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THE PACIFIC HERRING.

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Of the numerous species of fish found in the waters of the Pacific Ocean, adjacent to the coast of North America, none plays a more important rôle in general marine economy than a species that is rather despised from a commerical point of view, the Pacific herring. The salmon, the halibut and the cod receive almost all the consideration when North Pacific fish are mentioned, but the herring, if it is included at all, comes as an afterthought. This is not because of any lack of food value or any lack of supply, but rather because of a lack of appreciation of the truly wonderful possibilities of development in the value of the herring industry.

While in the case of the halibut and the salmon there are strong indications that human interference is more or less rapidly decreasing the numbers, in the case of the herring the human factor has been too insignificant to make any material impression.

As a species the herring has a more extensive distribution than any other food fish of the coast, with the possible exception of the spring salmon, as apparently there is an abundance all the way from San Francisco, or farther south, to the Arctic Ocean. In all the wide range there is little difference in general appearance and habits, as far as I have been able to ascertain, except that in Bering Sea there appears to be a race in which the individuals grow much larger than at other points along the coast. As I have been unable to get any of these for examination I have no opinion to offer as to the cause of such difference.

For several years I have made use of opportunities for observing the habits of the herring and for collecting data on the life history, and while much of the material remains to be worked up and many of the data are still to be correlated, since specimens have been obtained at all times of the year and at all ages a somewhat connected idea of the life history has been obtained.

Most of the observations have been made in the vicinity of the Biological Station, Nanaimo, B.C., and in general the statements made in this paper will have special reference to these.

In the herring the gregarious habit is carried to the extreme. To attempt to describe the size of, or the numbers in, a herring school to one who has never seen anything of that nature is but to court the destruction of one's reputation for veracity. To watch them as they feed near the surface of the water, or as they are rounded up in a seine, one is struck with the wonderful degree of uniformity in size of all the individuals of the school. Careful measurements of a large number bear out this fact. In the case of those caught in the purse seines, where none has a chance to escape, the average length is about 20 cm. or 8 inches, the caudal fin rays not included, and the average weight 100 grams or 3.6 oz.

The migrations of the herring have been considered among the wonders of the deep. Little speculation has been reported about the Pacific species, but its habits are much like those of the Atlantic species, about which so many theories have been propounded. There is nothing to indicate that the movements of the Pacific herring are any more mysterious than those of any other active fish, but since they move about in such large schools their presence or absence in any one location is much more readily observed. I cannot find any reason for thinking that any herring that are found in the strait of Georgia have ever been away from the strait or the various channels adjoining, and it may readily be that the radius of activity is limited to comparatively few miles. Their movements seem to be due largely to the necessity of following up the food supply. The main basis of that supply is provided by copepods. Among hundreds of stomachs examined I do not remember finding a single one in which the contents were recognizable where there were not copepods, as eggs, larvæ or adults, no matter what else was found. The necessity for a supply of these copepods is, therefore, constant. I have never counted the number present in the stomach of a mature herring, but in a young herring 6.6 cm. long, over 3,000 copepods were present. As digestion takes place very rapidly that would probably by no means represent the number taken in a whole day. When this is true for a herring six months old, how many must be needed for a mature fish, and then how many for a school of fish having several million individuals? When it is impossible to conceive of such a number is it any wonder that there is often a sudden migration of the fish to catch up with the food supply? Even if the copepods are numerous they do not remain indefinitely in any one locality. They are affected by temperature, intensity of light, by currents and probably by the degree of salinity and many other conditions, and in the case of some at least of these conditions, the change will affect the copepods in mass. In these wanderings the herrings must follow. A school of herring can be observed only when these herring are feeding near the surface of the water. They have not far to go from the shallow water near shore to get into water deep enough to cover up all evidence of their presence.

It is true that by going back to the copepods the matter of migration is simply removed one step further. Another step is made by passing on from copepods to diatoms on which they feed. This places a limit as far as organisms are concerned, unless bacteria have something to do with preparing the food for the diatoms. The processes preceding must be left to the physiologist, the chemist and the physicist. This is not all that is to be said in the matter however. In February and March, when copepods and diatoms are scarcer than usual in the surface waters of the strait, the herring find it necessary to supplement the copepod diet. 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 the 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. Mollusc eggs, decapod and other crustacean larvæ, ascidian larvæ and rotifers are also eaten, but in

no case have I found them to be the main portion of the diet. After the spawn has been deposited it appears to be a common thing for them to gorge themselves with it. On one occasion out of 94 herring examined 76 of them were so gorged. Later, when the eggs are hatched out, many of the young fry meet with the same fate. During all this time the large schools spend the greater portion of the time in shallow water, since the nature of the food at that time makes this a necessity.

Since the spawning season has been mentioned some consideration of this season here may be in place. As far as the Nanaimo district is concerned there is nothing perplexing about the spawning season of the herring as there is in the case of the North Sea herring, since there is a single quite definite season, the last days of February, through March and early April. All the evidence, and it is quite conclusive, goes to show that no spawning takes place at other times.

Herring are caught throughout the year. For some time after spawning the gonads are empty, very little evidence of renewal showing before the end of the third month. At the end of four months the eggs are still very small, each gonad weighing less than a gram. From that time on the growth is noticeable. Much variation in the size of the egg and the weight of the gonad is to be expected as the young fish spawning for the first time produces fewer and smaller eggs than older fish. At the end of six months the weight of the gonad varies from 2 to 5 grams, and this difference becomes more marked as the spawning season approaches. Young herring may have mature gonads with each gonad weighing less than 5 grams, while for a female the greatest weight observed was 18.6 grams and for a male 28 grams. The increase in the size of the egg will give some idea of the increase in the size of the gonad. On October 10 the average diameter was .7 mm.; on November 9, .85 to .9; on December 12, 1.0 to 1.05; on January 28, 1.1 to 1.2; on February 8, 1.25 to 1.30; on February 22, 1.35 to 1.40; and on February 28 (spawned), 1.4 to 1.6.

For several days before the spawning begins the herring appear in the shallow water near shore, actively feeding on the barnacle larvæ as well as any copepods that may be obtained. The fishermen say they come in to look for suitable grounds for spawning, but why should they do so such a length of time ahead when they have been in and out of the shallow water several times in the preceding months, and even when they are farthest from shore they could come in in a few hours at most? In any case spawning does take place in shallow water, so shallow at times that individuals perish by being left high and dry on account of a flip out of the water near shore. There must be a large supply of eel grass or seaweed of the pliable kind present, such stiff material as kelp being seldom made use of. Against the seaweed the female rubs as the spawn is liberated and, as the spawn is very adhesive, all of it remains attached. One fish may rub against many pieces of weed or grass before the spawn is all liberated, but as the fish are so close together and may spawn over the same area several days in succession, every particle of a weed may become coated several layers thick. Immediately after the female liberates the spawn the male follows, rubbing against the seaweed in the same way. The milt in mass adheres for a short time,

but it soon separates and permeates the water to such extent that the water becomes opaque. When the spawning of a large number takes place at the same time the opaque area may reach for miles, so dense that the herring darting through the water, even when only a few inches from the surface of the water, appear but as shadows and if they are down a couple of feet they will not be seen at all.

As the herring spawn somewhere in the vicinity of the Biological Station every year there has been plenty of opportunity for observation, and during several seasons a careful watch was kept over certain of these spawning areas. The herring do not spawn in the same place season after season as some other fish apparently do. A thorough survey of the spawning grounds of one year may be of no assistance in finding the spawning grounds of the next year. While the areas of one year may overlap the areas of another year I have never known them to correspond exactly in two succeeding years.

In a previous paper[1] some description of the spawning areas was given, but further observation has shown that the matter is not so simple as at first it seemed. The spawning dates for different areas were quite correct, but it was not realized that at times spawning takes place day after day for a considerable period; it may take place for a number of days in succession, cease for a short time and then begin again, or it may take place over a short period only, even for a single day. The longest period, day after day, recorded, extended from March 19 to April 5, 1916. This was around Horswell rock, at the northern entrance to Departure Bay.

Where spawning takes place in the same area day after day the spawning is by no means continuous. It seldom occurred outside of the period between 12 noon and 5 p.m. The height of the tide evidently had nothing to do with it as the spawning was at its height at different times of the tide each day. On this account, since the spawn is always deposited in shallow water, usually less than 6 feet, much of that which is deposited at high tide is left exposed for some hours at low tide, particularly at spring tide. These exposures seem to do no harm, unless there is too much bright sun during the exposure. As the majority of really low tides come at night during that season such a thing seldom happens.

It is not for lack of seaweed areas at greater depths that the shallow water is used, as it often happens that the bottom at a little greater depth is much more densely covered than the bottom near shore.

After spawning is over the herring are in no hurry to leave the shallow water. They have been seen in Departure Bay in intervals during April and May, and this year a small school stayed around continuously until the end of June.

The dangers of the deep water must be great if they are much greater than the dangers of the shore and shallow water. While the herring are spawning they are naturally not so active as at ordinary times and hence they fall a prey to their enemies the more readily. As they are so near the surface the gulls can see them and reach them readily. Since there are myriads of these they must cause the disappearance of innumerable herring just at the time when protection is most needed. The dogfish, doubtless their enemies at all times,

[1] On Clupea pallasii Cuvier and Valenciennes. Trans. Royal Can. Inst., 1916, p. 97-108.

are able to take their toll with greater ease and in consequence it is nothing out of the way to find one with five or six herring in its stomach. The spring salmon and many others of the larger fishes at times, at least, find herring a satisfactory diet.

The danger to the fish is not the only danger, however, as the spawn exposed at low tide is in position to suffer extensively. The effect of the weather has already been mentioned, but much greater destruction is caused by the animals that use spawn for food. In the Nanaimo district the various species of ducks, especially the surf scoter, take predominance in this regard. These may be seen by hundreds of thousands, and as each must get rid of millions of eggs per day, it would be hard indeed to estimate the damage done in a season in this way. I should have no hesitation in saying that I have seen sufficient numbers of ducks feeding within a radius of five miles to destroy more fish—in the embryo of course—in one day, than all the fishermen on the coast catch in a year. Many fish, including the herring itself, as well as shore species among the invertebrates, feed on this spawn, but all of these taken together must make a small showing when compared with that taken by the ducks. It is well that the embryonic life is short. If it were as long as that of the salmon, for instance, it would seem as though none of the eggs would ever get a chance to hatch.

Nor is the danger ended with the hatching out of the eggs. When the fry are still young, in the alevin stage, they are rather helpless since they are usually found carried into large masses by the currents in such a way that they can readily be seen and seized, more particularly by the many species of fish that enjoy very young herring for breakfast. Here again the mature herring is one of the many offenders.

The eggs when ripe are 1.4 to 1.6 mm. in diameter and in weight they run from 900 to 1,200 to a gram weight of ovary, and the number of eggs varies much with the age of the fish. Those spawning for the first time produce about 12,000 eggs, while the oldest or largest fish produce about 35,000. The development of the embryo until the time of hatching has been described in the paper to which reference has been made. After the yolk is absorbed the activity is immediately increased. The individuals become more separated, but still remain in large schools, and growth takes place quite rapidly.

The young herring just liberated from the shell membrane is 7 mm. long. When the yolk is all absorbed it is about 1 mm. longer. At this time the pectoral fins are present in the form of small flaps and the caudal fin is present, but the anal fin is not separated from it. These are not supported by fin rays. None of the other fins are distinct. At a length of 12 mm. the dorsal fin appears as a slight elevation; at 14 mm. the dorsal fin rays begin to appear. At 18 mm. the end of the vertebral column, which up to this time has been straight, begins to turn up to form the urostyle. At 20 cm. the urostyle is completely turned upward, the dorsal and anal fin rays begin to show; the dorsal fin has 16 rays. At 22 mm. a slight protuberance indicates the beginning of the pelvic fins; at 26 mm. these take definite shape; at 29 mm. the pelvic fin rays begin to appear. At 35 mm. definite pectoral fin rays appear.

Until now the young fish looks little like the older herring, but about this

time, 35 to 40 mm., the metamorphosis takes place, at which time the scales begin to grow. This occurs about the end of June or the beginning of July. In six months the fish are about 6 cm. long and in a year 9 to 10 cm. During all of this period they live in immense schools along the shore and more particularly around the wharves and floats, where they mix freely with sticklebacks, various species of young perch, sand launces and other small fish. Their staple diet, as in the case of the older fish, consists largely of copepods. These may make up the entire food supply and only occasionally does anything else predominate. Here also the diet may be varied by the nauplius and cypris larvæ of barnacles, other crustacean larvæ, molluscan larvæ and eggs, ascidian larvæ, rotifers and peridinia.

At much the same time as the mature herring leaves the shallow water for the deep, the yearlings do also. Nothing has been observed to indicate that they go out in the same schools. During the summer they are caught with hand lines in swiftly running water in some of the main passes between the islands, and in such cases they are not in very deep water. In the seine hauls made from September to March there are seldom any young fish. It might be supposed that they are small enough to pass through the meshes of the net leaving only the larger ones in the net, but this can scarcely be correct as there are exceptions to the general rule. One instance will illustrate. In November, 1914, the fishermen were working off Cowichan Gap (Porlier Pass) and all the catches lacked the usual uniformity. The fish were smaller than usual and consisted of fish of many different sizes. On November 27 Mr. H. McIndoo, Fisheries Overseer at Nanaimo, brought me in a pailful, taken without sorting, from one of the catches. The 79 fish brought in were of 50 different lengths, differing from 8.8 to 22.0 cm. One was in the first year, 6 in the second, 47 in the third, 15 in the fourth, 8 in the fifth and 2 in the sixth. From this it would seem that if the small fish were with the large ones on ordinary occasions they would be caught as they were in this case. Furthermore, on different occasions, I have watched a school of herring in continuous procession for hours pass a point and often for shorter periods without seeing any small fish among them.

In their third year some of the herring spawn and these appear with the schools of older fish, but comparatively few, even at this age, are found in the seines. Probably much greater numbers spawn for the first time in their fourth year. If the immature fish keep separate from the mature fish it will be a difficult matter to find the time of the year at which the segregation takes place or what determines the segregation. The North Sea investigators have concluded that there is a time for such segregation among the Norwegian herring, hence further work along that line may establish some important facts concerning this mixing.

Doubtless the immature fish wander in towards shore and out again as the mature fish do, but as they are small they are not observed readily. Whether the individual school retains its main components, making additions from year to year from the young fish to take the place of those that disappear or whether there is promiscuous mixing of schools may not be determined readily, although here again this seems to have been fairly well determined for the North Sea

herring. If the schools wander far there might easily be much mixing. If their wanderings are restricted to a comparatively small area such mixing would not so likely take place to any extent. Coast conditions along the British Columbia coast are not readily comparable to those of the Norwegian coast and with regard to two distinct species one may do nothing more than surmise that the same habits would prevail.

In any case, after a fish has once spawned there is every indication that the process is an annual one for the remainder of its life. It is probable that after the first spawning the individual remains with the same school throughout the rest of its life, although this would be a difficult matter to prove.

Extensive observations over a long period would be necessary to demonstrate the racial differences in the different schools, but there is little doubt that such differences exist, even though, in the main, their habits, times of migration, etc., may be very similar.

The majority of the fish caught in the purse seines are from 4 to 7 years old and none have been found of a greater age than 10 years.