How do Starfishes open Oysters?*

By

Dr. Paulus Schiemenz.

Many inhabitants of the sea know as well as men do that oysters are good to eat, and the destruction which they suffer on this account can scarcely be less than that brought about by human agency. Starfishes especially extirpate them in great numbers, and Möbius† maintains that they are the most pernicious enemies which the oyster possesses, although, on the other hand, people have not been wanting who held the destruction of oysters by starfishes to be a fable.‡

Collins‖ calculates the damage done by these voracious robbers on the oyster beds of Connecticut alone for the years 1887, 1888, and 1889, at 463,600, 613,500, and 412,250 dollars, whilst that done in all other ways, by molluscs, mud, frost, etc., only represented a total of 39,200, 46,750, and 52,450 dollars.

In view of this enormous injury caused by starfishes to the oyster beds, it will be worth while to endeavour to obtain a clear idea of how a starfish really succeeds in eating an oyster. It is generally known that bivalve molluscs, and amongst them oysters, can close their shells so tightly against enemies that considerable force is necessary to open them, and the question arises, Is a starfish able to exert that force?

For the purposes of our discussion, we shall divide the starfishes which attack molluscs into two groups. Those of the first group have

* *Mittheilungen des Deutschen Seefischereivereins.* Bd. xii. No. 6, 1896. Translated from the German by E. J. Allen.

My thanks are due to Professor Dr. Henking, the general secretary of the German Sea Fisheries Association, both for permission to publish the translation of this article, and also for the loan of the blocks from which the figures are printed. E. J. A.

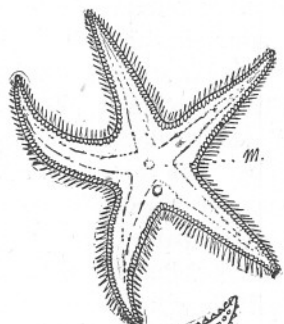
† Möbius, K. "Ueber die Thiere der schleswig-holsteinischen Austerbänke, ihre physikalischen und biologischen Lebensverhältnisse." *Sitz.-Ber. Akad. Berlin.* 1893, pp. 67–92.

‡ Fischer, P. "Faune conchyliogique marine du département de la Gironde." *Act. Soc. Linn. Bordeaux.* Tome 25, 1864, pp. 257–344.

‖ Collins, J. W., "Notes on the oyster fishery of Connecticut." *Bull. U.S. Fish. Comm.*, vol ix. pp. 461–497, 1891.

conical shaped arms, increasing in width from the apex to the base, the united bases forming a more or less marked central body (*m*, Fig. 1*a*). *Astropecten aurantiacus*, which is common at Naples, may be taken as the representative of this group.* It lives in places where there is more or less deep sand, half buried in which it pursues its prey. The latter consists, for the most part, of bivalves and gasteropods which also bury in the sand, and the starfish forces them, by means of its flexible tube-feet, into its mouth, which is capable of a very remarkable degree of extension. The number and size of these molluscs which an *Astropecten*

FIG. 1*a*.



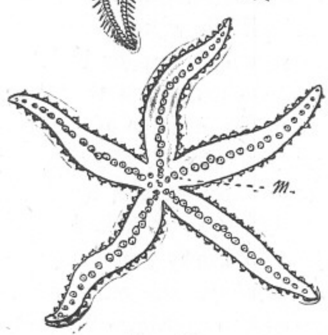


FIG. 1*b*.

is capable of swallowing passes belief, and the naturalist who keeps one of them in confinement is often astonished to find, sooner or later, quite a collection of shells in the dish, all of which had been concealed in the huge stomach of the starfish. Hamann † counted at one time ten *Pecten*, six *Tellina*, several *Conus*, and five *Dentalium*.

In the second group of starfishes (Fig. 1*b*) the arms are far from being so conical in shape, but are more or less cylindrical; indeed in the immediate neighbourhood of the body they are somewhat smaller than a little further off, and hence no true body exists. The members of this

* *Astropecten irregularis* may be taken as the representative of this group in British seas. E. J. A.

† HAMANN, O., *Beiträge zur Histologie der Echinodermen*. Heft 2. "Die Asteriden anatomisch und histologisch untersucht." Jena. G. Fischer, 8vo., 1885.

group, *Asterias glacialis,* for example, prefer rocky places, or at least hard ground, to a sandy bottom. *Asterias* devours all animals which it can overpower, having, like *Astropecten,* a preference for bivalves (especially oysters) and gasteropods which lie free on the surface. On account of the small size of the disc, the mouth of *Asterias* is capable of very little enlargement, and it would never be able to swallow oysters, which are its favourite food. Moreover, oysters remain firmly fixed to the bottom, and gasteropods also can often hold on so fast that it appears impossible that they should be passed into the stomach through the mouth. *Asterias* therefore takes up exactly the same position as Mahomed. As the mountain did not come to the prophet, the prophet went to the mountain, and as *Asterias* cannot bring his prey into his stomach, he sends his stomach into his prey, that is to say, he throws his stomach out like a proboscis, either wrapping it around or forcing it within the shell of his victim, and in this way digests it entirely outside his own body. The throwing out of the stomach of the starfish has been often seen and described: amongst others by Eudes-Deslonchamps,* McAndrew, and Barrett (according to Bronn), Forbes,† Rymer Jones,‡ Bronn,‖ Eyton,§ Schmidt,¶ Hamann,** and Möbius.††

The following example will show how cleverly *Asterias* can force his stomach through openings which appear little adapted to the purpose. One would think that a sea-urchin, with its thick array of movable spines, would be safe from the attacks of a starfish; but this is really not the case, as I was myself able to observe, through the kindness of Sgr. Lo Bianco, the conservator at the Naples Zoological Station. A moderately large sea-urchin was attacked by two starfishes, one on either side. One of these had only just commenced the onslaught. It had thrown its stomach through the narrow space between the spines until it reached the skin of the urchin, which, together with the muscles that attach and move the spines, it devoured, so that the spines by degrees fell off. The second starfish had in this way, as one might say, already digested for itself a road through the spines, and with its stomach had reached the mouth of the urchin. Through this, in spite of the urchin's strong teeth, it had inserted its proboscis, and so sucked out its victim like an oyster.

* EUDES-DESLONCHAMPS, "Notes sur l'Astérie commune." *Ann. Sci. Nat. Paris, Zool.* Tome 6, pp. 219–221, 1826.

† FORBES, EDW. *A History of British Starfishes and other animals of the class Echinodermata.* London 8vo., 1841.

‡ RYMER JONES, *Frorieps N. Notiz.* Bd. 12. Nr. 288, 1839.

‖ BRONN, H. G., *Klassen und Ordnungen des Thierreiches.* Bd. 2. Actinozoa, 1860.

§ EYTON, T. C., "A history of the oyster and the oyster fisheries." *The Edinburgh Review,* vol. cxxvii. pp. 43–76, 1868.

¶ In Brehm's *Thierleben. Grosse Ausgabe. Aufl.* 2. *Abth.* 4. Bd. 2. Leipzig, 1878.

** *Loc. cit.* †† *Loc. cit.*

Astropecten and *Asterias* possess tube-feet of very different structure. Those of *Astropecten* are conical and quite pointed at the end, and seem extremely well adapted to boring in sand. Suckers at their ends are entirely wanting. Such enlargements would only be a hindrance when boring in sand. On the other hand, *Astropecten* has no need of suckers, for it does not climb steep walls; the animals which it preys upon all move so slowly that they could not escape by flight, and therefore do not require to be held fast; and thirdly, this starfish does not need to open its victims. With its feet it brings them into the capacious stomach, from which they cannot again escape. It has now only to quietly wait its time, until the animals, killed by suffocation, open their shells and allow the digestive juices to reach them.

In the case of *Asterias* the circumstances are quite different. The animal is a zealous climber, and by preference clings to perpendicular walls. If, like *Astropecten*, it possessed pointed tube-feet without suckers, it could not do this, but would fall down as *Astropecten* does when it attempts to climb in confinement. The animals which *Asterias* eats are some of them capable of relatively rapid locomotion, and therefore require to be held fast. Many of them, too, have the power of tightly closing their shells, and if the *Asterias* wishes to get at their soft bodies, the shell must first be opened. For clinging, as well as for opening shells, pointed feet would be quite useless. Feet, however, provided with powerful suckers, such as *Asterias* possesses, are well adapted to these uses.

There is, too, a difference between the ways in which the feet of *Astropecten* and *Asterias* move. Whilst *Asterias*, when the suckers have been loosened, curves the feet outwards, and so draws itself back, *Astropecten* curves them inwards. It is obvious that the latter mode of progression is much better adapted to a life buried in sand, such as *Astropecten* leads.

Different views have been expressed as to the manner in which *Asterias* and similar forms succeed in opening the shells of molluscs. At the present time it seems to be generally considered that this is accomplished by the secretion of a stupefying fluid, or poison. As we shall see, however, further on, this view is a complete mistake.

In what follows we shall consider (1) the possible methods by which the opening of the shell could be accomplished; (2) which of these is to be considered the most probable; and, finally (3), we shall endeavour to prove that this method is, in fact, adopted. There appear to be altogether six possible ways:—

1. *The starfish might take the molluscs by surprise.*—Bivalves, including the oyster, are generally very watchful. A small change of light, a shadow, a slight movement of the water, or any trifling disturbance,

immediately causes the closing of the shell. Such sensitiveness seems to preclude completely the idea of their being surprised by the starfish, for before the latter could reach, say, an oyster with its mouth or its everted stomach, it has already freely touched it with the feet on its long arms, and thereby given it sufficient warning. But even if the oyster allowed itself to be taken by surprise, as soon as ever it felt the stomach of the starfish on its soft parts, it would immediately close the shell, and the starfish would generally only be able to escape by tearing off its stomach. If anyone is not prepared to accept this without further proof in the case of the oyster, he has only to consider, say, a *Venus,* with its strong shell-margins, which, when closed, do not let the very finest crevice be seen, and which would at once crush such a soft body as the stomach of a starfish. According to Forbes, it is the belief of some oyster-fishermen that *Asterias* insinuates an arm into the oyster's gape in order to devour it. The oyster then closes, and the starfish is caught. To free itself again, and not die miserably of hunger, it elects to sacrifice an arm, and this is the reason why so many mutilated starfishes are found. This is a very pretty fable, but it is no more than a fable, for a starfish of moderate size does not insert an arm into a living oyster, for the simple reason that the gape of an oyster, when open, is much too small.

2. *The starfish might beset the oyster so long that it would be compelled, by hunger and want of air, to open.*—This supposition is made by the brothers De Montagué* and by Smiley.† To say nothing of the possibility that, in this case also, the stomach might easily be bitten off by a renewed closing of the shell, the duration of the attack would be a very long one, for it is well known that bivalves, and especially the oyster, can remain closed for a great length of time without air and nourishment. I fancy that during this long siege the starfish would get such a strong appetite itself that it would prefer to look around for more manageable prey. Moreover, the supposition stands in direct contradiction to an observation of my own, according to which from fifteen to twenty minutes is generally sufficient for the opening of a *Venus.*

3. *The starfish might hypnotise the molluscs.*—It is known that certain animals, if their bodies are placed in a quite unaccustomed attitude, are subject to a kind of hypnotism. According to Apgar,‡ if a *Unio,* for example, is seized quickly, and the shell firmly pressed, so that the

* De Montagué, frères, "Etudes pratique sur les ennemis et les maladies de l'huître dans le bassin d'Arcachon." *Act. Soc. Linn. Bordeaux,* vol. xxxii. (4 ser. Tome 2). 1879.

† Smiley, Chas. W., "Notes Upon Fish and the Fisheries." *Bull. U.S. Fish. Comm.,* vol. v. 1885. (From a statement by Capt. S. J. Martin.)

‡ Apgar, Austin C., "The Musk-rat and the Unio." *Journal Trenton Nat. Hist. Soc.,* vol. i. pp. 58, 59; also in *Zoologist* (3), vol. ii. pp. 425–426.

protruding foot is squeezed, after half to three-quarters of a minute it becomes paralysed, and can make no more use of the adductor muscles. Apgar believes that the musk-rat (*Fiber zibethicus*) takes advantage of this fact in order to get at the soft parts of the mussel. In the case of the oyster, however, anything of this kind does not apply, for it cannot be brought into an unaccustomed attitude, nor has it any foot to protrude and be squeezed. This could, however, happen with other bivalves which are not fixed and which possess a protruding foot; for, whilst being eaten, these are constantly placed by the starfish in a position quite the reverse of the normal one; namely, with the hinge below, and the gape above. I have tried experiments on the point with *Venus verrucosa*, but have failed to notice any hypnotic or paralytic effect. I have made a *Venus* stand for many hours on the hinge, and have afterwards found exactly the same resistance to forcible opening as at other times. Since, however, the starfish can effect the opening in from fifteen to twenty minutes, the possibility of hypnotic effect is precluded.

4. *The starfish might make an opening in the shell with the help of a boring apparatus or an acid.*—No boring apparatus is possessed by *Asterias*, and the holes which one often finds in oyster shells are due to gasteropods, and not to starfish, although they have sometimes, in error, been ascribed to the latter; *e.g.*, by Ball and Forbes. I have neither been able to find holes in the shell of a *Venus* which has been devoured, nor an acid reaction in the everted stomach. It is, however, a difficult thing in sea water, which is slightly alkaline, to demonstrate an acid with litmus paper; but when we recollect that the opening is effected in so short a time, the acid would necessarily require to be very strong, and should be capable of demonstration even under such unfavourable conditions. One does often find regular holes on the shell-margin of oysters which have been eaten, but, as we shall see presently, these are produced, not by boring, but by breaking.

We come now to the possibility—

5. *That the starfish pours a poison over, or, rather, within the shell of its victim, whereby the muscular force of the latter is enfeebled, and the shell opened.*—In itself this is not unlikely, and I was at first of opinion that this was, in fact, the method by which the opening was effected, for it is known that many animals maim their victims by poison, derived generally from the salivary glands, before devouring them. However, even this power would not be of much use to the starfish. As already mentioned, a *Venus*, for instance, squeezes its shell so tightly together that one could almost speak of its being hermetically closed. A poison poured over the shell could not penetrate, but would flow off without effect. In this case also it would be first necessary to

bore in the shell an opening through which the poison could be injected. However, as we have seen above (*cf.* 4), no such boring of the shell does, in fact, take place. The action of poison was assumed by Eudes-Deslonchamps, Forbes, Rymer Jones, Bronn, Eyton, O. Schmidt (in Brehm), and Smiley (following Captain Martin). Hamann attempts a detailed description of the process; but, for myself, I fail to see upon what logical grounds, from the presence of a slimy fluid and the opening of the bivalve, a proof for the secretion of poison can be derived. It is not even shown whether the slime comes from the starfish or from the bivalve, and it is a fact, which anybody can easily observe, that bivalves and gasteropods commence a copious secretion of slime if their soft parts are handled. I have, however, made experiments which demonstrate quite certainly that *Asterias* does not secrete a poison, or, rather, that a maiming of its victim by this means does not take place. A *Venus verrucosa* was offered to an *Asterias* which had fasted for about a week, and was greedily taken. Whilst the starfish was busy opening, or, rather, eating this *Venus*, a second one was offered it. This also was immediately taken and, for the time, held fast, its hunger, after the long abstinence, not being satisfied in a moment. When the first mollusc was finished, and its empty shell thrown away, the second was carried by the tube-feet to the mouth, and brought into the usual position. In a short time this one also was opened, and opened extremely wide, but the stomach of the starfish was not thrown out, the animal being satisfied with what he had in hand. The *Venus* was now taken away from the starfish, whereupon it immediately closed, and was laid in a dish with sand. It was not long before it disappeared in the sand in the usual manner, and it afterwards continued quite normal. Specimens of *Venus* were, in a similar way, taken from other starfishes at different stages of the process of opening, and before digestion could commence. The result was always similar to that in the first case described, and the animals showed no trace of maiming or other disturbance. Experiments were also undertaken with gasteropods, and these were even more instructive, because the creatures are much livelier, and therefore promised to show more readily any disturbance of their organism. It was, at the same time, possible easily to observe directly all the details of what took place. I chose for these experiments my old friend *Natica* (sp. *millepunctata* or *ebrea*). Whilst experimenting I made a not uninteresting observation, which completes in a satisfactory way some work which I had formerly published. In a paper on the absorption of water by molluscs,* I had tried to establish the physiological significance of the

* SCHIEMENZ, P., "Ueber die Wasseraufnahme bei Lamellibranchiaten und Gastropoden (einschliesslich der Pteropoden)." 2 Theil. *Mitth. Zool. Stat. Neapel.* Bd. 7, pp. 423-472. 1887.

separate parts of the foot of *Natica,* and in a later paper* I added a further contribution to the subject. I was not quite clear at that time as to the significance of the "shell lobe" (Fig. 2, Sch. Lap.); that is to say, the portion of the foot which, in *Natica josephina* almost entirely, in *N. millepunctata* and *ebrea* only partially, under ordinary circumstances, covers the shell. I have now, however, been able to observe with certainty the use to which this portion of the foot is put. If a few *Natica* be placed in a dish in which there are some *Asterias,* rendered hungry by fasting, the molluscs immediately begin to creep about, and the starfishes endeavour to overpower them. The tube-feet of the *Asterias* are unable to fix themselves to the body of the *Natica* on account of its slimy surface, and there is only left them the uncovered remnant of the shell. (Fig. 2, Sch.) But here also the attachment is prevented, for the moment the *Natica* comes into contact with a starfish it pulls the "shell lobe" of the foot with a jerk over the previously uncovered part of the shell, and thus there is no place left to which the

FIG. 2.

suckers of the *Asterias* can fix. I have observed this proceeding a great many times, and it always takes place so promptly that there can be no doubt as to its connection with the means of defence against starfishes. The drawing of the shell lobe over the shell is brought about by the contraction of the transverse, or, rather, annular muscles of the lobe margin, which act like a sphincter.

In nature, of course, *Natica* hardly comes in contact with *Asterias,* but it does come in contact with *Astropecten,* and it is clear that the tube-feet of that animal, though they are quite pointed at their ends and have no suckers, will slip from the slimy surface of the *Natica* just in the same way as the tube-feet of *Asterias.*

If a *Natica* in the contracted state be given to an *Asterias,* the latter fixes its tube-feet upon all parts of the shell of the mollusc, carries it to its mouth, and tries to digest it. If the *Natica,* however, has lived for some time in the dish and become used to the conditions of confinement, it does not through terror remain closed, but, as a rule, comes out of its shell immediately, and endeavours to free itself from the starfish. A

* SCHIEMENZ, P., "Wie bohrt Natica die Muscheln an?" *Mitth. Zool. Stat. Neapel.* Bd. 10, pp. 153–169. 1891.

hard fight now commences. As soon as the mollusc begins to protrude its foot, the starfish also throws out its stomach and endeavours to commence the work of digestion. By feeling here and there with the margin of the anterior angle of the foot, which serves as a sense-organ, the gasteropod now tries to find a place somewhere between the tube-feet where there may happen to be a larger space, offering a chance of escape. As is natural, the starfish on its part makes convulsive efforts to hold its victim fast, and block every possible way of escape through the forest of tube-feet. If the *Natica* succeeds in protruding the fore part of its foot sufficiently far for the corners, upon which the apertures for taking in water are situated, to expand themselves, then the battle has been won. When it has made the fore part of the foot swell up a little, it swells the hind part, and from this the shell lobe; whereupon, by drawing the latter closely and tightly over the shell, it sweeps off all the suckers of the starfish. As soon as this has happened the mollusc is free and creeps away unhindered, in spite of the fact that the starfish, during the whole time, has partially covered it with its everted stomach. Thus no maiming by poison has taken place. As a further confirmation, though this was hardly necessary, I took away from the starfish a couple of *Natica* which had not been able to free themselves, and had been already somewhat digested during the fight, and bore wounds. These also recovered; so that there can be no talk of poisoning. Naturally the fight often ends in the destruction of the *Natica*, especially when the starfish has fixed a great number of feet on the operculum and just behind it; for it is then impossible for the mollusc to protrude its foot far enough to be able to swell it up. If the gasteropod perceives the uselessness of the attempt to escape, it withdraws into its shell, closing the latter with the operculum; and then the starfish must first of all open it again. For this purpose there remains one more possibility, namely:

6. *That he opens the shell by force.*—This supposition will be doubtless at first opposed by every reader, who knows from his own experience the strength with which bivalves and gasteropods can keep their shells closed. If, however, we consider the position into which the starfish brings his victim when he wants to open it, the supposition becomes more likely.

With oysters and fixed bivalves and gasteropods, *Asterias* cannot do very much: he must take them as they lie, and cannot alter their position. The circumstances are quite different, however, when he is dealing with a free-living mollusc. If we bring a *Venus* to the end of an arm of a hungry starfish, the first thing it does is to taste it with the long tube-feet, serving as sense-organs, which are situated there. In a few moments the many hundred tube-feet, with which it has been quietly holding on, come to life, and the whole animal pushes itself towards the side at which the mollusc is offered. The arms next to the ones touched are immediately brought near it; and with these three, or perhaps only with two of them, the *Venus* is held fast, the arms being gradually pushed over its shell and one sucker after another made fast to it. But the starfish does not stop moving as soon as the arms have reached the far side of the bivalve, and as fast as they are pushed beyond it the tube-feet fix themselves to the ground. Only when the *Venus* has in this way reached the middle-third of the arm does the starfish cease the forward movement and remain stationary. Meanwhile the bivalve is carried further forward by the tube-feet until it reaches the mouth of the starfish, and is there turned round into such a position that the hinge is below, and the margin of the gape lies exactly opposite the mouth of its enemy. (Fig. 3.) Hamann has already made mention

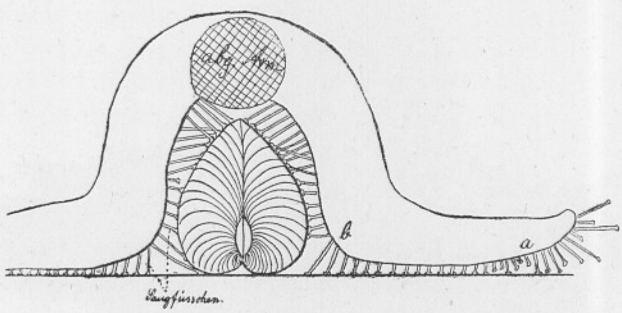


FIG. 3.

of this position. Whilst this is going on, the starfish raises its body and the portions of its arms next it into a peculiar mound, as represented in Figs. 3 and 4. The only writer I can find who makes mention of this curious attitude is Möbius.* When the starfish is resting on the bottom of the dish, what happens inside this mound, one is not, of course, able to see. In order to find out, the animal must be induced to ascend one of the vertical glass sides of the dish, which is not at all a difficult thing to do. By holding a mollusc in front of it, a hungry starfish may be enticed over considerable distances and led round the dish. If one does this too much, however, it ceases to respond; or, when the mussel is again offered after an interval, begins to crawl away.

It might at first sight appear as if this rising into a mound served only to hinder the victim from escaping. Apparently this is one of the reasons for it; for in assuming the position the arms are pressed together so tightly that not even a crevice is left through which escape could be effected. But a consideration of Fig. 3, which to some extent represents

* MÖBIUS, K., *Die Auster und die Austerwirthschaft*, p. 120. Berlin, 1877.

a section of Fig. 4, makes it at once evident that if the starfish intends to open the bivalve by force, he can only do so after he has brought himself and his prey into the positions there represented. I will not here go further into physical considerations, but only remark that the mound itself is extraordinarily rigid, and offers very great resistance to any attempt to press it down. The starfish can now divide its tube-feet in such a way that half of them are fixed to one valve of the shell, the other half to the other; and a pull in opposite directions can be exerted upon the two valves. If the mound formation is adopted in order to open the mussel in the manner indicated, a starfish which is prevented from adopting such a position will not be able to succeed in opening a free bivalve or gasteropod. I therefore made the following experiment: I took a small vertical dish with glass sides, and, by means of a glass

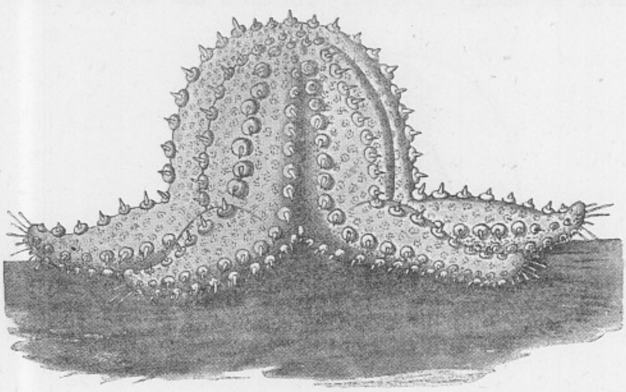


FIG. 4.

plate, separated off a compartment in which there was just depth enough for a starfish to creep, but in which he could not form a mound. When I had put a starfish, which had been prepared by previous fasting, into this small compartment, I offered him a closed *Natica*, which he immediately took. Now whereas, under ordinary conditions, provided a long fight did not take place, a starfish would open a *Natica* in a relatively short space of time,* this starfish wandered round the dish for nearly a whole day, from morning till evening, with his victim—which all the time remained closed—without managing to digest it.

It was only towards evening, after many vain attempts, that by all sorts of contortions of his arms he succeeded in forming a mound in a quite unnatural way, namely, between the glass sides and in a position

* There is no need to explain further that gasteropods are opened in exactly the same way as bivalves; some of the tube-feet of the starfish being fixed to the shell itself, whilst others are fixed to the operculum. The gasteropods are brought into an exactly similar position.

parallel to them. Then he set about opening and digesting the *Natica*. This result clearly confirms the correctness of the above supposition.

In the case of oysters the circumstances are different, in so far that, under natural conditions, these animals are fixed to the ground, and are also considerably larger than the other bivalves. If a starfish, wishing to open an oyster, can find suitable points for fixing his arms on the objects which lie around, it will give him no great trouble to pull his victim apart. Should he not, however, find these, he must form a mound exactly similar to that in Fig. 3. Physical considerations, however, show that under these circumstances, since he must support the portion of the arms marked *a—b* in Fig. 3 on the oyster itself, there will only be a prospect of success when this point of support of the arms lies quite far towards the hinge, or even beyond it, so that the

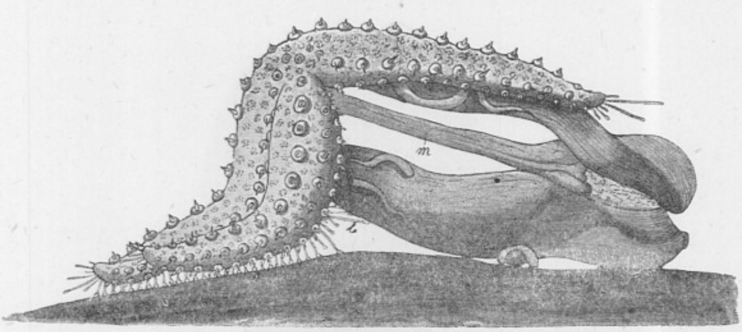


Fig. 5.

arms can mutually assist each other. There must therefore always be a definite size-relation between the oyster and the starfish; and from this it follows further that large oysters are relatively safe from the attacks of starfishes, whilst small and medium sized ones are specially liable to destruction. Perhaps some day an oyster fisherman will collect evidence on this point. In relation to the matter I must, however, remark that an oyster can only be regarded as successfully attacked when it has been actually opened; and a simple attempt on the part of the starfish of itself proves nothing. In the figures which Collins gives on Plate 165 (Figs. 1 and 2), the size-relation under discussion is clearly seen; and I believe I am not mistaken when I imagine that I can see in the positions of the starfishes in these figures the mound formation which I have described.

In Fig. 5, which I give here from an observation of my own, the starfish has already completed the work of opening; and has, indeed, already digested the greater part of its victim. There is nothing more to be seen of a mound formation, since it is no longer necessary, on account of the destruction of the adductor muscle. I give the figure, nevertheless, because in this case the starfish has made use of the bottom of the dish as the point of support, or attachment, for a portion of the arms. The position of these arms is exactly the same as in Fig. 3: the feet on the parts near their centres (above *b*) being fixed to the oyster's shell, those on the distal parts (*a*) to the bottom of the dish. In the figure is seen also very clearly the manner in which the stomach (*m*) is thrown out, and what a significant position it occupies. That I have not succeeded in this case, as I was able to do with *Venus*, in directly observing the whole process of opening, was due to the fact that the oysters were opened by the starfishes at night. Whether this was accidental or not I cannot say. *Venus* and *Natica* were taken and opened at whatever time of the day they were offered.

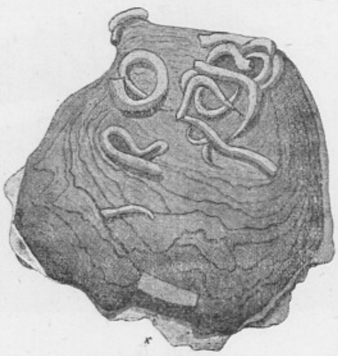


FIG. 6.

An examination of shells which have been eaten out, also shows that the starfish pulls powerfully upon the shell of an oyster which he is about to devour. The margin of oyster shells, at least at Naples, is always more or less laminated. Now, in oysters which have been eaten out, the laminated margin of the upper shell is always broken away for a greater or less distance, until the deeper and stronger layers are reached. Fig. 6 shows such a shell; on which, however, the injured place was specially conspicuous. I need hardly mention that I carefully examined the margins of the oysters before giving them to the starfishes. As no other animals were in the dish excepting oysters and starfishes, the effect upon the shells of the oysters which were eaten could only be due to the starfishes. Moreover, I have seen such broken portions of shell directly attached to the suckers on the feet of a starfish which was resting upon an oyster. Such broken places I have only found on the flat shell, which is clearly due to the curved shell being less laminated, and, therefore, less easily injured.

The points, recognisable by the injury just described, at which *Asterias* opens the oysters, show a certain degree of definiteness in position. They do not, however, as I at first suspected, exhibit a perfectly regular relation to a line drawn through the hinge and the muscle scar. In general, indeed, they lie on this line, and this can be readily understood, since the two shells of the oyster represent, to some extent, two levers, with a fulcrum at the hinge. The further the point of seizure lies from the hinge, that is to say, the longer the arm of the lever, the more effective will be the force applied. Precisely on the longest shells, nevertheless (Fig. 7, Nos. 3, 6, and 10), we find the point of seizure lies, not on the line mentioned, but displaced quite

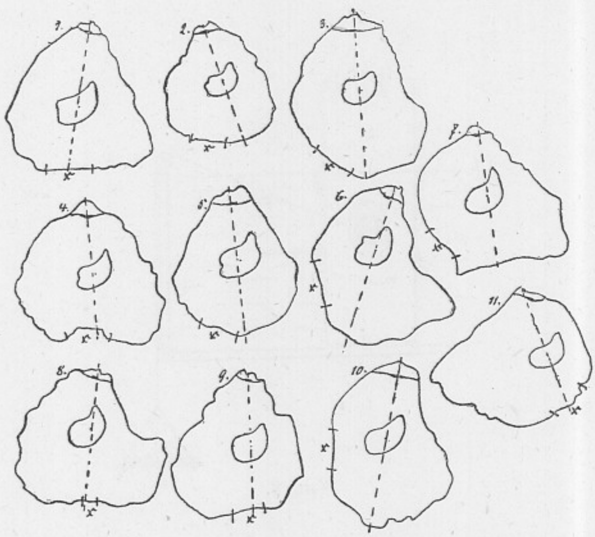


Fig. 7.

to one side. I can only explain this variation on the supposition that these oysters were of too great length in the direction of the line through the hinge and muscle for the arms of the starfish, and the latter had to find positions in which their arms could reach further over the shell. The point of seizure in these shells always lies on the side which exhibits the less vigorous growth. This seems to be a general rule in all cases in which the oysters show unequal growth (compare also Nos. 7 and 11 in Fig. 7), and possibly depends on the fact that on the side where there is less growth the shells are naturally less laminated, and the starfish, therefore, has more chance of coming to firm portions of the shell, upon which it can effectually fix its tube-feet. In oysters from other localities, whose shells are firm at the margin, and less laminated than those at Naples, such places as those just described, made by breaking away portions of the shell, will naturally not be found. On them, therefore, it will not be possible to ascertain the spot where the starfish has taken hold.

Thus, I have come to the conclusion that the starfish opens the shell of his victim by force, and I must now bring forward proof that the animal does actually possess sufficient strength for the purpose. To do this, the strength of a moderate-sized starfish must first of all be measured. As may be seen from Figs. 3, 4, and 5, the starfish does not use all its tube-feet in opening a bivalve, but, at most, only those on the central halves of the arms. In measuring the strength exerted,

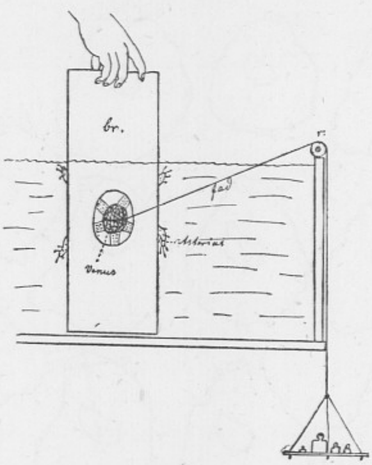


FIG. 8.

the other tube-feet, therefore, must be left out. I succeeded in doing this in the following way:—

A hole was cut in a board of a size corresponding approximately to that of the portion of the starfish which comes into play in opening molluscs. One side of the board was covered with a glass plate (in which was a corresponding hole), giving the starfish the opportunity of attaching itself firmly with the remainder of its tube-feet. An *Asterias* was now enticed with a bivalve on to the board, and the mollusc offered to him through the hole in the board. The bivalve itself was bound round with a string, which was passed, by means of a pulley, over the edge of the dish, and carried at its end a board upon which weights could be placed. After the starfish had taken the mollusc, weights were put on until it let it go. This happened with a weight of 1350 grams. This figure does not, however, represent exactly the strength of the starfish, but is considerably less. Indeed, I have observed that if one endeavours to pull away again a mollusc which has been offered it, a starfish will resist for some time, but if the pull lasts too long, or is too strong, it quite suddenly draws in all its tube-feet, lets the mollusc go, and cannot be persuaded to take it a second time. However, if we accept 1350 grams provisionally as representing the strength of the starfish, we shall, in what follows, be able to show that so much power is far from being necessary for the forcible opening of a moderate-sized *Venus*.

This sounds unlikely, especially since one knows that, according to Lawrence-Hamilton,* a *Venus* can, with its adductor muscles, withstand a strain equal to 2071 times its own weight (without the shell). I have myself seen that, with a momentary weight of 4000 grams, a

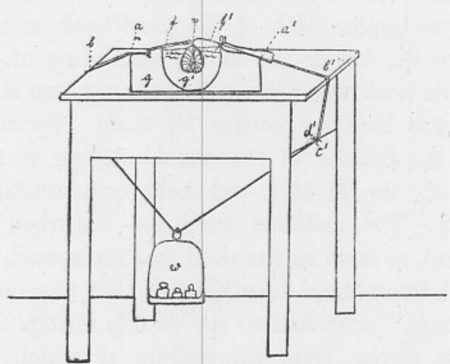


FIG. 9.

Venus does not think of opening. But the circumstances are completely changed when, instead of a momentary strain, a continuous one is applied. Everyone knows from his own experience that to lift a weight, and to support it for a long time, are two quite different things.

In order to investigate the resistance offered by *Venus* to a strain, I had a jar of sea water sent from Naples, followed, some days afterwards, by a number of *Venus verrucosa* (as samples without value) wrapped in moist linen. The latter arrived in Hanover in three days, and were in full vigour, protruding their siphons normally as soon as they were placed in their native element.

In order to measure their strength, I constructed, with the modest appliances at my disposal, the apparatus figured above. (Fig. 9.) The

* LAWRENCE-HAMILTON, J., "The Limpet's Strength." *Nature*, vol. xlv. p. 487. 1892.

apparatus had to be so devised that the bivalve, whilst remaining in water, could be placed in such a position that a measurement of the extent of opening of the shell could easily be made. A glass dish containing sea water (*g*) was placed on a small table. In this one stood a smaller but higher dish, also containing sea water, which could be renewed from time to time from the larger one. A *Venus* was now surprised, the handle of a scalpel being placed between the two shells before it had time to close them. The bivalve of course, as soon as the scalpel was put in, closed immediately, and held it fast, and so could easily be taken out. Two flesh-hooks were then taken: a short one made entirely of metal, with two teeth at each end (*f*), and a second one with a scalpel handle (*f′*). The two teeth at one end of the short hook were placed in the shell-opening. The teeth of the second hook were also placed in the opening in such a way that they came between the teeth of the short hook. A double string was then slung from the two hinder teeth of the short hook, and a similar string was made fast to the larger one at the beginning of the flat handle. The handle of this hook was placed between the two strings on its own side, so that it was kept in position by them. By this arrangement, with the aid of the friction of the double strings on the edges of the dish (at *a* and *a′*), the bivalve was held quite motionless, with the opening upwards. The molluscs were not disturbed by this experimental strain; but, as soon as the shell was far enough open, protruded their siphons and commenced breathing, so that one may say that they were simply normal. Attached to the double strings (at *d* and *d′*) was a single common string, from the middle of which a scale-pan (*w*) hung. The weights on this scale-pan were, of course, not all effective, on account of the considerable friction at the points *a*, *b*, *c*, and *a′*, *b′*, *c′*. In order to determine the true effective weight, I afterwards replaced the bivalve by a spring balance, which was pulled out by the weights. Such spring balances never weigh quite correctly; but in this case one or two grams does not matter, and I give, therefore, in the following tables, only round numbers (friction being allowed for):—

1. *Venus* 4 cm. long, 3·4 cm. broad.

7.55 a.m., loaded with 900 grams.
8.10 „ commenced to open.
8.15 „ open 2 mm.
8.30 „ open 3·5 mm.
1.0 p.m., open 3·5 mm.
6.10 „ open 4 mm.: then set free.

2. *Venus* 3·9 cm. long, 3·2 cm. broad.

6.15 p.m., loaded with 900 grams.
6.20 „ open nearly 2 mm.
6.30 „ open 4 mm.
7.5 „ open 6 mm.
8.7 „ open 5·5 mm. (because a lamp was brought near).
9.0 „ open 6 mm.
9.30 „ open 6 mm.
6.15 a.m. the next morning, open 6 mm.: then set free.

3. *Venus* 4 cm. long, 3·3 cm. broad.

7.0 a.m., loaded with 900 grams.
7.5 „ open 2 mm.
7.10 „ open 3·5 mm.
7.15 „ open 4 mm.
7.30 „ open 5 mm.

Load increased to 1250 grams.

7.38 a.m., load increased to 1700 grams.
7.46 „ load increased to 2000 grams.
8.10 „ open 7 mm.
8.15 „ adductor muscles ruptured.

4. *Venus* 3·6 cm. long, 3 cm. broad.

8.19 a.m., loaded with 900 grams.
8.40 „ open 3 mm.: then set free.

5. *Venus* 3·4 cm. long, 2·8 cm. broad.

8.40 a.m., loaded with 900 grams.
8.56 „ open 1·5 mm.
9.2 „ open 2 mm.
12.27 p.m., open 2·5 mm.

Load increased to 1000 grams.

2.0 p.m., open 2·5 mm.
6.45 „ open 2·5 mm.

Load increased to 1400 grams.

7.15 p.m., open 3 mm.
7.45 „ open over 3 mm.
9.50 „ open 4 mm.: then set free.

6. *Venus* 3·7 cm. long, 3 cm. broad.

9.50 p.m., loaded with 1000 grams.
10.15 „ open 2 mm.
10.30 „ open 4 mm.
11.30 „ open 4 mm.
7.0 a.m. next morning, found with adductor muscles ruptured.

7. *Venus* 3·3 cm. long, 2·8 cm. broad.

8.0 a.m., loaded with 900 grams.
8.24 „ open 1·5 mm.
9.45 „ open 2·5 mm.
10.20 „ open 3·5 mm.: then set free.

Several of the molluscs closed somewhat when approached or disturbed; but as long as the strain was continued they could never shut up completely, even when their soft parts were mechanically irritated. With the exception of the two which were torn apart, they all closed again completely and tightly immediately they were freed from the strain, and when left to themselves behaved quite normally.

It will be seen from the tables that different individuals resist the strain to a very different extent. Generally a weight of 900 grams* is quite sufficient to open a *Venus* in from five to twenty-five minutes, or, on an average, fifteen minutes. Further, it follows from experiments 3 and 6 that a strain of 2000, or even 1000 grams. exerted on both shells at once, is sufficient, if continued for some time, to rupture the adductors; whilst, according to the results both of Lawrence-Hamilton's experiments and of my own, not even a weight of 4000 grams is enough to bring about a sudden rupture. The difference in effect between a momentary and a continuous strain is thus most clearly shown.

We saw above that a starfish of moderate size can develop a force of at least 1350 grams with the tube-feet which come into play; so that it possesses more than sufficient strength to forcibly open a *Venus*, since for this purpose at most 900 grams is necessary. The conclusions we have come to are therefore completely confirmed by experiment.

What applies to a *Venus* applies also to an oyster; which, according to Lawrence-Hamilton, can only resist 1919·5 times its own weight (without the shell), and hence is somewhat weaker than *Venus*.

It hardly requires to be stated that every starfish cannot open every oyster or bivalve, and that the size and strength of the two must be in suitable proportion.

* I have not ascertained how small a load is necessary to cause a slight opening of the shell. It only concerned me to learn whether a weight of 1350 grams is large enough.

In order to afford an idea of the rapidity with which a starfish completely devours an oyster or bivalve, I may mention that a starfish of moderate size had completely digested a *Venus* 3·7 cm. long in $8\frac{1}{2}$ hours, and an oyster $2\frac{1}{2}$ cm. in diameter, which was given it open, in 4 hours.

In conclusion, I would point out that the oyster or mussel culturist should take the greatest pains to destroy starfishes wherever and whenever he can get hold of them. It is not sufficient, however, to tear them up, since they possess an extraordinary power of regeneration, and are able to replace lost parts in a relatively short time. The central body especially plays an important part in this process, and it is probably for this reason that (according to Forbes) regulations exist in certain parts of England which oblige the fishermen to tear or crush the central body of starfishes which they capture, before throwing them overboard. In many districts it would no doubt be worth while to bring the starfishes ashore, and use them as manure. The practical Americans have constructed a special dredge—the "star dredge"—an iron instrument carrying a number of tangles, with which they systematically capture starfishes on the oyster beds.