Contributions from the Biological Laboratory of the U. S. Fish Commission,
Woods Hole, Massachusetts.

THE NATURAL HISTORY OF THE STAR-FISH.

By A. D. MEAD, Ph. D.,
Associate Professor of Comparative Anatomy, Brown University.

The investigation of the habits and life-history of the star-fish has been carried on at the suggestion and under the auspices of the Rhode Island Commission of Inland Fisheries. The observations were made principally at the Kickemuit River, Rhode Island, where a houseboat, moored over one of the oyster-beds, served as a floating laboratory. Through the courtesy of the U. S. Fish Commission in extending to me the privileges of the Woods Hole Station and in giving me the use of one of the steam launches I was able to make observations upon the star-fish in other portions of Narragansett Bay and to extend the work into Buzzards Bay. From oystermen I have received valuable information and assistance, and on every occasion the kindest treatment. The report is presented in the form of questions and answers, the questions being such as would be propounded by a practical oysterman, and intended to bring out information of value in combating the ravages of the star-fish. This paper, in slightly different form, appears in the twenty-ninth annual report of the Commissioners of Inland Fisheries for the State of Rhode Island, January, 1899.

IDENTIFICATION AND DISTRIBUTION OF THE STAR-FISH.

I. *Does the animal known to our fishermen as the star-fish or five-finger belong to one or to several species?*

It is evident that if there are two or more species artificial or natural agents destructive to one may prove quite harmless to the others. There are in Narragansett Bay 4 species of star-fishes, out of the 800 or more which are known to occur the world over. They are: The common star-fish (*Asterias forbesii*); the purple star-fish (*Asterias vulgaris*); the blood star-fish (*Cribrella sanguinolenta*); the snake star-fish (*Ophiopholis aculeata*). Only the first two species are considered in this report. The last two are so distinctly different from each other and from the first two that there is no difficulty in identifying them; neither is harmful to the shell-fish fisheries.

The common star-fish and the related purple star vary so much with regard to color, shape of arms, size, number of species, etc., that the French naturalist Perrier has made five distinct species of *Asterias* to include those star-fish along our coast which according to American naturalists, L. Agassiz, Stimpson, and Verrill, belong to two species only. I have endeavored during the last year to ascertain whether some of these varieties were to be explained as a difference in sex, but have been unable to discover any such relation, and am not able to distinguish males from females except by the sexual products.

II. *What is the geographical and bathymetrical distribution?*

The reply to this question will indicate the area subject or most liable to invasion. The purple star ranges from Labrador (probably farther north) to Cape Hatteras, and is most common north of Cape Cod. The common star ranges from Maine to the Gulf of Mexico, and is the species most common south of Cape Cod. The bathymetrical distribution of the purple star is from high water to 208 fathoms, and of the common star from high water to 20 fathoms.

From the numerous dredging expeditions of the U. S. Fish Commission launches and the steamer *Fish Hawk* carried on in 1898 it appears that in Narragansett Bay the purple star-fish (*Asterias vulgaris*) is practically restricted to the lower portion of the bay, below Gould Island, though occasionally, perhaps, taken farther north. One, for instance, was taken near Dyer Island, among 1,000 or more of the common species. I have never known a single one among the thousands of bushels of star-fish captured on the oyster-beds in the upper half of the bay. The common star, on the other hand, occurs in greater or less abundance everywhere from Fox Point to the mouth of the bay, and is the only species that commits depredations upon our oyster-beds. (The purple star would doubtless be destructive if it were present.) The stars from the vicinity of the oyster-grounds are, moreover, very similar to one another in appearance, as compared with those collected in one locality at Woods Hole, where one haul of the mops may bring up stars which apparently belong to several quite different varieties.

There are other varieties differing from those on our oyster-beds and from the purple star, which seem to be characteristic of certain localities. Thus, at the head of Buzzards Bay, at Neys Neck, a large number of common stars were collected, which were very similar to one another, but quite different from those on our oyster-grounds. They had very large coarse spines and were of a bronze color. The specimens taken by the *Fish Hawk* in waters south of Narragansett Bay seem to constitute a variety (maroon star) which occupies this area to the exclusion of other kinds.

It is not known certainly whether each of these so-called varieties is an actual variety in the sense that the individuals breed true, or whether the peculiar appearance is due merely to the fact that the individual stars are bred and reared in a particular locality. If it should prove to be true that the young of a certain variety, e. g., the maroon star, are always like the parent stars, no matter where they grow, we might be able to determine to what extent the star-fish are dispersed while in the free-swimming larval condition.

MODE OF LIFE.

III. *What is the method of locomotion? (It is possible that some barrier might be arranged that would limit, if not prevent, invasion.)*

The star-fish crawls or glides over submerged surfaces by means of the very numerous "suckers," or feet, which protrude from the furrows on the under side of the arms. Small stars, ½ inch or less from tip to tip, are frequently seen, ventral side uppermost, moving along with their suckers reaching up to the surface of the water. This performance can be carried on only when the water is very quiet, and is not often observed outside the aquarium. The buoyancy of the water and the great number of sucking feet enable the animal to crawl over the softest silt and the smoothest hard surfaces with ease, while the remarkable suppleness of the body enables it to get through incredibly small crevices. Besides this ordinary mode of locomotion, another peculiar method has been accredited to the star-fish by many, namely, that of clinging together in great clusters and rolling along the bottom with the tide.

The tradition is that large numbers of stars cling together to form a compact ball from 1 to 3 feet or more in diameter, which is rolled along the bottom by the tide until, striking an oyster-bed, the ball goes to pieces and the stars begin work at once. It is difficult to find an actual eye-witness of this phenomenon, though Ernest Ingersoll tells of an old oysterman, "Captain Eaton, of New Haven, who said that he and his brother once raked up the end of a cylindrical roll of star-fishes clinging tightly together, which they hauled into their boat until it would contain no more, when they had to break the roll or 'string,' as he called it, which was a foot or more in diameter." The "string" was composed only of star-fishes. I have never observed anything to confirm in the slightest degree the truth of these stories, though I have seen balls of star-fish clinging to each other. Upon examination it was evident that the stars were all endeavoring to devour some animal held in their midst.

For the purpose of testing the ability of star-fish to creep over soft surfaces, vaseline was smeared thickly on a vertical glass plate and on the under side of a horizontal glass plate. These plates were submerged in the aquarium with the star-fish, which measured 2 or 3 inches from tip to tip. The animals were observed to crawl over both these surfaces with no apparent difficulty. Paraffin was used in the same way and with the same result. It would appear, therefore, that submerged surfaces, though ever so soft or slippery, would not be effective barriers against the invasion of stars. They will not crawl out of the water, nor even protrude an arm above the surface, but will move along over a surface covered with a very thin layer of water, even if it is not deep enough to cover the whole body. They are perfectly secure, therefore, in a dish of water as shallow as a soup plate, so long as the water does not flow over the edge; but if placed in an aquarium which is constantly overflowing, they will frequently crawl over the edge and down the outside. No barrier, therefore, over which even a thin layer of water is flowing would be effective.

IV. *To or from what distance may star-fish migrate?*

This is a problem which has a decidedly practical bearing, but we have as yet very little accurate data for its solution. I have been told by several oystermen that stars sometimes suddenly appear in great numbers upon oyster-beds, and move over them at the rate of ¼ mile per day, more or less. It is generally understood, also, that there is some sort of a seasonal migration, especially noticeable in spring and fall, but the character and extent of this migration, if it really occurs, is unknown.

If a star crawled constantly in one direction at the rate of 6 inches per minute, which is a fair rate for a medium-sized one, it would travel about 4 miles in a month. At this rate star-fish could go from one end of the bay to the other in the course of the summer. But there is no good evidence that they take such extended excursions. The fact that they can be found all the year round in the upper part of the bay, and on the oyster-beds, shows that there is no wholesale migration to great distances.

There are some other facts which seem to indicate that the wanderings of these animals are rather limited in extent. Certain kinds of star-fish which are common in one part of the bay are not found, or are rare, in other parts. The purple star and "maroon star" do not migrate into the upper half of the bay, although the purple star, at least, might live in these waters, as I have found by keeping them in confinement. The star-fish in two neighboring parts of the bay, namely, Mount Hope Bay and Kickemuit River, do not seem to migrate back and forth, for those caught in Kickemuit River, during the past two years at least, were for the most part small, rarely measuring more than 3 inches from center of disk to tip of arm, yet about a mile from the mouth of this river there have been great quantities of very large stars with arms 4 inches long or more. In Barrington River there seems to be a great preponderance of small stars, about 2½ inches (arm) or less, of a reddish-brown color and thus distinguishable from the average star-fish caught in the vicinity of Nayatt. After the great freshet in the spring of 1888 nearly all of the star-fish in the Kickemuit River perished, Mr. Bourne tells me, and were not again troublesome for three or four years.

These facts, though not conclusive, lead to the conjecture that natural barriers to the migrations of star-fishes exist in our bay. Some of these may be, depth of water, density of water, or a strip of barren bottom. If the conjecture is correct, that the migrations of the star-fish are confined to comparatively limited areas, the prospect of diminishing their numbers by a systematized effort is encouraging.

V. *What animals are devoured by the star-fish for food? If the young star-fish feed habitually upon certain animals, it is possible that the destruction of the latter will cause the former to perish.*

Star-fish, especially when young, are exceedingly voracious feeders, prey upon oysters, clams, mussels, barnacles, various kinds of sea-snails (including oyster-drills), worms, and small crustacea, and, if slightly pressed by hunger, turn cannibals and prey upon smaller star-fish. From its depredations upon the oyster-beds of New England the star-fish has become notorious. Collins (Notes on Oyster Fishery of Connecticut) estimates that in 1888 the damage done to the beds in the Connecticut waters alone was $631,500, although 42,000 bushels of stars were taken from the beds that year.

It was found during the summer of 1898 that the star-fish in Mount Hope Bay and in the vicinity of Nayatt were feeding in great numbers upon a little bivalve which closely resembles a young quahog, but which is an adult mollusk of another species (*Mulinia lateralis*). Fig. 1 represents a large specimen, natural size. The *Fish Hawk* recently found these animals exceedingly abundant in certain parts of the bay.

Mussels are a favorite food of the stars, and doubtless many thousand bushels of mussels are devoured by them every season. Indeed, some of the mussel beds have disappeared within the last few years, having been destroyed, probably, by the stars. Unlike the oyster-beds, the mussel-beds are not protected from the onslaughts of the stars, and we can appreciate the extent of the damage to the mussel, if we imagine the condition of a bed of small oysters unprotected from star-fish for a single season.

In rearing the young stars for the purpose of studying their rate of growth, etc., I found them to be very fond of small clams and barnacles, as well as of young oysters. A more detailed reference to the damage done to young clams by the star-fish will be found on p. 215. I have caught stars in the act of devouring oyster-drills, and believe it probable, therefore, that the drills, which are a serious menace to the oysters in some localities where the star-fish are rare, are to some extent held in check by the stars.

VI. *What is the method of feeding?*

The mouth of the star-fish is in the center of the disk on the lower side of the body. Comparatively small pieces of food are taken into the stomach, and the refuse ejected again through the mouth. But, since the mouth is small (about ¼ inch in a good-sized star) and surrounded by calcareous plates, larger animals, which form the greater part of the star-fish bill of fare, are necessarily digested without being taken in through the mouth. The stomach therefore is turned inside out and, wrapping itself about the animal to be devoured, digests it where it lies, and is then withdrawn to its normal position within the body. It is safe to say that the stomach can be protruded for a distance equal to the length of the star-fish's arm.

The greater part of the animals upon which the star-fish prey are mollusks protected by hard shells; for example, the sea-snails, mussels, quahogs, and oysters. How does the star get at the soft part of the mollusks? This question has given rise to a great deal of interesting, not to say amusing, speculation, especially with respect to the oyster. An old tradition in England and this country is to the effect that the star takes the oyster by suprise and puts an arm into its gaping shell; then a fight ensues. Sometimes the oyster is victorious, while the star-fish retreats minus an arm, but often the oyster succumbs, since it can not live long with its shell open, and the star then devours its prey at leisure. There are two facts that are sufficient to disprove this theory. In the first place, the oyster is very sensitive and feels the slightest disturbance in the vicinity of the margin of the open shell. In the second place, the shell does not open wide enough to admit the arm of the star. Moreover, simple observation of the star-fish during the process of eating disproves the story.

It is supposed by many that the star-fish injects a poison into the shell which causes the latter to open. But the valves of the shell can be shut water-tight and would exclude such a poison. I have taken away from the star-fish oysters, mussels, and drills which had already been opened, and placed them in an aquarium, where they soon recovered and behaved as though nothing had happened. Schiemenz found the same to be true in the case of the quahog (*Venus*).

Some have supposed that the star bores a hole through the shell of the victim, but the star has no boring apparatus, and the shells known to be opened by the star have no holes in them.

It is a very common belief that an acid is secreted by the star, which dissolves the shell so that an entrance is effected. After a successful opening, however, the litmus paper shows no acid from the stomach of the star-fish, and the margin of the shells shows no trace of having been acted upon by an acid. A considerable quantity of acid would be required to sufficiently dissolve the shell of a medium-sized oyster, and this would undoubtedly dissolve, at the same time, the unprotected calcareous spines about the mouth of the star-fish itself.

The most prevalent opinion is, perhaps, that the star chips away the thin edges of the shell until an entrance is gained to the soft parts. The broken edges of oyster shells which have been opened by the star seem at first to sustain this opinion. The process is thus described in a Providence newspaper:

> The star-fish seizes its prey by clasping its tentacles around the soft, fringy edge of the oyster, which it eats away until the soft oyster can be sucked from the orifice, etc.

Ingersoll, in an article on the oyster industry, after speaking of the alleged use of acid in opening the shell, says:

> Moreover, it seems unnecessary, since the appearance of every shell attacked at once suggests the breaking-down, chipping-off movement, which the star-fish might easily produce by seizing and suddenly pulling down with the suckers nearest the mouth, or by a contraction of the elastic opening of the stomach. At any rate, the thin edge of the shell is broken away until an entrance is made which the oyster has no way of barricading.

An oyster which has not been injured by rough treatment has the edges of the shell extremely thin and so fragile that they can be broken down with a camel's hair brush. The lower shell is particularly fragile near the edge. It will be noticed, however, that the valves frequently do not come together at all at the extreme edge, and the real line of contact, the biting edge, is one-fourth inch or more further back. The chipping of the margin of the shell by the star-fish is merely accidental, and avails nothing in getting at the soft parts of the oyster. I have carefully examined a large number of shells of oysters known to have been devoured by star-fish, and, though they appear to be badly chipped, the biting edge is never broken, and the shells have always been found to be water tight. If such a shell, recently opened by the star, be filled with water, and the valves held between the thumb and the finger, the water will not leak out even though the shell be violently shaken.

In mussels which have been opened by the star-fish there is no trace of any chipping at all. The reason is plain: the valves of the shell come together firmly at the very edge; there is no delicate fringe at the margin. The same is, of course, true of the quahog. Nevertheless, the small quahog and mussel are readily opened by the star-fish. It follows, therefore, that if the star gains entrance to the soft oyster by chipping off the edge of the shell, a different process must be adopted in entering a mussel or quahog, to say nothing of the snails which it also devours.

The credit of solving the problem—How do the star-fish open oysters?—is due to Dr. Paulus Schiemenz of Hanover, Germany, who carried on his investigations at the famous zoological station at Naples. The problem was suggested to him by Collins's report of the enormous injury done to the oyster-beds by the star fish in Long Island Sound. The process is briefly as follows: The star-fish so covers his victim that the suckers on the under side of the arms are distributed, part to one valve, part to the other, and the remainder frequently to some surrounding object. (In the case of the snails the suckers are attached to the operculum and to the shell.) The suckers are very numerous and stick fast, and a tendency to straighten the arms results in a constant pull on the shells in opposite directions, which, if strong enough, would open the shells. It is true that a star-fish is not strong enough to open an oyster or quahog immediately in this manner, but it can and does fatigue its prey. The constant, steady pull in opposite directions soon fatigues the muscle which holds the shell together, and the oyster or clam presently gapes open. The oyster can overcome a strong pull for a short time, but not a weaker pull for a long time. The same principle is well illustrated in the case of the periwinkle or conch. If a string be tied around the "foot" so as to give a good hold on the animal, a strong man can not pull the mollusk out of its shell, but if it be suspended by this string it can not sustain for a long time even its own weight. On the same principle a man who can hold at arm's length a weight of 20 pounds can not hold his empty hand in this position for 10 minutes. Schiemenz showed by experiment that the star-fish could exert a pull of over 1,200 grams, and that a pull of 900 grams is sufficient for opening a good-sized quahog if allowed to act for 30 minutes.

Often more than one star takes part in opening an oyster, and when opened other stars often enter into the feast. It is the young oysters that are in greatest danger from the stars, and the danger decreases as the oysters grow larger. Oysters of marketable size, that is, three or four years old, are comparatively unmolested. Of course the larger stars can open the larger oysters, but fortunately the larger ones are more easily caught in the "mops" and thus more easily kept off the beds. It has not been ascertained how large an oyster can be opened by a star-fish.

VII. *At what season of the year do the star-fish spawn? If at a particular season, a special effort should be made to kill the animals before spawning, and thus destroy both stars and spawn.*

I have attempted by two methods to determine the spawning season of the star-fishes in the upper portion of Narragansett Bay and at Woods Hole. The first method consisted in examining a large number of adult stars at intervals during the year, to see if they contained ripe eggs and milt. The second method consisted in dragging a fine silk "tow net" at the surface of the water, to catch the free-swimming young.

Most of the adult star-fishes examined were obtained through the kindness of the oystermen in Kickemuit River, Mount Hope Bay, and the vicinity of Rocky Point. On July 19 and 22, 1897, 630 stars were carefully examined, and the sizes of specimens and of sexual glands were tabulated. The specimens ranged from 1¼ to 3½ inches (taking distance from mouth to tip of arm). Fifteen contained eggs or sperm apparently ripe. In some, only one arm contained ripe products. None of these apparently ripe specimens were smaller than 2 inches. In the great majority the sexual glands were small, less than one-half the length of the arm. During the remainder of the summer, stars from these localities were frequently examined, and occasionally one was found with ripe eggs, but there was no general increase in the size of the glands.

On November 15 a lot of stars from Rocky Point was examined. They were nearly uniform in size, and measured about 3 inches. In about half of these specimens the glands were half the length of the arm, but none were ripe. Among the 75 specimens, measuring approximately 3 inches, collected at the same place November 29, 14 seemed to be nearly mature; the glands in 44 others were half the length of the arm; the remainder had small and immature glands.

January 6, 1898, Rocky Point: About 40 stars, 3½ to 4 inches in length, were examined. Only 4 had sexual products which seemed to be nearly ripe, while the majority seemed less mature than in November.

January 7, Kickemuit River: 50 stars ranging between 2½ and 3½ inches (4 specimens measured 4 inches). In 20 specimens the glands were considerably developed, but not nearly ripe. In the remaining 30 they were quite small.

January 15, Kickemuit River: 50 stars, measuring from 2½ to 3½ inches were examined. In general, there was, perhaps, a slight increase in size of glands, though in over 30 they were very small.

February 9, Rocky Point: 126 stars, 2½ to 4 inches long. In 3 the sexual products were ripe; in 10, nearly ripe; in 53, large and turning color, becoming slightly pink; in 47, small, but showing signs of seasonal development; in 12, very small.

February 12, Kickemuit River: 63 specimens, measuring from 2 to 3½ inches. In 6 the glands were large and beginning to show a pink color; 39 showed seasonal development, while 18 were very small.

March 4, Kickemuit River and Mount Hope Bay: 39 specimens, 2½ to 3½ inches in length; 1 was apparently quite ripe; 26 seemed nearly ripe; the glands in 7 were beginning to change color; in 3 immature but showing seasonal development; in only 2 specimens were the glands very small.

March 7, Rocky Point: 99 specimens, measuring 2 to 3½ inches; 5 were apparently fully ripe; 71 nearly ripe (very large glands); in 20 the glands showed the pink color slightly; in 2 the glands were small, but showed seasonal development; only 1 had very small glands.

It is evident that, during the latter part of January and throughout the month of February, there is a regular increase in the size of the sexual glands in nearly all the star-fishes from Rocky Point, Mount Hope Bay, and Kickemuit River. By the end of the first week in March, the great majority appear to be nearly mature, while the others, except in a few cases, show a distinct seasonal growth in the sexual glands. The stars at this time begin to look "fat," because of the increased size of these glands and of the digestive glands, usually called the "liver," which fill the arms.

April 5, Rocky Point: 197 specimens examined, varying in length from 2 to 4 inches; 137 had the appearance of being fully ripe; 32 were nearly ripe; in 20 the glands were beginning to show the pink color; in 9 they were smaller, but showed seasonal development; in 1 only were the glands very small.

April 13: 25 specimens, out of a basketful from Mount Hope Bay, were examined. All seemed ripe, and so the examination was not carried further. Although during the first two weeks in April the stars are all *apparently* ripe, they do not discharge the products for about two months. During this time they appear to be extremely "fat."

On May 17 the stars were examined again in Kickemuit River and Mount Hope Bay, and appeared very much as in April. They were, perhaps, more distended with spawn and milt, but had not yet discharged.

During the first four days of June, star-fish from many localities in the upper portion of the bay were examined on board the launch *Sagitta*, engaged by the United States Fish Commission. The stars were, almost without exception, full of very ripe eggs and sperm, which were easily shaken loose in the water. Small specimens, measuring in many instances only 1¼ inches, were fully ripe.*

The height of the spawning season occurred between this date, June 4, and June 16. From June 16 to June 28 the star-fish examined in many localities, especially at Kickemuit and Rocky Point, had extruded most of their eggs or sperm, but in some the ripe spawn was found in one of the arms, or merely in the base of the arms, as though not quite all had been extruded. Specimens in which some ripe products were left were more frequent on the 16th than on the 21st, 22d, and 28th of the month, which indicates that the spawning season was rapidly drawing to a close.

Star-fish examined in July, and occasionally during the rest of the summer, yielded the same results as those examined at the same season in 1897; most of them had very small sexual glands, but some were found with products apparently ripe.

On June 22 I searched carefully on the seaweed and eelgrass in Kickemuit River for very young stars, but not a single one (under one-half inch or more) could be found. On June 29 another careful search was made in the same locality, and countless numbers of minute stars were found, most of them about the size of the head of a pin. They were clinging by dozens to every spear of eelgrass, and scattered diffusely through the branches of fluffy seaweed, which is abundant in this locality; the larger of them were probably not more than a few days old (since time of setting), as I afterwards determined by watching the growth of those whose exact time of setting was known. Doubtless, therefore, the small stars were absent, and not overlooked, in the search on June 22. I feel sure, therefore, that in this locality the star-fish first begin to set, in considerable numbers, on June 28, or within a day or two of that date.

The first attempt to capture stars in the free-swimming stage of their existence was on June 27, at Kickemuit. The tow-net was dragged at the surface at intervals for two hours in the evening. The weather conditions were unfavorable, as I afterwards learned, and for this reason no young stars were caught. On the

* See remarks on "Age and size at sexual maturity."

following morning, June 28, a great many fry were swimming at the surface of the water. From this date until July 16 they could be taken at any time, unless conditions were particularly unfavorable. The few larvæ caught on July 16, however, were old, and all of them set in the aquarium during the next 12 hours. After this no more larvæ could be obtained, though the next few days were exceptionally favorable.

It is evident, therefore, that in Kickemuit River the season during which the star-fish larvæ set in considerable numbers began about June 28 and ended about July 16, a period of a little less than three weeks. Allowing that the larvæ set three weeks after the spawn is laid (which is the period given by Ingersoll), we may conclude that the beginning of the spawning season was about June 7, and the end June 28, while the height of the season was the first, and possibly the second, week in June. From the observations of the sexual glands of the adults, it appeared that the greater part of the spawn was extruded between the 4th and 16th of June. The facts, therefore, obtained by both of these methods agree very closely.

From Dr. Seitaro Goto, of Tokyo, Japan, who worked in Mr. Agassiz's laboratory at Newport in 1895, I have obtained the following interesting data. For one or two days before July 15 the larvæ had been very numerous. On the 15th they were decreasing in number, and after July 20 none were found. At Newport in 1895, therefore, the breeding season was nearly the same as that at the Kickemuit River in 1898.

At any time in the year a few star-fishes may be found which contain ripe eggs and spermatozoa, but it is not known that these eggs are laid out of season. If they are, the chance of their becoming fertilized is small. Dr. Goto writes me that a similar phenomenon is seen in a Japanese species of sea-urchin. He is able to obtain ripe eggs and sperm, and to fertilize the eggs artificially, even in the midst of winter, though the species probably does not breed in these waters at that season.

To answer briefly the ninth question we may say: The stars in the upper part of Narragansett Bay, and probably throughout the bay, have a short spawning season, beginning about the second week in June and continuing two or three weeks. The young fry begin to set the last week in June and continue to set until the middle of July. The fact that ripe stars may be obtained in very small numbers throughout the year is of no practical significance, for if they lay their eggs out of season the chances are comparatively slight of their being fertilized.

Observations were made at Woods Hole from March to the end of the summer I is rather difficult to interpret the results satisfactorily, for at no one period were more than a small proportion of the stars at Woods Hole ripe, or even approaching a ripe condition, and, on the other hand, a few ripe specimens could be found at any time. As a rule the sexual glands were very small, like those of the Narragansett Bay stars in midwinter, and it was noticeable also that in such specimens the digestive glands were also unusually small. The latter condition I take to be an indication of poor nourishment, judging from the condition of poorly fed stars kept in confinement as compared with well-nourished specimens. I am inclined, therefore, to assign the failure to breed to the same cause.

In this connection I may observe that in the specimens kept over winter at Kickemuit, with very little to eat, the sexual glands did not approach a ripe condition. An examination of stars taken in February and March from Narragansett Bay shows that by this season of the year they are eating voraciously, shells and even fragments of star-fish being found in their stomachs. In some years the stars have bred in abundance at Woods Hole, but the notes on the time of breeding are somewhat puzzling, as they indicate that the time varies considerably.

VIII. *What are the habits of the "fry" or free-swimming young? The young of many marine animals, while far more abundant than the adults, are much more delicate and easier of extermination.*

The ripe eggs of the star-fish are minute spherical objects, measuring about one-tenth the diameter of the head of a small pin. They are discharged from the female through minute pores near the base of each arm, into the water, where they may become fertilized by the spermatozoa discharged from the male in a similar manner. Each egg, soon after it is fertilized, begins to undergo a long series of changes in form. During the first stages of development there is little or no increase in size, and the egg rests, like a minute grain of sand, upon the bottom. In the course of a few hours, however, the internal changes which have been taking place express themselves. Vibratile cilia appear in certain areas on the surface of the egg, which now begins to rotate, and soon rises from the bottom as a free-swimming larva. Soon after this the mouth and stomach are developed, and the creature takes in food and grows. The growth is rapid, and during the next three weeks, more or less, the larva increases its diameter about 50 times. Meanwhile various internal organs and several long arms, and other external features, are developed. The older fry are called brachiolaria, from the fact that they have so many long arms. One of these brachiolaria of the largest size is represented in fig. 3, much magnified. The natural size is shown in fig. 4, where two specimens are figured, one on either side of the bit of eelgrass. The animal swims by means of the motile cilia, which are arranged in bands, represented by the heavy lines in the figure. They form a complicated pattern over the surface of the body, and extend out upon the arms. The body is quite transparent, and the tips of the arms, which are shaded in the figure, are light red. The larva represented in fig. 3 is old, and would probably have set within 12 hours. Already the rudiment of the resulting star-fish, the disk-shaped body at the bottom of the figure, can be seen within the brachiolarian. The five crenate lobes on the margin of the disk are the beginning of the five arms. The disk itself at this time is already somewhat opaque.

When the larva is about to "set," it attaches itself to some object, like a spear of eelgrass, by the suckers, shown at the top of the figure, and then a rapid transformation occurs. The whole superstructure above the disk collapses and becomes absorbed like the tail of a tadpole. In a few hours the brachiolarian has disappeared, and a star-fish proper has taken its place.

Although the free-swimming larvæ have a considerable power of locomotion, and can swim from one side of a dish to the other in a few minutes, they can not, of course, make headway against the tidal currents, and are carried hither and thither with their ebb and flow. Other extensive movements of larvæ are executed in response to such changing conditions as those of light and temperature; at times myriads of them are swimming at the surface, and in 12 hours not one specimen can be found. The brachiolarian, like more lowly organized forms of living creatures, although it has no eyes, is exceedingly sensitive to light, sometimes being attracted to it, and again being repelled by it. According to my experience, they were found at the surface in greatest abundance on cloudy or misty days and nights, and were much more rare, or absent altogether, on bright, clear days and moonlight nights. On June 27, for instance, I skimmed the surface with the tow-net from 9 until 11 o'clock, and not a single larval star was found, although there were millions of the larvæ of the annelid worm *Syllis*, and other organisms. The night was clear, with a bright moon, and the tide was rising. The next morning, June 28, was cloudy with some rain, and large numbers of the larvæ were taken in the nets, between 8.30 and 10 o'clock. In the evening of this day, between 9 and 11 o'clock, they were even more abundant than during the day. The evening was calm and cloudy, with a little rain. Afterwards I met with the same experience on several occasions.

Another question in respect to the movements of the free-swimming larvæ is of practical importance, inasmuch as they are thousands of times more numerous than the adult stars. To what distances may the larvæ be carried by the tides and currents in our bay? I can not answer this question directly, but there are certain facts which have an important bearing upon it.

Although the purple stars (*Asterias vulgaris*) are common in the lower portion of the bay in the vicinity of Newport and Seaconnet, they seem to be totally absent from the upper parts, although the adults, at least, can live in these waters. I have kept them for a long time in Kickemuit River. This would seem to indicate that the larvæ of purple stars are not transported by the tides from the lower to the upper portion of the bay. It may be, of course, that the larvæ, unlike the adults, can not abide in the upper portion, or that the young stars, as soon as they can crawl, return to the southward unnoticed; this seems to me, however, to be improbable.

The distribution of some other marine animals whose habits are similar to those of the brachiolaria is of interest in this connection. At Waquoit, about 10 miles northeast of Woods Hole, on the Vineyard Sound side, the water was fairly alive with the young of a certain species of jelly-fish, which could be obtained from this locality in immense numbers at any time for several weeks during the spring. At Woods Hole, however, these specimens were comparatively rare. Again, later in the summer, at Menemsha Bight, near Gay Head, another small jelly-fish was found in such abundance that every bucketful of water contained thousands of specimens, yet they were exceedingly rare, if present at all, at Woods Hole.

In the upper part of Buzzards Bay, at Neys Neck, the star-fish probably bred in great numbers, judging from the appearance of the adults earlier in the spring, yet the larvæ were rarely caught at Woods Hole.

These facts, and others of the same nature, certainly suggest that the larval star-fish may not be transported to great distances in the bay by the tides.

IX. *What are the habits of the young star-fish? It is possible that the young star-fish, like the young of many fish, tend to gather in schools. If so, the young might be killed off in thousands.*

The data with reference to the habits of the young stars were collected at Kickemuit, where it was possible to have a certain area along the shore under constant observation. Up to the very time when the larvæ are ready to set they swim freely in the water; and larvæ, caught in the tow-net, often set in the dish of water before I had returned to the houseboat, i. e., within an hour of the time they were caught. In this condition they attach themselves by their suckers (see fig. 3) to any object they happen to strike, and cling to it with great tenacity until the metamorphosis is completed. As the larvæ are borne along by the currents, the eelgrass, rockweed, and especially the fluffy, branching seaweed, naturally catch immense numbers of them. I think it would not be an exaggeration to say that on a single handful of seaweed which I picked up about the 1st of July there were more than a thousand young stars. For the next three weeks they remain for the most part crawling about over this vegetation, gradually working down among the roots of the rockweed and upon the large stones at the bottom. They grow rapidly during this time, but decrease in numbers, for they are bright and conspicuous objects for the small fishes; yet they are exceedingly numerous for a long time. In order to obtain a definite expression of their abundance, I scooped up a large handful of the fluffy seaweed, which, together with the water, filled about two-thirds of a paper pail, and from this 603 young stars were taken. The average size was about that in fig. 9. A cart load of seaweed taken out at this time would have destroyed millions of star-fish.

By the 1st of August the fluffy, branching seaweed, which bore so many young stars, was nearly all dead, and though the stars were still present in great numbers upon the eelgrass, rockweed, and stones covered with sea-moss, they were also frequently seen crawling along the muddy bottom. By August 15 the eelgrass was overgrown and lodged by a luxuriant growth of *Botrylus*, a compound ascidian, which appears as dark gelatinous patches. The small stars were still numerous upon it, but were rather thin and poor. The larger and better nourished stars had left the eelgrass and were searching for food upon the stones and along the bottom.

The small star-fishes, such as live upon the eelgrass, are remarkably hardy in some respects. They will live for weeks, and even months, in a small dish, without change of water and with a minimum amount of food. During the first week in July I carried a number of free-swimming brachiolaria, like fig. 3, to Providence for further examination. They were in a glass 1-quart jar, and, after one or two were taken out, the jar was closed and was left unopened during the rest of the summer. In a few days the larvæ had all set, and when I examined the dish again, on September 5, it contained still a few live stars, which were, however, very small. Upon watching them it was seen that the more enterprising individuals were eating their companions, and finally only one remained. This one lived in the jar for weeks, but, unfortunately, I am not able to record the exact date of his death.

On the other hand, the same young star-fishes, which can live so long without food or change of water, perish quickly if left out of the water, especially if the sun is shining. They can not live, therefore, above the low-water mark, unless sheltered by a dense growth of vegetation. Large stars can endure very much longer exposure, since their bulk prevents their drying so quickly. On July 16 I made a special search for young stars on the sea-weed, above the low-water mark. I found none, yet just below low-water mark they were excessively abundant. At the same time it was noticed that above the line where the star-fish were abundant there was a thick set of 1-year old oysters, while below it the oysters were absent. The oysters set somewhat later in the season than the star-fish, and the latter, therefore, are ready to prey upon the young oysters as soon as they appear. When, in addition to these facts, we take into account the extraordinary voracity of the young star-fish, their immense numbers, and their special fondness for oysters, we are led to conclude that one reason why a considerable set of oysters is so rarely obtained below low water is that they fall prey to the star-fish. The oysters which set above high water are comparatively safe, for when the tide leaves them uncovered they can endure for hours the direct heat of the sun, which would kill the young star-fish in a few minutes.

While the star-fish are living upon the eelgrass and seaweed they are supplied with an abundance of food in the form of the young of marine worms, snails, and other animals, which, like the stars themselves, swim freely in the sea for a time, and then settle down upon any object with which they happen to come in contact. Throughout July the water at Kickemuit was teeming with minute free-swimming creatures, and in the aquarium the growth of the youngest stars could be greatly accelerated by feeding them the contents of the tow-net. During the last four days of June innumerable larvæ of a marine worm (*Syllis*) were swarming at the surface, and on July 11 millions of the young of one of the sea-snails (*Littorina?*) were caught in the tow-nets.

The clam, also, is one of those unfortunate animals whose larvæ set at about the same time as the star-fish, and in the same places. The star-fish before they are 3 days old show a predilection for young clams, which apparently does not diminish so long as any clams remain. Fig. 2 was drawn from life last summer by Dr. J. L. Kellogg, and represents a characteristic scene in the marine tragedy.

In order to ascertain how fast the stars of the average size found upon the eelgrass would devour the young clams of average size, I placed one such star in a dish with 56 clams taken at random from the margin of a stone. The larger clams were about the length of one arm of the star, and they ranged from this length to 1 or 2 mm. The experiment was begun at 1.22 p. m. on July 18; at 5.40 p. m. 2 clams had been devoured, each about the length of the arm of the star, and during the evening a third was eaten. At 8 o'clock the following morning 5 had been eaten, at 9 o'clock 6, and at 9.05 the seventh clam had been attacked. I was absent from the laboratory for the next 4 days, and, returning on the 22d, found at 6 p. m. 29 empty shells whose contents had been eaten by the star, which had grown considerably and was eating faster than formerly. The next day 39 empty shells were found, and on the following day 46 were empty, while 10 more had disappeared altogether, having doubtless been devoured, shell and all, some time during the week. To make sure that the clams were killed by the star and did not die from some other cause, a control dish of clams was kept, in which all the specimens lived. *In six days a single star-fish devoured over 50 clams.* Both star-fish and clams represented the average size at this season. I regret that I did not record the exact dimensions of the star at the beginning of the experiment. Fig. 11 shows its approximate size at the end of the experiment on July 25.

When we recall how exceedingly numerous star-fish are, and that they are found in the same localities with the young clams, the result of this experiment becomes still more significant. At this rate 600 stars from one netful of seaweed could devour 30,000 clams in 6 days. The star-fish in a cartload of seaweed, if it contained 200 small forkloads, would have the capacity for destroying over 6,000,000 clams in a week.

From the foregoing it appears that the star-fish set for the most part during the last few days in June and the first week in July, some as late as July 16. They remain upon the seaweed in immense numbers until about the 1st of August, when many of them are found upon the bottom. By August 15 the greater portion of the stars have left the seaweed and gone to the bottom. The young stars do very great damage, not only to the young oysters, but also to the young clams.

The stars could be destroyed by hundreds of thousands in July by collecting and drying a few cartloads of seaweed taken below low-water mark. After the first week or two of July the collection of seaweed would do no injury to the clams.

X. *What is the rate of growth up to sexual maturity?*

The observations and experiments bearing upon this question were made at the Kickemuit River, and these methods were adopted:

(*a*) A large number of star-fish were kept under constant observation and were surrounded with natural conditions as far as possible.

(*b*) Frequent observations were made on the stars in their natural environment.

(*c*) Individual star-fish were reared under various conditions, and their growth recorded from time to time.

(*d*) Star-fish which were regenerating lost parts were kept under various conditions, to determine the rate of growth and the rate of regeneration.

(*a* and *b*) On June 29 a bunch of seaweed, on which were hundreds of small stars, was placed in a car at the house-boat. All the stars were very small. The greater number were about the size of that in fig. 5, but they ranged from the size shown in fig. 4, just setting on the eelgrass, to that in fig. 6.

On July 15 it was found that hundreds of stars had crawled through the wire netting and were thickly scattered about on the under side of the car. Here they had found an abundance of small barnacles, which to all appearances they very much relished. After preserving a few specimens, to compare with those taken from the seaweed, the rest of the stars were left unmolested upon the bottom of the car. The average size of the stars on the car was greater than the average of the larger specimens on the seaweed. This was doubtless due to the fact that the former were better fed. A difference in shape was also striking, those on the car being more plump. Figs. 7, 8, and 9 represent three specimens taken from the seaweed on this date, and fig. 10 one of the larger specimens (3 mm. from mouth to tip of arm) from the car, all natural size. The measurements which follow are all taken from mouth to tip of arm.

On July 18 the stars showed a very appreciable growth. One of the larger specimens, measuring 5 mm., is represented natural size in fig. 11.

On July 24 one of the largest measured 8 mm., and was preserved (see fig. 12).

On July 26 one could see an appreciable growth since the 24th, and the specimen shown in fig. 13 measures 9 mm. In 11 days (since July 15), therefore, there has been an increase of 300 per cent in the length of the arm, which is equivalent to a much larger increase in bulk.

The stars were taken from the bottom and put inside the car on August 1 and were fed with barnacles and small mussels. They had by this time eaten nearly all the barnacles on the bottom of the car and were doubtless in want of food.

On August 2 the largest specimen measured 11 mm., and is represented in fig. 14. Those on the bottom, however, which had left the eelgrass, were larger, some of them approaching the size of those on the car.

On August 13 a box thickly covered with barnacles was split up and pieces put into the car. The star-fish always preferred the under side of the boards, and the latter were therefore placed barnacle side down.

The stars on the eelgrass were examined on August 15 and the larger ones averaged about 2½ mm., or about the size of that in fig. 9.

On August 18 the largest measured slightly less than 18 mm (see fig. 15). This specimen was afterwards kept in a dish without food, and will be referred to again.

On September 5 one of the largest specimens was 26 mm. in length of arm (fig. 16). Another measured 27 mm., and several measured 25 mm. or more.

On September 26 the largest measured 35 mm., and is represented in fig. 17.

On October 12 the largest found was 42 mm. (fig. 18).

On October 25 one specimen measured 54 mm., or about 2¼ inches (fig. 19); this was preserved. The next largest (51 mm.), shown in fig. 19, is the largest star reared in captivity. It was almost exactly 4 months old, having set about June 28. The sexual glands were more highly developed than usual, even for larger stars at this season. From this date to November 11 there was no growth, but apparently a slight decrease.

The following gives in brief the measurements of some of the largest stars found on the car during summer and fall. The asterisk (*) indicates that the specimen was not returned to the car, so that a smaller specimen was recorded on the next date.

Date.	Milli-meters.	Date.	Milli-meters.	Date.	Milli-meters.	Date.	Milli-meters.	Date.	Milli-meters.
July 15	3	Sept. 5	25	Sept. 26	34	Oct. 12	38	Oct. 25	45
July 18	5*	Sept. 5	25	Sept. 26	33	Oct. 12	36	Oct. 25	44
July 24	8*	Sept. 5	25	Sept. 26	33	Oct. 12	35	Nov. 5	45
July 26	9	Sept. 5	24	Sept. 26	31	Oct. 12	35	Nov. 5	44
Aug. 2	11	Sept. 5	24	Sept. 26	30	Oct. 25	54*	Nov. 5	43
Aug. 18	18	Sept. 5	24	Sept. 26	30	Oct. 25	51	Nov. 5	43
Sept. 5	27	Sept. 5	23	Oct. 12	42	Oct. 25	50	Nov. 5	43
Sept. 5	26	Sept. 26	35	Oct. 12	40	Oct. 25	48	Nov. 5	42
Sept. 5	26	Sept. 26	35	Oct. 12	40	Oct. 25	45	Nov. 5	40

On September 5 a number of specimens (19 in all) were selected and placed by themselves in another car, so that I might be sure to measure the same individuals on succeeding days; these were measured on six occasions, with the following results:

Specimen.	Sept. 5.	Sept. 26.	Oct. 12.	Oct. 25.	Nov. 5.	Nov. 11.
No. 1	24	35	40	47	46	41(?)
2	24	31	35	40	38	41
3	20	30	35	38	38	40
4	19	29	34	38	38	39
5	19	29	33	38	38	38
6	19	28	32	37	38	38
7	18	28	32	36	38	36
8	18	28	31	36	37	36
9	18	27	31	36	37	35
10	18	26	30	36	37	35
11	17	26	30	35	37	35
12	16	26	30	35	37	35
13	16	25	29	35	34	35
14	16	25	29	35	35	35
15	15	24	28	34	33	34
16	15	23	28	32	33	34
17	15	21	27	30	32	33
18	14	21	25	30	32	31
19	12	21	....	29	31	31

It will be noticed that among these specimens, as well as among those in the original car, given in the first table, there is rarely any evidence of growth after October 25, but there is rather a slight decrease in size. On each occasion the measurements were made without referring to those of the preceding date, so that no personal prejudice might enter the results. For the most part the figures indicate a fairly uniform rate of growth among the different stars. In interpreting these figures there is one factor which is to be taken into consideration, namely, that star-fish over 20 mm. (sometimes less) are able to contract and expand, so that two careful measurements, taken within a few minutes of each other, may vary as much as 1 or 2 mm. The measurements in the last three columns, therefore, indicate that the star-fish in the car were of about the same size on November 11 as on October 25. The first measurement (41 mm.) under November 11 is doubtless an error.

It may be inferred, from what has already been said, that at any time during the summer, after the stars are all set, there is a great difference in size among them. To illustrate this point, I arranged on August 18 a series of specimens taken from the car and from the seaweed, and photographed them at natural size, by laying them down on the sensitive paper (with a thin transparent film between), and then exposing. The variation in size is shown in fig. 20, the first 5 specimens having been taken from the car, and the last 5 from the seaweed. This variation in size is doubtless due much more to the difference in amount of food than to difference in age.

The following experiments on the rate of growth support this view:

(*c*) *Rate of growth of individual star-fishes kept under various conditions.*—The largest of the stars in the car on August 18 (compare fig. 15) was kept in a dish with only a few very small barnacles for food. When taken from the car, it measured 18 mm.; slightly more when fully expanded. On September 25 it measured 18 mm., showing no growth. On September 26, 39 days after it was taken from the car, it measured between 15 and 16 mm. In the absence of food, therefore, it had lived and apparently was in perfect health, but had probably diminished somewhat in length, as well as in bulk. (Some allowance must, of course, be made for the contraction and expansion, as mentioned before.) During this time several of the stars, smaller than this one, remained in the car and grew to the length of 35 mm. (Fig. 17.)

A small star-fish which was caught in the tow, and which set on June 28, was kept in the dish with many others until June 23. On this date it was placed in a small dish by itself and fed with small clams and barnacles. Fig. 23 shows the growth of this specimen: *a*, 2 mm., July 23; *b*, 4 mm., August 13; *c*, 4½ mm., August 18; *d*, 5 mm., September 6. On September 6 it was transferred to a car where there was an abundance of small barnacles. Fig. 23, *e* (12 mm.), represents size on September 26; *f*, 21 mm., on October 12; *g*, 30 mm., on November 5.

As a control of this experiment, several star-fish, which also set on June 28, were kept with a minimum amount of food. One of these, photographed at natural size on September 6, is shown in fig. 21 *a*, while the largest star in the car (with plenty of food) is represented in fig. 21 *b* (27 mm.). The specimen figured in *a* is 39 days old, and that in *b* is within a day or two of that age.

The next experiment (illustrated by fig. 22) on the growth of stars was as follows:

On August 3 two stars of average size were taken from the original car and placed in another car with a bunch of mussels.

On August 3 (No. 1) = 7 mm., fig. *a*. On August 16 (No. 2) = 10½ mm., fig. *a′*.

During this time the stars had little or no food, since they could not, or would not, eat the mussels. On August 15 a lot of barnacles was placed in this car, and by September 5 the results of the new food were evident enough:

September 5: (No. 1) = 15 mm., fig. *c* (one arm was torn off in measuring). (No. 2) = 19 mm., fig. *c′*.

September 26: (No. 1) = 28 mm., fig. *d* (new arm 10 mm. measured from mouth, growth of 7 mm.). (No. 2) = 29 mm., fig. *d′*.

October 12: (No. 1) = 36 mm., fig. *e* (regenerating arm, 20 mm., from mouth, growth of 17 mm.). (No. 2) = 41 mm., fig. *e′*.

From August 3 to August 16, while these specimens were not growing at all, those in the car grew about 6 mm. These two specimens afterwards, however, having more food and no interference in eating it, made up this difference, and by September 26 had grown as much as those in the original car.

One interesting point brought out by the experiment is that a star which is regenerating an arm may grow as fast as a complete star. Compare next experiment.

(*d*) *Rate of growth and rate of regeneration.*—The star-fish, like the lobster and many crabs, has the habit of dropping off an arm which has been mutilated and regenerating a new one. Unless the arm is mutilated or some other shock administered, one may sometimes tear a star in two by pulling on the arms, while the latter still remain on the fragments of the disk. On the other hand, if the suckers are cut off from one arm, or the arm is crushed or cut several times, it will usually drop off, always at the same point near the disk, taking the sexual glands with it.

On September 26 five of the larger stars in the original car were deprived of the arm opposite the "eye;" or madreporic plate, and then placed in a car with barnacles for food. The subsequent measurements show that they kept on eating and growing at about the usual rate, like the specimen similarly treated in the last experiment described. The measurements are given in tabulated form below, the first measurement indicating the length of the longest arm.

Specimens.	Sept. 26.		Oct. 12.		Oct. 25.		Nov. 5.		Nov. 21.	
	Longest arm.	New growth.	Longest arm.	New growth.	Longest arm.	New growth.	Longest arm.	New growth.	Longest arm.	New growth.
A..........	32	0	36	3	42	7	41	11	40	12
B..........	30	0	35	3	38	7	41	12	40	11
C..........	28	0	30	3	35	7	38	10	38	12
D..........	27	0	29	3	30	6	35	9	38	11
E..........	25	0	28	3	....	....	34	7	35	9

A comparison of the table with that on page 217 shows that these stars which are regenerating an arm grew at about the same rate as the complete stars during the same period. The rate of regeneration was also about the same as the rate of growth in the original arms, except that toward the last the new members grew in some cases somewhat more rapidly.

Another experiment was made similar to the above, except that two arms were taken off instead of only one, and the stars were younger at the beginning. The stars were at first all about 12 mm. The eight detached arms were put in the car also, and on September 10, 26 days after they were detached, five were still alive and apparently in good health, but had neither grown nor shown any sign of regeneration. One is figured natural size in fig. 24 *b*.

The growth of these specimens is tabulated below. (Measurements were made from mouth to tip of new arm, but figures in table indicate merely new growth, and are derived by subtracting 3 mm. from original figures.)

Specimen.	Aug. 15.	Sept. 5.			Sept. 26.				Oct. 12.				Oct. 26.				Nov. 5.			
	Longest arm.	Longest arm.	First short arm.	Second short arm.	Longest arm.	First short arm.	Second short arm.	Newest arm.	Longest arm.	First short arm.	Second short arm.	Newest arm.	Longest arm.	First short arm.	Second short arm.	Newest arm.	Longest arm.	First short arm.	Second short arm.	Newest arm.
a	[1]12 (?)	22	....	8	34	18	17	....	42	32	30	....	....	....	....	....	....	....	....	....
b................	12 (?)	20	....	7	30	17	17	....	36	26	26	....	....	....	....	....	43	31	31	....
c................	12 (?)	18	....	5	25	[2]9	[3]9	....	37	16	15	....	....	....	....	....	40	24	24	....
d	12 (?)	18	....	5	23	14	12	[4]8	32	22	20	13	35	23	23	17	34	27	27	20

[1] It was intended at first to keep account only of rate of regeneration, and so four stars were picked out, of about the same size, and one only was measured. This was 12 mm. The others may have been 1 or 2 mm. larger or smaller. The growth of this specimen and the size of the single arm alone, on September 26, are given in diagram, fig. 24, *a* and *b* respectively.

[2] One detached arm, still alive, measures 7 mm.

[3] Tips cut off and arms slit on September 15. The longest arm was then 22 mm., and the regenerating arms 15 and 10 mm., respectively.

[4] Arm broken off, probably by handling, on September 5.

This experiment shows conclusively that when even two arms are lost the growth of the star-fish is not necessarily arrested or the rate of growth diminished. The rate of growth in the new arms was greater than in the original arms, and there was a tendency, therefore, for all to become ultimately of the same length.

The results show clearly that within very broad limits it is impossible to tell the age of a star-fish from its size. Star-fishes of all ages are able to live for months with very little or no food. The rate of growth depends directly upon the amount of food eaten. Star-fishes which are regenerating one, or even two, arms may, under ordinary circumstances, grow as rapidly as the complete stars. The growth of the new arms in the star-fish experimented upon was slightly more rapid than that of the original arms, showing a tendency in the organism to return to the original length In four months from time of setting, some of the larger stars kept in the cars under favorable circumstances attained a length of from 50 to 54 mm., or 2 to 2⅛ inches, measured from mouth to tip of arm. This is more than twice the length of many of the stars which were found just before the beginning of the breeding season, and which were therefore at least nearly a year old.

Allowing a moderate amount of growth during the winter and spring months, of 10 to 15 mm. (the amount of increase attained in one full month preceding October 12), the larger year-old star-fish in the early summer would be about 65 mm., or 2½ inches, in length, which is about the length of the greater number of stars taken on the mops in the Kickemuit River during the summer.

XI. *What is the size and age at sexual maturity?*

Among the star-fish caught in various parts of the bay on June 2, 3, and 4, several specimens only 1¼ inches, or 32 mm., were found to be very full of sexual products. This size was attained by many of the star-fish reared in the car on September 26, about three months from the time of setting. See table on page 217.* Great numbers of stars measuring about 2 inches, or 50 mm., were found ripe the first week of June. This was the size of several specimens in the car on October 25, which were not more than four months old, and whose sexual glands were well developed. In other words, a large number of the star-fish reared in the car were by the end of October as large as a great many which were sexually mature in June. Moreover, it was rare to find a specimen of this size on the 1st of June which was not full of ripe eggs, which were laid later, as the empty star-fish caught in July showed. It is an obvious conclusion, therefore, that, with fairly good opportunities to obtain food, the star-fish becomes sexually mature in less than a year, and that those hatched one season breed the next.

In his monograph on North American star-fishes, Alexander Agassiz gives his views with reference to their rate of growth in the following words (the figures referred to represent specimens, all of them smaller than that in our fig. 9, of a star about 2 weeks old raised in the car):

> The young star-fishes figured on this plate (pl. VIII) were all found attached to roots of Laminaria, thrown up on the beaches, in the neighborhood, after a storm; and from their different stages of growth, as compared with the oldest star-fish raised from a Brachiolaria (pl. VI, fig. 11), specimens of which were also found upon these roots, it is probable that the sizes here figured are 1 (fig. 1), 2 (fig. 8), and 3 (fig. 10) years old. A considerable number of specimens were picked up in this way, and they could all be arranged into very distinct groups, representing the star-fishes of the present and of two previous seasons. There seemed to be no gradation from one group to another, such as we have among the young sea-urchins, which, in consequence of their manner of breeding during the whole year, form series the relations of which it is impossible to determine. In this connection I would say that by arranging the star-fishes found upon our rocks into series according to their size we are able to obtain a rough estimate of the number of years required by them to attain their full development; this I presume to be somewhere about fourteen years.† They begin to spawn

* Eggs from a specimen of 38 mm. were readily fertilized with spermatozoa from a male of same size.

† For an account of the method adopted by Professor Agassiz for ascertaining the age of many of our marine animals, see Proceed. Essex Inst., 1863, p. 252.

before that time, as specimens have been successfully fecundated which evidently were not more than six or seven years old. It is during the fourth year that the rate of growth seems to be most rapid. A young star-fish, measuring 1½ inches across the arms, was kept during five months alive in Mr. Glen's tank at the museum, and during that space of time it grew to 3 inches.

It will readily be seen that my observations do not agree with those of Agassiz. I found no difficulty in obtaining all possible gradations in size among the stars in the late summer, and those represented by Agassiz as 1, 2, and 3 years old, respectively, more nearly correspond with those raised in cars when they were 1, 2, and 3 weeks old.

XII. *What are the natural enemies of the star-fish?*

The destructive agents and natural enemies referred to in the last report were cold and fresh water, various fishes which feed upon the larvæ, gulls and crows, and parasites. Some specimens which were attacked by the parasite frequently found in the fall of 1897 were kept over winter, and by spring the disease had disappeared; but the effects of the disease were sometimes visible. In one case an arm was entirely eaten through, about ¾ inch from the tip, but was not thrown off. The stump healed over, and the star was kept throughout the year. It showed almost no trace of regeneration, probably because food was rarely taken by the specimen.

The enemy which is doubtless the most destructive to the star-fish is the menhaden. In an article on the "Food of the menhaden," published in the United States Fish Commission Bulletin for 1893, Dr. James I. Peck showed that this fish feeds exclusively upon the minute organisms which swim or float free in the water. The open mouth of the menhaden has an area of about a square inch, and as the fish swims through the water with open mouth and gill-covers raised, a considerable column of water is passed through the mouth every minute (estimated by Dr. Peck at about 7 gallons). The gillrakers strain the water, and the organisms which are not too minute are caught in the mouth and swallowed. The star fish larvæ, of even small sizes, are far too large to pass through the gillrakers. Numerous schools of menhaden feed in our bay during the season when the star-fish larvæ are swimming at the surface, and undoubtedly destroy them by thousands of millions.

After the stars are set they are no longer in danger of being destroyed by the menhaden, but for several weeks are bright conspicuous objects upon the seaweed and eelgrass for eels and many small fishes to feed upon.

XIV. *Is the popular idea that the dismembered fragments of a star-fish will regenerate new star-fish founded on fact?*

This idea is commonly held, and is apparently founded on the fact that in nearly every lot of stars brought up in the dredges or on the mops a considerable number may be found which are regenerating lost parts. Frequently two, three, or even four arms are being regenerated, and these are much smaller than the original arms. Upon careful examination and inquiry into the extent of this regeneration I have never found a well-authenticated case among our species of stars in which part of the disk was being regenerated, except those reared with great care in the aquarium. With this point in view I have examined a large number of regenerating stars caught in their natural haunts, some of them reported to be regenerating part of the disk, but invariably the regeneration was limited to the arm. I have, however, made a few experiments in the aquarium and in the cars which have a bearing upon this question.

The fact that a mutilated arm is frequently loosened and dropped off at a particular point near the base and the rate of regeneration of specimens which have thus lost one or two arms are recorded previously (p. 219).

All of the arms may be pulled off and if the star is protected and fed all will regenerate. Such a specimen is sketched in fig. 25. This specimen was kept after the operation in a glass dish with frequent changes of water, and was fed upon the soft parts of crabs, etc. The regeneration was slow as compared with that given in the previous tables, the new growth shown in the figure (which is natural size) requiring five or six weeks, probably owing to the comparatively small amount of food taken.

Since a mutilated arm drops off from the disk so readily, the latter nearly always remains intact, and in ordinary cases, therefore, if two stars were to result from one, one of them must regenerate from a single arm. I have several times kept single arms for a long time in the aquarium or cars, but have never seen any trace of regeneration in them. On May 11 several arms were taken off at the usual line of detachment, and kept alive in the aquarium until June 9, when they showed no sign of regeneration. One of these was still alive on June 25, and at that time was apparently enjoying good health, and would turn over if put on its back. It had lived, therefore, for over six weeks, but showed no signs of regeneration.

Another experiment was started on August 15; two arms were taken off from each of four specimens. The rate of regeneration of these specimens is given in the tables on p. 219. On September 10, nearly three weeks afterwards, five of the single arms were found alive, but showed no regeneration. On September 5 the new growth in the arms regenerating from the disk was from 8 to 5 mm. On September 26, six weeks after the operation, one of the single arms was found alive (7 mm.) It had not shown any traces of regenerating a new arm, although it had healed. This arm is represented natural size in fig. 24, *b*, and the new growth which took place on one of the stars from which these arms were detached is shown in fig. 24, *a*. Similar experiments were tried last year with the same result. In a recent article by Miss Helen Dean King, in Roux's Archiv, it is stated that single arms were kept alive for two weeks, but never showed signs of regeneration.*

Several experiments were carried on to determine what regeneration would take place if the disk were cut through. On the 11th of May 19 specimens about 2½ inches in length were treated in the following manner: Two arms were pulled off, and at the base of one of the arms a piece was cut out from the top of the disk in the manner shown in fig. 26. These specimens were placed in a large car at Woods Hole without food (except what could be carried in the water). On June 9 there was a trace of regeneration in some of the arms. On June 25, a little more than six weeks after the operation, all the arms were growing out anew, and varied from a mere trace of a new arm with the terminal eye-spot (which always shows first) to arms ¼ inch (about 7 mm.) long. This experiment shows two things: that the new arm will regenerate if a portion of the disk is absent, and that the rate of regeneration, like the rate of growth, in normal specimens, is dependent upon the nourishment, for while the new growth in these cars was only 7 mm. in six weeks, those which were well fed at Kickemuit gained a new growth of from 13 to 18 mm. in the same time. See page 217.

Other experiments were tried, to determine what regeneration would take place if the whole star-fish were cut through in various ways, while the arms were left in place. It will be seen that the results were not always the same.

In the summer of 1897 several stars about 2½ inches in length were cut through so as to leave three arms and part of the disk on one piece and two arms and part

*During the summer of 1899 several single arms were kept alive from early in May until the middle of August, when they were destroyed by accident. There was no regeneration.

of the disk on the other. The smaller pieces perished, but the larger ones lived for several weeks and showed no sign of regeneration. All but one were destroyed by other star-fishes which got into their compartment of the car by accident. The remaining fragment, consisting of three arms and part of the disk, lived several months after the operation and did not regenerate.

On May 11, 1898, several stars about an inch long were cut as in fig. 27. One arm was pulled off and the disk then cut in two, leaving two arms with a part of disk and madreporic plate on one piece (= *a*); and two arms and part of disk on the other piece (= *b*). The fate of the single arm has been already considered (page 222). On June 9 all the pieces were alive. In the piece marked *a* (i. e., having madreporic plate) a trace of a new arm was visible on the side toward the lost arm, but in no other place. The pieces marked *b* showed no regeneration at all.

On June 25, 6½ weeks after the operation, the condition was as follows: All these parts of specimen 1 were alive. The fate of the single arm has been mentioned previously. The piece (*a*) with madreporic plate is sketched from the lower side in fig. 28. Two arms were well started and one minute arm was growing out between them. In the other piece (*b*) of this specimen, the wound was completely healed, but there was no visible trace of any new arms. Of specimen 2, only one piece (*a*) was alive. From the stump of the old arm a very small new arm appeared—no trace of any other. The two pieces *a* and *b* of specimen 3 were alive and healthy. In *a* two very small arms were visible (one could be seen only with the help of a hand lens) near together, and on one side of the cut surface; on the other side there was a trace of another arm, indicated by an eye-spot. *b* had healed up, but showed no trace of regenerating arms. Of the fourth specimen, piece *a* was alive with two very minute regenerating arms. These specimens had very little food, and it is hardly necessary to remark that they grew very little or not at all.

On September 5, 1898, another experiment, similar to the last, was commenced at Kickemuit River. Eight specimens were taken from those reared in the car and cut in two in the manner shown in fig. 29, leaving two arms and the madreporic plate on one piece and three arms and part of the plate on the other. The pieces of the latter sort died in a short time, and the following data refer to the pieces having two arms and the plate ("eye"). At the beginning of the experiment the specimens measured in millimeters, 23, 21, 21, 20, 19, 18, 18, 18.

September 26, 3 weeks after the operation:
A, 22 mm., bore trace of two new arms.
B, 18 mm., two new arms (preserved) unhealthy.
C, 18 mm., one new arm, 2 mm.
D, crushed.
E, 20 mm., healthy; no trace of another arm.
F, overlooked. See next, Oct. 12.

October 12:
A (?), 23 mm., two very small arms.
C, 20 mm., two arms, one smaller than the other.
E (?), 22 mm., no trace of regeneration.
F, 21 mm., one arm.
(all healthy.)

October 25:
C, 20 (?), two arms 8 to 10 mm.; no trace of other.
E, 22, *no trace of regeneration.*
F, {21 / 20} (?), one arm, 6 mm.; no trace of another.

November 5:
A, 25 mm., two new arms, 2 mm. each.
C, 21 mm., two new arms, 9 to 10 mm.; no trace of other.
E, 22 mm., one new arm directly in middle, 1 mm. long.
F, 19 (?), one arm, 4½ mm.; no trace of rest.

November 11 (fig. 30):
A, 23 mm., two small arms, about 3 mm.
C, 21 mm., two small arms, 10 and 12.
E, 21 mm., one arm, 1½ mm., directly in middle.
F, 20 mm., one arm, 6 mm.
(*no trace of other arms in any.*)

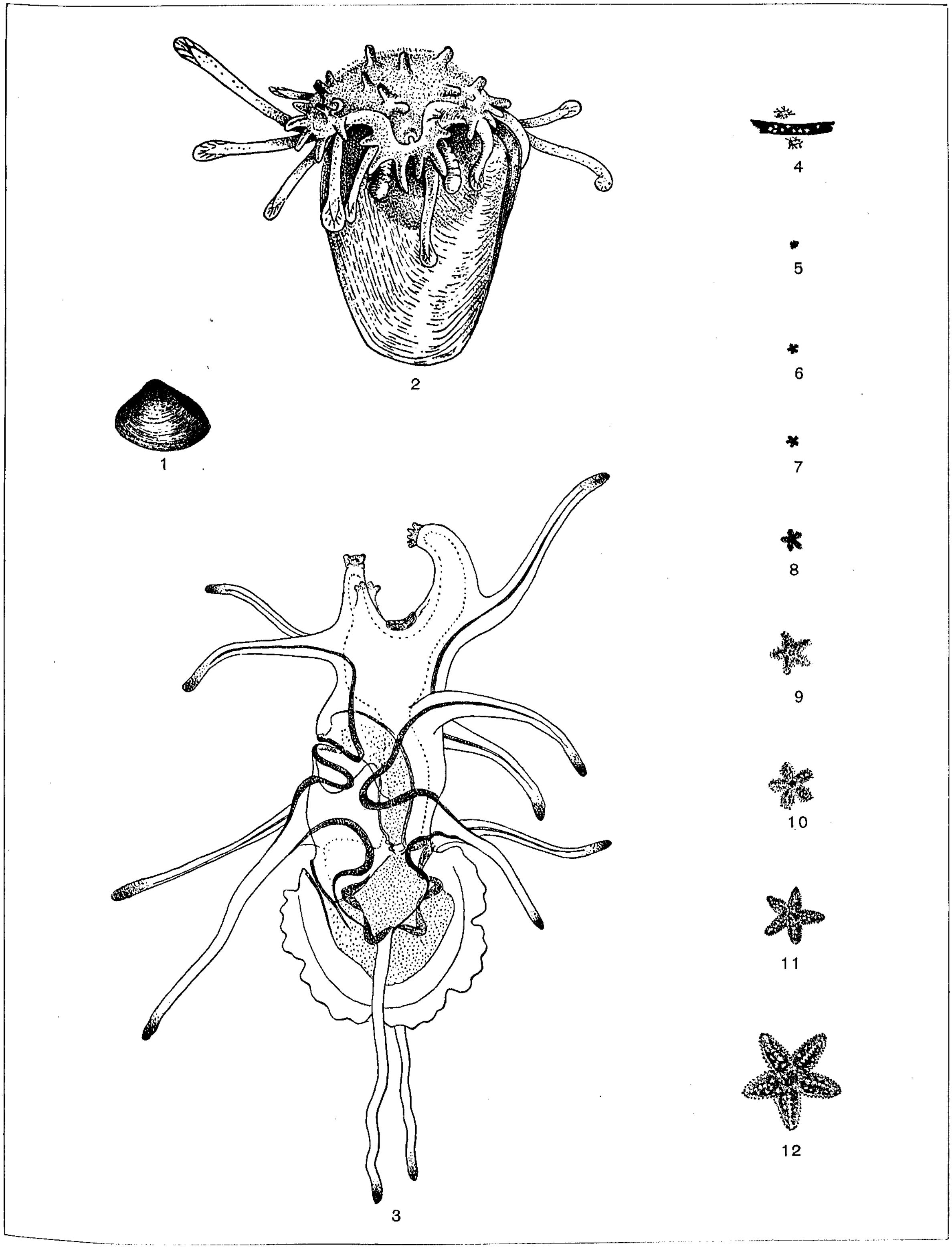
Similar experiments upon young stars about the first of August yielded essentially the same results, except that out of seven pieces which lived until September 5 four were without madreporic plate and three of these were regenerating new arms. Miss King, whose recent article has been already referred to, seems to have had better success than I, and says that from each of the pieces of a star cut in two a new star may be formed by regeneration. That the madreporic plate is not essential to the life of the star, at least for a very long time, is shown by another experiment: This organ was removed from five large stars on June 14, and on November 5 one of them was alive and healthy, but had not regenerated the lost structure. The madreporic plate was wanting in a specimen caught at Woods Hole on April 4. Another was taken which had an accessory madreporic plate, which was not, however, connected with the stone canal. In the last report I mentioned an experiment in which this body was extirpated and regenerated before the end of the season.

In every known case of regenerating star-fish caught on the mops and dredges the new growth is limited to the arms. The arms are readily loosened and cast off when injured, but almost certainly do not produce new stars, as is shown by the experiment in which single arms have been kept three months without trace of regenerating, and by the fact that single arms regenerating the rest of the stars have never been found among this species of star (they are common in some foreign species). Star-fish which have been cut in two behave differently in different cases. They may live for a long time without regenerating the remaining arms to the slightest degree; they may show no sign of regeneration for several weeks and then regenerate one or more arms; they may soon regenerate only one or two of the arms when three are required to complete the original form of the body. The rate of regeneration and perhaps the possibility of regeneration are, like the rate of growth, dependent on the food supply. It is probably possible for two or more complete stars to result from one, but in many experiments in which the stars were carefully protected this result has not been obtained by me. The probability of this result occurring when stars are torn apart and thrown overboard is doubtless very slight, for, as the experiments show, such stars have difficulty in obtaining food and are especially liable to injury and to destruction by other stars or enemies of various kinds.

XV. *What are the artificial methods of destruction now in use in Rhode Island or elsewhere?*

Star-fishes are caught in considerable numbers with the spear and tongs, but the more efficient method is the use of the "tangle" or "mop." The tangle consists of a number of mops of cotton waste or similar material attached to an iron bar. By dragging these mops over the oyster-beds the stars become entangled and are drawn up with the mops. The mops are usually detached from the iron bar and are thrown, together with the stars, into a tub of hot water. Meanwhile other mops are attached to the bar and thrown overboard. After the stars are killed they can be more easily picked off the mops than when they are alive. Some oystermen prefer to dredge up oysters, stars and all, and, after having culled out the stars, to replant the oysters.

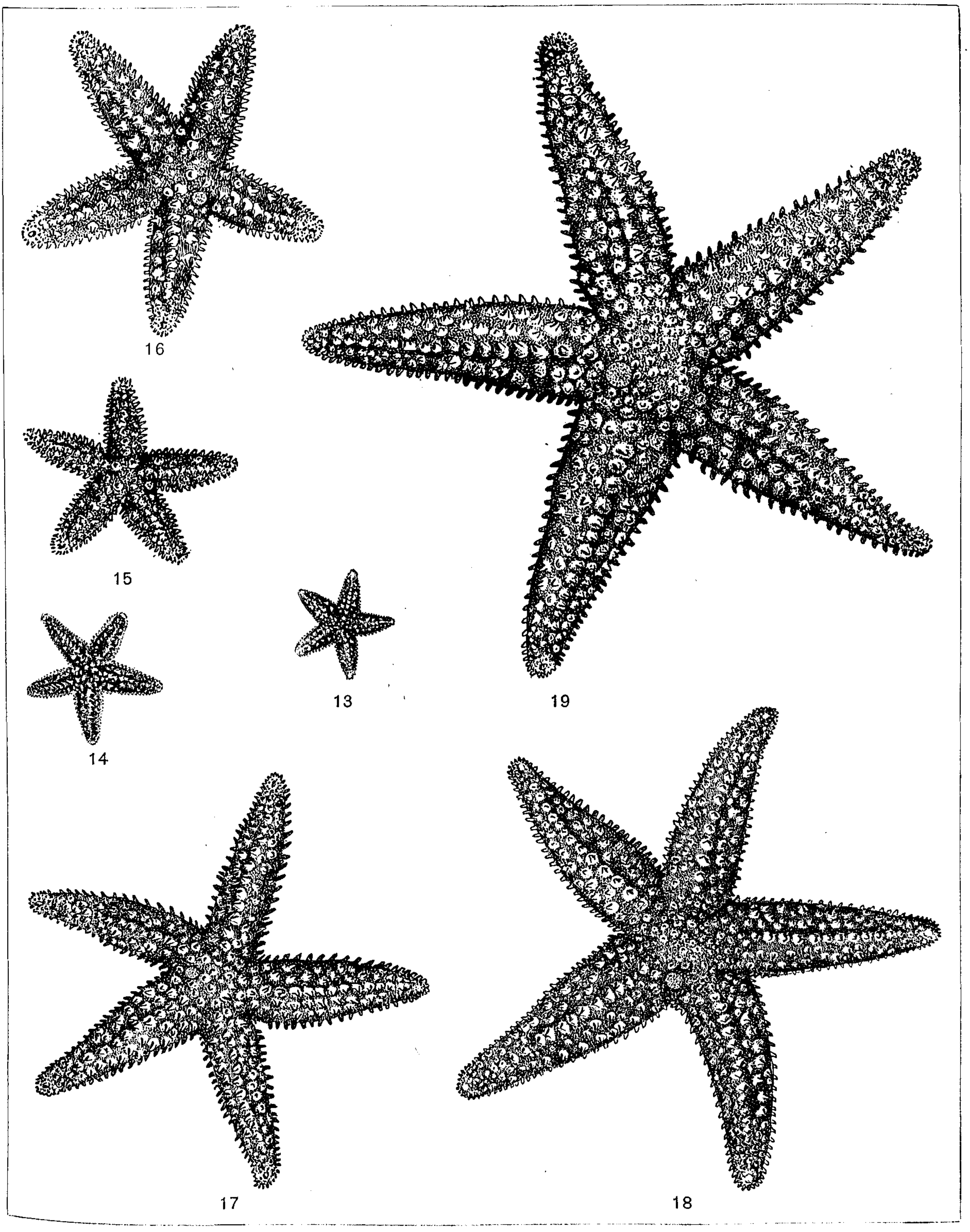
The star-fish become easily entangled in the mops, not only because they are rigid and covered with spines, but because the little forceps (pedicellaria) thickly scattered over the surface of the body catch hold of the threads of the mop. If one presses the upper surface of a live star-fish against the back of his hand he will find that these pedicellaria grasp the hairs on the hand tightly and will sustain the whole weight of the star-fish.



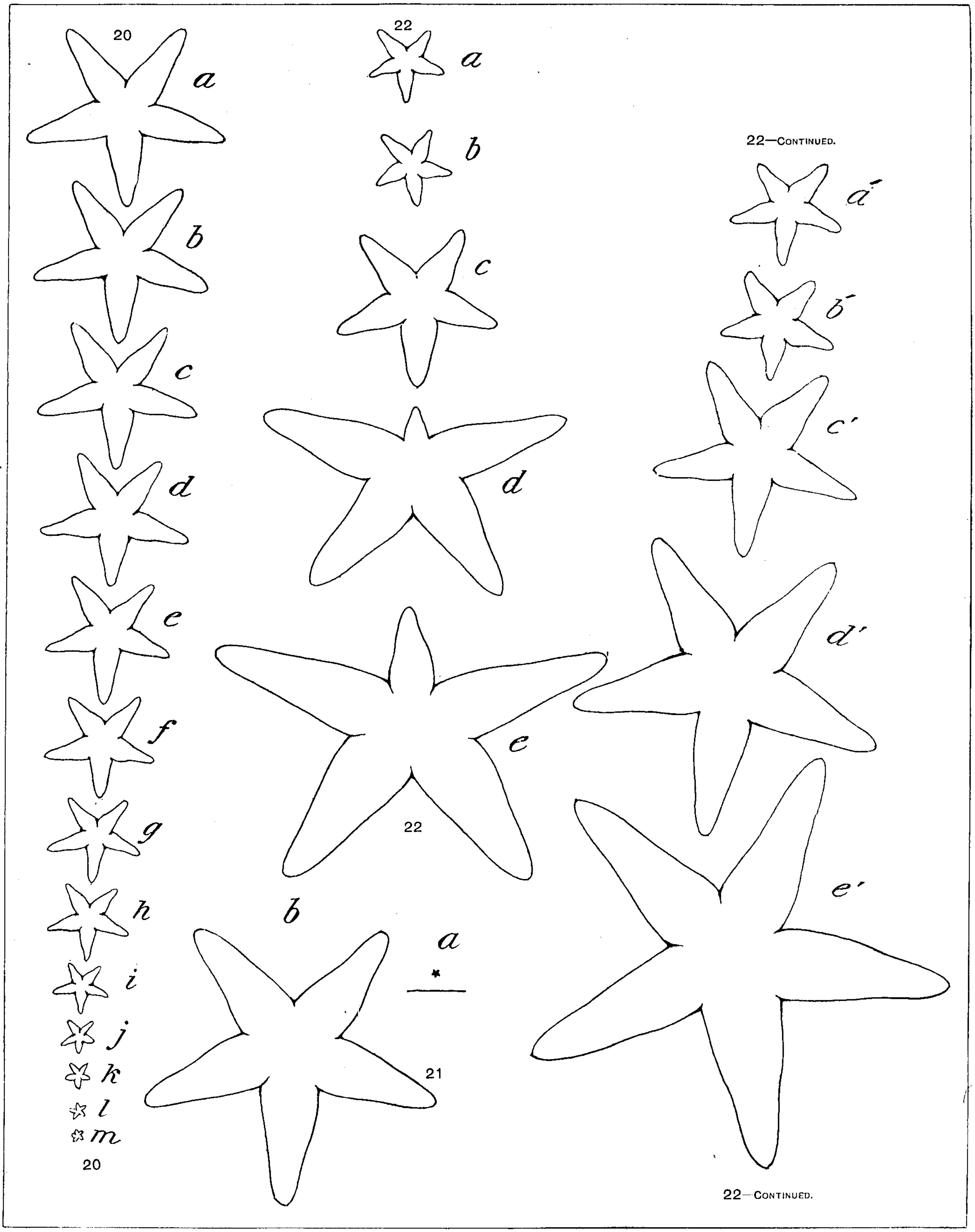
1. *Mulinia lateralis*, gray. Natural size.
2. Star-fish about 2 days old, much enlarged, devouring a clam. Outlines of stomach of star-fish can be seen through transparent shell of clam. (Drawn from life by Dr. J. L. Kellogg.)
3. Larva of star-fish, nearly ready to set, in side view; dark bands show position of vibratile cilia; intestine and stomach shaded; five lobes at lower portion of figure are beginning of the five arms. Larvæ of about the same age are shown in figure 4. (From life; much magnified.)
4. Piece of eelgrass with star-fish larvæ just undergoing their transformation; two larvæ at sides. Natural size.

5 to 8. Small specimens of star-fish from seaweed, about the first of July. Natural size.

9. Shows size of average star found upon eelgrass and seaweed, on July 15. Natural size.
10. Large specimen from car, July 15. Natural size, 3 mm.
11. From car, July 18, large specimen, 5 mm. Natural size.
12. From car, July 24, large specimen, 8 mm. Natural size.

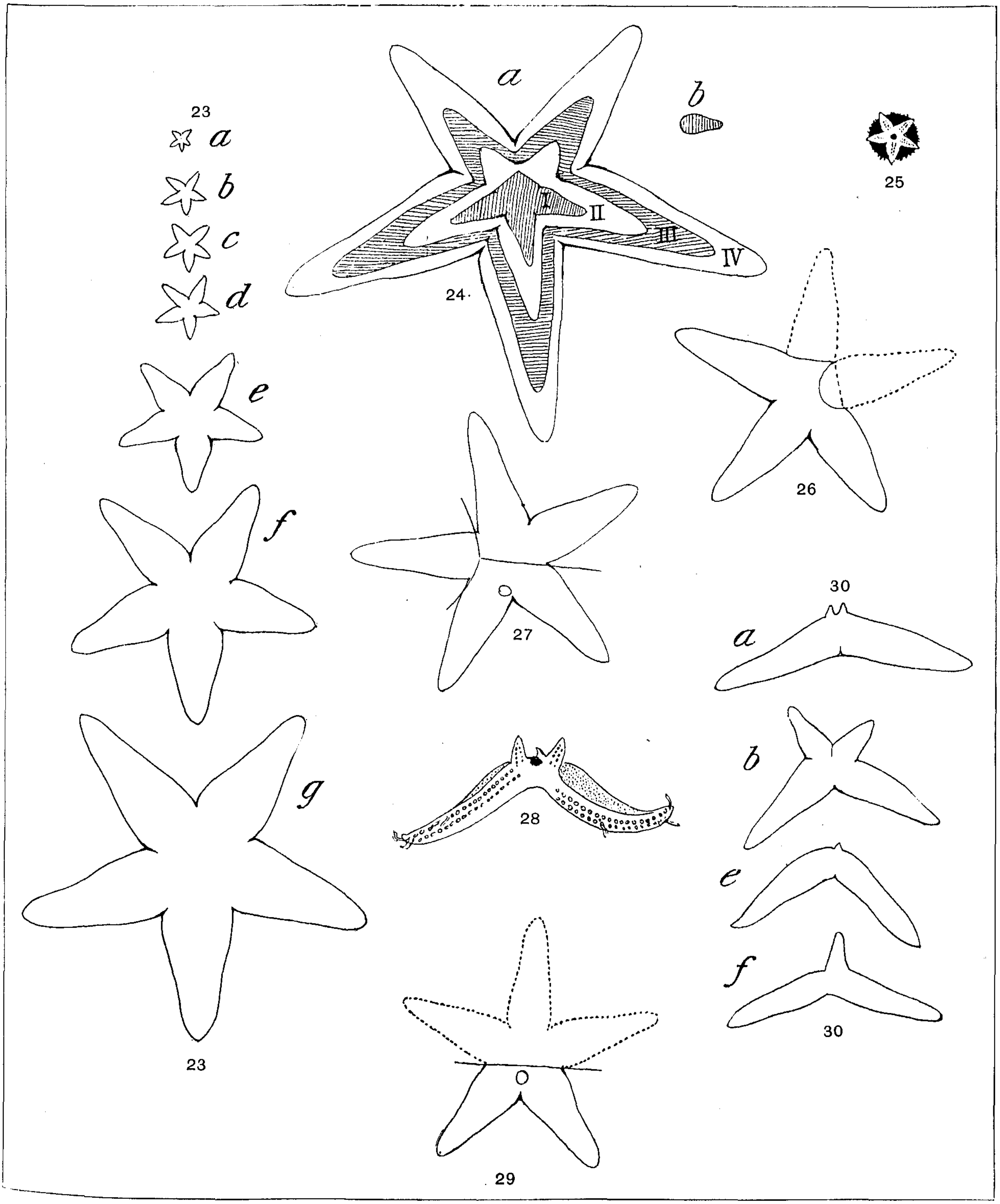


13. From car, July 26, large specimen, 9 mm. Natural size.
14. From car, August 2, large specimen, 11 mm. Natural size.
15. From car, August 18, large specimen, 18 mm. Natural size.
16. From car, September 5, large specimen, 24 mm. Natural size.
17. From car, September 26, large specimen, 35 mm. Natural size.
18. From car, October 12, large specimen, 42 mm. Natural size.
19. From car, October 25, largest specimen, 54 mm. Natural size.



20. Series of star-fish taken on August 18, showing variation in size; first 4 specimens from eelgrass, last 9 from car. Natural size.
21. *a*, Star-fish set June 28; kept alive in dish, and drawn natural size, September 6 (5½ weeks); *b*, from car, September 5, within a day or two of the age of *a* (p. 218). Natural size.

22. Shows rate of growth in two stars, *a*, *b*, etc., and *a'*, *b'*, etc.; *a* and *a'*, August 3, 7 and 10½ mm.; *b* and *b'*, August 16, 7 and 10½ mm.; *c* and *c'*, September 5, 15 and 19 mm. (one arm pulled off from *c*); *d* and *d'*, September 26, 28 mm. (new arm 10 mm.) and 29 mm.; *e* and *e'*, October 12; *e*, 36 mm. (new arm 20 mm.); *e'*, 40 mm. Natural size. See page 219.



23. Shows growth of single specimen collected as a larva and set June 28. *a*, July 23, 2 mm.; *b*, August 13, 4 mm.; *c*, August 18, 4½ mm.; *d*, September 5, 5 mm.; *e*, September 26, 12 mm.; *f*, October 12, 21 mm.; *g*, November 5, 30 mm. Natural size. See page 218.

24. *a*, Rate of growth and of regeneration: I, August 15; II, September 5; III, September 26; IV, October 12; *b*, single arm alive, from August 15 to September 26. Natural size. See page 219.

25. Star regenerating five arms from ventral side. Natural size. See page 222.

26. Showing manner of cutting the stars in the experiment described on page 222.

27. Showing manner of cutting the stars in the experiment described on page 223.

28. Showing the regeneration of the arms in the experiment described on page 223; a portion of the disk regenerating three arms. Natural size.

29. Showing manner of cutting the stars in the experiment described on page 223. Natural size.

30. The result of one of the regeneration experiments described on page 223; one or two arms regenerating from a part of the disk. Natural size.