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## THE SYNAPTAS OF THE NEW ENGLAND COAST.

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Through the kindness of the United States Commissioner of Fish and Fisheries special opportunities were enjoyed during the spring and summer of 1898 for carrying on biological investigations at the laboratory of the Fish Commission at Woods Hole, Mass. The few weeks at my disposal were devoted to the study of the two holothurians of the genus *Synapta* common at that place. Primarily the object in view was to determine the systematic position of our New England synaptas, their relation to each other and to European forms. At the same time experiments were carried on designed to throw light on the function of certain organs and on the possibilities of regeneration in *Synapta*. The latter were, however, limited by the shortness of my stay.

For the privileges of the laboratory I desire to express my thanks to the Commissioner, and particularly to the director of the laboratory, Prof. H. C. Bumpus, whose constant kindness and sympathy made the work doubly pleasant. I desire also to acknowledge my indebtedness to Mr. Charles M. Pratt, of New York City, for a very fine lot of synaptas from Naples, without which the relation of the American to the European species could not have been positively determined.

### THE SYSTEMATIC POSITION OF THE NEW ENGLAND SYNAPTAS.

On February 5, 1851, at a meeting of the Boston Society of Natural History, Mr. W. O. Ayres ('51) described under the name *tenuis* a synapta which he had found abundantly in Boston Harbor and also at Provincetown, Mass., and Sag Harbor, Long Island. He separated it from the European species on account of slight differences in the "hooks" and "plates." How little the anatomy of the animal was understood is shown by the description of the calcareous ring which he says consists "of 12 pieces of granulated structure, some of which are pierced with holes for the admission of water in respiration." The same year Pourtales ('51) read a paper at the meeting of the American Association for the Advancement of Science, in Cincinnati, "On the Holothuriæ of the Atlantic coast of the United States," in which he described the common New England synapta under the name *girardii*, but he says that the only differences he can find between it and the European *S. inharens* (O. F. Müll.) are that the anchors are less curved and the plates more rounded. He seems to have been unacquainted with Ayres's paper, which was presented three months before his own.

In 1867, Verrill ('67) refers to our common synapta under the name of *tenuis*, and proposes to make it the type of a new genus *Leptosynapta*, "distinguished by their more slender form, the absence of prominent verrucæ, fewer (12), shorter, and more

digitate tentacles, etc.," from "the typical species of synapta," which "have 15 tentacles and prominent verrucæ." This proposed genus has not been accepted by any writer on holothurians, because the form of the body and the prominence of the verrucæ are so closely connected with the degree of contraction of the muscles that they are virtually worthless as characters, while the number and shape of the tentacles differ in different species to such an extent that generic distinctions can not be based exclusively on them. Since Verrill proposed his genus *Leptosynapta* three species of synapta with normally 13 tentacles, one with 11, and two with 10 have been described, and species with 20 and 25 are also known. Doubtless the genus *Synapta* as at present constituted includes two or more natural genera, but Verrill's genus *Leptosynapta* is not sufficiently well characterized to stand. The same year in which this change was proposed saw the publication of Selenka's ('67) well-known monograph on the Holothurians. He pointed out that the name *tenuis* had been used for a synapta by Quoy & Gaimard in 1833, and accordingly suggests *ayresii* as a name for the form Ayres had called *tenuis*. He gives *girardii* Pourtales as a form from Cape Florida, evidently having read the original description hastily or carelessly, and he entirely overlooks its similarity to *tenuis* Ayres. In addition, he describes a species *gracilis* from Boston Harbor, which, as Théel ('86) has pointed out, is obviously based on specimens of *tenuis* Ayres, in which the calcareous bodies have evidently undergone some change due to the alcohol or other preservative used.

In 1874, Verrill ('74) gives the common New England synapta the name *Leptosynapta girardii*, accepting Selenka's objection to the name *tenuis* and recognizing the fact that Selenka's names *ayresii* and *gracilis* are but synonyms of Pourtales's name *girardii*. At the same time he gives a very brief and hasty description of a species of synapta from the New England coast which he calls *Leptosynapta roseola*. Thirteen years later Lampert ('85) gives *gracilis* Sel. the rank of a good species, but places *tenuis* Ayres, *girardii* Pourt., and *ayresii* Sel. as synonyms under *S. inharens* (O. F. Müll.). He ignores Verrill's *roseola* altogether, not even giving it the place of a synonym, though in his literature list he gives Verrill's paper (1874) as containing the description of one new synapta. The following year Théel ('86) placed the names *tenuis* and *girardii* in the list of synonyms of *inharens*. He says of Selenka's *gracilis* that it "seems very doubtful; doubtless identical with *inharens*," and of Verrill's *roseola*, "doubtless not a distinct species." The very best authority on the group, Ludwig ('92), gives *gracilis* Sel. and *roseola* Ver. as good species, but ignores *tenuis* Ayres, *girardii* Pourt., and *ayresii* Sel., apparently regarding them as synonyms of *inharens*.

American zoologists have generally followed Verrill in recognizing two American species of synapta, both distinct from the European species, and the names *Leptosynapta girardii* and *Leptosynapta roseola* have been in common use in this country. European zoologists, on the other hand, have generally credited us with but a single species, and that one identical with the common European form, *inharens*. A careful comparison of numerous specimens convinces me that truth lies between these two positions. American zoologists are right in supposing we have two species, but European writers are correct in considering *girardii* identical with *inharens*. The identity of the two forms seems to me to be beyond question, for there are absolutely no constant differences in either the gross or microscopic anatomy. A comparison of anchors and plates, both in size and shape, shows that while the individual differences may be great, they are entirely inconstant, and I could not find a single point by which the specimens from Naples could be distinguished from those collected at Woods Hole.

The name and synonymy of the common white synapta of the New England coast are therefore:

*Synapta inhærens*, (O. F. Müll.), Zool. Dan. 1779-1784.

*Synapta tenuis*, Ayres, Proc. Bos. Soc. Nat. Hist., vol. iv, p. 2.

*girardii*, Pourtales, Proc. Am. Ass. Ad. Sci., 1851, p. 14.

*ayresii*, Selenka, Zeit. f. wiss. Zool., 1867, vol. XIV, p. 362.

*gracilis*, Selenka, Zeit. f. wiss. Zool., 1867, vol. XIV, p. 363.

*Leptosynapta tenuis*, Verrill, Trans. Conn. Acad., vol. I, p. 325.

*girardii*, Verrill, Rep. on Inv. Ani. of Vineyard Sound, p. 422.

The status of Verrill's *Leptosynapta roseola* is quite different, and I believe that it must be accepted as a valid species. In living specimens there is never the slightest difficulty in distinguishing between *roseola* and *inhærens*. I have never seen but one specimen in which the color alone was not sufficient to distinguish them, and in that specimen even a very superficial examination showed that it was *roseola*. Alcohol makes the color differences even more marked, so that in preserved material the two species are very easily separated. But there are three points in the microscopic anatomy of *roseola* which serve to distinguish it readily from *inhærens*, and on these three points its claim to good standing as a species must rest:

(1) The most important point is found in the radial plates of the calcareous ring. In *inhærens* these plates are about three-fourths as high as broad, and each is perforated through the center for the passage of the radial nerve. In *roseola*, on the other hand, the radial plates are only about half as high as they are wide, and they are not perforated, the radial nerve passing over the top of each in a shallow notch. At first I thought this was simply a stage of development in the formation of the plate, but I was finally convinced that such could not be the case. No specimen of *inhærens*, however small and immature, had a radial plate which was not distinctly perforated through the center, and no specimen of *roseola*, however large, showed any condition beyond the notch. The differences in the calcareous ring are shown in figs. 1 and 2, plate 11.

(2) The calcareous spicules of the body wall present the second distinguishing characteristic of *roseola*. In form, proportions, and distribution of anchors and plates I could find no constant differences between the two species; and Verrill errs in saying that in *roseola* "the perforated plates are smaller and the anchors relatively much longer, with a very slender elongated shaft." Careful measurements, with the aid of a camera lucida, of a large number of anchors and plates taken at random in specimens of *roseola* and *inhærens* from Naples and from Woods Hole, gave the following results:

Species and locality.	Length of anchor.	Breadth of shaft.	Ratio of breadth to length.	Length of arms.	Ratio to length of anchor.	Breadth of arms.	Ratio to length of anchor.	Length of plate.	Ratio to length of anchor.	Breadth of plate.	Ratio to length of anchor.
Inhærens, Naples....	177 $\mu$	17+ $\mu$	.10	44 $\mu$	.25	83 $\mu$	.47	131 $\mu$	.77	100 $\mu$	.56
Inhærens, Mass.....	164	17+	.108	49	.30	92	.56	135	.82	93	.57
Roseola, Mass.....	142	16	.11	38	.27	76	.53	115	.81	72	.57

$\mu$  Abbreviation for micron.

In a still larger series:

Species and locality.	Average length of anchor.	Average length of plate.	Ratio of plate to anchor.
Inhærens, Naples.....	179 $\mu$	133 $\mu$	.74
Inhærens, Massachusetts.....	177	139	.78
Roseola, Massachusetts.....	164	131	.79

It would be absurd to attempt to make any specific character dependent on such slight differences, but in the other calcareous particles in the body wall, *roseola* differs markedly from *inhærens*. In the skin of the tentacles, especially on their inner side, we find in *inhærens* some small, simple particles, not at all branched (fig. 3). In *roseola* these particles are more numerous and are always very much branched and perforated (fig. 4). In the longitudinal muscles of *inhærens* are numerous small, round, or sometimes dumb-bell shaped, particles; they are never branched or perforated (fig. 5). In *roseola* the concretions of the longitudinal muscles are either C-shaped or perfect circles; more rarely they are somewhat branched (fig. 6). These differences, though seemingly slight, are remarkably obvious and constant and no signs of intergradations were found.

(3) The third characteristic of *roseola* is found in the size and shape of special ciliated funnels. In both species these large ciliated funnels seemed to be confined chiefly to the mesentery of the left dorsal interradius and occur singly every millimeter or two. Semon ('87) speaks of two sorts of ciliated funnels in *digitata*, but he does not seem to have observed them in *inhærens*. In the latter species the large funnels are from  $400\mu$  to  $1,200\mu$  high, and from  $150\mu$  to  $400\mu$  in diameter. Their shape is shown in fig. 7. In *roseola* they are smaller and much more slender, measuring less than  $300\mu$  high and  $80\mu$  in diameter (fig. 8).

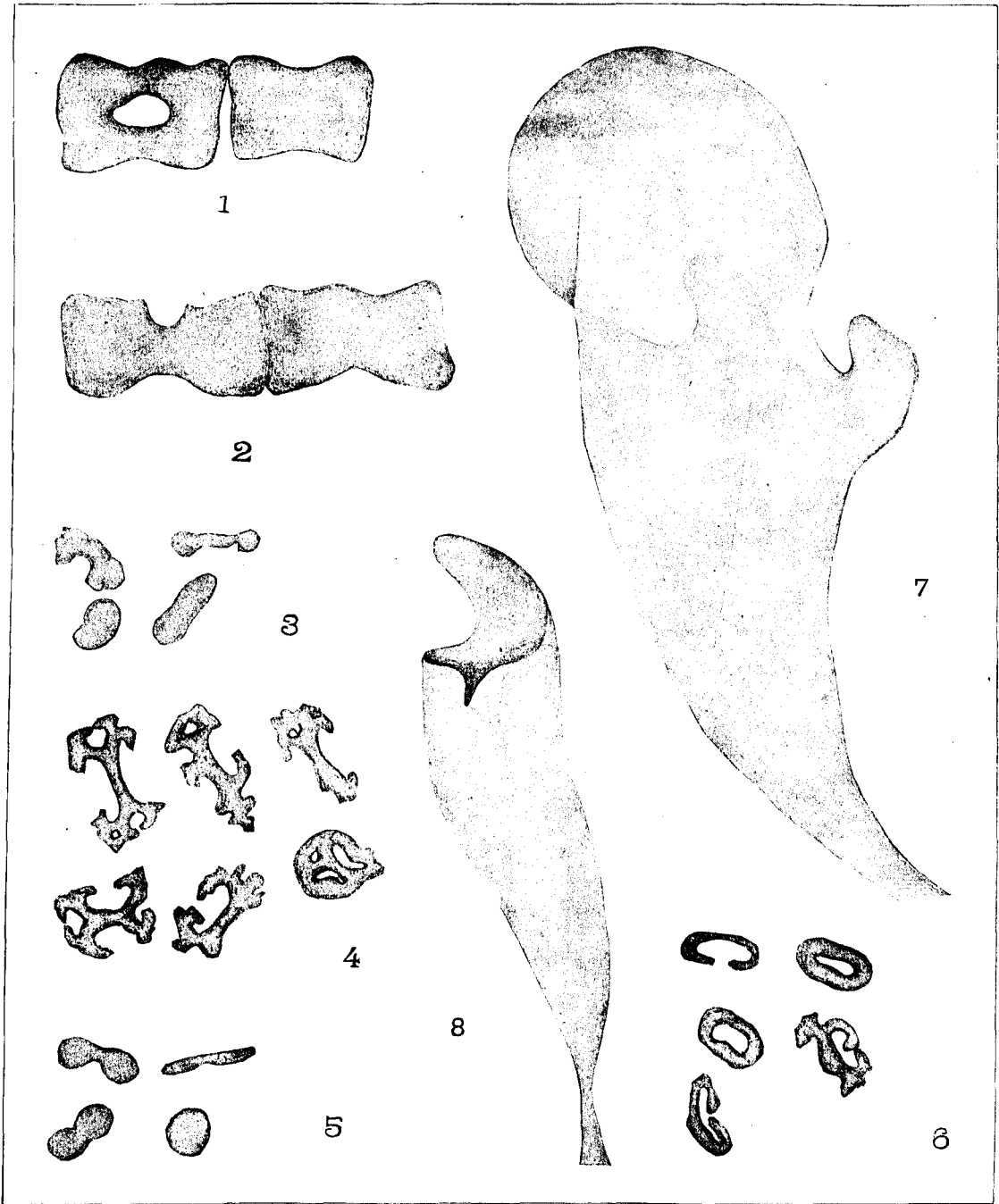
In addition to these points of anatomy, there are noticeable differences in habitat between the two species; *inhærens* occurs in sand or sandy mud, or even in pure mud, less commonly along gravelly shores; *roseola* occurs on rocky or gravelly shores under stones or among the pebbles, and never in pure sand or mud. I have never found *roseola* except where there was sufficient iron present in the soil to give it a decidedly rusty color, and it has occurred to me that there might be some connection between the very unusual amount of pigment developed in *roseola* and this excess of iron. Some specimens of *inhærens* show more or less pigment when carefully examined, and several specimens among those received from Naples were as rosy in color as the average *roseola*, but none of them show any approach to that species either in the calcareous ring, the concretions in the body wall, or the large ciliated funnels. Until intergradations are shown and some better explanation is offered of the constancy with which these characters separate *roseola* and *inhærens*, it seems to me they must be regarded as distinct species. As Verrill's description of *roseola* is so incomplete and is also erroneous, I venture to give the following summary of its characters:

*Synapta roseola* (Ver.).

*Leptosynapta roseola*, Verrill. Rep. on the Inv. Ani. of Vineyard Sound, 1874, p. 422.

*Synapta roseola*, (Ver.), Théel. Report of the *Challenger*, The Holothurians, vol. XIV, 1886, pt. XXXIX, p. 25.

More slender than *inhærens* and general appearance much more soft and delicate; usually much smaller, rarely exceeding 100 mm. in length, even when extended. Body wall white or colorless, thin, but thickly covered with verrucæ, which contain numerous pigment granules of a reddish color, giving a generally bright rosy color to the animal. The pigment resembles that found in *S. digitata* (Mont.) (see Semon, '87) in that it is scarcely at all bleached by alcohol even after months, but it is entirely destroyed by acids or corrosive sublimate. Rarely the body wall is yellowish or pale buff, making the general effect reddish-yellow. Tentacles 12, each with 2 or 3 (rarely 4) pairs of digits and with 7 to 15 sensory cups on the inner side. Genital glands much branched, and when filled with the sexual products very conspicuous through the pink skin. Polian vessel generally single. No cartilaginous ring. Calcareous ring narrow, the radial pieces not perforated for the passage of the nerves, but simply notched on the upper edge. Ciliated funnels numerous, of two kinds; the largest ones, measuring about  $300\mu$  high by  $60\mu$  in diameter, infrequent, confined almost exclusively to the left dorsal mesentery; the smaller ones measure hardly one-fourth as much in height but



EXPLANATION OF PLATE.

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| <p>1. Part of calcareous ring of <i>Synapta inharens</i>. 45X.<br/>                 2. Part of calcareous ring of <i>Synapta roseola</i>. 45X.<br/>                 3. Calcareous particles from the tentacles of <i>S. inharens</i>. 450X.<br/>                 4. Calcareous particles from the tentacles of <i>S. roseola</i>. 450X.<br/>                 5. Calcareous particles from the longitudinal muscles of <i>Synapta inharens</i>. 450X.</p> | <p>6. Calcareous particles from the longitudinal muscles of <i>Synapta roseola</i>. 450X.<br/>                 7. Large ciliated funnel of <i>Synapta inharens</i>. Seen from behind. 125X.<br/>                 8. Large ciliated funnel of <i>Synapta roseola</i>. Seen from in front. 337X.</p> |
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nearly as much in diameter. Anchors and plates not essentially different from those of *inharens*. Calcareous rods in the sides of the tentacles and in the digits slightly curved and knobbed as in *inharens*; besides these, numerous branched, curved, and perforated rods and plates occur abundantly on the inner surface near the base of the tentacles. Calcareous particles in the longitudinal muscles C or doughnut-shaped, rarely branched.

This species occurs between high and low water mark in gravelly banks or on rocky beaches, where there is considerable iron in the soil. Usually found near the surface and often underneath rocks.

#### PHYSIOLOGICAL NOTES.

Contrary to previous experience and to several writers on holothurians, I found during the summer of 1898 that *Synapta inharens* is very easy to keep in aquaria and *roseola* is about as hardy. On account of the greater abundance and larger size of the former, most of my observations were made on that species. When left in a vessel containing sea water only, the synaptas crawl about restlessly on the bottom, and unless fresh sea water is supplied they soon begin to constrict off parts of the body, beginning near the posterior end, and after a time nothing but small pieces will remain, and these soon die. If the supply of sea water is abundant and well aerated, this process may be delayed some hours, but it usually occurs in less than half a day. When, however, there is a sufficient amount of clean sand in the dish to allow the animals to burrow at will, they will live indefinitely if the supply of water is constantly renewed. By filling glass jars half full of sand, one is able not only to keep synaptas alive, but to study more or less of their underground habits. I agree entirely with Cuénot ('91) in believing that autotomy is not normal or defensive, but is due entirely to pathological conditions. I never saw a case of it in synaptas supplied with plenty of sand and an abundance of sea water. The fact that portions constricted off can not live is good reason for supposing the process is abnormal. An excess of magnesium sulphate in the water causes stupefaction and ultimate death, so that excellent specimens, either for laboratory purposes or for the cabinet, may be obtained by narcotizing with this salt and killing in strong alcohol or corrosive sublimate.

Both species of synapta breed during the spring and early summer. The sexual glands are well developed by the last of April, and individuals with ripe ova may be found well into August. About the last of June or early in July seems the height of the breeding season at Woods Hole. Personally I have had no success with artificial fertilization of the eggs, but Dr. W. R. Coe, of Yale University, states that he has found no difficulty in fertilizing the eggs of *S. roseola* artificially, though he has made no attempt to carry their development beyond the segmentation stages. In that species the ripe genital glands show plainly through the body wall, and individuals in which the male elements fill the glands are easily distinguished from those in which the ova are mature. Further investigations into the breeding habits and embryology of our two synaptas are very much to be desired.

Synaptas burrow into the sand head first and almost always go straight downward for some distance, but when once completely buried, they turn in any direction up or down or on the horizontal plane. They can and do turn in their burrows, but as a rule they make new tubes when they come to the surface. They are seldom still, and the old idea that they remained in the tube they have formed with their tentacles just above the surface is scarcely true. Sometimes they assume that position, but seldom remain so very long. They rarely leave their burrows and come out on the surface of the sand, and I doubt if they ever do so under normal conditions.

Passage through the sand is chiefly accomplished by means of contractions and extensions of the body, but is materially assisted by the tentacles. With the latter,

which are almost continually in motion, the sand is loosened and the grains more or less separated. By the contraction of the longitudinal muscles the rear of the body is brought up nearer to the head, and then the circular muscles contract and extend the body again. It is prevented from slipping back by the anchors, which are elevated by the contraction of the circular muscles and hold against the sand. Since the contraction begins next to the rear end and moves forward, the head end is pushed onward, the anchors there lying flat in the skin.

This process of alternate contractions of the two sets of muscles is very obvious to an observer, and takes place very continuously, though not rapidly. In this way a synapta can move through the sand from 2 to 3 centimeters a minute, and an *inharens* of average size can get entirely out of sight in 5 or 6 minutes. One of the most remarkable provisions for the use of the anchors in locomotion is *their much greater abundance and their considerably greater length in the posterior part of the body*. The use of this is clear when one realizes how the rear of the body acts as the resisting base against which the muscles work in pushing the anterior end forward. This difference between the anchors of the anterior and posterior ends of the body seems to have been overlooked hitherto, so great an authority as Ludwig ('98) saying of *inharens* "Anker und anker platten differieren in vorderen und hinteren körperabschnitt nicht merklich von einander." In the same paper, however, he calls attention to the fact that in *S. digitata* the anchors of the posterior end of the body are about 50 per cent longer than those in the anterior end. While the difference in *inharens* is not quite so great as that, yet it is very noticeable, being above 33 per cent. In both species there is an increase also in the length of the plates, but, as would naturally be expected from the passive part they play, it is not nearly as great. The following figures will bring out the condition in *inharens* very plainly. A specimen 14 cm. long was chosen at random and cut into seven approximately equal pieces, and in each piece 10 anchors and plates, selected entirely at random, were measured with these results, No. 1 being the most anterior, No. 7 the farthest back; measurements are all in microns:

	No. 1.		No. 2.		No. 3.		No. 4.		No. 5.		No. 6.		No. 7.	
	Average length of anchor.	Average length of plate.	Average length of anchor.	Average length of plate.	Average length of anchor.	Average length of plate.	Average length of anchor.	Average length of plate.	Average length of anchor.	Average length of plate.	Average length of anchor.	Average length of plate.	Average length of anchor.	Average length of plate.
Number.....	141	124	153	134.5	162.5	135.6	164	138	202	157	204	145	197	135
Ratio of plate to anchor.....	.88		.87		.83		.84		.75		.71		.68	
Per cent increase in length.....	.09		.08		.06		.008		.009 .017		.009 .077		.03 .07	
Maximum length of anchor in each section.....	155		171		178		197		220		220		224	

The most striking feature of this table is the abrupt and marked increase in the size of both anchors and plates in the fifth section. The average length of anchors for the first four sections is  $155\mu$ ; of plates,  $133\mu$ ; ratio = 86 per cent. For the last three,  $201\mu$  is the average length of the anchors,  $144\mu$  of the plates, and the ratio = 71 per cent. That is, the anchors increase 29 per cent and the plates 8 per cent. The slight decrease in the last section is probably due to the fact that comparatively little strain could be brought upon the anchors situated so very near the tip of the body, but it is noticeable that the longest anchor of all was found in that section. The



increase in the length of the anchors of the last two sections over those of the first one is over 40 per cent.

In two other specimens of *inhærens* and one of *roseola*, also selected at random, the following measurements in microns were made:

Measurements taken.	Inhærens.		Roseola.
Length of longest anchor anteriorly .....	160	160	151
Length of longest anchor posteriorly .....	226	249	195
Percentage of increase in length of anchors .....	41	56	29
Length of longest plate anteriorly .....	144	131	125
Length of longest plate posteriorly .....	169	178	153
Percentage of increase in length of plates .....	17	36	22
Average length of anchors anteriorly .....	149	140	142
Average length of plates anteriorly .....	134	121	118
Ratio of plates to anchors anteriorly .....	.90	.86	.83
Average length of anchors posteriorly .....	200	220	188
Average length of plates posteriorly .....	148	156	145
Ratio of plates to anchors posteriorly .....	.74	.70	.77
Percentage of increase in average anchor's length .....	33	57	38
Percentage of increase of average plate's length .....	10	20	23

These figures prove conclusively that the anchors at the posterior end of the body are from 30 per cent to 40 per cent longer than those near the head, while the plates only increase 10 per cent to 25 per cent, and, consequently, there is a decided drop in the ratio between anchors and plates in the two regions.

Now, in regard to the relative abundance of anchors and plates anteriorly and posteriorly, the following figures show that not only are the anchors shorter near the head but they are decidedly less frequent:

Species.	Average number of anchors per sq. mm. anteriorly.	Average number of anchors per sq. mm. posteriorly.	Percentage of increase.
Inhærens .....	10.3	14	36
Do .....	6.8	11.2	65
Roseola .....	12	23.6	96
Average of a large series .....	9.8	15.6	59

There does not seem to be any distinction in the size or abundance of the anchors between the dorsal and ventral surfaces of the animal.

Semon ('88) has expressed the opinion that synaptas are not subterranean in their mode of life, and he bases his opinion largely on the color of *S. digitata*. The question, however, does not admit of debate so far as *inhærens* and *roseola* are concerned, for not only do they never appear normally on the surface of the sand either along shore or in aquaria, but the arrangement of the anchors just described could only be of much practical service in a close-fitting burrow. The whole structure of the animal shows modification adapting it to underground life and the increase in size and number of the anchors posteriorly is one of the most interesting. When placed in a glass dish without sand, synaptas soon cease to contract the muscles of the body wall but drag themselves slowly along by means of the tentacles, thus showing that the anchors are of little use on a smooth surface. In crawling by means of the tentacles, the glandular *outside* of the tentacle tips and digits is used, so that many of the tentacles are

continually twisted around, making the process appear somewhat awkward. When in their tubes, however, the outer side of the tentacles would be most naturally used, and it is by their adherence to that side of the tentacles that particles of food and sand are brought to the mouth. This use of the outer side of the tentacles in locomotion was observed by Pourtales ('51) in the synapta from Florida, which he called *S. viridis*.

The New England synaptas seem to have organs of special sense of two kinds, olfactory and equilibratory or positional; no evidence of ability to distinguish between light and darkness could be detected and there are no anatomical structures to which this sense could be ascribed. The sense of smell is centralized in the cups on the inner side of the tentacles; that of position in the so-called "otocysts" or "auditory" organs. Semon ('87) has shown that *S. inhaerens* possesses the sense of smell, and similar experiments made at Woods Hole confirm his results. If a piece of any rank-smelling substance is placed near the tentacles of a synapta they are immediately retracted and the head is turned away. Small bits of decayed starfish were used and it was found that the synaptas would avoid them even when they did not actually touch them, and they seemed to avoid sand with which decayed starfish had been mixed. While the experiments were not conclusive by themselves, they were satisfactory as confirmation of Semon's work.

In regard to the so-called "otocysts" more numerous and more careful experiments were made, with results which seem to show conclusively that these organs are used to show the position of the animal in the water or sand. Semon ('87) has demonstrated the fact that synaptas appear to have no sense of sound and no ability to detect even strong vibrations in the water. He, however, left the function of these "otocysts" undetermined, but in a previous paper (Clark, '98) I suggested that in *S. vivipara* they determined the animal's position in the water. Experiments on *inhaerens* and *roseola* have fully confirmed this opinion and there can no longer be any doubt that this is their true function. In regard to their structure there is little to be added to Semon's ('87) description, as it has not yet been possible to demonstrate the cilia which line them. That they are lined with cilia, which are in constant motion, can be easily seen in the living animal under the microscope. The single vesiculated cell or "otolith" which each "otocyst" contains may be seen to be constantly revolving and never actually rests against the wall of the sac, but is kept out from it, apparently, by these cilia.

Cuénot ('91) in his description of these organs says that there are "un grande nombre d'otolithes spheriques" in each "otocyst," and Semon ('87) says there are one or more (often six or more) "bläschen" in each sac. I have examined a large number of living specimens of both *inhaerens* and *roseola* and I have never yet found a case where there was more than one. Whether these so-called otoliths are calcareous, as Cuénot thinks, or vesiculated cells filled with fluid, as Semon says, I have not been able to determine positively, though I incline to the latter view, as they do not appear calcareous when compared either by transmitted or reflected light with any undoubtedly calcareous body. But there can be no doubt that they are heavier than the fluid which surrounds them in the sac, as may be readily shown by the following simple experiment: If a pair of the sense organs are cut from a living synapta and placed under a cover-slip and examined under the microscope, the otolith will be seen in the center of the sac so long as the slide is perfectly horizontal. But if the microscope be tipped, so that the slide approaches a perpendicular position, the otolith will be seen to sink slowly to the lower side. (Owing to the reversal of upper and lower sides under the

microscope, of course the otolith appears to rise.) If the slide be turned around slowly the otolith keeps constantly at the lowest point, though kept out from the wall and in motion by the cilia.

In the case of *S. vivipara* I expressed the opinion that this otolith or vesiculated cell floated in the liquid and by touching the cilia or sensory hairs at the highest point gave rise to sensations of changed position. Now I am convinced that the inclosed cell does not float at all but always rests upon the cilia at the lowest point, thus arousing new sensations with every change of position. That the animal is affected by change of position was proven by the following experiment: Synaptas were placed on a piece of thin board which sloped sharply to the bottom of a dish of sea water. They always sought the bottom of the dish, no matter in what position they were placed on the board. Not a single instance occurred of the animal crawling upward. A single synapta was placed on the board and after it was well started on its way down the slope the board was very gently reversed so that the lower end became the higher. As soon as the board passed beyond the horizontal plane the synapta would stop and as the slope became greater it would turn and start back in the opposite direction, and every change in the slope of the board caused a reversal of direction in the movement of the synapta. This experiment was tried a number of times and on different individuals, but with unvarying results. The change in the position of the board was accomplished with the least possible disturbance of the water, and no one who saw the actions of the synaptas could doubt that it was the change of position which caused the change in the movement of the animal. In the light of these facts and the entire absence of any evidence to show that sound vibrations of any sort can be detected by these or any other organs, it would seem out of place to speak of them as "auditory" organs or even as *otocysts*, and I suggest the name *positional organs*.

A number of experiments were made to determine if possible the function of the ciliated funnels, and while the results were not entirely satisfactory they throw some light, I think, on the use of these curious organs. A large amount of carmine was thoroughly mixed with clean sand and, after it had settled and fresh sea-water had run over it for a little while, half a dozen specimens of *inhærens* were placed in the dish. They lived in the brightly colored sand for one week and were then washed and killed. They showed a very decided pink tinge, which was due only in a very slight degree to the carmine attached to the skin externally. Microscopic examination showed that in the connective tissues there were numerous reddish-brown granules and these were most abundant near the lines of ciliated funnels. No such granules were ever found in synaptas living in sand free from carmine.

While this experiment seemed to indicate that carmine taken in with the sand was in some way absorbed and formed the granules, it does not show that the ciliated funnels were in any direct way connected with the process. Accordingly another line of experiments was begun, carmine mixed with sea-water or the body-cavity fluid of other synaptas being injected directly into the body cavity by means of a fine canula through the body wall. Synaptas so treated were then killed at intervals of about twenty-five minutes for two or three hours, and then at intervals of several hours up to twenty-four. It was found that in a very few minutes the carmine began to gather along the lines of funnels and in a shorter or longer time, according to the individual synapta, the body would resume its normal more or less transparent whiteness, except along those lines which appeared as dark-red longitudinal stripes. An examination

under the microscope showed that the funnels were actually choked up by the excess of carmine, sometimes being almost buried in it. After a few hours these dark-red lines became less prominent and in a few days they generally were completely obliterated.

Microscopic examination of the various stages showed plainly that the ciliated funnels were very closely concerned with this change, and that with the disappearance of the carmine from the body cavity the reddish-brown granules appeared in the connective tissue. In spite of careful study and long search I was never able to discover a grain of carmine or one of the granules actually in the stalk of the funnel, yet in some way the carmine must pass from the inside of the funnel into the body wall. Since it is an undoubted fact that the stalk of the funnels is solid and not a tube, the only way by which particles could be conveyed from the cavity of the funnel into the connective tissue would be by means of "wandering cells," and I believe that is the process which actually goes on. Semon's ('87) view of the funnels, as "grosse und complicirt gebaute Lymphstomata der Leibeshölhe," seems to me a correct one, and I believe they perform their excretory function not only by sweeping up and collecting the waste matter in the body-cavity fluid, but also, as Semon suggests, by acting as starting-points for the movement of "phagocytic" wandering cells which destroy or carry into the connective tissue of the body the waste matter collected by the funnels. It seems to me that in view of these facts the ciliated funnels are evidently associated with the function of excretion and it is proper to regard them as excretory organs. Cuénot ('91) considers that their function is to keep up currents in the body-cavity fluid, but every movement of the animal starts new currents so that special organs for that purpose would be superfluous.

A number of experiments were made to test the tenacity of life and the possibility of regeneration in *synaptas*, and the results show that *inharens* is not a very sensitive animal. If an individual is cut in two the anterior end will live and grow as well apparently as any normal specimen, but the posterior end will only live for a few hours, or perhaps a day. So far as I could see, the only reason for its death was its inability to take in food; and I am inclined to think that if food could be provided the posterior half would live as well as the anterior. It seemed to make no difference whether the bisection occurred near to the head or far from it; the head always lived, and in the course of two weeks would show perceptible signs of growth. All that seemed to be necessary was the mouth and a small part of the digestive tract. That it was not the tentacles which were essential was shown by the fact that *synaptas* lived all right without them. Two or more tentacles were cut from a number of *synaptas*—in two cases every one being removed—yet they all lived and burrowed in the sand with more or less ease; and not only did they live, but regeneration began at once, so that in two weeks the new tentacles were large enough to bear a digit on each side. At first I thought the nerve ring was the essential part, but that seems to be doubtful, for the nerve ring was carefully and completely severed in a *synapta* without apparently causing any inconvenience. In other specimens it was cut in two or even three places, but with the same result. In no case were any serious effects shown, and the animals lived and burrowed in the sand with apparently as much ease as ever. I made no microscopical examination to show whether the nerve ends reunited or not, but the cuts apparently healed in a short time. The most striking fact was that with the cutting of the nerve ring there was not the least evidence of any lack of coördination in the movements of the tentacles, nor of the muscles of the body.

## CONCLUSIONS.

For the sake of clearness and conciseness the results of these investigations may be summarized as follows:

1. The common white synapta of the New England coast is *S. inhærens* (O. F. Müll.). *S. girardii* Pourt. and *S. tenuis* Ayres are synonyms of that species.
2. Verrill's genus *Leptosynapta* can not stand.
3. There is a second species of synapta found in suitable places along the New England coast easily recognized by its reddish color, *S. roseola* Ver.
4. *S. roseola* Ver. differs constantly from *S. inhærens* in the calcareous ring, the deposits in the tentacles and longitudinal muscles, and in the large ciliated funnels.
5. There are no important differences between the anchors or the plates of the two species.
6. The anchors are of real use to the animal in moving in its burrow, and those at the posterior end are most so. Accordingly we find they are there longer, larger, and more abundant.
7. The so-called otocysts are *not* auditory but are undoubtedly positional organs.
8. They never contain but a single otolith.
9. The sensory cups on the tentacles are seemingly olfactory organs.
10. The ciliated funnels are large and complex lymphstomata and may properly be called excretory organs.
11. Regeneration takes place readily and rapidly in synaptas where the mouth and part of the adjacent digestive tract are left intact.

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Amherst, Mass., October, 1898.

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