

NATURAL HISTORY OF MARINE ANIMALS

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Chapter 8

MARINE ANIMAL HABITATS

The habitats of marine animals may be divided roughly into five types: the open oceans, rocky shores, sandy beaches, estuaries, and ocean bottoms. The first three are usually separated by a rather abrupt line, but the sandy beach often merges into the estuarine and ocean-bottom conditions, and the estuarine gradually verges into the ocean bottom. Many references have already been made to animals and conditions that come under these five headings. We may now summarize more definitely the conditions or the physical factors typical of each habitat.

The Open Ocean. The chemical and physical conditions of the open ocean are for the most part quite stable. The animals living there have no contact with solid objects other than each other, and, with few exceptions, they merely drift in the waters. Though most of the drifting animals have means of locomotion, their rates of speed and hit-or-miss direction of movement serve the purpose mainly of keeping them at rather definite levels, or of escape, or of obtaining food, or of dispersing or scattering members of a species. Except for vertical or diurnal movements, animals of the open ocean show on the whole no tendency toward definite migration, though there are exceptions, such as shrimps, squid, and fishes, which undoubtedly do migrate. Because of the many difficulties involved in their study, few migratory routes even of the fishes have been established with certainty. Sometimes jellyfishes are brought near shore by changing currents and then are swept onto the beach in large numbers. Such calamities are exceptional, and the floating life of the open ocean is, for the most part, fairly uniform in its make-up. Since diatoms, the greatest source of food in the ocean, depend upon materials from the shores and from rivers, there is considerably more floating animal life within a few hundred miles of shore than in the more open regions. Thus the oceans have their productive regions but also their deserts or regions of little food and, consequently, sparse animal life.

Perhaps because animals in the open sea have no contact with solid objects, and because most of them remain beneath the influence of surface

disturbances, many are equipped with long, delicate appendages which they could not possibly bear in other regions. In any other locality animals with such appendages would be torn apart by the disturbances of the water, or the appendages would be worn off by coming in contact with solid objects.

Another interesting characteristic of the pelagic animals is that many of them are transparent. Sometimes a sample of sea water may look clear but in reality contain animals so transparent that they are invisible. Often we have hauled in plankton nets almost full of the sea gooseberry (the ctenophore *Pleurobrachia*, Fig. 33), which is so transparent that we were not aware of its presence until the net was lifted from the water. The arrowworms, or chaetognaths (Fig. 46), are sometimes very abundant, but they are not visible until preserving fluid is poured over them, whereupon their bodies become whitish. Perhaps the majority of the larval forms are also transparent. We have taken the young of the spiny lobster $\frac{1}{2}$ in. in length that were crystal clear. Since water is clear and is the medium in which pelagic or drifting animals live, being transparent may afford the animals a certain amount of protection.

Because they are sensitive to changes in temperature and oxygen and have always lived in a medium in which they do not come in contact with solid objects, most animals of the drifting-life zone are very difficult to keep in an aquarium.

The Rocky Shore. The rocky shore is usually an exposed region upon which the waves of the surf beat with more or less unceasing vigor, but its rough surfaces offer many opportunities for animals to seek refuge. The rocky beaches are the regions most productive of marine animal life.

Because of its importance to shore animals, especially rocky-shore animals, we should again consider the factor of the carrying power of moving water. The ability of moving water to carry objects with it varies as the sixth power of the velocity. This means that if the speed of a current that will move a rock 1 cu. in. in volume is doubled it could move a rock of 64 cu. in.

As a wave approaches shore the lower part is held back by the decreasing depth and the resulting friction with the bottom. The top begins to forge ahead until it finally topples over and "breaks." The force exerted by this falling top depends mainly on the speed with which the wave approaches shore and its amplitude and height.

When it falls, the crest of a wave follows the laws of falling bodies. The velocity with which a volume of water falls from the crest of a wave depends on the distance through which it falls ($V = 8.04\sqrt{h}$). A crest falling through 4 ft. strikes with a velocity of 16.08 ft. per sec. One falling through 16 ft. would have twice the velocity, or 32.2 ft. per sec.

If a wave falling 4 ft. and striking with a velocity of 16.08 ft. per sec. could move a 64-cu. in. rock (4 by 4 by 4 in.), one falling 16 ft. could move a rock 40.96 in. in each dimension, or 68,720 cu. in. It could move a rock containing 39.77 cu. ft., or nearly 1.5 cu. yd., as contrasted to one falling 4 ft. and moving only $\frac{1}{26}$ cu. ft. A wave falling four times as far would be capable of moving a rock not only four times as heavy but one over a thousand times as heavy.

A heavy surf is a much greater menace to marine animals on a rocky shore than one might realize without knowledge of the foregoing facts. When surf rollers are increasing in amplitude they usually break farther and farther at sea, and much or most of their devastating effect is dissipated before reaching the rocks. This applies to a gently sloping shore, and not to one that is abruptly sloping, where the waves break directly onto the rocks. The stationary rocks themselves break the force of the onshore waves, and, although the tops of rocks may take quite a beating, the depressions and crevices between them are not so greatly disturbed.

No two rocky shores are exactly alike. They are alike in that they provide attachment for animals and seaweeds, but they differ in ruggedness and exposure to surf and sun. The amount of sand in and surrounding rocky shores is also of great importance. Sand that is stirred up has a great eroding effect as it is carried about by the water. Few echinoderms are found where such a condition exists.

Food is abundant on rocky shores, since there are nearly always alongshore currents to transport it. Temperature is fairly constant except in regions exposed by the tide, and even here the rocks and seaweeds remain cool from the evaporation of water on their exposed surfaces. As far as temperature is concerned, perhaps the most dangerous place for animals is in tide pools that are left by the receding tides on a warm sunny day. These pools may become warmed and depleted of their oxygen to such an extent that many of the animals therein may die. At such times the alkalinity becomes much higher also.

Sandy Beaches. Compared with other regions the sand beach is an unfavorable place for marine animals because of the shifting sand caused by the incoming and outgoing tides and the beating of the surf. The sand-beach habitat extends from high-water mark out as far as the sand is moved by tide and wave action. The distance the sand beach extends below low-water mark varies with the condition of the shore line, *i.e.*, it will extend farther out and into deeper water in regions where the shore line is exposed and subject to bad storms, or where there is a wide, gently sloping beach. A sandy beach may in certain regions have a width of only a few feet and in other regions a width of a mile or more. In any case the dividing line between the sandy-beach habitat and the ocean

bottom can be said to coincide with the region in which the substratum or bottom is no longer disturbed by the wave action along the shore. This applies to average conditions and not to times of exceptionally severe storms that may occur only once a season or less frequently.

As far as temperature is concerned, conditions on the sandy beach are much the same as in the rocky regions, for the evaporation from the exposed beach helps to keep it cool, and most sandy-beach animals are able to dig rapidly and thus keep below the surface when the sand becomes too warm. Not many animals have become so highly specialized, however, and the sandy beaches have a population of fewer species of animals than any other habitat.

Estuaries. As has been said, the sandy beach verges into the muddy bottoms of inner bays and estuaries (see Frontispiece). Here the animals are not exposed to the beating of the surf, and the tidal currents bring in much seaweed, which is broken down into detritus. Considerable detritus is also formed from the decaying of plants growing in the estuaries themselves. In estuaries, therefore, we find that detritus forms the main food of the animals. Any movement on the surface stirs up this detritus and puts it in circulation. The tidal currents are the most important agents in moving this surface layer, thus bringing it within reach of mouths or tentacles of the inhabitants of the estuarine bottom. Many of these animals have ways of their own for procuring this surface layer with its content of rich organic food.

The consistency of the bottom of a mud flat is of great importance to estuarine animals. This consistency depends upon the fineness of the soil and the amount of clay it contains. In almost any estuary or bay all degrees of consistency may be found from thin slimy mud through heavy sticky mud to more and more sandy mud until the sandy beach is reached near the entrance. Those regions where the bottom is neither slimy mud nor shifting sand have the greatest animal population. It is in such stable sandy mud that permanent burrows can be made. Because of the stable conditions of the bottom and the abundance of food, the animal life of marine estuaries is very abundant.

Another important factor affecting the lives of animals in estuarine regions is the exposure of considerable portions of the bottom at low tide. At such times most of the animals living on the surface seek deeper water. But some of them burrow into the bottom and thus remain moist until the tide returns. Those animals that live permanently below the surface simply cease operations until the return of the tide. One would think that under the influence of the hot sun these exposed regions would become quite warm, but such is not the case, because the hotter the sun the greater the evaporation, and only the top 2 or 3 in. will become

dangerously warm as far as the animals living therein are concerned. We have tested this condition many times and found that at a depth of 3 or 4 in. the temperature seldom rises as much as 4 or 5°F. during tidal exposure.

Animals that live in permanent burrows in the mud flats of estuarine regions are quick to sense the uncovering of the surface by the receding tide and as quickly sense the return of the tide later. This can readily be verified by bringing such mud-flat animals as *Upogebia* (Fig. 135), *Urechis* (Fig. 58), *Callinassa* (Fig. 132), clams, and others into the laboratory where they can be placed in artificial burrows of glass. Then by artificially lowering and raising the level of the water below and above the entrances of these burrows, the reactions of the animals to exposure of the opening of their burrows to change of tide are readily ascertained.

The greatest lethal, or killing, factor is encountered in mud-flat regions where the surface becomes covered in the summertime with a felt of algal growth, such as *Enteromorpha*. Many animals become entrapped in this felt and are unable to reach regions of safety. Shallow burrowing animals, such as certain clams and worms, are killed by the warming of the water held by the feltlike covering. In such regions on a hot sunny day during tidal exposure the pH may rise to 9.8, and we have seen many places, one several acres in extent, where the animals were dying wholesale.

The Ocean Bottom. As we proceed oceanward from the estuarine regions we pass out the entrance and into the ocean bottom itself. This alongshore region is very similar to the estuarine, because conditions are very much the same except for exposure by the tides, and the principal source of food is again the layer of detritus. Here, too, the animal life is very abundant, becoming somewhat less so toward the edge of the continental shelf. From there down into the depths of the ocean farther and farther from shore the bottom life becomes less and less abundant, though, as far as is known, all depths of the ocean have their quotas of marine animals.

The depths of the ocean are silent, dark, cold, motionless regions subject to great pressures. Not much is known of the marine life of such regions, but, judging from the conditions and the lives of the animals that we do know, those living in the depths must have body processes that are far slower than those of alongshore species. Were we actually able to determine the ages of these denizens of the deep, it would not be surprising to find that some of them live for hundreds of years.

So much has been written and said about monsters of the deep that there is a general misconception of the little that is known about abysmal life. The animals that are brought to the surface from these great depths are not very large. As far as we know, no large fishes have ever been

brought up from the depths, and we are inclined to think that there are no very large animals in that area. Most of the deep-sea fishes that have so far been captured, with their monstrous teeth, great eyes, distensible stomachs, and barbel lures, range between 3 in. and 2 ft. in length.

There are two good reasons why no "monsters" are to be expected in the ocean depths. One is that the amount of food is too sparse even with the slower rate of living to sustain large animals. The other is that because the surface of a solid object or of an animal increases as the square, while the volume increases as the cube, the efficient animal of the depths must be small. If this is true, we can also say that large fishes have had no tendency to migrate to the depths.

Chapter 26

ECHINODERMATA

The phylum Echinodermata is divided into five subgroups, or classes: The Asterozoa, or starfishes; the Echinozoa, or sea urchins and sand dollars; the Ophiurozoa, or serpent stars and brittle stars; the Holothurozoa, or sea cucumbers; and the Crinozoa, or feather stars or sea lilies. There is not a single terrestrial or fresh-water representative. There are no parasitic echinoderms. The echinoderms are all more or less radially symmetrical, *i.e.*, the parts of the body are radially arranged around a central region in which the mouth is located, and in nearly all cases the body is five-rayed. Another characteristic of the echinoderms is the presence of a calcareous skeleton, made up either of definitely shaped plates more or less rigidly joined together or of scattered spicules or plates. The name of the phylum is derived from words meaning "hedgehog" and "skin" and refers to the spiny skin of many members of the group. In all except the sea cucumbers the outer skin is ciliated.

CLASS ASTEROIDEA

The body of a starfish consists of a central portion with, typically, five radiating processes or arms, although the number is by no means uniform throughout the group. At least one species (*Culcita tetragona*, from Europe) normally has only four arms, while others may have six, seven, eight, ten, and even as many as forty. Often a typically five-rayed starfish may be found with as few as four or as many as eight. The arms are not definitely separated from the central portion of the animal, *i.e.*, there is no line showing where the central portion ends and the arm begins. The proportion of the central part in relation to the arms varies markedly in the different genera. Some starfishes have long slender arms with a very small central portion, and in others the central portion and arms are so merged that the arms are only tips of a pentagon. The centrally located stomach extends out into the rays, as do the ovary and testis. The mouth is located in the center of the undersurface of the body, and the anus on the opposite or upper surface.

The calcareous plates forming the skeleton of starfishes are not fused together but are interlocked or overlapped in such a way that the rays may be flexed in any direction. In the leather star *Dermasterias imbricata*, the plates are small and so deeply embedded in the skin that the animal feels smooth. *Pycnopodia helianthoides* is covered with a soft skin that feels slimy.

In color, starfishes practically run the gamut of the spectrum. Some species have a definite color, with only variations in shade. Our com-

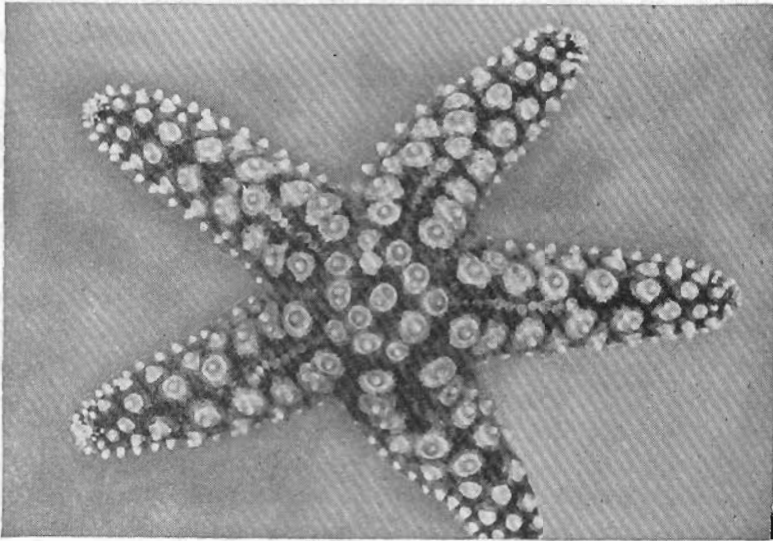


FIG. 84. A rocky-shore starfish, *Pisaster giganteus capitatus*. Note the large blunt spines, and the sense organs on the tips of the arms. $\times \frac{1}{6}$.

mon *Pisaster ochraceus* (Fig. 210) may be various shades of yellow, orange, brown, or purple. *Pisaster giganteus capitatus* (Fig. 84) is vividly colored around the spines.

Locomotion. Most free-living animals have an anterior-posterior region, *i.e.*, head and tail, with the head end containing most of the sensory organs. Such animals move forward, and the most highly sensitized portion of the body first meets the changing environment. Since each arm of a starfish is practically a duplicate of the others, with rather highly sensitive ends, a starfish can move in the direction of any arm. In this respect it differs from most other free-living animals, and it has the advantage of being able to reverse its direction of motion without turning around.

The echinoderms have a unique system of organs, which in some members of the phylum is given over largely to locomotion. Without

going into details, we may say that the main working portion of this system consists of a great number of so-called "tube feet," which, as part of a water-vascular system, are forced out by the contraction of a bulb at the interior end and are drawn back by relaxing this bulb and contracting the muscles in the walls of the tube feet. These muscles are of two kinds: the circular muscles that go around the tube feet and the longitudinal ones that lie lengthwise in the walls of the tube feet. In most of the starfishes these tube feet end in a sucking disk that enables



FIG. 85. A sand star, *Astropecten armatus*. This starfish comes into shallow bays. $\times \frac{1}{6}$.

them to adhere very firmly to any object against which they are pressed. Thus a starfish is able to cling firmly to a rock and resist the action of the surf. In fact, these sucking disks are so efficient that often when one pulls a starfish from a rock many of the disks break loose from the tube feet and remain clinging to the rock. If a starfish is placed on its back it can slowly right itself again by extending the tube feet near the tip of one or two arms until they can adhere to some surface. Then the body is pulled over so that more and more tube feet can attach, until the animal is finally right side up. An averaged-sized *Pisaster ochraceus* (Fig. 210) can sustain a pull of more than 100 lb. for a short time.

In starfishes the tube feet lie in grooves on the underside, one groove radiating out each arm from the mouth. They are all coordinated so that they work together to move the animal efficiently, even though the rate of progression is somewhat snaillike. Movement is effected by extending the tube feet ahead, attaching the suckers to an object, and then shortening the tube feet to exert a forward pull. The tube feet are then relaxed and again extended ahead for a new attachment.

Certain starfishes have become rather highly specialized, and some of these, e.g., *Astropecten* (Fig. 85) and *Luidia* (Fig. 86), have taken up their habitat on the sand or muddy bottom of the bays, estuaries, or oceans. In such a habitat, suckers on the tube feet would have nothing to which to attach. These starfishes have no suckers but insert the tube feet into the sand and use them as sort of movable traction devices by which to pull themselves along.

Pedicellariae. Starfishes are always clean and seldom have other animals growing on their backs or, as a zoologist would express it, on the aboral surface. Microscopic examination of this upper surface of a star-

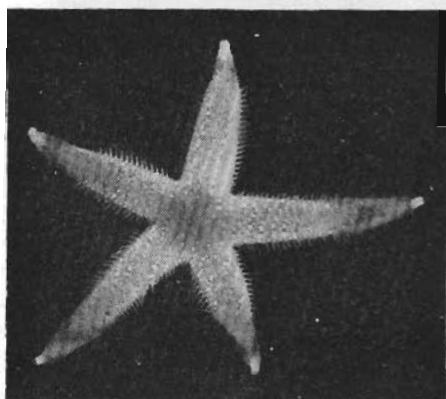


FIG. 86. A sand star, *Luidia foliolata*. From deeper water. Note the regenerating arms. $\times \frac{1}{2}$.

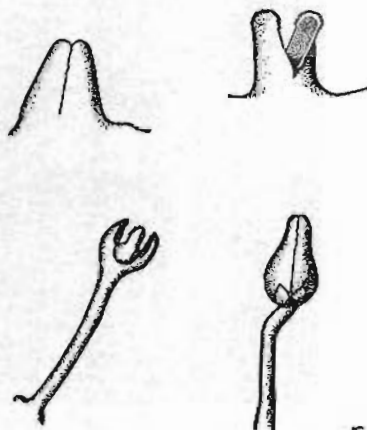


FIG. 87. Pedicellariae. The upper two from starfishes; the lower two from sea urchins. Greatly enlarged.

fish reveals over the backs and particularly abundant around the bases of the spines a great number of tiny pinching organs which grasp and crush any larvae or small animals that may land upon the surface of the starfish. Thus no animal is able to make attachment to a starfish. These little grasping or pinching organs, called *pedicellariae* (Fig. 87) are not confined to the upper surface alone but are found over nearly all the surface of the body of the starfish. To test the action of these forcepslike or scissorslike organs without being able to see them, one need only place a starfish upside down on the back of one's hand where hair is abundant, or even on the head. The tiny pincers will grasp the hair but usually are not sufficiently strong to pull out the hair when the starfish is removed. A few species of starfishes do not have pedicellariae. The West Coast *Henricia leviuscula* (Fig. 88) is an example of a starfish without these organs.

We have never seen an animal with ciliated epithelium that had other animals or plants growing upon it. An apparent exception to this is the sand dollar with a barnacle growing on its upper surface. Such cases are exceedingly rare, and we believe they are the result of a break or lesion in the epithelium.

Respiration. If one looks parallel to the surface of an ordinary starfish as it is under water, it seems to be covered with a soft furry substance. This appearance is caused by the outpouching of the thin lining of the body cavity through tiny holes in the skeleton covered by

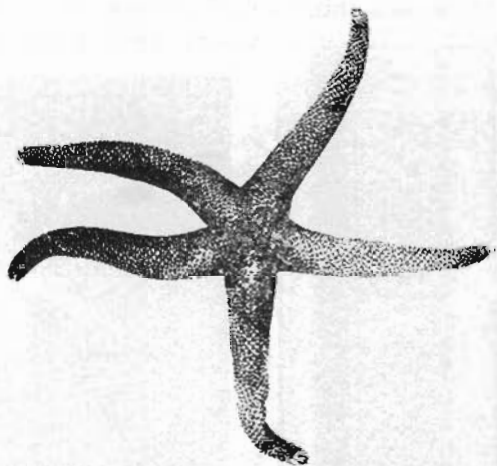


FIG. 88. *Henricia leviuscula*. A starfish without pedicellariae. Approximately $\times\frac{3}{5}$.

the thin ectoderm. These outpouchings, called *dermal branchiae*, or *skin lungs*, are equipped with cilia on both the outside and inside. The external cilia keep a current of oxygenated water flowing over the branchiae on the outside, and the internal cilia cause the body fluid to flow out into the branchiae and then back into the body. While the body fluid is in the outpouchings it is in close proximity with the surrounding water, so that it may take up oxygen and give off carbon dioxide, just as the blood in our own lungs flows past the tiny oxygen-filled air sacs contained in the lungs.

It was in the blood of starfishes that Metchnikoff first discovered phagocytes, those corpuscles whose function it is to swallow foreign materials that get into the blood. Wherever they are found in the animal kingdom, including man, phagocytes perform this function of engulfing foreign material in the blood.

Feeding. It is possible that all tube feet are more or less sensory, but at the outer tips of the arms the tube feet are modified and are entirely sensory in function. These enable the starfish to avoid danger

and to detect food. This latter function can easily be demonstrated by putting some food material like clam meat or a piece of fish into an aquarium with a starfish. The sensory tube feet at the ends of the arms begin to wave about in the water, and the starfish proceeds in the direction from which the stimulus of the food material comes. Certain investigators have maintained that starfishes come upon their food only by chance, but anyone who has the time and patience to experiment with starfishes will soon become thoroughly convinced that this is not true.

There is no doubt that animals in the ocean vary in their sensitivity to substances in the water just as animals on land vary in their ability



FIG. 89. A pink starfish, *Pisaster brevispinus*. A large species that has just been put in a bed of sand dollars. $\times \frac{1}{20}$.

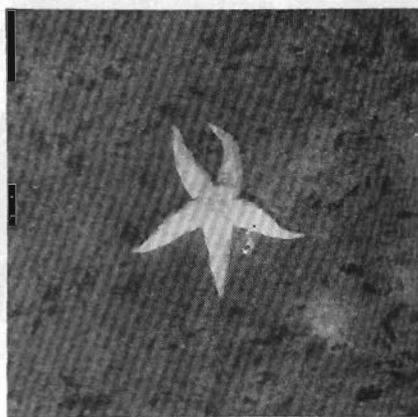


FIG. 90. Same bed of sand dollars as in Fig. 89. The sand dollars are hastily burying themselves in the sand.

to smell odors. If the starfish *Pisaster brevispinus*, which feeds on sand dollars (Fig. 89), is thrown into a bed of sand dollars, the sand dollars in a radius of at least 2 ft. will immediately burrow out of sight into the sand (Fig. 90). It is very noticeable that the stimulus to burrow becomes much weaker toward the outer fringe of the circle, for here the sand dollars bury themselves perhaps only halfway. When a *Pisaster brevispinus* passes through a bed of sand dollars, it leaves a track 4 ft. wide where the sand dollars have all gone down. Within half an hour after the starfish has passed, the sand dollars again come to the surface and renew their feeding activities. Not all starfishes have such an effect on the sand dollars, for *Astropecten armatus*, which does not feed on sand dollars, may pass through the same bed of sand dollars without disturbing them in the least. *Pisaster brevispinus* is a soft pink starfish, found from British Columbia to Newport Bay, and may reach a diameter of 2 ft.

Most starfishes are carnivorous, and the majority of them feed principally upon shellfish—clams, mussels, scallops, oysters, etc. When a starfish is in a mussel bed or an oyster bed, it finds its prey by searching, for a living mussel or oyster gives off practically no odor detectable by a starfish. This is no serious drawback, for oysters and mussels are so abundant in a bed that the starfish has no trouble finding its food. However, if an oyster or mussel is broken open or smashed, a starfish will sense the broken animal and go more or less directly to it. When a starfish eats a clam, oyster, or mussel, it attaches its tube feet to the valves of its prey, and, by raising its central portion in a tentlike manner, it is able to bring its arms into a position to exert a considerable pull from opposite sides. In practically all cases the starfish has more endurance than the animal it is trying to open, and the shell of the clam, oyster, or mussel soon begins to gape slowly. Then the stomach of the starfish, a thin, saclike affair, is extruded from the body and envelops the prey. The walls of the stomach surrounding the body of the prey secrete digestive juices that soon dissolve the flesh, and, as this process goes on, the fluid food is taken in and absorbed by the body of the starfish. After feeding, the stomach is withdrawn into the body.

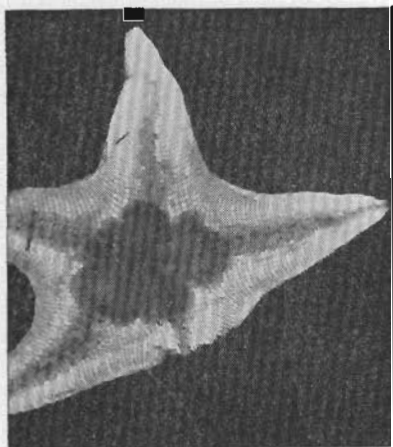


FIG. 91. The cushion star *Patiria miniata*. From the under, or oral, side, showing the stomach extruded. One arm is missing. $\times \frac{1}{3}$.

Most starfishes that use pelecypods for food are also scavengers. However, each and every species has its own particular or peculiar choice or preference for food. Some starfishes limit themselves to a single article, or at most a few particular articles, of diet. The English starfish *Asterina gibbosa* eats sponges and ascidians. *Pycnopodia helianthoides* will eat practically anything, but in rocky regions it feeds largely on sea urchins. We have found this multirayed starfish all over the mud flats in Tomales Bay, but we do not know what it feeds on in such places unless it be snails. *Astrometis sertulifera* feeds on the large chiton *Stenoplax conspicuus*, but it eats other things also.

Likewise, the common cushion star *Patiria miniata* (Fig. 91), of the Pacific Coast, will eat practically anything, even bits of seaweed. In an aquarium a member of this species extrudes its stomach and plasters it against the glass walls to dissolve off the diatom growth that accumulates

there. When there are quantities of edible sediment in the water *Patiria* sometimes secretes mucus on its undersurface, humping up somewhat so that the sediment may collect in the mucus as the water passes by. We have often stimulated *Patiria* to feed in this manner in aquariums by introducing into the water ground-up dried abalone, etc. Further evidence of the omnivorous appetite of *Patiria* is that we have seen it eating the sponge *Myrilla noxiosa* and even its spiny cousins the sea urchins. With the exception of the annelid *Capitella ovincola*, *Patiria* is the only animal we know of that can digest a string of squid eggs, and the starfish required 72 hr. to do so.

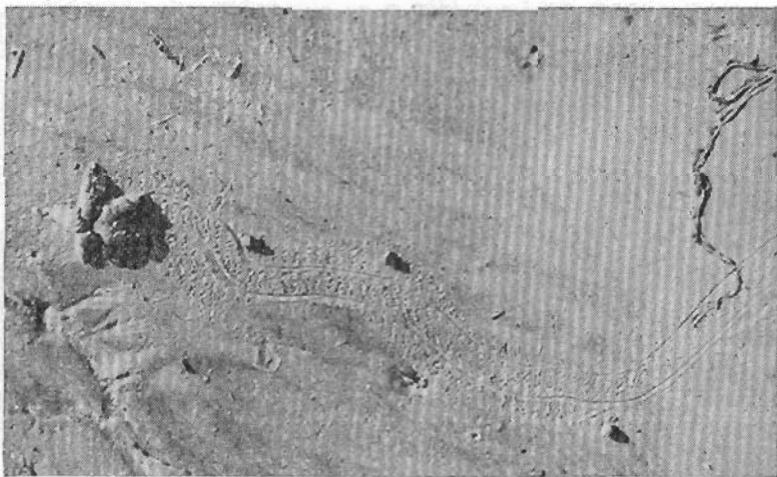


FIG. 92. A sand star, *Astropecten armatus*, crawling over the sand. Note the tracks. The upper surface of the starfish is covered with sand. $\times \frac{1}{15}$.

Pisaster ochraceus, the most common starfish on our Pacific Coast, feeds largely on mussels, but it also eats barnacles, snails, and even small crabs. The latter are caught and held by the pedicellariae. If other food is scarce, starfishes even feed on smaller members of their own kind.

The sand-dwelling *Astropecten* (Figs. 85 and 92) does not extrude its stomach to envelop its prey but swallows its food whole, the food consisting of small living snails or other material that it is able to find as it moves about over the ocean floor. It has a relatively wide mouth in proportion to its size. Sometimes three or four snails may be found at one time in the stomach of an *Astropecten*. After the flesh of the snail is digested, the shells are regurgitated, a process which, as we shall see later, is of interest to the hermit crab.

Reproduction. With few exceptions, the sexes are separate in the starfishes. Young *Asterina gibbosa* are all males, but as they grow

larger they become females and produce eggs only. In most starfishes the eggs or sperm are spawned into the water and the fertilized eggs develop into ciliated larvae that are free-swimming for from 2 weeks to 2 months. The larvae go through various changes before attaching themselves to rocks, seaweeds, etc., where they metamorphose into the adult form. *Patiria miniata*, which ranges from Sitka to La Paz, will shed its eggs or sperm at almost any time of the year if it is laid out of water—unless it has already spawned not more than 2 months previously. *Pisaster ochraceus* discharges its eggs or sperm into the water during the summer when the temperature of the water reaches a certain point. At Corona Del Mar we have observed *Astrometis sertulifera* spawning in December and July. We have known *Patiria miniata* to spawn at Corona Del Mar in January and again in July, and at Pacific Grove in July.

Several of our West Coast starfishes brood their eggs. The smallest species on this coast, *Leptasterias pusilla*, a six-rayed starfish from central California that does not exceed 1 in. in diameter, carries its eggs in clusters around the mouth. Two other six-rayed species also brood their eggs. *Leptasterias aequalis*, which reaches a diameter of over 2 in. and is found from Puget Sound to Newport Bay, may be found humped over its eggs in February and March at Pacific Grove, Calif. By arching the body and drawing the arms closer together, the mother starfish forms a cavity or tent that serves as a brood pouch. *Leptasterias hexactis*, of northern waters, also broods its eggs.

The red *Henricia leiuscula* (up to 5 in.), which occurs from the Aleutians to central California, stays hidden in the dark while brooding its eggs, according to other investigators, who found brooding females in January. We have observed spawning in this species in early March at San Luis Obispo. The disk of this species is small and the rays long. The East Coast species *Henricia sanguinolenta*, which is actually circum-polar, also broods its relatively large eggs. The larvae never swim at the surface but begin their free existence by gliding over the bottom.

Growth. The rate of growth of starfishes depends upon the abundance of food. A well-fed specimen may be many times the size of a poorly fed one at the same age. Starfishes may go without food for months, but during this time growth ceases, and, like the anemone, if starvation is continued long enough they may actually decrease in size, although this is not so noticeable as in the anemone.

At least in certain species, sexual maturity depends upon size rather than age. If the food supply is ample, many species of starfishes grow fast enough to be sexually mature by the end of the first year.

Each species of starfish has its own average age limit. Some, like

Astropecten, live only about five years, while others, like *Pisaster*, may live for twenty years.

Regeneration. All starfishes have great powers of regeneration, but there is great variation in these powers among the different species. If pulled in two, most species can regenerate the missing two or three arms, or, if all the arms are removed, the central disk can renew the arms. We have often watched *Astrometis sertulifera* (an active, slimy, dark-colored starfish found from Santa Barbara to Lower California) divide into five equal parts as its five arms began pulling in their respective directions.



FIG. 93. The variable starfish *Linckia columbica*. (Left) With all its arms in the process of regenerating; (right) four arms regenerating new starfishes. The piece at the far right will not cast off the new starfish after it is regenerated. $\times 1$.

It is probable that each arm regenerates a new starfish if conditions are favorable. Favorable conditions are necessary for any regeneration to take place, as any torn or mutilated animal falls easy prey to its enemies. In the laboratory, some of the arms with a portion of the central disk of the divided *Sertulifera* regenerated the missing four arms, and in our collecting we have occasionally found an arm of *Sertulifera* with its share of the central disk growing four new arms.

Luidia foliolata (Fig. 86), a gray, bottom-dwelling, active starfish found from British Columbia to San Diego, breaks off one or more of its rays when handled, and many of the specimens taken have one or more arms in the process of regeneration.

One genus of starfishes, and only one so far as is known, is capable of growing an entirely new starfish from just a piece of an arm. In some of our experiments a new *Linckia columbica* (Fig. 93) grew from a tip of an arm only 1 cm. (about $\frac{3}{8}$ in.) in length. A piece shorter than this seems to be incapable of regeneration and soon dies. Sometimes, at least, a much longer piece of arm will, after regenerating new arms for

about a year and a half, throw off this new set of arms. This tiny new starfish will in turn grow a new arm, making five. The original piece again begins to regenerate a second new starfish. This process has taken place twice in succession in experiments we made on this particular starfish. As it provides material for the new developing arms, the original piece decreases in size. If the amputated piece of arm is about 2 cm. ($\frac{3}{4}$ in.) or less in length, the new regenerated arms will not be thrown off but will be retained. If the piece of arm is longer than about $\frac{3}{4}$ in. it may drop off the newly formed starfish, thus shortening itself, and grow another new starfish until the balance of $\frac{3}{4}$ in. or less is established. The new starfish has arms about $\frac{3}{8}$ in. long at the time they are cast off from the original piece. It seems that an effort is thus made to maintain a balance between the length of the new arms and the piece that gives rise to them.

If a short piece is cut from an arm of a *Linckia*, it appears to regenerate the new starfish faster than a longer piece of arm. This faster rate of regeneration is only apparent, for after the larger piece begins to regenerate the new starfish, it grows much faster than one on a smaller piece of arm. This is due to the fact that the longer piece of arm has a larger diameter and requires longer for the healing that precedes the actual regeneration. But once this healing is finished, the regeneration is more rapid because there is a larger piece of arm from which to draw material.

During regeneration something frequently goes awry, for one often finds specimens of *Linckia* with from four to eight arms instead of five. *Linckia columbiae*, which reaches a maximum diameter of 4 in., is found on rocky, open shores from San Pedro, Calif. to the Galapagos.

Many interesting stories have been told in connection with the ability of starfishes to regenerate portions of themselves. At one time oyster men on the East Coast were so plagued with starfishes in their oyster beds that they hired a man to chop them in two with a hatchet as they were brought up with the oysters. This meant that within 3 months or less there would be two starfishes, in place of the one, to continue the plague.

Here on the Pacific Coast one of the beach communities became concerned about the starfishes exterminating the mussels. Some of the people organized themselves into two groups under two "generals" and, armed with hatchets, sticks, and what not, invaded the territory of this enemy to the mussels, chopping and jabbing at each starfish they could find. Although they may have experienced a pleasant afternoon and have gone home with a sense of having shown themselves superior to nature herself by coming to the assistance of one of the oppressed, it is

evident from what has been said that, as far as the mussels and starfishes were concerned, the total result was practically nil. The interesting point about this episode is that starfishes have been preying upon mussels for millions of years, yet mussels no doubt are as abundant as ever, and it is not likely that the starfishes would have annihilated the mussels in this community within a few short weeks.

CLASS ECHINOIDEA

The echinoids include the regular, or round, sea urchins, the heart urchins, and the flattened cake urchins or sand dollars.

All echinoids have pedicellariae, and as many as four kinds are found in some species. The function and action of these organs have been described by various workers. There are three-jawed pedicellariae that crush larvae that might settle on the animal. There are others that assist in removing foreign particles or prevent the settling of such particles. Others with powerful jaws seize and help hold very small animals until they can be conveyed to the mouth. Other three-jawed pedicellariae with almost globular heads have poison glands and are protective in function.

Sand dollars, heart urchins, and regular urchins grow by the deposition of shell on the outside by the external body membrane, or epithelium, and by the resorption of the shell on the inside.

REGULAR URCHINS AND HEART URCHINS

Although sea urchins and starfishes are little alike superficially, they are found to be very much alike when carefully examined. If one could remove the upper surface of a starfish, except for a little round disk in the center, bring the arms upward together so that their tips touch and surround the little disk, and then fuse all together, one would roughly have the body of a sea urchin. However, many technical adjustments would have to be made, such as moving the openings of the reproductive organs up to this little round disk in the center, supplying the mouth regions with a very efficient set of five teeth and jaws, elongating the spines, etc. As in the starfish, the mouth of the sea urchin is located on the underside and the anus on the upper side. The exception occurs in the heart urchins that are somewhat flattened and elongated, in which the mouth is located toward the forward end and the anus at the back, giving them a secondary bilateral symmetry. They move forward in the direction of the mouth.

Locomotion. Sea urchins are equipped with the same type of locomotor organs as are the starfishes. They have very long, slender, tube feet that are able to reach out beyond the ends of the spines and attach

to the surface upon which the sea urchin rests. Sea urchins also use their spines to help them walk about, but in varying degrees, some species making practically no use of the spines in locomotion while in others they are the chief means of movement. The spines can be moved in any direction, for they are hinged to the test by a ball-and-socket joint. One Hawaiian species of sea urchin (*Heterocentrotus mammilatus*) has somewhat flattened spines about $\frac{1}{2}$ in. wide and 5 in. long. Others have long slender spines, and still others have short, thick, blunt spines (Fig. 94).

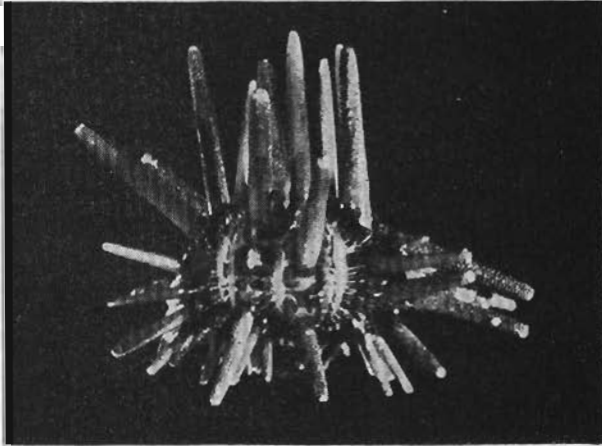


FIG. 94. A sea urchin, *Eucidaris thouarsii*. From Mexican waters. $\times \frac{2}{3}$.

Habitat and Habits. Some sea urchins along rocky shores remain practically fixed in one place, and it is said that by means of constant abrasion by their spines they are able to dig pockets in solid rock into which they fit and are thus protected from wave shock. However, since all echinoderms except the sea cucumbers have over the surface of their bodies a skin of ciliated epithelium, which covers even the spines themselves, we do not see how these spines can work through such a delicate covering to scrape away rock. We are more inclined to think that it is done by keeping the surface of the rock very clean, thus allowing the sea water gradually to dissolve the surrounding rock. This may be helped by the mechanical action of the sea urchin, particularly by the tube feet continually pulling off tiny bits of the rock as the solvent action of the ocean water takes effect. Such a cavity as we are discussing is not made in a day or a month or a year but in several years.

Along our West Coast there are only three common species of rocky-coast sea urchins. The one most commonly seen is *Strongylocentrotus purpuratus* (Fig. 95), a purplish form that may reach a diameter of 6 or 7

in. (depending on age) and that ranges from Alaska to Cedros Island. Young specimens may be greenish. *Strongylocentrotus franciscanus*, commonly called the red urchin (Fig. 96), covers the same range as does

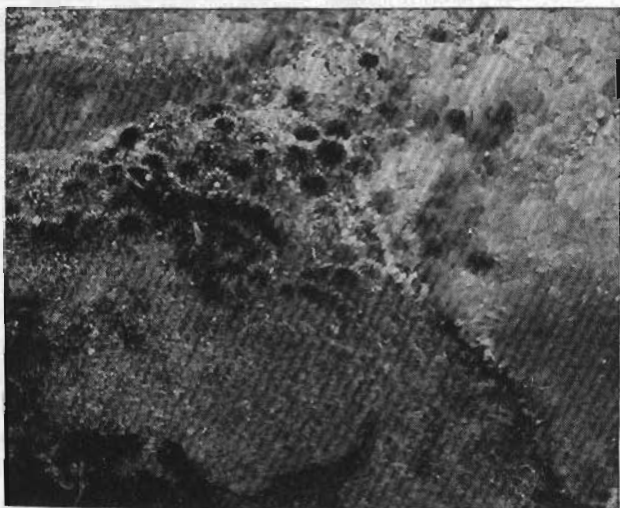


FIG. 95. The purple sea urchin *Strongylocentrotus purpuratus*. The common sea urchin of the West Coast, on surf-swept rocks. $\times \frac{1}{16}$.

the above species, but it occurs in deeper water and is seldom found except at the lowest tides. Its spines are longer and blunter than those of *Strongylocentrotus purpuratus*, and its test may reach a diameter of 10 in. in northern waters. *Strongylocentrotus drobachiensis* is a greenish urchin that is found in more protected rocky regions from Washington northward. It also occurs on the northeast coast of America and in Europe. Its spines are short and blunt.

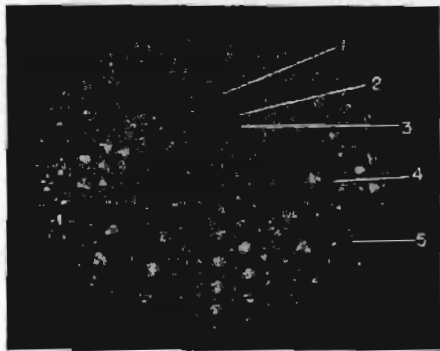


FIG. 96. Test of the red sea urchin *Strongylocentrotus franciscanus*. 1, Madrepore; 2, anal opening; 3, opening of reproductive ducts; 4, openings for tube feet; 5, tubercle on which the socket of the spine rests. $\times \frac{1}{3}$.

A deeper-water form, *Centrostephanus coronatum*, with a test 2 or 3 in. in diameter but with slender spines 4 or 5 in. long, occurs in rocky regions off the coast of southern California. On

several occasions we have found a few specimens of this species in shallow water along a rock-strewn shore of Newport Bay.

Echinus miliaris, a British littoral species, covers itself with fragments of shell and seaweed, which are held in position by the aboral tube feet.

Some of the sea urchins in the tropics and subtropics have poison glands at the bases of the spines that render such urchins rather dangerous, although one is not likely to be wounded by sea urchin spines unless one falls while carrying the urchins or while walking through a bed of them.

Not all sea urchins live in rocky regions. Many species live on the ocean bottom. For example, *Lytechinus anamesus* (Fig. 97), a whitish sea urchin about 1½ in. in diameter, which occurs along the coast of southern California and Lower California at depths of from 30 ft. to about 300 ft., lives in "herds" on the ocean bottom. This species is often used for experimental embryology, and we have sometimes searched for several days before finding a patch of them, but when such a "herd" is found they may be obtained in almost any number.

A very close relative, *Lytechinus pictus*, with a larger test and shorter spines, lives in bays and estuaries and near their entrances along the coast of southern California and Lower California.

On mud bottoms in Monterey Bay the somewhat depressed *Strongylocentrotus fragilis* may be found. Its spines are short, and the pinkish test is thin and delicate.

The heart urchins have become adapted to living on a muddy bottom. The mouth has been moved to one side and the anus down from the top, so that they have become bilaterally symmetrical animals that move in one definite direction. They plow along through the mud, ingesting it as they go, and from this surface or near-surface mud, which is rich in organic matter, they obtain their food. Their spines are all streamlined backward so that they interfere little with the progress of the animal. However, the spines are very sharp and, we imagine, efficient organs of defense. One heart urchin, *Lovenia cordiformis* (Fig. 98), that is dredged near our laboratory is so fragile that few specimens come up whole. The test of this urchin is about 3 in. long, and some of the dorsal spines are 4 in. long. The spines of the undersurface are short.

In many sea urchins the spines serve as a trap for gathering bits of seaweed to be passed around to the mouth, bitten into small pieces by

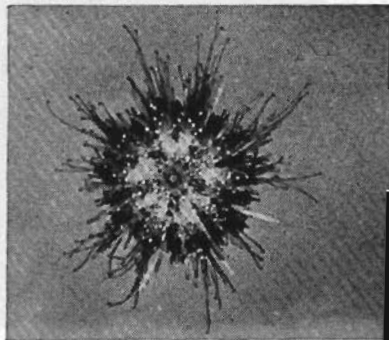


FIG. 97. A gregarious sea urchin, *Lytechinus anamesus*. Dredged from depths of 20 to 100 ft. $\times \frac{2}{3}$.

the five teeth, and swallowed. Most sea urchins will also eat flesh, but in nature the capture of such material is infrequent, for so many other more active animals are on the alert for it. With the aid of the pedicellariae very small animals may be caught and carried to the mouth. Small dead animals or portions of larger ones are easily transferred to the mouth.

When any sea urchin is prodded with a sharp object the spines in that vicinity all turn in the direction of the irritation and thus offer more defense in that particular area. Certain sea urchins, such as *Lovenia cordiformis*, retain this ability in broken portions of the shell.

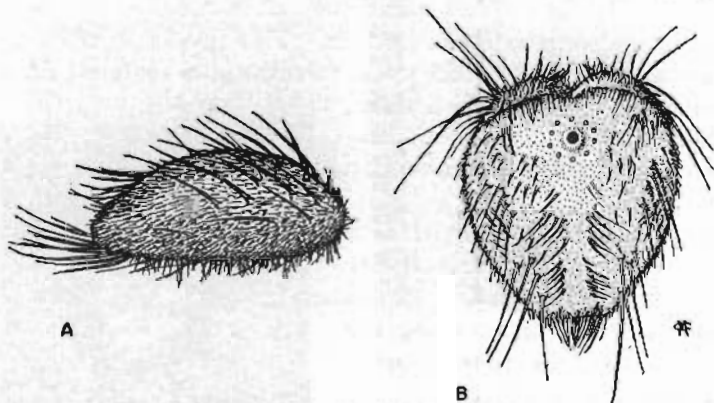


FIG. 98. A heart urchin, *Lovenia cordiformis*. A, Side view of animal crawling to the right. B, Ventral view, showing the mouth. $\times \frac{1}{2}$.

If a piece of *Lovenia* shell having long spines is broken off and placed in sea water, and even the organs removed from the inside, the spines will continue making defense reactions for several hours.

Respiration. Breathing is done mainly by the tube feet and by five groups of tube feet around the mouth that are modified into gills or branchiae. As the body of the sea urchin is a large rounded globe, and the cavity inside is large in proportion to the surface area, sea urchins have developed special ciliated blood cells that swim constantly, thus keeping all of the body fluid in circulation so that all of it may become oxygenated.

SAND DOLLARS

The sand dollars, sea biscuits, or cake urchins, as they are called in different localities, resemble very much flattened sea urchins with both upper and lower surfaces covered with short spines. When an object is round like a globe it has much more strength than does an object that is flattened or waferlike. Because of the manner in which sand dollars

live, it is advantageous for them to be waferlike. To strengthen their shells, they have built little supporting pillars on the inside between the upper and lower surfaces. These little pillars are absent in the central region where most of the viscera of the animal lie. Some sand dollars have even gone so far as to leave holes around the edge of the disk (Fig. 99). These holes no doubt help to strengthen the surrounding regions of the body.

In sand dollars the mouth with its five jaws is located in the center of the undersurface, but the anus has also moved to the lower surface near one edge or, in some cases, to the edge. This gives sand dollars

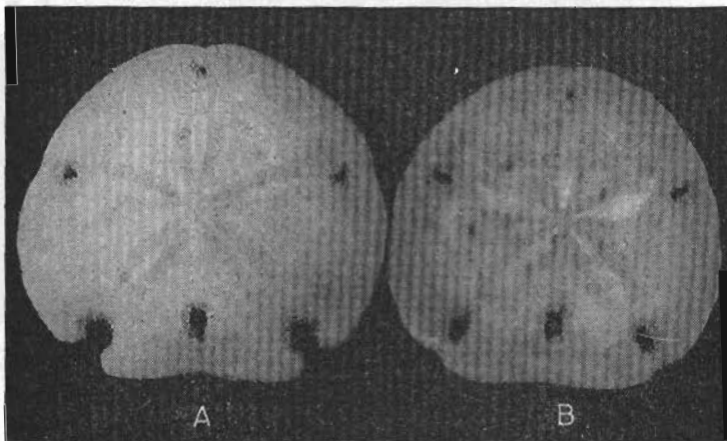


FIG. 99. Keyhole sand dollars, *Encope* sp. From Mexican waters. $\times \frac{1}{2}$.

a secondary bilateral symmetry, perhaps not so pronounced as that of the heart urchins but sufficiently that they move in a forward direction, *i.e.*, away from the side on which the anus is located. The mouth remains in the center, which is advantageous in view of their method of feeding.

Feeding. The spines on the upper side of the sand dollar are club-shaped and are covered with cilia. These cilia create currents that flow from the direction in which the animal is moving toward what could be called the posterior edge, or that edge on which the anus is located. As the currents flow through these spines, little eddies are created at the posterior sides of the spines. These eddies allow tiny particles and organisms to become entrapped in mucus that is secreted on the surface of the spines. This mucus goes downward and is led into tiny tracts to unite with others. These in turn unite again, passing around the edge to the underside, until near the mouth five tracts or strings of mucus feed directly into the mouth of the sand dollar. These tracts are shown on the underside of the sand dollar in Fig. 100.

Habitat and Habits. We have found several instances in which a knowledge of the natural history of marine animals has settled the question of whether two forms should be separated into two different species or not. The West Coast sand dollar *Dendraster excentricus* furnishes a good example.

One form of this sand dollar lives within estuaries and stands on edge oriented so that it is crosswise to the direction of tidal flow, but it shows no preference as to whether its mouth faces toward or away from the current. About one-third of the test is buried in the sand (Fig. 89), with the posterior end, or anal edge, upward. When bared by the tide, this sand dollar drops down flat and covers itself with sand (Fig. 101).

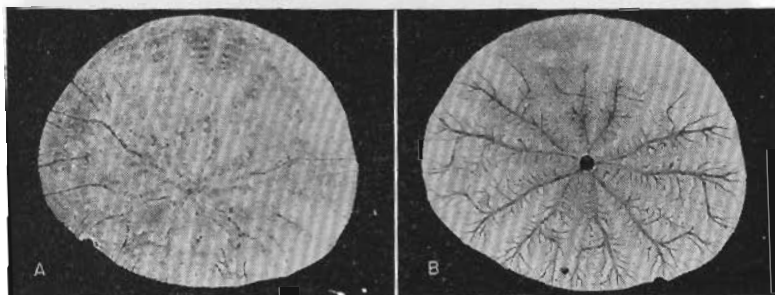


FIG. 100. The estuarine sand dollar *Dendraster excentricus* var. *elongatus*. A, Upper side of test, showing food tracts leading over the edge. B, Under, or oral, side, showing food tracts leading into the mouth. Anal opening in lower center. $\times \frac{1}{2}$.

The form that lives on the outside beach lies flat and moves slowly about just beneath the surface. This outside form is almost circular in outline, and the edges of the test are much thicker than those of the estuarine form. In the estuarine form the anterior end is somewhat narrowed and more convex, and the edges of the shell are thin. The central portion of the outside sand dollar is higher in proportion than that of the estuarine form.

But it is the difference in habits of the two forms that convinces us that they are two definite species. The outside form can be found within 2 miles of the estuarine form, yet there are never any gradations between the two. We have also brought the outside sand dollars into the bay by the laboratory, but they never show any inclination to stand on edge, although those of the estuarine form around them are in this position. The transplanted sand dollars did not survive within the bay.

These facts were brought to the attention of one of our friends, an echinoderm taxonomist, and he made of the inside form a new variety, *Dendraster excentricus* var. *elongata*. To one who has always classified animals on structural characteristics alone, it was logical to hesitate to

separate them into two distinct species, but, judging from their habits, we believe there is no doubt that these two forms are separate and distinct species of animals.

Both of these sand dollars occur very abundantly in beds. At Morro Bay we have counted as many as 67 *Dendraster excentricus* in an area of 1 sq. yd. At Corona Del Mar as many as 468 specimens of *Dendraster excentricus* var. *elongata* may be found in 1 sq. yd. This is a maximum population.

Commensals.—Elsewhere we have mentioned the isopod and the annelid worm that are commensal on the sea urchin *Strongylocentrotus*



FIG. 101. The estuarine sand dollar. Crawling just beneath the sand, moving to a new location. $\times \frac{1}{15}$.

purpuratus and sometimes on the red sea urchin, and also the crabs that live on sand dollars. Under "Protozoa" and "Platyhelminthes," mention was made of ciliates and a rhabdocoele that live in the intestine of the purple sea urchin.

Enemies. The principal enemies of the echinoids are starfishes and man. Certain starfishes feed on sea urchins and others on sand dollars (Fig. 90). The sea urchins can take certain protective measures against the starfishes, but unless the starfish is small in proportion to the sea urchin, the latter usually loses out. When a hungry starfish approaches a sea urchin, the protective pedicellariae grasp the tube feet of the starfish and exude a poison. As the starfish retreats the pedicellariae are pulled off. In the succeeding attacks more pedicellariae are pulled off until all are gone and the starfish is free to make a meal of the sea urchin.

In the event that the starfish is bested, the sea urchin can regenerate new pedicellariae.

In many countries the egg masses of sea urchins are sold in markets of coastal towns. In Italy they are sold as *Frutta di Mare* and in the West Indies as sea eggs. At low tide at Pacific Grove we have seen groups of Italians gather sea urchins, break them open, remove the egg masses and wash them in sea water, then fill 2-qt. jars to take home. Large specimens became increasingly difficult to find.

Reproduction. With few exceptions sea urchins and sand dollars simply extrude their eggs and sperm into the water, and the developing larvae (Fig. 102) are left entirely to their own devices.

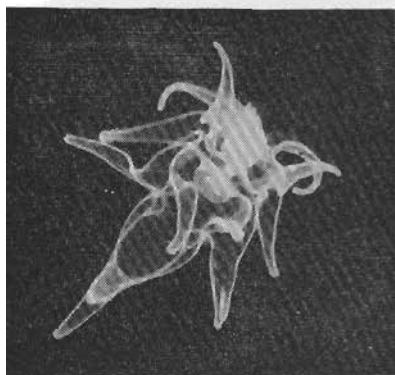


FIG. 102. Larva of sea urchin. Nearly microscopic.

Like most other marine animals that simply extrude their sexual products into the surrounding water, colonies of sea urchins, heart urchins, and sand dollars spawn simultaneously. The first individual to start spawning causes all of the surrounding individuals to spawn, and this spreads throughout the bed until all have shed their sexual products. In nature this first individual to spawn perhaps does so because it has become so gravid that it can no longer retain the sexual products and because of a rise in temperature, which usually produces spawning when the gonads are ripe. However, when the sexual products are ripe, even though the gravid condition has not been reached, a bed of any of these animals can be made to spawn by breaking open an individual and dropping the sex products into the colony. For this reason, whenever we break open a sea urchin or a sand dollar to see if the sex products are ripe, we are always very careful not to throw the broken specimen back into the water, for it might induce spawning, a month or two before they would spawn voluntarily, in animals that otherwise might be used for experimental embryology. The eating of a sea urchin by a sheepshead (fish) or the breaking of an urchin by some floating object or rolling rock could very well account for some of the great variation that we find in the time of spawning of a sea urchin bed. We have found that the time of spawning of sea urchins varies from year to year by as much as 3 months. Sand dollars, which are less liable to such accidents, have a much more limited time of spawning. We cannot ascribe this difference in time of spawning to accidents because we do not

know all the factors concerned, but we wish to point out that in some cases accidents may have a definite bearing on the time of spawning.

Along the shore of Monterey Bay where we have taken sand dollars for experimental embryology, we found that while the sand dollars were spawned out at one place there might still be perfectly good ones 4 or 5 miles up or down the beach. At our Coroná Del Mar laboratory we are able to obtain sea urchin eggs at almost any time of the year, for, although the urchins in some of the beds are spawned out, we can usually find one where they have not yet spawned.

Temperature and food supply are no doubt the most important factors regulating the time of spawning. If the food supply is abundant the animals will fill up with eggs or sperms in much less time than if it is scanty.

At Pacific Grove *Strongylocentrotus franciscanus* spawns from February to March, and at Corona Del Mar during December and January. At Pacific Grove *Strongylocentrotus purpuratus* spawns in March and April. Ripe eggs and sperms for experimental purposes may be taken over a longer season than the regular spawning season. We have found ripe *Lovenias* at Newport Bay in May and in September.

The sand dollar *Dendraster excentricus* spawns at Pacific Grove in May and June, and we have observed spawning in the southern form, variety *elongata*, in May and October.

One antarctic species of heart urchin, *Hemiaster philippi*, carries its eggs and developing young on its upper surface in the two posterior grooves, which are depressed and troughlike.

Regeneration. As compared with other echinoderms, there is little regeneration in the echinoids. Tube feet and pedicellariae are readily replaced, but a major injury to the test cannot be repaired. If the test is only cracked, healing occurs. If a portion of the test is crushed inward, the broken place may be repaired, but the deformity remains. If a portion of the outer edge of a sand dollar test is broken off, the wound is sealed off and the outer body membrane grows over it, but the part cannot be replaced.

CLASS OPHIUROIDEA

The name of this class is derived from words meaning "serpent-tail forms" and was applied to serpent stars and brittle stars because of their long slender arms with snakelike movements. The common name of brittle star came from the fact that these arms break very easily if the animals are handled or disturbed.

The ophiuroids have a relatively small round or pentagonal disk from which five arms radiate. In contrast to the starfishes, the disk is

definitely set off from the arms. The digestive and reproductive organs are located in the central disk and do not extend into the arms as in the starfish. The mouth is situated in the center of the lower surface, and, since there is no anal opening, indigestible material must be extruded through the mouth. The disk is covered with short spines or flat plates, and the arms contain articulated ossicles that permit varying degrees of movement, depending on the type of "joint." The arms are covered with plates, between which spines may project.

In one group of deep-water serpent stars, called the *basket stars*, the five arms branch dichotomously, *i.e.*, each arm divides into two branches, each of

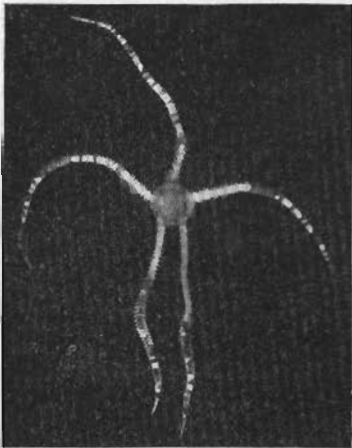


FIG. 103. A brittle star, *Amphiodia psara*. In swimming position. $\times 2$.

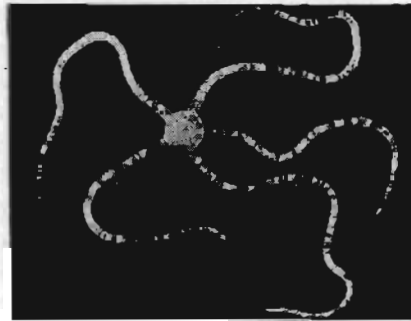


FIG. 104. A brittle star, *Amphiodia psara*. A mature specimen, with arms too long for swimming. $\times \frac{2}{3}$.

these branches into two more, and so on until a network of branches or "basket" is formed.

Locomotion. In the serpent stars the tube feet are small and are used more for sensory organs and for organs of respiration than for locomotion. The tube feet may aid in movement to some extent, but the flexible, jointed arms are the main organs of locomotion. In a small, six-rayed species, *Ophiactis arenosa*, common near our laboratory, the tube feet, equipped with suckers, are the major organs of locomotion. *Amphiodia psara* is able to move fairly rapidly by extending one arm ahead, trailing two behind, and using the remaining two as sort of wing-like structures to pull itself over the sand. It swims with the arms in the same position, using the two side arms as wings or fins (Fig. 103). Any one of the arms may be used as the forward arm. Fully grown specimens (Fig. 104) with longer arms lose the ability to swim. Other species, *e.g.*, *Ophiacantha eurythra*, swim by trailing just one arm behind and using the other four as propelling organs. With one arm trailing

behind and the other four curved forward and sideways, *Ophiacantha* travels along the bottom in sort of hopping movements. Still other species progress by using two of the arms for grasping objects and the remainder for pushing themselves forward. The spines along the arms assist in clinging to objects.

Habitat and Food. Perhaps because of their fragility, serpent stars are retiring by nature and nocturnal in habit, so that, although they are abundant, one must hunt for them among the seaweeds, under rocks, or on the ocean bottom.

Those living in rocky regions subsist mainly on detritus that gathers on the rocks or on the sand and mud, or on small dead animals or particles of larger ones. The tube feet aid in the selection of food particles and in passing them along the arms to the mouth.

One species, *Ophioderma panamensis*, which we have watched a great deal in aquariums in the laboratory, will grasp a piece of clam meat or fish flesh with the tip of an arm and then roll the arm up in a helical coil, thus bringing the food close to the disk where it is transferred to the mouth and eaten. This serpent star can sense the presence of food that may fall several inches away from its living quarters. It extends an arm to explore around to locate and then grasp the particle of food. This species occurs under rocks at low tide from San Pedro to Panama. It is reddish brown and reaches a span of 7 in.

Ophiothrix spiculata, which occurs from Pacific Grove to Central America, is a spiny ophiuroid that exhibits many variations in coloring. It may be a solid color, or the disk may be one color and the arms another, or the disk may be spotted with various colors and the arms banded. It is found in tide pools, among the holdfasts of kelp, and in crevices in rocks and debris from mid-tide to 200 ft. *Ophiothrix* cannot coil its arms vertically but bends them sideways.

Amphipholis pugetana, which is less than an inch in diameter, occurs from Alaska to Lower California. It is often found in aggregations under rocks. At Humboldt Bay we have found it among *Zostera* and at Monterey Bay in the holdfasts of kelp. *Ophionereis annulata*, a large gray ophiuroid with black and gray banded arms, also is often found in groups under rocks from San Pedro southward to Central America.

Some species of ophiuroids, with very long arms in proportion to the size of the disk, live buried in the mud. One of these, *Amphiodia barbarae* (Fig. 105), we found lives buried about 3 or 4 in. in the mud, where it makes a small cavity for its body. It extends its arms to the surface, where they sweep up the detritus, which is then transferred by mucus and ciliary tracts down the arms to the mouth. This *Amphiodia* is extremely difficult to remove from the mud without its losing part of

its arms. If one is handled it continues to throw off portions of its arms. Fig. 105 shows one specimen that was obtained fairly intact. Its range is from San Pedro to Ensenada. It is found in littoral sandy mud flats and in the ocean bottom out to 700 ft.

Our West Coast basket star *Gorgonocephalus caryi* is dredged in depths of from 50 to 3000 ft. Occasionally a specimen is washed ashore during a storm. It clings to objects with its branching arms and no doubt catches prey with its network of branched rays.

Respiration. On the underside of the disk of ophiuroids at either side of the base of each arm is a slit that leads into a small, thin-walled

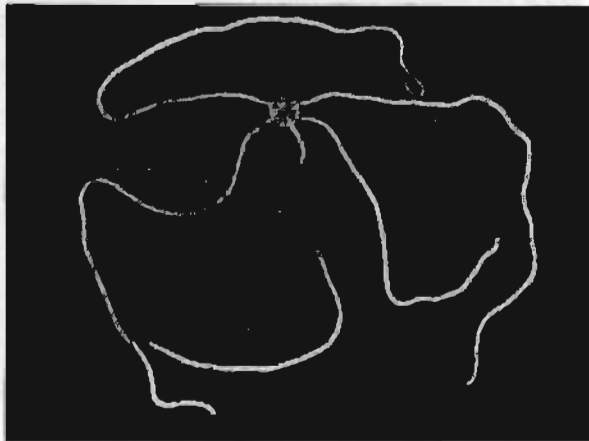


FIG. 105. *Amphiodia barbarae*. A mud-dwelling brittle star, or serpent star. $\times \frac{1}{2}$.

pocket, or genital bursa, lined with cilia. Two slits usually lead into one bursa, so that there are 10 genital slits and 5 bursae. In *Ophioderma panamensis* the slits are paired, making 20 in all. Since the ocean water can enter through the slits, and a current is maintained by the cilia, these bursae serve as respiratory organs. It is supposed that the tiny tube feet on the underside of the arms serve as respiratory organs for the arms, and the bursae supply oxygen for the body. If the water becomes too stagnant and the currents maintained by the ciliated bursae are insufficient to supply oxygen, several genera are known to elevate the disk and then lower it, thus pumping water into the bursae and forcing it out again.

Reproduction. On the wall of each bursa are two glands that produce either eggs or sperms, depending upon the sex of the serpent star. In practically all serpent stars the sexes are separate, and the eggs and sperm are simply discharged through the genital slits into the sea water. At breeding times ophiuroids of the same species congregate in large

numbers under rocks, etc. *Amphipholis squamata* and at least the British species of *Amphiura* are hermaphroditic, one gland in each bursa producing sperm and the other giving rise to eggs.

In November at Corona Del Mar we have watched the process of spawning in a male *Amphiodia barbarae* (Fig. 105). The animal humped up on all five arms so that the disk was held off the bottom. It then contracted, and sperm issued from all five bursae at the same time.

Some serpent stars brood their young. The eggs are retained inside the genital bursae and are fertilized by sperm entering through the genital slits with the respiratory current of water. The fertilized eggs develop into larvae that go through their metamorphosis while still in the bursae and are not liberated until they assume the adult form. On the Monterey Peninsula we have found young in the brood pouches of *Ophioplocus esmarki* in July. This brittle star has been found from Pacific Grove to San Diego.

Amphipholis squamata and the *Amphiura* mentioned above also brood their young. The top of the disk of *Amphipholis* is easily cast off and regenerated, and it is believed that throwing off the disk is the method of allowing the young to escape. But in *Ophioplocus esmarki* the young must escape through the genital slits, for this species does not have a deciduous disk.

Ophiactis virens, a species found around Naples, has six arms. It divides in two by transverse division, and each half regenerates three more arms. Consequently, specimens of this species usually have three large arms and three smaller ones. Genital bursae are not present. The six-rayed *Ophiactis arenosa* that is found at Corona Del Mar also reproduces by transverse division, particularly the younger individuals. We have found these young forms in all stages from the newly divided ones to those with three new arms nearly the size of the old. They are particularly abundant within the sponge *Halichondria panicea*.

Regeneration. Since the fragile arms of the serpent stars are frequently thrown off or broken off, one seldom finds a specimen that is not regenerating at least the tip of one or more arms. Some species throw off an arm or break an arm into many pieces when they are handled or disturbed. Others go so far as to throw off the upper part of the disk, leaving only the arms held together by the lower portion of the disk and mouth frame. The upper part of the disk is regenerated. *Ophiocantha eurythra*, found at depths of from 60 to 120 ft. off the coast of California, throws off its disk with little provocation. As far as is known, when any serpent star is cut in two, each part can regenerate a complete animal.

CLASS HOLOTHUROIDEA

At first glance sea cucumbers seem to have little in common with a starfish or sea urchin, but if one were to take a sea urchin by the mouth and anus and stretch it out into a tube, remove the spines and soften the body wall somewhat, this "made" animal would be a fair sea cucumber, although other technical changes would have to be accounted for as was the case with the sea urchin "made" from the starfish.

A cucumber has five regions running lengthwise of its body that are the same as, or homologous with, the five arms of a starfish or the five regions of a sea urchin where the tube feet are located. In fact, most cucumbers have tube feet (Fig. 110) along these areas, although in most

cases they are functional in only three of the areas, the other two being devoid of tube feet. Sea cucumbers have no pedicellariae.

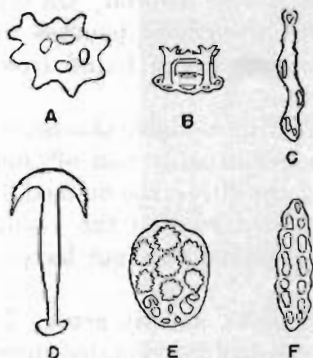


FIG. 106. Ossicles of sea cucumbers. A, From *Caudina*. B, C, and F, From *Stichopus*. D and E, From *Leptosynapta*. Approximately $\times 100$.

The skeleton of sea cucumbers is usually limited to scattered ossicles embedded in the skin. These are of various shapes and sizes, depending upon the species, and many vary in different regions of the body of the same species. There are platelike ossicles with smooth or serrated margins and with holes of varying number and size, wheellike ossicles complete with hub, and anchorlike ossicles (Fig. 106).

Respiration. Cucumbers have a peculiar method of breathing. They have a large, branching, treelike set of tubes inside the body, the trunk of which opens into a large cavity, called the *cloaca*, just inside the anus of the animal. By gulping in water through the anus and filling this treelike structure with fresh water, they are able to bring the oxygenated water to almost all portions of their inner regions and thus supply the body fluid with its required oxygen. After the oxygen has been partially used, the water is squirted out and a new supply taken in. In the Synaptidae there are no respiratory trees, and the members of this family (*Synapta*, *Leptosynapta*, *Chiridota*, etc.) breathe through the skin, which is usually thin.

Habits and Habitats. Sea cucumbers live on rocks, under rocks, in sand or mud, and on the surface. There is one free-swimming form, *Pelagothuria natans*, an Atlantic species.

In Puget Sound waters the large reddish *Cucumaria miniata* may be

found at the bases of rocks at low tide. It is from 6 to 10 in. long. Its rock-loving relative in the south, the yellowish-brown or reddish-brown tuberculated *Stichopus californicus* (Fig. 107) and its related species or

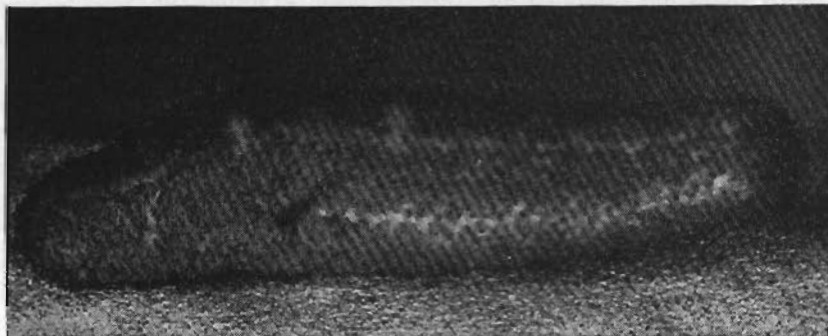


FIG. 107. A sea cucumber, *Stichopus californicus*. Tentacles withdrawn. Note the tubercles; also the commensal worm on the side. $\times \frac{1}{3}$.

subspecies, may be found occasionally at low tide at Pacific Grove and commonly at Newport Bay, but it is more common just below low-tide level. Average specimens are about 12 in. long, but they may reach a length of 18 in. They feed by sweeping the surface with their mucus-covered tentacles.

Other cucumbers live attached to rocks and, by leaving their tentacles expanded, feed on the microscopic organisms of the water (Fig. 108). One species, *Cucumaria curata*, which lives on ledges of rock on open shores on the coast of central California, furnishes a fine display of diatom shells if the stomach is opened and the contents smeared on a slide and examined under a microscope. Some cucumbers have become so dependent on the food brought to them by the water that they are practically sessile animals. One such slow-moving form is *Psolus*, flattened on one side, fitting tightly to the rocks, and with overlapping plates of ossicles on the upper surface like a coat of mail. The upper surface of *Psolus chitonoides* may range in color from cream to orange, but the large tuft of tentacles is reddish. This cucumber is found in Puget Sound waters at low tide and below tide level.

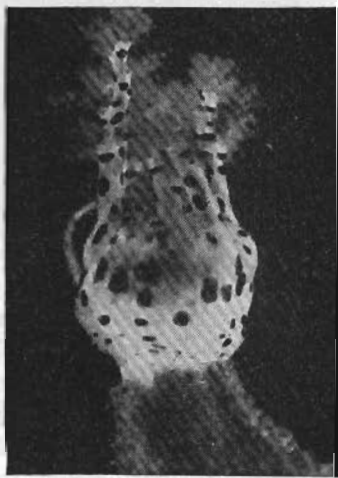


FIG. 108. A sea cucumber, *Cucumaria* sp. Showing expanded tentacles.

Certain cucumbers have lost their tube feet and are smooth on the

outside. One of these, *Caudina arenicola* (Fig. 109), looks somewhat like a sweet potato. It is spotted with jasper markings of brick red. At Newport Bay and southward *Caudina* lives in the mud and sand and feeds by ingesting the detritus from the sand, in much the same manner as does the annelid worm *Arenicola* described on page 201, with the exception that the front end of the body of *Caudina* is equipped with tentacles instead of just an eversible proboscis. By everting these tentacles and pushing them ahead into the sand or mud, particles of

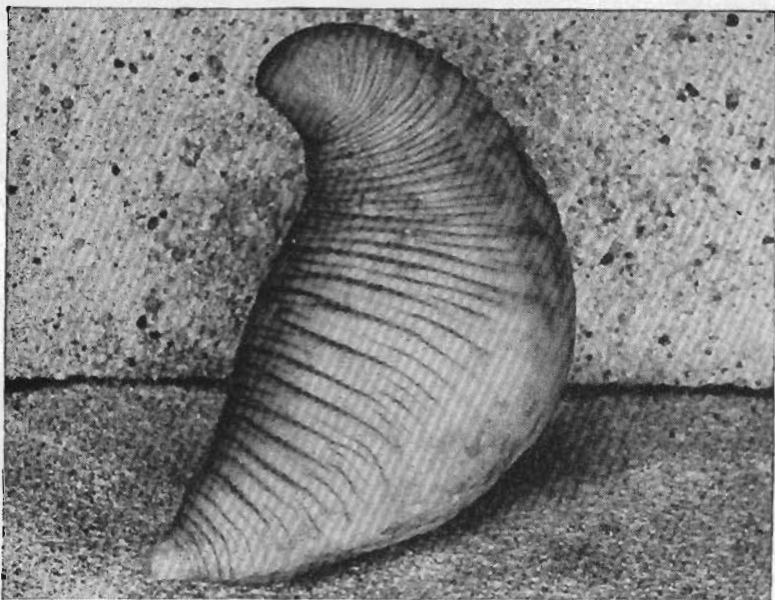


FIG. 109. A sand-dwelling sea cucumber, *Caudina arenicola*. This species has no tube feet. $\times \frac{1}{2}$.

detritus are entrapped and swallowed. And, as in the case of *Arenicola*, a great deal of sand or mud is swallowed in the process. *Caudina* lives in cleaner sand than does *Arenicola*.

As *Caudina* travels along just below the surface of the sand, its posterior end is kept at the surface, or slightly below, to facilitate respiration. Off Newport Beach we have dredged *Caudina californica* in 50 to 90 ft. of water but succeeded in getting only the "tail" or attenuated posterior end of the body. By virtue of its tail, *Caudina californica* can feed more deeply in the mud than *Caudina arenicola* and still extend the anal opening to the surface for respiration.

The synaptid cucumbers are also mud dwellers without tube feet. The walls of their bodies are full of little ossicles somewhat the shape of an old-fashioned sea anchor. When these cucumbers are handled, the

anchors often hook into others along the body, causing the two portions of the body to stick together. These anchorlike ossicles aid the animal in crawling through the mud, for the contraction of the circular muscles elevates the anchors and a certain amount of traction against the sand is thus secured. Contractions of the body and the action of the tentacles also are a part of the locomotory process. Two synaptids are common on our West Coast. *Leptosynapta albicans*, which, as its name suggests, is whitish, is found in gravelly or shelly or muddy bottoms at mid-tide level and out to 600 ft. It is 2 to 6 in. long. It occurs all along our West Coast, on the East Coast from Maine to South Carolina, and in Europe. It ingests sand and mud for the contained detritus. The tentacles may have some selective powers. In Puget Sound regions a related form, *Chiridota* sp., lives in a similar manner and in a like habitat.

Some cucumbers live in the mud and stick their tentacles out on the surface, and as the detritus washes back and forth past them the material is trapped and fed into the mouth in mucous strings. They lie with their anal opening at the surface, their bodies forming the shape of a widely broadened U. Several small cucumbers that live thus are often present in dredge hauls from off Newport Bay (Fig. 110). In a few cases we have dredged pieces of rock in which some cucumbers (*Cucumaria pseudopopulifera*) occupied the old burrows of rock-boring clams. They

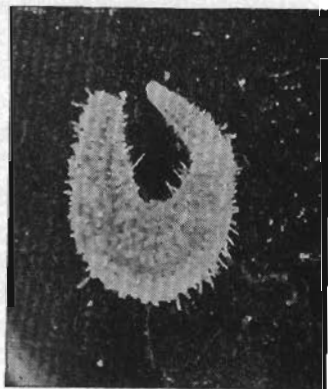


FIG. 110. A sea cucumber, *Cucumaria pseudopopulifera*. A mud-dwelling form from the ocean bottom. $\times 1$.

appeared to be imprisoned. This species always grows with the two ends of the body at right angles to each other, forming a 90° bend in the middle.

Commensals. The space, or cloaca, at the end of the alimentary tract of the sea cucumber makes a good place for an animal to live, for it is protected and well supplied with fresh water. In one of the larger cucumbers in the West Indies, a little fish lives in the cloaca, often putting its head out of the anal opening. At Newport Bay, the pea crab *Pinnixa barnharti* is almost invariably found in the cloaca of *Caudina arenicola*, and the ubiquitous *Ophisthopus transversus* is often found in *Stichopus*. The latter cucumber often has a scale worm clinging to its body. Under "Annelida" and "Protozoa" other commensals are mentioned.

Regeneration. When molested, some cucumbers, e.g., *Stichopus*, have a peculiar habit of throwing out through the anal opening all their

internal organs, including the respiratory tree and alimentary tract. Within a remarkably short time, an average of 6 weeks or 2 months, they regrow entirely new internal organs and are apparently none the worse for their experience. There is great variation among different species in this trait of throwing out some or all of the internal organs (*eviscerating*, as it is called). Some species do not eviscerate at all. If specimens of *Stichopus californicus* are placed in a container where the water becomes warm or stale, every one can be relied upon to eviscerate. The result is a disgusting-looking mess. *Thyone briareus* on our East Coast (Vineyard Sound and southward), throws its internal organs out through the mouth. However, only about one-third of the specimens can be stimulated to eviscerate even under provocation.

A European species, *Holothuria nigra*, known as the *cotton spinner*, throws out through the anus certain organs that, upon contact with water, become a mass of peculiar stringy mucus, which is very tough and sticky and in which attacking crabs or other predators are sometimes entangled.

When the Synaptidae are handled or disturbed they constrict across their bodies and throw off segments, first the tail end and then farther and farther forward until only the anterior portion remains. This part can regenerate the posterior end, but the other segments die.

Enemies. On the whole, sea cucumbers have few enemies. We have seen a few animals eating them, such as hungry sea gulls eating those left exposed by the tide. Man probably takes the heaviest toll, for in some localities sea cucumbers are dried and sold in the markets. Under the name of *trepang* and *bêche-de-mer* they are eaten by the Chinese and some of the South Sea Islanders.

Reproduction. The sexes are usually separate in sea cucumbers. Many discharge their sexual products into the sea water through an opening within or near the ring of oral tentacles. *Stichopus californicus* spawns in summer in northern waters, and specimens at Newport Bay have spawned in August.

The brooding of eggs and young is common among sea cucumbers. *Thyonopsisolus nutriens* (coast of central California) broods its young in little pouches in its back, somewhat after the habit of the Surinam toad of the Amazon regions. At Pacific Grove we have found it with brood in June and August. *Cucumaria curata*, a small black cucumber about an inch long, broods its young under the ventral surface of its body, *i.e.*, between itself and the rock to which it is attached. At Pacific Grove it may be found with brood in December. Members of the genus *Psolus*, including our northern *Psolus chitonoides*, carry their eggs among the calcareous plates on the back.

The European species *Phyllophorus urna* goes a step farther and retains its eggs in the body cavity while they develop. *Thyone rubra* (rocky regions of the coast of central California), a small red cucumber that is white underneath, also develops its young inside the body. The young, which are pure white while in the body of the female, may be nearly $\frac{1}{2}$ in. in length. We have found *Thyone* with young in July. The young escape through a rupture in the body wall.

CLASS CRINOIDEA

Although sea feathers, or sea lilies, or feather stars are abundant, most of them are deep-sea animals and are seen only by investigators on dredging boats or by visitors in museums. Over 2,000 fossil species have been described, and there are almost 800 living species, but practically nothing is known of their natural history. They have no pedicellariae and no spines.

Some of the sea lilies are permanently anchored to the ocean bottom by a stalk that projects from the aboral side. Thus anchored, mouth upward and with their branched and pinnated arms outspread, they feed on detritus or small organisms that are carried down the grooves by cilia. The grooves extend out along the branches of the arms to the tips.

The stalkless sea lilies are anchored while young, but the adults break loose from the stalk, retaining only a stump that is equipped with long attaching organs. By means of these organs they cling to a rock and feed as do the stalked forms. They can creep slowly over the rocks, and if they are disturbed or if conditions are unfavorable they can detach and, by waving their arms, swim away to another location. It is probable that some species make use of the detritus from the surface of the mud. Some of the stalkless species live in shallower water—less than 100 ft.

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