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Institution: Oklahoma State University

Location: Stillwater, Oklahoma

Title of Study: THE BIOLOGY OF THE COMMON STARFISH AS A SOURCE OF STUDY IN THE HIGH SCHOOL BIOLOGY CLASSROOM AND LABORATORY

Pages in Study: 38 Candidate for Degree of Master of Science

Major Field: Natural Science

Nature of Study: Many high school biology teachers find it necessary to use supplementary materials in presenting the starfish biology to the students. This report deals with such items as: the anatomy and physiology of the starfish; diagrams which can be used to present the material; methods for preparing laboratory specimens of the organism; outlines for laboratory exercises using the starfish; and a glossary of terms associated with the biology of this animal.

Use of Study: It is desired that the information presented in this report will be of value to secondary biology teachers in introducing the biology of the starfish to the high school student. Also, that some teachers who are not satisfied with the materials they currently employ may be assisted by the information or references presented.

ADVISER'S APPROVAL ______________________

THE BIOLOGY OF THE COMMON STARFISH AS A SOURCE OF STUDY IN THE HIGH SCHOOL BIOLOGY CLASSROOM AND LABORATORY

By

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1960

Submitted to the faculty of the Graduate School of
the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
August, 1963

THE BIOLOGY OF THE COMMON STARFISH AS A
SOURCE OF STUDY IN THE HIGH SCHOOL
BIOLOGY CLASSROOM AND LABORATORY

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ACKNOWLEDGEMENTS

The writer wishes to express his sincere appreciation and gratitude for the assistance and many valuable suggestions given him by Dr. James H. Zant and Dr. L. H. Bruneau, in the planning and writing of this report.

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CHAPTER I

INTRODUCTION

To the untrained eye the starfish seems to "have little excuse for being alive."[1] The animal possesses no true excretory system, no true circulatory system, and only the most primitive respiratory system. Regardless of these unusual characteristics, most biologists agree that the phylum Chordata arose in evolution directly from the phylum Echinodermata, which contains the starfish as one of its principal members.

Thus, the biology of the starfish offers the high school student an opportunity to compare the transition in form and structure combined with simplicity and complexity which is characteristic of many echinoderms. For this purpose the writer has chosen the common starfish, Asterias forbesi, as a representative of this group of invertebrates.

Compared to the other invertebrates, the starfish appears to be on a relatively low level of organization. However, it possesses one of the most complex nervous systems to be found in the invertebrate kingdom; its feeding mechanism is unique in the animal kingdom; its method of

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[1] Allison L. Burnett, "Enigma of an Echinoderm," Natural History, November,1961, p. 11.

locomotion is extremely complex, and is not duplicated outside of the phylum Echinodermata; and finally, the animal's ability to drop an arm when it is disturbed and to regenerate into a complete animal from only a small portion of the central disc is not equaled by any of the higher invertebrates.

The starfish has been studied thoroughly by modern scientists from the physiological and anatomical point of view. Yet less is known regarding the physiology of the starfish than any other major invertebrate animal. The nature of its digestive enzymes, the mechanism employed by the animal to drop an arm, the physiology of the nervous system, the cellular changes that occur during the regenerating process, the regulation of its locomotory apparatus, and the transportation of food materials within its body are still matters of highest speculation. It is only within the last decade that the mechanism involved in the animal's feeding process has been elucidated to any considerable extent.

The purpose of this study is three fold: (1) to provide the writer with a satisfactory knowledge of the biology of the starfish that may easily be communicated to the high school biology student; (2) to present a general guide which can serve as resource material for teachers in the teaching of the starfish biology at the high school level, and (3) to provide the teacher with a source of information for conducting laboratory exercises with this animal.

However, a detailed and extensive study of the starfish biology is beyond the scope of this report. With this fact in mind, the writer has attempted to present an elementary, yet informative, view of the biology of *Asterias forbesi*, the common starfish. Included with this are selected references that the writer considers the most important, an outline for the dissection and study of this animal in the high school biology laboratory, a section of diagrams showing the important structures of the starfish, and a glossary of terms associated with the anatomy and physiology of this animal.

CHAPTER II

HISTORICAL DEVELOPMENT

The starfish belongs to the class Asteroidea of the phylum Echinodermata. The starfish have been known from the earliest times, and the Greeks applied to them the name Aster, meaning star.[1] Aristotle was one of the first to observe and record the action of the starfish attacking and opening a clam. Linnaeus confused all the stellate echinoderms under the one name Asterias, and this confusion persisted for many years under names that were raised to familial or even ordinal rank. Lamarck, 1792, included the Asterias in the family Stelleridae. In 1837 Burmeister applied the name Asteroidea to the combined sea stars and serpent stars.

Valuable accounts of the asteroids were recorded by Sladen, 1889, during the voyage of the Challenger, by Ludwig, 1897, in his works on the asteroids of the Mediterranean, and by Fisher, 1911, in his purely taxonomic works. Preyer, 1886-7, made extensive observational and experimental studies on many echinoderms and contributed very accurate information on the starfish. Agassiz, 1877, is given much credit on the

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[1]Libbie H. Hyman, The Invertebrates: Echinodermata,(New York, 1955), p. 245.

the embryology of asteroids with his studies on Asterias forbesi.

In the present century Jennings, 1907, made a series of observations on the biological behavior of A. forbesi, and Vevers, 1949, contributed extensive information on the biology of this starfish. Anderson, 1954, demonstrated the anatomy of the cardiac stomach of the starfish.[2] Smith, 1937, has furnished the best description of the asteroid nervous system. The ecology of A. forbesi has been studied extensively by Galtsoff and Loosanoff, 1939, in which they observed the behavior reactions and ecology of this invertebrate in its natural habitat.

Much of the knowledge of the physiology of A. forbesi is due to the work of Buddington, 1942, in his studies on the cilia water currents, and by Paine, 1926, in her studies on the function of the tube feet.[3] Still further work was contributed by Maloeuf, 1937, on the respiratory function and by Van der Heyde, 1922, on the physiology of the digestive system in this starfish.

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[2]Ibid, pp. 276-281.

[3]Virginia Paine, "Adhesion of the Tube Feet in Starfish," Journal of Experimental Zoology, XLV (1926), pp. 361-366.

CHAPTER III

ANATOMY AND PHYSIOLOGY

The anatomy and physiology of the starfish offers the biology teacher an excellent source of material for classroom discussion. It gives the biology student an opportunity to compare the structure and body functions of this invertebrate with the other groups of animals, both vertebrate and invertebrate. The writer has attempted to include in this section a generalized view of the starfish biology which can be conveyed to the biology student.

Characteristic Features

Asterias forbesi, like all echinoderms shows radial symmetry inasmuch as each of its five arms contains the same set of organs. But this radial symmetry is not the original plan of structure and a closer examination of the starfish reveals the fact that it is built on the principle of bilateral symmetry. This plan is determined by the calcerous madreporic plate which is situated on the dorsal surface of the central disc between two of the arms. The plane of symmetry bisects therefore the madreporic plate, the anus which is situated in the middle of the dorsal surface of the central disc, and the arm or radius opposite to the madreporic plate. The two arms between which the madreporic plate is situated form the bivium, the remaining three form the trivium.

The external surface of the madreporic plate is cut by grooves which radiate from the center of the plate. Within the substance of the madreporite these grooves communicate with pores which in turn open into minute flagellated canals that unite to form collecting canals. These collecting canals empty into a dilated area, the ampulla, which gives rise to the stone canal of the water-vascular system. The flagella in the canals maintain a constant flow of water into the water-vascular system.

On the lower or oral surface of the central disc is situated the mouth, utilized as a point of reference in determining the ventral surface of the animal. The mouth is surrounded by a soft membrane, the peristome, immediately adjacent to which are five groups of oral spines. Extending radially from the vicinity of the peristome along the ventral surface of each ray is a groove, called the ambulacral groove, which contains four rows of tube feet or poda. The distal end of each podum is modified into a terminal disc or sucker, which works in the manner of a suction cup and enables the animal to attain a firmly adhesive grasp on the surface with which it is in contact.

At the distal end of each ambulacral groove there occurs a single terminal tentacle which contains a small red spot, the eyespot. This eyespot is a photoreceptor organ, and an important part of the nervous system of this animal. The edges of the ambulacral grooves are covered by a double row of spines, the ambulacral spines, that can be brought together to form a protective latticework over the tube feet in the ambulacral grooves.

The body surface is very thick and hard owing to the presence of calcified plates or ossicles in its inner layer. The ossicles of the dorsal surface are more or less irregular in shape and are held together by connective tissue and muscle fibers. The outer surface of the animal is pimpled with numerous white spines which are an elevation of the calcerous ossices in the dermis below. Around the bases of these spines, and between them, occur numerous small pincerlike mechanisms called pedicellariae. Each pedicellaria consists of two blades or jaws which have serrated-opposed surfaces. In general the pedicellariae, all of which are stalked, keep the surface of the animal devoid of debris and clear of organisms prone to settle on the softer parts of the body wall.[1]

The ventral surface is formed by articulated ossicles arranged in four rows in each arm. The two middle rows are formed by the ambulacral ossicles. Between these are the ambulacral pores through which the ambulacral feet project. The peristome is surrounded by a pentagon of oral ossicles. Outside of the adambulacral plates on the ventral surface and on the dorsal surface are numerous branchiae, protruding through the interstices between the ossicles. They are short, tube like projections of the coelomic cavity which serve for the purpose of respiration.

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[1] Hyman, p. 264.

The whole external surface of the starfish, even the exterior surfaces of such appendages as the tube feet, the pedicellariae, the spines, and the branchiae, is ciliated. This ciliation aids in ridding the surface of debris, and possible aids in the transportation of food to the mouth.[2]

Body Wall and Endoskeleton

From exterior to interior the body wall comprises epidermis, dermis, muscle layer, and parietal peritoneum. The epidermis is composed of ciliated columnar epithelium, with scattered spindle-shaped neurosensory cells, and mucous gland cells intermingled with muriform cells. The epidermis contains the pigment granules responsible for the external color. In the base of the epidermis is found a nervous layer, varying in thickness. A delicate basement membrane separates the epidermis from the underlying dermis.

The dermis, the thickest layer in the body wall, is made up of fibrous connective tissue. The dermis layer is permeated with a system of canalicular spaces that form a ring space around the base of each papula.

The skeleton is made up of calcerous plates or ossicles bound together by connective tissue contained in the dermis. The ossicles, as mentioned earlier, are regularly arranged about the mouth and in the ambulacral grooves and often

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[2]William T. Taylor and R.J. Weber, General Biology, (Princeton, New Jersey, 1961), p. 603.

around the sides of the arms, but are more or less scattered elsewhere. The shape of the ossicles is such that when they are bound together they form a reticulate skeleton, leaving spaces for the emergence of the papulae. The endoskeleton is divided into the main supporting system, embedded in the dermis, and the more superficial skeleton of projecting spines.

Muscular System

The narrow layer of smooth muscle, which comprises the muscular system, is divided into an outer circular layer and an inner longitudinal layer. These layers are rather thin and weak, resulting in somewhat flexible rays which are not rigid. A system of muscles operates the ambulacral grooves. Each pair of ambulacral ossicles is connected by an upper and a lower transverse muscle. The contracting and relaxing of the muscles regulates the size of the ambulacral grooves. The lower transverse muscle is found between the hyponeural canals and the radial water vessel. There are other short upper and lower longitudinal muscles between adjacent ambulacral ossicles along the whole length of each row. Their contraction tends to shorten the ambulacral grooves. The lateral transverse ambulacral muscles connect the outer end of each ambulacral ossicle with the adjacent adambulacral ossicle. Their contraction widens the ambulacral grooves.

Finally, there are longitudinal muscles between adjacent adambulacral ossicles that aid in lateral movement of the rays.

The Coelom

The body cavity is a true body cavity, or coelom, being enclosed on all sides by coelomic epithelium. The epithelium is of the simple cuboidal type and is ciliated. The coelom is filled with an albuminous fluid which is kept in a continuous state of circulation by the cilia of the coelomic epithelium.[3] This fluid receives soluble nutrients from the digestive system and distributes them to the tissues which it bathes.[4] It also receives the carbon dioxide and nitrogenous wastes from the tissues. The peritoneum that is applied to the organs is called visceral peritoneum, and that which lines the body wall is termed the parietal peritoneum. The body cavity is quite spacious and is often referred to as the perivisceral cavity since it surrounds the viscera. This coelom, however, is subdivided into a number of coelomic channels or sinuses. These are important because they enclose most of the haemal or circulatory system of this animal. One of these sinuses is the vertical axial sinus which encloses the stone canal of the water-vascular system. The axial sinus communicates dorsally with the aboral sinus which lies immediatley under the dorsal body wall of the central disc. Below the axial sinus joins with the inner division of the oral ring

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[3]L. Irving, "Ciliary Currents in Starfish," _Journal of Experimental Zoology_, XLI (1924), pp. 115-118.

[4]R.A. Buddington, "The Ciliary Transport System of _Asterias_," _Biological Bulletin_, LXXX (1942) p. 438.

sinus; the oral ring sinus being divided by a septum into an outer and inner division. The outer division of the oral ring gives rise to the hyponeural radial sinuses, each of which extends into a ray and subtends the radial nerve cord in its course through the arm. The coelom also has an excretory function, to be discussed later.

Digestive System

The mouth occupies the central portion of the perioral membrane and is controlled by a sphincter muscle. From the mouth there arises a short esophagus which opens above into a spacious cardiac stomach that occupies the greater part of the central disc. This stomach is held in place by two mesenteries originating from the peritoneum on the ambulacral ridges. The lateral wall of the cardiac stomach is evaginated into ten pouches, two of which project into each arm for a short distance. The stomach is eversible through the mouth during feeding and can be retracted by the previously mentioned sphincter muscle.[5] Dorsad of the cardiac stomach lies the pyloric stomach. This portion extends into each arm as a pair of glandular appendages called the pyloric ceca. These are suspended in each arm by mesenteries extending from the upper portion of the arm. Each pyloric cecum, brownish or greenish in color, is a hollow glandular structure with greatly evaginated walls. Each cecum is lined with ciliated columnar epi-

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[5]A. Reese, "The Old Starfish-Clam Question," Science, XCVI (1942), p. 514.

thelium, some of which are believed to secrete the digestive enzymes. A duct arises from each cecum and then unites with the ducts from the other cecae to form a main pyloric duct that opens into the pyloric stomach. Cilia in the pouches direct the flow of the enzymes with the currents created by their beating. The enzymes digest the food in the pyloric and cardiac stomachs and the digested food is then directed into the pyloric cecae for absorption. The pyloric cecae also secrete such enzymes as protease, amylase, and lipase.

A short narrow intestine arises from the pyloric stomach and extends to the anus on the dorsal surface of the central disc located above. The intestine diverticulates into a bi-lobed intestinal cecum lined with mucous and glandular cells.

The following tissues comprise the digestive system: a ciliated columnar epithelium, a layer of nervous tissue, a connective tissue, and a muscular layer. There are variations in thickness in the layers going from one organ to another.

In the feeding process, the starfish seizes the prey, usually bivalve molluscs, so that the free edges of the shell are brought into close association with the mouth of the starfish.[6] The pressure exerted by the tube feet of the starfish force the valves apart; at the same time a part of the cardiac stomach is everted through the mouth of the starfish by a constant pressure exerted on the coelomic fluid and cavity, and by the musculature of the arms and body. The stomach is then inserted into the opening between the valves of the

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[6]Ibid, p. 515.

mollusc. Potent protolytic enzymes from the pyloric ceca then pass through the cardiac stomach into the softer part of the bivalve's viscera. These enzymes bring about almost complete disolution of the viscera. The cilia of the cardiac and pyloric stomachs produce currents to convey the digested products upward to the digestive system of the starfish where further digestion occurs. The starfish then withdraws its stomach by the contraction of the retractor muscles and the mouth is closed by the contraction of the oral sphincter muscles.

Besides the bivalve molluscs, the starfish is predatory on other animals such as: sea urchins, snails, worms, fish, and small crustaceans. However, its favorite food seems to be bivalve molluscs such as clams and oysters.

Water-Vascular System

This system, embryologically derived from the coelom, begins with the madreporite (madreporic plate). It communicates below with the dilated upper end of the stone canal, the ampulla. The stone canal extends from the ampulla ventrad to join with the ring canal which circles around the inner surface of the peripheral area of the perioral membrane. The stone canal is ciliated and contains calcerous deposits which give it a rigid texture. From the inner aspect of the ring canal arise nine small vesicles called Tiedermann's bodies.[7]

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[7]Taylor and Weber, p. 608.

It is thought that the phagocytic coelomocytes occuring in the water-vascular system are formed in these vesicles. Five radial canals arise from the ring canal, one of which traverses the length of each arm dorsad of the ambulacral groove to end in the terminal tentacle. As each radial canal extends through the ray, it gives off podial canals which connect with the tube feet on the ventral side of the ambulacral pores. Each tube foot has a sac-like component, the ampulla, which lies within the arm on the dorsal surface of the ambulacral pore. This ampulla is lined with longitudinal muscle fibers. This organ plays an important part in the regulation of the water pressure in the tube feet.[8] Longitudinal muscles also occur in the tube feet themselves.

In locomotion, the tube feet push the animal forward. The ampullae contract, forcing fluid into the tube feet. The hydrostatic pressure resulting from this intake of fluid causes the extension of the feet in the direction of movement.[9] The terminal discs on the tube feet serve as suction cups as they come in contact with the substrate. The feet then push forward, resulting in the pushing of the animal forward. The longitudinal muscles in the tube feet then contract forcing the fluid into the ampullae. The ampullae then contract,causing the fluid to enter the tube feet, causing their extension, and then the cycle described is repeated. The backflow of fluid

[8] Paine, p. 362.

[9] G. Kerkut, "The Forces Exerted by the Tube Feet During Locomotion," Journal of Experimental Biology, XXX (1953), pp. 575-583.

into the lateral canals is prevented by small valves in these canals.

In the mechanism of locomotion there is involved a very complex system of coordination between the nervous system and the tube feet. Apparently most of the reflex coordination of locomotion is accomplished by the circumoral ring, to be discussed later.

The water-vascular system, so important in locomotion and feeding, must be kept filled with fluid. Water intake through the madreporite is a continuous process and is due principally to currents set up by the cilia in the canals. The fact that there is a steady fluid intake through the madreporite implies that there may be some leakage through the tube feet.

Structurally, the individual tube foot is a very weak organ, but the combined effect of the entire number provide the mechanism of locomotion and the opening of the shells. On soft surfaces, such as sand and mud, the suckers on the feet are of little use and they then act as legs.

Nervous System

The nervous system is described as being composed of three interrelated systems.[10] The main part is the oral or ectoneural system, situated just beneath the epidermis. This is composed of the nerve ring, the radial nerves, and the general subepidermal plexus. The circumoral nerve ring, pen-

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[10] Hyman, p. 270.

tagonal in shape, is situated in the peristomal membrane near its periphery. It supplies nerve fibers into the peristomal membrane and the esophagus, and gives off radial nerves that run the length of each arm in the bottom of the ambulacral groove. It then terminates in the eyespot of the terminal tentacle. The radial nerve consists of fibrillae arranged in layers. It is continuous with a general subepidermal plexus spread throughout the entire body wall and supplying all of the body wall appendages. The fibers of the radial nerve synapse with the cell bodies in the necks of the ampullae of the tube feet. As mentioned previously, these coordinate the many activities of the feet in locomotion and feeding.

There is an extensive subepidermal neural plexus which comprises fibers of sensory, association, and motor neurons. It connects with the central nervous system, especially by way of the radial nerves. The subepidermal plexus has been demonstrated to be capable of localized reflex activity. The plexus is thickened into a cord extending the length of each arm on each side, called the marginal nerve cord. This in turn gives off a longitudinal series of motor nerves called the lateral motor nerves. A pair of these extend to each ambulacral ossicle. These eventually reach the coelomic lining where they form a plexus. This plexus controls the muscular layer of the body wall and gonads. This system is referred to as the entoneural system.

The third portion of the nervous system is the hyponeural system which occurs as a nervous layer in the lateral part of the oral wall of the hyponeural sinus, beneath the coelomic epithelium lining the sinus. This nervous layer, known as Lang's nerve is separated from the lateral part of the radial nerve only by a thin layer of dermal connective. tissue. Lang's nerve gives off a series of nerves along the arm into the adjacent lower transverse muscle that extends between the ambulacral ossicles in the roof of the hyponeural sinus. The hyponeural nervous system is primarily motor.

The circumoral ring is of great importance in the neural coordination of the starfish. This is especially true in the actions of the tube feet during locomotion. Severance of the ring from the radial nerve cords results in the rays acting independently of each other.

The epidermis is permeated with neurosensory cells which serve as tactile and chemoreceptors. Tactile receptors are quite numerous in the terminal discs of the tube feet and on the terminal tentacles. These neurons are slender cells, more or less spindle shaped, which possess a nucleus, a distal thread-like process reaching to the cuticle, and a proximal fiber entering the subepidermal nerve plexus.

The most complex sense organ is the eyespot, occur at the base of the terminal tentacle. Each eyespot is composed of a number of cup-shaped concavities. The epidermis in these concavities is modified into alternating pigmented and retinal cells. The pigmented cells contain an orange pigment, while each retinal cell bears distally a knobbed visual rod that extends into the concavity.[11]

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[11]Ibid, p. 275

Reproduction

The starfish exhibits sexual, asexual, and regenerative types of reproduction. To perform the sexual processes of reproduction the starfish possesses a pair of gonads in each arm. They are located aborally in the proximal portions of the ray. They lie free in the perivisceral coelom except for attachment near the genital pores, a pore for each gonad being located close to the interradial line. The gonads begin their existence as outgrowths of the aboral sinus. Each gonad, resembling a grapelike cluster, extends from its point of attachment at the base of the ray where it lies lateral to a pyloric cecum. Close to the time of spawning the gonad generally extends through the whole length of the ray. The male gonads are usually pale gray in color, while the female gonads vary in color from pink to orange. The sexes are separate, although hermaphroditic specimens have been found. The sexes usually cannot be distinguished externally except in the case of brooding females.

Both male and female starfish discharge their gametes into the water. Fertilization of the ova follows. Each zygote then undergoes total and equal cleavage into a bipinnaria (bilaterally symmetrical larval organism). Metamorphosis into a mature adult usually requires 1-3 years. In many cases the starfish is able to reproduce after one year of growth. Starfish have been observed to live for as long as 20-25 years.

In certain cases starfish undergo asexual reproduction by a process known as autotomy. This process occurs by a splitting of the disc along a more or less preformed line that avoids ossicles and that leaves the arms intact. The individual parts then reproduce into an entire organism. A-sexual reproduction is affected by environmental and physiological factors.

The third type of reproduction, regeneration, is closely associated with autotomy in that a lost part is replaced. This part may be lost by shedding (autotomy) or by external forces. The most common body part lost and regenerated is the ray. The regeneration of the ray involves the formation of the terminal tentacle, the terminal ossicles, and the tissue of the eye-spot followed by the pyloric cecae, the radial canal of the water-vascular system and, the radial nerves. In some isolated cases an entire central disc has regenerated all of the missing parts.

Haemal (Circulatory) System

The entire circulatory system follows the course of the ambulacral system under which it is situated. It is composed of a system of sinuses and a system of lacunae, with the axial organ. Immediately below the ambulacral ring is the oral ring sinus divided by a septum into an external and an internal oral sinus. The external sinus gives rise to five radial sinuses. Each radial sinus is divided longitudinally by a septum inclosing the radial lacuna. The radial sinus runs under the radial canal of the ambulacral system to the end of the arm, the left and right channels uniting in the tentacle. The radial sinuses give off transverse sinuses to the ambulacral feet. The internal oral sinus gives rise to the axial sinus which runs along the hydrophoric canal. The aboral ring-sinus connects with the dorsal end of the axial sinus; the ring-sinus giving rise to five genital sinuses. The axial organ is a glandular part of the axial lacuna, in which the lacunae form a plexus. Functionally, the dorsal portion of the axial gland has been shown to be contractile. This is regarded as the force responsible for the movement of coelomocytes and fluid in the haemal system. The axial sinus, axial lacunae with the axial organ, and the hydrophoric canal are all together inclosed in a peritoneum and form an axial complex.

As already mentioned, the coelomic fluid receives soluble nutrients from the digestive system and distributes them to the tissues. It also functions to remove wastes from these tissues.

Excretory System

The absence of a true excretory system in the starfish is one of the biological mysteries of nature.[12] It is very strange that an animal, high up in the evolutionary tree, with a complex nervous system and many other complicated structures would possess only a reminant of an excretory mechanism. The function of excretion is accomplished by the amoebocytes in the coelomic fluid, aided by the rectal cecae. These amoeba-like bodies transport the matabolic wastes to the dermo-

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[12] Burnett, p. 11.

branchiae where they pass out into the surrounding water by diffusion. These phagocytic cells are derived by budding from the cells of the coelomic epithelium. The amoebocytes are of two main types; those with ordinary slender pseudopods and those with petaloid pseudopods. These cells are highly phagocytic and ingest the particles to be excreted.

Respiratory System

The respiratory function is the responsibility of the dermal branchiae, through which oxygen is absorbed. The intake of oxygen is also performed by the water currents moving into the starfish. These currents are kept in motion by the flagella of the coelomic epithelium. There is a general internal flow toward the tips of the rays with a return current along the inner surface of the ray sides. As it flows along this path, it presumbably picks up oxygen from the dermal branchiae for distribution to the various tissues and organs.

CHAPTER IV

ECOLOGY AND BEHAVIOR

Asterias forbesi is found on most of the eastern seashore, ranging from Maine to the Gulf of Mexico and may be found from lowtide level to a depth of about 50 meters. As is typical of the more specialized groups of Asteroidea, this species integrates with closely related species. Specimens are found either singly or in large aggregations on rocky or shelly bottoms. This starfish has been the source of extensive study because of its economic importance as a predaceous oyster-eating organism. Each year the oyster industry suffers tremendous losses due to this animal. In addition to feeding on oysters, the starfish includes in its diet such organisms as clams, mussels, sea snails, dead fish, worms, and in rare cases, other starfish.

It is understood that some sort of seasonal migration occurs among the starfish, but the character and extent of this migration is unknown.[1] The rate of locomotion in this organism has been observed to be very slow, an average rate of 6 inches per minute. However, according to the isolated geographic distribution of this species, facts seem to indi-

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[1]A.D. Mead, "The Natural History of the Starfish," *Bulletin of the U.S. Bureau of Fisheries*, XVIX (1899), p. 205.

cate that the wanderings of these animals are rather limited in extent.

Like all other forms of life, the starfish has natural enemies. Some of these destructive agents and natural enemies are cold and fresh water, various fishes, gulls and crows, and parasites. The enemy which is doubtless the most destructive to the starfish is the menhaden. This fish feeds exclusively upon the minute organisms which swim or float in the water. The larvae of the starfish are safe from this fish only after they have set. The setting involves a process of metamorphosis and attachment to some object on the bottom. The diet of the free swimming larvae consists of minute algae and other microscopic forms of plankton.

As mentioned above, the starfish is subject to attack by parasites. The parasitic organisms attack the gonads of the starfish, destroying the tissue and rendering it partially or fully sterile.

CHAPTER V

OUTLINE FOR LABORATORY DISSECTION AND STUDY

As a supplement to the classroom discussion of the starfish, the body structures of this animal provide ample source for laboratory exercises in which dissection and observation of body parts are performed by the students. The following section provides the teacher with an outline for the preparation of specimens and instructions for laboratory exercises using these specimens.

Preparing Material

Preparing dry specimens: A perfect dry specimen may be obtained by placing the starfish in a dish in a perfect radial symmetrical position and then pouring boiling water into the dish. This tends to relax the body and allows for dehydration to follow after removing from the bath. This process is excellent for studying the skeleton of the starfish.

Preparing injected specimens: This type of specimen is especially useful in the study of internal organs and the ambulacral system. The injection may be accomplished through one of the radial canals and should be continued until the ambulacral feet of all radi are injected. The specimen may then be preserved in formalin or alcohol.

Preparing fixed specimens: Very small specimens may be fixed for sections in Perenyi's fluid.[1] Decalcifying before embedding is necessary. Sodium hypochlorite is useful for this decalcification. The sections should be prepared and then stained in haemotoxylin and eosin.[2] This type of specimen is excellent for the study of the nervous system.

Preparing living specimens: It is desirable to have living specimens to demonstrate external structures and activities of the animal. Dissection may be carried out on a living form after anesthetizing it with about 15 ml. of 10% MgCl.

Laboratory Exercises Using Dry Specimens

Instructions: (a) Make a full size drawing of the dorsal surface of the starfish showing the central disc and all arms, madreporic plate, tubercles, and pedicellariae. Indicate the plane of symmetry and label the bivium and trivium. Draw the details only in one arm. (b) Remove with a forceps the ambulacral feet of one arm. Make a full size drawing of the ventral surface, shwoing mouth, oral spines, ambulacral grooves with rows of pores between the ambulacral ossicles, spines on the adambulacral ossicles, ectoneural nerve ring, and ectoneural radial nerve. Draw the details only in one arm. (c) Examine under low power the madreporic plate and make a drawing showing its structure. (d) Remove with a scapel some of the small pedicellariae, place them in a drop of water on a slide, ex-

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[1]Alexander Petrunkevitch, Morphology of Invertebrate Types, (New York, 1929), p. 174.

[2]Ibid.

amine under a microscope, and make a drawing showing both types of pedicellariae.

Laboratory Exercises Using Injected Specimens

Instructions: (a) Place the specimen in a dissecting pan with water; examine the oral surface and sketch a drawing of the ambulacral feet, eyespot, tentacle, mouth, oral spines, and ambulacral grooves. (b) Examine the dorsal surface and draw the madreproic plate, tubercles, pedicellariae, and the branchiae. (c) With strong scissors make a lateral incision around the whole animal taking care not to ruin the internal organs. Make a circular incision around the madreporic plate. Lift the dorsal wall, with forceps, at the end of each arm and press the digestive glands down, tearing the mesenteries with the scapel. Cut the intestine near the anus and remove the entire body wall. Make a drawing of its inner surface showing the network of ossicles and spaces between them. (d) Make an enlarged drawing of the digestive system showing the cardial pouches, pyloric portion of the stomach with the 5 pyloric cecae, and the intestine with its intestinal cecae. Label the parts indicated. (e) Using forceps, remove the entire digestive system, using care not to tear the peristomal membrane. Make a drawing of the reproductive organs. (f) Remove the reproductive organs (gonads). Make a full size drawing of the ambulacral system shwoing madreporite, hydrophoric canal, Tiedemann's bodies, the five pairs of ampullae, and the four rows of ampullae in one of the arms. Include in the drawing the peristomal membrane and the axial organ of the circulatory system.

Laboratory Exercises Using Fixed Sections

Instructions: (a) Using a microscope or hand lens, study the external characteristics. Make a drawing showing the central disc, arms, madreproic plate, tubercles, and the small pedicellariae. (b) Observe the cross section of a ray, indicating on a drawing the reproductive organs, radial nerve, the tube feet, coelomic cavity, and any other visible organs. (c) Observe the slides under low and high magnification. Label all parts indicated above.

CHAPTER VI

INSTRUCTIONAL DIAGRAMS

The teaching of the starfish anatomy and physiology can best be facilitated by the use of diagrams ro drawings showing the major divisions and structures of the organism. The writer has attempted to include in this section some illustrations which will be helpful to the teacher in presenting the material to the biology student.

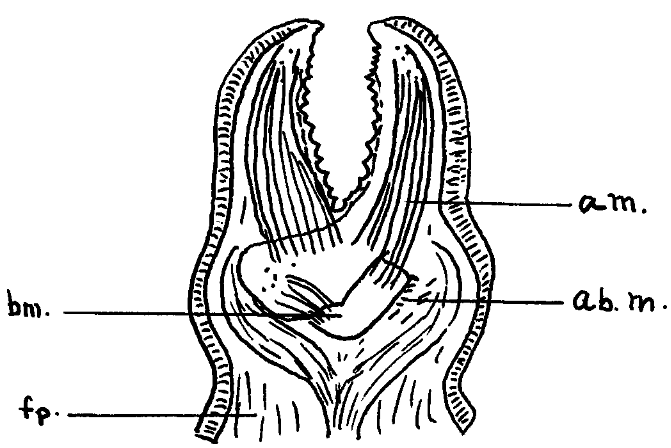

Fig. 6-1 Crossed pedicellaria of Asterias. am. adductor muscle; ab.m. abductor muscle; bm. basilar muscle; fp. fibrous peduncle.

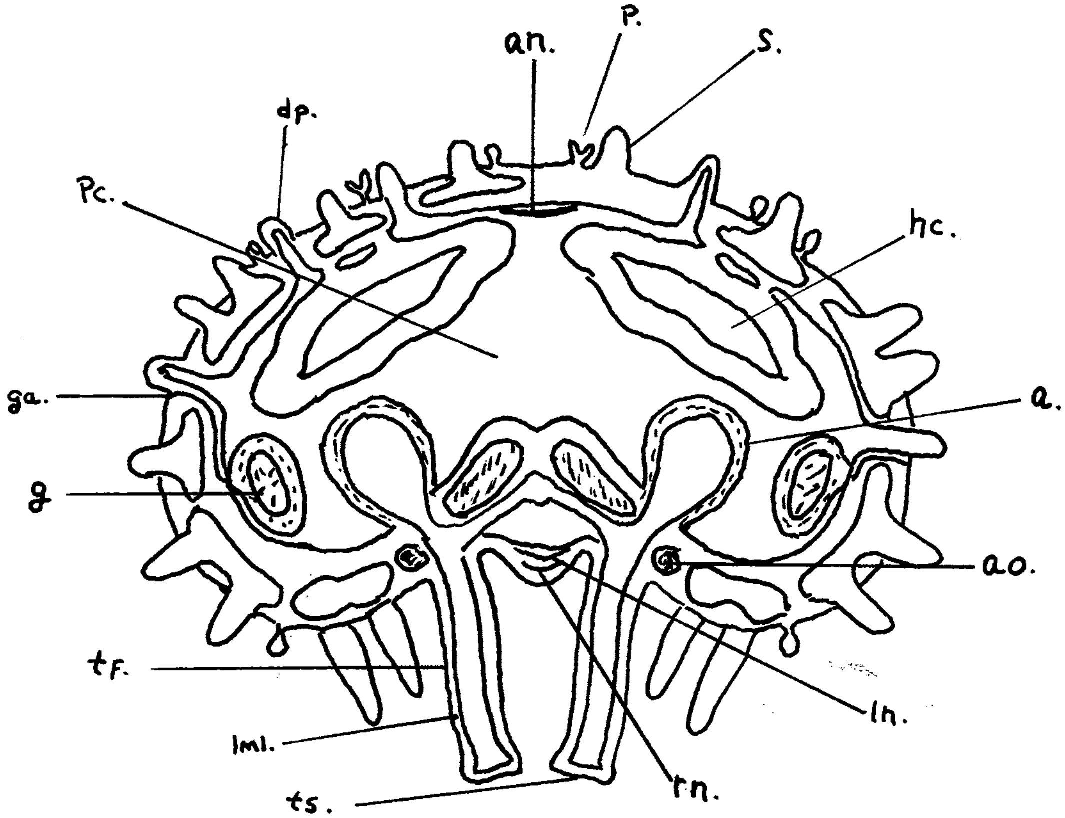

Fig. 6-2. Diagrammatic cross section of the ray of a starfish. a. ampulla; an. apical nerve; ao. ambulacral ossicle; dp. dermal papula; ga. genital aperture; g. gonad; hc. hepatic cecum; lml. longitudinal muscle layer; ln. Lang's nerve; p. pedicellaria; pc. perivisceral cavity; rn. radial nerve; s. spine; tf. tube foot; ts. terminal sucker.

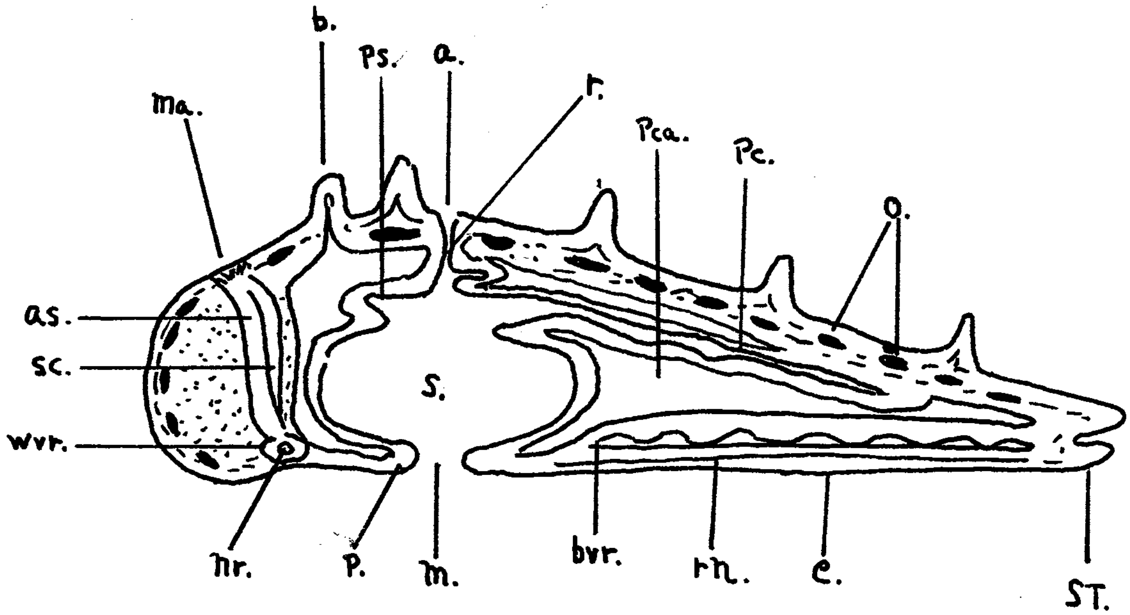

Fig. 6-3. Diagrammatic section through the disc and one arm of a starfish. a. anus; as. axial sinus; b. branchiae; bvr. blood-vascular ring; e. epidermis; m. mouth; ma. madreporite; nr. nerve ring; o. ossicle; p. peristome; pc. pyloric cecum; pca. perivisceral cavity; ps. pyloric sac; r. rectum; rn. radial nerve; s. stomach; sc. stone canal; st. sensory tentacle; wvr. water-vascular ring.

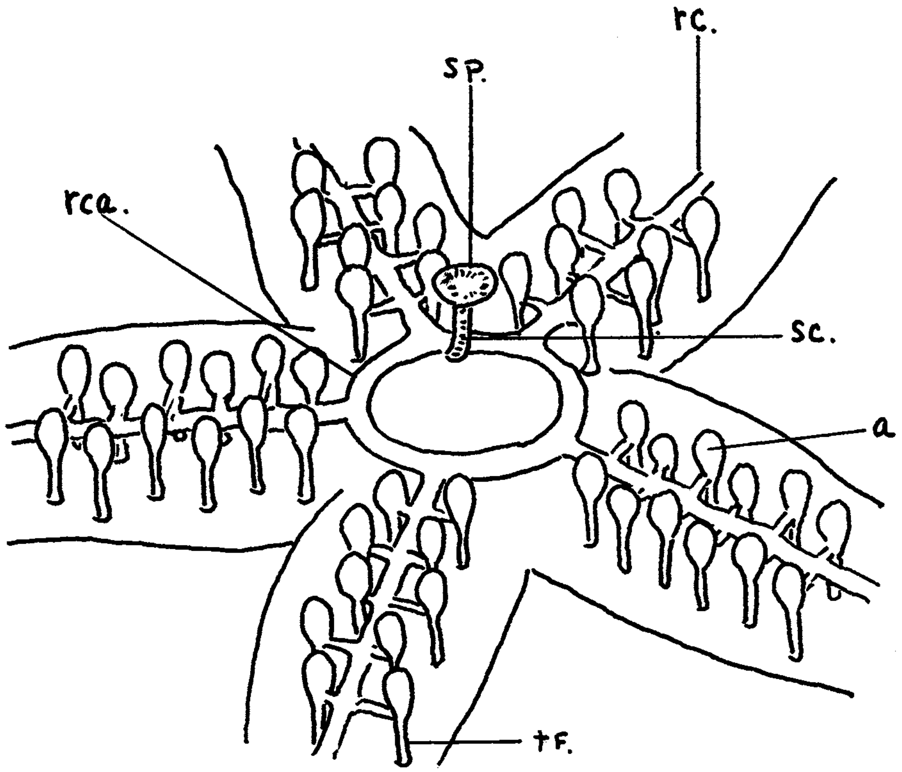

Fig. 6-4. Water-vascular system of the starfish. a. ampulla; rc. radial canal; rca. ring canal; sc. stone canal; sp. sieve plate (madreporite); tf. tube foot.

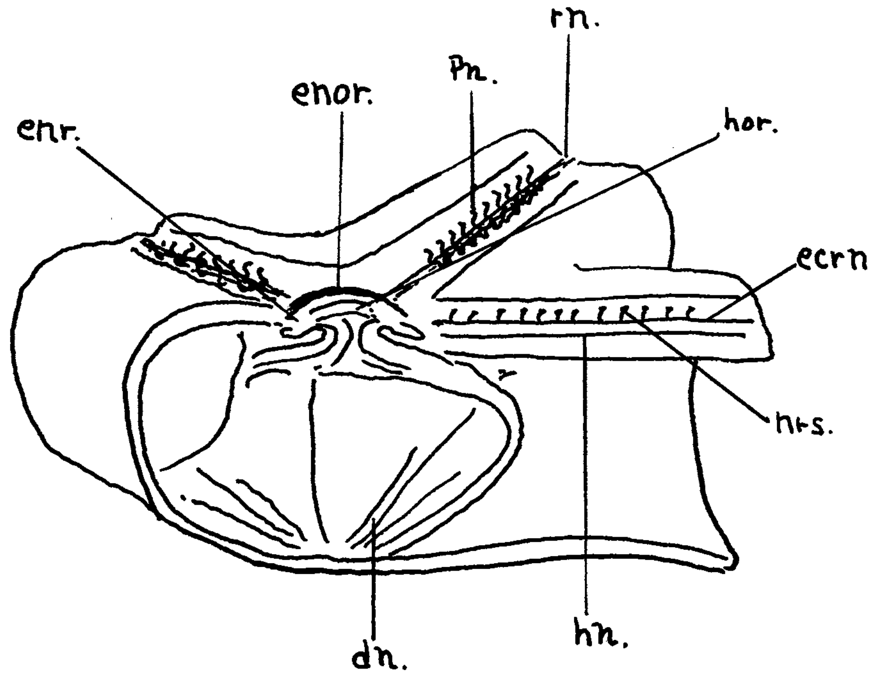

Fig. 6-5. Nervous system of the starfish. dn. deep dorsal nerves; ecrn. ectoneural radial nerve; enr. esophageal nerve ring; enor. ectoneural oral ring; hn. hyponeural nerve; hor. hyponeural oral ring; nrs. nerve ring of suckers; pn. pedal nerves; rn. radial nerve.

CHAPTER VII

GLOSSARY

Ambulacral feet: The tube feet which lie in the ambulacral grooves.

Ambulacral groove: A groove, extending radially from the vicinity of the peristome along the ventral surface of each ray, which contains the four rows of tube feet.

Ambulacral ossicles: Calcified plates located in the ambulacral region of the body wall.

Ambulacral pores: Pores or openings through which the tube feet project.

Ambulacral spines: Tiny projections of the body wall in the ambulacral region.

Ampullae: Bulb-like sacs extending into the coelom which connect directly with the tube feet. They function in regulating water pressure in the feet.

Autotomy: The process whereby the starfish sheds an injured ray.

Axial sinus: A cavity, involved in circulation, which runs along the hydrophoric canal.

Bilateral symmetry: The symmetrical arrangement whereby the body can be divided into two corresponding sides by a line drawn through the center of the disc.

Bipinnaria: The bilaterally symmetrical larval stage of the inmature starfish. This is the free-swimming stage.

Bivium: The two rays closest to the madreporite.

Branchiae: Short, tube-like projections of the coelom which protrude through the outer body covering. They serve for the purpose of respiration.

Circumoral ring: The nerve ring encircling the mouth. It is situated in the peristomal membrane near its periphery.

Coelom: The body cavity of the starfish.

Coelomocytes: Phagocytic cells found in the coelomic fluid which aid in excretion and transportation of food particles. They are somtimes called amebocytes.

Ectoneural system: Superficial portion of the nervous system which follows the plan of the ambulacral and circulatory system. It functions in sensory perception.

Entoneural system: The deep dorsal portion of the nervous system which consists of five nerves radiating from the central disc. This system belongs to the dorsal coelomic epithelium.

Hydrophoric canal: A short, stout, and somewhat curved canal extending from the madreporic plate ventrad where it connects with the ring canal. It is sometimes called the stone canal.

Hyponeural system: The motor system which is separated from the ectoneural only by a thin membrane of connective tissue.

Lang's nerve: The dorsal portion of each radial nerve cord containing motor nerve fibers.

Madreporic plate: A circular, grooved plate situated on the dorsal surface of the central disc. It functions in water intake.

Ossicles: Calcified plates found in the inner layer of the body which give the characteristic hardness of the skin.

Pedicellariae: Small, pincerlike mechanisms found projecting from the epidermis of the starfish. They are used to keep the surface clean.

Peristome: The soft membrane surrounding the mouth.

Perivisceral cavity: The body cavity which surrounds the viscera.

Pyloric ceca: Digestive glands situated in each arm which are sac-like portions of the pyloric stomach.

Radial canal: Water-vascular canals which extend into each arm from the ring canal.

Radial nerve cord: The nerve cord running along the ambulacral groove in each ray.

Radial symmetry: The body having parts arranged like rays, with each part having the same set of organs.

Ring canal: The water-vascular canal located in the central disc and surrounding the mouth. This gives rise to the five radial canals in the rays.

Subepidermal plexus: The plexus of sensory, association, and motor fibers which connect with the central nervous system by way of the radial nerves.

Tiedemann's bodies: Minute glands which produce amoebocytes. These glands open into the ring canal and consist of nine separate structures.

Trivium: The three rays furtherest from the madreporite.

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