our samples represent the commercial take; but in a fishery so scattered and in which the season in a given locality may be exceedingly short, it is not only difficult to obtain a full representation of the commercial catch, but it is difficult to be certain that the commercial catch from year to year is taken from the same section of the actually existing population.

In pursuing this study it should be remembered that such knowledge must be made use of to explain the fluctuations in the catch, and that without adequate records of the catch from year to year, it may be impossible to establish and prove a definite connection between dominant year classes and unusual abundance or periods of scarcity. Until such a connection is proved to exist, and until its extent can be tested, no prophesies as to the catch can be ventured upon, and it is impossible to assume that depletion is not occurring or that the presence of dominant year classes in our samples is reflected in the catch. The trade alone can furnish such statistics to the Government.

Since the presence or absence of depletion must manifest itself through the commercial take, as evinced by the total catch or by the catch per unit of gear, reliable statistics must be obtained. At present the presumption in the public mind is that depletion occurs whenever herring become scarce in a given locality; and there is no logical way to disprove this save by advancing and proving some other explanation for a decline, such as the passage and disappearance of a dominant year class.

In determining the causes of the fluctuations in abundance one of the most important questions to be faced is that of the degree of migration, as upon that depends the relative interdependence of the populations of different regions. The existence of a single stock of herring, freely intermingling and migrating along the narrow coastal banks, would mean that any fluctuations or depletion would be widespread, and that any regulations, to be effective, would have to consider the whole coast as a unit. On the other hand, if local "races" were present, each locality would have to be treated as a separate unit, since it would then be possible to greatly reduce the supply in one area without affecting it elsewhere. A great deal thus depends on the existence or nonexistence of local "races" or populations of herring, and much of our study has been on this problem.

Whether any of the changes in abundance can be due to overfishing is a question often asked. At present our chief criterion of depletion is afforded by the statistics of the commercial catch. In some cases these statistics do not give an adequate or detailed enough picture of what has occurred, yet in a few cases the changes in abundance have been so great that they would be difficult, indeed, to obscure. However, even when a decrease in abundance is shown by statistical criteria, the conclusions drawn from them should be corroborated, if possible, by biological evidence, such as a decrease in the abundance of the older fish, a failure in areas or with types of gear depending chiefly on the schools of larger fish, or a shift in the fishing grounds. The significance of the last-named criterion will depend on the proof of the existence of separate stocks of herring in the localities in question.

Racial data have been gathered on the spawning populations, inasmuch as a comparison of the spawning populations with those comprising the main commercial catch (taken in the summer months) will show on which spawning areas each of the races taken during the progress of the summer fishery is dependent. The spawning habits may be one of the limiting factors of their abundance; and the extent of the spawning grounds, and the number of spawners present, from time to time, may give some rough idea of the actual abundance of the herring. Overfishing should manifest itself by a decrease in the quantities of mature fish, consequently the spawning grounds should be the first to feel the effects of depletion.

The age at which the herring reach maturity has a direct influence on the amount of strain that the fishery will bear; in some fishes, as the halibut, where maturity is reached long after the fish are of a size to enter the commercial catch, there is no breeding stock that is not drawn upon by the fishery.

The preliminary nature of this report should be clearly kept in mind. In some cases the data are sufficient to warrant fairly definite conclusions, but in other cases the data are few and are presented for whatever they may show. This study will be continued indefinitely, and it is hoped that future contributions will fill in gaps and amplify the data now presented.

DESCRIPTION OF THE FISHERY

THE SEINE FISHERY

The methods of fishing have undergone considerable modification since the early days of the fishery. At that time beach seining was the method most commonly used by the small operators from Petersburg and Juneau. The only large company, that at Killisnoo, on upper Chatham Strait, used an old Norwegian method in which a large seine was placed on two boats, with about eight men per boat, the two rowing about 20 to 30 feet apart. When a school of fish was discovered they rowed around its opposite sides and pursed the seine by hand from one boat, brailing the haul into a steamer. Capt. Elling Arentsen used this type of gear for one of his boats at Big Port Walter until 1927. The seine was 14 fathoms deep and 175 fathoms long, with 1½-inch mesh, stretched measure.

Soon after 1900 the small operators of Petersburg and Ketchikan commenced using purse seines from power boats. This method of seining did not immediately supplant the Norwegian method of seining from row boats, which was continued by the Killisnoo plant until about 1924, and by the Big Port Walter plant until 1927. By 1918, however, the majority of the operators in southeastern Alaska, and all of those in the newly exploited fishery in Prince William Sound were using the power seine boats.

In 1918 the power seine boats in southeastern Alaska had an average net tonnage of 17, ranging from 11 to 31 tons. They were all powered with gasoline internal-combustion engines and carried a crew of from five to seven men. In 1927 in southeastern Alaska the purse-seine boats had an average net tonnage of 31, ranging from 20 to 42 tons, the smaller sizes having lost favor owing to their small carrying capacity. One-half of the present fleet (practically all of the newer boats) is powered with Diesel engines to cut the cost of operation. Each boat carries a crew of from six to eight men.

The purse seines employed at present range from about 175 to 250 fathoms in length and from about 12 to 30 fathoms in depth. The webbing comes in strips 3½ fathoms in width, so that the depth of a seine is easily changed by adding or taking off a strip. In the early summer, shallow seines of 4 or 5 strips are used, but in the autumn the fishermen usually have to deepen them in order to make good catches, 6, 7, and as high as 9 strips being used. The meshes are 1½ inches and occasionally 1¾ inches.

Most of the purse seining is done at night, but occasional good hauls are made in daylight, especially in the Kodiak-Afognak district. The seine boats arrive at the fishing grounds about dusk and cruise slowly about with a man always on watch. He discovers the presence of a school of herring either by seeing them "flipping" at the surface, or, if it is too dark to see, by hearing the gentle splashing. The herring "flip" best at dusk and just before dawn. Sometimes when the herring are not "flipping" the fishermen resort to "leading." A man rows slowly about in a small skiff, dragging a very fine line, to the end of which is attached a heavy piece of lead. This holds the line taut and perpendicular, so that one can tell when the line is passing through a school of herring by feeling the line jerk as the herring strike against it.

When a school of herring is located one of the crew jumps into a skiff, which the seine boat is towing, and releases the end of the seine from the seine boat. The weight of the skiff is now pulling on the seine, which commences to play out over the roller in the turntable, the man in the skiff meanwhile pulling backwards with his oars to keep the cork line tight. The seine boat sets the net in a circle and purses it as quickly as possible to prevent the herring swimming out underneath. (Fig. 1.) The net may then be hauled in slowly until the fish are crowded enough to brail into the boat with a large dip net. (Fig. 2.)

If the fish contain too much "feed" to salt immediately, or if the haul is too large for the plant to use in one day, the fish are impounded, conditions permitting. In this case the net is pulled in far enough so that the herring will not get it tangled into bags and smother themselves but not far enough to crowd them, for overcrowding causes them to lose their scales and die in the pound.

The pound has usually been placed in readiness beforehand, and the seine boat blows its whistle to summon its towboat to come and tow it to the pound. The towboat may be almost any small gas boat or discarded seine boat. A bridle is attached to the bow and stern of the seine boat and it is towed sideways toward the pound dragging the seine full of herring. On reaching the pound the edge of the seine is attached to the edge of the pound, the two cork lines are held below the water, and the seine pulled into the boat, forcing the herring into the pound. There are usually a number of seine boats fishing on the same ground, so that whenever one makes a set it turns on a red light as a warning to other boats not to run over the seine. These lights are usually arranged to help the towboat in identifying its own seine boat in the dark.

If the herring contain "red feed," which is composed of small crustaceans, they are left a few days in the pound before being used. This gives them time to clean themselves of the feed which would otherwise cause them to spoil when pickled. Occasionally the herrings' stomachs contain "black feed" composed of pteropods. When this is the case they are extremely difficult to cure, even after several days in the pound, and do not bring the highest prices..

By impounding herring the plants are able to have a constant supply of fish, which enables them to make a larger pack. However, impounding has disadvantages from the standpoint of conservation. When the wind and tide are unfavorable, or when the haul is made too far from the pound, there is great danger of the herring being smothered by being forced into dense masses during the towing. In some cases the pounds have been placed in water too shallow and the receding tide has left the herring stranded. Occasionally storms drag a pound ashore, smothering the herring. Even with the best of care a small percentage of the impounded herring will soon die from infection where the scales have been rubbed off against the web.

The herring pounds are of 1¾ or 2 inch mesh (stretched measure) and of heavier web than the seines. Since they must be left in the water for a long time, they are never tanned but are heavily tarred. They are simply strips of webbing about 80 fathoms in length, put out to form a square with floats on the top and weights underneath to keep the web on the bottom.

THE GILL-NET FISHERY

In Alaska gill nets are used chiefly in Halibut Cove and a few scattered localities such as Simeonof Bay in the Shumagin Islands. (Fig. 3.) Those used at Halibut Cove are 50 fathoms in length and 100 meshes (about 3 fathoms) in depth and are anchored in one spot while fishing. The mesh used is supposed to be 3 inches across (stretched measure).[2]

Since herring seldom gill in daylight, the nets are usually let down at night. The gill nets, or set nets, as used at Halibut Cove, are anchored at both ends and kept up with buoy kegs. In the morning it is usual to lift the net, to go along it shaking the herring into the boat, and then to drop the net back into the water so that on reaching its far end it has been reset.

Gill netting is advantageous where the fish are desired for salting and where the majority of the herring are too small for pickling, since, if a proper size of mesh is used, only the larger herring are captured.

Some have ascribed the failures of the herring fishery in the various localities of central Alaska in recent years to the inability of the gear to catch the herring, except when they come into the bays. Some of the proponents of this theory have made attempts in Alaska to gill-net herring by the European method, in which a large power vessel operating at a distance from shore puts out a very long cable buoyed up at intervals with kegs. To this cable are attached a number of gill nets. Neither the boat nor the cable are anchored while fishing, hence the name "drifting" is applied to this method.

The power schooner *Decorah* attempted this method in Prince William Sound in 1924, but had no success. In 1928 the power schooner *Roald Amundsen*, equipped with 40 gill nets, each 12 fathoms long by 300 meshes deep, "drifted" all summer on the Portlock and Albatross banks, off the Trinity Islands, in Shelikof Strait, all around Kodiak Island inshore and offshore, and in Cook Inlet. This attempt also met with failure. These failures would seem to bear out the evidence of our racial investigations; that the herring, being divided into a number of local races, can not be found in any large body offshore.

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[2] Koelz (1926) made experiments illustrating the difference in effectiveness of nets which differ only ¼ inch in size of mesh. In two experiments in Lake Ontario he found that gill netting of 2½-inch mesh caught double the number of fish of netting with 2¾-inch mesh.

This is significant in that there is a distinction between meshes as manufactured and as fished. The 9 or 12 thread cotton gill netting used in Alaska shrinks in tanning and in the water. Thus the 3-inch mesh cotton gill netting used at Halibut Cove is 3 inches as manufactured, but is almost invariably 2¾ inches as fished.

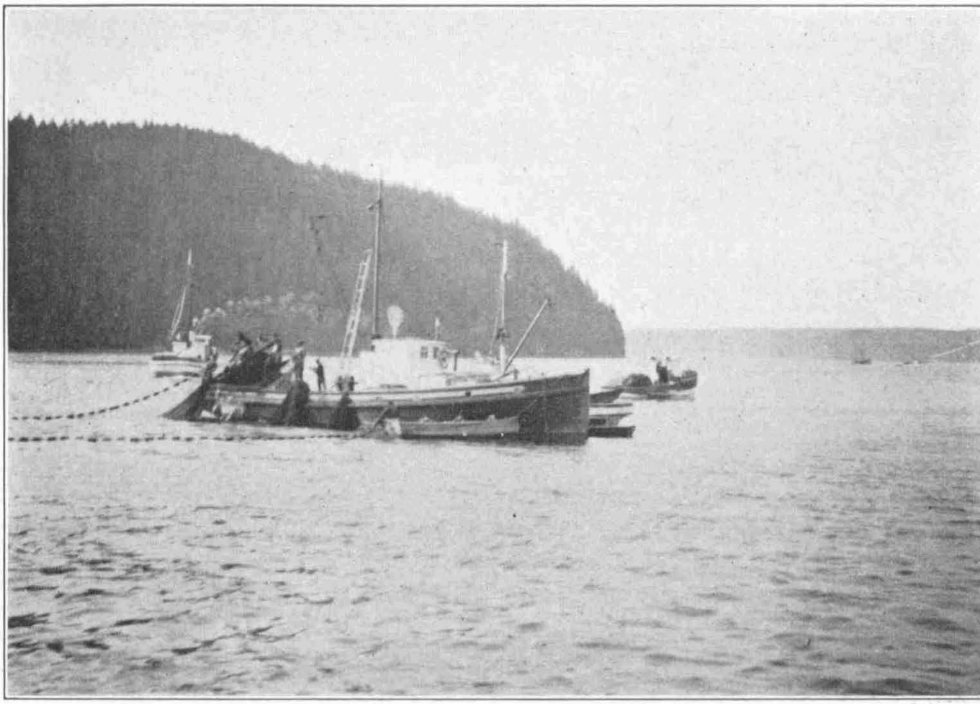

FIGURE 1.—Purse seining for herring in Red Fox Bay, Shuyak Strait. This tiny bay was a heavy producer of herring from 1924 to 1926. Thirty purse-seine boats gathered here for the opening of the season on July 15, 1926

FIGURE 2.—Brailing herring from the pound into the seine boat at Dutch Harbor

FIGURE 3.—The type of small saltery used in the gill net fishery at Halibut Cove, Kachemak Bay

LOCALIZATION OF BRANCHES OF INDUSTRY

In Alaska herring are utilized mainly in four ways: For oil and fertilizer or fish meal, for pickling, for halibut bait, and for dry-salting, and the requirements vary accordingly. It is found that particular localities are favored for each of these phases of the herring industry.

The oil and fertilizer industry requires a fairly constant and cheap supply of fat herring. Cheapness implies that they are too small to be used for pickling, necessitating that small herring be more abundant at times than large herring for the industry to be profitable.

The pickled (or salted) herring industry utilizes, as a rule, only herring of over 10½ inches in total length. The herring must be fat and are much better if free from feed, as it causes the pack to spoil.

For halibut bait the herring are best in the winter and spring months, when they are thin and firm, as they stay on the hooks longer and keep much fresher than when fat. Medium sized or small herring are preferred.

For dry-salting the herring are best in the late fall and winter months, as they must be free from feed or fat, and should have the milt and roe developed. The size makes but little difference as long as they are mature fish.

The oil and fish-meal industry centers in Chatham Strait and is found to some extent in Prince William Sound, but is entirely lacking farther west. This distribution results from the large, fairly constant supply of small fat herring in Chatham Strait from June to October, and the predominance of small herring in Prince William Sound in the early summer. In southeastern Alaska the small herring so predominate as to make pickling unprofitable except as an adjunct to the oil and fish-meal industry. In Prince William Sound the schools of herring are so mixed in size that it is necessary for the plants to maintain reduction works to utilize the enormous waste, yet the supply has not been large enough to encourage the manufacture of oil and fish meal as an independent industry. All of the larger establishments in this district operate reduction plants in conjunction with their salteries. Farther west than Prince William Sound most of the herring are large enough for pickling, leaving only a small residue for reduction, while the plants are practically all either floating salteries or very small shore plants, with no room for the operation of fertilizer plants. For these various reasons no reduction plants have been operated west of Prince William Sound.

The pickled (or salted) herring industry is of greatest importance in western Alaska and the Kodiak-Afognak and Cook Inlet districts, owing to the large herring obtained in these areas. In Prince William Sound it is of about equal or of slightly greater importance than the reduction industry, but is a minor industry in southeastern Alaska.

The bait industry centers in southeastern Alaska, for it is here that the halibut boats land most of their catches. During the summer months the halibut vessels obtain fresh bait from the herring plants, but in the spring and fall months, when the herring plants are not operating, the supplying of fresh bait to the halibut fleet is a separate industry. A supply of bait is frozen during these months, when the herring are thin, and sold to the boats during periods when fresh bait is unobtainable.

At present the dry-salting of herring is of very minor importance, being carried on only in Cook Inlet in the late fall and early winter months.

HISTORY OF THE FISHERY

DEVELOPMENT OF VARIOUS PHASES OF THE INDUSTRY

The first commercial use to which herring were put in Alaska was the manufacture of oil and fertilizer. A plant for this purpose was established on the site of an old whaling station at Killisnoo on upper Chatham Strait in 1882. This was the only herring reduction plant in Alaska until 1919, in which year there were 3 on Chatham Strait. In 1920 there were 7 on Chatham Strait and 2 in Prince William Sound. In 1921, due to the low price of herring oil, only 3 of the 9 reduction plants operated—2 in southeastern Alaska and 1 in Prince William Sound. By 1923 the price of herring oil had risen to such an extent that the industry boomed until, in 1927, there were 25 herring reduction plants in the Territory—18 large plants in southeastern Alaska and 7 smaller plants in Prince William Sound. Over 100,000,000

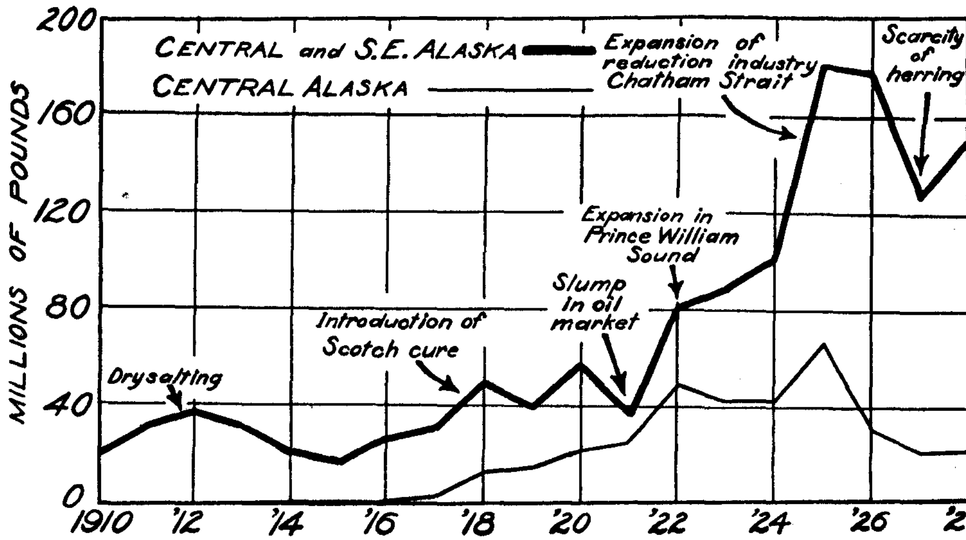

FIGURE 4.—The total catch of raw herring in central and southeastern Alaska from 1910 to 1928, inclusive

pounds of raw herring have thus been utilized annually since 1925, the peak being reached with 150,000,000 pounds in 1926.

Although a few barrels of herring were salted in various localities previous to 1900, the pickling industry may be said to have commenced about that time at Petersburg. Instead of building shore plants the fishermen packed on scows, which they towed about from place to place with their power boats, extending their operations as far as Chatham Strait by 1916. (Fig. 5.) During these years the herring were practically all packed by the Norwegian method, in which the herring are heavily salted, poorly gutted, and not carefully graded into sizes. For these reasons, and because of careless packing, the market remained very restricted. In 1917 the United States Bureau of Fisheries introduced into Alaska the Scotch method of curing herring, in which the herring are carefully graded into sizes, properly gutted, salted lightly, and neatly packed into barrels.

The attractive pack and war prices stimulated the industry, resulting in the building of several large salteries in Chatham Strait and in Prince William Sound in 1918. (Fig. 6.) Over 100,000 barrels of herring were salted in Chatham Strait, but partially on account of the war ending, and partially on account of the careless

FIGURE 5.—The type of small seine boat and floating saltery prevalent in Chatham Strait about 1917

FIGURE 6.—A typical herring saltery and reduction plant in Evans Bay, Prince William Sound

salting of the 1918 pack, a great slump occurred in the market. A good share of the 1918 pack was sent to the reduction works in Seattle and it took over two years for the pickling industry to recover. In the meanwhile it had become firmly established in central Alaska, while in southeastern Alaska, owing to the comparatively small size of the fish, it had waned and never recovered the importance it held in 1918, the pack exceeding 20,000 barrels only in 1922 when 30,000 barrels were packed. In central Alaska, however, over 100,000 barrels of herring were pickled in 1922 and again in 1925.

The growth of the third type of herring industry, that for bait, is correlated with the growth of the halibut fishery which it supplies. The halibut fishery commenced in 1888, the first fishing being done on the banks of Washington and British Columbia. The fishery gradually worked north. By 1912 or 1913 it had become an important Alaska industry. The catch of halibut of the whole coast now totals about 53,000,000 pounds. Herring is the bait used to the practical exclusion of everything else. Since the halibut fishermen prefer fresh bait, claiming that the halibut take it more readily than the frozen, the majority of the bait herring are kept alive in pounds and sold fresh as needed, the cold-storage plants serving to tide over the too frequent periods when fresh herring are not obtainable. In 1927 the halibut industry used over 8,000,000 pounds of herring bait from Alaska. Of this, 4,600,000 pounds represents frozen bait from southeastern Alaska. Of the 3,400,000 pounds of fresh bait used, 2,800,000 pounds were from southeastern Alaska and 600,000 pounds from central Alaska. The bait statistics, especially those for fresh bait, are very incomplete, but it is practically certain that the amount of bait consumed has reached over 8,000,000 pounds for several years preceding 1927.

Some dry-salting of herring in bulk for the oriental market has been done. In 1910, Capt. A. W. Thomas built a large saltery for this purpose in Ketchikan, and in 1911 over 3,000,000 pounds were salted. In 1912, more competitors entered the field and over 13,700,000 pounds were prepared, but in 1913, in spite of the increased effort, the production fell to 8,700,000 pounds, and in 1914 most of the operators went out of business. Since that time, 1918 is the only year in which the dry-salted product in southeastern Alaska has exceeded 1,000,000 pounds. In recent years herring have been dry-salted in Cook Inlet to be sold to the domestic market for smoking, as much as 2,500,000 pounds being prepared in 1924.

During the early development of the Chatham Strait and Prince William Sound fisheries, the herring companies made a determined effort to establish a market for canned kippered herring. Commencing with nearly 20,000 cases in 1916, the output was increased until it reached over 100,000 cases in 1919, but all efforts to find a satisfactory market failed. In 1920, the last year, only 3,600 cases were canned. All of the product was canned in southeastern Alaska, with the exception of 34,000 cases canned in Prince William Sound in 1919.

A few minor industries may be mentioned. In 1904 the Juneau Packing Co. canned over 3,000 cases of herring at Juneau as one-quarter oil and three-quarters mustard sardines, but were unable to compete with those from the Atlantic coast. In 1926 a company on Chatham Strait installed a refrigeration unit and commenced shipping freshly kippered herring to the States. Another company followed suit in 1927. This development holds great promise for the future.

AREAS FISHED

The areas fished at different times by different phases of the industry have varied in accordance with such economic factors as labor and shipping facilities, and such biological factors as size, fatness, and quantity of herring available. In some

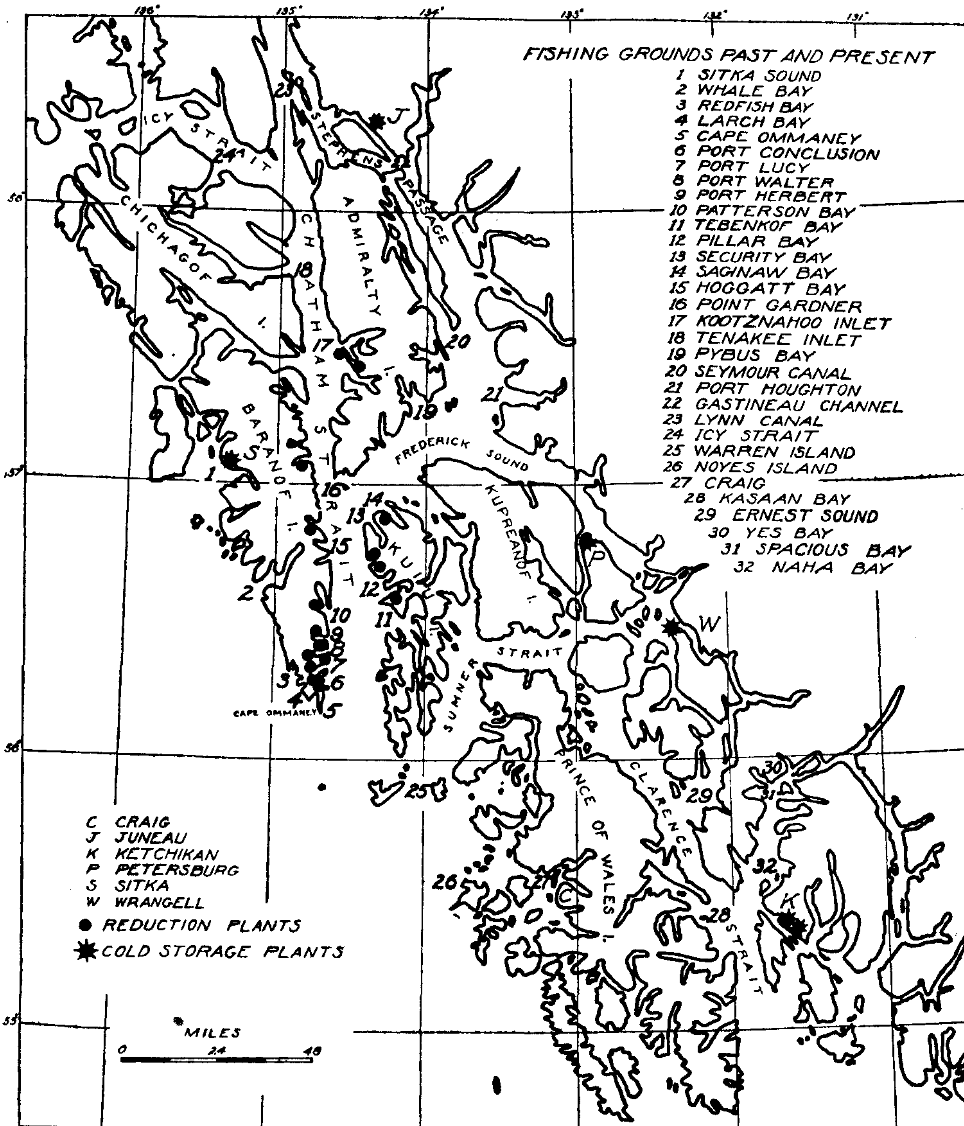

FIGURE 7.—Southeastern Alaska, showing the herring plants and the fishing grounds

localities herring appear only in the summer months, while in others they are taken only in the late fall or during spawning in the spring.

In southeastern Alaska (fig. 7) during the very early years of the fishery the one reduction plant at Killisnoo fished along Chatham Strait, especially in Kootznahoo Inlet (No. 17, fig. 7), and along the northern shore of Kuiu Island, while the other companies fished chiefly in the inside waters near Juneau and Petersburg—Pybus Bay, Seymour Canal, Port Houghton, Gastineau Channel, etc. (Nos. 19, 20, 21, and

22, fig. 7). From 1910 to 1914 an intensive fishery for herring to dry-salt for the oriental trade was carried on during the fall and winter months in Yes Bay and vicinity. (Nos. 30 and 31, fig. 7.) During these years the pickled-herring industry was gradually abandoning the waters near Petersburg and spreading toward Chatham Strait, which since 1916 has been the center of all phases of the industry, except the minor fishery for halibut bait. The bait fishermen continued to fish in the inside waters (which were close to the cold-storage plants), although with decreasing success, a large proportion of the bait used in the last few years being taken near the spawning grounds at Craig and in Sitka Sound. (Nos. 27 and 1, fig. 7.)

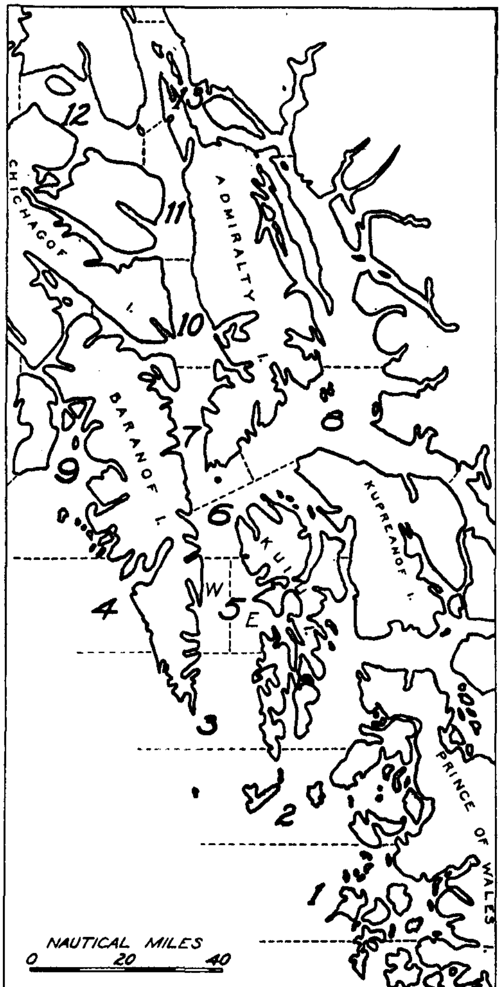

FIGURE 8.—Areas of southeastern Alaska by which the summer fishery has been analyzed in Table 1

Information on the areas exploited by the summer herring fishery of southeastern Alaska, from 1922 to 1928, is contained in accurate records kept by a plant at Red Bluff Bay (on Baranof Island, in area 6, fig. 8). In compiling these records the fishing grounds have been divided into areas of approximately equal size. (Fig. 8.) Since the amount of gear used varied from year to year, only the percentage of the catch taken in each locality has been given. For 1927 and 1928 records are available for other plants and we have given the catches of two of these—from Big Port Walter in area 5W and from Killisnoo on Admiralty Island in area 10—so that the effect of the location of the plant on the areas fished might be observed. The table follows.

TABLE 1.—*Per cent of catch taken in definite areas by certain plants in southeastern Alaska from 1922 to 1928, inclusive*

Area fished		Location of plants										
		Red Bluff Bay							Big Port Walter		Killisnoo	
No.	Designation	1922	1923	1924	1925	1926	1927	1928	1927	1928	1927	1928
1	Noyes Island							14.5	4.5	10.1		
2	Warren Island					0.6	2.1		1.9	.3		
3	Cape Ommaney	10.6	29.3	17.5	6.2	57.0	80.1	55.9	80.0	72.7	60.0	11.0
4	Whale Bay				.4	1.4	1.8		6.2	.3		
5W	Patterson Bay	29.5	6.8	2.6	42.4	8.4	1.4	.7		16.1		.4
5E	Tebenkof Bay	15.6	50.3	21.0	33.5	31.8	13.3	9.6	5.9	.2	2.5	
6	Security Bay	19.6	11.2	38.4	12.3	.5	1.6	.2			3.8	1.2
7	Point Gardner	24.9	.9	20.6	4.8	.2			.4	.2	25.0	.8
8	Pybus Bay				.3							1.0
9	Sitka Sound											10.6
10	Kootznahoo Inlet								1.1		5.4	7.9
11	Tenakee Inlet		1.5									.7
12	Icy Strait										3.3	13.8
13	Lynn Canal							19.2				52.6

The table shows several interesting facts. The amounts taken from areas 5, 6, and 7 (fig. 8) have decreased, and those from area 3 have increased. The amount taken from area 4 by the Red Bluff Bay plant was slight, but those plants located in area 3 obtained a large percentage of their 1925 catch from area 4. One of the most interesting and significant developments is the exploitation of distant areas, such as Noyes Island, Warren Island, Sitka Sound, Icy Strait, and Lynn Canal, in 1927 and

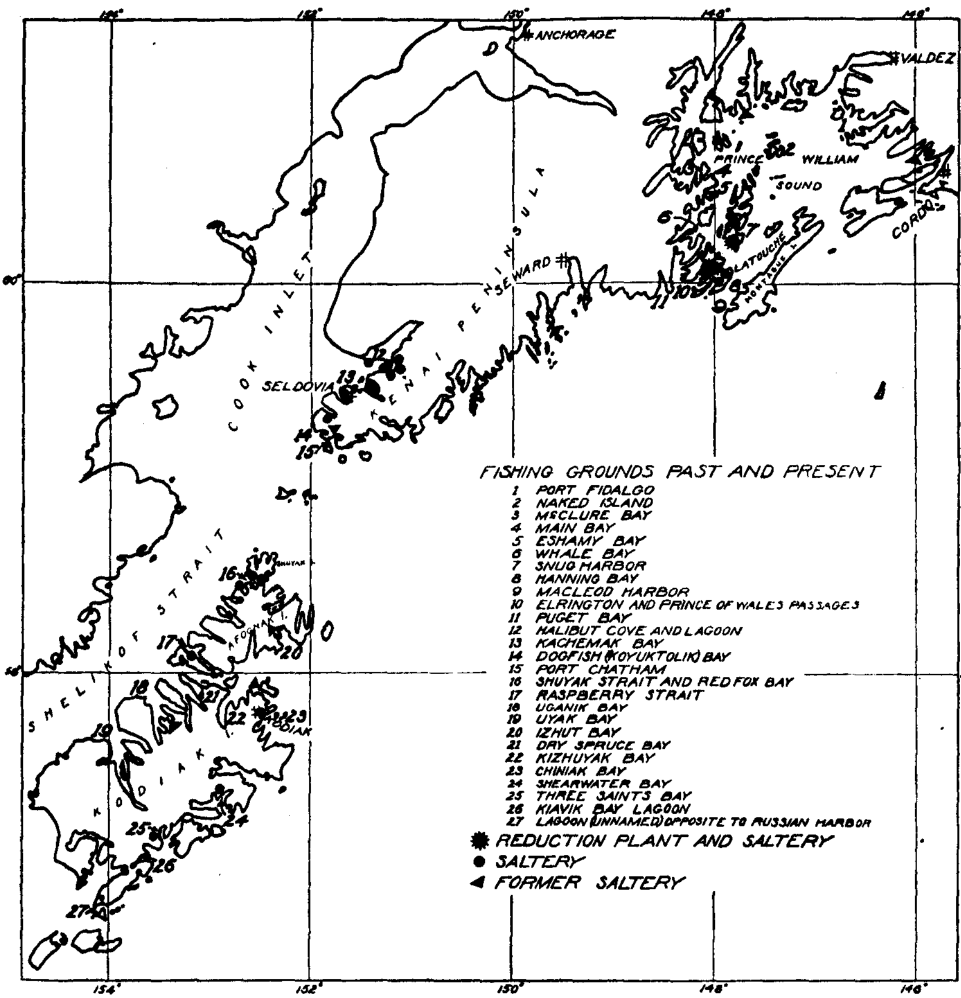

FIGURE 9.—Central Alaska, showing the herring plants and the fishing grounds

1928. This may indicate that a greater decrease in abundance has occurred than is shown by the catch analysis (to be discussed later, see fig. 47), the catch being maintained by shifting of the fishing grounds.

The central Alaska fishery is more recent. The western side of Prince William Sound has been subjected to intensive fishing since 1918. (Fig. 9.) In Cook Inlet gill-net fishing was commenced at Halibut Cove, Kachemak Bay, in 1914, and has continued up to the present, purse seining in Cook Inlet not commencing until 1923. On Kodiak Island fishing in a small way was being carried on in the vicinity of Kodiak by 1916, and Shearwater Bay has been exploited since 1921. On Afognak

FIGURE 10.—Small saltery erected at Unalaska in 1928. Herring were so plentiful that their pound, consisting of a small beach seine, is right alongside of the dock. The men in the foreground are obtaining herring from the pound for the day's operation

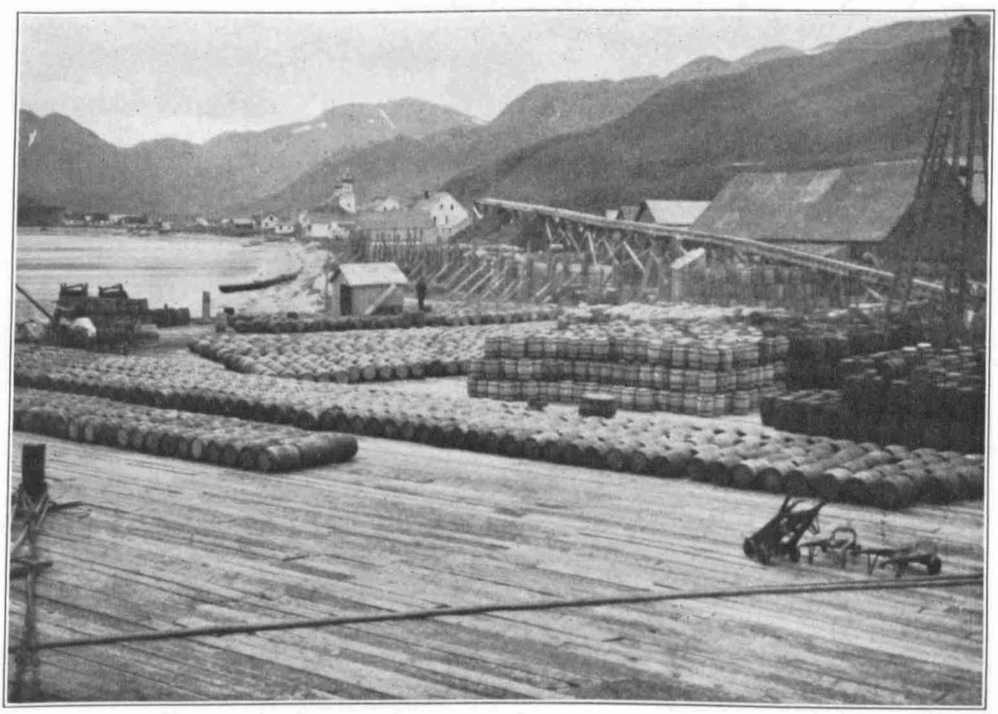

FIGURE 11.—The dock at Unalaska during the height of the herring run in August, 1928, showing the piles of empty barrels and the rows of packed barrels ready for shipment

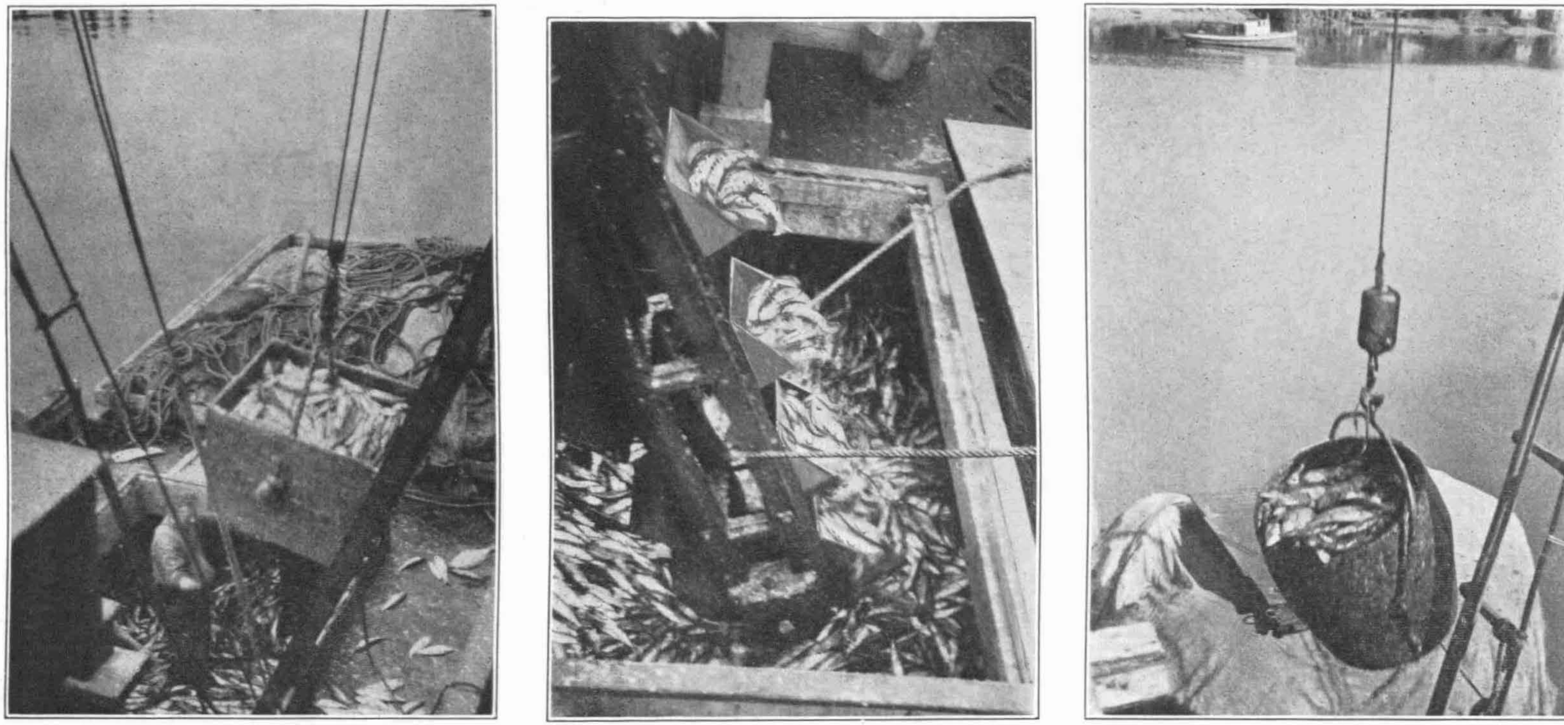

FIGURE 12.—Three methods of unloading herring from the seine boats

Island purse seining was first carried on in 1922 in Raspberry Strait and Izhut Bay. Since 1923 it has been largely confined to Shuyak Strait.

In western Alaska a very small gill-net fishery was established on Simeonof Island, one of the Shumagin group, in 1906. About the same time a small fishery was commenced near by at Chignik on the Alaska Peninsula. These two minor fisheries have continued up to the present. A small fishery has been carried on at Golovin Bay, in the northern part of the Bering Sea, since before 1909. However, no extensive fishery existed in western Alaska until 1928, when about half of the central Alaska purse-seine fleet fished at Unalaska (Dutch Harbor) in the Aleutian Islands. (Figs. 10 and 11.)

COLLECTION AND DESCRIPTION OF SAMPLES

SELECTION OF THE SAMPLE

In the collection of samples an effort was made to obtain a truly representative sample from each load. Care was taken not to select the sample in such a manner as to influence the size of the fish that were to be contained therein. The usual procedure was to hold a bucket under the fish elevator in such a manner that the fish dropped into it without any voluntary selection. (Fig. 12.) This was always done after the fishermen had shoveled off the top of the load since there is a tendency for the larger fish to rise to the top of the load and for the smaller fish to sink to the bottom. This tendency appears to act only upon the upper and lower few inches of the load, so that by taking samples from the middle of the load one does not incur the danger of under-representing the extreme sizes. In localities where the fish in the same load tend to cover a large range of sizes, samples of about 100 fish were usually taken. Where the range of sizes in the same load tended to be small, but the average sizes of fish of different loads varied considerably, then smaller samples of about 25 to 50 fish were taken, and an endeavor was made to sample more loads.

DATA TAKEN ON EACH SAMPLE

Having collected a random sample from a load of herring, the next step was to lay the herring in a row. Then a scale sample was taken from each fish from the middle of the side below the dorsal insertion. The scales were preserved in serially numbered coin envelopes and the corresponding number given each fish when its measurements were entered on the data sheet.

The fish were next measured, the measurements all being taken parallel to the body axis from a plane at right angles to the body axis at the tip of the mandible with the mouth closed. These were read in millimeters on an improved model of the fish-measuring board employed by Thompson (1917) in his investigation of the herring of British Columbia and later modified by Thompson (1926, p. 60), Elmer Higgins, and the author for taking sardine measurements at the California State Fisheries Laboratory (see fig. 13).

In making the measurements the wire on the cross arm of the measuring board was invariably aligned with its own reflection in the mirror. This always insured the eye being held vertically above the wire. As soon as each fish had been measured it was weighed on a spring balance graduated to 2 grams, with a capacity of 500 grams. After the measurements were all completed, the rays in the dorsal and anal fins were counted and the sex was then determined. The fish was reweighed with the entire contents of the body cavity removed. With a sharp scalpel the flesh was cut from one side, exposing the vertebræ which were scraped clean and counted.

The complete list of data taken is as follows:

Measurements:
- From the tip of the closed mandible to—
  - The posterior end of the opercle, designated as the "head length."
  - The insertion of the dorsal fin.
  - The insertion of the anal fin.
  - Where the silvery epidermis of the body ends, more or less truncately, on the sides of the caudal peduncle, this measurement designated as "body length."
  - The ends of the caudal rays when the edges of the caudal fin are held parallel to the body axis, thus securing what is here called the "total length."

Counts:
- Vertebræ, excluding the hypural.
- Unbranched and branched dorsal rays.
- Unbranched and branched anal rays.

Weights:
- Total.
- With the entire contents of the body cavity removed, designated as the "cleaned weight."
- Gonads.

Other observations:
- The state of maturity of the gonads.
- Age, from sample of scales taken from the side under the insertion of the dorsal fin.

The head lengths and the distances to the insertions of the fins were expressed in all computations as percentages of the body length, these percentages being calculated with sufficient accuracy by means of a slide rule.

TABLES OF SAMPLES

The samples taken in this investigation from 1925 to 1928, inclusive, are presented in the following tables:

TABLE 2.—*1925 samples* [1]

Date	Number in sample [2]	Locality	Apparatus	Remarks
1925				
June 20	65	Clarence Straits, (Gravina Island)	Salmon trap	
26	100	Craig	Purse seine	Confined since April in pound, caught when spawning, thin and firm.
July 3	100	Whale Bay (Baranof Island)	do	
5	100	Tebenkof Bay (Chatham Strait)	do	
16	75	Point Gardner (Chatham Strait)	do	
17	35	do	do	
26	45	Elrington Passage	do	
27	45	Prince of Wales Passage (Elrington Passage)	do	
28	75	Shuyak Strait	do	Taken from boat in Evans Bay.
31	100	Procession Rocks (Elrington Passage)	do	
Aug. 3	50	Shuyak Strait	do	Do.
4	30	do	do	Do.
6	100	Dogfish Bay (Koyuktolik Bay)	do	Confined several days in a pound, very thin and firm.
7	75	Naked Island	do	
12	25	Shuyak Strait	do	
23	105	Lagoon on Kodiak Island opposite Russian Harbor.	Gill net of 3-inch mesh	

[1] All measured while fresh.

[2] Only one sample on each date.

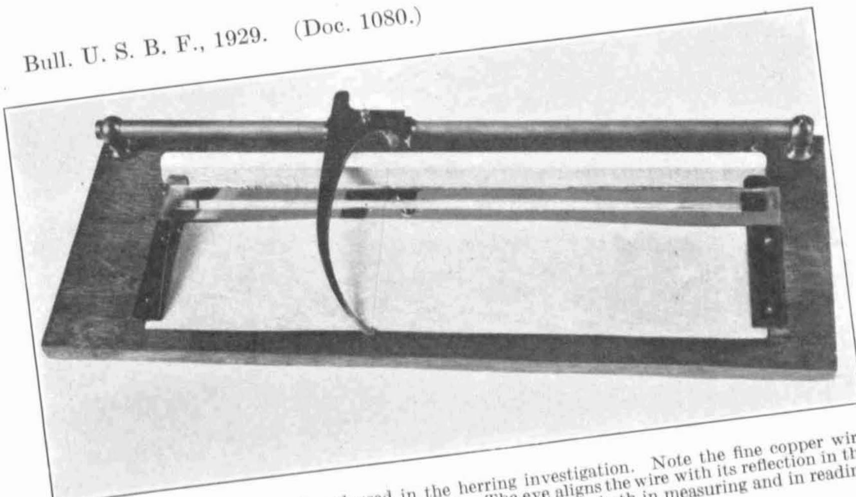

FIGURE 13.—Fish measuring board used in the herring investigation. Note the fine copper wire on the cross arm, and the mirror under the scale. The eye aligns the wire with its reflection in the mirror so that the eye is always held at right angles to the scale both in measuring and in reading

TABLE 3.—*1926 samples* [1]

Date	Number of samples	Number in samples	Locality	Apparatus	Remarks
1926					
Apr. 12	1	161	Halibut Cove lagoon (Kachemak Bay)	Gill net of 3-inch mesh	
22	1	233	do	Beach seine, fine mesh	
27	1	47	Halibut Cove (Kachemak Bay)	do	
29	1	250	do	do	
29	1	41	do	Gill net of 3-inch mesh	
May 12	1	125	Behind McDonald Spit (Kachemak Bay).	Hands	Caught while spawning.
15	1	100	Homer Spit in lagoon (Kachemak Bay)	Dip net	Do.
18	1	10	Halibut Cove (Kachemak Bay)	Gill net of 3-inch mesh	
June 25	1	100	Elrington Passage	Purse seine	
26	4	200	do	do	
27	1	75	do	do	
28	1	100	do	do	
30	1	120	do	do	
30	1	75	Prince of Wales Passage (Elrington Passage).	do	
July 1	4	175	Cape Elrington (Elrington Passage)	do	
2	2	150	do	do	
8	1	50	Elrington Passage	do	
18	1	60	Red Fox Bay, Shuyak Strait	do	Impounded since July 15.
30	1	52	do	do	Do.
Aug. 5	1	22	do	do	
12	1	115	Old Harbor (near Three Saints' Bay)	Salmon trap	Thin spents.
19	1	100	Off McDonald Spit (Kachemak Bay)	Gill net of 3-inch mesh	
25	1	168	do	Purse seine	
27	1	100	Off McEwan Flats (Kachemak Bay)	do	
28	1	100	do	do	
29	1	100	do	do	
30	1	100	do	do	
Sept. 12	1	75	Off Falls Bay (Eshamy Bay)	do	
18	1	150	Eshamy Bay	do	
19	1	100	do	do	
20	1	150	do	do	
21	1	50	Off Glacier Spit (Kachemak Bay)	do	Taken from tender in Evans Bay, poor condition.
Oct. 25	1	324	Golovin Bay, Norton Sound	Beach seine	Full to throat.
Dec. 13	1	408	San Diego Bay	Gill net	Part very ripe, part of them developing, with small gonads.
Summer	1	456	Simeonof Bay (Shumagin Islands)	do	Recently spent, poorly preserved.
Summer	1	107	Chignik Lagoon	Beach seine	Well preserved.

[1] All measured while fresh except the following: Golovin Bay, Simeonof Bay, and Chignik Lagoon, salted; San Diego Bay in formalin.

TABLE 4.—*1927 samples*

Date	Number of samples	Number in samples	Locality	Apparatus	Remarks	Preservation
1927						
Feb. 3	1	25	Yakutat (wharf)	Dip net	All very small, immature	Formalin.
17	1	100	Puget Sound	(?)		Fresh.
Apr. 25	1	100	Halibut Cove (Kachemak Bay)	Beach seine		Do.
May 4	1	25	do	do		Do.
11	1	50	do	do		Do.
June 12	1	75	Naked Island	Purse seine	Impounded from May 29 to June 6. Pound covered with spawn. Very thin.	Do.
13	1	130	Macleod Harbor	do	Contain some belly fat	Do.
16	2	100	Prince of Wales Passage (Elrington Passage).	do		Do.
16	1	100	Naked Island	do	From same pound as June 12.	Do.
17	1	50	Prince of Wales Passage (Elrington Passage).	do		Do.
21	1	100	do	do		Do.
25	1	100	Elrington Passage	do		Do.
25	1	45	Procession Rocks (Elrington Passage)	do		Do.
28	1	75	do	do		Do.
July 1	1	100	Macleod Harbor	do		Do.
2	1	50	Procession Rocks (Elrington Passage)	do		Do.
5	2	100	do	do		Do.
6	1	50	do	do		Do.
9	1	50	Macleod Harbor	do		Do.
13	1	285	Tebenkof Bay (Chatham Strait)	do	Small, poorly preserved	Formalin.
13	1	181	Larch Bay (Chatham Strait)	do	Poorly preserved	Do.
13	1	190	Point Gardner (Chatham Strait)	do	Preservation fair	Do.
14	1	168	Surprise Harbor (Point Gardner)	do	Well preserved	Do.
14	1	211	Shuyak Strait	do	Preservation fair	Do.
16	1	198	Outside north arm Pillar Bay (Chatham Strait).	do	Well preserved	Do.
19	1	199	Tebenkof Bay (Chatham Strait)	do	do	Do.

TABLE 4.—*1927 samples*—Continued

Date	Number of samples	Number in samples	Locality	Apparatus	Remarks	Preservation
1927						
Aug. 3	1	201	Larch Bay (Chatham Strait)	Purse seine	Well preserved	Formalin.
5	1	97	do	do	Preservation fair	Do.
10	1	50	Off McDonald Spit (Kachemak Bay)	do		Fresh.
18	1	8	Belkofski Bay	Salmon trap		Formalin.
23	1	50	Off McDonald Spit (Kachemak Bay)	do		Fresh.
24	2	50	do	do		Do.
25	3	75	do	do		Do.
27	2	50	Off Yukon Island (Kachemak Bay)	do		Do.
Sept. 8	1	25	1 mile off between McDonald Spit and Barabara Point (Kachemak Bay).	do		Do.
21	1	50	Off Yukon Island (Kachemak Bay)	do		Do.
29	1	75	McClure Bay	do		Do.
30	3	100	do	do		Do.
Oct. 2	1	25	do	do		Do.
3	1	25	do	do		Do.
Dec. 17	1	52	Halibut Cove Light (Kachemak Bay)	Gill net, 3-inch mesh.	Well preserved	Formalin.
19	1	87	do	do	do	Do.
19	1	150	Halibut Cove Lagoon (Kachemak Bay)	do	do	Do.

TABLE 5.—*1928 samples* [1]

Date	Number of samples	Number in samples	Locality	Remarks [2]	Preservation
1928					
Jan. 27	1	975	¾ mile south of Eagle Harbor, Stephens Passage.	Good condition	Frozen.
Mar. 25	1	100	West coast Fish Egg Island (near Craig)	Good condition, taken while spawning	Do.
26	2	200	do	do	Do.
June 23	1	45	Elrington Passage	Fair condition	Fresh.
24	1	177	Puget Bay	Poor condition	Salted.
26	1	80	Macleod Harbor	Good condition	Fresh.
27	1	150	Snug Harbor, Knight Island	do	Do.
28	1	80	do	do	Do.
29	1	90	do	do	Do.
30	1	30	do	do	Do.
July 1	1	30	do	do	Do.
2	1	137	Port Fidalgo	do	Do.
5	1	60	Macleod Harbor	do	Do.
6	1	30	do	do	Do.
7	2	80	do	do	Do.
8	2	60	do	do	Do.
9	1	30	do	do	Do.
11	1	60	Bluff Point, Kachemak Bay	do	Do.
13	1	50	McDonald Spit, Kachemak Bay	Taken from boat in Shuyak Strait	Do.
30	1	90	Red Fox Bay, Shuyak Strait	Good condition	Do.
Aug. 9	1	50	do	do	Do.
20	1	40	Dutch Harbor, Unalaska Bay	Impounded 10 days	Do.
21	1	45	do	Good condition	Do.
27	1	60	do	Impounded Aug. 21	Frozen.
Sept. 9	1	100	Macleod Harbor	do	Fresh.
12	1	50	Dutch Harbor, Unalaska Bay	Good condition	Frozen.
12	1	50	do	Impounded Aug. 15	Do.
13	1	90	Macleod Harbor	Good condition	Fresh.
19	1	50	Dutch Harbor, Unalaska Bay	do	Frozen.
24	1	50	Macleod Harbor	Well preserved	Formalin.
25	1	50	do	do	Do.
Oct. 2	1	50	do	do	Do.
5	1	50	do	do	Do.
7	1	50	do	do	Do.
Autumn	1	166	Shearwater Bay	Preservation good	Salted.

[1] A sample of frozen fish from Sitka is on hand but not yet examined. [2] All samples caught with purse seine.

OTHER SAMPLES

In addition to the above data we were kindly given the length measurements of many samples of herring collected and measured to the quarter inch in total length by Clarence L. Anderson, a former technologist of the United States Bureau of Fisheries, at Franklin Packing Co., Evans Bay. The 1924 samples contained 200 fish each, the 1925 samples 100 fish each. The samples whose measurements are used in this report are as follows:

Date	Number	Locality	Date	Number	Locality
1924			1925		
July 17	1	Elrington Passage.	June 25	2	Elrington Passage.
18	1	Do.	26	4	Do.
18	1	Prince of Wales Passage (Elrington Passage).	27	2	Do.
19	1	Do.	July 10	2	Do.
21	1	Do.	11	2	Do.
24	1	Do.	12	1	Do.
25	1	Do.	12	2	Cape Elrington (Elrington Passage).
26	1	Do.	13	1	Do.
28	1	Do.	13	2	Elrington Passage.
29	1	Do.	14	2	Do.
			15	2	Do.
1925			16	1	Do.
June 22	2	Elrington Passage.	23	1	Do.
24	2	Do.	25	2	Do.

BIOLOGY OF THE PACIFIC HERRING

SYSTEMATIC RELATIONSHIPS

The family Clupeidæ contains many of the most important commercial fishes of the world. The herring occupies first place, followed by the menhaden, the sardines or pilchards, the shads, the alewives, the lake herrings, and many others of minor importance. The sardine or pilchard, Sardina, is perhaps the closest relative to the genus Clupea, which contains the herrings. Both genera contain Atlantic and Pacific species.

It is fitting that a survey be made of the degree of relationship existing between the Atlantic and Pacific herrings, *Clupea harengus* and *C. pallasii*, in order to justify the use in this investigation of some of the methods of research employed upon the Atlantic species. In Jordan and Evermann (1896, pp. 421–2), the European or Atlantic herring, *C. harengus* L., is described as having 18 dorsal rays, 17 anal rays, 57 scales on the lateral line, and 56 vertebræ; the Pacific herring, *C. pallasii* Cuv. and Val., as having 16 dorsal rays, 14 anal rays, 52 scales on the lateral line, and 50 vertebræ. When the Pacific form was described as a separate species, only specimens from the southern portion of the range were obtained, and, due to the fact that they differed widely from the Atlantic species in vertebral count, etc., the two were considered to be well defined. But we have had specimens of the Pacific form covering its range from San Diego Bay, near the Mexican border, to Golovin Bay in the northern part of the Bering Sea. Examination of these more representative samples shows that the differences between the two forms are not clear-cut, as one would infer from the taxonomic descriptions.

A summary of "racial" work on the European herring, by himself and other investigators, has been written by Johansen (1924). The total range of the vertebral count, excluding the hypural, in the North Sea and adjacent waters, is from 50 to 59 or a range of 10. For the Pacific herring (Table 6) the total range is from 45 to 57, or 13. The averages for the European herring (exclusive of the White Sea) vary from 53.78 for Zuider Zee herring (Delsman, 1914) to about 56.50 for Norwegian herring. Within the White Sea the averages of different "races" vary from 52.14 to 56.18 (Averinzev, 1926). For the Pacific herring the averages vary from 50.68 to 54.67. It is plain that the vertebral count is not a specific character in this case. In the White Sea herring the dorsal rays range from 16 to 22, with averages from 18.20 to 18.95; in the Pacific herring, from 15 to 21, with averages from 18.70 to 19.36. The anal rays range from 13 to 19, with means of 16.30 to 17.35 in the White Sea;

and range from 14 to 20, with means of 16.61 to 17.23 in the Pacific. Clearly neither the dorsal nor anal rays can be used as a specific character.

This leaves only a few minor characters with which to differentiate between individuals of the two species. However, Averinzev (1928) shows that the number of caudal and precaudal vertebræ and the number of keeled scales is practically the same between herring of the White Sea and a sample of Pacific herring from near Vladivostok. He believes the two species to be connected by forms extending across northern Siberia.

DISTRIBUTION AND SIZES

RANGE

The Pacific herring is found along both shores of the North Pacific, ranging from San Diego Bay on the south, north and west to the Aleutian Islands, and across to Japan and Siberia. They occur on both shores of Bering Sea, extending at least to Bering Strait. On this coast they occur in sufficient abundance in British Columbia and Alaska to support a considerable industry.

SIZE AND OCCURRENCE OF YOUNGER AGE GROUPS

In the herring, as in most pelagic fishes, the schools are not uniform as to the sizes and ages of the individuals contained therein. There is differential schooling, according to size, age, and sexual maturity. The degree and kind of segregation will vary at different seasons of the year, the schooling at spawning time depending chiefly on the state of maturity. The individuals in their first year are very small; those in Cook Inlet, from scale studies given later, are shown to be about 60 to 70 millimeters in body length when a year old. Fraser says (1916, p. 107) concerning the herring in the Straits of Georgia, "After a couple of weeks there is a gap until the fish is about 6½ months old on October 9. By this time the average length is about 5.2 centimeters and the weight 1.5 grams. The scales are already well started. On February 16 they have reached a length of 6.3 centimeters; April 4, 6.5 to 7.0 centimeters; and on May 16 (14 months), 7.6 centimeters." Thompson (1916, p. S48) gives the length frequencies of three samples of young herring taken in British Columbia in October, 1916, the samples varying from 6.7 to 7.7 centimeters in average length.

Very little is known as to the distribution of herring of this size, except that they can often be seen in immense numbers, never far from shore. We obtained a sample in Halibut Cove Lagoon with a fine-meshed beach seine, and Will F. Thompson obtained a sample at Yakutat by means of a light and a lift net.

During the summer of their second year the herring are about 120 to 140 millimeters in body length. In many of the inlets herring of this size are extremely numerous, and during the summer months the surface of the water close inshore often appears as though sprinkled with fine rain when they are feeding at the surface. Herring of this size are only occasionally taken with the larger sizes. The fishermen rarely deliberately make a catch of this size alone as they gill in the seines causing a great deal of extra work.

OCCURRENCE OF MATURE HERRING

The mature herring must approach the shore at least once each year in order to spawn. After spawning, the spent herring may disappear for a time. Whether they go into deeper water or are merely widely scattered is uncertain. In a few localities, as San Diego and San Francisco Bays, this spawning period is the only time at which the herring are observed and taken. In Alaska they spawn in late spring and then may disappear for a time. They reappear in early summer and are found feeding close to the surface. Thus, schools of fattening herring, actively feeding, appear in late May in Chatham Strait and in early June in those western passages which lead into Prince William Sound. Schools of fat herring are caught in various parts of Chatham Strait until August, after which the bulk of the herring taken are caught off Cape Ommaney at the mouth of the strait, in September. In Prince William Sound the herring occur in the western passages in June and remain during part of July. In late September and October, schools of herring of larger and more uniform size occur in a few of the bays on the western shore of the sound.

In none of these cases does it seem possible, as yet, to trace a well-defined migration except perhaps between Shuyak Strait and Halibut Cove, Cook Inlet. Schools of large, fat, mature herring occur in Shuyak Strait in July and may remain during part of August. About six weeks after the appearance of the schools in Shuyak Strait, schools of large herring appear in lower Kachemak Bay. It is possible that these are the same schools. They gradually work farther up the bay until in September or October they appear off Halibut Cove. By this time the schools also contain fish of smaller sizes. Herring now enter Halibut Cove and the lagoon, where they are found until the following spring. Herring of all ages and sizes were found in the lagoon, apparently wintering there.

After the summer and fall fishery is over, herring occur during the winter months in some of the bays in southeastern Alaska where they do not usually occur in any quantity during the summer; for example, Ernest Sound, Stephens Passage, and Klawack Inlet, all of which are close to spawning grounds. But not enough is known to justify the view that these are regular migrations.

VARIATIONS IN SIZE OF MATURE HERRING

The variation in size of herring taken in different portions of their range plays a large part in determining their utilization, since for pickling purposes only large herring are desired. The herring are naturally smaller in some parts of their range than in others. This may be due to enormous differences in growth rate, as that between Unalaska and Stephens Passage, or largely to differences in age composition, as that between Prince William Sound and Cook Inlet.

N. B. Scofield (1918) says of the herring entering Tomales Bay, Calif., "They are considered the best herring in California and many of the fish reach a length of 10 or 11 inches and are fatter than those found in other parts of the State." He is evidently speaking of the total length. He says further, "The herring of Shelter Cove and Humboldt Bay are reported as being only 7 or 8 inches in length, * * *." The longest herring in Thompson's San Francisco Bay material (1916) was about 10 inches in total length.

Fraser (1922) mentions not finding any over 10 inches in length to the base of the caudal fin in British Columbia, and 10 inches to the base of the caudal was the longest recorded by Thompson (1917).

In southeastern Alaska herring of mixed sizes occur in the schools. The herring here may attain 12 inches in total length, but probably less than 10 per cent are over 10½ inches in total length.

The Prince William Sound herring are larger than those of southeastern Alaska. In the fall, some loads have as high as 75 per cent of the fish, by volume, over 10½ inches in total length, or about 9½ to 11 ounces in weight. Schools in this district are composed of herring of mixed sizes.

In Shuyak Strait the schools taken up to 1927 were made up almost entirely of large mature herring, many of them attaining a length of 14 inches. In 1928 only schools of small herring appeared. Herring of the same large size occur in Kachemak Bay in August, but a month later they are mixed somewhat with smaller sizes.

At Unalaska in 1928 the herring were very large, many of them being almost 15 inches. A very few persons have mentioned to the writer that they measured central Alaska herring that were 16 inches in length, but these were apparently exceedingly rare.

INDEPENDENCE OF AREAS

METHODS OF STUDY

Alarming changes in abundance have occurred in many localities. For instance, in Yes Bay and Kootznahoo Inlet in southeastern Alaska, herring were exceedingly abundant during the early years of the fishery, but soon became scarce and have remained so for many years. What caused the failure of such fisheries?

In studying these changes in abundance the first question raised is whether they are due to depletion or to variations in the migratory habits. Do the herring of the Alaska coast belong to one population that moves about at will, striking the coast wherever or whenever conditions impel it, or is each locality inhabited by a local stock that mingles but slightly, if at all, with the populations of adjacent areas? In the first case, fishing at any point on the coast would affect the supply at every other point, and if depletion occurred it would be general. In the second case, intensive fishing in one locality would not endanger the supply elsewhere, but the danger of local depletion would be highly intensified. The movement of the herring schools therefore becomes of great importance.

A study of these movements by the direct method of tagging the individual fish and obtaining records from the fishermen of the places of recapture has been successful in the cases of the plaice, cod, mackerel, salmon, halibut, and other fishes, but never in any of the clupeoid fishes. The ease with which impounded herring become infected with fungous growths, even when only a few scales have been lost, makes it appear probable that any wounds made in tagging might easily lead to death. Detection of the tagged individuals among the great numbers of the species taken at one time would be difficult enough without such heightened mortality. In the case of the Pacific herring it was felt that if attempted, tagging would never be successful except perhaps in a few localities. In southeastern Alaska and Prince William Sound, where the principal fisheries are conducted, a very large proportion of the herring are used for reduction purposes, and, since these fish are not handled individually, the chances of detecting a tagged fish, even if recaptured, are infinitely small. Because of these reasons, tagging was not seriously considered as a feasible means of studying migration in the herring and indirect methods were concentrated upon. However, owing to the concrete results to be attained by successful tagging we were unwilling to relinquish this method of investigation without giving it some trial.

Halibut Cove, Kachemak Bay, was chosen as the most favorable location for a test. In this district practically the entire catch is pickled, insuring the detection of any recaptured fish, since in this method the fish are handled one by one. Accordingly in the spring of 1927, 3,071 herring of pickling size were tagged with No. 3 monel metal strap tags attached to the caudal peduncle, as in the salmon.[3] The results, however, were negative.

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[3] A full description of this type of tag, with illustrations, is given by Gilbert and Rich (1925). The No. 3 tag, used on the herring, weighs 0.5 gram, is 3.3 millimeters in width, and about 14 millimeters in length when clinched.

The chance of success with a fish as small and delicate as the herring would seem to be very slight without the evolution of some special technique for handling the fish while tagging, and of some lighter and less cumbersome form of tag. It may well be that further experiments with such a tag would succeed.

Lacking successful direct methods, the widely used study of racial peculiarities becomes of primary importance. It is a well known fact that within the same species the isolation of particular stocks of fish tends to develop differences in their characteristics. These differences may exist in their physical structure or certain aspects of their life history, and may be too slight to detect in the individual but show in averages. They may be entirely the direct result of environment, or they may be inherited. But if two such stocks were to intermingle freely, so that half in each locality would have originated in the other, then any such differences would necessarily vanish, as the averages in each case would be the same. A difference which could originate as the result of different feeding conditions for a few months would not have the same significance as a difference which would require isolation for generations, and which might be deeply seated in heredity. Nevertheless, the existence of differences between any two localities is prima facie evidence of the more or less complete lack of intermingling, and the more deep seated and clear cut the difference, the less the rate of intermigration must have been. The relative importance of the parts played by heredity and environment in causing the constancy of these differences between populations is a moot question, but the important point at issue is not the cause of such differences, but rather their existence and extent.

Four of the structural characters were found to be of value—the counts of the vertebræ, of the dorsal rays, of the anal rays, and the measurements of the head length. The gill-raker count was taken on a number of samples, but it was found that accurate counts were not obtained under ordinary field conditions; and time in the laboratory was not available to make the enormous number of counts that would be required in order that their analysis might be of value. On a number of samples, measurements were made to the insertions of the dorsal and anal fins, but the variability was found to be so great that enormous numbers would have to be measured before any value could be attached to the results.

RACIAL SAMPLING

Samples were obtained from the southernmost limits of the herring's range, San Diego Bay, and from there in various regions west to the Aleutian Islands, and north to Golovin Bay in the northern part of the Bering Sea, an area covering 32 degrees of north latitude and 45 degrees of west longitude. Within this great area was obtained a fairly complete chain of samples. They were taken at San Diego Bay; Monterey Bay; San Francisco Bay; Puget Sound; southern British Columbia; southeastern Alaska; Yakutat; Prince William Sound; Cook Inlet; the Kodiak-Afognak district; from Chignik, the Shumagin Islands, and Belkofski Bay on the Alaska Peninsula, from Unalaska in the Aleutian Islands, and from Golovin Bay in the northern part of the Bering Sea. Unfortunately some of the samples, those from Yakutat and Belkofski Bay for example, are too small to give reliable averages for the characters.

Besides having samples from many localities, it is also important to have samples for more than one year from the same locality to study the amount of variability to be found in the same character at the same place. In this regard samples are present for 2 years from Kachemak Bay, 3 years from Prince William Sound, and 4 years from Shuyak Strait.

VERTEBRÆ

RELIABILITY OF VERTEBRAL COUNT

Of the four characters chosen to show structural differences, the vertebral count is the most reliable. The count is not altered by preservation and can be made with absolute accuracy and with greater ease than those of the fin rays. The number of vertebræ is determined at a very early stage, before or shortly after the hatching of the ova, so that it is not altered by any subsequent environmental conditions. Since the ova are attached, it is obvious that one adult population can not contribute, before the characters become fixed, to another adult population with different structural characters, as might be were the ova floating freely in the currents. On account of these advantages the differences in the vertebral count have received the chief emphasis in this analysis.

There are now available for comparison 10,132 vertebral counts of the Pacific herring. Of these counts, those from San Diego Bay, Puget Sound, and Alaska, totaling 7,960, are original. Those from Monterey Bay, the first two San Francisco Bay counts, and those from the Straits of Georgia are by Carl L. Hubbs (1925); the last San Francisco Bay count and the remainder of the British Columbia counts are by William F. Thompson (1916).

COMPARISON ALONG WHOLE LENGTH OF COAST

The average number of vertebræ increases to the northward and westward from San Diego. For the purpose of showing this, Table 6 and Figure 14 are presented. Table 6 gives the frequency distributions of vertebral counts in various localities and Figure 14 gives the means for each locality plotted against the distance from San Diego, following the general trend of the coast. The trend of the line of means has been drawn in by inspection.

TABLE 6.—*Variation in number of vertebræ in all samples of all localities*

No.	Locality	Vertebræ													Number	Mean	Probable error	Standard deviation of distribution
		45	46	47	48	49	50	51	52	53	54	55	56	57				
1	San Diego Bay					12	148	209	38	1					408	50.68	0.023	0.691
2	Monterey Bay					2	20	41	25	1					89	51.03	.06	
3	San Francisco Bay	1		1	4	18	256	410	125	5					820	50.78	.019	.797
4	Puget Sound				1		3	25	65	6					100	51.71	.052	.768
5	South British Columbia				1	1	28	354	738	138	3				1,263	51.78	.01	
6	Gravina Island							7	23	17	3				50	52.32	.075	.786
7	Craig						2	22	176	126	18				344	52.40	.026	.712
8	Larch Bay							13	173	239	36	2			463	52.66	.021	.681
9	Tebenkof Bay						2	20	228	381	50	1	1		683	52.68	.018	.683
10	Point Gardner							9	108	210	24	1			352	52.72	.023	.634
11	Whale Bay								6	15	4				25	52.92	.078	.580
12	Stephens Passage			1		3	3	86	459	368	40	2			962	52.33	.017	.769
13	Yakutat Bay						2		10	8	5				25	52.48	.163	1.205
14	Puget Bay							17	75	74	11				177	52.45	.038	.750
15	Elrington Passage						1	13	118	220	48	1			401	52.76	.024	.719
16	Macleod Harbor					1		14	116	192	42	2			367	52.72	.027	.755
17	Snug Harbor			1			1	16	139	143	22				322	52.55	.029	.772
18	Eshamy Bay							1	41	91	16	1			150	52.83	.035	.636
19	McClure Bay							5	45	143	30	1			224	52.90	.030	.657
20	Naked Island							3	41	75	19				138	52.80	.040	.693
21	Port Fidalgo						1	7	66	57	6				137	52.44	.040	.692
22	Dogfish Bay						1	9	34	51	5				100	52.50	.051	.763
23	Kachemak Bay				1	1		26	228	378	98	8			740	52.76	.031	.790
24	Shuyak Strait						1	20	180	261	66	3			531	52.72	.022	.757
25	Zachar Bay							2	21	52	12				87	52.85	.048	.670
26	Shearwater Bay							5	42	82	35	1			165	52.91	.041	.776
27	Old Harbor							1	30	63	17	3	1		115	52.95	.050	.790
28	Chignik							4	5	55	39	3	1		107	53.33	.053	.806
29	Shumagin Islands							1	7	36	130	213	62	7	456	54.67	.029	.928
30	Belkofski Bay								1	5	2				8	53.13		
31	Unalaska								20	106	54	3			183	53.22	.032	.650
32	Golovin Bay							2	43	77	18				140	52.79	.038	.671

It is obvious that the extreme variations shown in Figure 14 are significant, there being some underlying correlation between geographical distribution and number of vertebræ. The correlation is not an even one from south to north since the two localities farthest north, Golovin Bay and Eshamy Bay (Nos. 32 and 18, fig. 14) at

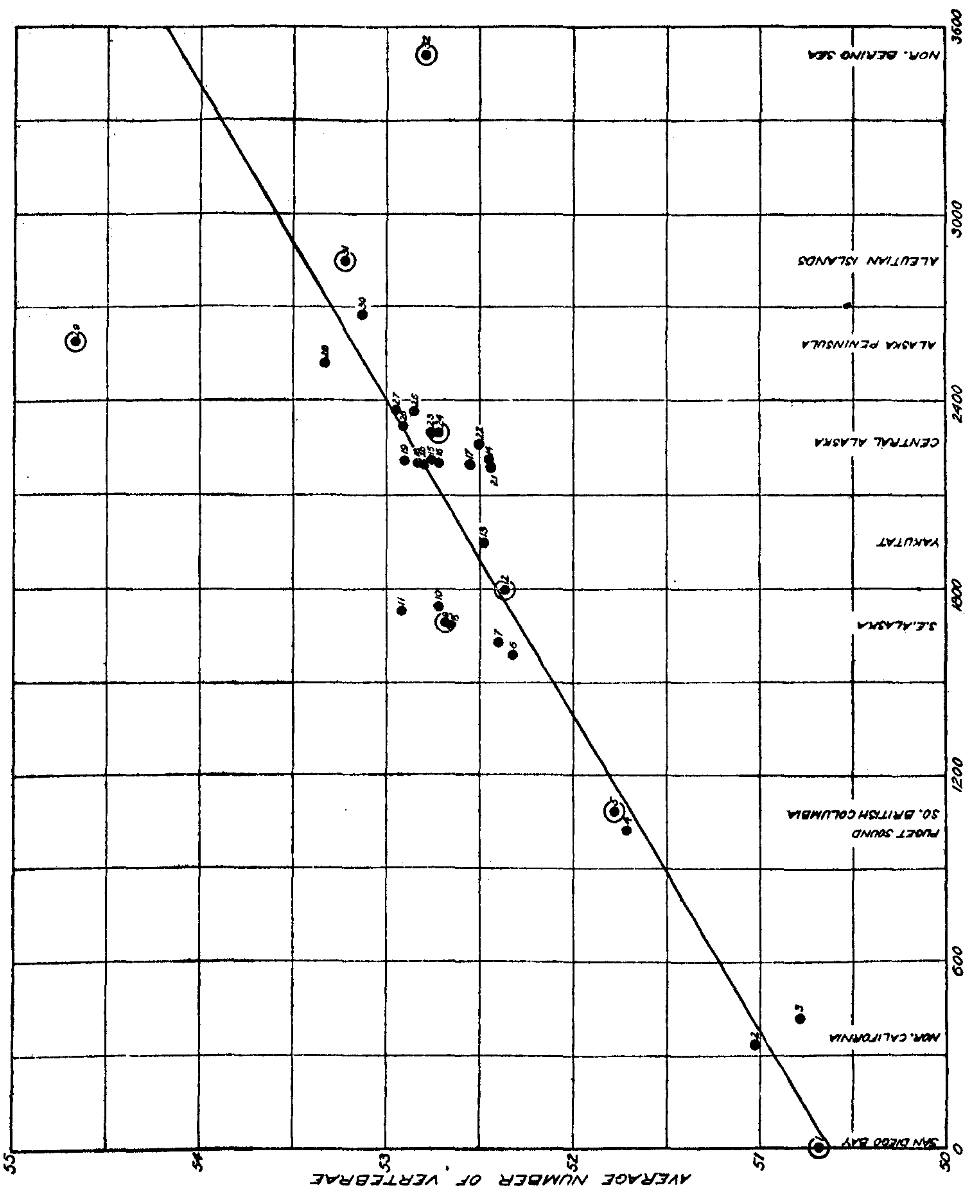

FIGURE 14.—Showing the increase in the average number of vertebræ following the general trend of the coast northward and westward from San Diego. Each locality numbered as in Table 6

64° 30′ and 60° 30′ north latitude, have means of only 52.79 and 52.83, while Chignik, the Shumagin Islands, and Unalaska, far to the south, have means of 53.33, 54.67, and 53.22, respectively. Except for the Shumagin Islands and Golovin Bay all of the localities follow the same trend. The existence of a more or less systematic change with geographical location indicates the reality of the differences aside from any consideration of adequacy of sampling.

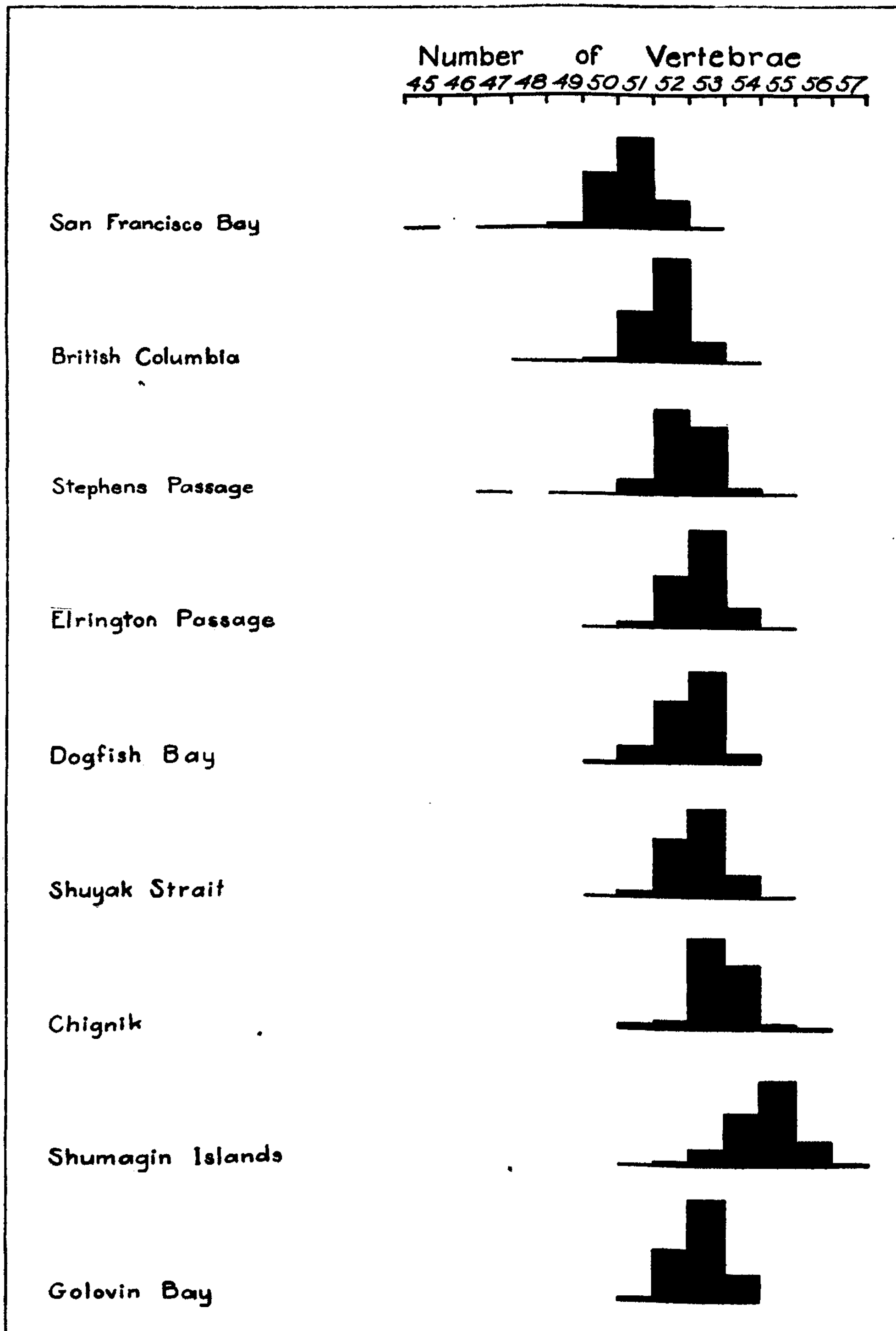

FIGURE 15.—Histograms showing the percentage of the vertebral distribution falling at each count

This method of comparison does not bring out the significance of differences as clearly from a mathematical standpoint as will the comparison of eight principal localities given in Table 7. (These eight localities are marked in fig. 14 by circles.) Here the averages for each locality are compared with those for the other localities, and their differences considered in relation to the probable errors of these differences, calculating the probable errors upon the assumption that the samples adequately represent the populations from which taken.

TABLE 7.—*Comparisons of the means of the vertebral counts of some distant localities*

[Asterisk shows differences that are not significant]

Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference
San Diego Bay and South British Columbia	1.10	0.025	44.0
San Diego Bay and Stephens Passage	1.28	.029	44.1
San Diego Bay and Tebenkof Bay	2.00	.029	69.0
San Diego Bay and Shuyak Strait	2.04	.032	63.8
San Diego Bay and Shumagin Islands	3.99	.037	107.6
San Diego Bay and Unalaska	2.54	.039	65.2
San Diego Bay and Golovin Bay	2.11	.044	48.0
South British Columbia and Stephens Passage	.58	.020	29.0
South British Columbia and Tebenkof Bay	.90	.020	45.0
South British Columbia and Shuyak Strait	.94	.024	39.2
South British Columbia and Shumagin Islands	2.89	.031	93.2
South British Columbia and Unalaska	1.44	.033	43.6
South British Columbia and Golovin Bay	1.01	0.039	25.9
Stephens Passage and Tebenkof Bay	.32	.025	12.7
Stephens Passage and Shuyak Strait	.36	.028	12.9
Stephens Passage and Shumagin Islands	2.31	.034	67.9
Stephens Passage and Unalaska	.86	.036	23.9
Stephens Passage and Golovin Bay	.43	.042	10.2
Tebenkof Bay and Shuyak Strait	.04	.028	* 1.4
Tebenkof Bay and Shumagin Islands	1.99	.034	58.3
Tebenkof Bay and Unalaska	.54	.037	14.6
Tebenkof Bay and Golovin Bay	.11	.042	* 2.6
Shuyak Strait and Shumagin Islands	1.95	.036	54.2
Shuyak Strait and Unalaska	.50	.039	12.8
Shuyak Strait and Golovin Bay	.07	.044	* 1.8
Shumagin Islands and Unalaska	1.45	.043	33.7
Shumagin Islands and Golovin Bay	1.88	.048	39.2
Unalaska and Golovin Bay	.43	.050	8.6

It will be observed that this method indicates that local stocks of herrings, which are not shown to be obviously different by the visual comparison used in Figure 14, are actually sharply distinct from a mathematical viewpoint. Thus the difference between the herring of Tebenkof Bay and of Stephens Passage is significant, the difference between the means being 0.32 ± 0.025 or 12.8 times the probable error.

COMPARISON OF STOCKS OF ADJACENT LOCALITIES

This method of comparison may be applied also to closely adjacent localities within the same region. Thus Tables 13, 14, and 15 give comparisons of the means of the vertebral counts for southeastern Alaska (localities 7-13 of Table 6), Prince William Sound (localities 14–21), and Cook Inlet-Kodiak district (localities 22–27). Tables 8, 9, 10, 11, and 12 present the frequency distributions of vertebral counts upon which these comparisons are made, each minor locality being given separately and contributing to the totals for the general regions as listed in Table 6.

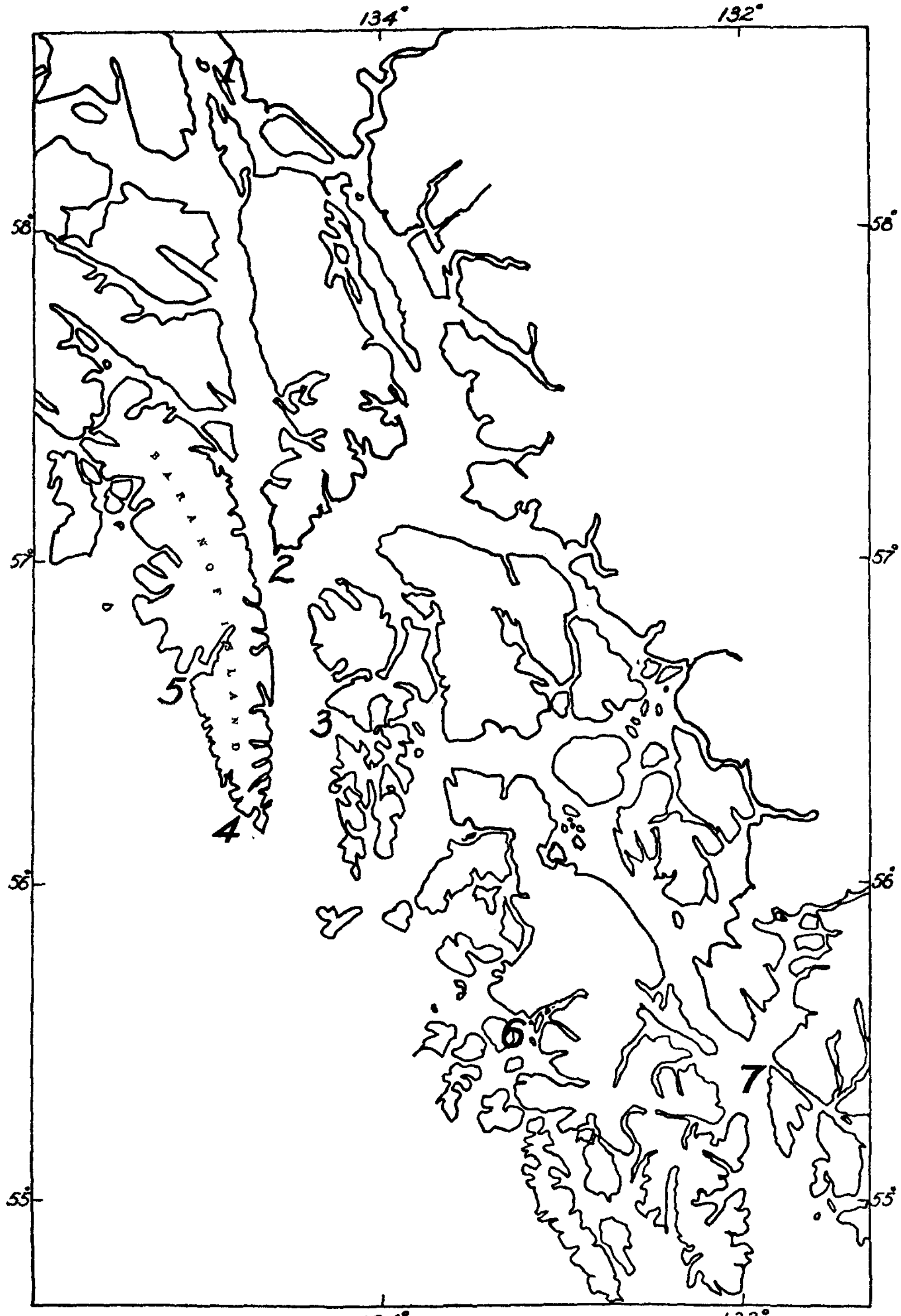

FIGURE 16.—Showing stations where vertebral count samples were obtained in southeastern Alaska: (1) Stephens Passage, 52.36±0.017; (2) Point Gardner, 52.72±0.023; (3) Tebenkof Bay, 52.68±0.018; (4) Larch Bay, 52.66±0.021; (5) Whale Bay, 52.92±0.078; (6) Craig, 52.40±0.026; and (7) Gravina Island, 52.32±0.075

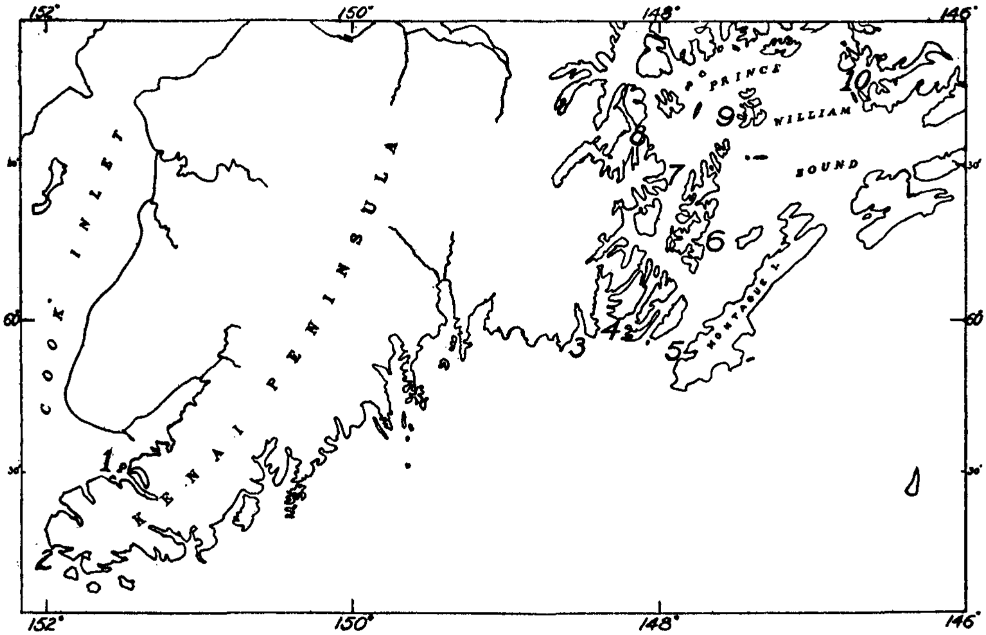

FIGURE 17.—Showing stations where vertebral count samples were obtained in Prince William Sound and Cook Inlet: (1) Kachemak Bay, 52.76±0.031; (2) Dogfish Bay, 52.50±0.051; (3) Puget Bay, 52.45±0.038; (4) Elrington Passage, 52.76±0.024; (5) Macleod Harbor, 52.72±0.027; (6) Snug Harbor, 52.55±0.029; (7) Eshamy Bay, 52.83±0.035; (8) McClure Bay, 52.90±0.030; (9) Naked Island, 52.80±0.040; and (10) Port Fidalgo, 52.44±0.040

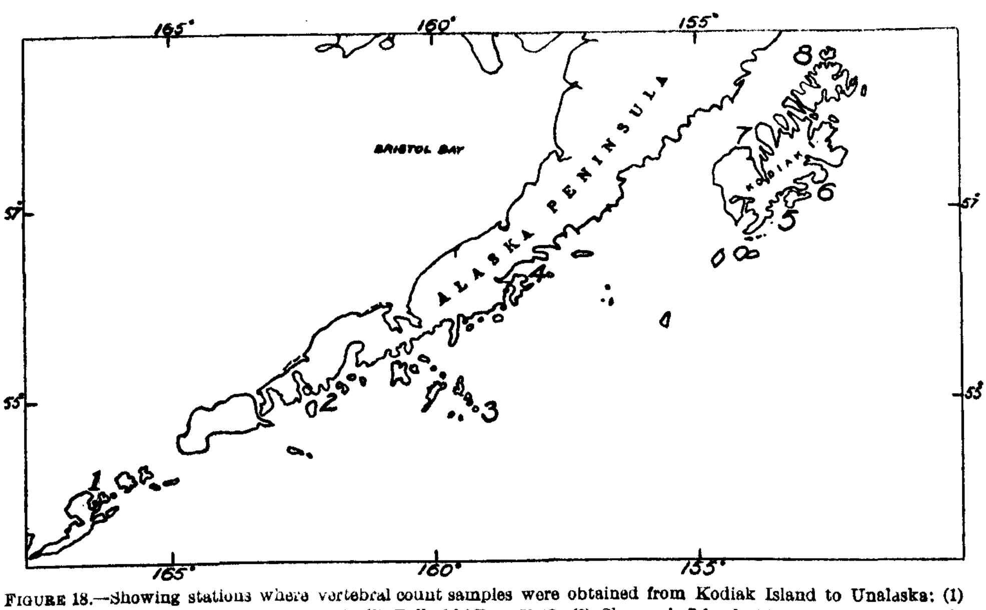

FIGURE 18.—Showing stations where vertebral count samples were obtained from Kodiak Island to Unalaska: (1) Unalaska (Dutch Harbor), 53.22±0.032; (2) Belkofski Bay, 53.13; (3) Shumagin Islands, 54.67±0.029; (4) Chignik, 53.33±0.053; (5) Old Harbor, 52.95±0.050; (6) Shearwater Bay, 52.91±0.041; (7) Zachar Bay, 52.85±0.048; and (8) Shuyak Strait, 52.72±0.022

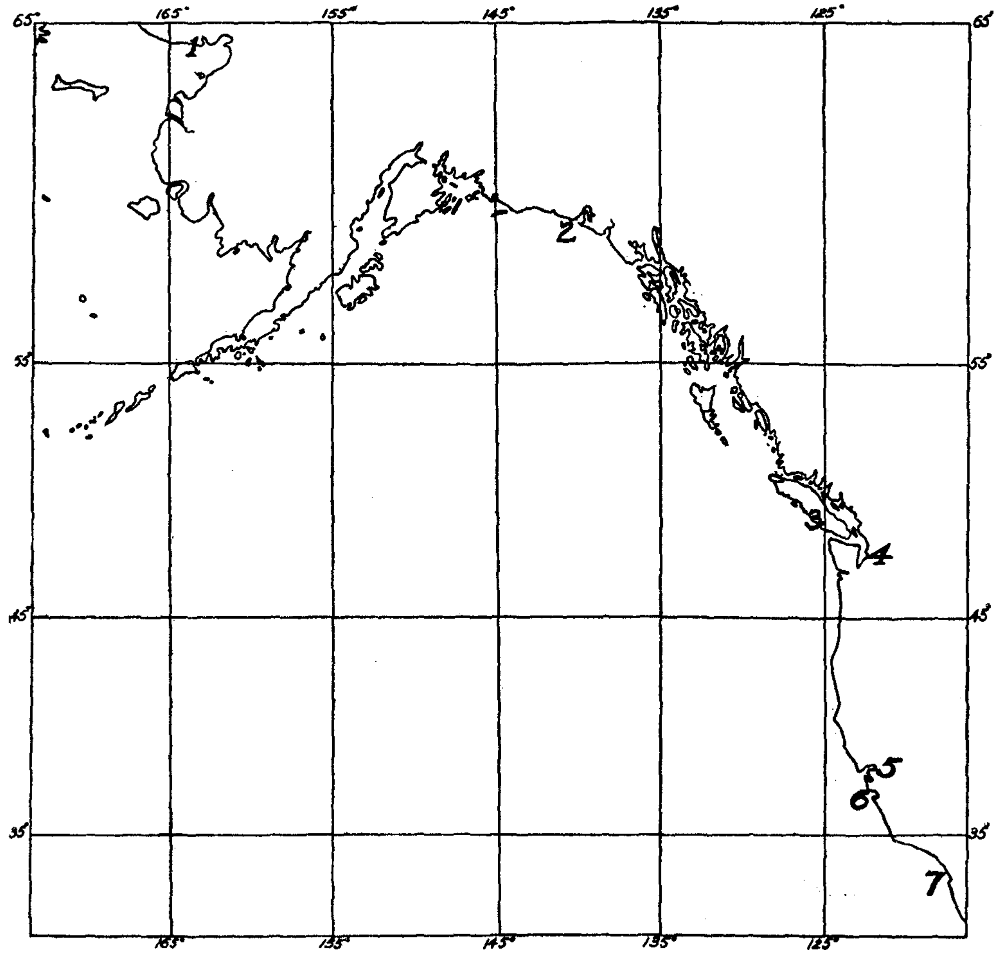

FIGURE 19.—Showing stations not on area maps where vertebral count samples were obtained: (1) Golovin Bay, 52.79±0.038; (2) Yakutat Bay, 52.48±0.163; (3) South British Columbia, 51.78±0.010; (4) Puget Sound, 51.71±0.052; (5) San Francisco Bay, 50.78±0.019; (6) Monterey Bay, 51.03±0.060; and (7) San Diego Bay, 50.68±0.023.

TABLE 8.—*Variation in number of vertebræ from California to British Columbia*

Locality	Date	Vertebræ										Number	Mean	Probable error	Standard deviation of distribution
		45	46	47	48	49	50	51	52	53	54				
San Diego Bay	1926					3	33	47	10	1		94	50.71	0.051	0.739
Monterey Bay	(?)					2	20	41	25	1		89	51.03	.06	
San Francisco Bay	1923			1	1	10	153	249	85	5		504	50.83	.02	
	1923					5	74	122	30			231	50.77	.03	
	1915	1			3	3	29	39	10			85	50.53	.08	
Total		1		1	4	18	256	410	125	5		820	50.78	.019	.797
Puget Sound	1927				1		3	25	65	6		100	51.71	.052	.768
British Columbia:															
Nanaimo	1915						4	51	136	19		210	51.81	.03	
Point Grey	1915						5	50	88	19	1	163	51.76	.04	
Straits of Georgia	1915						1	33	62	12		108	51.79	.04	
	1915				1		1	35	53	10		100	51.69	.05	
Pender Harbor	1915					1	7	89	150	32	2	281	51.75	.03	
	1915						2	23	60	11		96	51.83	.04	
Kildonan	1915						8	73	189	35		305	51.82	.02	
Total					1	1	28	354	738	138	3	1,263	51.78	.01	

TABLE 9.—*Variation in number of vertebræ in southeastern Alaska*

Locality	Date	Vertebræ										Number	Mean	Probable error	Standard deviation of distribution
		47	48	49	50	51	52	53	54	55	56				
Gravina Island	1925					7	23	17	3			50	52.32	0.075	0.786
Craig	1925				1	5	25	17	2			50	52.28	.074	.776
	1928					5	51	37	6			99	52.44	.046	.685
	1928					5	52	34	6			97	52.42	.047	.686
	1928				1	7	48	38	4			98	52.38	.049	.722
Total					2	22	176	126	18			344	52.40	.026	.712
Stephens Passage	1928	1		3	3	86	459	368	40	2		962	52.36	.017	.769
Tebenkof Bay	1925					1	10	13	1			25	52.56	.086	.638
	1927				2	12	94	153	12		1	274	52.60	.029	.709
	1927						61	113	18			192	52.78	.029	.601
North arm of Pillar Bay	1927					7	63	102	19	1		192	52.71	.035	.713
Total					2	20	228	381	50	1	1	683	52.68	.018	.683
Point Gardner	1927					3	62	111	12			188	52.70	.021	.608
Surprise Harbor	1927					6	46	99	12	1		164	52.73	.035	.671
Total						9	108	210	24	1		352	52.72	.023	.634
Larch Bay	1927					1	28	59	5			93	52.73	.040	.571
	1927					8	80	73	7	2		170	52.50	.037	.705
	1927					4	65	107	24			200	52.76	.033	.682
Total						13	173	239	36	2		463	52.66	.021	.681
Whale Bay	1925						6	15	4			25	52.92	.078	.680

TABLE 10.—*Variation in number of vertebræ in Prince William Sound*

Locality	Date	Vertebræ									Number	Mean	Probable error	Standard deviation of distribution
		47	48	49	50	51	52	53	54	55				
Elrington Passage	1925						10	29	6		45	52.91	0.053	0.526
Bainbridge Island	1925				1	4	33	46	16		100	52.72	.055	.814
Prince of Wales Pass	1925					2	14	22	6		44	52.73	.076	.750
Elrington Passage	1926					4	21	41	8	1	75	52.75	.060	.768
	1926					1	11	34	4		50	52.82	.056	.590
Prince of Wales Pass	1927					2	12	29	5		48	52.77	.064	.684
Procession Rocks	1927						17	19	3		39	52.64	.068	.628
Total					1	13	118	220	48	1	401	52.76	.024	.719
Macleod Harbor	1927					6	28	55	11		100	52.71	.050	.739
	1927					5	29	52	12	2	100	52.77	.054	.798
	1927					1	13	29	7		50	52.84	.064	.674
	1928			1			22	32	2		57	52.58	.065	.723
	1928					2	24	24	10		60	52.70	.068	.780
Total				1		14	116	192	42	2	367	52.72	.027	.755
Puget Bay	1928					17	75	74	11		177	52.45	.038	.750
Port Fidalgo	1928				1	7	66	57	6		137	52.44	.040	.692
Snug Harbor	1928					9	66	65	10		150	52.51	.039	.708
	1928					2	11	11	2		26	52.50	.089	.746
	1928				1		42	38	7		88	52.57	.057	.892
	1928	1				2	8	16	2		29	52.45	.195	1.557
	1928					3	12	13	1		29	52.41	.090	.720
Total		1			1	16	139	143	22		322	52.55	.029	.772
Eshamy Bay	1926						29	59	11	1	100	52.84	.044	.644
	1926					1	12	32	5		50	52.82	.060	.623
Total						1	41	91	16	1	150	52.83	.035	.636
Cabin Bay, Naked Island	1925					1	21	44	9		75	52.81	.050	.647
South Bay, Naked Island	1927						6	6	1		13	52.62		
	1927					2	14	25	9		50	52.82	.073	.767
Total						3	41	75	19		138	52.80	.040	.693
McClure Bay	1927					1	2	19	3		25	52.96	.081	.599
	1927					1	3	17	4		25	52.96	.089	.662
	1927						6	17	2		25	52.84	.073	.543
	1927					3	15	46	10		74	52.85	.062	.791
	1927						14	29	6	1	50	52.88	.065	.682
	1927						5	15	5		25	53.00	.085	.632
Total						5	45	143	30	1	224	52.90	.030	.657

TABLE 11.—*Variation in number of vertebræ in Cook Inlet and Kodiak-Afognak district*

Locality	Date	Vertebræ 48	49	50	51	52	53	54	55	56	Number	Mean	Probable error	Standard deviation of distribution
Kachemak Bay:														
Halibut Cove lagoon	1926	----	----	----	2	16	36	6	1	----	61	52.80	0.062	0.720
Homer Spit lagoon	1926	----	----	----	1	32	56	11	----	----	100	52.77	.044	.646
McEwan Flats	1926	----	----	----	4	21	29	9	1	----	64	52.72	.071	.838
McDonald Spit lagoon	1926	----	----	----	4	39	61	18	3	----	125	52.82	.049	.804
Off McDonald Spit	1926	----	----	----	2	29	35	10	----	----	76	52.70	.056	.726
	1926	----	----	----	4	36	44	15	1	----	100	52.73	.054	.798
McDonald Spit	1927	----	----	----	----	8	16	1	----	----	25	52.72	.091	.531
Halibut Cove Light	1927	----	----	----	4	25	42	14	2	----	87	52.82	.062	.857
Halibut Cove lagoon	1927	----	1	----	4	11	27	7	----	----	50	52.68	.092	.947
Halibut Cove Light	1927	1	----	----	1	11	32	7	----	----	52	52.79	.084	.927
Total	--------	1	1	----	26	228	378	98	8	----	740	52.76	.031	.790
Shuyak Strait	1925	----	----	----	1	27	38	9	----	----	75	52.73	.053	.680
	1925	----	----	----	3	14	26	7	----	----	50	52.74	.065	.770
	1925	----	----	----	----	14	13	3	----	----	30	52.63	.081	.650
	1926	----	----	----	1	8	11	4	1	----	25	52.84	.119	.880
	1926	----	----	----	1	7	15	2	----	----	25	52.72	.090	.666
	1926	----	----	----	5	14	23	9	1	----	52	52.75	.086	.920
	1927	----	----	1	3	71	106	27	1	----	209	52.76	.034	.728
	1928	----	----	----	2	12	13	2	----	----	29	52.52	.091	.724
	1928	----	----	----	4	13	16	3	----	----	36	52.50	.090	.799
Total	--------	----	----	1	20	180	261	66	3	----	531	52.72	.022	.757
Dogfish Bay	1925	----	----	1	9	34	51	5	----	----	100	52.50	.051	.763
Old Harbor	1926	----	----	----	1	30	63	17	3	1	115	52.95	.050	.790
Shearwater Bay	1928	----	----	----	5	42	82	35	1	----	165	52.91	.041	.776
Zachar Bay	1928	----	----	----	2	21	52	12	----	----	87	52.85	.048	.670

TABLE 12.—*Variation in number of vertebræ in western Alaska*

Locality	Date	Vertebræ 51	52	53	54	55	56	57	Number	Mean	Probable error	Standard deviation of distribution
Chignik	1926	4	5	55	39	3	1	----	107	53.33	0.053	0.806
Shumagin Islands	1926	1	7	36	130	213	62	7	456	54.67	.029	.928
Belkofski Bay	1927	----	1	5	2	----	----	----	8	53.13	--------	--------
Unalaska	1928	----	3	21	15	1	----	----	40	53.35	.067	.654
	1928	----	6	22	16	----	----	----	44	53.23	.068	.668
	1928	----	6	33	11	----	----	----	50	53.10	.055	.574
	1928	----	5	30	12	2	----	----	49	53.22	.065	.677
Total	--------	----	20	106	54	3	----	----	183	53.22	.032	.650
Golovin Bay	1926	2	43	77	18	----	----	----	140	52.79	.038	.671

In southeastern Alaska (Table 13) the three localities in Chatham Strait, Point Gardner, Tebenkof Bay, and Larch Bay show no differences which could be regarded as significant even were the samples truly representative. Both Craig and Stephens Passage show significant differences from these three Chatham Strait localities. Craig and Stephens Passage do not differ significantly from one another, but considering their geographical location, with the three Chatham Strait localities interposed, it may be supposed that they represent separate populations. In support of this contention, there are large spawning grounds, occupied at the same season of the year, both at Craig and in Stephens Passage. The samples from Gravina Island, Whale Bay, and Yakutat are only considered to be sufficient in numbers to give a general indication of the true mean.

TABLE 13.—*Comparisons of the means of the vertebral counts in southeastern Alaska*

[Asterisk shows differences that are probably significant]

Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference	Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference
CHIEF LOCALITIES				MINOR LOCALITIES			
Craig and Stephens Passage	0.04	0.031	1.3	Gravina Island and Craig	0.08	0.079	1.1
Craig and Larch Bay	.26	.033	*7.9	Gravina Island and Larch Bay	.34	.078	*4.4
Craig and Tebenkof Bay	.28	.032	*8.7	Whale Bay and Craig	.52	.082	*6.3
Craig and Point Gardner	.32	.035	*9.1	Whale Bay and Larch Bay	.26	.081	3.2
Stephens Passage and Larch Bay	.30	.027	*11.1	Yakutat Bay and Craig	.08	.165	.5
Stephens Passage and Tebenkof Bay	.32	.025	*12.8	Yakutat Bay and Larch Bay	.18	.165	1.1
Stephens Passage and Point Gardner	.36	.029	*12.4				
Larch Bay and Tebenkof Bay	.02	.028	.7				
Larch Bay and Point Gardner	.06	.031	1.9				
Tebenkof Bay and Point Gardner	.04	.029	1.4				

In Prince William Sound (Table 14), the differences between the localities are not as great as in southeastern Alaska. It will be noted that there are three localities—Puget Bay, Snug Harbor, and Port Fidalgo—that do not differ significantly among themselves, but each of which differs from all of the other localities in Prince William Sound by an amount over four times its probable error, the significance of which will be discussed later. The only other differences of any possible significance occur between McClure Bay and Elrington Passage, and between McClure Bay and Macleod Harbor.

TABLE 14.—*Comparisons of the means of the vertebral counts in Prince William Sound*

[Asterisk shows those statistically significant]

Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference	Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference
Elrington Passage and Puget Bay	0.31	0.045	*6.9	Puget Bay and Port Fidalgo	0.01	0.055	0.2
Elrington Passage and Macleod Harbor	.04	.036	1.1	Macleod Harbor and Snug Harbor	.17	.040	*4.3
Elrington Passage and Snug Harbor	.21	.038	*5.5	Macleod Harbor and Eshamy Bay	.11	.045	2.4
Elrington Passage and Eshamy Bay	.07	.043	1.6	Macleod Harbor and McClure Bay	.18	.040	*4.5
Elrington Passage and McClure Bay	.14	.038	3.7	Macleod Harbor and Naked Island	.08	.048	1.7
Elrington Passage and Naked Island	.04	.047	.9	Macleod Harbor and Port Fidalgo	.28	.048	*5.8
Elrington Passage and Port Fidalgo	.32	.047	*6.8	Snug Harbor and Eshamy Bay	.28	.045	*6.2
Puget Bay and Macleod Harbor	.27	.047	*5.7	Snug Harbor and McClure Bay	.35	.042	*8.3
Puget Bay and Snug Harbor	.10	.057	1.8	Snug Harbor and Naked Island	.25	.049	*5.1
Puget Bay and Eshamy Bay	.38	.052	*7.3	Snug Harbor and Port Fidalgo	.11	.049	2.2
Puget Bay and McClure Bay	.45	.048	*9.4	Eshamy Bay and McClure Bay	.07	.046	1.5
Puget Bay and Naked Island	.35	.055	*6.4	Eshamy Bay and Naked Island	.03	.053	.6
				Eshamy Bay and Port Fidalgo	.39	.053	*7.4
				McClure Bay and Naked Island	.10	.050	2.0
				McClure Bay and Port Fidalgo	.46	.050	*9.2
				Naked Island and Port Fidalgo	.36	.057	*6.3

In the Cook Inlet and Kodiak-Afognak districts (Table 15) the extreme differences between localities are slightly less than in Prince William Sound, but there are several differences of probable statistical significance. Dogfish Bay differs from both Kachemak Bay and Shuyak Strait, the two nearest localities, by four probable errors. Shuyak Strait differs from both Shearwater Bay and Old Harbor by four probable errors. All of the differences in these districts are of slight magnitude.

TABLE 15.—*Comparisons of the means of the vertebral counts in the Cook Inlet and Kodiak-Afognak districts*

[Asterisk shows those statistically significant]

Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference	Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference
Kachemak Bay and Dogfish Bay	0.26	0.060	*4.3	Dogfish Bay and Old Harbor	0.45	0.071	*6.3
Kachemak Bay and Shuyak Strait	.04	.038	1.0	Shuyak Strait and Zachar Bay	.13	.053	2.5
Kachemak Bay and Zachar Bay	.09	.057	1.6	Shuyak Strait and Shearwater Bay	.19	.046	*4.1
Kachemak Bay and Shearwater Bay	.15	.051	2.9	Shuyak Strait and Old Harbor	.23	.055	*4.2
Kachemak Bay and Old Harbor	.19	.059	3.2	Zachar Bay and Shearwater Bay	.06	.063	1.0
Dogfish Bay and Shuyak Strait	.22	.055	*4.0	Zachar Bay and Old Harbor	.10	.069	1.4
Dogfish Bay and Zachar Bay	.35	.070	*5.0	Shearwater Bay and Old Harbor	.04	.065	.6
Dogfish Bay and Shearwater Bay	.41	.065	*6.3				

In western Alaska (Table 7) the Shumagin Islands, Unalaska, and Golovin Bay have already been compared and the differences found to be large. The mean of the Chignik sample (Table 12) is lower than that of the Shumagin Islands, only 90 miles distant, by 1.34 ± 0.060 or 22 probable errors—a large difference from a mathematical standpoint.

VALIDITY OF DIFFERENCES IN VERTEBRAL COUNT

It is necessary to bear in mind that there are sources of variability other than those of pure chance, since the latter may not prevail in what we have regarded as random sampling. The actual significant variability which thus arises within each population must be determined empirically, since such internal variability could not be regarded as significant from the standpoint of the determination of the distinctness of populations. Without an understanding of the extent of these variations, one may be led into the fallacy of believing that any difference that is statistically significant denotes a racial difference, since the whole theory of probable errors presupposes that the samples compared represent adequately their respective populations. The variation which can be shown to actually arise *within* each stock furnishes a means of measuring the significance of differences between adjacent stocks. If the latter exceed the maximum internal difference, it is probably significant of isolation.

In Table 16 is given a comparison of different age classes from the same locality. The data are not extensive and the numbers involved are rather small, yet both Naked Island and McClure Bay show significant differences between the means of different year classes. The maximum significant difference found was 0.67 ± 0.113 or 5.9 times the probable error between two age classes of McClure Bay.

TABLE 16.—*Variation between the means of the vertebral count of different year classes from the same locality*

[Asterisk shows those statistically significant]

Locality	Year classes compared	Difference between means	Probable error of difference	Difference divided by probable error of difference	Locality	Year classes compared	Difference between means	Probable error of difference	Difference divided by probable error of difference
McClure Bay	1920, 1921	0.19	0.073	2.6	Elrington Passage	1920, 1921	0.07	0.074	0.9
	1920, 1922	.06	.082	.7		1920, 1922	.07	.075	.9
	1920, 1923	.48	.103	*4.7		1920, 1923	.13	.071	1.8
	1921, 1922	.25	.095	2.6		1921, 1922	.14	.084	1.7
	1921, 1923	.67	.113	*5.9		1921, 1923	.20	.081	2.5
	1922, 1923	.42	.119	3.5		1922, 1923	.06	.081	.7
Eshamy Bay	1920, 1921	.09	.128	.7	Macleod Harbor	1922, 1923	.36	.133	2.7
Naked Island	1920, 1921	.50	.112	*4.5		1922, 1924	.25	.165	1.5
						1923, 1924	.11	.117	.9

This goes far toward explaining the variations to be found between samples from the same locality, as the mean of each sample will depend on the proportions of each year class present. As a rule, with samples of mature fish, one will have several year classes represented, so that means of successive samples will not fluctuate widely. However, in some cases, especially with schools of young fish, the sample may be composed very largely of fish of one year class. If this happens to be a year class that deviates widely from the average of the means of the year classes for that locality then the mean of the sample may differ considerably from the average for the locality.

Thus, in comparing two samples from the same locality one could expect to find a difference in means as great as 0.67 plus or minus its probable error (as in Table 16) if each of the samples contained fish of only one age, but of a different year class in each case. In comparing samples of fish from the same locality composed of several age groups such a large difference can not be expected, as the presence in the samples of fish spawned in several different years will cause the samples to show less variability than if composed of one age group.

Therefore, in evaluating the differences between any two localities, we must, if each sample is composed of one age group, have a difference of over 0.67 plus or minus its probable error before it approaches racial significance. This condition is seldom fulfilled, but, if not, we are confronted with another problem. Owing to changes in the proportions of each age group in different samples from the same locality there will be differences, aside from those due to chance, and the magnitude of these expected differences must be known so that they can be discounted in comparing samples from adjacent localities.

The magnitude of these expected differences for any two samples taken the same year in the same locality is shown by Table 17. These differences are not great, the average for the table being only 1.7 times its probable error. In Tebenkof Bay and Larch Bay the differences have statistical significance, being 4.4 and 5.2 times their probable errors, but in both of these cases the sample that varied most from the mean for the locality was composed largely of very small fish (between 120 and 150 millimeters), presumably largely of one age class. The effect this might have on the means has already been discussed. The actual difference between the means in Tebenkof Bay and in Larch Bay is 0.18 and 0.26, respectively. Elrington Passage and Unalaska have differences between samples of 0.19 and 0.25, respectively, which approach statistical significance, and as in this case none of the samples were composed of fish of only one age class, one may conclude that in comparing samples from adjacent localities a difference of 0.25 plus or minus its probable error must be expected, and that any such difference should not, without further proof, be considered as due to the existence of distinct populations.

TABLE 17.—*Maximum variations between the means of the vertebral count of any two samples taken the same year in the same locality*

Locality	Year sampled	Difference between means of two samples	Probable error of difference	Difference divided by probable error of difference	Locality	Year sampled	Difference between means of two samples	Probable error of difference	Difference divided by probable error of difference
San Francisco Bay	1923	0.06	0.036	1.7	Snug Harbor	1928	.16	.106	1.5
Straits of Georgia	1915	.10	.064	1.6	Eshamy Bay	1926	.02	.074	.3
Pender Harbor	1915	.08	.050	1.6	McClure Bay	1927	.16	.112	1.4
Craig	1928	.06	.071	.9	Kachemak Bay	1926	.12	.074	1.6
Tebenkof Bay	1927	.18	.041	[1] 4.4		1927	.14	.111	1.3
Point Gardner	1927	.03	.041	.7	Shuyak Strait	1925	.11	.104	1.1
Larch Bay	1927	.26	.050	[1] 5.2		1926	.12	.149	.8
Elrington Passage	1925	.19	.076	[2] 2.5		1928	.02	.128	.2
	1926	.07	.082	.9	Unalaska	1928	.25	.087	[1] 2.9
	1927	.13	.093	1.4					
Macleod Harbor	1927	.13	.081	1.6					
	1928	.12	.094	1.3					

[1] Statistically significant. [2] Approaching statistical significance.

But, aside from chance, the mean of any population will vary, not only between samples taken the same year, but between those taken in different years, owing to the changes in the proportions of the age classes and to the annual addition of a new year class. The magnitude of these variations is shown by Table 18. The average differences are 1.9 times their probable errors, only slightly higher than the difference between samples taken the same year. The largest difference found between any two samples is that of 0.30 ± 0.082 or 3.7 probable errors for San Francisco Bay. This difference, however, will not be applied to the present analysis for two reasons; first, because the two samples were counted by different investigators (1915 by Thompson, 1923 by Hubbs), and second, because the two samples were taken eight years apart, admitting of the possibility of this difference being caused by a long-time fluctuation that will not enter into our samples, none of which were taken over four years apart.

TABLE 18.—*Maximum variations between the means of the vertebral count of any two samples taken different years in the same locality*

[Asterisk indicates those approaching statistical significance]

Locality	Years compared	Difference between means of two samples	Probable error of difference	Difference divided by probable error of difference	Locality	Years compared	Difference between means of two samples	Probable error of difference	Difference divided by probable error of difference
San Francisco Bay	1915, 1923	0.30	0.082	*3.7	Kachemak Bay	1926, 1927	0.11	0.104	0.1
Craig	1925, 1928	.16	.083	1.9	Shuyak Strait	1925, 1926	.21	.144	1.5
Tebenkof Bay	1925, 1927	.22	.091	*2.4		1925, 1927	.13	.087	1.5
Elrington Passage	1925, 1926	.16	.080	2.0		1925, 1928	.24	.111	*2.2
	1925, 1927	.27	.088	*3.1		1926, 1927	.08	.124	.6
	1926, 1927	.18	.088	2.0		1926, 1928	.34	.149	*2.3
Macleod Harbor	1927, 1928	.26	.091	*2.9		1927, 1928	.26	.096	*2.7
Naked Island	1925, 1927	.01	.088	.1					

Eliminating the San Francisco Bay samples, the maximum differences that approach statistical significance (between 2.7 and 3.1 times their probable errors) are those of Elrington Passage, Macleod Harbor, and Shuyak Strait, 0.27, 0.26, and 0.26, respectively. Although these differences are not of statistical significance, yet the fact that they appear in three localities attests to their validity. Hence in comparing samples from adjacent localities the significance of the differences must be open to question if they are smaller than 0.27.

Returning to the differences in vertebral count between distant localities (Table 7), it is apparent that they are very far in excess of any differences found between samples from the same locality, except in three cases (marked in Table 7 by an asterisk), in each of which the two populations compared were far apart and separated by others that are very distinct. This lack of difference is probably due entirely to accidental similarity.

In southeastern Alaska (Table 13), Craig and Stephens Passage (Nos. 7 and 12, Table 6 and fig. 14), both differ from the three Chatham Strait localities (Nos. 8, 9, and 10, Table 6 and fig. 14) by more than the maximum variability found between samples from one locality, 0.27 (Table 18), except in the case of Craig and Larch Bay, where the difference is only 0.26. In this case, however, the difference is 7.9 times its probable error, while the maximum difference found in the same locality (Table 18) is only 3.1 times its probable error, indicating that the difference between Craig and Larch Bay may be valid. Craig and Stephens Passage do not vary significantly between themselves, but their geographical position, with the distinct Chatham Strait stock between them, would indicate their independence.

In Prince William Sound (Table 14), as aforementioned, there are three localities—Puget Bay, Snug Harbor, and Port Fidalgo—that do not differ among themselves, but each of which shows a statistically significant difference with all of the other localities in Prince William Sound. In all three of these localities the range of sizes was small, varying chiefly from 150 to 190 millimeters, and so presumably the samples were composed very largely of 3-year-olds. As the fish in these samples were largely of one year class, the expected variability would presumably be analogous to that of the differences found between age classes of which the maximum was 0.67 ± 0.113, or 5.9 probable errors. The largest difference, that between Puget Bay and McClure Bay, is only 0.45 ± 0.048, or 9.4 probable errors so, although on the assumption that the sampling was truly random the difference is significant, we will not regard it as denoting a race because we know that the samples do not represent the same populations in age. McClure Bay differs from Elrington Passage by 0.14 ± 0.038, or 3.7 probable errors, and from Macleod Harbor by 0.18 ± 0.040, or 4.5 probable errors. Both of these differences are less than the 0.27 maximum variability between samples from the same locality, so they will not be considered as valid. Our data do not, therefore, demonstrate the existence of more than one stock of herring in Prince William Sound.

In the Cook Inlet and Kodiak-Afognak districts the maximum differences between localities are small. Dogfish Bay shows statistically significant differences between both Kachemak Bay and Shuyak Strait, but the actual differences, 0.26 and 0.22, are slightly less than 0.27—the maximum difference found between samples in one locality—hence Dogfish Bay can not safely be considered as racially distinct, especially as only one sample was obtained. Shuyak Strait differs from both Old Harbor and Shearwater Bay by four probable errors, the actual differences being

0.19 and 0.23, respectively. Although these actual differences are less than the maximum actual difference, 0.27, found between samples in the same locality, yet there is good reason for considering them to be valid. The Shuyak Strait mean is derived from nine samples taken over four years and representing a number of year classes, so that it should not be expected to vary as widely as the mean of a single sample. The Old Harbor and Shearwater Bay samples, from practically the same locality, containing 115 and 165 specimens, respectively, differ only by 0.04, although taken two years apart, in 1926 and 1928. This would attest to the reliability of their means. Hence we have provisionally considered Shuyak Strait and Old Harbor-Shearwater Bay to be racially distinct.

In western Alaska (Table 7) the Shumagin Islands, Unalaska, and Golovin Bay have already been shown to differ by amounts well in excess of any differences found in the same locality. The mean of the Chignik sample (Table 12) is lower than that of the Shumagin Islands, only 90 miles distant, by 1.34 ± 0.060, or 22 probable errors. This also is considerably in excess of any variations found in the same locality, so Chignik may be considered racially distinct.

SUMMARY OF VERTEBRAL COUNT FINDINGS

1. Following the general trend of the coast northward and westward from San Diego the means of the vertebral counts increase with the distance, the general trend being practically linear and widely departed from only by the herring of the Shumagin Islands and Golovin Bay.
2. Statistically significant differences are found between the vertebral count of different age classes from the same locality.
3. Successive samples from the same locality show differences larger than any assignable to chance.
4. In practically every case distant localities show differences greatly in excess of any that can be assigned to variations within the same population, as determined by the maximum variation between the means of samples from the same locality.
5. Many closely adjacent localities also show differences in excess of any assignable to variation in the same locality.
6. The analysis of the means of the vertebral counts indicates the distinctness of the populations in the following areas from the stocks of other areas sampled: California, southern British Columbia, Craig, Chatham Strait, Stephens Passage, Cook Inlet-Shuyak Strait-Prince William Sound, Shearwater Bay-Old Harbor, Chignik, Shumagin Islands, Unalaska, and Golovin Bay.

DORSAL RAYS

We have for comparison 3,864 dorsal-ray counts distributed from Puget Sound to Unalaska (Table 19). To avoid all errors in counting due to preservation, we have only used counts made on fresh specimens. Counts are available from other investigators but we do not care to use them in comparison with our own due to the chances for personal error in counting.

TABLE 19.—*Variation in number of dorsal rays*

Locality	Date	Number of rays							Number	Mean	Probable error	Standard deviation of distribution
		15	16	17	18	19	20	21				
Puget Sound	1927			1	34	54	3		98	18.73	0.043	0.627
Southeastern Alaska:												
Craig	1925			3	38	52	7		100	18.63	.045	.660
	1928			2	34	44	7	1	88	18.67	.055	.763
	1928				25	60	13		98	18.88	.042	.610
	1928			3	31	52	11		97	18.73	.048	.696
Total for Craig				8	128	208	38	1	383	18.73	.023	.673
Whale Bay	1925	1		1	38	54	4	1	99	18.62	.049	.723
Tebenkof Bay	1925			5	28	58	9		100	18.71	.047	.699
Point Gardner	1925			1	46	52	2		101	18.55	.037	.556
Stephens Passage	1928		1	9	249	562	128	6	955	18.86	.015	.670
Total for southeastern Alaska		1	1	24	489	934	181	8	1,638	18.79	.011	.676
Yakutat	1927				2	12	11		25	19.36	.082	.609
Prince William Sound:												
Elrington Passage	1925				10	28	7		45	18.93	.062	.613
Prince of Wales Passage	1925			2	12	26	5		45	18.76	.070	.706
Procession Rocks	1925			3	29	50	17	1	100	18.84	.052	.773
Elrington Passage	1925				13	32	5		50	18.84	.055	.580
Do	1925			1	34	30	10		75	18.65	.056	.724
Total for Elrington Passage				6	98	166	44	1	315	18.80	.027	.706
Macleod Harbor	1927				16	43	10		69	18.91	.049	.607
	1927			1	21	22	6		50	18.66	.068	.710
	1928				17	37	6		60	18.82	.051	.590
	1928			1	15	35	8	1	60	18.88	.061	.703
Total for Macleod Harbor				2	69	137	30	1	239	18.83	.029	.659
Snug Harbor	1928			1	12	27	10		50	18.92	.067	.716
Eshamy Bay	1926			2	33	74	16		125	18.83	.039	.654
McClure Bay	1927			2	19	45	8		74	18.80	.052	.657
	1927				5	17	3		25	18.92	.075	.559
Total for McClure Bay				2	24	62	11		99	18.83	.043	.636
Naked Island	1925				23	43	9		75	18.81	.049	.628
Port Fidalgo	1928	1		2	23	41	10		77	18.73	.063	.815
Total for Prince William Sound		1		15	282	550	130	2	980	18.81	.015	.686
Dogfish Bay	1925			1	15	65	16	3	100	19.05	.046	.684
Kachemak Bay:												
Halibut Cove lagoon	1926			1	12	31	6		50	18.84	.061	.644
Homer Spit lagoon	1926			3	34	51	12		100	18.72	.048	.710
McDonald Spit lagoon	1926			2	54	54	15		125	18.66	.043	.710
Off McDonald Spit	1926		1	3	36	50	15		105	18.71	.051	.779
	1926			3	37	54	6		100	18.63	.043	.643
	1927				6	15	3		24	18.87	.077	.599
Total for Kachemak Bay			1	12	179	255	57		504	18.70	.021	.702
Shuyak Strait	1925			3	25	36	11		75	18.73	.059	.755
	1925			3	12	27	6	2	50	18.84	.082	.860
	1925				8	17	5		30	18.90	.080	.650
	1926			1	24	23	2		50	18.52	.058	.609
	1926				7	14	1		22	18.73	.077	.539
Total for Shuyak Strait				7	76	117	25	2	227	18.72	.032	.718
Old Harbor	1926			2	41	51	15		109	18.73	.046	.715
Unalaska	1928			2	14	21	3		40	18.62	.074	.696
	1928			2	10	29	3	1	45	18.80	.072	.718
	1928				12	25	12		49	19.00	.067	.700
	1928				14	26	9		49	18.90	.065	.677
Total for Unalaska				4	50	101	27	1	183	18.84	.035	.710

Table 19 shows that the means of the dorsal-ray counts do not exhibit any general change throughout the range, as do the vertebræ, but appear to vary independently of geographical location. The nine principal localities are compared in Table 20. Out of 36 comparisons there are 16 that may be significant from a mathematical standpoint (see footnotes 1 and 2, Table 20). However, before considering these differences as valid we must know the amount of variability to be expected within any one locality.

TABLE 20.—*Comparisons of the means of the dorsal-ray counts of the principal localities*

Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference	Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference
Puget Sound and Southeastern Alaska	0.06	0.045	1.3	Yakutat and Kachemak Bay	0.66	0.085	[1] 7.8
Puget Sound and Yakutat	.63	.093	[1] 6.8	Yakutat and Shuyak Strait	.64	.088	[1] 7.3
Puget Sound and Prince William Sound	.08	.046	1.7	Yakutat and Old Harbor	.63	.094	[1] 5.2
Puget Sound and Dogfish Bay	.32	.063	[2] 5.1	Yakutat and Unalaska	.52	.089	[1] 5.8
Puget Sound and Kachemak Bay	.03	.048	.6	Prince William Sound and Dogfish Bay	.24	.048	[2] 5.0
Puget Sound and Shuyak Strait	.01	.054	.2	Prince William Sound and Kachemak Bay	.11	.026	[2] 4.2
Puget Sound and Old Harbor	.00	.063	-------	Prince William Sound and Shuyak Strait	.09	.035	2.6
Puget Sound and Unalaska	.11	.056	2.0	Prince William Sound and Old Harbor	.08	.048	1.7
Southeastern Alaska and Yakutat	.57	.083	[1] 6.9	Prince William Sound and Unalaska	.03	.038	.8
Southeastern Alaska and Prince William Sound	.02	.019	1.1	Dogfish Bay and Kachemak Bay	.35	.050	[2] 7.0
Southeastern Alaska and Dogfish Bay	.26	.047	[2] 5.5	Dogfish Bay and Shuyak Strait	.33	.056	[2] 5.9
Southeastern Alaska and Kachemak Bay	.09	.024	[2] 3.8	Dogfish Bay and Old Harbor	.32	.065	[2] 4.9
Southeastern Alaska and Shuyak Strait	.07	.033	2.1	Dogfish Bay and Unalaska	.21	.057	[2] 3.7
Southeastern Alaska and Old Harbor	.06	.047	1.3	Kachemak Bay and Shuyak Strait	.02	.038	.5
Southeastern Alaska and Unalaska	.05	.036	1.4	Kachemak Bay and Old Harbor	.03	.050	.6
Yakutat and Prince William Sound	.55	.083	[1] 6.6	Kachemak Bay and Unalaska	.14	.040	3.5
Yakutat and Dogfish Bay	.31	.094	3.3	Shuyak Strait and Old Harbor	.01	.056	.2
				Shuyak Strait and Unalaska	.12	.047	2.6
				Old Harbor and Unalaska	.11	.057	1.9

[1] Of possible racial significance. [2] Of probable statistical significance.

The maximum differences between the means of any two samples taken the same year in the same locality are shown in Table 21. In three localities the differences between the means of the samples approach statistical significance (3.0 to 3.3 times the probable error) the maximum difference being 0.28 ± 0.084 or 3.3 probable errors. This would cast serious doubt on the significance of any difference not greater than 0.28, thus invalidating five of the differences in Table 20 that are valid from a mathematical standpoint.

TABLE 21.—*Maximum variations between the means of the dorsal-ray counts of any two samples taken the same year in the same locality*

[Asterisk indicates those approaching statistical significance]

Locality	Year sampled	Difference between means of two samples	Probable error of difference	Difference divided by probable error of difference	Locality	Year sampled	Difference between means of two samples	Probable error of difference	Difference divided by probable error of difference
Craig	1928	0.21	0.069	*3.0	Kachemak Bay	1926	0.21	0.075	2.8
Elrington Passage	1925	.28	.084	*3.3	Shuyak Strait	1925	.17	.100	1.7
Macleod Harbor	1927	.25	.084	*3.0		1926	.21	.097	2.2
	1928	.06	.079	.8	Unalaska	1928	.28	.100	2.8
McClure Bay	1927	.12	.083	1.4					

The maximum variations found between the means of any two samples taken different years in the same locality are shown in Table 22. In two cases the differences are probably of statistical significance, being 0.25 ± 0.062 or 4.0 at Craig and 0.38 ± 0.099 or 3.8 probable errors for Shuyak Strait. As the maximum difference found between any two samples from the same locality, 0.38, is of probable statistical significance we can not claim as racial any lesser difference. This invalidates, from a racial standpoint, four more of the differences that are significant from a statistical standpoint (Table 20), leaving only seven differences that can be regarded as having possible racial significance.

TABLE 22.—*Maximum variations between the means of the dorsal-ray counts of any two samples taken different years in the same locality*

[Asterisk indicates those of probable statistical significance]

Locality	Years sampled	Difference between means	Probable error of difference	Difference divided by probable error of difference	Locality	Years sampled	Difference between means	Probable error of difference	Difference divided by probable error of difference
Craig	1925, 1928	0.25	0.062	*4.0	Kachemak Bay	1926, 1927	0.24	0.088	2.7
Macleod Harbor	1927, 1928	.22	.091	2.4	Shuyak Strait	1925, 1926	.38	.099	*3.8

Returning to Table 20, those differences that are statistically significant and exceed the maximum variability found between samples of the same locality are shown by footnote 1 reference. It is noted that all of these differences are between Yakutat and other localities, Yakutat differing significantly from all except Dogfish Bay. None of these differences are excessive, and we are inclined to doubt seriously their racial validity, for the Yakutat sample, besides being small in numbers, was composed entirely of very small fish (64 to 85 millimeters in length) which might introduce two sources of error, one being due to counting the rays of such exceedingly small fish in a different manner than those of larger specimens (a low power of the microscope was used), and another to the fact that they were all of one year class, which as we have seen in the case of the vertebral count, might easily account for large differences between the means.

In conclusion it may be said that the dorsal-ray count has not shown the distinctness of any populations.

ANAL RAYS

The anal-ray data contains 1,175 counts of fresh specimens (Table 23). In making the anal-ray count, doubt often arises owing to the diminutive size of the first, and often the second, unbranched ray. For this reason we have not compared our counts with those made by Thompson (1917) or Hubbs (1925), as there is no means of correctly evaluating any personal error that may have arisen as a result of this difficulty.

TABLE 23.—*Variation in number of anal rays*

Locality	Date	Number of rays							Number	Mean	Probable error	Standard deviation of distribution
		14	15	16	17	18	19	20				
Puget Sound	1927	----	5	40	37	11	1	----	94	16.61	0.056	0.808
Southeastern Alaska:												
Craig	1925	2	7	45	37	6	3	----	100	16.47	.061	.900
Whale Bay	1925	----	6	19	55	15	4	----	99	16.92	.056	.817
Tebenkof Bay	1925	----	5	22	40	23	9	----	99	17.09	.068	1.000
Point Gardner	1925	----	5	29	39	24	3	----	100	16.91	.062	.919
Total	--------	2	23	115	171	68	19	----	398	16.85	.032	.950
Prince William Sound:												
Naked Island	1925	----	3	17	38	10	7	----	75	17.01	.074	.946
Deep Bay, Elrington Passage	1925	----	4	8	20	12	1	----	45	16.96	.095	.940
Prince of Wales Passage (Elrington Passage)	1925	----	2	10	15	15	3	----	45	17.16	.099	.990
Procession Rocks (Elrington Passage)	1925	----	1	16	45	28	9	1	100	17.31	.062	.915
McClure Bay	1927	1	1	11	30	24	7	----	74	17.30	.076	.967
Total	--------	1	11	62	148	89	27	1	339	17.17	.035	.957
Dogfish Bay	1925	----	3	18	42	28	8	1	100	17.23	.065	.970
Halibut Cove	1926	----	1	13	26	9	----	----	49	16.88	.069	.718
Shuyak Strait	1925	1	9	49	73	21	2	----	155	16.71	.046	.844
Unalaska	1928	----	1	13	18	8	----	----	40	16.82	.082	.770

The means of the anal-ray counts do not show the same tendency to change with the distance along the coast as is present in the vertebral counts, as shown by Table 24 which compares the means of the principal localities. There is as great a tendency for large differences between adjacent localities as between distant localities. Thus of the 11 differences that may have statistical significance, 4 are between adjacent localities, and of the 10 differences that probably have no significance 8 are between distant localities.

TABLE 24.—*Comparisons of the means of the anal ray counts of the principal localities*

Localities compared	Difference between means	Probable error of difference	Difference divided by probable error of difference
Puget Sound and southeastern Alaska	0.24	0.064	[1] 3.8
Puget Sound and Prince William Sound	.46	.066	[2] 7.0
Puget Sound and Dogfish Bay	.62	.086	[2] 7.2
Puget Sound and Halibut Cove	.27	.089	3.1
Puget Sound and Shuyak Strait	.10	.072	1.4
Puget Sound and Unalaska	.21	.099	2.1
Southeastern Alaska and Prince William Sound	.32	.047	[1] 6.8
Southeastern Alaska and Dogfish Bay	.38	.072	[2] 5.3
Southeastern Alaska and Halibut Cove	.03	.076	.4
Southeastern Alaska and Shuyak Strait	.14	.056	2.5
Southeastern Alaska and Unalaska	0.03	0.088	0.3
Prince William Sound and Dogfish Bay	.06	.074	.8
Prince William Sound and Halibut Cove	.29	.077	[1] 3.8
Prince William Sound and Shuyak Strait	.46	.058	[2] 7.9
Prince William Sound and Unalaska	.35	.089	[1] 3.9
Dogfish Bay and Halibut Cove	.35	.095	[1] 3.7
Dogfish Bay and Shuyak Strait	.52	.080	[2] 6.5
Dogfish Bay and Unalaska	.41	.105	[2] 3.9
Halibut Cove and Shuyak Strait	.17	.083	2.0
Halibut Cove and Unalaska	.06	.107	.6
Shuyak Strait and Unalaska	.11	.094	1.2

[1] Of probable statistical significance.

[2] Possibly a valid racial difference.

In inquiring into the validity of these differences it may be noted that in Elrington Passage the means of two samples taken the same year differ by 0.35 ± 0.113, or 3.1 probable errors. The maximum variability between any two samples from the same locality may well be larger, but at least this provides some measure of the expected differences.

Using this measure of variability it is found that in only six cases is the difference between the means of two samples greater than the 0.35 maximum variability found between samples from the same locality. Dogfish Bay is found to differ significantly from Shuyak Strait, Unalaska, southeastern Alaska, and Puget Sound. It differs from Halibut Cove by 0.35, which, being exactly the same amount as the maximum variability found between samples from the same locality, can not be considered as a valid racial difference. Puget Sound differs significantly from Prince William Sound. Prince William Sound differs from Shuyak Strait by 0.46 ± 0.058, or 7.9 probable errors, which is somewhat in excess of the variability found within one locality.

To conclude, the anal-ray count does not show any general change associated with distance as is the case with the vertebral count. Differences between distant localities are shown in a few cases. Taking into consideration the variability within one locality, it suggests that Shuyak Strait is independent of either Dogfish Bay or Prince William Sound.

HEAD LENGTHS

The length of the head increases with the growth of the fish but does not increase as rapidly as the length of the body. For this reason only head lengths of fish of approximately the same body length are strictly comparable. This being the case the head lengths have been expressed as percentages of the body length. (Table 25.)

TABLE 25.—*Average per cent head is of body length at each centimeter*

Length in millimeters	Puget Sound		Craig		Stephens Passage		Southeastern Alaska, total		Elrington Passage, 1925		Elrington Passage, 1926		Elrington Passage, 1927	
	Number	Average	Number	Average	Number	Average	Number	Average	Number	Average	Number	Average	Number	Average
60-69														
70-79														
80-89														
90-99														
100-109					1	25.7	1	25.7						
110-119					5	26.1	5	26.1					1	24.6
120-129					21	25.3	21	25.3						
130-139					22	25.3	22	25.3					6	24.6
140-149					20	24.6	20	24.6					8	23.9
150-159					25	23.9	25	23.9					3	23.3
160-169	1	24.1	3	24.4	65	23.7	68	23.7					1	23.2
170-179	7	23.8	23	23.8	129	23.6	152	23.6	5	23.0			8	22.6
180-189	29	23.3	60	23.7	205	23.5	265	23.5	13	22.6	4	22.2	17	22.3
190-199	34	23.0	68	23.4	204	23.4	272	23.4	11	21.9	5	22.1	22	22.1
200-209	24	22.7	54	23.2	118	23.3	172	23.2	21	21.8	12	21.8	9	21.7
210-219	4	22.9	43	23.0	61	23.1	104	23.0	28	21.5	24	21.3	6	21.5
220-229	1	22.7	31	22.8	64	22.8	95	22.8	31	21.5	35	21.3	16	21.6
230-239			15	22.8	24	22.8	39	22.8	24	21.1	25	21.0	22	21.2
240-249			1	22.6	2	23.0	3	22.8	13	21.4	11	21.0	18	21.1
250-259									15	21.3	3	21.8	2	21.3
260-269									21	21.3	2	21.1	4	21.4
270-279									7	20.5	3	21.3	3	21.8
280-289									1	21.3				
290-299														
300-309											1	19.7		
310-319														

TABLE 25.—*Average per cent head is of body length at each centimeter*—Continued

Length in millimeters	Macleod Harbor, 1927		Eshamy Bay, 1926		McClure Bay, 1927		Naked Island, 1925		Naked Island, 1927		Prince William Sound, total		Dogfish Bay	
	Number	Average	Number	Average	Number	Average	Number	Average	Number	Aver age	Number	Average	Number	Average
60–69														
70–79														
80–89														
90–99														
100–109	1	26.5									1	26.5		
110–119											1	24.6		
120–129	2	24.2							1	24.2	3	24.2		
130–139	1	23.0									7	24.4		
140–149											8	23.9		
150–159	1	23.3									4	23.3		
160–169	7	23.2							1	23.8	9	23.3		
170–179	16	22.6	1	24.1					1	24.2	31	22.8		
180–189	31	22.4	1	22.4	1	22.4	1	23.2	5	23.4	73	22.5		
190–199	66	22.1	4	22.6	3	22.4	4	22.9	13	22.7	128	22.2		
200–209	39	22.0	3	21.8	12	22.3	7	22.1	12	22.5	115	22.0		
210–219	15	21.5	15	21.7	7	22.2	19	21.8	5	22.8	119	21.6		
220–229	7	21.1	27	21.4	13	21.5	27	21.6	8	22.4	164	21.5	1	22.3
230–239	6	21.0	90	21.3	20	21.4	8	21.7	14	22.0	209	21.3	3	22.1
240–249	6	21.6	41	21.0	29	21.6	1	21.7	9	21.8	128	21.3	6	21.8
250–259	2	21.9	11	21.1	11	21.1	2	21.6	3	20.8	49	21.2	21	21.7
260–269			2	21.0	1	21.0	4	21.3	2	21.1	36	21.3	47	21.5
270–279			5	20.7	2	21.7	2	20.8	1	21.1	23	21.0	20	21.3
280–289					1	21.2					2	21.3	2	19.9
290–299														
300–309											1	19.7		
310–319														

Length in millimeters	Lower Kachemak Bay, 1926		Lower Kachemak Bay, 1927		Halibut Cove, 1926		Halibut Cove, 1927		Shuyak Strait		Shuyak Strait, Halibut Cove, Lower Kachemak Bay, total		Russian Harbor	
	Number	Average	Number	Average	Number	Average	Number	Average	Number	Average	Number	Average	Number	Average
60–69					2	26.7					2	26.6		
70–79					20	26.4					20	26.4		
80–89					2	25.8					2	25.8		
90–99					1	26.6					1	26.6		
100–109					1	26.5					1	26.5		
110–119					8	24.9					8	24.9		
120–129	3	24.1			16	24.8					19	24.7		
130–139	1	24.4			8	24.2					9	24.2		
140–149	1	22.4			9	24.4					10	24.2		
150–159					9	23.9					9	23.9		
160–169	1	22.9			2	22.5					3	22.6		
170–179					6	22.8	3	23.5			9	23.0		
180–189	1	21.3			4	22.2	3	23.0			8	22.4		
190–199			1	21.7	5	22.1	1	23.0			7	22.2		
200–209	5	21.5	4	21.6	8	22.2	8	22.7			25	22.1		
210–219	7	21.3	19	21.1			8	22.2	1	20.6	35	21.4		
220–229	2	21.3	33	20.9	13	21.5	15	21.8	2	20.8	65	21.2		
230–239	11	20.6	27	20.8	13	20.9	13	21.7	10	21.0	74	21.0		
240–249	12	20.5	16	20.8	10	20.9	9	21.2	19	20.6	66	20.8	1	19.3
250–259	34	20.1	16	20.5	30	20.6	3	21.1	40	20.3	123	20.5	10	19.7
260–269	66	20.0	21	20.0	51	20.5	4	21.5	58	20.4	200	20.3	26	19.8
270–279	88	19.7	33	20.2	49	20.3	3	21.2	79	20.2	252	20.1	25	20.0
280–289	54	19.7	25	20.0	18	20.1	4	20.7	27	19.9	128	19.9	19	19.6
290–299	23	19.6	4	20.0	10	19.9	1	20.8	22	19.7	60	19.8	19	19.9
300–309	4	19.9	1	19.9	2	20.2			1	20.2	8	20.0	5	19.8
310–319	2	19.1							1	19.4	3	19.2		

In treating the data the percentages have been averaged for centimeter body-length catagories, not using any averages from a category having a frequency of less than five. For each centimeter body-length category, the average per cent head length was used to calculate the average actual head length for that category. A straight line was then fitted to each actual head-length body-length relation by the method of least squares. The points on this straight line were then converted into percentages at each length and replotted. The resulting smoothed curves gave a fair fit, as illustrated by Figure 20, showing the average percentages in each centimeter category and the smoothed curves for Elrington Passage in 1927 and Stephens Passage in 1928.

The smoothed head-length curves are shown in Figures 21, 22, and 23. Figure 21 shows that Craig and Stephens Passage are very similar, but southeastern Alaska

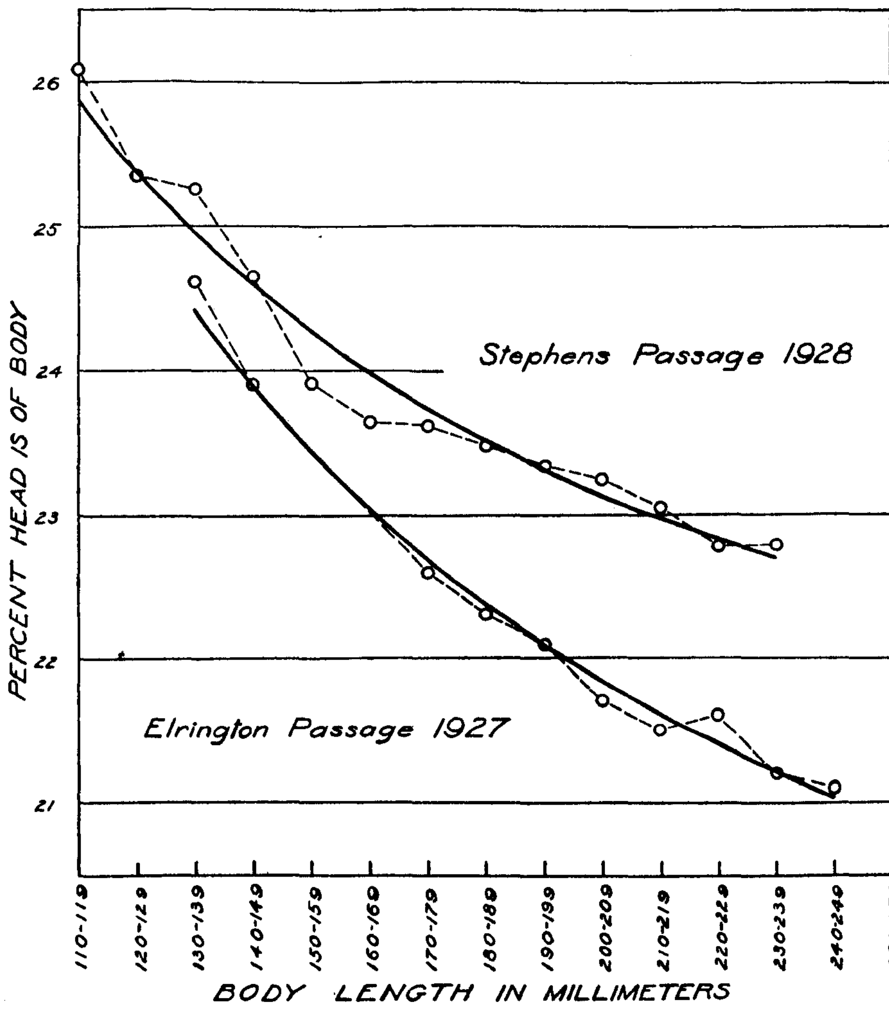

FIGURE 20.—Percentage head is of body. Smoothed curves and actual data for Elrington Passage, 1927, and Stephens Passage, 1928, to illustrate the closeness of fit of the smoothed curves

(the combination of the two curves) shows distinct differences from both Prince William Sound and the other central Alaska curve.

The component samples of the Prince William Sound curve are given in Figure 22. The McClure Bay and the two Naked Island samples are slightly above the main group but do not approach the southeastern Alaska group.

There is one disturbing factor in the comparisons of these head-length curves, and that is condition. The two Naked Island samples are a good illustration. The 1925 sample was taken in August when the fish were fat, while the 1927 Naked Island fish, with longer head measurements, were taken early in June and were extremely thin.

It would seem that when fat, fish might be expected to have a lesser head length than when thin, as the bulging of the sides of the fat fish, by increasing the angle between the opercle and the axis of the body, would tend to shorten the head-length measurement, which is taken to the posterior edge of the opercle.

Figure 23 gives the curves for the remainder of central Alaska. The dotted curve does not include the Dogfish Bay or Russian Harbor samples. All of the component curves, except that for Halibut Cove in 1927, fall in one group. Here again condition is a disturbing element. The 1927 Halibut Cove curve comes considerably

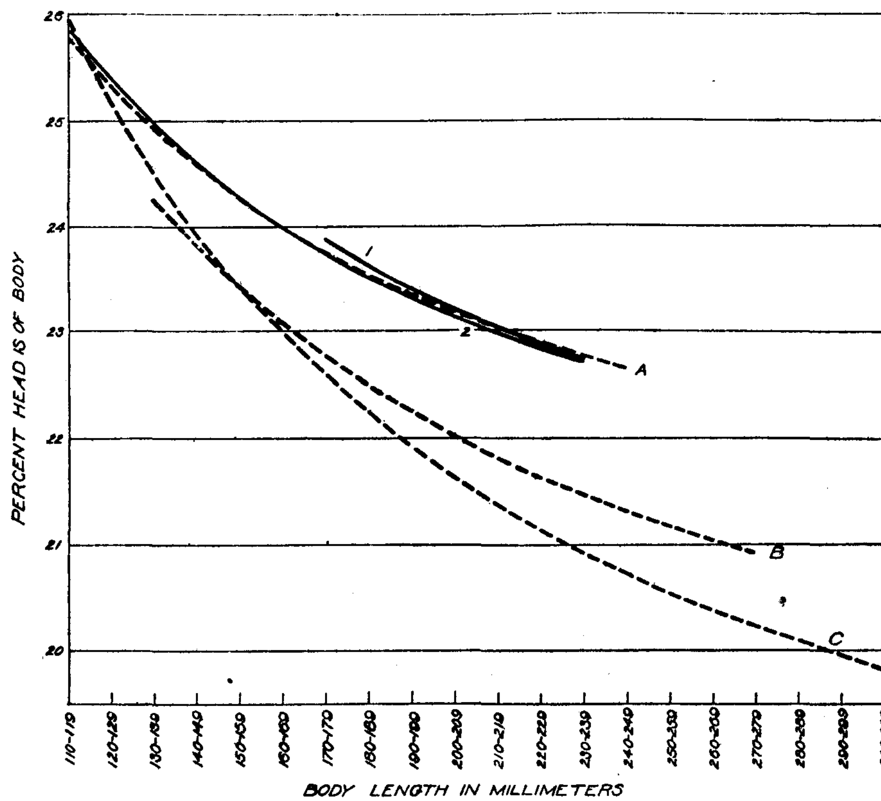

FIGURE 21.—Percentage head length is of body length. Showing: A, southeastern Alaska, (1) Craig; (2) Stephens Passage; B, Prince William Sound; and C, Shuyak Strait, lower Kachemak Bay, and Halibut Cove

above that for 1926. Reference to the section on condition shows that the 1927 fish were much thinner than the 1926 fish.

The Dogfish Bay curve is 1 per cent higher than the combined curve for Shuyak Strait, Kachemak Bay, and Halibut Cove—a difference of 2.5 millimeters in fish of 250 millimeters in body length. The Dogfish Bay fish, although taken in August, were very thin, yet it seems improbable that such a difference could be entirely dependent on condition.

Certain conclusions may be drawn from the head-length analysis:

1. The head lengths in general decrease from the south toward the north and west, thus showing a change with distance, as do the vertebral counts.

2. While the differences between the curves can not be calculated mathematically owing to the differences in slope, the fact that the curves for the individual localities

from each main group do not overlap the curves for the other main groups, except in the cases of Dogfish Bay and Halibut Cove, 1927 (which, as mentioned before, may be due to condition), is sufficient proof of the real significance of at least the main groups.

3. The head lengths separate the populations of Prince William Sound from those of the Kodiak-Afognak district and of Kachemak Bay—a distinction of stocks not shown by the vertebral counts.

OTHER CHARACTERS

Besides the structural characters there are other differences between the stocks of herring that while not strictly "racial" differences yet indicate the degree of inde-

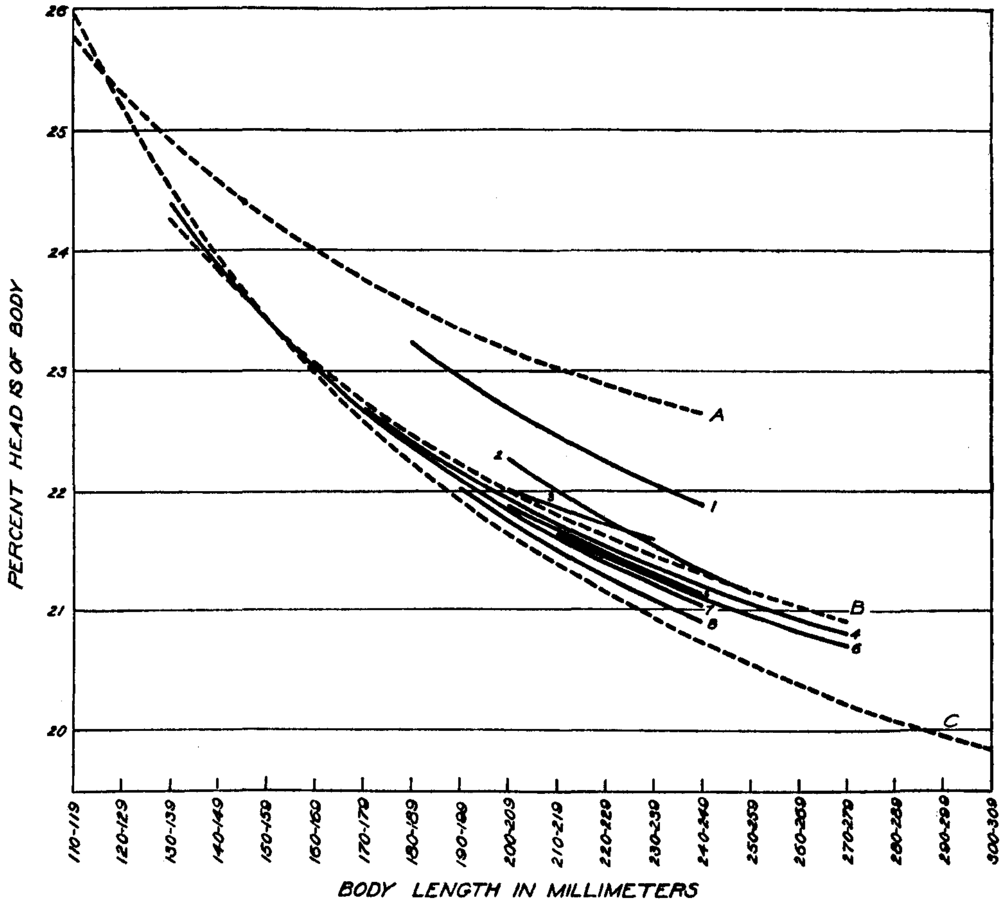

FIGURE 22.—Percentage head length is of body length. Showing: A, Southeastern Alaska; B, Prince William Sound, (1) Naked Island 1927, (2) McClure Bay 1927, (3) Naked Island 1925, (4) Elrington Passage 1925, (5) Macleod Harbor 1927, (6) Eshamy Bay 1926, (7) Elrington Passage 1927, (8) Elrington Passage 1926; and C, Shuyak Strait, lower Kachemak Bay, and Halibut Cove

pendence of the various areas. Since these other "characters," such as growth rate, size and age composition, condition, and spawning season are treated fully in their various sections they will only be alluded to here. The differences in size and age composition (and growth rate) between the herring of Prince William Sound and the other central Alaska localities, for instance, are large enough to indicate the essential independence of Prince William Sound and the areas farther west. And such differences in growth rate as those between Unalaska and central Alaska or Stephens Passage are certainly indicative of the independence of the stocks of herring involved.

CONCLUSIONS

A summary of the conclusions reached by the analysis of each character permits us to say with confidence that the following populations have been demonstrated to be independent: California, southern British Columbia, Craig, Chatham Strait, Stephens Passage, Prince William Sound, Kachemak Bay-Shuyak Strait, Shearwater Bay-Old Harbor, Chignik, Shumagin Islands, Unalaska, and Golovin Bay. Dogfish Bay may also be a distinct stock, but more data is needed to confirm this.

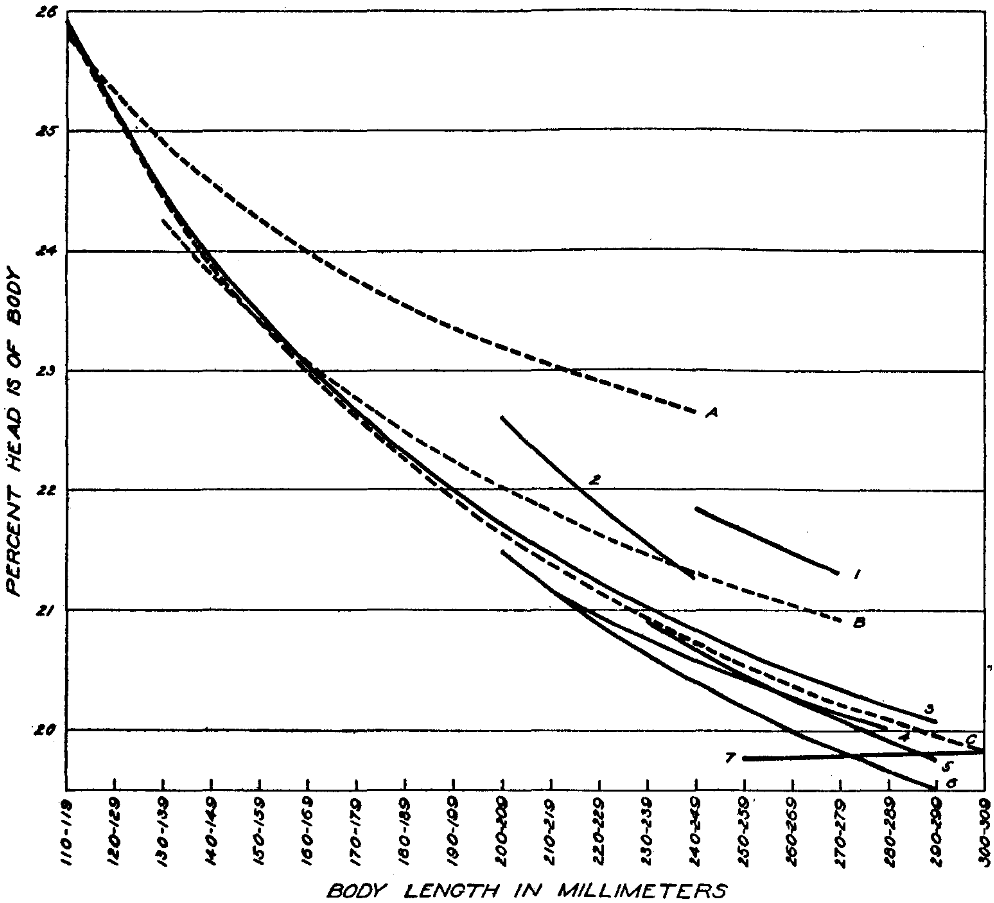

FIGURE 23.—Percentage head length is of body length. Showing: A, southeastern Alaska; B, Prince William Sound; C, Shuyak Strait, lower Kachemak Bay, and Halibut Cove, (1) Dogfish Bay, (2) Halibut Cove 1927, (3) Halibut Cove 1926, (4) Lower Kachemak Bay 1927, (5) Shuyak Strait, (6) Lower Kachemak Bay 1926, and (7) Russian Harbor

SPAWNING

SPAWNING HABITS

The spawning habits of the Pacific and Atlantic herring differ somewhat. The Atlantic herring spawn on the gravelly bottom of the sea, usually in many fathoms of water, and in several cases on banks far from land. The Pacific herring, on the contrary, deposit the adherent spawn thickly on pliable vegetation, such as eel grass and seaweed that grows along the shore. The spawn is all deposited from near the high-tide line to only a few feet below low tide. The Pacific herring has never been known to spawn in deep water. Relative to spawning in shallow water, Fraser says (1922, p. 4):

They come into shallow water at times and feed on the nauplius and cypris larvæ of the barnacles and for days at a time they remain in the barnacle zone. This is most noticeable about spawning time, hence, although it is usually stated that they come into shallow water to spawn, it is possible that the reason of their presence is entirely or largely due to the food supply, the spawning in shallow water being merely incidental.

From San Diego to the Bering Sea the Pacific herring spawn in shallow water, and no evidence has ever been adduced to show that they spawn elsewhere. We do not believe that this is due to the food supply, since examination of the stomachs of herring in Halibut Cove, just previous to and during spawning, showed a complete absence of food, whereas soon after spawning the herring were seen actively feeding.

In the Atlantic there are in many regions two groups or populations of herring known as spring spawners and autumn spawners, according to the season of the year at which they spawn; but in the Pacific, although the time of spawning may vary from December until June according to the locality, there is but one spawning season in each area.

In the Pacific species there seems to be a schooling or migration in the autumn or early winter, at which time the herring come quite near the shore and remain in close proximity to it throughout the winter months until just after spawning. As the herring approach the shore in the fall they often enter small bays and lagoons, many of them with extremely narrow, and often very shallow, entrances. Many of these places are entered annually, and the herring may stay for weeks or months, often not leaving until spawning time. The lagoon at Halibut Cove, described below, is the best example of this, but there are many others. For instance, at Seldovia the herring enter a lagoon, roughly about 500 yards across and about 1 or 2 fathoms in depth. The entrance channel is about a mile long and at low tide runs dry except for a small fresh-water stream that enters the channel about midway of its length. Many years ago this little lagoon was crowded with herring every fall, and a few stragglers still enter it. Other instances can be mentioned, such as the lagoon at the head of Kiavik Bay on Kodiak Island, and the lagoon opposite Russian Harbor on the southwestern tip of Kodiak Island.

The small size of many of the lagoons entered and the numbers of herring that occasionally crowd into these small bays is indicated by the following quotation from Bower and Fassett (1914, p. 127):

Last January at Klawak on the west coast of Prince of Wales Island there occurred an unusually enormous run of herring. So numerous were the fish as they crowded into the bay that hundreds of thousands or even millions were stranded and suffocated. When the tide receded they were left in a solid mass over the beach to a depth in places of several feet.

This habit of entering such small bays and lagoons where they are subject to easy capture may be one factor that causes the herring of Alaska to be readily depleted.

Some rough idea of the relative abundance of herring would well be gained by observing the numbers on the spawning grounds, since at this season all of the mature herring come into shallow water to spawn, where they are easily observed. Only in a few places, such as Fish Egg Island (near Craig) and Sitka Sound in southeastern Alaska, are they known to spawn in any abundance. How, then, as some assert, can one believe that farther offshore there are vast schools of herring yet untouched by the fishery?

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OBSERVATIONS ON SPAWNING IN KACHEMAK BAY IN 1926 AND 1927

In the spring of 1926 observations were made on the spawning in Kachemak Bay. (Fig. 24.) The herring in this bay usually enter the lagoon at Halibut Cove some time between October and January of each year and remain at a depth of several

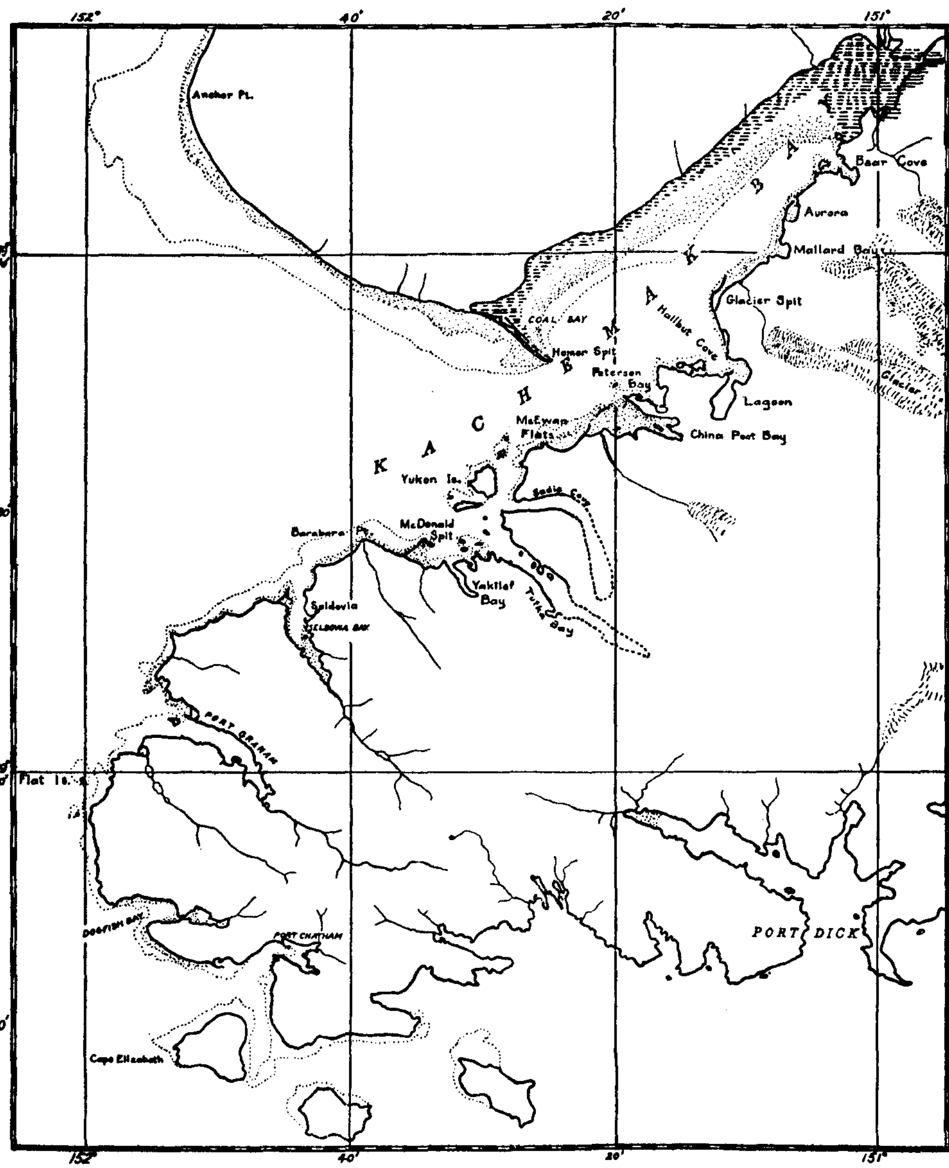

FIGURE 24.—Map of Kachemak Bay

fathoms until nearly time to leave the lagoon to spawn. The lagoon is between 25 and 45 fathoms in depth with steep shores. The entrance channel, which is about a mile long, is very narrow, not over 50 feet wide and 2 or 3 feet deep at low tide. Consequently on big tides the current flows at several miles an hour.

On April 12 a sample of herring, gill netted at a depth of 20 fathoms, was obtained from Halibut Cove lagoon. (Table 26.) All of the herring were mature and most of the roe contained translucent eggs, although there were a few in which the eggs were still opaque and a very few in a transition stage. The eggs in the herring are opaque during most of the year but turn translucent when fully ripe.

TABLE 26.—*Actual and percentage length of herring taken before and during spawning*

Length in millimeters	Halibut Cove, gill netted, Apr. 12, 1926		Halibut Cove lagoon, beach seined, Apr. 22, 1926		Halibut Cove, beach seined, Apr. 27, 1926		McDonald Spit, spawning, May 12, 1926		Homer Spit lagoon, May 15, 1926		Craig, Mar. 25, 26, and 28, 1928		Stephens Passage, Jan. 27, 1928	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
65-69			2	0.9										
70-74			12	5.2										
75-79			8	3.5										
80-84			2	.9										
85-89														
90-94			1	.4										
95-99														
100-104			1	.4										
105-109													1	0.1
110-114			2	.9									1	.1
115-119			8	3.5									4	.4
120-124			12	5.2									9	.9
125-129			6	2.6									12	1.2
130-134			7	3.0									5	.5
135-139			3	1.3									18	1.8
140-144			8	3.5									14	1.4
145-149			6	2.6									7	.7
150-154			11	4.7									11	1.1
155-159			4	1.7									15	1.5
160-164			2	.9							1	0.3	28	2.9
165-169			3	1.3							2	.7	38	3.9
170-174			5	2.1							10	3.4	62	6.4
175-179			1	.4	2	4.2			1	1.0	13	4.4	69	7.1
180-184			3	1.3	2	4.2			10	10.0	22	7.4	90	9.2
185-189			1	.4			2	1.6	11	11.0	38	12.8	117	12.0
190-194			4	1.7	1	2.1	4	3.2	16	16.0	32	10.7	106	10.9
195-199			3	1.3	1	2.0	8	6.4	18	18.0	36	12.1	98	10.0
200-204			10	4.3	3	6.4	16	12.8	17	17.0	33	11.1	72	7.4
205-209			8	3.5	2	4.2	7	5.6	13	13.0	21	7.0	47	4.8
210-214			3	1.3			7	5.6	6	6.0	18	6.0	33	3.4
215-219			1	.4			6	4.8	1	1.0	25	8.4	28	2.9
220-224			6	2.6	5	10.6	11	8.8	4	4.0	20	6.7	32	3.3
225-229			8	3.5	4	8.5	10	8.0	1	1.0	11	3.7	32	3.3
230-234			2	.9	6	12.8	9	7.2	2	2.0	12	4.1	16	1.6
235-239			5	2.1	5	10.6	8	6.4	1	1.0	3	1.0	8	.8
240-244			5	2.1	2	4.2	3	2.4			1	.3	2	.2
245-249	4	4.0	6	2.6	2	4.2	10	8.0						
250-254	11	11.0	8	3.5	3	6.4	2	1.6						
255-259	8	8.0	8	3.5	1	2.1	3	2.4						
260-264	18	18.0	11	4.7	4	8.5	3	2.4						
265-269	20	20.0	9	3.9	1	2.1	7	5.6						
270-274	13	13.0	5	2.1	1	2.1	1	.8						
275-279	14	14.0	11	4.7	1	2.1	4	3.2						
280-284	5	5.0	6	2.6			4	3.2						
285-289	2	2.0	5	2.1										
290-294	2	2.0												
295-299	2	2.0												
300-304	1	1.0			1	2.1								
305-309														
310-314														
315-319														
320-324			1	.4										
Total	100		233		47		125		100		298		975	

On April 21 we entered the lagoon at high tide. Over all the lagoon the herring were commencing to approach the surface in small schools. About 50 belugas (a species of small white Arctic whale) were raising havoc, and thousands of sea gulls were scattered everywhere. Cormorants, murres, surf scoters, and divers were there in tens of thousands, and scores of bald eagles were circling about.

Reentering the lagoon on the morning of the 22d we discovered that the herring had risen to the surface. An attempt was made to obtain a sample with a 30-fathom beach seine, but the sun was too bright to catch them. That night a sample was taken just inside the narrows with the beach seine. This seine had about 1¼-inch mesh, stretched measure, so that all sizes were obtained, from several only 3 inches in length to one great herring of 15 inches—the largest encountered in four seasons of field work.

On examining this sample it was noticed that some of the mature herring had spawn which ran easily—the eggs being clear and translucent with a faint yellowish tinge—while other mature herring had eggs practically as large as the translucent ones, but opaque and white. The opaque eggs were found equally in all sizes of fish, making it appear as though age or size does not influence the exact time of ripening of the eggs, but this point, however, will bear further investigation.

During the next few days we watched for the herring to leave the lagoon as they were expected to spawn outside. On the 26th of April we noticed a small school of herring outside of the lagoon in Halibut Cove in the morning and a large school in the evening, which must have come out on the night tide of the 25th, which we were unable to observe.

In the early afternoon of April 27 we entered the lagoon on the flood tide. Acres of herring were breasting the current on the lagoon side of the narrows. As soon as the tide slackened enough for them to make headway against it they commenced to leave and were carried through the channel on the first of the ebbing tide, passing as a steady stream of herring for over half an hour.

Later we learned that a school of herring spawned on the early morning tide of the same day on Homer Spit, a distance of about 7 miles from the lagoon. A few also spawned on Homer Spit on the 1st and 2d of May. We had occasion to visit Homer Spit on May 10 and discovered that the herring had entered a lagoon that extended lengthwise of the narrow gravel spit for about 3 miles and was from 100 to 200 yards in width and a few feet in depth. This lagoon is entered on the Kachemak Bay side of the spit through an entrance about 25 yards wide, so shallow that only about a 17-foot tide flows through it. There is no vegetation on the muddy bottom of the lagoon, which is in reality an immense tide pool. The herring had entered the lagoon on an 18-foot tide, one of the highest tides of the month, causing the water to overflow the banks of the lagoon and covering to the depth of a foot or more much of the short, sparse, wiry grass that fringed them. Not having any other vegetation available, the herring had spawned in this scanty grass above the reach of ordinary high tides.

When the place was visited over a week later the sea gulls were still gathered in thousands, and for a couple of miles the grass was trampled flat. So thoroughly had the birds done their work that it required careful search to find any of the eggs, and nowhere did we find more than one or two to the square inch. Practically all of the eggs found were shriveled by the sun and wind. That many of them could survive a several days' wait for another tide high enough to immerse them appeared impossible.

From the 27th to the 29th of April several schools of herring were observed in Halibut Cove, and on the 29th a sample was seined in the little harbor behind Ismailof Island. These herring were the ripest so far encountered, as in this sample the eggs and milt flowed freely while brailing them into a skiff with a scoop net, whereas in all previous samples they would flow only under a slight pressure.

On the 30th of April the harbor behind Ismailof Island was again full of large herring swimming close to the surface around the shores, but none spawned.

On the following day all of the large herring had departed. The shores of Ismailof Island and Peterson Bay were searched without success. On May 2 we entered the lagoon, but found little sign of herring; even the gulls and sea birds had left.

For several days the shores of Kachemak Bay, from Bear Cove to Seldovia, were searched without success, but finally on May 12, returning from Homer Spit, a flock of sea gulls was noticed behind McDonald Spit. It was 3 o'clock in the afternoon and high tide when we entered a lagoon behind a sand bar that comprised about a square mile. The water was clear, smooth, and transparent. Schools of herring, showing a marked range in size with the smaller fish in the majority, were swimming about everywhere, exhibiting little fear of our boat. As soon as the tide commenced to fall they approached the shore and rippled the surface as they swam restlessly about. When the tide was about a quarter out they commenced to spawn all around the shores of the lagoon in the eel grass which grew abundantly about a foot in length. Many, left stranded by the falling tide, were being devoured by thousands of sea gulls that had gathered as if by magic.

At first the herring spawned only around the shores, but when the tide had fallen farther, they spawned over the entire floor of the lagoon, which at low tide was covered with about 2 feet of water and carpeted luxuriantly with eel grass. For a while the water was a light brown from the agitated mud, but gradually as the milt became disseminated the water became lighter until finally it was so milky that the eye could penetrate it a bare 6 inches.

In spawning, the female, quivering from head to tail, turns on her side and moves slowly about, often describing a circle, meanwhile extruding the eggs in a thin stream which she rubs against the seaweed and eel grass. The eggs, coated with a gummy secretion, stick instantly to anything with which they come in contact. In like manner the male follows a few inches behind the female covering the attached eggs with a stream of milt.

The herring seemed to be spawning in pairs, but several times we noticed one busily spawning away by itself. The spawning continued throughout the night and they were still spawning the next morning on a rising tide.

On the 15th of May we obtained a sample of herring from Homer Spit that had spawned that morning. It would have been 10 days before the tide would again be high enough to cover their eggs. Many of the short spears of wiry grass not over a millimeter in diameter were covered with eggs until the mass was over a centimeter in diameter. These herring were all small and none were more than 4 years of age and many only 3, so that it was the first spawning for many, if not all, of this school. We were informed that the herring that had spawned at Homer Spit two weeks previously were larger.

For several days the harbor at Halibut Cove had been filled with small herring, so small that on the 17th and again on the 18th of May we could only catch a dozen overnight in a gill net with 3-inch mesh, stretched measure. These few stragglers were extremely ripe. No more herring were obtained in Kachemak Bay until the summer fishing.

In 1926 the herring were not seen leaving the lagoon until the 27th of April, whereas in 1927 when we arrived at Halibut Cove on the 17th of April the herring had already left the lagoon and large numbers had been congregated in the harbor behind Ismailof Island for over a week. The herring did not spawn for another three weeks, and yet, unlike the previous year, they were almost fearless. The harbor must have contained several thousand barrels of herring. They were so crowded and so unafraid that one rubbed the oars against them when rowing.

Figure 33 shows that they were much thinner than in 1926. A great many of them, especially the larger ones, were a little "scabby," having scales missing in spots on their sides and often from the top of the caudal peduncle. To just what extent their apparent fearlessness can be attributed to this emaciated condition can only be surmised. In the three weeks from the 18th of April to the 11th of May the water temperature only increased from 3° C. to 5.5° C., and the herring were not feeding.

On April 21 we entered the lagoon. A small school of belugas and a few sea gulls indicated the presence of a few herring, but it was evident that the main body of herring had left. On the 24th of April we again entered the lagoon. We noticed the sea gulls catching an occasional herring, so we made two hauls with the beach seine without success. The previous year we had caught a few yearling herring between 60 and 80 millimeters in body length mixed among the other herring in the lagoon, but we did not obtain any herring under 2 years of age in many beach seine hauls

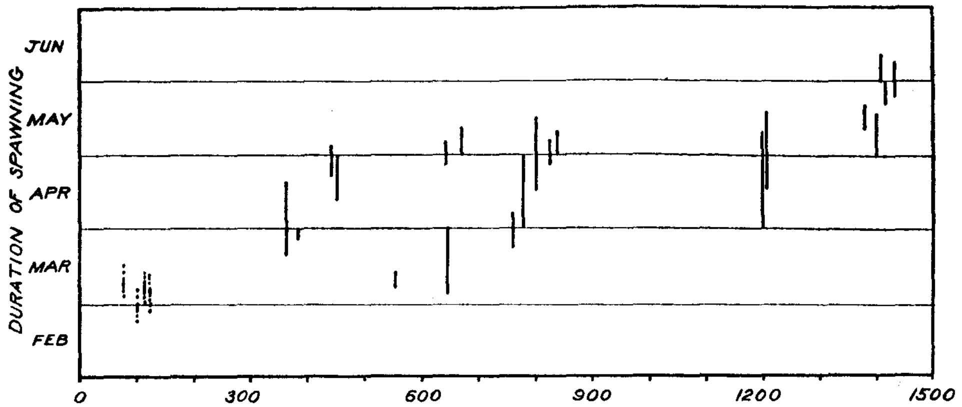

FIGURE 25.—Duration of spawning

made behind Ismailof Island, although not over a mile and one-half from the entrance channel of the lagoon.

The herring remained in the harbor behind Ismailof Island until the 8th of May, when a small school was observed spawning on the western end of the island. On the 9th of May the herring spawned all along the shore from the light on the eastern end of Ismailof Island almost to the entrance to Peterson Bay. This stretch of shore is bold and rocky. The spawn was extruded on the seaweed until in places the shore appeared gray. Immediately after spawning the herring disappeared.

No herring spawned on Homer Spit, but they spawned behind McDonald Spit on the 14th and 15th of May and also about a week previously. A few spawned at Aurora about the 13th of May.

By the 28th of May the eggs were commencing to hatch on Ismailof Island and by June 3 the seaweed was bare of spawn.

TIME AND LOCALITIES FOR SPAWNING

The time of spawning varies considerably between different localities. Figure 25 shows the duration of spawning in some of the places for which we have been given dates that are fairly reliable. This shows a distinct tendency for the herring to spawn later toward the north and west, due possibly to the herring awaiting a favorable water temperature before spawning. There are some few localities, such as

Fish Egg Island near Craig and Sitka Sound, where the herring spawn annually, but most of the evidence shows that the herring do not spawn in exactly the same locality every year. (Fraser, 1916, p. 100.)

The following list of places where herring have been reported to have spawned doubtless contains some inaccuracies both as to time and place, but it is given for what it is worth:

San Diego Bay.—Obtained a sample with ripe spawn on December 13, 1926.

San Francisco Bay.—Carl Hubbs (1925) mentions the breeding season commencing on December 21 and ending on April 17. Scofield (1918) gives January to April.

Scofield (1918) mentions spawning in Tomales Bay from December to March, and also mentions the following places: Morro Bay, Drakes Bay, Bodega Bay, Shelter Cove, and Humboldt Bay.

Captain Freeman informed W. F. Thompson that he had seen herring spawn at the following places in British Columbia: Spider Island, March 20 to April 20; Scudder Point, April 14 to April 30; Burnaby Narrows, April 21 to May 8; Seaforth Channel (south side), last of March; Kitkatla Inlet, about middle of April; Rennell Sound, March 10; Kano Inlet, March 10; Port Neville; White Beach Passage; Quatsino Sound; Nanaimo; Reed Island; Smith's Inlet, Takush; Browning Pass; Shedwell Pass, Bardswell group in narrow channel; Swindle Island; Price Island in narrow channel; Georgetown, between Prince Rupert and Port Simpson; Ikeda Bay (not every year); Jedway (Queen Charlotte Islands); Schooner Point; Cumshewa; Lyle Island in narrows; Skidegate; and Tartoo.

Dr. C. M. Fraser (1916) mentions noting spawning at Nanoose Bay and Departure Bay in 1913. In 1914 he carefully noted the following localities: Yellow Point, February 20; Breakwater Island, February 26; Gabriola Pass, February 26; north shore Pylades Channel, February 26; Pilot Bay to Berry Point on Gabriola Island, March 9 to 11; northeast coast of Gabriola Island from Berry Point to Flat Top Island, March 12 to 13; East side of Gabriola Island, to March 17; Big Qualicum, March 8; entrance Nanoose Bay, March 10; and Ganges Harbor, Saltspring Island March 20.

Edward W. Nelson (1887) describes the spawning in the vicinity of St. Michaels, Alaska, in June.

The writer has had the following list of spawning places reported by various persons:

In southeastern Alaska.—Loring, last of April and first part of May; Port Stewart, last of April and first part of May; Vixen Inlet (Ernest Sound), one week later; Spacious Bay; Morgan's Cove, Trunk Island, Cape Caamano; Union Bay; Meyer's Chuck; Fish Egg Island (Craig), March 27 to April 1 in 1914, March 10 to March 20 in 1915; In Bay on Clam Island, same time; Sugar Point (near Craig), same time; Tonowek Narrows; Big Harbor; Sierra Sound; Rose Inlet; Warmchuck on Heceta Island (occasionally a few); Eleven Mile (near Craig); Tuxekan Pass; Shakan Pass; Hornbrooke Island; Sitka, Silver Bay to Whitestone Narrows, March 20 to April 15; Biorka Island; Killisnoo Lagoon (Angoon), April 1 to end of April; Calico Bay (Kootznahoo Inlet); Hood Bay, May 1 to May 25; Stretchers Cove; Redfish Bay, a little later than Sitka; Port Alexander, May 18; Pybus Bay, May; Seymour Canal at Pleasant Harbor, Mole Harbor and head of the bay, mid April to mid May; Duncan Canal; Port Houghton; Hamilton Bay; Rocky Pass Inlet; Kake; Port Frederick; Idaho Inlet; Mud Bay; Flynn Cove; Tee Harbor, first part of May; Stephens Passage from Point Stephens to about 1½ miles south of Point Lena; Point Louisa; Auke Bay; Coghlan Island; and north end of Douglas Island.

In Prince William Sound.—Ellamar, April; Kniklik, April to middle of May; inside of Fairmont Island, April to middle of May; Knight Island (upper end); Sawmill Bay (few); and both shores of Main Bay between Port Nellie Juan and Crafton Island.

In Cook Inlet.—Port Graham, middle of May; Seldovia Bay; McDonald Spit, first half of May; Tutka Bay, same; Homer Spit, last of April, first of May; Halibut Cove, first of May; Mallard Bay, same; Aurora, same; and Bear Cove, same.

In the Kodiak-Afognak district.—Shangan's Bay, Shuyak Island; Uganik Bay, first part of June; Zachar Bay, June; Shearwater Bay, last of May; and Three Saints' Bay, last of May, first of June.

In the Bering Sea.—Unalaska.

AGE AT MATURITY

The only data obtained that give much indication of the age at maturity in central Alaska were taken from the sample caught with a beach seine in Halibut Cove lagoon. In this sample no 2-year-olds were mature; out of twenty-five 3-year-olds, 13, or 52 per cent, were mature; out of twenty-four 4-year-olds, 20, or 83 per cent, were mature; all of the 5-year-olds were mature.

The sample of mature herring from Homer Spit on May 15 were all 3 and 4 years of age. From the scale readings there were twenty-nine 3-year-olds and sixty-one 4-year-olds, 32 and 68 per cent, respectively. If we take only the mature 3 and 4 year olds from the Halibut Cove lagoon sample we find that 39 per cent of them were 3-year-olds and 61 per cent were 4-year-olds, making the proportions between mature 3-year-olds and mature 4-year-olds in the two samples rather similar.

In Stephens Passage, southeastern Alaska, all 2-year-olds were immature; out of twenty-two 3-year-olds, 19, or 84 per cent, were mature; all of the 4 and 5 year olds were mature.

Comparing Stephens Passage with Halibut Cove, in Stephens Passage 62 per cent more spawned at 3 years and 20 per cent more spawned at 4 years than at

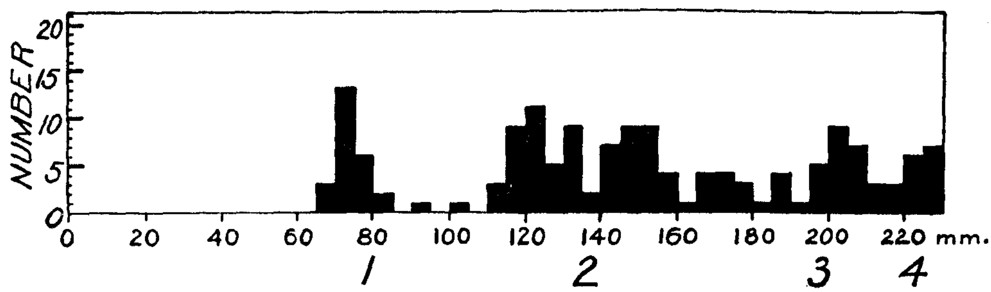

FIGURE 27.—Length frequency of herring under 230 millimeters in length taken in the lagoon at Halibut Cove with a beach seine, April 22, 1926. The large figures show the position of the age groups as determined from scale readings of Halibut Cove samples

Halibut Cove. This is even more remarkable considering the much faster growth rate at Halibut Cove.

AGE AND GROWTH

DETERMINATION OF AGE

A knowledge of the proportions of fish of various sizes in the commercial catch is necessary in determining the causes and extent of the fluctuations in abundance. But information as to the sizes present is chiefly of value in the light of knowledge as to the ages and rates of growth.

We have determined the age of the Pacific herring by the well-known method of making a microscopic examination of the scales and counting the number of annual rings (Fig. 26). Our age determinations among the younger age groups are partially confirmed by size frequencies. Figure 27 shows the length frequencies of herring under 230 millimeters in length, taken in Halibut Cove lagoon, April 22, 1926. The large figures are placed at the mean lengths of the younger age groups as taken from the curve in Figure 29. Figure 27 shows the 1-year group (in this case almost exactly 1 year old) quite distinctly, but the other year groups are not very clearly shown, as the number of specimens is too small. Figure 28 shows the length frequency of 463 Cape Elrington herring taken on August 25, 1925. This curve shows well the 2-year group (in the second summer) between 130 and 160 millimeters. The 2 and 3

FIGURE 26.—Scale of a male, 286 millimeters in body length, taken at McDonald Spit, Kachemak Bay, in August, 1926. The scale shows about 16 annual rings, illustrating the difficulty of age determination in the older fish

year groups do not enter the commercial catch in any numbers, while the 4-year group is well represented. Because of this fact, the 3-year group, being close to the 4-year group and overlapped by it, does not show clearly in the length-frequency curves.

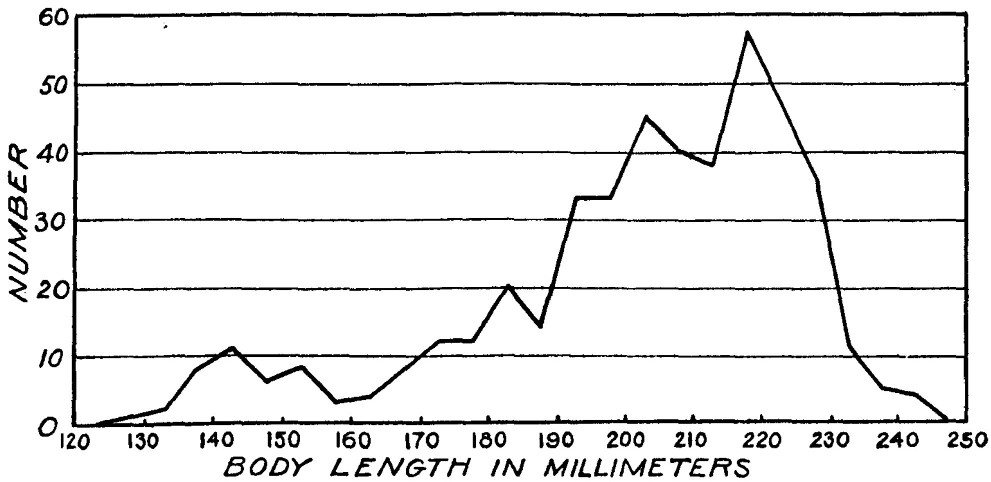

FIGURE 28.—Length frequency of 463 young herring from Cape Elrington, Prince William Sound, August 28, 1925

Otoliths and scales were collected from 50 herring from Elrington Passage, Prince William Sound, on July 6, 1927. Both the scales and the otoliths were legible for 45 of these 50 fish. The results of the readings are tabulated in Table 27.

TABLE 27.—*Relationship of age readings by means of scales and otoliths*

Age as shown by otoliths	Age as shown by scales				
	3	4	5	6	7
	Number	*Number*	*Number*	*Number*	*Number*
3	1				
4		23			
5			6	2	
6				4	3
7					6

The two readings agree except in five cases. In two cases the scale readings showed the fish to be in the sixth year, whereas the otolith readings showed the fish in the fifth year. In three cases fish seven years by the scales were six years by the otoliths. There was no disagreement among the younger age groups. In each case of disagreement it was due to the otolith lacking one year. The otoliths are very small, and the outer rings are so close together in the older fish as to make it difficult to distinguish them by either reflected or transmitted light.

The positive correlation between the readings of the scales and of the otoliths helps in confirming the results of our scale readings and shows that the annual rings on the scales are due to some general physiological change, probably associated with growth or spawning, that affects other hard parts as well as the scales.

During the middle of April, at Halibut Cove, the last ring had not yet formed on many of the scales but was barely discernible on the majority. This is in accordance with Lea's results with the spring spawning herring of Norway (1911). On following the growth of the herring in one locality throughout the year he found that during April the percentage of fish showing a ring near the very edge of the scale increased steadily until all had it. At Halibut Cove the herring spawn during the last part of April and May. In a sample of spawning herring from San Diego Bay in December, the ring could barely be discerned on a small percentage of the fish.

The scale reading presents some difficulties. As just stated, the ring seems to form about the time of spawning, which would indicate that it is due to the growth of the herring being almost or completely at a standstill at that time. The clearness of the ring would thus depend a great deal on how completely and for how long a time the growth was retarded.

Thompson (1917) describes in some detail the difficulties that he encountered in attempting to read the scales of the herring in British Columbia. He mentions finding a winter zone in which the circuli seem to differ from the remainder. The inner margin of this zone tends to be marked by a "check" of some distinctness, but the winter mark is formed at the outer margin of this zone. He says that this is so often met with that it can not be regarded as otherwise than a normal phenomenon. Other difficulties were exceedingly wide summer zones, numerous more or less distinct "checks," and the uncertainty of distinguishing the winter rings near the margin of scales of older fish.

We have met with similar difficulties, but judging from Thompson's text and plates the scales of Alaska herring are very much clearer than those of British Columbia. The scales of the San Diego Bay herring are slightly less clear than those of Alaska.

One difficulty met with in the very old fish, besides the difficulty of distinguishing between the marginal rings, is that of distinguishing the first and often the second annual ring of the scale. Whether this is due to the more numerous layers of scale substance in the older fish changing the refraction of light is uncertain.

All of the samples contained fish with well-defined rings on their scales, likewise all of the samples showed fish with regenerated scales, which are worthless for age determinations. The proportion of regenerated scales on the individual fish varied greatly, so that in reading the age of an individual from two to a dozen scales were usually examined, this often being necessary in order to obtain ones that were fully legible. For this preliminary report we have read chiefly scales from central Alaska. (Table 33.)

GROWTH RATE

A knowledge of the rates of growth in the various localities is desirable because of its many applications. Whether the difference in average size between any two localities is due to a difference in rate of growth or to a difference in the age composition (possibly due to a reduction of the numbers of older fish in one of the localities) is important in studying depletion. The differences in growth rate are also a valuable aid in studying the independence of areas, as, where the differences are great, it shows a lack of migration. For instance, the differences in growth rate between Unalaska and Stephens Passage herring are enormous, those at Unalaska (Dutch Harbor) at 6 years of age being 6½ centimeters greater in body length than those of Stephens Passage.

To grasp the real significance of these differences in growth rate the comparisons should be made on the basis of weight, as any given increase in length represents a far greater amount of growth in a larger fish than in a smaller fish. The weight varies a great deal within the same locality at different seasons but only slightly between different localities at comparable seasons of the year. Therefore, not having weight-length curves at comparable seasons for all of these localities, we shall use the weight-length curve for Halibut Cove (fig. 33) in making comparisons between the weight for any given age in different localities shown in Figure 29.

Using these weights, at 6 years of age the Stephens Passage herring would weigh 91 grams, the Dutch Harbor herring 253 grams, or 2.8 times as much. Since the smallest-sized herring packed as a "medium" is over 10½ inches in total length, or about 225 millimeters in body length, and 170 grams in weight, the Stephens Passage herring do not attain a size suitable for packing as "mediums" until about 9 or 10 years of age. On the other hand, the Dutch Harbor herring at only 6 years of age are being packed chiefly as "large" (11½ to 12½ inches). The differences between

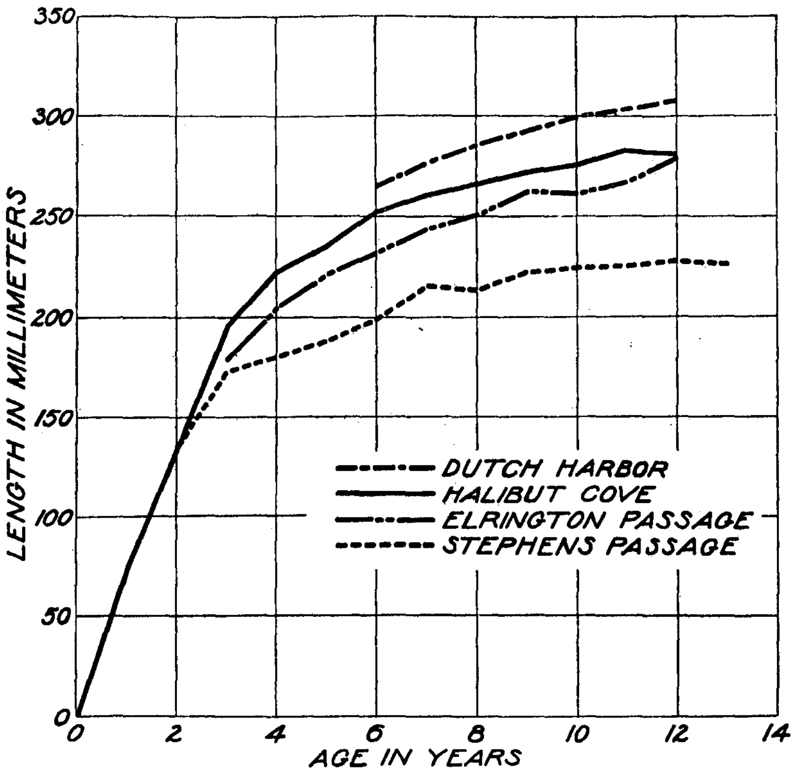

FIGURE 29.—Growth curves showing the age-length relationship

the other localities are not so great, 6-year-old Dutch Harbor herring being only about 19 per cent heavier than those of Halibut Cove and 62 per cent heavier than those of Elrington Passage.

The evidence shows that the growth curve for Stephens Passage is not representative of southeastern Alaska as a whole. If the data for Larch Bay were plotted (Table 28), the curve would come very slightly below that of Elrington Passage. Since the Larch Bay sample was preserved in formalin the curve would probably be very close to that of Elrington Passage, if one allows a trifle for shrinking of the length.

Farther south in British Columbia, Thompson (1917, p. S64) obtained data at Nanaimo and Point Grey in the Strait of Georgia, and at Kildonan on the west coast of Vancouver Island, that show them to have a rate of growth comparable to that of Stephens Passage. A very few age readings from San Diego Bay indicate a rate of growth but slightly higher than that of Stephens Passage.

It may be pointed out that although there seems to be a tendency for slower growth to the southern and eastern portion of the range, it also seems that the growth rate is in each general area slower in inclosed waters. To illustrate, the Prince William Sound growth rate is slower than that of Shuyak Strait, and the Stephens Passage rate of growth slower than that of Larch Bay.

Similar results have been obtained in the study of the European herring, those from the White Sea, the Lysefjorden (West Norway), the Zuider Zee, and the east coast of Sweden being slow growing, while those from the western North Sea, the Atlantic Ocean, around Iceland, and the outside waters of western Norway are all fast growing. (Hjort, 1914.) The herring in some of the fjords on the Baltic coast of Sweden were found by Hessle (1925) to be slower in growth than those of the main Baltic.

The growth-rate curves shown in Figure 29 are not constructed from calculated growths, but each point in the curve is the average length of the fish actually taken at that age. Growth curves based on scale measurements will be presented in a later report.

TABLE 28.—*Observed lengths at each age in millimeters*

Age (years)	San Diego Bay,[1] December, 1926	Stephens Passage	Larch Bay,[1] August, 1927	Halibut Cove, April 1926	McDonald Spit, May, 1926	Homer Spit, May, 1926	Kachemak Bay, August, 1926	Shuyak Strait, July, 1925 and 1926	Dogfish Bay, August, 1925	Naked Island, August, 1925	Elrington Passage, June–August, 1925 and 1926	Dutch Harbor, August, 1928
1				74.1								
2		134.9		134.0			131.0					
3		170.3		195.7	199.1	195.9	[2] 188.7			[2] 192.5	179.2	[2] 190.0
4	[2] 200.0	180.0	203.3	221.5	222.7	201.1	220.2	[2] 220.0		205.4	205.0	
5		187.7	218.2	234.7	235.7		224.9	241.0	[2] 220.0	222.9	220.8	
6	[2] 213.7	[2] 198.7	223.0	252.1	[2] 260.0		252.5	252.2	[2] 235.2	[2] 229.0	231.4	265.2
7	217.0	[2] 215.3	235.8	260.2	252.7		263.0	252.0	[2] 241.0	[2] 240.5	243.0	276.1
8		213.2	234.8	265.9	[2] 265.5		268.1	264.5	[2] 255.0		250.0	[2] 284.8
9	226.8	221.8	[2] 232.0	271.8			272.6	271.2	261.4	[2] 268.0	261.6	
10		[2] 224.2		275.2	276.8		273.7	272.7	263.3	[2] 260.0	261.0	[2] 299.3
11		[2] 225.0		282.8	269.8		279.4	275.2	262.6	[2] 267.0	266.9	
12		[2] 227.5	[2] 243.0	[2] 281.7	[2] 282.0		284.1	287.5	266.8		[2] 279.0	[2] 307.5
13		[2] 226.0					285.4	[2] 277.5				
14								[2] 282.7				
15							[2] 290.0					
16												
17							[2] 286.0					
18												
19				[2] 320.0								

[1] Preserved in formalin. [2] Average contains a frequency of less than 5.

CONDITION

CONDITION FACTOR

It is desirable to know the condition or "fatness" of the herring at different seasons and in different localities since the value of the raw herring depends to a very large extent on the condition. It is a great economic waste to catch herring for oil and fish meal when the oil content is low, or to catch herring for pickling and discard large fish that are too thin. If the changes in the condition of the herring are known, regulations for opening and closing the fishing season may be so framed as to reduce this waste to a minimum thus aiding in the conservation of the supply. For these reasons the investigation of the condition is of great importance so that accurate information may be available.

Weights have been taken to enable us to follow the changes in the condition of the fish during the seasons of 1926 and 1927. Owing to the erratic appearance of herring in central Alaska, we have been unable to obtain a complete series of weights over the entire season in any one locality for use as a basis of comparison to discount seasonal and size changes.

We have data for both years for Halibut Cove, lower Kachemak Bay, and Elrington Passage and vicinity in Prince William Sound. We also have weights for Shuyak Strait and Eshamy Bay in 1926, and from McClure Bay, Naked Island, and Macleod Harbor in 1927.

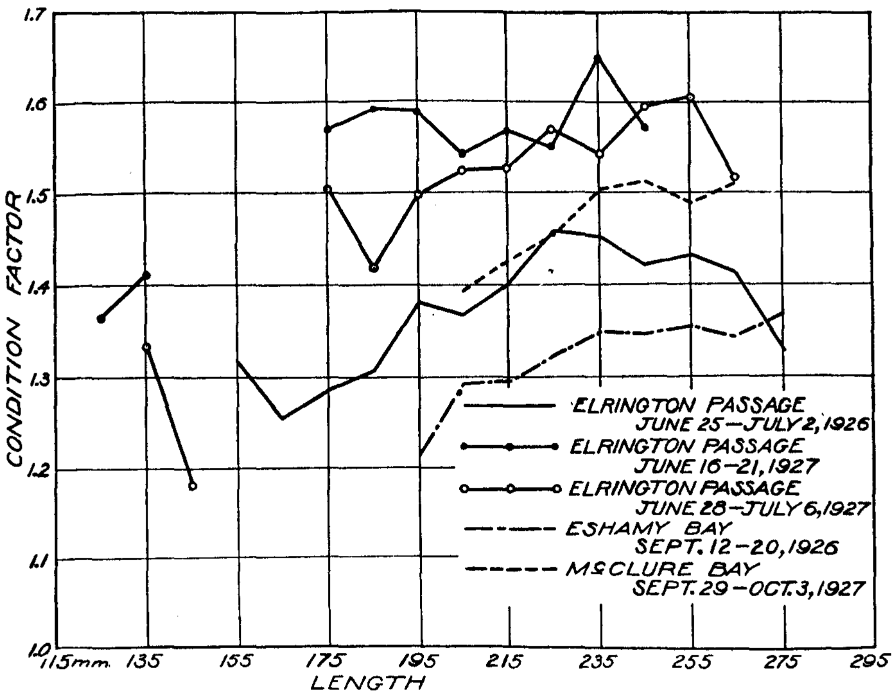

FIGURE 30.—Condition factor for herring in Prince William Sound

As a standard of comparison we have shown the relation of the weight to the length by using a condition factor obtained by the formula:

$$K=\frac{100W}{L^3}$$

in which K is the condition factor, W the weight, and L the length. The weight does not increase exactly as the cube of the length, but this factor is valid for comparing fish of the same length. (Clark, 1928.) Besides a difference throughout the season and in different localities, there is also an annual variation, not only in the time when a certain condition is reached in each individual but also in the maximum condition obtained. The condition factor naturally changes with the size of the fish represented in the catches.

In Prince William Sound the fish were in better condition in 1927 than in 1926, as shown in Figure 30. During the period from the 25th of June to the 2d of July, 1926, in Elrington Passage and vicinity in Prince William Sound, the herring up to 225 millimeters in body length were in fair condition and contained an abundance of "belly fat" or ister (fat stored in the body cavity among the entrails), but the herring above 225 millimeters in body length in the same samples contained very little fat and were rather thin. In the female gonads from one to half a dozen ripe eggs were often found, and the male gonads had blood clots. Both the female and the male gonads were flabby. All of these facts tend to show that it was probably not long since they had spawned.

The data for Elrington Passage for 1927 are shown as two separate curves. The first of these curves, from June 16 to 21, 1927, was taken on the average about 10 days

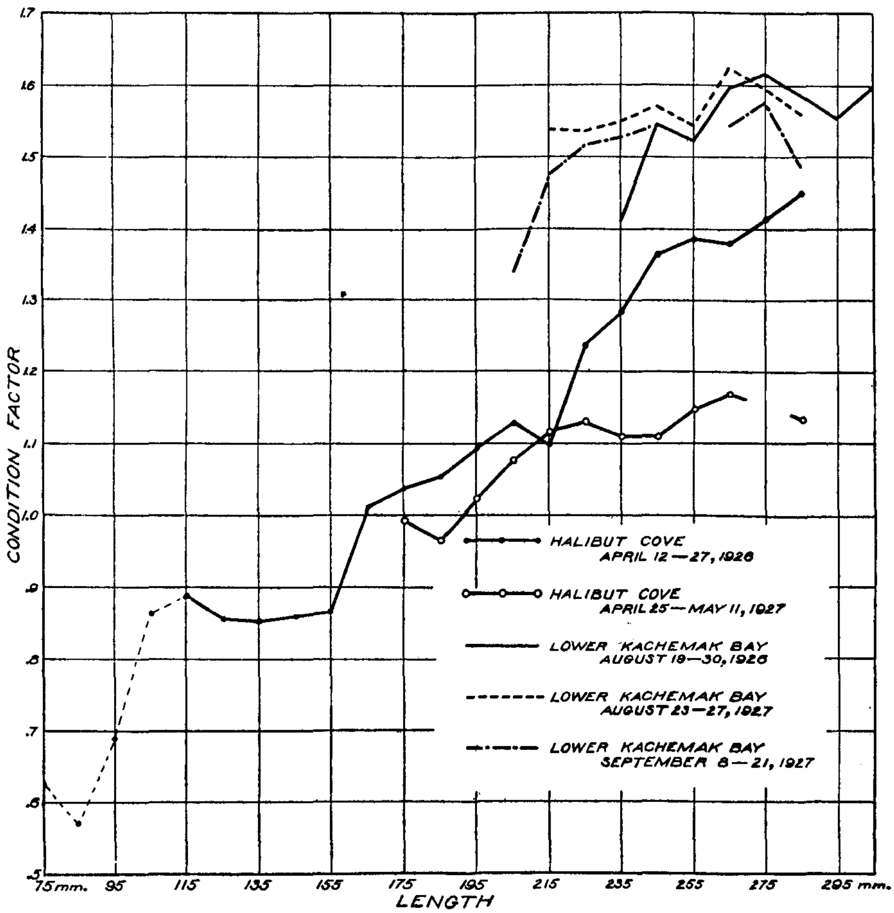

FIGURE 31.—Condition factor for herring in Kachemak Bay

earlier than the 1926 curve; while the second curve, from June 28 to July 6, 1927, was taken about 3 days later than the 1926 curve. Both of the 1927 curves are considerably above the 1926 curve.

The same superior condition of the 1927 samples is shown elsewhere in Prince William Sound. In Eshamy Bay, from September 12 to 20, 1926, the herring were all rather thin with only a trace of ister; a few, especially the larger ones, were too thin to salt. No herring were caught in Eshamy Bay in 1927, but we have samples from McClure Bay. The two localities are only 12 miles apart, so they can be compared for the two years. The McClure Bay samples were taken from September 29 to October 3, 1927, an average of two weeks later than the Eshamy Bay samples of 1926, but the Eshamy Bay fish were rather thin while the McClure Bay fish contained an abundance of ister and were in excellent condition.

In 1927 the herring in Elrington Passage in June and the first part of July attained a fair condition earlier than in 1926, and in McClure Bay they were in excellent condition at the 1st of October in 1927, while in Eshamy Bay they were thin in the middle of September in 1926. Thus it appears that in Prince William Sound in 1927 the herring were in good condition for a much longer time than in 1926 and probably also attained a much higher maximum condition. Only study for several years can tell which year comes closer to being normal.

Similar comparisons for Kachemak Bay are given in Figure 31. Halibut Cove herring were in better condition just before spawning the last part of April, 1926, than the last part of April and first part of May, 1927, just the reverse of conditions in Elrington Passage. Herring from lower Kachemak Bay for the last part of August were quite similar in condition in 1926 and 1927. In September, 1927, the condition, while still excellent, had commenced to fall slightly.

Samples were taken at Shuyak Strait on July 15 and August 5, 1926. The herring were in excellent condition and their condition-factor curve is very nearly the same as that for lower Kachemak Bay from August 19 to 30, 1926.

Besides a difference in condition in different years and at different times, there is also a difference between localities. Samples were obtained from Naked Island and from Macleod Harbor in Prince William Sound on the 12th and 13th of June, respectively. (Table 29.) The sample from Macleod Harbor was but little below the samples from Elrington Passage taken a few days later, whereas the herring from Naked Island were much lower. The latter herring were quite thin, containing no ister, and had spawned on the webbing of the pounds in which they were confined.

TABLE 29.—*Condition factor and weight at different lengths in 1926 and 1927*

[Points marked with an asterisk have a frequency of less than five]

(A) CONDITION FACTOR

Length in millimeters	Halibut Cove, Apr. 12–27, 1926	Halibut Cove, Apr. 25, May 4 and 11, 1927	Shuyak Strait, July 15–Aug. 5, 1926	McDonald Spit, Kachemak Bay, Aug. 19–30, 1926	McDonald Spit, Kachemak Bay, Aug. 10, 1927	McDonald Spit, Kachemak Bay, Aug. 23, 24, 25, and 27, 1927	McDonald Spit, Kachemak Bay, Sept. 8–21, 1927	Naked Island, June 12, 1927	Macleod Harbor, June 13, 1927	Elrington Passage, June 25–July 2, 1926	Elrington Passage, June 16, 17, and 21, 1927	Elrington Passage, June 28–July 5 and 6, 1927	Macleod Harbor, July 1–9, 1927	Eshamy Bay, Sept. 12–20, 1926	McClure Bay, Sept. 29, 30, Oct. 2 and 3, 1927
60–69	*0.728														
70–79	*.626														
80–89	*.570														
90–99	*.688														
100–109	*.864														
110–119	.888										*1.390				
120–129	.855			*1.152				0.884	*1.389		1.366				
130–139	.853	*0.956		*1.016					*1.502		1.411	1.334			
140–149	.859	*1.075		*1.050						1.410		1.181			
150–159	.867								*1.126	1.319		*1.244			
160–169	1.011	*1.074		*1.291				*1.074	*1.440	1.256	*1.526	*1.538	*1.563	*1.202	
170–179	1.037	.993						*1.343	1.356	1.286	1.569	1.504	1.500	*1.101	
180–189	1.053	.965		*1.327				1.250	1.456	1.308	1.593	1.420	1.463	*1.263	*1.303
190–199	1.094	1.021				*1.575	*1.604	1.260	1.471	1.381	1.591	1.499	1.516	1.212	*1.312
200–209	1.128	1.076		*1.364	1.650	*1.438	1.338	1.183	1.464	1.367	1.543	1.523	1.450	1.291	1.393
210–219	1.097	1.118		*1.363	1.581	1.537	1.474	1.291	*1.550	1.400	1.569	1.526	1.435	1.295	1.425
220–229	1.237	1.129		*1.446	1.482	1.533	1.513	1.347	*1.568	1.459	1.551	1.569	1.657	1.322	1.453
230–239	1.282	1.110	1.433	1.412	1.554	1.547	1.525	1.312	*1.553	1.450	1.650	1.542	*1.529	1.349	1.502
240–249	1.362	1.110	1.564	1.543	*1.606	1.569	1.542	1.345	*1.418	1.421	1.571	1.597	*1.490	1.346	1.511
250–259	1.386	1.146	1.532	1.520	1.603	1.543	*1.496	*1.346		1.433	*1.446	1.607	*1.552	1.355	1.489
260–269	1.380	1.169	1.618	1.596	1.501	1.624	1.541	*1.255		1.412	*1.481	1.517		1.343	1.509
270–279	1.413	*1.231	1.625	1.615	*1.697	1.594	1.575	*1.174		1.328	*1.463			1.369	*1.306
280–289	1.448	1.132	1.547	1.585	1.627	1.559	1.485								*1.563
290–299		*1.152	1.554	1.553	*1.577	*1.460									
300–309				1.597		1.522	*1.556								
310–319				*1.269											

(B) WEIGHT

60-69	2.0														
70-79	2.7														
80-89	*3.5														
90-99	*6.0														
100-109	*10.0														
110-119	13.5										*18.5				
120-129	16.7			*22.5				*17.0	*24.0		23.6				
130-139	21.0	*21.0		*25.0					*33.0		31.0	29.3			
140-149	26.2	*29.5		*32.0						*43.0		32.4			
150-159	32.3								*38.0	49.1		*42.0			
160-169	45.4	*44.0		*58.0				*44.0	*59.0	56.4	*62.5	*63.0	*64.0	*54.0	
170-179	55.6	48.8						*66.0	66.6	68.9	77.1	73.9	73.7	*59.0	
180-189	66.7	56.3		*84.0				70.0	84.9	82.8	92.9	82.7	85.3	*80.0	*76.0
190-199	81.1	70.0				*108.0	*110.0	86.4	100.9	102.4	109.1	102.8	104.0	89.9	*90.0
200-209	97.2	86.1		*117.5	*132.0	*115.0	107.0	94.6	117.1	117.8	123.4	121.8	116.0	111.2	111.4
210-219	*109.0	103.5		135.5	146.4	142.3	136.5	119.6	*143.5	139.1	145.3	141.3	132.9	128.7	132.0
220-229	140.9	120.2	*144.0	*164.7	157.8	163.2	161.1	143.4	*167.0	166.2	165.1	167.1	176.4	150.6	154.7
230-239	166.4	135.1	*186.0	183.3	189.1	188.2	185.6	159.6	*189.0	188.2	200.8	187.6	*186.0	175.1	182.8
240-249	200.3	153.5	230.0	221.2	*222.0	216.9	213.2	185.9	*196.0	209.0	217.2	220.8	*206.0	197.9	208.9
250-259	229.8	179.0	254.0	252.0	250.4	241.1	*233.8	*210.3		237.6	*226.0	251.1	242.5	224.6	232.6
260-269	256.8	205.5	301.0	297.0	263.8	285.5	270.8	*220.5		262.8	*260.3	266.6		250.0	265.3
270-279	293.8	*242.3	338.0	335.8	*334.0	313.8	310.0	*231.0		276.1	*288.0			284.7	*257.0
280-289	335.2	248.6	358.0	366.9	357.2	342.2	326.4								*343.0
290-299	*333.0	*281.0	399.0	398.8	*384.7	*356.0									
300-309	*372.0		*434.0	453.1		*411.0	*420.0			*315.0					
310-319				*435.5											
320-329	*462.0														

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LENGTH WEIGHT RELATIONS

Figures 32 and 33 show the length weight curves for some of the localities smoothed by the method of least squares, using the equation $W = KL^x$, where W = weight, L = length, and K and x = constants.

The equations for all of the curves are:

Halibut Cove:	
Apr. 12–27, 1926	$W = .0584\ L^{3.63}$
Apr. 25–May 11, 1927	$W = .0371\ L^{3.43}$
Lower Kachemak Bay:	
Aug. 19–30, 1926	$W = .0272\ L^{3.43}$
Aug. 10, 1927	$W = .0125\ L^{3.19}$
Aug. 23–27, 1927	$W = .0126\ L^{3.19}$
Sept. 8–21, 1927	$W = .0210\ L^{3.34}$
Red Fox Bay, Shuyak Strait: July 15–Aug. 5, 1926	$W = .0651\ L^{3.01}$
Elrington Passage and vicinity:	
June 25–July 2, 1926	$W = .0123\ L^{3.18}$
June 16–21, 1927	$W = .0177\ L^{3.31}$
June 28–July 6, 1927	$W = .0262\ L^{3.42}$
Eshamy Bay: Sept. 12–20, 1926	$W = .0185\ L^{3.28}$
McClure Bay: Sept. 29–Oct. 3, 1927	$W = .0240\ L^{3.38}$
Naked Island: June 12, 1927	$W = .0382\ L^{3.49}$
Macleod Harbor:	
June 13, 1927	$W = .0369\ L^{3.54}$
July 1–9, 1927	$W = .0169\ L^{3.29}$

Neither the condition factor nor these values of K and x can be used for racial studies until a far more thorough study of them is made for each race. A constant difference between the fish of two localities may be due to environmental conditions only, but this difference may be of value in the study of migration.

CLEANED WEIGHT

In comparing the weights of fish of any given length by Figures 32 and 33, it must be borne in mind that a considerable difference in weight is caused by either gonads or ister. Figure 34 shows the total weight, cleaned weight, and gonad weight for 1927 for Halibut Cove, April 25–May 11, and for lower Kachemak Bay, August 23–27. Note that the actual difference in weight resulting from cleaning for each of the two localities is very similar, despite the fact that the Halibut Cove material was taken just before spawning. In the Halibut Cove data most of the difference between the cleaned weight and the total weight is in the weight of the gonads. In the lower Kachemak Bay data the gonads are but slightly developed, and the difference between the cleaned weight and the total weight is caused chiefly by a large amount of ister in the body cavity.

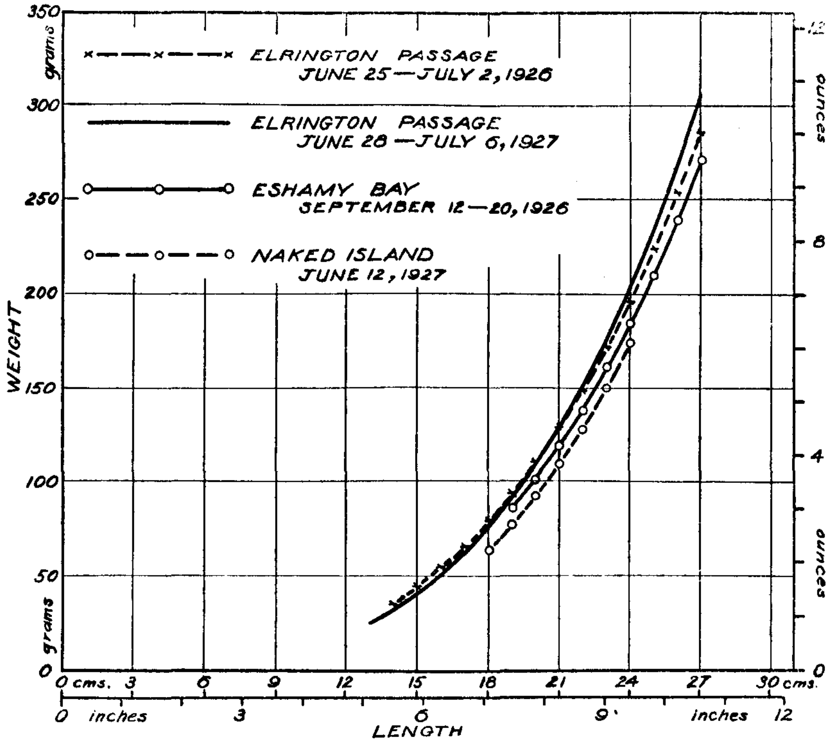

FIGURE 32.—Length-weight curves for herring in Prince William Sound

TABLE 30.—*Cleaned weight at different lengths*

Length in millimeters	Halibut Cove, May 4 and 11, 1927	Lower Kachemak Bay, Aug. 10, 1927	Lower Kachemak Bay, Aug. 23, 24, 25, 27, 1927	Lower Kachemak Bay, Sept. 8 and 21, 1927	South Bay, Naked Island, June 12, 1927	Macleod Harbor, June 13, 1927	Prince of Wales Passage, June 21, 1927	Procession Rocks, June 28, 1927	Procession Rocks, July 5–6, 1927	Macleod Harbor, July 9, 1927	McClure Bay, Sept. 29–30, Oct. 2-3, 1927
120–129	----	----	----	----	[1] 16.0	[1] 21.5	----	----	----	----	----
130–139	----	----	----	----	----	[1] 28.0	----	24.8	----	----	----
140–149	----	----	----	----	----	----	----	[1] 30.0	----	----	----
150–159	----	----	----	----	----	[1] 34.0	----	[1] 35.0	----	----	----
160–169	----	----	----	----	[1] 38.0	[1] 50.5	----	----	----	----	----
170–179	[1] 45.3	----	----	----	----	58.7	[1] 63.8	[1] 65.0	65.0	[1] 65.3	----
180–189	[1] 47.7	----	----	----	[1] 66.7	74.6	78.9	75.5	72.4	74.9	[1] 68.0
190–199	[1] 64.0	----	[1] 95.0	[1] 94.0	76.2	87.2	91.9	89.3	88.9	91.7	[1] 79.3
200–209	70.6	[1] 111.0	[1] 99.5	94.7	83.9	100.3	107.0	105.7	104.3	99.9	98.1
210–219	88.4	129.0	125.2	121.0	[1] 103.7	[1] 128.5	[1] 124.0	[1] 136.0	118.3	107.8	117.3
220–229	95.1	136.1	141.8	139.8	128.6	143.0	[1] 139.0	144.6	141.5	[1] 165.0	135.0
230–239	107.9	162.6	163.2	162.1	140.3	[1] 145.0	[1] 171.5	[1] 120.0	162.2	----	159.4
240–249	123.3	[1] 189.7	187.9	183.9	170.7	[1] 169.0	[1] 151.0	[1] 180.0	180.7	[1] 156.0	179.0
250–259	[1] 137.3	213.0	209.5	[1] 200.0	[1] 183.0	----	[1] 181.0	----	[1] 211.0	----	203.3
260–269	[1] 167.8	226.0	246.8	236.0	[1] 195.0	----	----	----	[1] 226.7	----	227.2
270–279	[1] 194.3	[1] 289.0	272.7	252.9	[1] 207.0	----	----	----	----	----	[1] 243.7
280–289	[1] 185.0	306.5	298.8	284.4	----	----	----	----	----	----	[1] 343.0
290–299	[1] 236.0	[1] 327.3	[1] 312.8	----	----	----	----	----	----	----	----
300–309	----	----	[1] 367.0	[1] 370.0	----	----	----	----	----	----	----

[1] Averages contain a frequency of less than 5.

CONCLUSIONS

1. In Prince William Sound the date at which the herring reach a condition suitable for packing or commence to be rather thin for packing in any certain locality will vary at least two weeks in different years.

2. There may be a considerable difference in the condition attained in different localities in Prince William Sound by the same date.

3. The maximum condition attained will probably vary considerably from year to year.

CONDITION OF THE FISHERY

It is our purpose to discover how the species is faring under the changed conditions of survival incident to an intensive fishery. In determining this condition we must first discover what changes in abundance have occurred. Our only measure of the abundance is obtained from the catch of the commercial fishermen which is influenced by various economic factors and by changes in the amount and kind of

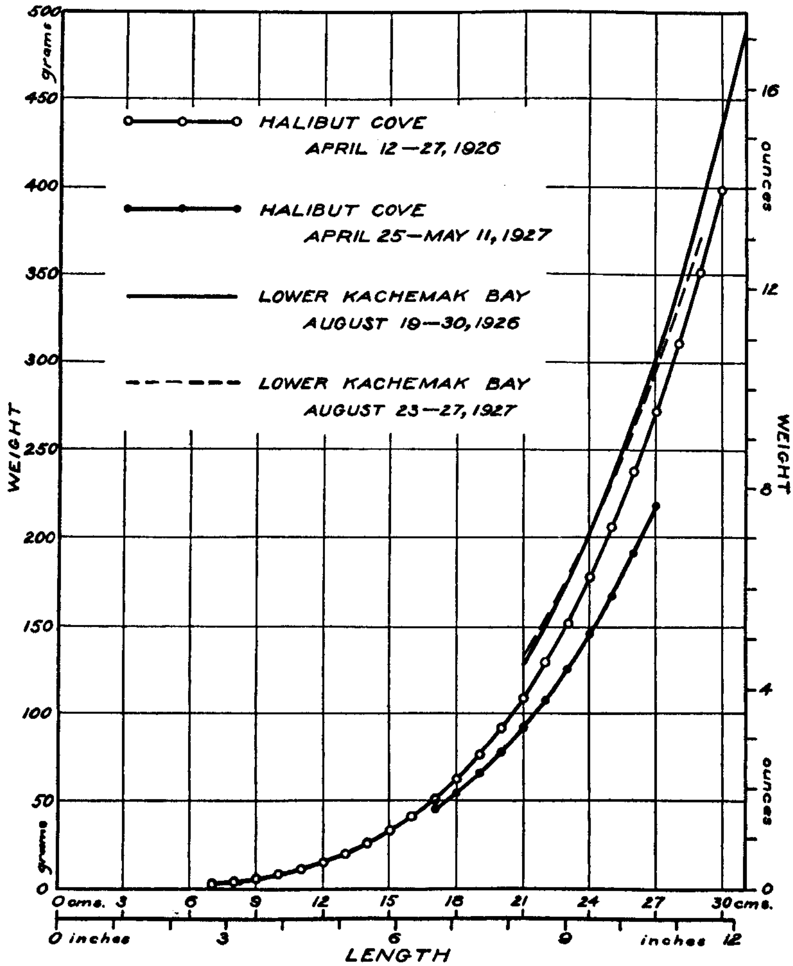

FIGURE 33.—Length-weight curves for herring in Kachemak Bay

gear used. Hence, in determining the actual abundance, as shown by these records, one can not use the total catch, but must employ some other measure of abundance, such as the catch per unit of fishing effort. Furthermore, the catch of each area must be segregated and analyzed separately, for the study of the independence of areas (see p. 246) has shown that, in the Pacific herring, the population of each region is independent of those of neighboring regions.

In determining the causes of these changes in abundance within each area a knowledge of the size and age composition of the catch is fundamental. In many species of fishes, due to variations in hydrographic or other conditions, the amount of success attending spawning varies greatly from year to year, it being quite usual to have periods of years when but few young survive, and occasional years in which exceptionally large numbers of young survive. These unusually abundant year classes, termed "dominant" year classes, have been found in the cod, the plaice, the mackerel, and in the very close relations of the Pacific herring—the California sardine (Higgins, 1926; Scofield, 1926) and the Atlantic herring (Hjort, 1914; Lea, 1919, 1924)—and the presence of these dominant year classes causes natural fluctuations in abundance. A temporary decline in abundance, due to the passing out of the catch of a dominant year class, must not be confused with a decrease due to overfishing. Therefore, in attempting to explain the fluctuations in abundance of the

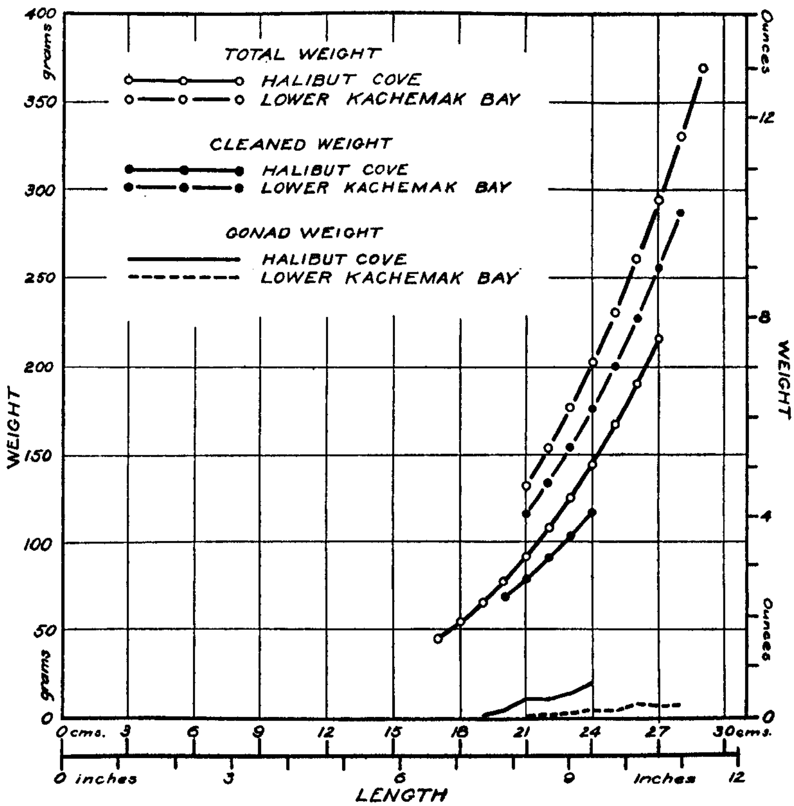

FIGURE 34.—Total weight, cleaned weight, and gonad weight for herring in Halibut Cove and lower Kachemak Bay for 1927

Pacific herring, one of our first aims was to demonstrate the existence or nonexistence of this phenomenon of dominant year classes and its effect on the catch.

COMPOSITION OF THE CATCH

SAMPLING FOR SIZE AND AGE COMPOSITION

In order to connect the changes in the composition of the catch with fluctuations in the yield of the fishery, it is necessary to follow such changes as may occur in the size and age of the population.

For this knowledge of the herring population we must depend upon the portion taken by the fishermen. Of this portion consisting of many thousands of barrels of fish only a few thousand individuals can be measured. Hence, the question naturally arises, How accurately do these few individuals represent the population?

Sette (1926) made a study of this sampling problem with the California sardine (*Sardina cærulea*) at Monterey. He obtained a very complete series of samples throughout the season and made the assumption that these represented the commercial catch. He then endeavored to discover by mathematical means how frequently samples need to be taken in order to represent the series with reasonable accuracy. He found that by taking samples at least semiweekly the desired result could be obtained.

No such series of samples is available for the herring. The herring "runs" are more erratic than those of the sardine, because in many localities the herring can be sampled for only two or three months out of the year, and the total catch of the year may be made on as few as 10 different days. Indeed, in Red Fox Bay, Shuyak Strait, in 1926, the whole catch of about 13,000 barrels was taken in two nights' fishing. Sampling twice a week might be theoretically correct, but under such conditions it is impossible from a practical standpoint, except perhaps for the duration of a "run."

With the herring it is highly probable that in each locality a much smaller population is sampled than with the sardine. So far but very little evidence has been found to show the existence of local races in the California sardine (Hubbs, 1925, p. 12), while studies have shown the Pacific herring to be divided into many local races. The catch landed in a given port may come from several of these, making the sampling of the herring much more complex.

These facts tend to show that in the case of the Pacific herring sampling can not be made as exactly as in that of the California sardine, so that in order to prove the validity of our sampling a more complete dependence must be placed upon the repeated occurrence of consistent variations (Thompson, 1926a). The inability to obtain samples over a long period during each season will make it less likely that our samples will represent the same portion of the population year after year, thus decreasing our chances of proving the consistency in occurrence of any variations and making it more difficult to foretell in advance what fluctuations in abundance may be expected.

Even if it were true that the commercial catch is taken each year from the same section of the population, it might be difficult to demonstrate clearly the exact manner in which dominant year classes would come into evidence. Thus in the sardine of California the dominant year classes affect the commercial take unequally at different sizes and ages, and prophecy of the catch is thereby limited. (Thompson, 1926a.)

EVIDENCE OF DOMINANT YEAR CLASSES

In order to prove the existence or nonexistence of dominant year classes, samples are needed over a period of years from one locality. (Table 31.) The longest period for which consecutive samples are available extends from 1924 to 1927. These were taken in, or in the immediate vicinity of, Elrington Passage, one of four channels connecting the western side of Prince William Sound with the open ocean. All of the data for 1924 and a portion of those for 1925 consist only of length measurements, which were obtained from Clarence L. Anderson, a former technologist of the United States Bureau of Fisheries. Ages are available for a portion of the 1925 data, and for most of those of 1926 and 1927.

TABLE 31.—*Length frequencies of summer herring*

Length in millimeters	Southeastern Alaska 1925 Actual	Southeastern Alaska 1925 Per cent	Elrington Passage 1925 Actual	Elrington Passage 1925 Per cent	Elrington Passage 1926 Actual	Elrington Passage 1926 Per cent	Elrington Passage 1927 Actual	Elrington Passage 1927 Per cent	Macleod Harbor 1927 Actual	Macleod Harbor 1927 Per cent	Macleod Harbor 1928 Actual	Macleod Harbor 1928 Per cent	Eshamy Bay 1926 Actual	Eshamy Bay 1926 Per cent
100-104									1	0.5				
115-119							2	0.3						
120-124							2	.3	1	.5				
125-129							10	1.7	1	.5				
130-134							8	1.4						
135-139							7	1.2	1	.5				
140-144							12	2.1						
145-149					2	0.2	2	.3						
150-154					5	.5	1	.2	1	.5	2	0.6		
155-159					8	.8					11	3.4		
160-164	2	0.4			18	1.7	1	.2	4	2.0	20	6.3		
165-169	4	.8			18	1.7	2	.3	3	1.5	23	7.2	2	0.5
170-174	4	.8			30	2.9	12	2.1	6	3.0	22	6.9	1	.2
175-179	4	.8	5	2.6	33	3.2	14	2.4	10	5.0	25	7.8	1	.2
180-184	8	1.7	7	3.7	33	3.2	30	5.1	15	7.5	36	11.3	1	.2
185-189	7	1.5	6	3.2	39	3.7	37	6.3	16	8.0	45	14.1	1	.2
190-194	13	2.7	3	1.6	22	2.1	53	9.1	29	14.5	36	11.3	5	1.2
195-199	24	5.1	8	4.2	42	4.0	46	7.9	37	18.5	15	4.7	3	.7
200-204	34	7.2	9	4.7	43	4.1	34	5.8	29	14.5	8	2.5	1	.2
205-209	38	8.0	12	6.3	68	6.5	36	6.1	10	5.0	20	6.3	5	1.2
210-214	37	7.8	15	7.9	98	9.4	17	2.9	8	4.0	16	5.0	5	1.2
215-219	44	9.3	13	6.8	93	8.9	15	2.6	7	3.5	15	4.7	21	5.0
220-224	54	11.4	21	11.1	84	8.1	25	4.3	2	1.0	10	3.1	40	9.5
225-229	52	11.0	10	5.3	126	12.1	27	4.6	5	2.5	8	2.5	43	10.2
230-234	31	6.5	16	8.4	108	10.4	42	7.2	4	2.0	1	.3	95	22.5
235-239	39	8.2	8	4.2	80	7.7	48	8.2	2	1.0	3	.9	87	20.6
240-244	32	6.8	7	3.7	42	4.0	41	7.0	4	2.0	3	.9	56	13.3
245-249	18	3.8	6	3.2	11	1.1	34	5.8	2	1.0			23	5.5
250-254	11	2.3	8	4.2	7	.7	8	1.4	2	1.0	1	.3	11	2.6
255-259	10	2.1	7	3.7	11	1.1	5	.9					6	1.4
260-264	8	1.7	11	5.8	7	.7	7	1.2					6	1.4
265-269			10	5.3	3	.3	2	.3					3	.7
270-274			6	3.2	4	.4	2	.3					5	1.2
275-279			1	.5	5	.5	3	.5					1	.2
280-284			1	.5										
285-289														
290-294														
295-299														
300-304					1	.1								
305-309														
310-314														
Total frequency	474		190		1,041		585		200		320		422	
Number of samples	6		4		17		11		3		9		4	

Length in millimeters	McClure Bay 1927 Actual	McClure Bay 1927 Per cent	Dogfish Bay 1925 Actual	Dogfish Bay 1925 Per cent	Shuyak Strait 1925 Actual	Shuyak Strait 1925 Per cent	Shuyak Strait 1926 Actual	Shuyak Strait 1926 Per cent	Kachemak Bay 1926 Actual	Kachemak Bay 1926 Per cent	Kachemak Bay 1927 Actual	Kachemak Bay 1927 Per cent	Russian Harbor [1] 1925 Actual	Russian Harbor [1] 1925 Per cent
100-104														
115-119														
120-124														
125-129									3	0.4				
130-134									1	.1				
135-139														
140-144									1	.1				
145-149														
150-154														
155-159														
160-164														
165-169									1	.1				
170-174														
175-179														
180-184	2	1.0												
185-189	2	1.0							1	.1				
190-194	2	1.0												
195-199	1	.5									2	0.6		
200-204	2	1.0									5	1.4		
205-209	13	6.5							6	.9	6	1.7		
210-214	5	2.5							5	.7	12	3.4		
215-219	9	4.5			1	0.6			6	.9	27	7.7		
220-224	9	4.5	1	1.0	1	.6	1	0.9	4	.6	27	7.7		
225-229	12	6.0							6	.9	34	9.7		
230-234	17	8.5	1	1.0	2	1.1	1	.9	6	.9	27	7.7		
235-239	27	13.5	2	2.0	4	2.2	5	4.7	11	1.6	23	6.6		
240-244	37	18.5	2	2.0	8	4.4	2	1.9	15	2.2	17	4.9		

[1] Gill netted, other samples purse seined.

TABLE 31.—*Length frequencies of summer herring*—Continued

Length in millimeters	McClure Bay		Dogfish Bay		Shuyak Strait				Kachemak Bay				Russian Harbor	
	1927		1925		1925		1926		1926		1927		1925	
	Actual	Per cent	Actual	Per cent	Actual	Per cent	Actual	Per cent	Actual	Per cent	Actual	Per cent	Actual	Per cent
245-249	26	13.0	4	4.0	6	3.3	3	2.8	17	2.5	15	4.3	1	1.0
250-254	16	8.0	12	12.0	15	8.3	6	5.7	29	4.3	11	3.1	3	2.9
255-259	10	5.0	9	9.0	15	8.3	10	9.3	38	5.6	14	4.0	7	6.6
260-264	3	1.5	28	28.0	18	10.0	9	8.4	46	6.8	19	5.5	14	13.3
265-269	3	1.5	19	19.0	28	15.6	13	12.1	79	11.6	20	5.7	12	11.4
270-274	2	1.0	18	18.0	29	16.1	19	17.7	104	15.3	25	7.1	14	13.3
275-279	1	.5	2	2.0	23	12.8	12	11.2	125	18.4	21	6.0	11	10.5
280-284			1	1.0	14	7.8	9	8.4	91	13.4	20	5.5	12	11.4
285-289	1	.5	1	1.0	4	2.2	3	2.8	43	6.3	16	4.1	7	6.6
290-294					8	4.4	12	11.2	22	3.2	5	1.4	16	15.2
295-299					3	1.7	1	.9	10	1.5	2	.6	3	2.9
300-304							1	.9	5	.7	2	.6	3	2.9
305-309									2	.3			2	1.9
310-314					1	.6			2	.3				
Total frequency	200		100		180		107		679		350		105	
Number of samples	6		1		4		3		6		11		1	

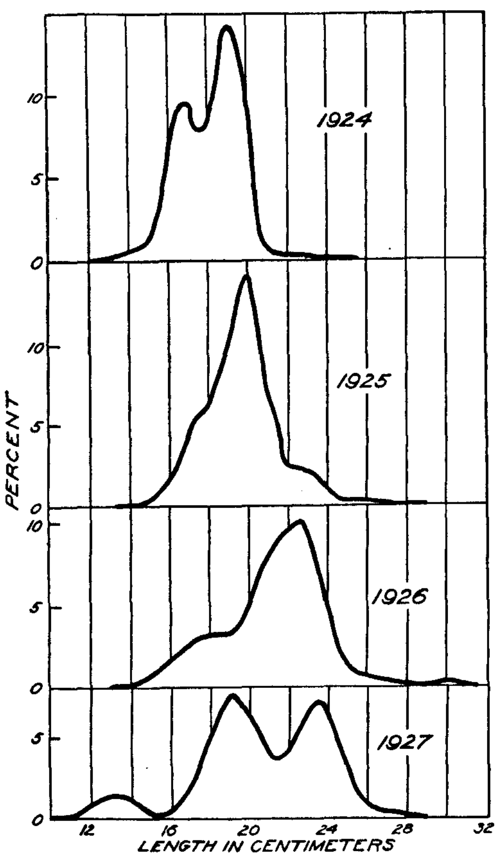

FIGURE 35.—Length frequency distributions for the summer herring of Elrington Passage and immediate vicinity from 1924 to 1927

The lengths were first grouped in half-centimeter categories and then smoothed twice by three's to remove minor modes due to chance sampling. (Fig. 35.) These smoothed length distributions reveal a shifting of sizes from year to year, the mode shifting from 20 centimeters in 1925 to just over 22 centimeters in 1926. This same mode appears to have shifted to 23.5 centimeters in 1927. The bimodal distribution of 1924 suggests that the single mode of the later years is composed of at least two age groups. The mode at 19 centimeters in 1927 appears at 17 centimeters in 1926. This group is numerous enough in 1927 to cause the mode at 23.5 centimeters to appear relatively less important than in the previous year. Some of the modes are no doubt partly concealed, others distorted or exaggerated by various factors, but, nevertheless, these factors are not sufficient to seriously obscure the presence of a dominant size group and its progression through the commercial catch.

Although the data in this form show well the dominance and progression of certain size groups, yet they do not show the relative lack of certain size groups, not only as compared to the other sizes for the same year but as compared to the average of the same sizes over the entire period of four years. The average curve for these four years was obtained by summing the weighted frequencies (percentage frequencies) of each of the four yearly curves and dividing by four to get the arithmetic mean for each ordinate. (Fig. 36, top curve.) With this average curve as a base, the deviations of each of the four years from the average curve were plotted so that frequency greater than the average appears above the line (as solid black), less than the average below the line.

Figure 36 shows more clearly than Figure 35 the progression of sizes through the commercial catch from small fish (roughly 16 to 19 centimeters) in 1924 to large fish (roughly 22.5 to 25.5 centimeters) in 1927. It shows even more clearly the progression of a poorly represented size group, which, commencing at 15–17 centimeters in 1925, moves to 17–20 centimeters in 1926, and to 18.5–21.5 centimeters in 1927. The group between 17 and 21 centimeters in 1927 appears from the size distributions of Figure 35 to be of great importance, but Figure 36 shows it to be below the averages for those sizes, while the group from 11 to 15 centimeters in 1927 appearing from the size frequencies to be unimportant is shown by Figure 36 to deviate almost in its entirety above the average frequency for the four years.

The view that the progression of sizes in Elrington Passage is due to the growth of fish of dominant age groups is sustained by age analyses. (Fig. 37, Table 32.) The age histogram for 1925 represents only a small portion of the fish in the length distribution, but those for 1926 and 1927 are quite representative. The shift of the 1919 and 1920 year classes from 4 and 5 years of age in 1925 to 6 and 7 years of age in 1927 is very apparent. While there is undoubtedly a small percentage of error in the age readings yet 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 evidence of their validity.

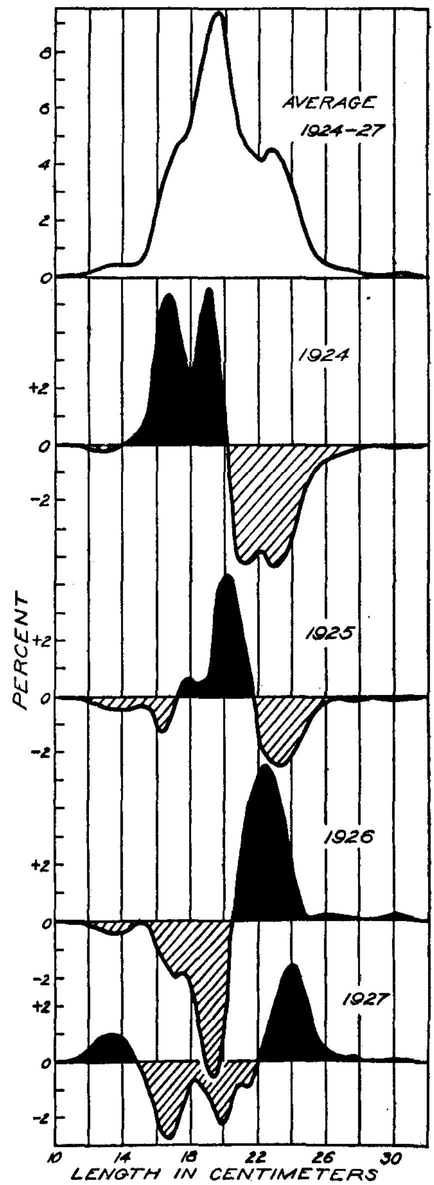

FIGURE 36.—Deviations of the length frequency distributions of each year from 1924 to 1927 from the average of the four years for summer herring of Elrington Passage and immediate vicinity

Eshamy Bay and McClure Bay, about 10 miles apart, show no racial differences, so their length and age distributions have been compared for 1926 and 1927. (Figs. 38 and 39.) Both of the length frequencies present very distinct and sharply defined modes, the 1926 Eshamy Bay mode being at 23 centimeters and the 1927 McClure Bay mode at 24 centimeters, a forward progression of 1 centimeter. The age histograms show that this shifting in the length mode was due to the growth of the dominant 1920 year class, which was 6 years old in 1926 and 7 in 1927.

The age frequencies presented in Table 32 show that in no case is there a symmetrical distribution of ages around a mode, such as one would expect to find in a population in which the annual increments of new members were about equal. In fact, very unequal proportions of different age groups seems to be the rule. Therefore, it is safe to conclude that our data demonstrates conclusively that dominant year classes are ordinarily present in the Alaska herring.

TABLE 32.—*Frequency at each age*

Age (years)	San Diego, December, 1926		Stephens Passage, January, 1928		Larch Bay, August, 1927		Halibut Cove, gill netted, April, 1926		Halibut Cove, beach seined, April, 1926		Dogfish Bay, August, 1925		Lower Kachemak Bay, August, 1926		Shuyak Strait, July, 1925	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
1									24	7.1						
2			9	4.9					66	*19.4*			5	2.0		
3			22	*11.9*					64	*18.8*			3	1.2		
4	1	2.2	9	4.9	12	19.0			79	*23.2*			5	2.0	1	0.7
5			109	*59.2*	20	*31.8*	2	2.2	31	9.1	1	1.2	14	5.7	2	1.3
6	4	8.7	4	2.2	15	23.8	1	1.1	10	2.9	1	1.2	30	*12.2*	4	2.7
7	35	76.1	3	1.6	8	12.7	31	*34.8*	22	6.5	3	3.5	9	3.7	28	*18.8*
8			6	3.2	5	7.9	33	*37.1*	22	6.5	3	3.5	55	*22.4*	18	*12.1*
9	6	13.0	13	7.0	2	3.1	4	4.5	4	1.2	8	9.4	58	*23.7*	7	4.7
10			4	2.2			11	*12.4*	8	2.4	43	*50.6*	12	4.9	63	*42.3*
11			2	1.1			6	6.7	8	2.4	22	*25.9*	14	5.7	20	*13.4*
12			2	1.1	1	1.6	1	1.1	2	.6	4	4.7	33	*13.5*	4	2.7
13			1	.5									5	2.0	1	.7
14															1	.7
15													1	.4		
16																
17													1	.4		
Total	46		184		63		89		340		85		245		149	

Age (years)	Shyak Strait, July, 1926		Elrington Passage, July and August, 1925		Elrington Passage, June and July, 1926		Elrington Passage, June and July, 1927		Eshamy Bay, September, 1926		McClure Bay, September, 1927		Dutch Harbor, August, 1928	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
1														
2							21	4.9			1	0.6		
3			13	7.9	35	9.0	13	3.0	4	2.2	1	.6	1	1.2
4	1	1.3	42	*25.5*	137	*35.4*	207	*48.4*	17	9.5	30	17.6		
5	6	7.9	59	*35.8*	82	21.2	52	*12.1*	27	15.2	31	18.2		
6	10	*13.2*	11	6.7	120	*31.0*	38	8.9	114	*64.1*	23	13.5	58	*68.2*
7	2	2.6	11	6.7	3	.8	78	*18.2*	6	3.4	68	*40.0*	16	18.8
8	16	*21.0*	6	3.6	3	.8	2	.5	1	.6	1	.6	4	4.7
9	16	*21.0*	4	2.4	1	.3	9	2.1	1	.6	7	4.1		
10	3	3.9	9	5.5	1	.3	4	1.0	2	1.1	6	3.5	4	4.7
11	6	7.9	10	6.1	3	.8	3	.7	1	.6	1	.6		
12	13	*17.1*			2	.5	1	.2	5	2.8			2	2.4
13	1	1.3									1	.6		
14	2	2.6												
Total	76		165		387		428		178		170		85	

OCCURRENCE OF DOMINANT YEAR CLASSES

Whether the conditions that cause certain year classes to survive in unusual numbers are entirely fortuitous or whether these conditions recur in cycles, is a question. Linked with this comes the question as to the effect the spawning of a dominant year class will have on the stock of the following years. Gilbert and Rich (1927) found that in the Karluk River the red or sockeye salmon (*Oncorhynchus nerka*) presents 5-year cycles. Quoting:

The graph shows clearly the cyclic character of the runs of red salmon in the Karluk River. Since the Karluk salmon are predominantly 5-year fish, we anticipate a correlation between the run of any year and that of the fifth year preceding, the fifth year following, etc. * * * If it can safely be assumed that spawning escapements are in the main roughly proportional to the catch, it becomes apparent that they are the predominating factor in determining the size of the runs.

In the salmon, which spawn but once in a lifetime, such a correlation between spawners and offspring is easier to trace than with a fish that may spawn several times during its life. However, Jensen (1927) has attempted to trace just such a correlation in the case of the South Baltic autumn herring, a single local race of herring around Bornholm, spawning in September and October. He found that the catch anomalies (per cent from normal) of the herring fishery at Bornholm showed fluctuations covering three or four years. During 26 years he noted seven fluctuations averaging 3.7 years. Jensen says:

> The periodicity is to be explained as a consequence of the varying amount of fry produced by the varying number of spawning herrings. The Baltic herring generally matures in its third year and the shoals of spawning herrings accordingly consist of fish 3 years old and more. As the herrings of the year classes III and IV in the Baltic greatly predominate over the older year classes, and therefore as a rule produce the largest quantity of fry, the observed periodicity can be explained in this way.

On the other hand the great fishery for the Atlanto-Scandian spring herring shows violent fluctuations due to dominant year classes that appear at irregular intervals (Lea, 1924), seemingly without regard to the number of spawners present.

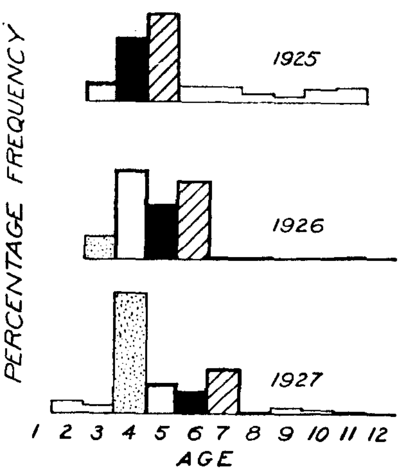

FIGURE 37.—Age histograms of Elrington Passage, Prince William Sound, for 1925, 1926, and 1927

Even in the case of a clear-cut periodicity as in the Karluk salmon, or of a lesser correlation as in the salmon of the Gudenaa (Jacobsen and Johansen, 1921, p. 12–15), it would seem that, owing to the fact that the salmon do not all return to their native stream the same number of years after leaving it (in the Karluk about 85 per cent return at 5 years of age and 10 per cent at 6 years of age), in a comparatively limited number of years the effect of the spawning of a dominant year class would be so distributed that soon its successors in the 5-year cycle would no longer be dominant. That such is not the case causes one to ask if there may not be some other condition present, possibly meteorological, that favors such a 5-year cycle.

If the dominant year classes in the Alaska herring recur in regular cycles, as in the Bornholm autumn herring, then the trend of the fishery should not be hard to establish; but if they recur at irregular intervals, and if successive dominant year classes are of greater or lesser dominance, as in the Norwegian spring herring, then the solution may be more difficult.

EFFECT OF DOMINANT YEAR CLASSES ON THE CATCH

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 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. Evidence of such changes in size, due to the progression of dominant year classes, is shown in Elrington Passage by accurate records kept by one of the packers, giving the proportion of the catch pickled each year and the trade categories, according to the size of the fish. To make each year comparable the records have been compared for the month of July:

Year	Number barrels	Per cent pickled	Per cent matjes	Per cent medium	Per cent large
1924	8,125	10.0	71.5	14.4	14.1
1925	4,355	9.3	56.6	25.6	17.8
1926	3,239	15.9	----------	90.9	9.1
1927	2,271	29.1	13.2	77.6	9.2

Matjes are herring from about 9½ to 10½ inches in total length (197–215 millimeters in body length); mediums from about 10½ to 11½ inches in total length (215–232 millimeters in body length); large from about 11½ to 12½ inches or over (232–249 millimeters in body length). Of course, the proportions of each kind pickled will depend to some extent on market conditions, and the sizes included under each name will fluctuate slightly from year to year, but, in the main, the proportion of the catch pickled and the percentage of each class will depend on the raw material available. There are two features so pronounced as to appear valid; one is the increase in the total amounts pickled in 1926 and 1927, the other is the shift in sizes pickled. These changed from over 70 per cent matjes and 14 per cent mediums in 1924 to no matjes and over 90 per cent mediums in 1926. In 1927 the percentage of mediums packed is less than in 1926 owing to the packing of 13 per cent of matjes, but the percentage of the total catch pickled as mediums in 1927 is actually greater than in 1926 and the same is true of the large.

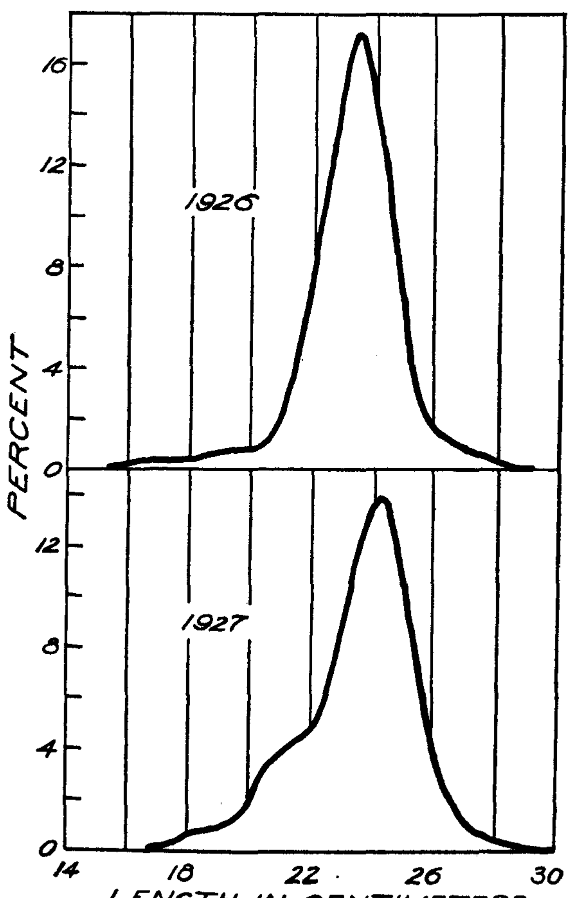

FIGURE 38.—Length frequency distributions for the Eshamy Bay and McClure Bay fall herring for 1926 and 1927, respectively

Comparing these annual changes in the sizes and amounts pickled with the percentage of herring at each size as shown in Figure 35 the existence of a rough correlation is at once apparent, lending support to our biological findings, and thus demonstrating an important point; namely, that the effect of the progression of sizes due to the growth of dominant year classes, as shown by our sampling, is reflected in the commercial catch.

DOMINANT YEAR CLASSES SHOW RELATIONSHIP OF AREAS

In nearly every case the age distributions of any two localities differ considerably in the proportions of fish of each year class. Thus the age frequencies of Elrington Passage show no similarity to those of samples taken farther to the westward, and the dominant year classes may well be different. This lack of agreement in most cases may be due to different physical conditions in each locality at the time of spawning, although the correlation of these dominant age groups with the physical conditions is far in the future. While this lack of agreement may possibly be wholly environmental in cause, it indicates the lack of migration between stocks of different localities. Indeed, the age frequencies differ between all localities, for which ages have been read, which are shown to be racially distinct (see Independence of Areas p. 272), thus corroborating the evidence of lack of migration between certain stocks set apart by the investigation of their structural differences.

There is a slight possibility that this lack of agreement between the age frequencies in different localities might be due largely to chance. That the reverse is true is strongly suggested by a comparison of the 1926 age frequencies of the summer herring of Shuyak Strait and Kachemak Bay. (Fig. 40, Table 32.)

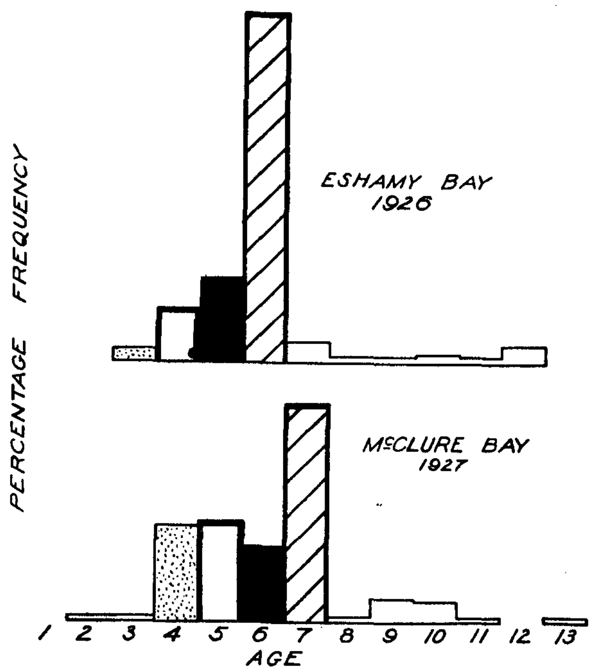

FIGURE 39.—Age histograms of Eshamy Bay, 1926, and McClure Bay, 1927

The Shuyak Strait samples were caught on July 15 and the Kachemak Bay samples from August 25 to 28, about six weeks later. Herring were caught in Shuyak Strait for two days following the opening of the season on July 15 and then disappeared, so that it is quite possible that the Kachemak Bay samples came from the same school.

Assuming that the sampling was truly random and the age readings correct, a mathematical means of testing the significance of the similarity exists, and a measure of judging the probability that two frequency distributions are samples of the same population may be obtained by the formula:

$$\chi^2 = N_1 N_2 S \left\{ \frac{\left(\frac{f_1}{N_1} - \frac{f_2}{N_2}\right)}{f_1 + f_2} \right\} \qquad \text{(Pearson, 1914)}$$

where f_1 is the frequency in a given class of one frequency distribution and f_2 is the frequency in the corresponding class of the other frequency distribution. N_1 and

N_2 are the total number of items in the respective frequencies. S is the summation of these values for each class.

The probability, P, that chance alone would cause the same or a greater divergence between two random samples of the same population is obtained by the formula:

$$P = \epsilon^{-\frac{1}{2}\chi^2}\left(1 + \frac{\chi^2}{2} + \frac{\chi^4}{2\times4} + \frac{\chi^6}{2\times4\times6} + \cdots + \frac{\chi^{y-3}}{2\times4\times6\times\cdots\times(y-3)}\right)$$

where y equals the number of classes, and ϵ equals the base of the Napierian system of logarithms.

From the calculation we obtain P as 0.621, meaning that the age frequencies of 6 out of every 10 samples of the same population would differ as much as these two frequencies.

Application of the formula to the size frequencies gives a value for P of 0.0898, quite different from that of the age readings. This may be due to erroneous age

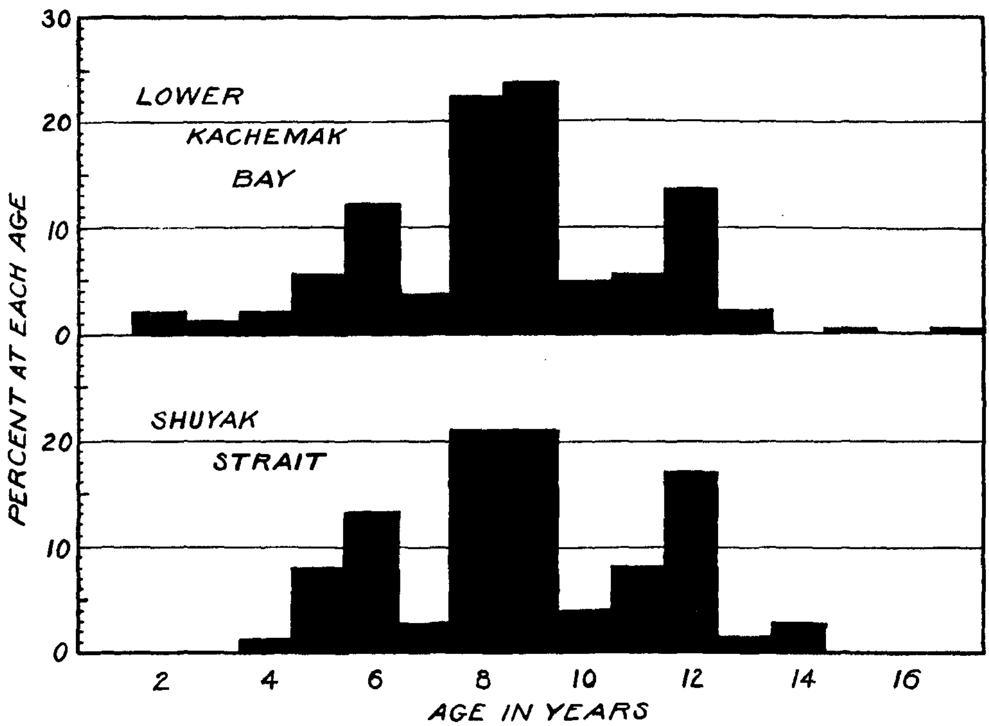

FIGURE 40.—Age histograms of Shuyak Strait and lower Kachemak Bay for 1926

readings or to chance, but an examination of the length frequencies (Table 31) causes one to believe that it is largely due to growth as the two frequencies are very similar, the chief difference being that the modal length in Kachemak Bay is half a centimeter greater than in Shuyak Strait. As mentioned above the Kachemak Bay samples were taken six weeks later than those of Shuyak Strait. The period thus covered, from July 15 to about August 27, is one in which the herring make a large part of the season's growth. These facts could account for the half centimeter difference in modal length, which would cause P to be very low, whereas without the growth in the period intervening between the collection of the samples P would undoubtedly be much higher.

The racial analysis shows that these two localities do not differ significantly in any of the characters compared, their condition factors (Table 29) follow almost exactly the same trend, and their rates of growth (Table 28) are comparable, so there is no reason for supposing them to be separate stocks.

CONCLUSIONS

1. Owing to the short periods during which samples are obtainable from one locality, the proof of the validity of sampling must be placed largely upon the repeated occurrence of consistent variations.
2. Dominant year classes are normally present.
3. The progression of sizes due to the growth of dominant year classes is reflected in the commercial catch.
4. The similarity or difference between the dominant year classes in two adjacent localities gives indications for or against the independence of the two populations.

ANALYSIS OF CATCH STATISTICS

SOURCES OF STATISTICS

The statistics which have been used in studying the changes in abundance have been derived from a number of fairly reliable sources. For the very early years of the fishery (previous to 1904) we have had to rely wholly on published records. Moser (1899 and 1902) and the United States Senate (1912) published the best records of the Killisnoo plant, and Cobb (1906) summarized all of the early records obtainable.

Since 1904 the Bureau of Fisheries has required every individual or company fishing in Alaska to make a sworn annual return of the total amounts and kinds of fishery products prepared, and of the amounts, kinds, and value of fishing gear, boats, and other apparatus used. These sworn returns constitute one of the main sources of information. Another major source of information is the annual statistical review and the monthly numbers of the Pacific Fisherman, a trade journal published in Seattle, Wash. Many of the herring companies have kept careful records of their catches for several years, to which we have had access. A fifth source of information, available since 1926, is contained in detailed records giving the amount, date, and location of every catch made by each individual boat. These records are kept by the herring companies on duplicate receipt books issued by the Bureau of Fisheries, a system which we patterned after that planned by Will F. Thompson and used successfully for several years by the Division of Fish and Game of California. These sources have been supplemented by field notes.

TREATMENT OF DATA

The records do not give the quantities of raw herring captured (except in the case of halibut bait), but give the amounts of various finished products prepared. In analyzing the statistics, it was necessary for purposes of comparison that all amounts be put on a common basis. The unit selected was the pound of raw herring as delivered to the plant. Some of the factors used in converting the weights of finished products into the weights of raw herring were more or less empirically determined, which may have allowed some small errors to creep in. However, the advantages of such a method of treatment are obvious, and such errors as may have arisen as a result are too small to have any appreciable effect on the analysis. For the conversion of canned herring into raw, 75 pounds of raw herring have been allowed for every 48 pounds of canned herring. No statistics are available on the amount of shrinkage undergone in the kippering of the herring prior to canning, but the total shrinkage here adopted is considered to be a very close estimate by one of the packers who has canned about two-thirds of all that has been prepared in this manner in Alaska. Any errors due to inexactness of the conversion factor, will affect only a few years, as the total amount canned was never large except in 1919.

All of the oil and fertilizer produced in southeastern Alaska from 1882 to 1918 were made by one plant at Killisnoo, and the records of the raw herring used are available up to and including 1911. From 1912 to 1920, when this company failed, 44.9 pounds of raw herring were allowed for each gallon of oil, the factor being calculated for the period from 1909 to 1911, inclusive (a new cooker was installed in 1909, United States Senate, 1912). For the rest of southeastern Alaska from 1919 to 1928 (and for the new company that organized to run the Killisnoo plant since 1923) the raw herring used for reduction has been calculated by allowing 50 pounds of raw herring per gallon of oil and 65 pounds of raw herring per pound of fish meal. The two results were then added and divided by two as the meal and oil came from the same fish. These two factors were calculated from careful records kept by the plant at Red Bluff Bay from 1922 to 1927, inclusive. In Prince William Sound the conversion factors used were 61.2 pounds of raw herring per gallon of oil, and 8.25 pounds of raw herring per pound of meal, as calculated from careful records kept from 1923 to 1927, inclusive, by a plant in Evans Bay. The factors vary some from year to year, but it was found that the factors for oil and meal hardly differed in their reliability, the coefficient of variation $\left(V=\frac{100\,\sigma}{\text{Mean}}\right)$ for the oil factor being 0.213; for the meal factor 0.162.

For the pickled products, 20 per cent shrinkage of the raw herring has been allowed in all districts; that is, the finished product must be increased 25 per cent to represent the raw herring actually used in its preparation. (Figs. 41 and 42.) In addition, certain allowances must be made for waste of small herring. No waste is allowed for herring pickled by companies operating reduction units, as this waste is included with the raw herring for the oil and meal. For the other companies varying allowances have been made in the different districts.

The waste allowed in southeastern Alaska previous to 1918 was only 20 per cent as practically all of the herring were cured by the Norwegian method in which quite small herring are used. To allow for this, the amount of raw herring actually used in the finished product was increased another 25 per cent. From 1918 to 1928 the records differentiate between the Norwegian and Scotch cured products. During this period the waste on the Norwegian cure is the same, but 40 per cent waste was allowed on the Scotch cure, which utilizes only the larger fish.

In Prince William Sound accurate records are available for the amounts of raw herring wasted by a company without a reduction plant in 1922 and 1923. In 1922 they wasted 18 per cent; in 1923, 26 per cent; which means that the raw herring actually used for pickling were increased by 22 per cent and 33⅓ per cent, respectively, to allow for waste. All of the packers are agreed that the waste in Prince William Sound was less in 1922 than in any other year, so the 1923 factor was applied to all of the other years. In Prince William Sound, in the later years especially, a portion of the waste of the companies without reduction plants (of which no accurate

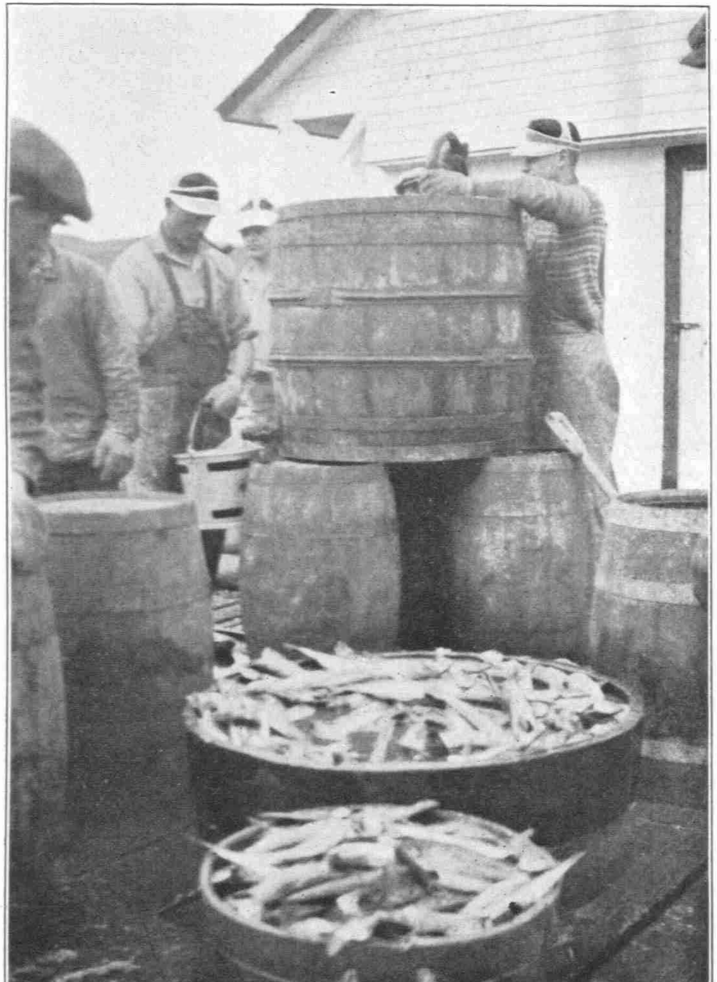

FIGURE 41.—Repacking at Dutch Harbor. Brine is being mixed in the large tierce and drawn off through a spigot. The herring that are to be used in filling up the barrels are being washed in the half tierce in the foreground.

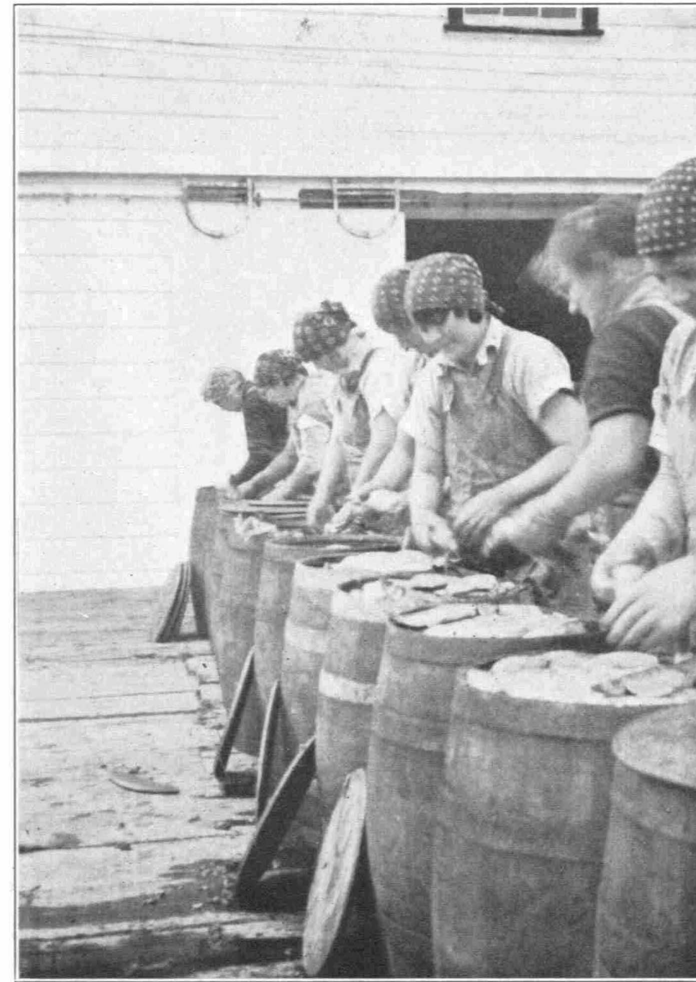

FIGURE 42.—Repacking at Dutch Harbor. The herring shrink about 20 per cent in curing and the deficiency is made up by repacking the top of the barrel with herring of the same day's cure

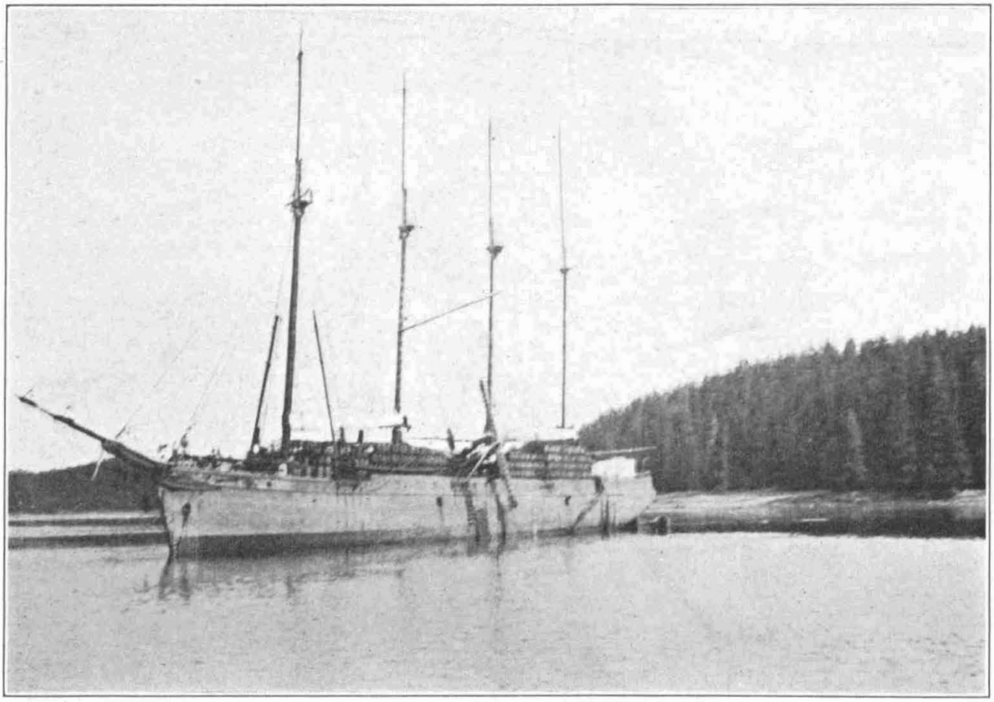

FIGURE 43.—The Schooner *Rosamond*, a floating saltery at anchor behind McDonald Spit, Kachemak Bay

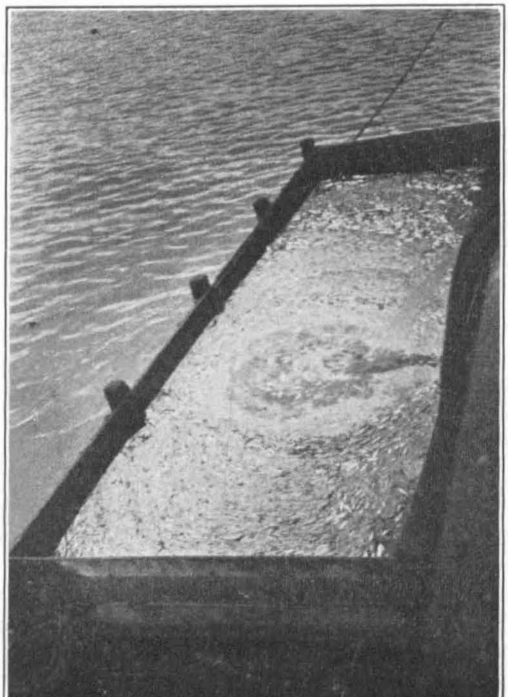

FIGURE 44.—Herring too small to be salted are collected in this manner and dumped outside of the harbor at Halibut Cove, Kachemak Bay. Taken August 24, 1927

records are available) was delivered to the reduction companies to be made into oil and fish meal. This causes a slight error in our calculations, but the amount pickled in Prince William Sound by companies without reduction plants in the later years has been very small. Also it is not an error that will in any way affect our conclusions since it will slightly enlarge the amounts taken in the later years, thus tending to conceal any depletion that may have occurred.

For Cook Inlet the waste on pickled herring up to and including 1923 has been placed at 15 per cent, as determined by a company putting up large packs of pickled gill-net herring in 1921 and 1923. That is, after the pickled product has been increased 25 per cent to allow for the 20 per cent shrinkage in the herring actually pickled, this amount is then increased 17.5 per cent more to allow for the 15 per cent waste. From 1924 up to the present more herring were purse seined than gill netted in Cook Inlet, and 20 per cent has been allowed for waste since purse-seine gear takes a greater proportion of small fish. (Fig. 44.) For all of the localities on Kodiak and Afognak Islands 20 per cent was allowed for waste.

On dry-salted herring 40 per cent was allowed for shrinkage, and, since small fish are used, no allowance was made for waste. No accurate records are available on which to base the actual shrinkage for dry-salted herring, the 40 per cent being more or less arbitrarily decided upon. However, this factor is very nearly correct, and the amounts of dry-salted herring are far too small to affect the results in any manner.

The miscellaneous products are chiefly very small amounts of spiced, kippered, or smoked herring on which 20 per cent has been allowed for shrinkage.

The available data have made it possible to obtain the total net tonnage for the purse-seine fleet in southeastern Alaska. The average was computed for all of the boats for which the tonnages were available, and this average was then multiplied by the total number of boats. The percentages of the fleet for which tonnages were available from 1922 to 1928 are as follows: 1922, 71; 1923, 100; 1924, 65; 1925, 61; 1926, 98; 1927, 91; and 1928, 87 per cent.

ANALYSIS OF FLUCTUATIONS BY LOCALITIES

SOUTHEASTERN ALASKA

The records are incomplete for the years previous to 1910, except for the reduction plant at Killisnoo, for which complete records are available from the time of its founding in 1882 up to the present. From 1910 to 1918 about 50 per cent of the southeastern Alaska catch was taken by this plant and a larger proportion in the earlier years so their records are quite representative of the early catch. (Fig. 45.) The trend in Figure 45 has been obtained by the method of least squares. The changes in the catch have doubtless been influenced by a multiplicity of factors; thus the low point of 1896 coincides with a period of great economic depression, and that of 1888 (not used in determining the trend) with the failure and reorganization of the original company. The fishing effort expended was about equal in the various years. (United States Senate, 1912, p. 15.) The drop of 25.5 per cent in the trend between 1884 and 1920—a period of 37 years—is surely significant and would indicate depletion. It may indicate a considerable degree of depletion whose effects have been concealed by the fishermen seeking new fishing grounds as the older were exhausted.

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The catches of the Killisnoo plant show large variations that may be partially caused by biological factors, such as the passage through the catch of dominant year

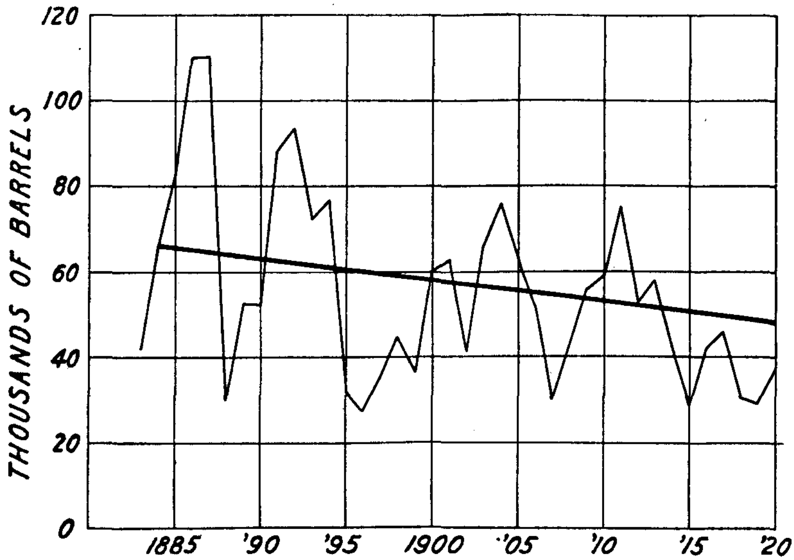

FIGURE 45.—The catch of raw herring by the reduction plant at Killisnoo, on upper Chatham Strait, from 1883 to 1920, inclusive. The trend was obtained by the method of least squares (omitting 1883, because the guano plant was not installed until 1884, and omitting 1888, in which year the first company was reorganized)

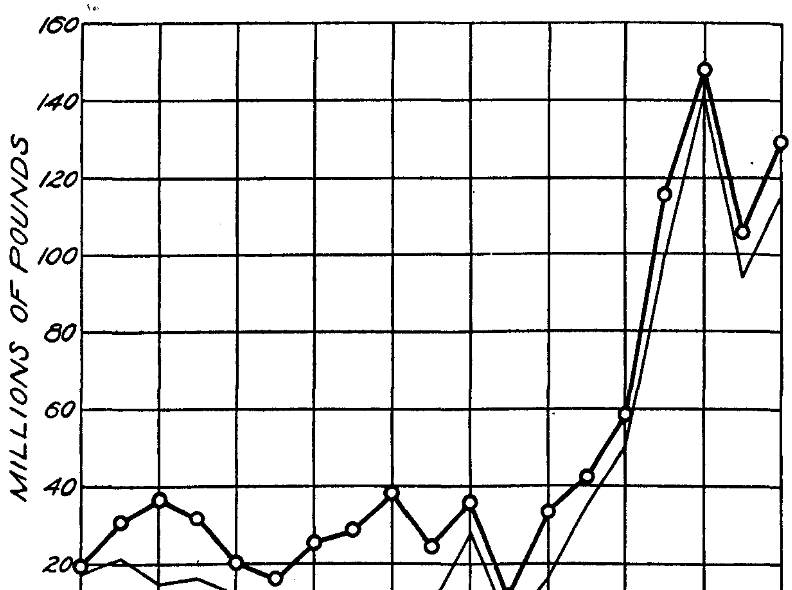

FIGURE 46.—Catch of raw herring in southeastern Alaska from 1910 to 1928, inclusive. Heavy line, total catch. Light line, amount converted into by-products. Broken line, amount pickled by the reduction companies since 1920

groups. But it would be presuming to definitely ascribe any of the changes in the catch to biological factors without an intimate knowledge of the many other factors concerned.

The total catch for southeastern Alaska from 1910 to 1928 is given in Figure 46. As is shown by Table 33 the mode from 1911 to 1913 was caused by dry salting of herring, which was done in Yes Bay, on Behm Canal, near Ketchikan. The failure of this business in 1914 was caused by the dwindling of the herring runs in this vicinity, which does not appear to have been caused by a temporary scarcity, as herring have never been abundant in this locality since that time. The rise from 1916 to 1920 was due to the exploitation of southern Chatham Strait, the introduction of the Scotch method of curing herring aided by war prices, and an attempt to can kippered herring on a large scale. The canning project failed for want of a market, and the pickling industry waned owing to the small size of the southeastern Alaska herring in comparison with those taken in the newly opened Prince William Sound district. These facts, together with a tremendous slump in the herring oil market, are responsible for the drop in 1921 which can in no way be assigned to biological factors.

TABLE 33.—*Pounds of raw herring caught in southeastern Alaska, 1910 to 1928*

Year	Used for reduction	Pickled	Used for bait	Dry salted	Canned	Miscellaneous	Total
1910----------	11,780,000	305,448	1,573,359	76,152	----------	----------	13,734,959
1911----------	15,052,000	743,496	5,096,000	3,217,890	----------	4,000	24,113,386
1912----------	10,540,000	1,130,376	6,711,500	13,702,093	----------	51,000	32,134,969
1913----------	11,660,000	912,512	5,613,689	8,783,398	----------	21,714	26,991,313
1914----------	8,640,000	1,150,198	5,800,180	1,045,420	----------	----------	16,635,798
1915----------	5,835,000	2,690,116	5,403,410	----------	----------	----------	13,928,526
1916----------	8,474,000	7,586,480	4,407,050	328,990	1,488,750	102,000	22,387,270
1917----------	9,236,000	5,688,696	6,247,380	25,050	3,693,375	----------	24,890,501
1918----------	6,170,000	21,022,917	4,871,935	1,169,000	2,378,925	37,500	35,650,277
1919----------	7,330,818	5,386,798	3,284,455	851,700	5,070,075	----------	21,923,846
1920----------	25,520,118	1,578,102	5,525,500	----------	269,775	11,500	32,904,995
1921----------	4,529,250	3,620,068	3,875,048	----------	----------	----------	12,024,366
1922----------	16,558,025	14,314,926	2,964,015	----------	----------	62,750	33,899,716
1923----------	34,928,897	3,744,463	3,807,139	----------	----------	----------	42,480,499
1924----------	50,631,732	4,409,372	3,449,800	287,240	----------	12,000	58,790,144
1925----------	100,859,050	6,903,483	7,331,825	455,910	----------	12,750	115,563,018
1926----------	141,956,289	2,014,577	3,706,878	----------	----------	8,688	147,686,432
1927----------	93,825,293	4,414,776	7,413,655	----------	----------	23,788	105,677,512
1928----------	117,552,660	5,831,643	7,070,626	----------	----------	----------	130,454,929
Total----------	681,079,132	93,448,447	94,153,444	29,942,843	12,900,900	347,690	911,872,456

Since 1922 the causes of the fluctuations in the catch may be more readily ascertained owing to the completeness of our records, and the adoption by that date of the power purse-seine boats by all except the Killisnoo and Big Port Walter plants. The catches and the boats of these two plants have been excluded in order that our data might be comparable from year to year. The catches of all of the other reduction plants, the number of purse-seine boats employed, and their total net tonnage have been plotted on a logarithmic scale, so that their rates of change might be readily compared. (Fig. 47.) The number of boats increased at a very slightly lower rate than the catch, but this is to be expected owing to the larger size of the newer boats. The total net tonnage has been plotted so that the catching capacity of the purse-seine fleet may be comparable from year to year. For five years, from 1922 to 1926, the total net tonnage and the catch increased at almost identically the same rate. In 1927 the catch decreased sharply but commenced to rise again in 1928, although at a slightly lower rate than formerly. At the same time the number of boats showed a very slight drop, compensated for by the increase in the net tonnage.

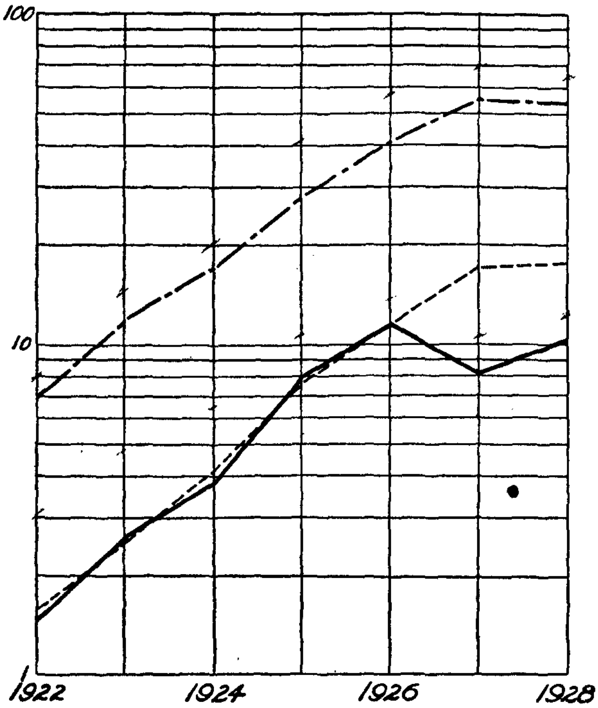

FIGURE 47.—The catch of raw herring and the gear used in southeastern Alaska from 1922 to 1928, inclusive (see text), plotted on a logarithmic scale to show the comparative rates of change. Dot and dash line, number of purse-seine boats. Broken line, total net tonnage of the purse-seine boats in hundreds of tons. Solid line, catch of raw herring in tens of millions of pounds

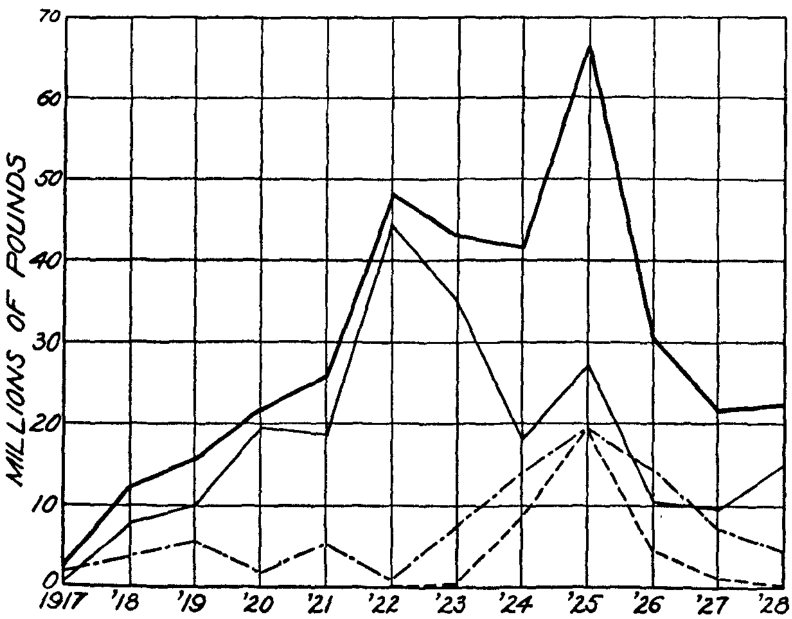

FIGURE 48.—Total catch of raw herring in central Alaska from 1917 to 1928, inclusive. Heavy solid line, total. Light solid line, Prince William Sound. Dot and dash line, Cook Inlet. Broken line, Shuyak Strait

The conclusions are that up to 1926 these statistics of the catch give no evidence of a decline in southeastern Alaska. Since that time the herring have decreased in abundance. Whether this is due to depletion or to a temporary natural fluctuation is not known, but if the catch continues to decline it must be taken as evidence of depletion.

CENTRAL ALASKA

The fishery of central Alaska covers a greater area than that of southeastern Alaska and is more sharply demarked into districts, of which there are three—Prince William Sound, Cook Inlet, and the Kodiak-Afognak Islands. Although these districts are separated from one another by a considerable distance, yet most of the larger operators fish in all three. For this reason the whole area will first be considered as a unit. (Fig. 48, Table 34.) As shown by Figure 48, far the greater part of the c tch has come from Prince William Sound, Shuyak Strait, and Cook Inlet. The simultaneous rise in the Cook Inlet and Shuyak Strait catches in 1924 and 1925 was caused by the expansion of the fishery. Prior to 1923 no one had fished in Shuyak Strait, and the Cook Inlet fishery was limited to gill netting in Halibut Cove.

TABLE 34.—*Pounds of raw herring caught in central Alaska, 1912 to 1928*

Year	Used for reduction	Pickled	Used for bait	Dry salted	Canned	Total
Prince William Sound:						
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
Cook Inlet:						
1914		311, 346				311, 346
1915		29, 400				29, 400
1916		138, 474				138, 474
1917		1, 886, 745				1, 886, 745
1918		3, 970, 029				3, 970, 029
1919		5, 246, 386	50, 000			5, 296, 386
1920		1, 918, 497				1, 918, 497
1921		4, 587, 576		634, 600		5, 222, 176
1922		606, 890		400, 800		1, 007, 690
1923		7, 455, 105		107, 251		7, 562, 356
1924		11, 551, 371		2, 528, 631		14, 080, 002
1925		18, 049, 333		1, 176, 148	2, 850	19, 228, 331
1926		14, 188, 231		84, 168		14, 272, 399
1927		6, 887, 314	109, 500	184, 535		7, 181, 349
1928		3, 864, 112		440, 045		4, 304, 157
Shuyak Strait:						
1923		397, 800				397, 800
1924		8, 421, 660				8, 421, 660
1925		19, 095, 172	30, 000			19, 125, 172
1926		4, 720, 677	45, 700			4, 766, 377
1927		1, 097, 031	177, 000			1, 274, 031
1928		3, 120				3, 120
Izhut Bay:						
1922		19, 500				19, 500
1924		273, 000				273, 000
1925		808, 470				808, 470
Raspberry Strait:						
1922		563, 745				563, 745
1923		12, 363				12, 363
1927		263, 055				263, 055
Uganik Bay:						
1923		46, 800				46, 800
1924		167, 115				167, 115
1925		29, 578				29, 578
Uyak Bay:						
1917		5, 304				5, 304
1918		33, 384				33, 384
1919		624				624
1920		5, 304				5, 304

TABLE 34.—*Pounds of raw herring caught in central Alaska, 1912 to 1928*—Continued

Year	Used for reduction	Pickled	Used for bait	Dry salted	Canned	Total
Dry Spruce Bay: 1922		30,615				30,615
Kizhuyak Bay: 1922		930,540				930,540
Vicinity of Kodiak:						
1912			40,000			40,000
1916		140,400				140,400
1917		270,504				270,504
1918		203,424				203,424
1919		514,800	4,000			518,800
1920		86,424				86,424
1921		194,688				194,688
1923		110,136				110,136
1924		207,870				207,870
1926		21,645				21,645
1927		22,815				22,815
Shearwater Bay:						
1921		681,174				681,174
1922		1,420,770				1,420,770
1923		75,855				75,855
1924		576,420				576,420
1925		30,810				30,810
1926		573,885				573,885
1927		3,625,830				3,625,830
1928		2,856,945				2,856,945
Three Saints' Bay: 1926			231,700			231,700
Kiavik Bay lagoon: 1921		1,014,000				1,014,000
1912			40,000			40,000
1914		311,346				311,346
1915		29,400				29,400
1916		278,874				278,874
1917		2,392,011	270,482			2,662,493
1918		11,437,737	691,800			12,129,537
1919		12,866,658	465,126		2,565,300	15,897,084
1920	10,355,700	11,195,816	20,000		375	21,571,891
1921	1,914,000	23,186,677	12,000	634,600		25,747,277
1922	6,784,757	40,717,285	524,600	400,800		48,427,442
1923	13,854,488	27,828,962	1,451,759	107,251		43,242,460
1924	12,446,879	25,413,459	1,387,750	2,528,631		41,776,719
1925	17,117,594	48,086,699	44,250	1,176,148	2,850	66,427,541
1926	7,479,322	22,091,217	989,950	84,168		30,644,657
1927	4,771,314	16,275,463	628,250	184,535		21,859,562
1928	13,863,218	7,657,604	340,000	440,045		22,300,867
Total	88,587,272	249,769,208	6,865,967	5,556,178	2,568,525	353,347,150

The number of purse-seine boats and the catch for central Alaska are shown on a logarithmic scale in Figure 49. From 1918 to 1923, inclusive, all of the gill-net

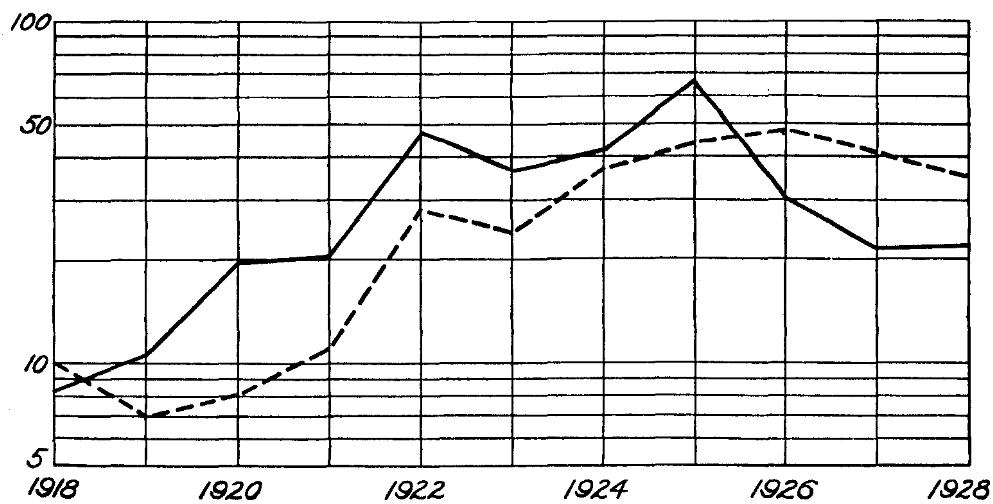

FIGURE 49.—The catch of raw herring and the gear used in central Alaska from 1918 to 1928, inclusive (see text), plotted on a logarithmic scale to show the comparative rates of change. Broken line, number of purse-seine boats. Solid line, catch in millions of pounds

catch from Cook Inlet has been subtracted from the central Alaska catch. From 1924 on, the gill-net and purse-seine catch for Cook Inlet can not be accurately segregated, but the purse-seine catch makes up much the greater part, the gill-net portion being less than in the previous years. However, any slight error in the comparison introduced by the inclusion of this small amount of gill-net catch, being present only since 1924, is an error that will tend to obscure rather than to emphasize any depletion that may have occurred. Up to 1925 the catch increased at a very slightly lower rate than the number of boats, then the catch declined sharply in 1926 and 1927, rising only a trifle in 1928. The fact that the catch declined in spite of the exploitation of new areas suggests depletion.

Prince William Sound.—The fishery of Prince William Sound—the largest producing district in central Alaska—deserves special mention. Figure 48 shows that the total catch rose to a maximum in 1922 and has since declined. Reference to Figure 50, in which the catch, the number of purse-seine boats, and the pickled portion of the catch are plotted on a logarithmic scale shows that the catch and the number of boats increased almost proportionately until 1922, while since that time

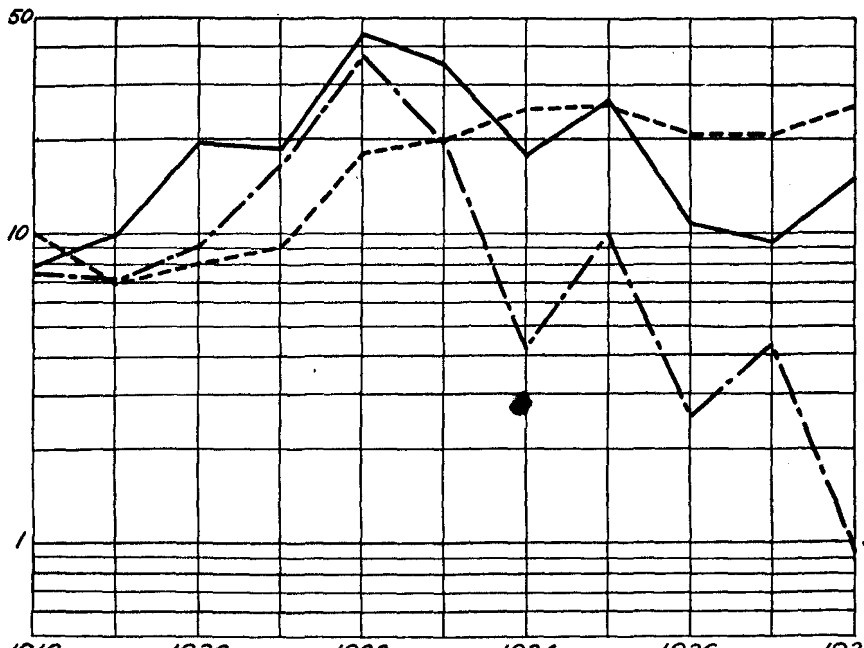

FIGURE 50.—The catch of raw herring and the gear used in Prince William Sound from 1918 to 1928, inclusive, plotted on a logarithmic scale to show the comparative rate of change. Broken line, number of purse-seine boats. Solid line, total catch in millions of pounds. Dot and dash line, portion of catch used for pickling

the number of boats shows a slight increase but the catch has declined rapidly. The low catch per boat in 1918 is undoubtedly due to the fact that nearly all of the Prince William Sound plants were built in that year.

Of far greater importance, however, than the fall in the total catch, is the decline in the amount of the catch used for pickling, since this portion of the catch (composed of fish over 9½ to 10 inches in total length) represents the bulk of the mature spawning population on which the fishery must depend for its continuance. From 1922 to 1928 the amount of herring used for pickling has decreased at the average rate of about 45 per cent per year. Even this does not give an adequate picture of the true significance of the fall unless one remembers that the bulk of the herring pickled in 1926 and 1927 (see figs. 37 and 39) were spawned as early as 1920, and the very small portion of the catch which was pickled in 1928 was composed largely of herring spawned in 1922 and 1923. Just because fluctuations in the catch may be caused by dominant year classes, it must not be supposed that a very small spawning population is sufficient for the continuance of a prosperous fishery, and the very fact that the success of spawning does vary, makes it more necessary that there be an adequate number of spawners to tide over periods of unfavorable years. Since the offspring of the abundant adult population of the early years were so greatly reduced in numbers before reaching maturity, one can not hope that the small numbers of offspring that will survive to maturity from the spawning of as scarce an adult population as that of 1928 will be sufficient to maintain the fishery.

Cook Inlet.—The analysis of the data in Cook Inlet is complicated by the fact that two methods of fishing are employed, gill netting and purse seining. Previous to 1923 only gill nets were employed, but in that year one purse seine was used, and

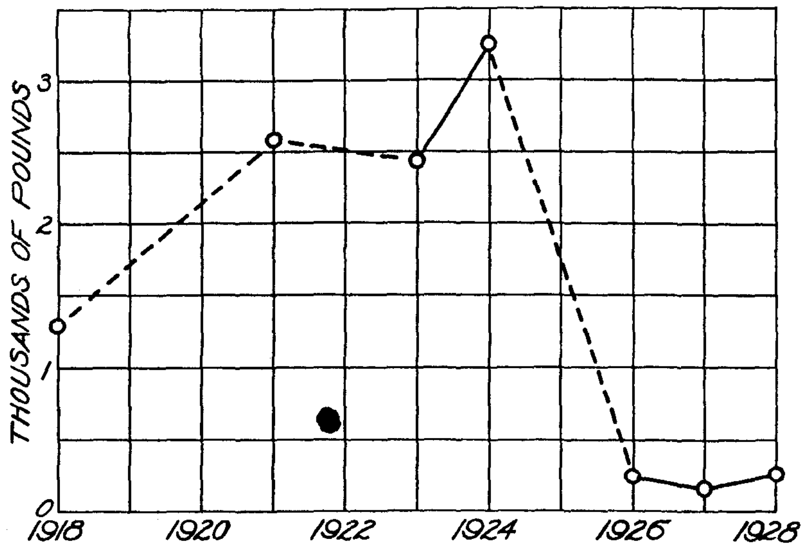

FIGURE 51.—Th catch of raw herring per fathom of gill net in certain years from 1918 to 1928, inclusive, in Kachemak Bay, Cook Inlet

since then gill netting has played a minor rôle. Unfortunately, no records are available which show the total number of gill nets fished each year, or which separate the gill-net and purse-seine catches of those operators employing both methods of fishing. However, there are seven years in which we have accurate records of the fathoms of gill net used by a portion of the operators. For these years the following data are available:

Year	Fathoms of gill net	Pounds of raw herring caught	Year	Fathoms of gill net	Pounds of raw herring caught
1918	1,782	2,313,339	1926	4,370	1,051,932
1921	500	1,293,968	1927	6,110	982,181
1923	450	1,097,355	1928	3,075	795,115
1924	550	1,810,496			

From this has been calculated the average catch per fathom of gill net. (Fig. 51.) Among the earlier years there are records of the gear only in 1918. If this one year is representative of the abundance of that period, there was a considerable rise up to the level of 1921 to 1924. If this rise is valid it can be accounted for by a change in the gill nets themselves, for during the early years of this fishery the fishermen used chiefly salmon purse-seine web of 3½-inch mesh (stretched measure). Their use at Halibut Cove is mentioned in the Pacific Fisherman as recently as April, 1920. Residents of Halibut Cove say that since that time 3-inch mesh herring gill nets of finer twine were used exclusively. Although the points on the curve for 1921, 1923, and 1924 are not based on many data, yet their close agreement lend them validity. The 1926, 1927, and 1928 points are based on ample data. The fall between 1924 and 1926 would appear to be rather too sudden to be caused by depletion (when the gill-net fishery had kept up so long) were it not for the fact that this is the period when the purse seiners commenced an intensive fishery just outside of Halibut Cove. We must conclude that the gill-net fishery in Halibut Cove presents strong evidence of a decline in the numbers of older fish.

As mentioned above, all of the purse-seine and gill-net catches can not be accurately segregated, but since the great bulk of the take since 1924 has been caught by

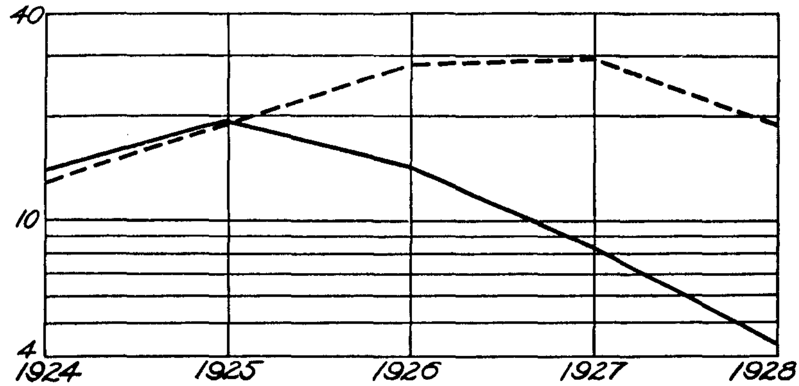

FIGURE 52.—The catch of raw herring and the gear used in Cook Inlet from 1924 to 1928, inclusive (see text), plotted on a logarithmic scale to show the comparative rates of change. Broken line, number of purse-seine boats. Solid line, catch in millions of pounds

purse seiners, the rates of change in the total amount of the catch and the number of purse-seine boats have been compared by plotting them on a logarithmic scale. (Fig. 52.) The data for the number of boats is subject to the following minor errors—to plus or minus one boat in 1924 and in 1925, and to the exclusion from the number of boats in 1928 of several that visited the district for short periods and left because of lack of fish. The errors in 1924 and 1925 are too small to be regarded. In 1928 those boats making short stays in the district were excluded so as to allow no personal judgment to creep into the analysis as to which boats could be said to have actually fished in the district. In 1924 and 1925 the boats and the catch increased at practically the same rate. Since then the catch has decreased at an average rate of over 35 per cent each year, while the boats continued to increase until 1927, then decreased between 1927 and 1928 although at a lower rate than the catch. From the evidence afforded by this analysis of the purse-seine catch it must be concluded that the Cook Inlet fishery shows a decline in abundance. This is substantiated, as mentioned above, by the failure of the gill-net fishery.

Shuyak Strait.—For Shuyak Strait the catch and the number of boats are shown in Figure 53. They have not been plotted on a logarithmic scale because it is felt that in this instance the two are proportional only within certain limits. All of the fishing is carried on in one tiny, sheltered bay, about 1½ miles by 1 mile. Due to the restricted area fished and the ease of impounding there is doubt that, after reaching certain limits, trebling the number of boats would materially affect the catch. During the first two years of the fishery the catch was limited chiefly by the lack of sufficient packing facilities. In 1925 these facilities were taxed to the utmost, but were probably sufficient for nearly the maximum possible pack, since, owing to the ease of impounding, surplus fish could be held for many days and the plants kept constantly busy.

From 1926 on, the facilities have been sufficient for a much larger pack than that of 1925. The drop in the number of boats in 1927 was due to the closure of the waters of Afognak reserve to all but native fishermen, but it can readily be seen

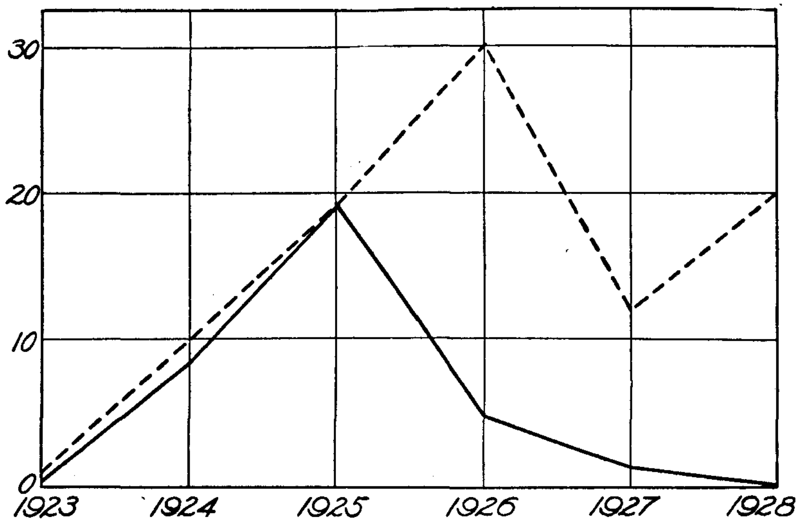

FIGURE 53.—Catch of raw herring and gear used in Shuyak Strait from 1923 to 1928, inclusive. Broken line, number of purse-seine boats. Solid line, catch in millions of pounds

that the number of boats was sufficient for a much greater pack had fish been available. From the catch analysis one must conclude that there has been a tremendous decrease in abundance.

CONCLUSIONS

From the statistical analysis of the catch the following conclusions may be drawn:

1. In southeastern Alaska the abundance remained practically at a level from 1922 to 1926, fell sharply in 1927, but recovered slightly in 1928.

2. In central Alaska as a whole, owing to the exploitation of new areas, the rates of change of the catch and the numbers of boats were similar from 1918 to 1925, but the catch has declined markedly the past three years.

3. In Prince William Sound except for minor fluctuations the abundance has declined progressively since 1922. This fall in abundance has been especially rapid in the larger sizes.

4. In Cook Inlet the fall in the catch per fathom of gill net indicates a tremendous decrease in abundance of at least the larger sizes between 1924 and 1926.

5. In Cook Inlet the abundance, as shown by the comparative rates of change of the catch and of the purse-seine fleet, has fallen steadily since 1925.

6. In Shuyak Strait the catch commenced to decline in 1926 and reached the vanishing point by 1928.

EVIDENCE OF DEPLETION

The results of the statistical analyses, the study of the composition of the catch, and other information give evidence that, in some instances, points to depletion.

One evidence of depletion, the value of which is strengthened by the results of the study of the independence of areas, is the lack of continuity of the fishery in any one locality. The occasional appearance of dominant year classes may serve to explain fluctuations in abundance but hardly explains the scarcity of herring over long periods of years in localities where they formerly were abundant. This condition exists in Kootznahoo Inlet (Moser, 1899), Yakutat (Moser, 1902; Alexander, 1912), and Yes Bay (Bower and Fassett, 1913). That this discontinuity can scarcely be due to migration is shown by the results of the studies on the independence of areas. Depletion would seem to be the logical cause for these declines in abundance.

In the summer fishery of southeastern Alaska the abundance, as shown by the rates of change of the catch and the number of seine boats, decreased sharply in 1927, but recovered somewhat in 1928. However, in 1928 a considerable portion of the pack came from areas 1, 9, 12, and 13 (fig. 8), distant areas scarcely touched by the summer fishery of previous years, so that the decline in abundance shown in 1927 may have actually continued in 1928, although obscured by the exploitation of these more distant areas. Should this decline continue it must be considered as evidence of depletion.

Another possible evidence of depletion in southeastern Alaska is the failure of the amount pickled, consisting of larger fish (fig. 46), to rise in conjunction with the tremendous increase in the total catch. However, there are so many factors involved, economic and otherwise, as to make any conclusions speculative, for in this district the pickling of herring has long been merely an adjunct to the oil and fish-meal industry. The increase in the size of the boats and the spread of the fishery to more distant areas would have much influence on the condition of the fish as received at the plant, perhaps preventing an increase in the amount pickled.

In Prince William Sound the abundance has declined since 1922 with minor fluctuations. This decline has been especially sharp in the pickled portion of the catch, consisting of the larger fish. In this case the decrease in the amount pickled represents a real decrease in the abundance of older fish, as in this area the pickling of herring has always been the major object of the fishery. Although there are minor fluctuations that may be caused by factors which we can not estimate, such as the varying accessibility of the schools, yet the sharp downward trend over a 6-year period gives evidence of depletion.

In Cook Inlet the great decrease in the catch per fathom of gill net since 1924 indicates a decrease in abundance of at least the larger fish. The analysis of the purse-seine fleet shows that during this period both the gill-net and purse-seine catch were decreasing. The age analyses show that there were many year classes present so that the decline in abundance can not be construed as a mere temporary decline due to the passage of dominant year classes. Hence, depletion is believed to have occurred.

In Shuyak Strait the catch commenced to decline in 1926 and had fallen to practically nothing by 1928. The presence of fish of many year classes in the catch indicates that this decrease can not be assigned to the passage of dominant year classes. The decrease in abundance has been so rapid and so great as to cause one to question whether it can be due to depletion, but the concentration of large quantities of gear in the very restricted area fished makes it appear quite probable that such has been the cause.

SUMMARY

The following brief summary is given of the main conclusions reached in this paper:

BIOLOGY

1. The Pacific herring is very closely related to the Atlantic herring.
2. Herring of 1 and 2 years of age occur close inshore. In the summer months they mingle only slightly with the schools of older fish.
3. The schools of mature herring disappear after spawning and reappear in summer. They approach the shore in the fall and remain in close proximity thereto until spawning time.
4. The herring are naturally smaller in the southern part of their range and increase in size toward the north and west, the largest being found along the Alaska Peninsula and in the Aleutian Islands.
5. The existence of separate populations of herring has been demonstrated in California, southern British Columbia, Craig, Chatham Strait, Stephens Passage, Prince William Sound, Kachemak Bay-Shuyak Strait, Shearwater Bay-Old Harbor, Chignik, Shumagin Islands, Unalaska, and Golovin Bay. Dogfish Bay herring may also be a distinct stock but more data are needed to confirm this.
6. The herring spawn later in the northern and western portions of their range than in the southern.
7. In Kachemak Bay, central Alaska, 52 per cent of the 3-year olds, 83 per cent of the 4-year olds, and all of the 5-year olds were mature.
8. In Stephens Passage, southeastern Alaska, 84 per cent of the 3-year olds and all of the 4 and 5 year olds were mature.
9. The age of the Pacific herring can be determined with a fair degree of accuracy from the scales.
10. The differences in rate of growth are marked. At 6 years of age the Unalaska herring are 6.5 centimeters longer and 2.8 times heavier than Stephens Passage herring.
11. The date of attainment or loss of sufficient fatness for pickling will vary at least two weeks in different years.
12. The condition (or fatness) attained by any certain date may vary considerably between adjacent localities.
13. The maximum condition attained will vary considerably from year to year.

CONDITION OF THE FISHERY

1. Owing to the short periods during which samples are obtainable from any one locality in central Alaska, the proof of the validity of sampling must be placed largely upon the repeated occurrence of consistent variations.
2. Dominant year classes are normally present.

3. The progression of sizes due to the growth of dominant year classes is reflected in the commercial catch.

4. The similarity or difference between the dominant year classes in two adjacent localities gives indications for or against the independence of the two populations.

5. In southeastern Alaska the abundance of herring remained practically at a level from 1922 to 1926, fell sharply in 1927, but recovered slightly in 1928.

6. In central Alaska, owing to the exploitation of new areas, the rates of change of the catch and the number of purse-seine boats were similar from 1918 to 1925, but the catch has declined markedly in the past three years.

7. In Prince William Sound, central Alaska, except for minor fluctuations the abundance has declined progressively since 1922. This fall has been especially rapid in the larger sizes.

8. In Cook Inlet, central Alaska, both the catch per fathom of gill net and the comparative rates of change of the number of purse-seine boats and the catch show a decline in abundance since 1925.

9. In Shuyak Strait, central Alaska, the catch commenced to decline in 1926 and reached the vanishing point by 1928.

10. The lack of continuity of the fishery in any one locality gives evidence of depletion.

11. There is some evidence of depletion in southeastern Alaska, but the data on hand do not offer sufficient proof.

12. The data indicate severe depletion in Prince William Sound.

13. Depletion has probably occurred in Cook Inlet and in Shuyak Strait.

14. Due to the rapid growth in the third and fourth summers, any certain weight of herring of 2 or 3 years of age is probably more valuable to the species than an equal weight of older fish, indicating that this may be one of the best points in their life history at which to apply protection.

15. It is deemed necessary that additional protection be applied to the herring in the Prince William Sound, Cook Inlet, and Shuyak Strait areas.

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