XII.—ON THE SPAWNING AND DEVELOPMENT OF THE COD-FISH.*

By Professor G. O. SARS

Commissioned by the Norwegian government to examine our cod-fisheries, in order to arrive at practical results that may be useful to our fishermen, I have been enabled to observe the spawning and development of the cod-fish, (*Gadus morrhua,*) and shall endeavor to present the results of my observations. I have already, in my former reports to the department, briefly spoken of the most important observations and showed their practical bearing, so that in the following I shall refer only to the scientific features of the subject. It is true that a subject of such general physiological interest as the propagation and development of the higher classes of animals has already been thoroughly treated by many scientists, so that it would seem almost superfluous to write a treatise on this subject; but with regard to the propagation and development of fishes there are but few works, and these comprise only a few kinds, (all fresh-water fishes,) while the observations regarding the numerous salt-water fishes are only scattered here and there in the shape of incidental remarks. Thinking that for the sake of comparison it might be interesting to secure a somewhat connected representation of the spawning and development in one class of salt-water fishes, I determined during my stay on the Lofoten Islands, in the year 1865, to give particular attention to this point, especially as, during former visits to these islands, I had already made very remarkable and unexpected observations of this kind.

Of all our cod-fisheries that which is carried on during the first four months of the year along the Lofoten Islands is the most important and the most profitable. The winter cod-fish at that season approaches the coast in vast numbers for the purpose of spawning. The regularity with which, from time immemorial, the cod-fish has at a certain season come here to spawn, notwithstanding the many difficulties thrown in its way, especially by nets, would lead us to the conclusion that it must find spawning-places here which, on account of the nature of the bottom, are particularly favorable, and where, by instinct, it was compelled to deposit its roe. I was therefore much astonished to hear that this was not the case, and that the cod-fish has no spawning-places which are determined by the nature of the bottom, but that it drops its spawn free in the sea

* Om Vintertorskens, (*Gadus morrhua.*) Forplantning og Udvikling: *in* Forhandl. Vid. Selsk. Christiania, 1866, pp. 237–249. Translated by H. Jacobson.

at a considerable distance from the bottom, and, what is all the more remarkable, that the spawn does not sink to the bottom, but goes through all the stages of its development swimming free in the sea quite near the surface. Nothing like this has hitherto been observed in fishes or any other class of animals, and even the fishermen, who every day for years have had occasion to observe this phenomenon, have a very incorrect idea of the actual facts. They have all observed that at the time when the cod-fish spawns the sea was thick and opaque, as if it were muddy, and all agreed that this must be caused by the spawn of the fish. Some more inquisitive fishermen even tried to examine the matter more closely by taking some of this water home with them. They then saw that the water was swarming with very small transparent bodies looking like pearls, but none of them would admit that this was the spawn of the cod-fish. They thought it might be the empty shell of the spawn which, after the young had crept out, came up from the bottom and floated about on the surface of the sea. The circumstances are so peculiar that I myself, the first time I met these but slightly developed and sporadically occurring little bodies, transparent as a drop of water, was doubtful as to their real nature. By microscopic observation, however, I very soon became convinced of the actual facts. Some time later, when the spawning was going on, I also found these small bodies in great numbers and in every stage of development, even up to the young fish, with all its most important organs clearly developed, lying in the egg ready to slip out. By a study of this egg, from its impregnation till the time when the young fish emerges, I sufficiently convinced myself that this spawn floating about in the sea belonged to the cod-fish and to no other. But as it has thus been proved that the spawning proceeds just as well in the open sea as near the coast, what must, then, be assigned as the cause of the cod-fish's seeking the coast with such eagerness? Two reasons may be assigned for this: the cod-fish does not originally seem to be a gregarious fish, and while it lives in the open sea it, in all probability, is found over a very large area. In order, now, that the spawn may come into close contact—in other words, that the roe may become impregnated—it is absolutely necessary for the cod-fish, which spawns free in the sea, that the originally solitary living fishes should come together in greater numbers, and this could scarcely be done unless they all moved toward the same common rendezvous. Another reason may be the instinctive care which they have for their tender offspring, as it is easier to find food for it near the coast in this the first stage of its development; for, at the same period, many smaller marine animals are just developing themselves. At this season, particularly, I have seen the sea swarming with the small, peculiar-looking larvæ of the balanus, which might very well furnish a suitable food for the young cod-fish.

The approach of the cod-fish takes place early in the season, often long before New Year, and occurs in schools, in such a manner that the schools, which in the beginning are only small, gradually grow larger,

till the time for spawning arrives, when they frequently assume such enormous dimensions that the term "fish-mountain," which is sometimes applied to them, does not seem exaggerated. In all these schools, even in those which come first, the male and female fishes are intermingled, which but rarely occurs among other kinds of fish. Thus, as to the herring, the female fishes always come first, and are followed by the males, which pour their milt over the roe. This peculiarity in the cod-fish is easily explained by the above-mentioned character of its roe; thus, in order that an impregnation may take place, the roe and the milt must be poured out at the same time and mix in the sea. In those fishes which arrive first, the roe and the milt, although tolerably developed, are as yet far from being matured. The roe is still so small-grained that without the microscope the small eggs can scarcely be distinguished. These eggs are of a light yellowish-red color, and show under the microscope a very light outer ring, and an inner opaque fine-grained mass, (yolk.) All the eggs in this stage are connected by a fine texture full of blood-vessels, mostly in irregular, conical processes, all which converge toward the center of the roe-bags. These encircle an inner hollow, into which the eggs are received as soon as they are matured, in order to be carried out through the two longer channels, which start from the inner side of the roe-bag, and which unite toward the back in one. In their further development the eggs constantly increase in size, and, at the same time, become more transparent, till they are almost colorless. They are now almost mature, but still loosely connected by a thin texture, and surrounded by a thin covering, in which the feeding blood-vessels spread in a branch-like manner. Soon, however, this covering bursts, and the mature egg is now cut off from its connection with the rest, and falls into the inner hollow of the roe-bag, from which, by a gentle pressure on the fish's abdomen, it can be brought out through the sexual opening (*porus genitalis*). The eggs are now as transparent as water, about one millimeter in diameter, and appear to the eye like small pearls of clear crystal. Placed in a glass with sea-water, they first sink to the bottom, on account of the downward movements of the water, but rise again, as soon as the water has become calm, to the surface, where they form a closely-packed floating layer. Their specific weight is less than that of the sea-water, and greater than that of fresh water, of which fact one may easily be convinced by placing them in a glass of common drinking-water, in which they rapidly sink to the bottom, without rising again.* The yelk of those eggs which have but recently come out from the ovarium appears, under the microscope, quite clear and transparent,

* This accurately-measured specific weight is of the greatest importance for the development of the egg. If, for instance, it should storm and rain for several days, there might easily be formed a thin layer of mixed sea and fresh water, which would contain less brine; so that if the specific weight of the roe floating in the sea were only a small particle less, this circumstance would have a very injurious effect on its development.

with a very faint yellowish tinge, almost completely filling the egg, and leaving only an extremely narrow space between it and the outer cover, filled with a colorless and utterly incongruous mass. The outer cover or skin is tolerably firm and elastic, and consists, as I have convinced myself by dissecting it, of four different closely-joined layers. One can discover, with the aid of a strong microscope, numerous small oil-bladders of different sizes, and scattered irregularly over the whole surface of the yelk. The egg has another peculiarity, which in the beginning I overlooked, but which, after having had my attention drawn to it, I found invariably in every egg. This is a small dark spot, only discernible through the microscope, which is found in the outer skin, and which is always near that part of the egg that is turned downward. Its location is not exactly the same in every egg, for sometimes it is quite close to the lower part, and sometimes a little higher up on the side of the egg; but among the many hundreds of eggs which I have examined I did not find a single one where this dark spot was above the lower quarter of the egg's diameter; nor a single one where it occupied exactly the lowest point of the egg. This spot is the so-called *micropyle*, which answers a two-fold purpose, namely, to allow the spermatozoa to enter the egg, and, also, during the various stages of development, to draw in water; in other words, it forms the channel of impregnation, and serves as a respiratory organ. Through the most powerful microscope this spot appears as a circular disk of yellow color, surrounded by a somewhat raised edge, and looking as if it were polished. From this spot a narrow channel passes through the skin of the egg, which ends in a funnel-shaped opening. I have not been able to discover any distinct opening in the above-mentioned round disk. It is certain, therefore, that it is not merely a hole in the egg, but seems to be of a porous nature and to possess a peculiar power of suction. But how can the spermatozoa get into the egg through this disk? To the solution of this problem I have devoted special attention by pouring a drop of milt to the eggs, while under the microscope. I have frequently seen the spermatozoa, as often as they came in contact with this disk, remain hanging there, and I could for a long time observe the movements of the tail outside, but I never could see them enter into the egg, although this is so entirely transparent that one necessarily must have seen them if they had entered the clear space filled with water between the skin and the yolk. The most plausible explanation of this phenomenon seems to be this, that the spermatozoa, which in reality are only cells, after having been for some time in close contact with the micropyle, were ruptured in consequence of the latter's suction-power, and that their contents only are absorbed by the egg, a view which, so far as I am aware, has never before been expressed. The spermatozoa of the cod-fish are oval, or rather pear-shaped bodies, to whose pointed end the tail is fastened. The milt, like the roe, is of less specific weight than the sea-water, and it therefore floats upon the surface as soon as it is poured out. This

circumstance may account for the fact that the male fish during the act of spawning generally swims deeper than the female; and likewise for the fact that the micropyle is located near the lower portion of the egg, while with other fish which have been observed this order of things is reversed. After the egg has floated in the water for some time, it undergoes a very striking change. At the lower end the yelk becomes thicker, and viewed from the side appears like a crescent-shaped edge, of a deep yellow, and much more compact than the rest of the yelk. This compact mass grows constantly more distinct, till at last it forms a tolerably large semicircular projection. The yelk has thus secreted those parts which are to serve in the formation of the young fish from the remainder, which is to serve as its food. This portion, however, has still to undergo considerable changes till it is fit to produce the young. At the same time one can observe how the oil-bladders, which were originally scattered over the whole surface, gradually flow together and form larger bladders, gathering in a close circle round the micropyle, and so growing together form a transparent circle round it. These changes take place both in the impregnated and in the unimpregnated egg. The first visible effect of the impregnation takes place after the lapse of a few hours. In the middle of the disk a faint furrow is seen, which gradually becomes deeper, till at last it divides the disk into two symmetrical halves. After this furrow has become somewhat less marked, another one appears in each of the halves, striking the first one perpendicularly, by which process the disk is divided into four divisions of a spherical shape. Each one of these is again divided, so that there are eight divisions, and these again into sixteen, thirty-two, sixty-four, &c., divisions. Finally the disk becomes divided into so many divisions, and these divisions become so small, that the surface of the disk seems just as smooth as at first. With this process *the first period* in the development of the egg terminates. It has continued about four days, (112 hours.) Nothing as yet can be seen of the fœtus, and the disk has only just been prepared to produce it.

The *second period* commences by the disk's upper side, which is turned towards the yelk, and which till then has been quite flat, rising like a watch glass in the direction of the yelk, so that it assumes the shape of a strongly convex lens, one half of which stretches into the yelk, while the other half is outside. In the middle it has a thin circular rim, outside of which numerous small globular bodies can be discerned, arranged like a wreath round it. These seem to be some of the small particles produced by the last dividing process, which have been loosened from the disk and are floating about in the clear oily border surrounding it. When that part of the disk which is protruded into the yelk has reached its greatest height, which is often much greater than the outer part, it begins to collapse, but in such a manner that the process is completed more rapidly on one side than on the other. At this place it becomes more compact, and here it is that the fœtus is

first seen. The disk, therefore, which orginally had a flat and then a convex upper side, now begins to be considerably hollowed out in the middle, so that, at last, it presents the shape of a thin helmet-like covering round the lower part of the yelk. Seen from below, the egg now shows the disk consisting of two leaves, (the vegetative and the animal,) an inner lighter zone, and a more compact circular rim, which soon appears on that side, where the above-mentioned thickening took place, broader and more compact than on the other sides. During the further development, the disk (statoblast) rapidly increases in size, encircling a larger and larger portion of the yelk; the outer rim produces a triangular continuation turned inside, which with its lower pointed end, gradually approaches the lower part of the egg, so that the inner lighter zone of the disk assumes more and more the shape of a crescent. In this continuation the incipient embryo can very soon be seen quite distinctly, even before the disk has surrounded half of the yelk. First, a faint longitudinal elevation is observed, thicker at the lower end, on the sides of which two hemispherical projections can be seen indistinctly. This longitudinal elevation is the spinal marrow of the embryo; the lower and more compact portion is the head, or, properly speaking, the brain; and the two lateral projections are the beginning of the eyes. During the eighth day after the impregnation, the disk may be seen surrounding the whole of the yelk with the exception of a small portion of the upper part, which appears like a ring-shaped opening surrounded by a thicker edge. At the same time the triangular continuation has become considerably elongated and has assumed the form of a narrow ribbon, which stretches almost from one end of the egg to the other. On the inside of this ribbon, but in the upper portion of it, the embryo is now seen quite distinctly, the extremity of the tail being in immediate connection with the disk, or rather with the ring encircling it.

The *third period* in the development of the egg may properly be placed as the time when the disk or skin has completely enveloped the yelk. This phenomenon is accompanied by other essential phases of the development, as several organs of the embryo, which before this could not be seen, now first begin to show themselves, such as the lens of the eye, the *chorda dorsalis*, the ear-bladders, the liver, the breast-fins, and the heart. The beginning of the heart is seen by a faint swelling in the region of the neck back of the eyes, in which a small circular bladder is perceived, which, however, as yet shows no sign of any movement. This bladder soon changes into a hollow cone placed obliquely on the embryo, and shows a few irregular contractions, till at last it commences its peculiar rhythmical movements. At the same time may be noticed the first movements of the embryo itself inside the egg. These, at first, consist of a faint, almost imperceptible trembling, which at greater or less intervals is repeated in a more energetic manner. The pigment now begins to show itself distinctly on the iris of the eyes in the shape of small dots, and on the rest of the body as irregular stripes. The

young fish has meanwhile grown so much, that its body already shows a complete circular bend following the outlines of the egg, so that the tail-end, which is now surrounded by a membrane clearly perceived, (the embryonal fin,) reaches to the mouth, and later, even somewhat beyond it.

At the end of the sixteenth day, the young fish is ready to slip out of the egg. Its movements inside the egg have now become so powerful, that it frequently assumes an entirely different position from that which it had at first. The iris is completely colored and even shows traces of that peculiar silvery gloss which is so prominent in the more developed fish. It has a deep incision in its lower rim which only gradually disappears. The pigment of the body is diffused in such a manner that it appears in larger quantities at the root of the breast-fins and along the upper side of the entrails; also on the back part of the body, where it forms two dark ribbons, consisting of numerous star-shaped dots, which remain unchanged long after the fish has left the egg. At last the skin of the egg bursts, and the young fish slowly frees itself from the remnants still clinging to it. At first the body has still the bent shape which it had while inclosed in the egg, but finally it straightens, and the young fish moves about with its special tremulous motions. It has now that peculiar undeveloped appearance so characteristic of all young fish, and so different from that of the adult. This peculiar appearance is chiefly produced by the large yelk-bag still clinging to it, and which is arranged so as to furnish its only supply of food, till the mouth has opened and the intestinal channels have formed themselves into a closed tube, connecting with the mouth. The body is very thin and tender, and with the exception of the above-mentioned pigment gatherings, almost entirely colorless, showing distinctly in the middle the *chorda dorsalis*, and on both sides of this the regularly-arranged muscles of the body. The front part of the body still shows a faint downward bend, a reminiscence of the fœtal curve; the head projects sharply from the rest of the body, looks as if it were swollen, and has a round shape, the mouth, or rather the region of the forehead, projecting a little. On the upper side of the yelk-bag can be seen the intestinal channel. It is still almost entirely straight and terminates at about one-third part of the body, or in that place where the back part of the yelk-bag is closed. At its foremost end, which is bent somewhat to the right, a round fine-grained mass is seen, which is the liver; and immediately above this are, on each side, the round breast-fins, turned upward, and transparent as clear water. The body is surrounded by a transparent membrane, which begins immediately above the mouth and stretches round the whole body as far as the yelk-bag. Its foremost part is widened out to a sort of cap, while toward the tail it is strongly compressed; and while the animal is in motion this takes the place of those fins which are still wanting. The yelk-bag now begins gradually to collapse, and at the same time begins the formation of the mouth by the lower jaw, which formerly was firmly joined to

the upper one, becoming gradually detached from it. When the yelk-bag has become completely absorbed, which takes place about two weeks after the slipping out of the young fish, the mouth is already distinctly developed, but as yet of a shape very different from that of the grown fish, as the lower jaw, as in the case of those deformed fishes called "cod-fish kings," projects considerably beyond the upper one, which rises quite straight. The young fish now already shows its peculiar gulping movements, and eagerly snaps after microscopical animals and algæ. It is no longer so much exposed to the currents and the winds as formerly, when the yelk-bag kept it up on the surface of the water, but often makes short excursions to a considerable depth, in order to hunt small animals, with which the sea at this time is swarming. The changes that follow are chiefly in the inner organs; thus the bile develops itself distinctly; the blood, which at first was entirely colorless, assumes a faint yellowish tinge, and can be seen circulating through the body in regular courses; the intestinal channel has increased in length, and in order to find room, must describe one or several convolutions; the shoulder girdle is already distinctly developed, &c. In the most advanced stages of development which I observed, and which took place in the beginning of May, the body was less transparent, and showed, especially on the head, a distinct yellow color. The distribution of the pigment was also somewhat uneven, being most distinctly visible on the upper side of the head and along the back and the belly. The intestinal channel, in which a wider fore part, (the stomach,) and a thinner loop-shaped and bent hind part, (the entrails,) could already be distinguished, showed yellowish contents, changing into green in the hind part. In the region of the heart, the blood had already a distinct red color. Near the hind part of the body, on the lower side, some fine rays showed themselves in the embryonal membrane, as the first sign of the tail-fin beginning to form under the extremity of the *chorda dorsalis*.

My observations on the development of the cod-fish extend no further than this; but I hope next year to be able to continue them through all those interesting changes through which the young fish passes before it becomes fully mature.

I must remark, in conclusion, that the above-mentioned peculiarity in the roe of the cod-fish, viz, that it develops swimming free in the sea, occurs also in the roe of other fish. During my last stay on the Lofoten Islands, I caught, also, with the aid of a fine net, the roe of three other different kinds of fish, entirely unknown to me, and floating in the sea in exactly the same manner. I am convinced, too, that this is also the case with the roe of the haddock, (*Gadus æglefinus*,) which spawns about the same time as the cod-fish. On the whole, this may indeed be the case with a much larger number of salt-water fish than is generally supposed. I consider it, in all probability, applicable to the whole large cod-fish family, and on closer investigation it may be found to extend even much further than this.

NOTE.

The following note, in continuation of the preceding investigation, from Professor Sars to Professor Agassiz, was published by Mr. Theodore Lyman, in the report of the Massachusetts commissioners of fisheries for 1871:

"It was my intention to continue the investigation of the young of the winter-cod, which I had pursued the previous year. I then showed that the fish often considered as a separate species, and known on the northwest coast of Norway by the names of smaagjed, tarefisk, and grundfisk, is nothing but the young of the winter-cod. I further observed that the great variations in color are only the effects of different bottom and different food.

"It was my task this year to follow the further development of the smaagied during the summer. The conditions were now quite different; for whereas during the winter I could, from a boat or from the beach, easily study my objects, now the fish had retired to the deep water and could only be got by hook and line—a difficult matter, by reason of the scarcity of bait, for the muscle rocks had been ransacked by the winter fishermen, and herring were not to be had. Beginning on the 20th of May, at a place called Skraaven, I set my line in 20 to 30 fathoms water, in the sandy channels of the outer holms, but got only fish too large to be yearlings. I then set in the 'sculls' near the rocks, and took great numbers of small cod, corresponding perfectly with the tarefisk, and which were colored of a brownish-red by the *tare* or rock-weed, (*Laminaria.*) These sculls are very dangerous to approach, especially in the winter-time, and are characterized by a periodic ground-breaker. The sea will appear perfectly tranquil for a time, when suddenly there will arise gently, over the scull, a low, broad pyramid of water, which as gently descends, and again the surface is unruffled. The wary fishermen mark well these upliftings, and keep the boat away from them. Presently you observe that the pyramid has again risen, but with increased size and with smoke curling from its apex; there is a sort of forward pushing motion and a sullen roar, and in an instant the sea rises in a vast, glittering, green bank, capped with devouring foam. With a fearful crash it precipitates itself to the very bottom, leaving a great circle of white froth. Your boat, safe in the offing, is lifted high on a huge wave, and the distant thunder on the beach announces that the great breaker has struck. The hapless boat that gets caught over one of these sculls is dashed in a hundred pieces against the rock bottom. These violent periodic ground-breakers are what attract the smaagjed, for they wash out the small crabs from their hiding-places among the sea-weed, and the young cod, dashing forward with the returning sea, devour them greedily. I thought now I should get plenty of yearlings on the sea-weed ground during the whole season, but I was mistaken. Toward the end of June they almost wholly disappeared from that lo-

cality, and were captured only near sandy channels. Their color, too, changed from the red-brown of the sea-weed to a fine greenish, with silvery sides. In their stomachs were found quantities of sül, (*Ammodytes lancea*—sand-eel,) which now were approaching the coast, and the tarefisk had evidently left the crustucea to prey upon them. The sül, less common and important in Southern Norway, is abundant on the northwest coast, and is held in high esteem. Although too slender to be captured in nets, it is taken by a large, coarsely woven cloth, worked by several boats. This cloth is slipped under a school of sül, and the corners being raised the catch is dumped into one of the boats and piled in heaps on the shore. These heaps are left there without further care, and the mass, half putrid, is accounted good food by the inhabitants, and is also served to animals. The cod are more dainty, and will not touch stale fish of any kind. Therefore, the sül for the fishery are got by digging in the sand where they have buried themselves, and where, at this season, they deposit their spawn. I took in the sandy channels plenty of cod, of one, two, and three years; also some very large 'süclod,' three feet long, and these I saw were the same as the 'winter-cod,' except that the spawn was but little developed. At this season, also, came the sei, (*Gadus carbonarius*—pollack.) It was a singular spectacle to watch the sea-mews sitting in solemn lines and in perfect silence along the rock ledges, their heads all at one angle. Suddenly, as if by common impulse, they would spread their wings, and with a shrill cry hasten toward a foamy surface on the sea. This was occasioned by the sei, which had rushed to the surface in pursuit of a school of sül, and the birds were coming to share the prey. Thither, too, came the fishermen and trolled with artificial minnows, taking, strange to say, some cod with their other fish, which shows that cod occasionally are attracted to the surface. Later in the season, the cod refused sül, which seemed to be because they were in pursuit of the young herrings, then abundant in Vestfjord."