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ECOLOGICAL ASPECTS OF A CALIFORNIA MARINE ESTUARY

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Introduction

This paper is an account of general ecological studies made at Elkhorn Slough, a tributary of Monterey Bay, California, on the west coast of North America. The work was carried on over a period of eight and one half years (June, 1926 to January, 1935), and was done to obtain a comprehensive view of animal life as a whole, particular attention being given to the relation of one species to another, and the adaptation of each species to its environment.

Most of this investigation was carried on directly in the field so that it might be useful as a foundation for solving specialized problems which are yet to be worked out. The aim has been to record observations which logically should precede, rather than supplement, laboratory work. Such observations, by providing the natural background for laboratory studies, should make the latter more interesting and significant. It is hoped that the study has been conducted in a manner that will make it of practical use for all who may be concerned in any way with the animal life of the Slough.

Possibly no locality offers a better opportunity for ecological study than does Elkhorn Slough. There is little fresh water disturbance; the exposed sand flats are fairly permanent; the salinity is that of the ocean, and the temperature but little higher; it is too narrow to be disturbed by storms; but few dwellings are located there, hence there is little pollution; and many of the animals are long-lived and practically sessile. These factors make it possible to carry studies through for almost any length of time and to make comparisons which would be impossible under ocean beach conditions.

The bottom of the Slough as a whole may be considered a specialized portion of the ocean floor conveniently located for study. This fact is more forcibly emphasized year by year as a result of continued investigation by dredging in the outside ocean. During the middle of December, 1931, two species of clams, *Schizothaerus nuttallii* and *Saxidomus nuttallii,* were washed in on the west beach of the grounds of the Hopkins Marine Station by a very heavy surf. Prior to this I had considered both of these clams strictly estuary animals. This surf also brought in many other deeper water animals which were living below the lowest range of low tide.

When one stands on the edges of the bank of the Slough at low tide and looks out across the mud flats, life in the Slough seems quite meager, for about the only living things apparent are the birds. Even after walking about, without rather close observation, life appears scarce, and everything except the water is a uniform grayish color. Yet in a circular area 45 inches in diameter and 18 inches deep, 974 macroscopic animals were counted, and several hundred more were doubtless overlooked. These animals belonged to 34 known species.

The work done in the preparation of this paper was carried on from the Hopkins Marine Station of Stanford University and the Kerckhoff Marine Laboratory of the California Institute of Technology. I wish to express my gratitude to Dr. W. K. Fisher, Director of the Hopkins Marine Station,

where the major portion of the work was done, for his wholehearted interest, encouragement and aid; and to Dr. T. H. Morgan, Head of the Department of Biology of the California Institute of Technology, for opportunity and encouragement to continue this type of investigation. I am also greatly indebted to my wife, Nettie MacGinitie, for her unstinting interest and help both in the laboratory and field. My thanks are also due the following people for aid as indicated:

To Dr. C. V. Taylor of Stanford University for identifying the genera of Protozoa; to Dr. M. W. de Laubenfels of the Pasadena Junior College for identifying the sponges and checking the identification of the birds; to Dr. John Guberlet of the University of Washington for naming two new ectoparasitic trematodes; to Dr. H. W. Stunkard of New York University for naming an endoparasitic trematode; to Dr. Chas. O'Donoghue of the University of Edinburgh for identifying some of the bryozoa and opisthobranchs; to Dr. Wesley R. Coe of Yale University for identifying the nemerteans; to Dr. W. K. Fisher for identifying the sipunculids; to Dr. Elizabeth Deichmann of Harvard University for help with the holothurians; to Mrs. Edith Berkeley of the Pacific Biological Station at Nanaimo, B. C., for identifying annelids; to Mrs. Ida S. Oldroyd of Stanford University for identifying clams and snails; to Dr. Robert Miller of the University of Washington for identifying the shipworms; to Dr. C. B. Wilson of the State Normal School, Westfield, Mass., for identifying and naming the copepods; to Mr. Clarence Shoemaker of the United States National Museum for identifying the amphipods; to Dr. Waldo Schmitt and Dr. Mary J. Rathbun of the National Museum and to Dr. F. W. Weymouth of Stanford University for checking the identifications of the decapods; to Dr. Carl Hubbs of the University of Michigan for supplying the names of the fishes; to Dr. Rolf Bolin of the Hopkins Marine Station for the synonomies of the fishes; and to Mr. E. F. Ricketts of the Pacific Biological Laboratories at Pacific Grove for help with all groups.

Materials Used

Field Materials:
- Shovel
- Screens
- Collecting box, jars and vials
- Buckets
- Net
- Plankton net
- Vegetable strainers
- Thermometer
- Salinometer
- Ruler
- Camera

Laboratory Materials:
- Aquaria
- Limoria
- Sorting pans
- Battery jars
- Glass tubing
- Killing pans
- Containers for preserved animals
- Menthol
- Magnesium sulphate
- Formalin
- Chloretone
- Fresh water
- Alcohol
- Glacial acetic acid
- Killing fluid (either Bouin's or Ladvowsky's).

The materials used in this study were not elaborate, although they might have been elaborate without limit. My aim was to obtain as far as possible a first hand knowledge of what these animals are doing in their natural habitat, hence, for example, I was concerned with what temperatures these animals actually experience, rather than what extremes of temperature they may be able to stand under laboratory conditions. To do this elaborate materials were not considered necessary. Too, the fact that supplies had to be transported to and from the Slough in a car precluded the use of bulky or elaborate apparatus.

A shovel is the best general excavator. It should be of the proper shape, it should not be too large, and it should be light in weight, with a shank and handle (not a D handle) just long enough to enable one to use his hand over the end of it when desired. An ordinary long-handled shovel may be used if about an inch is cut off from each side of the blade, and the shank straightened and the handle shortened to suit. Such an instrument is often referred to by clam diggers as a "clam gun." The importance of a satisfactory shovel for mud flat work can not be overemphasized. This is evident when it is remembered that with this shovel one may have to excavate an entire Upogebia burrow, which may necessitate the removal of heavy sticky mud to a depth of 2.5 or 3 feet over an area averaging at least 20 square feet, and that this must be done between tides. The narrow blade can be more easily freed of this sticky heavy mud. Again the shovel may be used to dig a gaper or Geoduck clam in fairly loose sand where the sides will cave and where speed is an important factor. Here, too, the narrow shovel is much more efficient. It is doubtful if I ever made a trip to Elkhorn Slough without moving at least a cubic yard of mud, and usually considerably more.

Screens: For most purposes a box with a bottom of iron window screen served very well. This type of screen was made of common window screen with box sides, and was 18 by 24 inches. At times, however, a nest of screens was used, the screen ranging in coarseness from 20 openings per square inch to 100 per square inch. A screening device somewhat on the order of a gold rocker was also used when large amounts of material were to be handled. This screen, though bulky, screened sand and mud more efficiently and rapidly than the others. It was double decked, with an upper large meshed screen of about four openings to the square inch, and a lower finer screen with about 20 openings to the square inch.

A collecting box with a handle was made to hold eight quart jars. One space was used for lids, and at one end there was space for ten 25 by 95 mm. vials. Even in addition to buckets, seven jars were none too many in which to keep the collection properly segregated and labeled. Pint jars could be used when desired. A salinometer and thermometer were carried in hollow bamboo tubes fastened to the sides of this box.

The net was of strong material and was about the size of a trout landing net so that it could always be carried along. It was not often needed, but was indispensable when needed. The vegetable strainer was used when a finer mesh was needed.

The aquaria were regular laboratory aquaria, size 14 by 14 by 28 inches, inside measurement. As many as four "limoria" could be placed within one of these. The word "limorium" was coined to designate a frame filled with mud. A limorium is a narrow frame with two glass sides, and of a length and depth to fit loosely in an aquarium. The bottom and ends were made of 1.5 by 2 inch sugar pine with two rabbits which would allow double strength glass to slide into them. The top bar is a brace, the ends of which extend to rest on the ends of the aquarium. The rabbits are from three fourths of an inch to one and one fourth inches apart, and the top is of the same width so that a pane of glass can be shoved down into the rabbited grooves. The side glasses are of a height to come below the water level in the aquarium. When these limoria are two thirds filled with mud, and animals are placed in them, the burrowing habits of the latter can be easily observed.

Sorting pans should be kept very clean. They should be shallow and of ample dimensions, preferably at least 12 by 18 inches, and from 2 to 3 inches deep. The killing pans used were of a different size so that they could not become mixed with the sorting pans.

Glass tubing of several sizes was indispensable for making artificial burrows for various animals, and for preserving annelids.

Killing procedures are different for all animals. Fresh water works well in some cases. It may be added in quantity with some species, certain echinoderms for example, but must be added slowly drop by drop with others. Menthol, chloretone, and magnesium sulphate were found to work well, especially for annelids and coelenterates. Plenty of time is the most important factor in obtaining well preserved specimens.

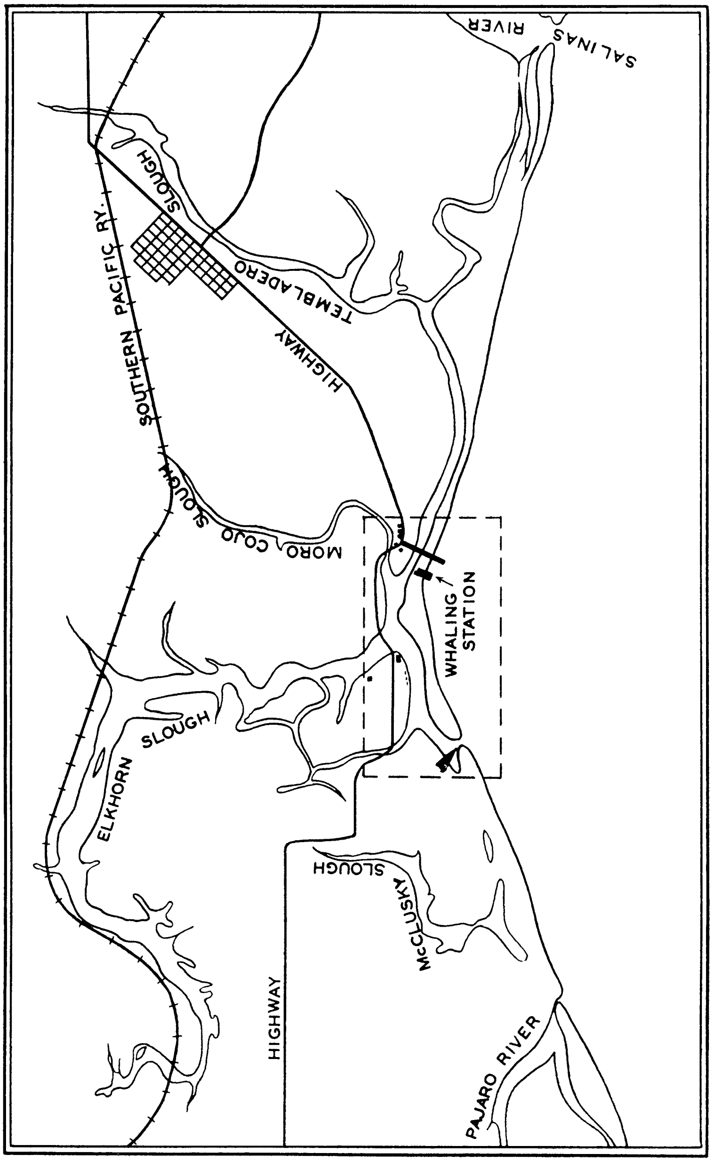
The preservation of specimens was necessary for two reasons: (1) a collection of animals from the area studied was wanted for future reference, and (2) as far as possible, specimens were sent to authorities on particular groups for identification or to be checked. When it is remembered that perhaps nine tenths of the animal groups in existence today are found in the ocean, the inability of any field investigator to classify all specimens or name new species will be readily understood.

Location and Physical Features

Elkhorn Slough (Map 1, Fig. 1) is on the east side of Monterey Bay, midway between Pacific Grove and Santa Cruz. It is twenty-three miles north, by road, from the Hopkins Marine Station at Pacific Grove. It is at the head of a submerged river gorge, which was, perhaps, before subsidence, the Salinas River. A Coast and Geodetic Survey map of 1878 shows the Slough as a part of the Salinas River, and that at that time it was the outlet of the river. It continued to serve as the outlet of this river until 1908.

In times past the Pajaro River to the north may also have used the Slough as an outlet. Soundings show that at one time, before subsidence of the land, the Pajaro and Salinas Rivers united at a point which is now three or four miles out in the Bay, and the two then flowed down the submerged gorge mentioned above. There is also a theory that the Sacramento and San Joaquin Rivers may have emptied into the ocean by way of this gorge (Snyder, 1913).

In summer the Salinas River always becomes blocked off from the sea. The sea wall builds up at the mouth to a height which prevents the washing in of any ocean water or the flowing out of any fresh water from the river. The seepage through this sea wall to the ocean takes care of what little water comes down the river during the summer and fall. When the first storms of winter occur the river continues to fill up back of this sea wall until the



Map 1. Map of Elkhorn Slough, which also shows the mouths of the Salinas and Pajaro Rivers. Scale, ⅔ of an inch = 1 mile. North is to the left.

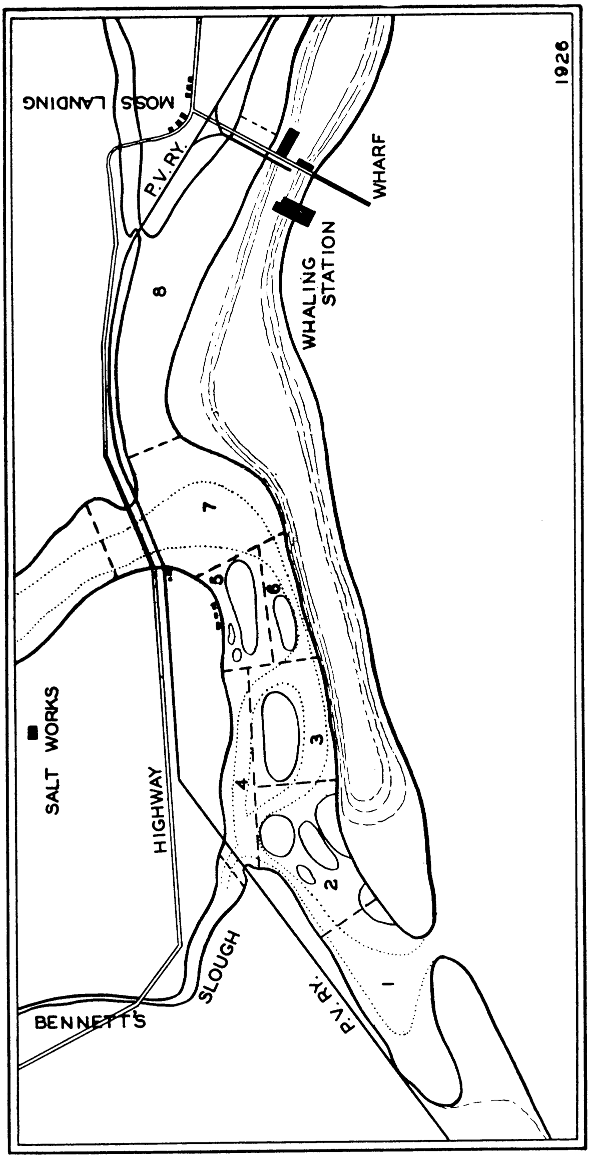
inside pressure either moves the sand out in a body of considerable size, or the water breaks through in a small channel near the top of the sea wall and the large body of water held in the reservoir back of it soon scours out a deep straight channel into the ocean. When the sand of the sea wall moves out

Fig. 1. Portion of Elkhorn Slough, showing practically the entire region studied. Looking down the Slough from the east bank at Station 8.

en masse it is dangerous to be near the mouth of the river. In the early winter of 1929 three boys fishing in a skiff near the sea wall were carried out with this rush of sand and water and were drowned. Just before the river breaks through into the ocean the water may run over the bank to the north and thence into Elkhorn Slough, the quantity depending upon the height of the sea wall built up at the mouth of the river.

At the present time the connection between the Salinas River and the Slough is disestablished, and during the last nine years water from the Salinas has entered Elkhorn Slough in small quantities only during the winters of 1929, 1930, 1931 and 1934, before the river broke through directly to the sea. To all intents and purposes, therefore, Elkhorn Slough at the present time may be considered strictly a salt water estuary.

At their mouths, unless confined by bluffs on either side, rivers have a tendency to creep along the beach. When the current does not run straight out, the washing away at the bend carries the sand out on the beach and it is moved up and back of the direction of movement of the mouth, forming the sea wall as the river mouth moves up or down the beach. When the distance increases too greatly a balance begins to be established due to the weaker eroding effect of a slow current, and then the sand begins to pile up directly at the mouth. This decreases the run-out, and, as a consequence,



Map 2. Map of region studied in this investigation. Map made in June, 1926. Numbers 1 to 8 represent Stations. North is to the left.

the carrying power of the current. Sand, therefore, piles up faster than it is swept out by the water, resulting, finally, in a blocking of the mouth of the river. A freshet or an unusually high surf is generally necessary to supply a sufficient quantity of water to open a new channel. Such a channel usually breaks almost directly across the bar. When the feet-per-second discharge of a river is great enough, the new outbreak will occur before the river is entirely blocked. Complete blocking occurs during the summer or fall, the seasons of low water.

The same conditions prevail to some extent at the Slough, except that the volume in and out during tides prevents the complete closing of its outlet, and the movement of the outlet north or south is not so great. The height of low tides within and the amount of run-out is greatly affected by the condition at the mouth (Fig. 2), however, and this will be taken up in more detail under "Tides." The map (Map 2) shows on the north a bight of water whose extension depends upon the movement of the outlet north or south.

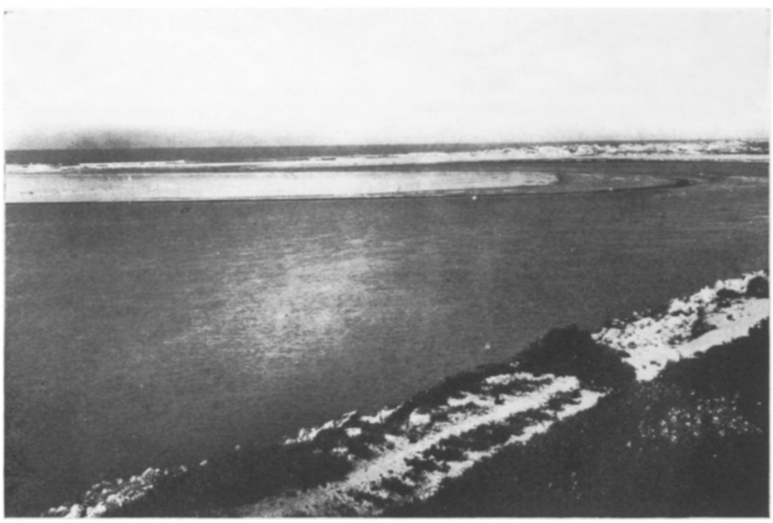


Fig. 2. Station 1. The mouth of Elkhorn Slough is shown in the upper left background beyond the sand spit.

The Slough has several branches, but none add greatly to its storage powers. The main body extends east and north for about eight miles, and for most of its length it is form one hundred to three hundred yards wide. The fall is not appreciable throughout its entire length.

This paper deals only with that part of the Slough lying between the highway and the ocean, to the west, from Moss Landing to its northernmost limits (Maps 2 and 3). Above the highway bridge there are no mud flats and the banks and bottom are of a soft muddy character which tends to prevent the establishment of animal life to any great extent. Here the only areas possible to investigate without expensive dredging operations are the rather steep banks. Along these banks may be found some of the animals which occur nearer the entrance where the conditions are more favorable, but they are never abundant here. Such animals, for instance, as *Callianassa, Upogebia, Macoma nasuta, Cryptomya californica,* and others may occur here, but not in very great numbers.

Tides

On the Pacific Coast of North America there are two tides each day, which means, of course, two high tides and two low tides (Marmer, 1926). These tides are seldom equal and are referred to as the high high tide, the low high tide, the high low tide, and the low low tide. The datum point or mean low water as used by the Coast and Geodetic Survey, and as shown in tide tables for this coast, is the mean of the low low tides. The range varies for different localities. For Monterey Bay the mean range is 3.5 feet, the spring range is 5.3 feet, and the greatest range or difference for spring tides of June and December for any one day is about 8.2 feet. The high high tide always precedes the low low tide.

For collecting on the open beach the extreme low low tides of the spring, or dark and full moon periods, are the best. This is complicated at Elkhorn Slough, however, by another factor which may make these tides poor for collecting at the latter place, or, stated otherwise, a poor tide for collecting on the open beach may be a good tide for collecting at Elkhorn Slough. The mouth of the Slough is about 2.5 feet above mean low water or 0.0 feet as shown in the tables. Not only is the entrance higher than 0.0 feet, but the height of 2.5 feet is variable, ranging between 2 feet and 3 feet. This variation is governed by four factors: (1) the position of the mouth (as noted in the preceding topic); (2) the surf; (3) the height of tides, i.e., whether spring or neap, and whether mid-summer or mid-winter; and (4) the wind.

If the mouth of the Slough is fairly straight, if the preceding tides have been high spring tides to scour it deeper, and if the surf is fairly smooth, then one may expect good collecting tides within the estuary. Wind is an important factor only in summer and fall, when the prevailing northerly winds are so continuous and of such velocity as to pile the sand across the mouth during slack water.

Such optimum conditions as indicated in the previous paragraph are usually found in spring, as at this time the mouth has been deepened by the extreme spring tides of winter; the surf is lighter, for the winter storms are over; the wind has not yet begun to blow from the north; and the mouth has been made fairly direct by the high tides and heavy surf of winter.

The heavy surf may drive in the water with the inflowing spring tides of winter and cause the height of tide within the estuary greatly to exceed that to be expected. This larger amount of water has a much greater scouring effect on the entrance. However, at times of good collecting the surf should be light.

When four factors in combination are causing an effect it is, of course, obvious that only generalizations can be made, and good collecting tides, therefore, may be found to exist at any time of the year. During the greater part of one summer (1927) the tides were such that no low tides which could be called good collecting tides occurred within Elkhorn Slough, but in other years, although the tides of the spring months were best, collecting was good the year round.

For better understanding let us contrast two different days. On January 14, 1934, the high high tide on the open beach rose to 6.7 feet at 9 a.m., and the surf was high. The Slough was filled to capacity and overflowing. The following low tide was -1.7 feet on the open beach at 4 p.m., but, since the Slough is many miles long and ramified, there was not sufficient time for all the water to run out and it was still higher than usual for an estuary low tide at 7 p.m. when the returning low high tide began to run in. It should also be noted here that, as would be expected, the tides in the Slough lag behind those on the open ocean. No collecting tide occurred on this day.

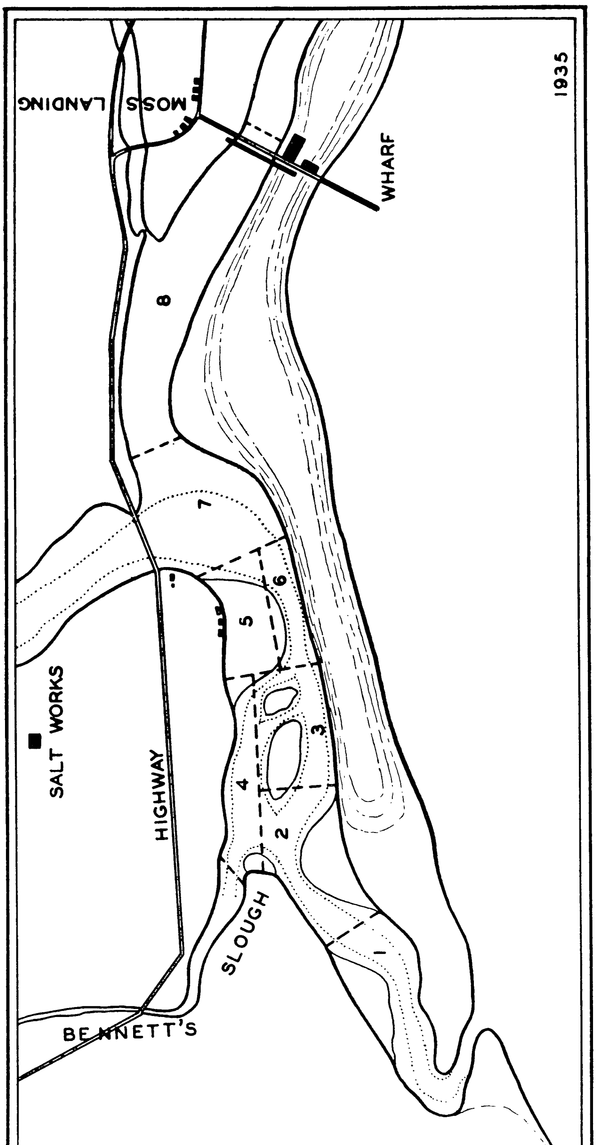
On March 22 the high high tide of 4.8 feet was at 3 a.m., the surf was smooth, the mouth entrance was low, say 2.2 feet, and the low low tide of 0.5 foot was at 11 a.m. The neap tide of 4.8 feet did not fill the Slough, hence the water soon ran out, and by 9 a.m. collecting became good. More important still, the following low high water was only 3.9 feet at 6:30 p.m., and therefore did not begin to run into the Slough until 4 p.m. Consequently the mud flats were exposed from nine until four o'clock, or for seven hours.

Because of the conditions as outlined above the mud flats may at times be exposed for nearly 18 hours, a condition of great importance to the animals of such a region. The water in the burrows of certain animals may thus remain unchanged, except for seepage, for many hours.

Bottom Soil

The soil of the Slough bottom varies from ocean beach sand to very stiff clay. The area investigated in the preparation of this paper might be divided into three parts: the west side (ocean side), the middle ground, and the east side. By omitting Station 8 (Map 2) one can make the generalization that the west side is sandy, the east side clayey, and the middle ground sandy clay or clayey sand. This holds true throughout the entire distance for the east and west sides, but the middle ground varies from a very sandy condition near the mouth to a heavy sandy clay at Station 7. The east and west banks are practically free from vegetation, but the middle ground supports more and more plant life as one proceeds inland. The entire Station 8 is a heavy clayey mud.

The following is a detailed description of the condition of the bottom at each station (Maps 2 and 3). Though the general grade of bottom soil for each station remains the same throughout many years, the portions exposed at low tide vary a great deal, particularly at Stations 1, 2, 3, 5 and 6. An account of the changes occurring since 1926 to date is given under each station. As Station 1 includes the entrance to the Slough the west portion of it changes continually. Due to the sandy condition of the bottom soil at



Map 3. Map of region studied in this investigation. Map made in January, 1935. Numbers 1 to 8 represent Stations. North is to the left.

Station 2 and its proximity to the entrance, changes occur more rapidly there than at the stations farther inland, but not so rapidly as at the west side of Station 1.

The stations as laid out most conveniently divided the Slough into workable areas. It is worthy of note that, with the exceptions of Stations 7 and 8, all the stations have changed, since this work was begun, to such an extent that, had the investigation not been started until the present time, different boundaries would have been made.

Station 1.—Quite sandy at the outlet, often affected by inflow from the outside. Rocky along the east side, bordered by rather hard blue clay and riprap of railroad. Usually a dead water area to the north of the outlet. Continual change buries much organic matter. Never the same from month to month.

Station 2.—Area just below the railroad bridge at Bennett's Slough. Quite sandy, water saturated. Digging almost impossible in places because of a tendency toward a quicksand condition. Less disturbed than Station 1. Patch or two of Zostera at the upper limit. (Fig. 3.)

Fig. 3. Station 2 in upper right quarter of picture. A portion of Station 4 is shown in the upper left corner. Other stations in the background.

During the summer of 1927 the main area which was exposed at low tide was traversed by a layer of loose sand about 100 feet wide and 2 feet deep which moved out across it from southwest to northeast. On July 30 it was possible to wade directly across the Slough at this point. This area changes more or less from year to year. At the present time, with the exception of one island, it has returned to a condition almost identical with what it was in 1925.

Station 3.—Mostly a large island at low tide. Soil permanent enough to give distinct iodoform odors. Partly saturated with water. Upper limit more solid. During the last three years a channel has cut off one third of the island on the south. This channel is about 40 feet wide. (Fig. 4).

Station 4.—The mouth of Bennett's Slough and immediate territory, including a small island and a strip south along the east bank. Railroad bridge piling surrounded by rocks. Recently the island has united with the east bank north of the bridge, and a new colony of *Urechis caupo* has become established here.

Fig. 4. Station 3. Portion of Station 4 in immediate foreground.

Station 5.—Two muddy islands at low tide, surrounded by channels filled with *Zostera*. Soil permanent and little affected by currents of water. Continually worked by clam diggers. During the past four years the channels have disappeared between these islands and this station is a mud flat continuous with Station 6. (Fig. 5).

Station 6.—An island practically continuous with Station 5, but of a more sandy nature and barely exposed at low tide. Almost free from *Zostera*. Deep channel along the west side. Life less abundant than at Station 5. At present this island is well exposed at low tide and is becoming much more productive of life, particularly of *Schizothaerus, Phoronopsis* and *Urechis*.

Station 7.—Bottom muddy. *Zostera* plentiful. No exposed portions except banks. Highway and railroad bridges. Riprap at the approaches. Unchanged. (Fig. 6).

Station 8.—Quite muddy. *Zostera* not so plentiful as at Station 7. Water warmer, due to less movement of the water than at other stations. Highway and railway bridges across to the beach. Unchanged.

Plant Life

The plant life at Elkhorn Slough is quite abundant, and the uniform conditions at certain regions allow beds of *Zostera* to become established and continue from year to year. Most of the algae are annuals, and they cover

Fig. 5. Station 5 in foreground (lower two thirds of picture); Station 6 in background.

large areas where *Zostera* does not grow and where the bottom is not exposed at low tide.

The abundance of algae varies somewhat from year to year. In 1926 the crop was poor, but in 1927 the tide flats were not bared and *Enteromorpha* became very abundant (see "Condition at the Slough on July 7, 1927," p. 669). Diatoms seem to be more plentiful in the spring than during the summer They cover nearly everything to which they can attach.

Plant life becomes more abundant in direct proportion to the distance from the mouth of the Slough. The upper reaches of the Slough have a much greater quantity of plant life than do the lower, because the former are not disturbed and have no tide flats exposed. Along the north side above the highway bridge *Zostera* extends in an area several feet in width. *Polysiphonia* forms a soft fur three or four inches thick in patches several acres in extent, and *Enteromorpha* is evident in beds at frequent intervals.

The importance of the plants of the Slough in the food chain is discussed under "Food Supply," page 647.

In addition to being a source of food supply plants are an important part of the associations at the Slough because they form breeding grounds and a place of attachment for the eggs of many animals. Some of the animals show a decided preference for certain plants. The bubble shell, *Haminoea,* and the eolid, *Hermissenda,* use *Enteromorpha;* while the snail, *Nassa,* and the tectibranchs, *Tethys* and *Phyllaplysia,* attach their eggs to *Zostera. Enteromorpha* supplies a fine refuge for mating crabs and ovigerous females.

Fig. 6. Station 7 in foreground; Station 8 in center distance. The portion of Station 7 including the highway bridge is just out of the picture to the left.

A fairly complete list of the plants is given below:

Zostera marina grows in patches from Station 2 up as far as Station 7, where it becomes very plentiful.

Enteromorpha is the most abundant of any of the algae. It is exceedingly abundant at Stations 2, 3, 5, and 6.

Vaucheria was collected from pilings under the wharf on the northeast side of the highway bridge at Station 7.

Ulothrix was found on boat bottoms and stakes at Station 7.

Pyramomonas was found associated with *Ulothrix.*

Lyngbya grows on boats, stakes, oyster shells, barnacles and *Zostera.*

Oscillatoria is associated with *Lyngbya.*

Griffithsia may be found quite plentifully along the straight bank on the ocean side of Bennett's Slough. In July tetrasporic plants were found in fruit.

Polysiphonia grows in bunches quite plentifully at all stations. It is often attached to the siphon plates of the gaper clam, *Schizothaerus nuttallii.*

Porphyra is quite common on *Zostera* at Stations 3, 4, 5, 6 and 7.

A few fronds of *Bryopsis* were found growing attached to the plates of a chiton, and to the vertical portion of the bank at Stations 2 and 4.

Temperature

The temperature remains fairly constant at the Slough. The daily change of tide prevents water standing long enough for it to warm more than one or two degrees above that of the outside water. Occasionally pools of water may be left when the tide is out, and these places when exposed to the sun may warm to a temperature which would be lethal to the animals living there were it continued for a long period of time. The highest temperature recorded in such a place was 23°C. Unless there is an abundance of *Enteromorpha* in such places, no ill results to the animals living therein have ever been noted. In any case it affects only the surface animals, for on the same day and in the same place where the temperature of the water was 23°C., at a depth of 6 inches in the underlying mud the temperature was 15°C. The highest temperature ever recorded in the mud at a depth of 3 inches, whether covered with water or not, was 19°C., and at a depth of 6 inches it was 17.5°C. Even when the surface of the mud flats is exposed to the direct rays of the sun, evaporation prevents any appreciable rise in temperature unless exposed for many hours. Often the exposed mud, unless exposed until completely dry, may be cooler than mud under a few inches of still water, no doubt due to the evaporation. In the deeper channels where the water is moving the temperature is much nearer that of the open ocean.

Since cold water, unless extremely cold, has little effect on marine animals other than to slow down their metabolic rate, little attention was paid to this side of the problem. The lowest temperature was 11°C. In winter the temperature in the mud does not go lower than 12 or 13°C.

From the above it will be seen that the surface animals over a period of nearly ten years may have experienced a range of temperature from 11 to 23°C., those in the mud from 12 to 19°C. From this it will be evident that burrowing animals have advantages other than refuge.

Oxygen

There are two main ways in which the oxygen supply of the Slough is kept rather high. The incoming tide brings water which has been well aerated by the action of the surf, and the Slough, which for the most part is shallow, allows a great surface to be in contact with the air per volume of water. The action of the waves in that portion of the Slough extending east from the highway bridge is sufficient on most days to cause white caps in considerable numbers.

The plant life of the Slough no doubt has an augmenting effect on the oxygen content of the water, especially during the summer months. When the water is warmed by the sun it loses oxygen, but this is replaced by the oxygen that the plants give off during photosynthesis. It is true that the plants give off carbon dioxide during the night; but, because of the colder temperature, the oxygen which is dissolved in the water during the day, and which is in excess of the equivalent of carbon dioxide given off at night, is not lost rapidly at night. Therefore, the plants tend to stabilize the oxygen content of the water by balancing to some extent the effects of daily change of temperature.

Slough animals have one problem to solve in regard to oxygen which animals on the ocean floor outside do not have, and that is how to obtain oxygen when the tide is out. Redfield and Florkin (1931) measured the oxygen content of the water in the burrows of *Urechis* when the tide was out; they found that it decreases to a certain level and then remains fairly constant. This is no doubt due to the seepage water contained by the flats when the tide is out. It may be interesting also to note at this point that practically all the animals which burrow in the mud and which are exposed by tide cease all activity and conserve their energy, expending but very little when the tide is out. If such animals as the clams, *Urechis, Upogebia* and *Callianassa* are placed in a jar of water and then the oxygen is removed from the latter by bubbling nitrogen through it, or if they are placed in water which has been boiled and then cooled, they will become entirely quiet and scarcely can be prodded with a glass rod sufficiently to make them show any activity.

Except at times of low tide, oxygen supply is never a problem so far as slough animals are concerned.

Salinity

The water of Elkhorn Slough has practically the same salinity as that of the ocean. The Slough drains but little country, hence the fresh water content, even during the rainy season, is slight. During the rainy season the high tides and high surf cause a much greater movement of water, and even though small amounts of fresh water may drain in, its effect is offset by this increase in movement of the water. In periods of slight water movement the salinity of the upper reaches of the Slough may be somewhat higher, because the Slough is relatively wide for its depth and there is considerable evaporation.

During December, 1930, a series of 22 water samples which were run by Miss Lucina Stanford of the Hydrobiological Survey at the Hopkins Marine Station, gave salinity readings of 33.35 to 33.86. These samples were taken so as to include all regions which might show variation, but the readings approximated closely those of the open ocean.

The following is a report by Miss Maurine Leslie, Assistant to Dr. Bigelow, on samples taken by me in July, 1928, at Station 7 in Elkhorn Slough, and at the Salinas River bridge, five miles distant:

In the table below the numbers represent milligrams per liter of silica, phosphate and nitrogen in the form of SiO_2, P_2O_5, and NO_3.

	SiO_2	P_2O_5	NO_3
Elkhorn Slough	2.80	0.343	0.007
Salinas River	12.82	0.338	0.007

The regional variation of these constituents in the surface water of the bay (Monterey) was so great during the short time we investigated it (Bigelow and Leslie, 1930) that it appears probable that the seasonal variation is as great if not greater. So an average of the 20 values we found would hardly be a fair standard for comparison. But I can give you this much of an idea of the relative magnitudes: The water from Elkhorn Slough had about four times as much phosphate and silica as did the richest water we found in the bay. On the other hand, nitrate value of 0.007 is very low indeed. Some stations in the bay were quite nitrate free, i.e., even less than 0.007 mg./l., but most of them showed considerable quantities of nitrate.

Light

Since the Slough is shallow everywhere except in the deep channels, the light is quite intense. However, most of the animals are mud-dwellers and live in the dark. Even the majority of the surface animals seek protection from the sunlight by hiding under whatever they can find which is suitable. In addition to the mud, the rocks at Stations 1 and 4 afford some darker corners, and there are depths in some of the channels from twelve to fifteen feet deep which afford darker places for the larger crabs, fish, and other animals. How dark the burrows of mud-dwellers are will be exemplified by a forthcoming paper on the natural history of the blind goby, *Typhlogobius californiensis*, which lives in the burrows of *Callianassa affinis*. This fish is blind and pink, having lost both eyes and pigment.

Pollution

Pollution as yet has not become a menace to life in the Slough because the population is so sparse that there is but little sewage. When the Salinas River breaks through into the Slough there is considerable danger of pollution from the sugar factories along the former, and, in addition, the fresh water which afford darker places for the larger crabs, fish, and other animals. How ever, during the nine years that this investigation has been carried on the inflow of fresh water from the Salinas River has never been serious.

Food Supply

From an environmental standpoint three things are necessary for the persistence of the higher animals as species. These three factors are a safe breeding place, a refuge from enemies, and an ample food supply. In the study of invertebrate sea life one of these factors, namely, a safe breeding place, is not important, because for the most part invertebrate animals lay eggs in great numbers, many by the millions yearly (MacGinitie, 1934b).

Most of the animals of the Slough, because of their burrowing habits, have an excellent refuge in the mud. How important this refuge is will be shown later where the life cycles of certain species of animals are discussed with reference to their age. But, because it is so evident that the majority of the animals of the Slough have an adequate refuge, this factor need not be considered at length in a discussion of their ecology. On the other hand, because so many of the animals are more or less permanently located in the mud, their food supply does require considerable study. When one takes up the matter of food supply it is well to keep in mind certain fundamentals which make the study of food more comprehensive. In its last analysis all life is some form of energy which has been derived from the rays of the sun as they strike the earth. Sun rays are not life, but life depends upon the capturing of this radiant energy and upon its storage in the cells of an organism.

Since plants are the only organisms that use this solar energy directly, animals are, therefore, directly or indirectly dependent upon plants; in other words, the animal kingdom is parasitic upon the plant kingdom.

Hence, in order to begin the study of the food used by the animals of the Slough we must begin with its original source, plants, and trace it through step by step until the food of all the animals represented is accounted for. In this chain plants come first, then the animals which transform plant tissue to animal tissue, and lastly those which feed on other animals.

In the plant link the important items are *Zostera, Enteromorpha, Polysiphonia,* and pieces of algae which float in with the tide. All others are relatively insignificant, unless it is diatoms. Plankton tows show floating diatoms to be relatively scarce, for two reasons. They do not occur in such great numbers at the surface of the ocean, which is the source of the tidal water in the Slough, and, too, as they pass through the surf at the entrance they are destroyed. But fixed forms grow quite abundantly on objects like *Zostera,* mussels, etc. However, examination of the stomachs of a great many clams and mud-dwelling shrimps showed diatom shells to be quite scarce in the ingested material.

So the source of food for the animals at Elkhorn Slough must be the above plants. As we turn to the animals which form the next link we are at first at a loss to determine which ones use this plant material and transform it into animal tissue, for very few of these animals feed directly on the growing plants. Those which do, e.g., *Pugettia* and *Tethys,* are decidedly not abundant enough to have any appreciable effect on the food chain. Also, as we look over the animals we find that the greater bulk are not equipped for feeding directly upon growing plants nor upon other animals. If we were to weigh all the animals of the Slough we would find that perhaps 95 per cent by weight of the animals do not feed directly on the growing plants nor upon other animals, but feed upon microscopic material.

The matter of weight ratio is rather important, for, in a food chain, the energy at one end must equal the energy at the other. That is, the stored-up sunlight energy in the form of plant tissue and animal tissue is released in only one way; namely, by the breaking down of these tissues through oxidation or by decomposition. This breaking down may take place within the animal or plant during metabolism or after death during decomposition, and the energy released equals the energy stored. We can never have any link in the chain on the plant side of less weight than one toward the animal end. That is, plant weight at the beginning of the chain is greater than any weight following because energy, and therefore food, which is weight, is being dissipated all along the chain.

So, then, if 95 per cent by weight of the animals at the Slough do not feed upon other animals, their food must be plants—but in what form? As we examine the food-taking equipment of clams we find that these animals comb their food from the stream of water passing through them. An examination of a great many intestinal samples from clams shows that very few diatom shells are present, hence their food is not plankton. Next to clams in numbers of individuals comes the orange colored mud shrimp, *Callianassa californiensis*. An examination of several hundred stomachs reveals the fact that the food of these shrimps is like that of the clams, although the shrimps do not comb their food from the water but ingest it with sifted mud. *Upogebia* strains its food directly from the water. Among the other animals which have similar habits of obtaining food are *Lumbrinereis, Phoronopsis, Urechis,* and *Dendrostoma*. Very few diatom shells will be found in stomach samples taken from any of the animals.

The problem then becomes: What are the steps between the growing plant and the condition in which this is used by clams, mud shrimps, and others?

When we examine the stomach contents of the clams or the mud shrimps we find that, though diatoms are lacking, the material is especially rich in bacteria and particles of decaying plants or, as it is commonly called, detritus. Since the stomachs of the animals never contain anything except this material it must mean that their food is the organic material from the detritus. This detritus is formed from the decaying parts of plants. When used by these animals the detritus is in the form of a very fine gray coating over all parts of the Slough bottom and also over the growing plants so as almost to obscure their color. (See *Macoma nasuta,* p. 726). The following quotation from Irving A. Field (1921-22) substantiates this opinion:

> Another great source of marine food supply has been suggested by Petersen (1890), who expressed the idea that the abundance of fish on the Danish coasts was due chiefly to *Zostera*, which is better known to fishermen as eelgrass. Petersen and Jensen (1911) tried to show that, in all probability, the plants of the eelgrass belt and not the plankton organisms should be regarded as the main sources of the organic matter of the sea bottom in Danish waters. Their reason is based on the fact that the quantity of carbon in a series of bottom samples is directly proportional to the amount of Zostera vegetation and not to the quantity of plankton present.

Our chain then becomes plants, plants to detritus, detritus to clams, mud shrimps, annelids, and others less numerous; and, as stated above, these form 95 per cent of the weight of the animal life at the Slough.

In most food chains it takes but a few years to complete the cycle, and, too, in most food chains each link is about one tenth the weight of the link preceding it. For example, 10,000 pounds of algae make 1,000 pounds of tiny crustacea, 1,000 pounds of tiny crustacea make 100 pounds of small fish, 100 pounds of small fish make 10 pounds of large fish, and 10 pounds of large fish make one pound of man. This proportion is different at the Slough. We might state that 10,000 pounds of plants make 1,000 pounds of detritus, 1,000 pounds of detritus make 100 pounds of clams or mud shrimps; but 100 pounds of clams give little to any link following it except sting rays and man. So one has 10,000 pounds of plants supporting 100 pounds of clams by weight.

In examining the detritus feeders from the viewpoint of time we find positive evidence that clams live to be quite old. Judging by the evidence that could be obtained from the shells, fifteen years would be a conservative estimate of the age of the gaper, *Schizothaerus nuttalli,* one of the most abundant clams at the Slough. There is evidence that the orange mud shrimp, *Callianassa,* lives a long time. This animal is very abundant, yet small specimens three-fourths of an inch or less are rarely seen. No doubt its period of highest mortality is just after hatching. The larger specimens have a rather uninterrupted existence. They are out of sight in the mud, their burrows are inter-connected, and they are seen only rarely by clam diggers. Except in the larval stage these mud shrimps do not come out on the surface, no animal living in the mud preys upon them, and dead ones are very rarely seen; so, on the whole, the evidence is that they live to a ripe old age. *Urechis,* another detritus feeder, shows indications of longevity.

Longevity, then, of the detritus feeders accounts for their predominance by weight over the other animals. Their longevity probably may be due to their efficient refuge, made possible by their burrowing habit, and burrowing in turn is made possible by the physical nature of their habitat; namely, a slowly changing mud bottom. Energy is being dissipated by these creatures for a long period. Each year, as detritus forms, much of its energy and weight is expended by the detritus feeders.

While on the whole marine animals use much less energy than land animals, nevertheless, they use more than one might at first expect. *Callianassa* is a very active and abundant animal, always busy extending its burrows, aerating its eggs, cleaning itself, etc., hence the manifestation of its expenditure of energy is evident. Clams, though inactive, expend their share of energy in glandular activity and the beating of cilia. A gaper, *Schizothaerus nuttallii,* 3.5 by 5 inches, has approximately 75 square inches of ciliated surface which moves water. *Urechis* is more sluggish, but it is compelled, except at low tide, to keep water moving continually through the burrow by body peristalsis for respiration and feeding.

The remaining part of our chain is the accounting for the 5 per cent that are strictly carniverous feeders. Although these are only 5 per cent in weight they are represented by about half the number of species, including the nemerteans, the nereids, *Olivella, Nassa,* some of the crustacea, and nearly all the fish. To this should be added the birds, which feed on the animals of the Slough. The nemerteans feed on the nereids; the nereids feed on *Lumbrinereis* and *Notomastus* and on each other, the larger feeding on the smaller. *Olivella* and *Nassa* plow through the mud in search of decaying flesh. The shore crabs, *Hemigrapsus* and *Pachygrapsus,* feed on anything they can pick up. The smaller ones feed on algae to quite an extent; while the older ones are scavengers. The Cancer crabs have a similar diet. The fish feed on almost any of the living things they can catch and swallow. The sting ray, *Myliobatis californicus,* which has crushing plates for teeth, digs in the mud for clams. The goby, *Clevelandia ios,* feeds upon small crustacea and larvae; the cabezon, *Leptocottus armatus,* and the terns feed upon smelt, and to some extent on *Clevelandia ios.* The loons, herons, hakes, and striped bass feed on the cabezons, smelt and perch. The scoters feed on *Hemigrapsus.*

This practically completes the food chain, which in sequence is: Plants→ detritus and bacteria→detritus feeders→animal feeders→birds. Thus it can be seen that the food chain of the Slough is quite different from that of the pelagic animals of the open ocean. Its study presents a quite different problem because of the use of detritus rather than straight plankton.

There are many little side chains that are interesting. The accompanying diagram (Fig. 7) shows graphically the main features of the food chain, and one side chain in which tiny crustacea feed directly upon plants.

Bacteria play a very important part all along the length of this chain. Not only do they break down vegetation in a way which makes it suitable for food for detritus feeders, but they themselves are used directly as food. I performed an experiment in feeding young *Urechis* on a sterile bacterium culture (MacGinitie, 1932a). These young *Urechis* made more rapid growth when fed this culture in quantity than they do under natural conditions. It has long been my contention, as indicated by the evidence shown in the preceding paragraph, that bacteria have not been given their just dues for the important part they play as food for higher organisms. Some day it is hoped that an enterprising young bacteriologist will arise who will not be afraid of getting his hands dirtied with mud, and who will actually investigate the activity of the bacteria at Elkhorn Slough or similar places. The importance of bacteria may be underestimated even in oceanographic investigations (Kofoid, 1903). But of a certainty they are far more important as a direct source of food in an estuary like Elkhorn Slough or on other mud bottoms than they have been given credit for in the past.

Decomposition is a very complex process, but finally the resulting products are much as shown. Carbon dioxide for plant growth no doubt comes principally from the air, yet carbon dioxide is a product of decomposition. Another important item is the carbon dioxide which is made into carbonates by the molluscs for shell structure, for this removes it, for many years at least, from the carbon dioxide cycle.

Detritus is not uniformly distributed throughout the Slough, but is more abundant where there is little movement of the water, and especially among *Zostera,* not only because the latter gives rise to detritus, but also because it tends to catch and hold it. And it is in and near the *Zostera* regions that we find the greatest abundance and variety of life.

When the mud flats are bare for a considerable period the drying no doubt helps to kill plant tissue and start its decomposition into detritus. The continual activity of the animals and the movement of the water tend to keep the detritus in motion, so that it is available to all the animals over the bottom of the Slough.

Most plant growth occurs in the summer, but decomposition of plant

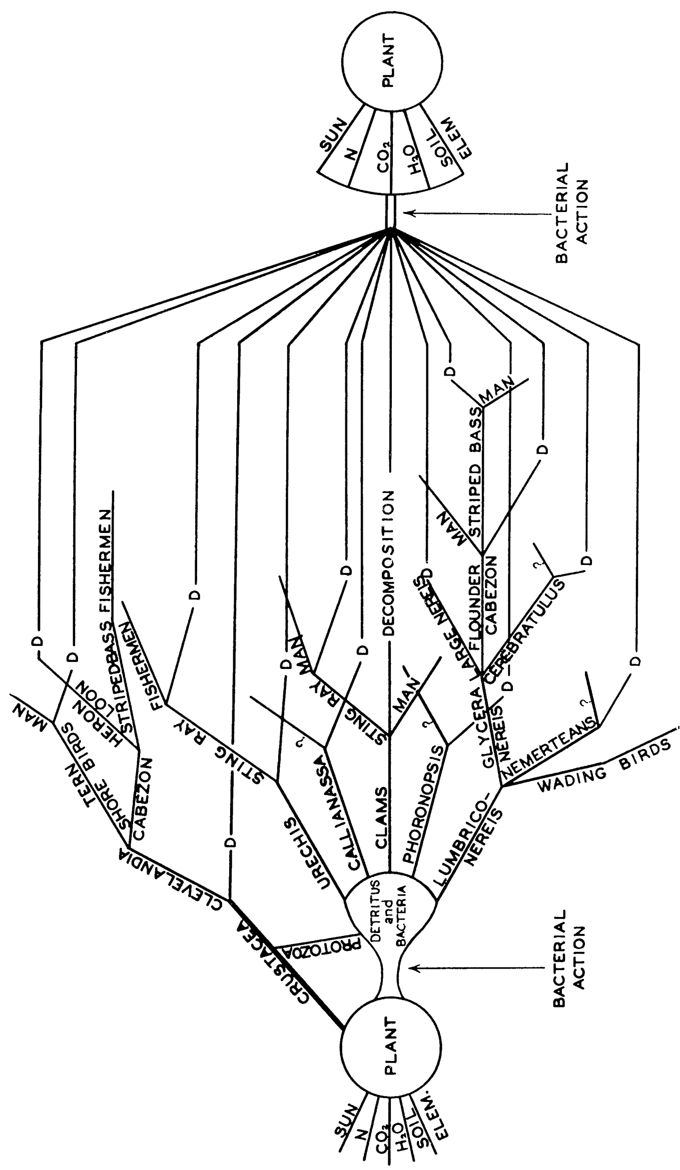


Fig. 7. Diagram of food chain. (*Lumbriconereis* should read *Lumbrinereis* and *Notomastus*).

tissue is a relatively slow process, so no doubt the supply of detritus is fairly constant throughout the year.

Man's part in the life chain is interesting only because of its negative influence. Clams are dug by sackfuls. I have seen five sacksful of *Saxidomus,* the finest clam of the Slough and of the Pacific Coast, taken by four Italians, and nine sacksful taken by Japanese. Japanese comb out everything which is not protected by law, and the law protects only crabs and one clam—and that not an important one. In digging for clams all other life is destroyed wholesale. When man is included in the food chain, the prospects of life continuing in its present abundance is not bright.

Association, Zoning and Numbers

It seems to be the general procedure in ecological investigations to list the species of organisms under associations and zones. So strong has been this custom that I am quite sure it has been very decidedly overworked. In the first place I believe that it has carried over from plant ecology, which was the original ecology; and while it may work very well for a fixed floral region, this custom should be used in animal studies with a great deal of circumspection. I think that in investigations carried on over a long period of time one becomes less and less sure just how much value such compilation of the marine animals according to associations and zoning may have. Hence, in this paper little attempt at association or zonal lists has been made. However, the following discussion is of such importance that the omission of such lists should in no way detract from the value of the paper.

As is brought out in "Geological Indications," the animals at the Slough tend to segregate in groups, and, in so far as they do this, they may be placed in associations with some one animal being predominant. From this habit of animals I think comes the idea of dominance, which is quite all right if all such groupings were permanent, and if all other phenomena are taken into consideration. For example, in a *Callianassa* bed there is no doubt that *Callianassa* is the dominant animal, and its activities regulate to quite an extent the activities of those animals associated with it. Because of its particular type of activity it not only regulates the activities of the animals about it, but, to some extent at least, provides a set of conditions which determine what animals may live within the boundaries of its association. The more abundant *Callianassa* is, within certain limits, the truer are the foregoing statements. Because the soil of the bed is being moved so rapidly no fixed animal like *Phoronopsis* or the gaper clam occurs here, although a clam like *Cryptomya californica,* or worms which make no permanent burrow, like *Glycera,* are much more abundant here than elsewhere. The continual movement of the soil by *Callianassa* uncovers other organisms which are of value as food to the predaceous worms.

Here, then, in a *Callianassa* bed is an association which is regulated by the dominant animal *Callianassa,* but this is confined to a particular portion of the Slough, say an acre or two in extent. Five years later this same area may contain no *Callianassa,* but show indications of becoming a bed of *Urechis, Phoronopsis* or clams, although the conditions again may be optimum for *Callianassa.* And the same region which may once have been a thriving *Callianassa* community is now nothing of the kind. Too, in another slough, such as Newport Bay, the dominance of *Callianassa* may be partly taken over by *Upogebia. Callianassa* also occurs where it is not dominant, i. e., where it is scattered.

Height of tide is an important factor in the segregation of these animals, and in their location as to particular areas, but it is by no means the whole story. A great deal of misinformation has been submitted under the guise of distributing animals according to some unit factor. In view of the fact that the environment of the animals is the sum total of all the external forces which affect them (MacGinitie, 1932b), such accounts on the face of them are ridiculous. *Upogebia* has a tendency to live higher with relation to tide than does *Callianassa,* but *Upogebia* may live higher at one place than it does at another. A simple analysis would simply place *Upogebia* in certain limits with regard to tide, and the deduction no doubt would be made that it was limited at least in the higher tidal regions by the length of time in which it could feed, that is, the length of time in the long run that the entrance of its burrow would be covered with water. Again this is not the whole story. An analysis of the available food for *Upogebia* will show that in certain places algae, which, of course, include diatoms (but at this height of tide mostly single celled green algae), grow and reproduce so rapidly at the edge or just about the edge of high tide that the lapping of the water on the incoming tide may stir up a food supply which makes it unnecessary for *Upogebia* to feed so long as it otherwise would need to. Therefore, the conditions which are most optimum for the algal growth has as much to do with the distribution of *Upogebia* according to tide as does the height of tide itself. The range of the sand dollar in the ocean beach is restricted to a particular locality for exactly the same reason.

Then, again, let us consider *Callianassa.* Its activities are such that the animal of necessity lives more on the open mud flat than on the banks, particularly where the banks are steeper. I think there is no doubt that *Callianassa* could live much deeper than it does, but the stronger currents of the channels would upset its activities as they would make it impossible for the shrimp to keep open the entrances of its burrows. However, *Callianassa* does occur much deeper in dead or slow water than would be expected from the casual investigation of a flat in the open, where it is limited to a certain depth by the movement of the current. In view of these facts, then, it is evident that zoning does not mean nearly so much as it is usually given credit for, and that associations are subject to change. However, associations are met with, and these associations are quite comparable wherever they occur, whether it be at Elkhorn Slough, Humboldt Bay or Newport Bay; and, in general, animals of the mud flats do conform to a certain amount of zoning with reference to tide.

Had I not studied thoroughly the life histories of the so-called dominant animals within the confines of the Slough, no doubt this paper would contain lists of animals according to associations and zones, which lists I would perhaps not be inclined to consider even arbitrary. What shore ecology has so far been done has been done from this point of view, therefore most of it will have to be done over to arrive at actual truths. However, because of the facts as stated above I consider the intimate study of particular animals of a region of greater importance than any other one thing that can be done.

Zoning is of great importance in the distribution of terrestrial animals, but in the Slough, where the rise and fall is only about two feet, an attempt to make tidal zones would be of little use. However, in a bay with a deeper entrance such zoning might be more significant. Even on the open beach there are not more than three well-defined zones. The discussion of the animals, together with what is known of their natural history, in the later portions of this paper indicates their association with other animals in so far as it has been deemed important and well established.

It seems to me that there is no present day tendency in biological science so illogical as the continued attempts to place animals in a chemical periodic table so to speak. The greatest fundamental *truth* in biology is variation. It is upon this variation that evolution, i.e., the deployment of animals in time and space, depends. Every species of animal is different from every other, and this applies to its instinctive inheritance as well as to its morphological and physiological inheritance, and the first is fully as important as the latter two. (See Cook, 1930).

Numbers of animals in particular localities seems to me to be of much more importance, as, with the exception of intensive life history work on particular members of associations, their quantitative relationship gives one a much better idea of their success as a species. But numbers alone would mean very little in this respect if one were not well acquainted with the activities of the different species. For example, in a square meter of animals removed from a mussel bed on a rock on the open beach of the Hopkins Marine Station grounds I found that the mussel, *Mytilus californianus,* was in proportion to the isopod, *Cirolana harfordi,* as one is to four and seven tenths. It would be correct to say that perhaps not a single *Cirolana* would have occurred in this square meter if it had not been for the protection of the overlying mussels. Here, then, it is not the *Cirolana* which is particularly successful, but the mussel, and the abundance of *Cirolana* depends upon the mussel. If one is to obtain reliable data on the exact numerical occurrence of animals within an association, an enormous amount of work is involved, particularly in mud flats. It would necessitate the sifting of mud or sand to a depth of 2 feet over large areas, which could not be done between tides.

Spot sampling is not only unreliable, but has the added disadvantage of often supplying information which is entirely at variance with the actual facts. The following example is submitted as evidence of this fact. Packard, in his work on the molluscan fauna of San Francisco Bay (1918), says of the orange-peel dredge:

This apparatus has an advantage over the various types of trawl dredges in that it permits the taking of large masses of mud from a single spot, besides rendering possible the capture of deeply burrowing organisms. . . Thus the average per haul for each species should give some clew to the most favorable environment of that species. *Cardium corbis*, *Macoma nasuta*, *Mya arenaria*, and *Zirfaea gabbi* are, according to such reasoning, predominately mud dwellers. On the other hand, *Mya californica*, *Macoma balthica*, *Macoma inquinata*, *Ostrea lurida*, and *Thais lamellosa* predominate on the sandy bottoms. Here again the conclusion drawn from the quantitative work does not agree with that based upon the qualitative hauls. It has already been stated (p. 239) that *Cardium corbis*, *Macoma nasuta*, *Mya californica*, and *Ostrea lurida* do not show a distribution pattern that appears to be related to any particular type of bottom. In this case it is not unlikely that the latter conclusion is the more nearly correct.

The actual conditions are as follows: *Cardium corbis* prefers sand or sandy mud; *Macoma nasuta* the same, possibly preferring a more muddy soil. *Mya arenaria* is successful wherever it can burrow, providing there is some dilution by fresh water, and *Zirfaea gabbi* burrows only in hard clay or soft rock. *Cryptomya (Mya) californica,* as shown later in this paper, lives in regions where it can extend its siphons into the burrows of other animals, and a knowledge of the habits of the animals whose burrows it uses shows that they prefer a sandy mud or muddy sand bottom. I am not familiar with the habits of *Macoma balthica,* but *Macoma inquinata* has been found in quantity along with *Cryptomya californica,* tending possibly toward a more sandy habitat. *Ostrea* lurida is found anywhere that it may attach and keep its valve openings above the sand or mud. It particularly likes to attach to any pieces of iron, such as bolts, cables, wire, pipe, etc. It has absolutely no preference as to what the bottom beneath it may be. *Thais lamellosa* does not live on either sand or mud bottom, and the fact that Packard (1918) found *Ostrea lurida* on sandy bottoms accounts for his finding that *Thais lamellosa* occurs more abundantly on sand also, for no doubt the *Thais* were on the shells of *Ostrea* and whatever hard objects to which this oyster was attached. If sampling with an orange-peel bucket dredge is more efficient than most sampling that is done, as the above quotation would lead one to believe, then, certainly up to this date, no dependence can be put upon any quantitative sampling reports that have been done. If Packard had relied entirely upon this sampling for distributional data (as is often done), his conclusions would have been about 90 per cent in error.

In conclusion it may be said that if one desires to know how abundant animals are, where they occur, and what they are doing, there is only one way to find out, and that is to go out and live with them, not for a week or a month, or even a year, but for years. Even then, one only begins to know.

Abundance of Organisms

In August, 1926, in a bed of *Zostera* at Station 5, a 45-inch circle was excavated to a depth of 30 inches, making a volume of 27.6 cubic feet of soil (11 square feet of surface). Practically all the organisms are found in the first 18 inches, or, in this case, in 16.56 cubic feet of the total 27.6 cubic feet of soil. The top inch of soil was sifted through a rather coarse screen (12 openings to the inch). The following animals were found:

Echinoderms
2 *Amphiodia occidentalis*

Annelids
2 *Halosydna insignis*
4 *Nephthys assimilis*
30 { *Nereis procera*, *Nereis dumerilii*, var. *agassizi*, *Nereis monterea* }
14 { *Glycera rugosa*, *Hemipodia borealis* }
2 *Onuphis elegans*
1 *Lumbrinereis japonica*, var. *index*
2 *Lumbrinereis impatiens*
? *Notomastus tenuis*
48 *Pectinaria auricoma*
1 *Loimia montagui*
286 Small annelids (unclassified)

Crustacea
5 *Crago nigricauda*
14 *Callianassa californiensis*
1 *Pinnixa faba*
1 *Pinnixa longipes*
1 *Scleroplax granulata*
61 *Hemigrapsus oregonensis*

Molluscs—gasteropods
4 *Philine* sp.
1 *Coryphella* sp.
1 *Dendronotus* sp.
3 *Nassa fossata*
16 *Lacuna porrecta*
5 *Lacuna unifasciata*

Molluscs—Pelecypods
22 *Saxidomus nuttallii*
1 *Paphia staminea*
277 *Macoma nasuta*
5 *Solen sicarius*
38 *Schizothaerus nuttallii*

Fishes
121 *Clevelandia ios*
1 *Gillichthys mirabilis*
4 *Leptocottus armatus*

This makes a total of 974 individuals and at least 34 species. Since the screening was hastily done between tides, and since only a small portion of the soil was screened, a great number of individuals and perhaps some species were missed, which would have been obtained had a more efficient method been used. Classification of all the worms would also increase the number of species.

In the above association I defy any ecologist to choose a dominant animal and substantiate his findings. If any organism is dominant it is the eelgrass.

New Species and Extension of Ranges

Elkhorn Slough has yielded some rare species and some new ones. Twenty-two new species have been added to the animal list as a result of this study. In the following list an asterisk indicates that the species has been named and described. These descriptions will be published soon.

List of New Species

Mycale macginitiei de Laubenfels	sponge
Undescribed anemone	
Stylochoplana heathi Boone	turbellarian
**Epibdella* ________ Guberlet	epizoic trematode
**Udonella* ________ Guberlet	epizoic trematode
**Probolitrema* ________ Stunkard	trematode
Phyllobothrium? sp.	cestode
Cerebratulus ________ Coe	nemertean
Cerebratulus sp.	nemertean
Micrura sp.	nemertean
Dendrostoma perimeces Fisher	sipunculid
Urechis caupo Fisher and *MacGinitie*	echiuroid
Hesperonoe adventor (Skogsberg)	polynoid

Hesperonoe sp.		polynoid
**Argulus melanostictus*	Wilson	copepod
**Hemicyclops thysanotus*	Wilson	copepod
**Hemicyclops callianassae*	Wilson	copepod
**Modiolicola gracilis*	Wilson	copepod
**Dendronotus*	MacFarland	nudibranch
**Doto*	MacFarland	nudibranch
**Coryphella*	MacFarland	nudibranch
**Galvina*	MacFarland	nudibranch

Another interesting feature of the work has been the discovery of animals both north and south of their recorded range, the majority, however, being northward extensions. Twenty-three species are listed below.

Northward Extension of Range

	Former Range
Coelenterata	
Harenactis attenuata	San Diego to San Pedro
Annelida	
Leodice longicirrata	As far north as Panama
Loimia montagui	As far north as Panama
Crustacea	
Betaeus longidactylus	San Diego to San Pedro
Cancer anthonyi	Lower Calif. to Long Beach
Pinnixa tomentosa	Gulf of Calif. to San Clemente Is., Calif.
Mollusca	
Navanax inermis	San Diego to Catalina
Sanguinolaria nuttallii	Lower Calif. to San Pedro
Modiolus capax	Peru to Santa Barbara, Calif.
Tagelus californianus	Mexico to Santa Barbara, Calif.
Tunicata	
Halocynthia johnsoni	San Diego to San Pedro

Southward Extension of Range

Annelida	
Pilargis berkeleyi	Known only from San Juan Islands
Crustacea	
Phyllodurus abdominalis	Puget Sound to San Francisco Bay
Pinnixa faba	Alaska to Humboldt Bay, Calif.
Pinnixa franciscana	Known only from San Francisco Bay.
Pinnixa schmitti	Port Levasheff, Alaska, to San Francisco Bay
Mollusca	
Phyllaplysia taylori	Known only from Nanaimo, B. C.
Pseudopythina rugifera	Puget Sound to San Francisco

Other Extensions

Trematoda	
Udonella	Genus new to America
Sipunculoidea	
Phascolosoma gouldi	New to west coast of America
Annelida	
Chone infundibuliformis	New to west coast of America
Holothuroidea	
Caudina chilensis	Coast of Chile, Aleutian Islands, Asamushi, Japan
Amphipoda	
Ampithoe lacertosa	New to west coast of America.

When rare specimens wash up on the open beach they soon die and dry out; but when they wash into the Slough they may continue to live for a long time. This may account for one or two rare specimens that were obtained.

Too, one must be continually on the alert for introduced species. Oyster spat which is shipped in for planting may contain foreigners. Mrs. Oldroyd informed me that approximately twenty-five species of molluscs were found in a shipment of oysters from Japan. Only occasionally, of course, is an animal able to survive the change in temperature, and still fewer are able to reproduce.

Parasitism and Commensalism

Many of the animals of the Slough confine themselves to a limited area, and some to the degree of being practically sessile. This renders a study of their parasites easy, for fresh material is obtainable at any time. The most interesting problem of this nature which came to my attention is the tetraphyllid cestode so common in the gaper clam, *Schizothaerus nuttallii,* and whose primary host is the sting ray. Practically no time was given to anatomical investigation in the preparation of this paper, so no doubt there are many other parasites of equal interest.

Commensalism is carried on to a great extent by many of the animals. There are at least four species of polynoids commensal in the burrows of animals of the Slough. Small crabs are commensal with *Urechis,* with the tube worms, and with the mud shrimps, *Upogebia* and *Callianassa.* The clam, *Pseudopythina,* hangs on the under side of *Upogebia. Cryptomya californica* is commensal in that it depends upon the burrows of other animals for its source of water supply. The isopod, *Phyllodurus abdominalis* attaches to the abdomen of *Upogebia.*

The little goby fish, *Clevelandia ios,* uses all the burrows that open on the surface. From observations made in the laboratory, *Clevelandia ios* must respire through its integument as well as by means of its gills, for it often lies on the bottom for many minutes with no apparent movement of the operculi.

A true commensal cannot live without its host. There are certain reasons why the burrows of such creatures as *Upogebia, Urechis,* etc. must be inhabited by the owner if they are to contain a commensal. Chief among these is that the current of freshwater maintained by the host is necessary for respiration and food supply for the commensal. The burrow must be kept open, a task beyond the powers of the commensal. In addition, food discarded by the animal is often acceptable to the commensal. Grades of commensalism range from that of *Clevelandia,* which simply makes use of a burrow as a temporary refuge, to animals like *Hemicyclops callianassae* and *Hesperonoe adventor,* which show signs of becoming parasitic. All degrees of relationships may be found at Elkhorn Slough from independent free living through all stages of commensalism (which in itself gradually verges into parasitism) to such parasitism as that of the body fluke of the sting ray, and *Sacculina* on *Pugettia producta.*

The following is a list of the commensals and parasites from Elkhorn Slough, which, in general, conforms to the gradation mentioned above, the first species being practically free living, while the last is a highly specialized internal parasite.

Commensal or Parasite	Host or Habitat
Clevelandia ios	Free, or in burrows of *Urechis, Upogebia* and *Callianassa.*
Cryptomya californica	Burrows of *Urechis, Upogebia* and *Callianassa.*
Gillichthys mirabilis	Same as *Clevelandia ios.*
Betaeus longidactylis	Same as *Clevelandia ios.*
Halosydna insignis	Free, tube of *Pista elongata* and *Loimia montagui*
Pseudopythina rugifera	Free in burrow of *Upogebia.*
Pseudopythina compressa	*Upogebia.*
Opisthopus transversus	*Sanguinolaria nuttallii.*
Scleroplax granulata	*Urechis, Callianassa* and *Upogebia.*
Pinnixa faba	*Schizothaerus nuttallii.*
Pinnixa longipes	*Pectinaria auricoma* and burrow of *Urechis.*
Pinnixa franciscana	*Urechis, Callianassa* and *Upogebia.*
Pinnixa schmitti	Tube of *Pista elongata.*
Pinnixa tubicola	Tube of *Pista elongata?*
Pinnixa tomentosa	Tube of *Pista elongata.*
Hesperonoe adventor	*Urechis.*
Hesperonoe sp.	*Upogebia.*
Hesperonoe complanata	*Callianassa.*
Hemicyclops thysanotus	*Callianassa* and *Hermissenda crassicornis.*
Hemicyclops callianassae	Gills of *Callianassa.*
Phyllodurus abdominalis	Abdomen of *Upogebia.*
Livoneca vulgaris	Gills of flat fishes.
Argulus melanostictus	External on fishes.
Trebius caudatus	*Myliobatis californicus.*
Modiolicola gracilis	Gills of *Mytilus edulis.*
Udonella	*Trebius caudatus* (copepod), which in turn is parasitic on *Myliobatis californicus.*
Epibdella	*Myliobatis californicus.*
Branchellion sp.	*Myliobatis californicus.*
Probolitrema	*Myliobatis californicus.*
Phyllobothrium? sp.	Clams and *Myliobatis.*
Sacculina sp.	*Pugettia producta.*

Tropisms in General

The tropisms of the animals in the Slough offer a very interesting phase of the study. Many of the animals which live in the soil soon die when placed in a condition where they cannot come in contact with an object on all sides, e.g., the mud shrimps, *Callianassa* and *Upogebia,* and some of the worms. Certain of the isopods, e.g., *Pentidotea resecata,* and the tectibranch, *Phyllaplysia taylori,* orient themselves lengthwise of *Zostera* blades, which they resemble in color. The longitudinal markings on the *Phyllaplysia* aid the deception, for they resemble the veining of *Zostera.* Pipefish stand on their tails among the *Zostera* blades so that it is difficult to distinguish them from the latter.

The sand and mud snails, such as *Olivella, Polinices* and *Nassa* all bury themselves when left exposed by the tide; sand dollars do likewise. *Navanax* covers itself with slime. Several animals, such as the goby, *Clevelandia ios,* and the juvenile crabs, resort to using the burrows of other animals when the tide goes out. But they simply use a ready-made burrow. Most surface animals, however, seek deeper water.

On the whole it seems that, once the burrowing habit was established, evolutionary development continued until some means for procuring food was supplied which did not necessitate the animal leaving its hidden refuge. As these food-getting advantages were developed, certain physical structures became degenerate through disuse, or were modified to function in some way which was advantageous to the animal in its new habitat.

To one who has spent a great deal of time with animals outdoors, tropisms is a subject which seems to be overworked. I have heard men who profess to be authorities on the subject make statements which it would be absolutely impossible for them or anyone else to prove. They blithely make the statement, for example, that a certain animal is positively geotropic when the chances are just as great that it is negatively phototropic. This statement was actually made by such an authority concerning the reaction of polyclads, but I happen to know that polyclads come up at nighttime and feed.

One would expect that many of the animals at the Slough would show strong geotropic responses. However, if an animal like *Callianassa, Upogebia,* or *Urechis* is watched as it carries on its activities in the burrow (in a mud frame or glass tube), it will be seen that it shows very little response to gravity. Even when in an open dish *Urechis* shows no geotropism, *Upogebia* but little, and *Callianassa* but little more. *Upogebia* will often roll onto its side or back and make no such frantic effort to regain its upright position as will such an animal as a crayfish or lobster. It makes no attempt to dig or burrow into the bottom of the dish. However, if placed on sand or mud it at once begins to burrow. *Urechis, Upogebia* and *Callianassa* show no inclination to seek a dark corner unless there is opportunity therein to come in contact with more surface. A strong light focused on any of these animals as they are carrying on their daily activities in an artificial burrow or in a limorium his never been noted to have any effect whatsoever. The chances are then that the tropism most manifest in these animals is thigmotropism.

It might be stated then that they simply have the instinct to burrow and are satisfied only when they are entirely surrounded with mud on all but the anterior and posterior limits. Even after they have gone below the surface of the mud they are not satisfied and will make no attempt to carry on feeding activities until the burrow is complete to the extent that water may be pumped in one entrance and out another.

Through long contact with a particular environment, invertebrate animals develop a form of response which is entirely instinctive; and the attempt to analyze such instinctive reactions can much better be done in the gross by a thorough understanding of the environment and of their feeding habits. One may bring an animal into the laboratory and control all stimuli except that one which will demonstrate a particular tropism, but this does not prove that the animal would respond in the same way in nature where other tropic stimuli are not controlled. After a long study of invertebrate animals outdoors one finds that he can more accurately anticipate what responses an animal will make than would be possible from a background of laboratory controlled experiments.

The detritus feeders are not strongly chemotropic, although they all show a response to abundant food material, that is, detritus. The other animals, however, are all very sensitive as far as their ability to detect food materials at considerable distances is concerned. At one time at Morro Bay I saw a dead fish lying in the channel as the tide was running out, and below this fish a stream of *Nassa fossata* was approaching it, some from a distance of over 100 feet. I counted nearly one hundred of these snails slowly but surely plowing their way toward this food material. The crustacea are all very sensitive to food materials. It is surprising to what distances a nemertean can scent its annelid prey. When *Cerebratulus* is burrowing in the mud and comes in contact with a worm burrow it will shoot out its proboscis along this burrow for a distance of two or three feet.

Nocturnal Activities

Several nights were spent at the Slough in order to determine whether any activities were carried on at night that were not apparent in the daytime. Some of the nights were partly moonlit, but others were in the dark of the moon. It was thought that some of the mud-dwellers, if negatively phototropic, might come out at night; but I found that no burrowing animals feed at the surface, and that their night activities are the same as those of the day. Digging revealed that the mud-dwellers were no more inclined to be near the surface at night than in the daytime. Needless to say, every precaution was taken not to disturb them, and it cannot be said that they were frightened down by footseps or by light.

Thirty *Callianassa* which were dug up were found to be at varying depths just as they are in the daytime. Tides seem to influence their position in the burrows more than any other factor. At night, as in the daytime, they may be most easily dug just as the tide is leaving or returning to the entrance of their burrows.

The molluscs seem to carry on exactly the same activities at night as they do in the day. *Haminoea* and *Hermissenda* were laying eggs. The clams were inactive where the tide was out, but those which were covered with water had their siphons extended and open and were busily pumping.

In certain ways, however, the Slough is different at night. *Pachygrapsus* leaves his shallow burrow along the bank and *Hemigrapsus* comes up from his daytime hiding place. Both of these crabs are especially active at night and are much in evidence. *Pachygrapsus* stays along the shores, but *Hemigrapsus* usually perches on the *Zostera,* drawing several blades together and thus buoying itself up. So far as could be determined these crabs were not feeding directly on the *Zostera,* but were picking at things here and there, searching for whatever suited their gastronomic inclinations. Pugettia seem relatively scarce during the day, but at night they are everywhere and busily feeding. They, too, buoy themselves up with the *Zostera,* but stay lower down than *Hemigrapsus* does. The Cancer crabs stay on the bottom, as during the day, but they seem to be much more active at night.

Fish, and the surface living crustacea, show the greatest increased activity of all the animals. Striped bass may be heard splashing about. Smelt, cabezons and flounders are everywhere about one's legs or under foot. When the direct beam of a flashlight is once fixed on a fish it remains perfectly still and is easily netted. Several smelt *(Atherinops affinis),* cabezons *(Leptocottus armatus),* and gobies (both *Clevelandia ios* and *Gillichthys mirabilis)* were netted in this way.

No birds were about and, with the exception of an occasional squawk from a great blue heron which was roosting in a nearby tree, none were heard. Night herons feed at night, but are relatively silent about it. The absence of the fish-eating birds may in part account for the greater activity of fishes at night.

Concerning Migrations from Ocean to Land

The thesis is often offered that animals which migrated from the ocean to land have done so through river mouths or estuaries, of which Elkhorn Slough is a type. In such a place, therefore, one would expect present day indications of transitory stages. While it is possible that in times past some animals have migrated to land by this route, present day indications of this are not evident in the Slough, or at least not nearly so evident as they are on the open beach.

Most persons who have offered the thesis that estuaries and river mouths have been the gateway to the land habitat for marine animals do so, I believe, without careful consideration and without knowledge of actual conditions. They feel that the surf would be a barrier to the migration from sea to land. I am firmly convinced that the greatest obstacle confronting an animal which may have a tendency to leave the ocean is the complete reorganization of the embryology of such creatures to allow for such a change. The chemistry of such reorganization has been ably discussed by Needham (1931). Not only are great chemical changes necessary, but physical and instinctive ones as well. The egg must be provided with more yolk, as well as with an impervious covering; and some form of maternal care usually accompanies such changes. Stated otherwise, any animal which tries to migrate from a marine habitat to land, should first have as a part of its inheritance the instinct to care for its eggs.

On the open beach around Monterey Bay we have several animals which are showing a tendency to leave the ocean. When we consider causes for their tendency to migrate to land perhaps the first one which comes to our attention is that of space. In a Pacific Grove tidepool the keenest factor of competition between animals, at least within the surf zone, is for a space to attach or hang on, and animals which can use the region above the surf line have, of course, a much less crowded environment. Any animal which can use the sand beach, even, occurs in great numbers as compared with those animals which depend upon rocky regions for habitats, because the former have less competition. Few animals, relatively speaking, have been able to adapt themselves to the surf region of sandy beaches because of its unstable conditions. In the Slough or river mouths this competition for space, while keen, is not so great as it would be in an equal area on the rocks outside. Also, entrance to the Slough must be made by migrating over a sandy area. Conditions within a slough are already somewhat drastic (due to tidal exposure, greater temperature range, etc.), in that they limit the numbers of species which have been able to adapt themselves to the conditions found in such places. Inhibiting factors are even greater at the mouths of rivers, for, in addition to the same sandy condition which exists at the entrance to a slough, there is the great dilution by fresh water, as well as a tendency for animals to be washed back to the sea by currents. With these facts in mind, I think that one really should expect more animals to cross through the surf zone and take up a terrestrial abode than to make their way to land through estuaries and river mouths. On the open beach we have many animals which are undoubtedly moving landward, for, even today, with the considerable competition which they meet from the already established land fauna, they find conditions less crowded and more favorable the freer they are from the surf zone. As examples of such animals we might cite *Lygida, Pachygrapsus, Exosphaeroma, Orchestoidea*. It will be noted that these are all crustacea, and also that they are quite active ones, which has considerable to do with their tendency to seek higher places and gives them the advantage of being able to seek refuge quickly. *Lygida* may be drowned in either fresh or ocean water. *Exosphaeroma oregonensis* may be found either in the ocean or in strictly fresh water springs which are at a considerable distance from the surf, but it cannot live out of water. Among other groups of animals we have less indication of landward migration. Many of the limpets have gone high on the beach, and the two Littorines, *Littorina planaxis* and *Littorina scutulata*, also spend most of their time out of the water. It is said of *L. scutulata* that when exposed to dry conditions for a sufficiently long time its gill cavity takes on characteristics resembling those of the pulmonates. However, all of these molluscs have done little to free their eggs from the necessities of a marine environment. A few other animals, such as the flatworm, *Planocera californica,* and the nemertean, *Paranemertes peregrina,* show some tendency to migrate to a high level, but since they are found at about the same level as a serpent star, they yet must be considered strictly marine animals.

It is only natural to suppose that any representatives of the above mentioned animals which have for their main habitat the outer beach, should, when they occur in the Slough, retain these habits, as, for example, does *Pachygrapsus.* I believe it can be safely said that those animals in this locality which are tending toward a terrestrial habitat are migrating through the surf and not through estuaries like Elkhorn Slough.

Geological Indications

If, for a period of many years, one carries on an investigation in a region like Elkhorn Slough, with its rich fauna, a great deal of first hand information concerning the formation of sedimentary rocks may be obtained. A complete record, with the necessary illustrations, of the data which would be of interest to the geologist and paleontologist would make a compilation sufficiently great to preclude its inclusion within this paper. But, in order to show the significance of geological data which may be obtained by a prolonged investigation of such an area, I shall herewith attempt to submit certain outstanding features which should be of interest not only to the geologist but to the biologist as well.

As stated under "Bottom Soil," a considerable movement of the materials forming the flats and bars of the lower regions of the Slough takes place over a period of several years. This movement is due to several causes, (1) currents within the Slough, which are greatly variable on account of the tide and surf on the ocean beach, (2) winds, (3) plant life, and (4) the activities of the animals themselves (see *Callianassa,* p. 709). The changing state of this bottom soil gives rise to conditions which leave deposits comparable to those which can be found in geological strata in many regions of the earth. For example, in 1927 there was a large bed of the big gaper clam, *Shizothaerus nuttallii,* at Station 2. These clams showed an age of approximately 17 years; hence, in view of their great size and their inability to move after they are once established, it is evident that conditions had undoubtedly been favorable for their growth for at least 17 years. Just what the factor was which caused the moving sand to fill in over this large clam bed is not definitely known, but it was apparently due to the sand from the eroding dunes on the ocean side sweeping down and piling up over the clam bed until the surface of the soil was raised to a height which finally killed the entire bed of gapers. As the sand was building up the clams extended their necks higher and higher to keep them at the surface, but when it reached a point where their siphons were extended to a height of two feet and over they began to die quite rapidly. Later this sand was again removed, but to a level only a little under what it had been in the beginning. One year later the surface of the mud flat in this region showed no indication of the great number of large gaper clam shells which remained beneath, and animal life, including quite a number of young gapers, had reestablished itself.

This same phenomenon has occurred on a lesser scale at several places near the entrance of the Slough, but nowhere were the clams more than half the size they were in the bed just described. Of course, there were many other clams, such as *Macoma secta, Macoma nasuta, Macoma inquinata, Sanguinolaria nuttallii, Saxidomus nuttallii,* and *Cryptomya californica,* which had also succumbed at the same time. These shells were interspersed with the big gaper shells, although for the most part they were somewhat higher in the soil. Here, then, is a stratum containing mollusc shells in considerable abundance, which was ready for stratification in geological formation by subsidence or elevation. Not a great way distant other spots were also prepared for geological deposition, but the shells were smaller as far as gapers were concerned. Will some investigator one half million years from now, upon discovering this bed of large gaper shells, and upon comparing it with beds of smaller gaper shells, make two different species of this mollusc?

Another way in which shells are prepared in beds for deposition as we often find them in geological strata, occurs where the erosion of the upper surface of some flat washes out all the molluscs, and the shells of these, being heavier than the sand which is washing away, remain more or less *in situ,* and sometimes, due to a depression, a bed of shells several inches thick may result (Fig. 8). Later, by another change of the bottom soil, these will become covered and possibly the particular area in which they are deposited may never again be uncovered. Such shell conglomerates are quite abundant in sedimentary stratification.

In addition to such rather striking depositions a great many of the Slough animals show possibilities of leaving records which would be of extreme interest to the geologist in determining under what conditions certain sedimentations have been laid down. The tracks of the surface animals are each and every one distinguishable from any other. The olive shell, *Olivella biplicata,* leaves a V-shaped track which circles and winds in almost all directions and may be as long as 15 or 20 feet between tides. Practically all of these are washed out by the next tides. However, it is quite possible for many of them to become filled with sediment of a different grade of fineness from that of the soil in which they were made. The same thing applies to other tracks, such as those of the moon shells, *Polinices,* which are similar to those of *Olivella,* but much larger and deeper. The track of *Nassa fossata* is usually flat and broad, say one millimeter deep and 15 mm. wide. The surface crabs leave a band of small punctate marks, their width depending upon the size of the crab. Sometimes if the mud is quite soft part of the marks may be obliterated by the dragging of the body, and, in soft mud, of course, the punctations are much deeper. Even the fish leave their telltale marks in the mud. *Leptocottus armatus* and the flounders bury themeselves in the mud while waiting for their prey. The sting ray, *Myliobatis californicus,* may in one night dig a channel 18 inches deep and 10 or 15 feet long, as he burrows for the clams on which he feeds. Due to the sorting action of the water this ditch may, in the course of the next few days, become filled with an entirely different deposit of either finer or coarser material than that in which it was made.

The worm tubes, which are different for each species, will in the event of some calamity, be the only record left to show that such animals once inhabited that particular soil. The abundance with which these tubes may

Fig. 8. Shells washed out at Newport Bay, ready for sedimentary action.

become a part of a deposit may be indicated by reference to the paragraph on *Phoronopsis* later in this paper. (Fenton, 1934c)

Fecal pellets are accumulated in quantity where the sand is rippled by the action of the current. The quanity of fecal pellets to be found at low tide, which would be only those deposited during the foregoing tide, is amazing to one unacquainted with the number of animals there may be under the surface of the mud. Since, in general, the most abundant animals of the Slough region tend to segregate in colonies, the fecal pellets trapped by the sand ripples are usually all of one kind in a given area. Below a *Phoronopsis* bed they will be the tiny thread-like castings of this animal. Below a *Callianassa* bed will be those of *Callianassa,* which are about the size of the lead in a pencil, and which, as they are extruded, break up into pieces less than a centimeter long (Edge, 1934). They may be readily distinguished by the roughness at each end. Those below the beds of *Urechis* are about the same size in diameter, but may be twice as long, and, unless broken, are rounded at each end. The castings of certain worms leave surface markings quite comparable to those of the earth worm on land. These may range in size from the tiny castings of *Notomastus* to those large twisted ropy mounds pushed up by *Arenicola,* which may be one centimeter in diameter. (Fig. 9).

In addition to the fecal pellets are the burrows of the animals (see Fig. 10,

p. 683). Due, possibly, to the oxygenating effect of the water which is pumped through the burrows of such animals as *Callianassa, Upogebia, Urechis,* etc., the soil immediately surrounding such burrows out for a distance of about 2 cm. is lighter in color than the rest. When an animal like *Urechis* dies, the burrow usually fills with material much finer than that of the surrounding soil, and, since it contains a considerable amount of detritus or decaying vege-

Fig. 9. Casting of *Arenicola.*

table matter, there is a tendency in time for this core to become more compact than the surrounding soil.

From the foregoing statements it may be seen that the present day animals may leave a wealth of indication in the sedimentation which can furnish a great deal of information as to how the older sediments were built.

In the introduction it was noted that the Slough could be considered a portion of the ocean bottom drawn inland. From experience gained by several years of dredging off Newport Bay I am convinced that very much the same conditions exist outside, and that what has been said here concerning records left by animals in sediments applies equally well to the ocean bottom. Animals tend to colonize outside just as they do in the Slough, and bottoms near shore are subject to the influence of rather strong currents. One dredge haul will bring up fine mud, another may bring up almost pure shell, while others will show intermediate conditions. The animals brought up may have certain preferences for particular types of soil or may occur in a region simply because they are there. The sea urchin, *Lytechinus anamesus,* may occur over an area not more than an acre in extent, yet in that region a small dredge will bring up a bucketful of the animals, and the soil may be of any texture. The same is true of sand dollars, of certain crustacea, worms, etc. They all seem to have either a preference for a certain locality or a gregarious instinct which causes them to occur in colonies. The spotted nature, therefore, of sedimentary deposits with reference to their contained fossils can no doubt be accounted for in this way.

In addition to the foregoing ways in which animal remains may become fossilized, there is another condition which has been found to exist at the Slough, which would not be found in the outside ocean bottom. This condition was observed several times, but a description of only one of the most severe cases is given here.

Condition at the Slough on July 7, 1927

Because of the shifting of the mouth of the Slough, as explained under "Location and Physical Features" the tide on this date was quite low, after a month with scarcely any runout. The *Enteromorpha* became very abundant wherever the water was shallow, and, of course, this was over the places usually bare at low tide. When the tide went out on July 7 the *Enteromorpha* covered the islands like a felt blanket. The day was unusually sunny and warm. A great many animals were left high and dry, e.g., the bubble shell, *Haminoea;* the eolid, *Hermissenda;* Cancer crabs (chiefly young ones); and the cockle, *Cardium corbis*. The covering of *Enteromorpha* prevented the water running off the flats as rapidly as usual, and perhaps the animals that could have escaped had little stimuli to cause them to seek deeper water until it was too late. Too, the alga made locomotion very slow for most creatures.

At one place, and covering a space about 50 feet in diameter (upper end of Station 3), where the water was left only six inches deep, some disturbance seemed to be killing all living things. Animals were leaving the mud and were coming up into the tangle of *Enteromorpha* to die. Two clams, *Siliqua* and *Solen,* and many worms that have never been seen except in the mud, were found lying on top of the alga, or were twined about in it. Not only were the mud-dwellers coming out and dying, but such animals as the kelp crab, *Pugettia,* and the bubble shell, *Haminoea,* were found dead in considerable numbers. Young gaper clams, *Schizothaerus,* were found with their necks entirely out and sometimes with most of the shell protruding, so that they could easily be lifted out of the mud.

Cockles, *Cardium corbis,* were found gaping widely, and when picked up they were able to make but a feeble, ineffectual effort to close. The foot of these cockles was bluish, apparently discolored by the mud, which was very black and had a strong odor of iodoform.

The alga, which, when covered with water afforded such a good refuge and breeding place, was a death trap when left above water; and where water remained a few inches deep without moving the conditions were even worse. The usual condition of daily bared flats prevents the growth of *Enteromorpha,* and sluggish animals like *Haminoea* do not ordinarily frequent flats which become exposed. Others, such as the crabs, usually leave the flats for deeper water when the tide becomes shallow, and still others, e.g., *Callianassa* and the worms, sink deeper into the mud, and the clams withdraw their siphons.

Another such area as described above was found on July 12, 1927, at the upper end of Station 5. This area was of about the same extent and the conditions were much the same. As noted below, the hydrogen ion reading for this area was pH 9.8. To date this phenomenon has been noted many times. For a discussion of the chemical processes involved see Galliher (1933).

pH Readings for July 11, 1927

Station No.	Condition of Area	pH Reading
1	Shallow water near mouth	8.5
1	Deep water near mouth	8.6
2	Deep channel	8.6
3	Deep channel	9.4
3	Shallow water, bottom covered with *Enteromorpha*	9.4
4	Deep channel	9.2
5	Open channel	9.4
5	In region of decaying *Enteromorpha* and dying animals	9.8

It was interesting to note that where the pH was over 9.5 the animals were suffering from abnormal conditions, and where it was 9.8 they were dying in great numbers. These readings are for the most abnormal conditions ever noted at the Slough. Ordinarily the pH below the highway bridge is that of the open ocean. Above the highway bridge it may reach a pH of 9.0 during slack water at low tide.

Phyletic Catalog of Animals, With Natural History Notes

The greatest obstruction to the completion of this paper has been a taxonomic one. In some cases I have been waiting eight years to have species named by those who are authorities on certain groups. The condition of the taxonomy of the animals of our west coast is well exemplified by the statement in a previous topic where, out of a list of 207 species, it was noted that 22 animals were new and the ranges of 23 others were extended. In other words, before this investigation, forty-five, or over 21 per cent, of the animals found at Elkhorn Slough were new species or represented an extension of range. I can not refrain from remarking here that in view of this condition it seems that some attention should be paid to our own ocean fronts, which could be done at much less expense than can the naming of a few new animals found on expeditions to the Galapagos, Bermudas or the South Seas.

In the following listing of the animals complete synonomies are not given; but in most cases the reference for the original description is given, and is followed by the reference which first used the present accepted name of the animal. In a few cases references were not available, so that one or the other of the two references is lacking. In many cases the original descriptions are difficult of access, and often, because of the subsequent description of so many new species, they are not sufficiently detailed to be of much value. Unfortunately, the species of many groups of the animals of the west coast have not been monographed. But in most cases where it has been possible to cite a reference to a monograph or a fairly recent and accessible paper, such a reference is given in parentheses following the other two references. In the case of the molluscs, all the original descriptions of the marine shells of our west coast have been compiled in four volumes (Oldroyd, 1924, 1927).

Throughout this paper, where the generic name of a new species is followed by dots it indicates that the species has been named and described, and that the description will be published soon.

PROTOZOA

There are three reasons, even if one were to consider no others, which would indicate that Protozoa are plentiful at the Slough both in numbers of individuals and in numbers of species. First, because of the abundant vegetative growth and consequent decay there are a great many bacteria which serve as food for Protozoa; second, the mean average temperature is higher than that of the ocean, and during the day, especially where it is shallow, the water warms quickly; third, the conditions at the Slough are fairly stable.

In September, in a period of two and one half hours at low tide, Dr. C. V. Taylor, of the Hopkins Marine Station, collected representatives of nineteen genera of Protozoa. To this I have added two more, which brings the total number of genera listed in this paper to twenty-one. Since no special study was made of the Protozoa, those listed probably represent only a small percentage of the actual number. Dr. Taylor and I are of the opinion that many of these Protozoa confine themselves to definite localities. This seems to be borne out in practice, for many times I have collected certain forms, for example, *Frontonia,* in a special place. Many of the Protozoa no doubt have definite ways of passing the tide.

Because of the reasons given above, and because of the likelihood of parasitic Protozoa among the burrowing animals, the Slough ought to furnish excellent material for those interested in Protozoology.

The abundance of Protozoa has a direct bearing upon the food supply of the other animals of the Slough, but it is undoubtedly less important than decaying plant material and bacteria.

Noctiluca is exceedingly abundant. It is found in holes left by clam diggers, and several hours after exposure by low tides it often becomes so numerous as to color the water in these holes a pale orange.

Vorticella is often found on hydroids and on the legs of several of the Crustacea.

The following is a list of the genera of Protozoa which Dr. Taylor collected on September 1, 1927.

Sample 1, *Station* 2. Bottom sample from among algae and *Phoronopsis.*

Amphisia	(numerous)	*Onychaspis*	
Condylostoma	(several)	*Trachelocerca*	(numerous)
Cypridium	(scarce)	DINOFLAGELLATES	
Loxophyllum	(scarce)		

Sample 2, *Station* 2. Bottom sample from among *Phoronopsis,* but no algae.

Frontonia		*Uronychia*	
Loxophyllum		MONADS	(numerous)
Trachelocerca		DINOFLAGELLATES	

Sample 3, *Station* 2. Sample taken at the tops of algae at the edge of a channel.

Frontonia	(fairly numerous)	*Trachelocerca*	
Hypotricha	(one)		

Sample 4, *Station* 2. Sample from among holdfasts of algae and debris, no *Phoronopsis.*

Frontonia	(one)	MONADS	

Sample 5, *Station* 2. Bottom sample, same conditions as Sample 1, but another pool.

Frontonia		*Stylotricha*	

Sample 6, *Station* 2. Bottom sample.

		Coleps	

Sample 7, *Station* 2. Sample from tops of algae.

Dinophrys	(fairly numerous)	*Loxophyllum*	(fairly numerous)
Frontonia	(fairly numerous)		

Sample 8, *Station* 3. Sample from bottom among algae in a tide pool two feet in diameter.

Amphisia	(fairly numerous)	*Loxophyllum*	(numerous)
Condylostoma	(fairly numerous)	*Pleuronema*	(exceedingly numerous)
Frontonia	(exceedingly numerous)	*Strombidium*	(exceedingly numerous)
Loxodes			

Sample 9, *Station* 3. Sample from a pool one foot in diameter, near pool of Sample 8.

Condylostoma	(few)	*Pleuronema*	(very numerous)
Cypridium	(fairly numerous)	*Uronychia*	(few)
Frontonia	(numerous)		

Sample 10, *Station* 3. Sample from bottom in a grayish-black sludge; very active decomposition going on. Teeming with Protozoa.

Amphisia	(abundant)	*Frontonia*	(teeming numbers)
Condylostoma	(probably new species)	*Pleuronema*	(abundant)
Cyclidium	(numerous)	*Strombidium*	(teeming numbers)

Sample 11, *Station* 2. Sample of water spouted from siphon of a clam.

Euplotes		*Loxophyllum*	
Frontonia		*Pleuronema*	

Sample 12, *Station* 5. Sample from the top of a burrow of a clam siphon —siphon retracted.

Pleuronema	(great numbers)	*Uronychia*	
Strombidium		MONADS	
Stylotricha (?)			

PORIFERA

As one would expect, sponges are not very abundant in Elkhorn Slough because of their habit of attaching to solid objects. However, they are found at Stations 1 and 4 attached to rocks and to the molluscs and barnacles which grow on these rocks. Four species were identified, and one or two other species, which I was unable to get identified, were found.

The mud-flat sponge, *Tetilla mutabilis* de Laubenfels, which is so common at Newport Bay, was looked for at Elkhorn Slough, but was never found there, nor at Morro Bay.

Order MYXOSPONGIDA
Family *Halisarcidae*
Genus *Halisarca* Johnston
Halisarca sacra de Laubenfels

Halisarca sacra de Laubenfels, 1930, p. 25.

This soft, encrusting sponge is found associated with *Mycale macginitiei* on the rocks at Station 4. It is very pale yellowish brown.

Order CHORISTIDA
Family *Clionidae*
Genus *Cliona* Grant
Cliona celata Grant, var. californiana de Laubenfels.

Cliona celata californiana de Laubenfels, 1932, p. 47.

This boring sponge is not very abundant, but is occasionally found in adult or dead *Ostrea lurida* shells at Station 4.

Order POECILOSCLERINA
Family *Desmacidonidae*
Genus *Mycale* J. E. Gray
Mycale macginitiei de Laubenfels.

Mycale macginitiei de Laubenfels, 1930, p. 26.

Small patches of this dirty-white encrusting sponge may be found on the rocks and on some of the sessile animals, such as barnacles, at Station 4.

Order HAPLOSCLERINA
Family *Haliclonidae*
Genus *Haliclona* Grant
Haliclona cinerea (Grant)

Spongia cinerea Grant, 1827, p. 204.
Haliclona cinerea de Laubenfels, 1932, p. 120.

The habitat of this sponge is practically the same as that of the above species, and it is about equally abundant.

COELENTERATA

The coelenterates are represented by nine hydroids, five anemones, and what is supposed to be the scyphistoma stage of *Aurelia aurita*. With the exception of two or three hydroids and one anemone, these are usually quite abundant. Three of the anemones, *Metridium dianthus Bunodactis xantho-*

grammica and *B. elegantissima*, are not confined to the Slough, but are very common along the coast outside. The anemone *Harenactis attentuata* is, as far as I have been able to determine, strictly a mud-flat animal. The most interesting animal, as far as the coelenterates are concerned, is an undescribed ten-tentacled anemone, which is very similar to *Harenactis* in its habits. However, it seems to be much more active than *Harenactis*, and its stinging cells are much more potent.

The hydroids vary a great deal from year to year. On the whole, during the winter months they are somewhat scarce, but in the summer months quite often the piling and the bottoms of skiffs which are kept for hire at the Slough, become covered with a fur of hydroids two to four inches long, consisting mainly of *Tubularia* and *Obelia*. Fresh water undoubtedly has some influence on these animals as it has been noted that immediately following the two worst floods of fresh water into Elkhorn Slough the hydroids were nearly all wiped out.. One would think that such a purely oceanic animal as *Aurelia* would have scyphistoma which would be quite sensitive to fresh water dilutions, but no effect of this kind has ever been noted. They seem to be more abundant, if anything, after fresh water floods. However, these floods occurred in December, and the main strobilizing season of the scyphistoma is in January, when they would, of course, be more conspicuous than at other times.

Class Hydrozoa
Order Calyptoblastea
Family *Campanularidae*
Genus *Obelia* Péron and Lesueur
Obelia longissima (Pallas)

Sertularia longissima Pallas, 1766, p. 119.
Obelia longissima Hincks, 1868. (Fraser, 1911, 1914)

This hydroid is found at all stations except perhaps Stations 1 and 2. It is most abundant at Station 8 on the pilings, but it is even found growing attached to the blades of *Zostera* and the valves of *Mytilus edulis*.

Like all the hydroids at the Slough *Obelia* is always more or less covered with diatoms and detritus.

Colonies from which medusae were escaping were found in August and again in January.

Obelia gracilis Calkins

Obelia gracilis Calkins, 1899, p. 353.

This species is not so plentiful as the above, but is found associated with it at Station 8.

Genus *Opercularella* Hincks
Opercularella lacerata (Johnston)

Campanularia lacerata Johnston, 1847, p. 111. (Hincks, 1868)
Opercularella lacerata Hincks, 1868, p. 114. (Fraser, 1914, illus.)

This species was found growing luxuriantly on the plates of large chitons, *Mopalia muscosa hindsii,* which were attached to the bridge pilings at Stations 4 and 7.

On July 11, gonangia with escaping medusae were found.

Genus *Campanularia* Lamouroux

Campanularia (sp. undetermined)

One small colony of this species was found, associated with *Opercularella lacerata,* growing on the plates of a chiton, *Mopalia muscosa hindsii,* taken from the piling at Station 4.

Family *Sertulariidae*

Genus *Abietinaria* Kirchenpauer

Abietinaria filicula (Ellis and Solander)

Sertularia filicula Ellis and Solander, 1786, p. 57.
Abietinaria filicula Kirchenpauer 1884, p. 32.

This hydroid was found at Stations 3, 5 and 6, growing on *Zostera* blades. It was found only occasionally.

Family *Plumularidae*

Genus *Aglaophenia* Lamouroux

Aglaophenia struthionides (Murray)

Plumularia struthionides Murray, 1860, p. 251.
Aglaophenia struthionides Marktanner-Turneretscher, 1890, p. 265 (Fraser, 1914)

This species was found occasionally on *Zostera,* often associated with *Obelia,* but the colonies were usually in poor condition.

Order GYMNOBLASTEA

Family *Syncorynidae*

Genus *Syncoryne* Ehrenberg

Syncoryne mirabilis (Ag.)

Coryne mirabilis Agassiz, L., 1862, p. 185.
Syncoryne mirabilis Torrey, 1902a, p. 31.

At times this species is exceedingly abundant on the pilings at Station 8, and it was also found sparingly at Station 4.

Family *Bougainvilleidae*

Genus *Bougainvillea* Lesson

Bougainvillia mertensi Agassiz, L.

Bougainvillia mertensi Agassiz, L., 1862, p. 344.

Like the above, this hydroid is at times very abundant at Station 8. It was also found on the pilings at Station 7.

Family *Tubularidae*

Genus *Tubularia* Linnaeus

Tubularia crocea (Agassiz)

Parypha crocea Agassiz, L., 1862, p. 249.
Tubularia crocea Allman, 1871. (Fraser, 1914)

After the disappearance of this species from the Slough in the early part of 1924, it was not observed again until August, 1927, when it was found on rocks at Station 4. Later it again became common at Station 8, and during the next few years it became exceedingly abundant at this station and also on the pilings at Station 7.

Fruiting bodies were found in August.

Class ANTHOZOA
Order ZOANTHARIA
Family *Halcampidae*
Genus *Harenactis* Torrey
Harenactis attenuata Torrey

Harenactis attenuata Torrey, 1902b, p. 384.

This sand anemone was found at Stations 2, 3, 4, 5 and 6. Solitary individuals are sometimes found, but they usually occur in beds, being especially abundant in beds of *Enteromorpha*, or in uncovered sandy mud.

Harenactis extends into the sand to a depth of from 6 to 10 inches, leaving only its tentacles exposed and spread out on the surface of the sand. When disturbed, or when the tide is out, the animal withdraws into its burrow, leaving a hole which resembles the siphon holes of many of the small clams, but which can be distinguished from the latter by the short rays around the opening where the tentacles have lain. This anemone inflates its basal disk to form a flattened bulb for anchoring itself in the sand. If it is placed in a battery jar containing a little sand its basal disk attaches to the jar in the same manner as do other anemones. It is also capable of burrowing through the sand at the rate of about one inch per hour. Worms, and fish or clam flesh were readily accepted for food.

During the extremely low tide of July 7, 1927 many *Harenactis* came to the surface to the extent that one half of their bodies were out of the burrows and lay drooping on the *Enteromorpha* which everywhere covered the sand.

I also found this anemone at Morro Bay, Tomales Bay, and Humboldt Bay, as well as on the southern mud flats. This makes a long northward extension of range from San Pedro.

Family *Bunodactidae*
Genus *Bunodactis* Dana?
Bunodactis xanthogrammica (Brandt)

Actinia (Taractostempanus) xanthogrammica Brandt, 1835, p. 12.
Bunodactis xanthogrammica Dana, 1846, p. 149, pl. 4, fig. 38.

Small specimens of this species are abundant on the rocks at Stations 1 and 4. They are disturbed a great deal at these stations, as are other living things, by the Filipinos who turn over the rocks looking for the "midshipman," *Porichthys*.

Both this species and *B. elegantissima* are green, due to the symbiotic alga, *Zoochlorella*.

B. xanthogrammica reproduces during the summer months.

Bunodactis elegantissima Dana

Bunodactis elegantissima Dana, 1846.

This small anemone is likewise found at Stations 1 and 4.

It is somewhat difficult to distinguish in appearance from small specimens of *B. xanthogrammica*, but its habits are entirely different from the latter. It readily divides by fission and soon covers large areas on rocky surfaces. Isolation seems to stimulate it to divide. When the tide goes out it covers itself so completely with sand and shell that many collectors pass it by without notice. This habit no doubt helps to protect it from the rays of the sun. It ranges higher above low tide mark than does *B. xanthogrammica.*

Family *Sagartidae*
Genus *Metridium* Oken
Metridium dianthus (Ellis)

Actinia dianthus Ellis, 1767, p. 428, pl. 19, fig. 67.

Metridium dianthus Oken, 1815, p. 450. (McMurrich, 1901; Torrey, 1902b)

Large and small specimens of this anemone are found attached to the pilings at Station 7. They vary in color from snowy white to a rich brown.

It has been claimed that *Metridium* was introduced from the east coast with oyster spat. This is no doubt a mistake, for it is circumboreal in distribution.

A New Species of *Anemone*

As a result of rather careful screening of the sand at Station 5, four specimens of a ten-tentacled anemone were found in July, 1926, among the *Zostera* roots.

This anemone is slender, about 4 inches long and three eighths inch in diameter when extended. There are only ten tentacles. The distal end forms a bulb for anchoring in the mud, and it moves much as does a clam, by extending the posterior end, enlarging it, and then drawing the body along.

A specimen which was kept in the laboratory was fed worms and particles of fish. On one occasion it fastened its tentacles near the telson of a *Callianassa* which was about two inches in length. The shrimp made frantic attempts to dislodge it, and finally succeeded after three or four minutes, but for another full minute it continued making movements as though trying to escape. One half hour later the shrimp was dead, apparently from the effects of the stinging cells, which seem to be more potent than those of most anemones.

Scyphistoma sp.

Colonies of a species of Scyphistoma, probably that of *Aurelia aurita,* were found at Stations 1, 4 and 7. They attach to the under side of rocks, and although many rocks often have to be turned over before finding them, when a colony is found it is usually quite extensive.

There has never been a time during the last nine years when it was not possible to find these Scyphistoma, sometimes in great quantities. They keep nicely in the laboratory and should make good material for experimentation.

In the Slough they strobilize in winter and early spring. It might be that they could be forced to strobilize in the laboratory at other times by lowering the temperature of the water.

CTENOPHORA

Order CYDIPPIDA
Family *Pleurobrachiidae*
Genus *Pleurobrachia* Fleming
Pleurobrachia bachei A. Agassiz

Pleurobrachia bachei Agassiz, A., *in* L. Agassiz, 1860, p. 294 (no description)
Pleurobrachia bachei Agassiz, A., 1865, p. 34.

On January 5, 1929, enormous numbers of this species were carried in with the tide and were left lying all over the bars as the tide receded. This happens at irregular intervals of a few years.

The "By the Wind Sailor," *Velella lata* (a siphonophore), does likewise, washing up on the open beach in sufficient numbers to cause a very unpleasant odor for many days. Personally, I have never collected any *Velella* within the Slough, although residents of the region have reported doing so.

PLATYHELMINTHES

Class TURBELLARIA
Order POLYCLADIDA
Suborder ACOTYLEA
Family *Leptoplanidae*
Genus *Stylochoplana* Stimpson
Stylochoplana heathi Boone

Stylochoplana heathi Boone, 1929, p. 35.

Only three specimens of this new species were found. One was screened from the sand among *Zostera* roots at Station 5 and two from the sand at Station 2.

These polyclads were about 15 mm. long, and were gray in color. They were given to Dr. Heath, of the Hopkins Marine Station, who subsequently gave them to his student, Miss Boone, for identification. She named the new species for Dr. Heath.

Suborder COTYLEA
Family *Euryleptidae*
Genus *Eurylepta* Ehrenberg
Eurylepta aurantiaca Heath and McGregor

Eurylepta aurantiaca Heath and McGregor, 1912, p. 481, pl. 14, fig. 18.

This species is rare at the Slough, probably because of lack of a very suitable habitat. One coral-pink specimen was taken from a rock on the east side of Station 1.

The color of the worm is due to the food it has eaten, empty individuals being light gray. A well-gorged worm will retain the coloration from the food it has eaten for two weeks or more without taking additional food.

Class TREMATODA
Order MONOGENEA
Family *Tristomidae*
Genus *Epibdella* Blainville
Epibdella . . . . Guberlet, sp. nov. (ms.)[1]

Several specimens of this new trematode were found in the buccal cavity of the sting ray, *Myliobatis californicus*, in July, 1927, as well as on later dates. They were white, and were about 5 mm. long.

Family *Udonellidae*
Genus *Udonella* Johnston
Udonella . . . . Guberlet, sp. nov. (ms.)[1]

Many of these tiny trematodes were found clinging to a parasitic copepod *(Trebius caudatus)* taken from the surface of the sting ray, *Myliobatis californicus*. The trematodes are about one millimeter in length, and often a dozen or more were clinging to one copepod, although the latter is only about 5 mm. in length. The *Udonella* were nearly always attached to the egg cases or to the posterior parts of the body of the copepod.

This genus is new to America.

Order DIGENEA
Family *Gorgoderidae*
Genus *Probolitrema* Looss
Probolitrema . . . . Stunkard, sp. nov. (ms.)[2]

This new trematode was found unattached in the coelom of the Sting Ray, *Myliobatis californicus*. It was first taken from four sting rays on July 20, 1927. Practically all the sting rays which were later opened contained several specimens of *Probolitrema*.

This trematode, which is about the size of one's fingernail, is thin and transluscent. It makes excellent material for classroom use or for slides, for the anatomy is clearly visible in both the living and the mounted states. One can watch the ootype function in the living worms.

Class CESTODA
Order TETRAPHYLLIDEA
Family *Phyllobothriidae*
Genus *Phyllobothrium* van Beneden
Phyllobothrium sp. (sp. nov.)

The larval form of this parasite was first found in the gaper clam, *Schizothaerus nuttallii*. The larvae occur in great numbers in this clam, being encysted throughout the muscles of the foot. There are from one to five individuals in a cyst, and 140 of the cysts were taken from a single gaper

1 This trematode has been named and described by Dr. John Guberlet of the University of Washington. His paper will probably appear in an early issue of the Trans. Amer. Microsc. Soc.

2 The name and description of this trematode is appearing in the October issue of the Journal of Parasitology.

clam. They were also found, in much lesser numbers, in *Paphia staminea,* and occasionally in *Macoma nasuta.* The cysts were subsequently found in *Schizothaerus* at Humboldt Bay and at Newport Bay, and at the latter place they were also found in small numbers in *Pecten circularis aequisulcatus.* I have never examined a *Schizothaerus* which did not contain cysts of this cestode, but *Saxidomus nuttallii,* which is often associated with it at the Slough, is apparently immune to the tapeworm. This is another reason why this clam should be protected in preference to *Schizothaerus.*

When removed from the cysts the larval cestodes remain active for at least 24 hours, during which time they continue to make attaching movements. Under the microscope flame cells along the grooves of the bothria may be observed in action.

The adult form of this species is found in the spiral valve of the sting ray, *Myliobatis californicus.* The adults are quite small, from 4 to 6 mm. long, with from 4 to 6 proglottids.

NEMERTEA

Five species of nemerteans, four of which are burrowing forms, were found at Elkhorn Slough. One, a species of *Cerebratulus,* becomes quite large, for several specimens which were found exceeded a yard in length after being taken from the sand. They are abundant where the surrounding mud contains a great many annelids.

Three of the five species of nemerteans which were collected are new. They are being described by Wesley R. Coe, of Yale University.

Order PALEONEMERTEA

Family *Carinomidae*

Genus *Carinoma* Oudemans

Carinoma mutabilis Griffin

Carinoma mutabilis Griffin, 1898, p. 204. (Coe, 1904, 1905)

This white nemertean is fairly common at Stations 3, 5 and 6, where it is found in areas which are well exposed at low tide. It is associated with the annelid, *Notomastus tenuis,* which it probably uses for food.

Carinoma mutabilis has not been reported from this region before, the previous records being Puget Sound and San Diego.

Order HETERONEMERTEA

Family *Lineidae*

Genus *Micrura* Ehrenberg

Micrura sp. (sp. nov.)

This small brown nemertean is found rather close to the surface, being most abundant in regions of decaying vegetation.

This species is not so active as *Cerebratulus.* It also fragments much less easily than the latter.

Genus *Cerebratulus* Renier

Cerebratulus . . . . . Coe, sp. nov.

This reddish-brown nemertean is the largest one found at the Slough. It is found associated with large annelids, which constitute its food.

Specimens often exceed a yard in length; one which I collected at Morro Bay was 12 feet long when contracted. The length to which they may extend is astounding. I have seen many of these worms evert the proboscis, and in all cases it was everted at least twice the length of the body of the worm. It is quite possible that the Morro Bay specimen would have measured 75 feet with its body extended and its proboscis everted.

This species is a good swimmer and can bury itself rapidly. In the latter process it uses the undulating membranes of the oral grooves to loosen the sand while the point of the head is being worked in. In this way the body moves quite steadily out of sight into the mud. It is very difficult to remove whole from the mud, for it fragments upon the least disturbance.

This species reproduces in the summer.

Cerebratulus sp. (sp. nov.)

This is a small species of *Cerebratulus* which is found in regions of decaying *Enteromorpha,* being most common at Station 2.

It has a white body with a head which is nearly black. It is further characterized by the unique extension of the lateral keels to the base of the oral grooves.

Order Hoplonemertea

Family *Emplectonemidae*

Genus *Paranemertes* Coe

Paranemertes peregrina Coe

Paranemertes peregrina Coe, 1901, p. 33, pl. 2, fig. 6; pl. 3, fig. 5. (Coe, 1905).

A single specimen of this species, which Dr. Coe described as a new color variety, was found at Station 2 in July, 1927.

This worm, which feeds on small annelids, is very common on rocky beaches outside Monterey Bay. At Point Lobos, south of the Hopkins Marine Station, it may be found in considerable numbers searching for food above low tide mark. If a small annelid is placed near one, it can always be depended upon for a demonstration of the eversion of a proboscis.

SIPUNCULOIDEA

Genus *Dendrostoma* Grube

Dendrostoma perimeces Fisher

Dendrostoma perimeces Fisher, 1928, p. 196, pl. 6, figs. 3, 3a; pl. 7, fig. 1; pl. 8, figs. 2, 2a.

This sipunculid worm is fairly plentiful among the roots of *Zostera,* in regions which are usually not entirely uncovered at low tide.

It seems to occur somewhat in colonies, for sometimes when one is digging in the *Zostera* several may be found, and at other times none. Individuals extend from 10 to 14 inches below the surface; their typical position is lying in their burrow with their tentacles projecting and spread out in the water. When the tide is low or when they are disturbed their tentacles are withdrawn below the surface. In color they resemble very closely the dark sandy mud in which they live.

The food of *Dendrostoma,* which is evidently the same as that of the clams, is carried into the mouth by ciliated grooves along the tentacles.

Dendrostoma is easily kept in limoria in the laboratory. I kept three of them thus for a year at the Hopkins Marine Station.

Genus *Phascolosoma* Leuckart

Phascolosoma gouldii (Pourtalès)

Sipunculus gouldii Pourtalès, 1852, p. 40.
Phascolosoma gouldii Diesing, 1859, p. 764.

A single specimen of this sipunculid was found at Station 6 in July, 1927. It was dug at just about low tide mark in a region where the bottom was covered with *Enteromorpha.*

When partially extended this specimen was 74 mm. long and 6mm. in diameter. The fact that it was so well established so far from the mouth of the Slough leads one to believe that it was but a single specimen brought from the east coast with *Ostrea elongata.*

ECHIUROIDEA

Family *Urechidae*

Genus *Urechis* Seitz

Urechis caupo Fisher and MacGinitie

Urechis caupo Fisher and MacGinitie, 1928a, p. 199, pl. 9, figs. 1-6.

This echiuroid is found abundantly at Stations 3, 4, 5, 6 and 7.

It is proving to be such a valuable animal for experimental purposes, especially experimental embryology, that considerable space is given here to its natural history.[3]

Urechis (Fig. 11) lives in muddy sand in burrows shaped like a widely expanded U, the two openings of which are from 16 to 38 inches apart, the average being about 27 inches. The diameter of the tunnel varies with the size of the animal, and the apertures are about one third the diameter of the tunnel. These burrows are permanent, the only changes being enlargement and elongation to compensate for the growth of the animal, which is very slow, or occasionally repair or renewal of a damaged entrance.

Locomotion.—The rapidity and manner of locomotion of *Urechis* suggests that of the earthworm. It can move backward or forward with about equal rapidity. It elongates the anterior portion of the body, then, by contracting the circular muscles of the posterior portion of the body, most of the viscera and weight of the animal are forced into the anterior end. Then the

3 Condensed from Ann. Mag. Nat. Hist. (Fisher and MacGinitie, 1928b), with additional notes on feeding and commensals.

posterior part of the body is drawn forward, the walls of the burrow serving to anchor the anterior portion during this process.

Digging.—When digging a tunnel *Urechis* forces its proboscis into the mud and works out a hole until its body can be drawn into it. This process is repeated until a U-shaped burrow open to the surface at both ends is completed. Then the bore of the tunnel is enlarged by scraping material from

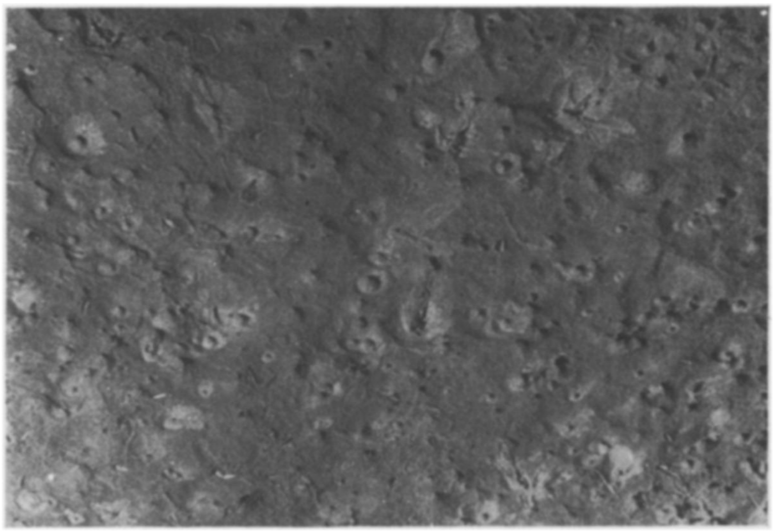


Fig. 10. Burrows of *Callianassa californiensis* and of *Upogebia pugettensis*. The volcano-like burrows are those of *Callianassa*, the others those of *Upogebia*.

the sides by means of the anterior setae, working it backward with the anal setae, and then blowing it out backward by means of accumulated respiration water from the hind gut. Sand is loosened from all sides of the burrow by protruding the oral setae and drawing them backward through the sand. The anal setae, which consist of 10 or 11 forward curving bristles encircling the body a short distance from the anus, are sometimes used to assist in ridding the burrow of the loosened material accumulated in digging. The mid-ventral seta is lacking, and the ventral ones are shorter than the dorsal, hence the posterior portion of the body may be folded under without injuring the body. With the posterior end of the body in this position a vigorous straightening of this portion of the body causes the dorsal setae, now ventral in position, to scrape along the burrow and that, together with the flip of the body, forces the loosened soil backward. The ventilation current through the tunnel and the anal jet help to carry this material still farther backward. The process is then repeated, until the burrow is cleared of debris. Another method of cleaning the burrow is by blowing the sand along by anal water jets aided by the ventilation current.

Castings are allowed to accumulate in the burrow and then are ejected in quantity from one entrance. This is usually done by means of water currents, but sometimes the posterior setae are used as described above. The narrow aperture of the tunnel is no doubt an advantage in cleaning operations, for it increases the velocity of the water and hence greatly increases its carrying power.

After an *Urechis* is once established in a permanent burrow its daily activities consist of respiratory movements, feeding, cleaning the burrow, and resting. It never leaves a burrow of its own volition.

Respiratory movements.—The respiration of *Urechis* is anal. The posterior portion of the hind gut is a thin-walled muscular cloacal chamber. Water is inhaled through the anus by a series of from one to thirty intakes. The water taken in by these inhalations is then usually exhaled in a single discharge, although it may be in two or more separate jets, with a rest in between. The rate of respiration is not uniform, for in one instance two inspirations covered 25 seconds and was followed by an expiration period of 10 seconds, whereas in another case 25 inspirations covered 25 seconds, and the expiration ten. In one instance 30 inspirations occupied 90 seconds, the expiration 25 seconds. Inspirations fewer than twelve are the rule. The water for respiration is kept fresh by peristaltic movements of the body which pump the water through the tunnel along the outside of the body. These peristaltic waves begin at the base of the proboscis and as one reaches the posterior portion of the body a new one begins anteriorly. The rate at which these waves travel varies for different waves, and for the same wave in different parts of the body.

Feeding.—*Urechis* employs a unique method of obtaining food, which is undoubtedly generic. A short distance posterior to the oral setae is a zone of mucous glands, which encircle the body. When *Urechis* is ready to feed it expands this region until it presses against the sides of the burrow (usually near the mouth). The animal then begins to secrete slime, and as it backs down the burrow it leaves a slime tube, one end of which is attached to the burrow, the other to its own body. As the tube is being spun the normal respiratory peristalsis takes place, but the portion of the body anterior to the attachment of the slime tube is constricted and undergoes a peculiar spiral peristalsis. The slime tubes may be from two to eight inches in length. When a tube is completed the spiral peristalsis ceases, and normal pumping or ventilating perstalsis continues until, apparently, the water current is blocked by the clogging of the mucus with detritus. Then the animal slips the tube forward, catches it with the proboscis, and proceeds towards the entrance of the burrow, swallowing the tube with its intercepted detritus as it goes. The length of time required for the tube to become clogged with detritus varies with the richness of the water. Sometimes an animal may pump for an hour, but if a diatom culture is introduced with a pipette the tube soon becomes clogged and is swallowed. The slime tube or food funnel is very efficient, for it allows liquid to pass through while intercepting the finest particles. It is perfectly transparent when first secreted, but as it collects detritus it darkens and its outlines become visible.

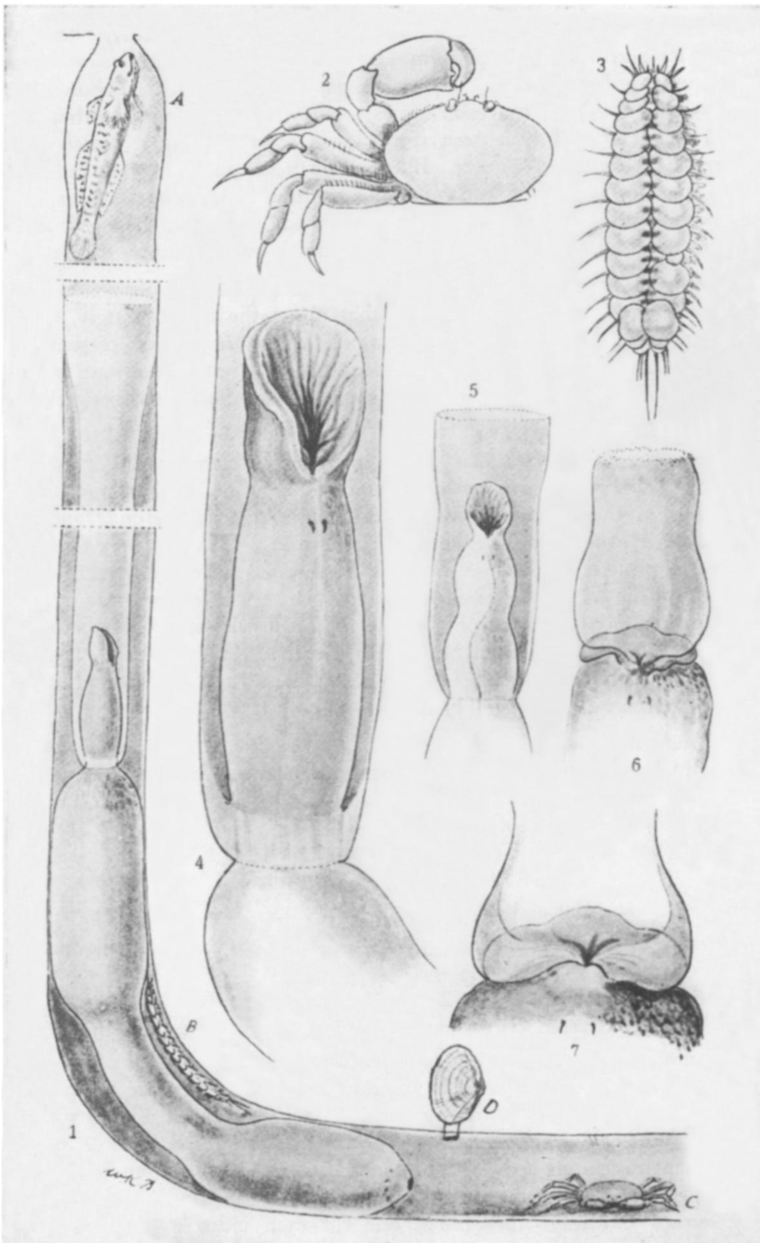


Fig. 11. *Urecihs caupo* and its commensals, from Annals and Magazine of Natural History, after Fisher and MacGinitie (figure D added). The commensals shown are A, *Clevelandia ios;* B and 3, *Hesperonoe adventor;* C and 2, *Scleroplax granulata;* and D, *Cryptomya* californica. 1. *Urechis* in position in tube, feeding. 5. Spinning slime tube. 6 and 7. Swallowing slime tube.

Urechis feeds to some extent, although not very efficiently, when lying without its burrow in an aquarium. In such a position it will swallow sediment from the bottom of the aquarium, gathering it with its proboscis. Even when within a tube it may sometimes swallow food materials without spinning a slime tube. I have seen this happen when feeding it a rich diatom culture or a bacterium culture. But I have never had one live indefinitely which was not kept in a tube, for the continued uninhibited expansion of the body causes small sores to form on the body wall, and these in time will break through into the coelom, causing the death of the animal.

Resting.—After a period of feeding *Urechis* goes to the horizontal portion of the burrow, contracts its body so that it fits the tunnel snugly, and lies in a state of suspended activity during which even respiration ceases. These rests may last for an hour or more, but the long rests are always preceded by one or more short rests, which last from 4 to 8 minutes, and between which respiratory water is expelled and more taken in.

Commensals.—*Urechis* has three permanent commensals, *Hesperonoe adventor, Scleroplax granulata* and *Pinnixa franciscana.* Sometimes all three are found in the same burrow, but usually only a *Hesperonoe* and either *Scleroplax* or *Pinnixa* are present in a single burrow. In addition, *Cryptomya californica* projects its siphons into the burrow to make use of the water in the burrow for its source of food and oxygen. At Newport Bay a pair of either *Betaeus longidactylus* or *Crangon californiensis* have often been found permanently established in the burrows of Urechis. The polynoid, *Hesperonoe adventor,* is commensal with *Urechis* throughout its range from Humboldt Bay to Newport Bay. (Fig. 11).

Reproduction.—*Urechis* has stored sex products throughout the year, although occasionally in late summer most specimens may be spawned out.[4]

PHORONIDA

Genus *Phoronopsis* Gilchrist

Phoronopsis viridis Hilton

Phoronopsis viridis Hilton, 1930, p. 33.

This species occurs at Stations 1, 2, 3, 5 and 6, but most abundantly at Stations 2 and 3.

The tubes are from 100 to 200 mm. in length and about 3 mm. in diameter. They are covered on the outside with uniform grains of sand.

Phoronopsis viridis occurs in such numbers in certain regions of the Slough that when they are covered with water and their tentacles are expanded the bottom of the Slough takes on almost a solid green color. They have a tendency to form colonies, and some of the colonies are nearly an acre in extent. They do not occur in beds of *Zostera* to any extent, but seem to prefer the more open slough bottom. In regions where they are uncovered at low tide they retract and leave tiny holes, one for each individual. Two hundred

4 For information on the production and storage of eggs and sperm in Urechis see MacGinitie, 1935a and 1935b.

eighty-one of these holes were counted in an area of 100 sq. cm. This gives some idea of their abundance. To quite an extent these tubes prevent the washing of the soil.

At Elkhorn Slough *Phoronopsis viridis* reproduces in April. Eggs and sperm are easily removed, and larvae may be raised in the laboratory.

BRYOZOA

Several species of Bryozoa besides those listed below occur at Elkhorn Slough, but the encrusting forms on the rocks at Stations 1, 4 and 7 were not identified.

Class ENDOPROCTA
Family *Pedicellinidae*
Genus *Barentsia* Hincks
Barentsia gracilis Lomas

Barentsia gracilis Lomas, 1886, p. 190.

This species is quite abundant among the rocks at Station 4, and less so at Station 7. It was found especially abundant on the backs of a chiton, *Mopalia muscosa hindsii,* where it had not confined itself to the plates, but was growing on the girdle as well. Some individuals had even attached themselves to the opercular plates of barnacles which were also growing on the chiton.

Family *Vesiculariidae*
Genus *Bowerbankia* Farre
Bowerbankia gracilis Leidy

Bowerbankia gracilis Leidy, 1855, p. 142.

Specimens of this bryozoan are often taken from the carapace of *Upogebia, Callianassa* and other underground crustacea.

Class ECTOPROCTA
Family *Membraniporidae*
Genus *Membranipora* Blainville
Membranipora membranacea (Linnaeus)

Flustra membranacea Linnaeus, 1766, p. 1301.
Membranipora membranacea Blainville, 1834, p. 447.

This encrusting bryozoan, which grows in radiating patches, is found wherever there is *Zostera.* It also grows on the carapace of the adult shore crabs, *Pachygrapsus crassipes.*

ANNELIDA

Since they are exceedingly abundant in the soil at the Slough, annelid worms form a very important part in the animal association. Out of the 974 animals counted from a 45-inch circle 390 were annelids (see "Abundance of Organisms," p. 656). The specimens of *Notomastus tenuis* were not counted, because they are so long and stringy and fragment so easily that, unless one has adequate time and screening facilities, he can not be sure of their number.

Since some species of annelid has adapted itself to practically any condition, the annelids of Elkhorn Slough show a great variety of structural and instinctive adaptations which make them a very interesting group indeed. However, I spent less time with the natural history of this group than any other in the Slough. This was partly due to the great abundance of other materials, such as Crustacea and Molluscs, which were more easily obtained and identified; but was largely due to the fact that I could identify only a few of the species of annelids and could get no one to identify them for me. It is evident that it is difficult to keep records of so many unidentified forms. Recently, through the greatly appreciated kindness of Dr. Edith Berkeley, of Nanaimo, the names of most of these worms have been obtained. I hope to spend more time with this group in the future and expect to be able to report later on some very interesting habits and life histories.

Order POLYCHAETA
Family *Polynoidae*
Genus *Halosydna* Kinberg
Halosydna insignis Baird

Lepidonotus insignis Baird, 1863, p. 106.
Halosydna insignis Baird, 1865, p. 188.

In addition to being common in a free living state among the rocks, mussels and hydroids at Stations 1, 4, 7 and 8, this worm is often commensal with *Pista elongata* and *Loimia montagui*. It is also abundant on the ocean beach.

When the eggs and sperm of *Halosydna* insignis are ripe they furnish good material for artificial fertilization. Male and female worms may be easily distinguished under the binoculars. Eggs or sperm may be obtained by squeezing a worm between the thumb and finger to rupture the parapodia. Sex products are mature during spring and summer, and eggs may be fertilized whenever the worm is sufficiently laden that the parapodia rupture under pressure.

Genus *Hesperonoe* Chamberlin
Hesperonoe adventor (Skogsberg)

Harmothoe adventor Skogsberg, 1928, p. 253, figs. 1-17.
Hesperonoe adventor Berkeley (ms)

This polyclad is specific to the burrows of *Urechis caupo*. Its structural adaptations and its habits show that it has been associated with *Urechis* for a long period of time. It is commensal with *Urechis* throughout the range of the latter from Humboldt Bay to Newport Bay. Practically every burrow of *Urechis* contains a single specimen of this commensal.

The food of *Hesperonoe adventor* consists of particles rejected by *Urechis* when swallowing its slime tube. These particles consist of either living or dead animals which wash down the burrow with the current and become entrapped in the slime. *Hesperonoe* shows indications of verging toward a parasitic relationship with *Urechis*, for sometimes when the latter is swallowing its slime tube the polynoid will crawl forward and eat part of the tube with its contents. It is very aggressive toward intruders within the burrow other than the commensal crabs. Only one *Hesperonoe* occurs within each burrow, and if another enters the two will fight until one is killed or driven from the burrow. This polynoid has a very efficient, rather short, eversible proboscis which it can evert with a sharp snap sufficiently loud to be heard quite distinctly through the walls of a limorium, the water and the glass walls of an aquarium. Other annelid worms which may find their way into the burrow are speedily dispatched and devoured.

Hesperonoe stays with its dorsal surface in contact with the body of *Urechis,* moving along the burrow with the latter by making little short runs as the peristaltic movement of the body of *Urechis* passes by. It always faces the same direction as does the *Urechis,* and when the latter turns in its burrow the polynoid quickly does likewise.

The sex products of *Hesperonoe adventor* are liberated within the burrow and are washed outside as are the sex products of its host. Ripe sperm and eggs may be obtained from the polynoids in March.

Hesperonoe complanata (Johnson)

Harmathoe complanata Johnson, 1901.
Hesperonoe complanata Berkeley (ms)

Dr. Skogsberg, who named *Hesperonoe (Harmothoe) adventor,* and examined all three of the species of *Hesperonoe* from Elkhorn Slough, found that the ones commensal with *Callianassa* and *Upogebia* were also new species. Mrs. Berkeley, however, finds that the species commensal with *Callianassa* has already been named, as shown in the synonomy.

The burrows of *Callianassa* are continually running into each other, so that the *Hesperonoe* commensal with this shrimp has not the seclusion from its own kind that those with *Urechis* and *Upogebia* have. This perhaps accounts for the habit which the juveniles of this species have of lying across the abdomen of adult *Callianassa* until they are at least one third grown. When they reach a size which will not allow this habit to continue, they take up a free living abode in the burrows of their hosts, but, still conforming to the ancestral traits, they do not live in harmony.

This *Hesperonoe* is not so abundant that it can be said that there is one in each burrow. In one instance when digging about fifty *Callianassa* conditions were such that practically all of the *Hesperonoe* living with these were obtained, or about ten specimens. This indicates that they occur in the proproportion of about one *Hesperonoe* to five *Callianassa.* As will be seen from the natural history of *Callianassa* (McGinitie, 1934a), the *Hesperonoe* living with this shrimp would be better supplied with food than those living with *Urechis* or *Upogebia,* therefore, the only way I can account for their not being more plentiful in these burrows is because of their pugnacious attitude toward other members of their own species.

Hesperonoe sp. (sp. nov.)

This *Hesperonoe* is commensal only in the burrows of *Upogebia pugettensis.* There is but one polynoid to each pair of *Upogebia,* or, in other words, to each burrow. The habits of this *Hesperonoe* are much the same as those of the one commensal with *Urechis*.

Family *Sigalionidae*
Genus *Sthenelais* Kinberg
Sthenelais fusca Johnson

Sthenelais fusca Johnson, 1897, p. 185, pl. 9, figs. 60, 61, 61a, b; pl. 10, figs. 64, 64a-g. (Rioja, 1918)

A few specimens of this worm were found at Stations 4 and 5. The longest one measured 140 mm. when relaxed, and was slate-blue in color.

Family *Amphinomidae*
Eurythoe californica Johnson

Eurythoe californica Johnson, 1897, p. 159, pl. 5, figs. 8-14. (= *E. pauper* Grube)

This species is very common in sandy mud at Stations 2, 3, 4, 5 and 6.

Family *Hesionidae*
Pilargis berkeleyi Monro

A few specimens of this species were taken from the heavy mud at Station 4. Only one other specimen, an incomplete one, has been recorded before. It was taken from the San Juan Island region, near British Columbia.

Family *Nereidae*
Genus *Nereis* Cuvier
Nereis virens Sars

Nereis virens Sars, 1835, p. 58, pl. 10, fig. 27.

This species of Nereis was taken from the sandy mud at the west side of Station 6, where they are not uncommon.

Nereis virens var. *brandti* (Malmgren)

Alitta brandti Malmgren, 1865, p. 183.
Nereis virens, var. *brandti Treadwell*, 1914, p. 190.

Several specimens of this annelid were found, the largest at Station 4. When relaxed it measured 5.5 feet. Other specimens were from one to 2 feet long.

Nereis procera Ehlers

Nereis procera Ehlers, 1868, p. 557, pl. 23, fig. 2.

This nereid, which is quite common, was taken at Stations 3, 4 and 5.

It builds tubes of what appears to be a permanent nature on blades of *Zostera* and among *Enteromorpha*. By means of an undulating movement of the body a current of water is kept circulating through the tube. I believe that it is strictly carnivorous, living on small animals which are brought to it in the current of water or which it may capture at the entrance of the tube.

Nereis vexillosa Grube

Nereis vexillosa Grube, 1851, p. 4, pl. 2, figs. 1, 5, 6.

This annelid is very common in mussel beds of both *Mytilus californianus* and *M. edulis*, but is also found in other habitats. It is of course, not common at Elkhorn Slough except under the rocks at Station 1 and on the rocks and pilings at Stations 4 and 7. Specimens 10 inches long are not uncommon.

Nereis vexillosa feeds on the smaller animals with which it is associated in the mussel beds. It is equipped with a very efficient pair of jaws for grasping its prey.

This species spawns in the spring of the year.

Nereis dumerilii var. *agassizi* Ehlers

Nereis dumerilii (Audouin and Milne-Edwards) var. *agassizi* Ehlers, 1864, p. 542, pl. 23, fig. 1.

This nereid accommodates itself to a variety of habitats, but at the Slough it was commonly found at the bases and among the roots of *Zostera* at Stations 2, 5 and 7.

Heteronereis stages were seen in February.

Nereis monterea Chamberlin

Nereis monterea Chamberlain, 1918, p. 174.

A few specimens of this annelid were screened at Station 5 from a bed of *Zostera*.

Family *Nephthydidae*

Genus *Nephthys* Grube

Nephthys assimilis Oersted

Nephthys assimilis Oersted, 1843, p. 33, figs. 93, 100.

This species was taken at Stations 2, 5 and 7, especially in regions of eelgrass. It is found at depths of from 10 to 18 inches.

I have a specimen of this annelid, about 6 inches long, the posterior third of which is divided into two complete posterior ends, one of which is but slightly smaller than the other. This worm was kept alive at the laboratory for several days, during which time it was found that both divisions of the posterior portion of the gut functioned equally well, for faecal pellets were extruded from each anus.

Nephthys caeca var. *ciliata* McIntosh

Nephthys caeca, var. *ciliata* McIntosh, 1910?

Several specimens of this worm were found at Station 2.

Family *Glyceridae*

Genus *Glycera* Savigny

Glycera robusta Ehlers

Glycera robusta Ehlers, 1868, p. 656, pl. 24, fig. 31, 32.

This species of *Glycera* seems to prefer heavier mud, as it was found only at Station 4 in such a habitat.

It burrows to a depth of several inches and lives and feeds entirely underground, using other annelids for food. This and the following species obtain their prey by everting the rather large and extensible proboscis which is equipped on the distal end with four hooks. The proboscis is also used for burrowing. The proboscis is everted into the mud ahead of the animal, and then anchored while the rest of the body is drawn after it. By this means the worm burrows quite rapidly.

Mature sperm and eggs have been obtained from this worm in late spring and early summer.

Glycera rugosa Johnson

Glycera rugosa Johnson, 1901, p. 409, pl. 10, figs. 101-102.

This species was found abundantly in the eelgrass regions at Stations 5 and 6.

It is much more common at the Slough than is *G. robusta*. At times almost every shovelful of mud turned up in the eelgrass region will yield from one to four of these worms. They are somewhat more active than the above species.

Sex products mature in late spring or early summer.

Glycera alba var. *macrobranchia* Moore

Glycera alba Rathke, 1843, p. 173, pl. 9, fig. 9
Glycer alba, var. *macrobranchia* Moore, 1911, p. 301.

A few specimens of this species were found at Stations 3 and 5.

Hemipodia borealis Johnson

Hemipodia borealis Johnson, 1901, p. 411, pl. 10, figs. 104-104a.

This slender, slate blue, glycerid worm was found at Stations 2, 3 and 7. At Station 2 it was found in the first 2 or 3 inches of soil, living among the *Enteromorpha* and *Phoronopsis*.

Family *Leodicidae*

Genus *Onuphis* Audouin and Milne-Edwards

Onuphis elegans Johnson

Onuphis elegans Johnson, 1901?, p. 406, pl. 8, figs. 77-85.

This worm was found at Stations 2 and 5. It builds a tube in which sand is incorporated. The tubes do not become rigid after construction and apparently are not permanent, but are built up as the animal moves about.

Onuphis eremita Audouin and Milne-Edwards

Onuphis eremita Audouin and Milne-Edwards, 1832-34.

Only one specimen of this worm was found, and that was at Station 8. This is the first record of this worm from the west coast of North America.

Genus *Leodice* Savigny

Leodice longicirrata Webster

One specimen of this worm was found at Station 3. This is the first record of its being found north of Panama.

Genus *Lumbrinereis* Blainville

Lumbrinereis japonica var. *index* Moore

Lumbrinereis japonica Marenzeller var. *index* Moore, 1911, p. 288, figs. 119-127.

This worm, which is fairly common, is found at Stations 1, 5 and 6. As yet I know nothing of its natural history.

Lumbrinereis impatiens Claparède

Lumbrinereis impatiens Claparède, 1868, p. 455, pl. 9, fig. 2.

Lumbrinereis impatiens is fairly abundant at Stations 3, 4 and 5.

This species is much more abundant than the one above. Specimens are exceedingly long and slender; one which I preserved has 604 segments.

Family *Cirratulidae*

Genus *Audouinia* Quatrefage

Audouinia tentaculata (Montagu)

——— *tentaculata* Montagu, 1808?
Audouinia tentaculata Saint-Joseph, 1894, p. 48, pl. 3, figs. 55-57.
(= *Cirratulus spirabranchus* Moore?, 1904, p. 492, pl. 38, figs. 26-27.

This worm builds a tube in the heavy mud at Station 1. The tube is really a burrow, that is, it has no distinct structure, other than just the hole in the mud. The animal feeds by extending its cirri onto the surface of the mud and using them to draw in detritus. These cirri are covered with cilia which carry the detritus along the cirri to the opening of the burrow, where it is taken in by the mouth of the animal.

Family *Chlorhaemidae*

Genus *Styllaroides* St. Delle-Chiaje

Styllaroides plumosa Müller

Styllaroides plumosa Müller, 1788?

(= *Trophonia papillata* Johnson, 1901, p. 416, pl. 12, figs. 122-123.)

This species was found among the rocks at Station 7. The worm is a very slow-moving creature. Nothing is known of its natural history.

Family *Opheliidae*

Armandia brevis (Moore)

Ammotrypane brevis Moore, 1906, p. 354, fig. 1.

This worm, which is very common at stations along the west side of the Slough, prefers a loose sandy soil.

It can burrow very rapidly, and in its activities it reminds one somewhat of *Amphioxus*. *Armandia brevis* can swim through loose sand as rapidly as some worms are able to swim in the water.

Its sex products are ripe in early summer.

Family *Capitellidae*

Genus *Capitella* Blainville

Capitella capitata (Fabricius)

Lumbricus capitatus Fabricius, 1780, p. 279. (Rioja, 1917)

This species was found in sandy soil at Station 2.

Genus *Notomastus* Sars

Notomastus giganteus (Moore)

Dasybranchus giganteus Moore, 1909, p. 278, pl. 9, fig. 56.

Two specimens of this beautiful worm were found in a bare sandy region at the lower end of Station 5.

This species has an eversible proboscis which is much furrowed and lobed. The first segment of the animal is bare, the next eleven have four rows of setae, two dorsal and two lateral. These setae are tree-shaped and have many fine setal hairs.

The first gill filaments of *Notomastus giganteus* appear in the twentieth segment, and at about the fortieth segment they become well-developed. These branched and eversible gills extend in a double row along the dorsal portion of the body, growing smaller in the posterior end. When the gills are first everted they unfold into beautiful white leafless-tree-like structures, which, when entirely everted, flush red with blood; then they whiten again and invert. When viewed under the microscope this is a wonderful performance. Peristaltic waves running along the body in a posterior direction cause the branchiae to disappear in advance of them and reappear as they pass. When the gills are inverted only the very tips, which are then white, are visible at the surface.

Notomastus tenuis Moore

Notomastus tenuis Moore, 1909, p. 277, pl. 9, fig. 55.

This long stringy worm is very common everywhere that the bottom is permanent or relatively so, hence at Stations 4, 5, 6 and 7.

Specimens of this species may be located without digging by noting the little black spots over the surface where they have thrown up soil. These spots are about a quarter of an inch in diameter, and the number of worms may be judged by the number of spots. In places the worms are so plentiful that they fairly bind the soil together. They no doubt form one of the most important items of food for the rest of the burrowing worms.

Notomastus tenuis is reddish in color and is about as large as a coarse thread. It is very elastic, stretching out to a length of 10 or 12 inches. Worms of this species lived for a year in limoria at the Hopkins Marine Station. They made sinuous burrows which were roughly V-shaped, and which were longer than the body of the worm.

Family *Amphictenidae*

Genus *Pectinaria* Lamarck

Pectinaria auricoma (Müller)

Amphictene auricoma O. F. Müller, 1788-1806?
Pectinaria auricoma Moore, 1908, p. 357.

Pectinaria auricoma is quite plentiful among the *Zostera* roots at Station 5, and also at Station 4.

The worm is inclosed by a conical sand tube, the small end of which, since it is not rigid, usually breaks off when the animal is dug up. The length of this more fragile, chitinous part of the tube is not known; but, since a current of water is kept circulating through the tube, it is probable that as the worm digs into the mud it leaves behind it a fragile U-shaped tube which extends to the surface. The firmer portion of the tube averages about 50 mm. in length and about 8 mm. in diameter at the oral end.

Pectinaria digs into the mud or sand by means of its oral setae, which are used as a shovel. The anterior portion of the worm is extended beyond the tube, much as a clam extends its foot, and then at intervals, as the setae dig, the tube is drawn in. This process is repeated until the worm with its tube completely disappears. As the worm is digging into the sand or lying in a dish a current of water can be seen flowing from the small end of the tube.

Pectinaria feeds much as does *Loimia* and *Pista*, except that *Pectinaria* feeds underground instead of on the surface. The cirri are extended through the sand in all directions from the open end of the tube for a distance of 6 or 8 inches to gather detritus on their slime-coated surface. The cirri are then retracted to the mouth, where they are cleaned of the adhering food. *Pectinaria* may feed while oriented in any direction.

The bristles of this worm are often found in the stomach of the Sting Ray.

Practically every specimen of *Pectinaria* which I collected contained one or more *Pinnixa longipes* within the tube.

Pectinaria spawns in the spring. Eggs or sperm are given off from the tip of the last segment of the animal. When spawning, this tip elongates and the eggs or sperm issue in a stream.

Family *Terebellidae*
Genus *Pista* Malmgren
Pista elongata Moore

Pista elongata Moore, 1909, p. 270, pl. 9, figs. 45-47.

This species (Fig. 12) is found in the sand at Station 3. It builds a U-shaped tube which is covered on the outside with sand.

The activities of this worm are much the same as those of *Loimia mon-*

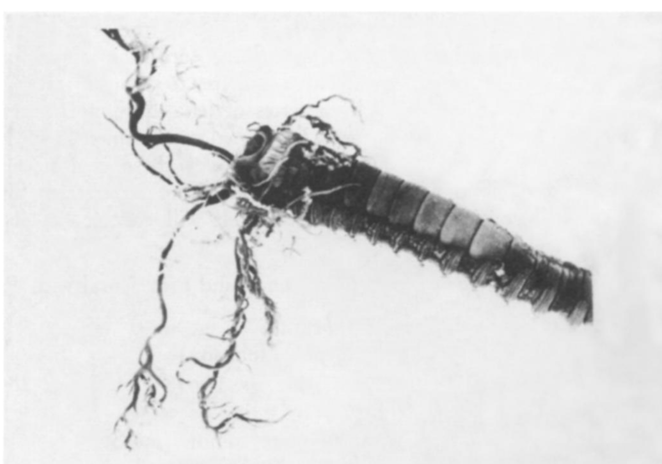


Fig. 12. *Pista elongata*. Natural size.

tagui, but it does not make any attempt to camouflage the entrance of its burrow as does the latter. The entrance of its tube is about even with the surface of the sand.

A juvenile male *Pinnixa schmitti,* and a female *Pinnixa tomentosa* were taken from tubes of *Pista.*

Terebella robusta (Johnson)

Amphitrite robusta Johnson, 1901, p. 425, pl. 16, figs. 164-168.

A few specimens of this species were found at Stations 3 and 4.

Loimia montagui (Grube)

This worm is found in the mud at Stations 2, 3 and 5.

It builds U-shaped tubes covered on the outside with sand and particles of shell. A continuous stream of water is kept flowing through the tube. Although the worm fits the tube quite snugly it can turn around within it at will. The tube projects above the mud 2 or 3 cm., and the entrance is on the side rather than at the end. From its appearance some effort seems to have been made to camouflage the entrance, for tentacle-like strings of the shell and chitinous material of the tube are left about the opening. The tubes are about 10 mm. in external diameter and are about 600 mm. in length. They are always U-shaped in the soil, the two ends usually being about 16 inches apart. Because of its fragility and the tortuous course of the tube the worms are very difficult to dig out. The worms fragment easily, especially if removed from the tube.

When *Loimia* is undisturbed its cirri are allowed to flow out the entrance of the tube. These cirri are very extensible and may reach out in any direction from the burrow for a distance of at least 12 inches, thus giving the worm a feeding surface 2 feet in diameter. Each cirrus moves independently of the others, and there may be twenty-five or more of these cirri stretched out on the surface of the mud at one time. Slime forms on the surface of the cirri and the fine particles of detritus adhere to them. After being extended a cirrus is drawn backward by a series of jerks until it is practically at the entrance of the tube, whereupon it is turned to the mouth where the food material is removed and swallowed. If one of these cirri is cut off, the circulation of the blood within it, which consists of an efferent and an afferent current, will continue, and the cirrus itself will continue to live for several days in sea water.

A dark form of *Holosydna insignis* is often found commensal with *Pista.*

Family *Sabellidae*

Eudistyllia polymorpha (Johnson)

Bispira polymorpha Johnson, 1901, p. 429, pl. 17, figs. 179-183; pl. 8, figs. 184-185.
Eudistyllia polymorpha Treadwell, 1914, p. 225.

This beautiful feather duster worm is quite common at Station 4 among the beds of *Zostera,* where its vari-colored plumes present a marked contrast to the drab surroundings.

Chone infundibuliformis Kröyer

(Rioja, 1925)

One specimen of this cirratulid was found among the eelgrass at Station 5. It was 2 inches long when preserved.

This worm has not previously been reported from the west coast of North America.

Class HIRUDINEA
Order RHYNCHOBDELLIDA
Family *Ichthyobdellidae*
Genus *Branchellion* Savigny
Branchellion sp. (sp. nov.)

Branchellion was found only on the sting ray, *Myliobatis californicus*, but nearly every specimen of the latter which was obtained harbored from one to four or more of these leeches. They ranged from 12 to 36 mm. in length.

ECHINODERMATA

Although only five species of echinoderms were found at Elkhorn Slough, they represent four of the five classes of this phylum, and, with one exception, they are sand forms of these classes. The sand dollar, *Dendraster excentricus*, is the only one of these five species which is abundant. Only one specimen each was found of the two species of holothurians, and two of the serpent star, *Amphiodia occidentalis*.

Class ASTEROIDEA
Order FORCIPULATA
Family *Asteriidae*
Genus *Pisaster* Müller and Troschel
Pisaster ochaceus (Brandt)

Asterias ochracea Brandt, 1835, p. 69.
Pisaster ochraceus Verrill, 1909, p. 63.

This species was found at Stations 2, 4, 6 and 7.

It is the only starfish that lives at Elkhorn Slough, and the only specimens which I obtained were pulled up from the bottom of deep channels with fish-hooks by fishermen. Contrary to what one would expect, none grow on the rocks and pilings at Stations 1, 4 and 7.

Class OPHIUROIDEA
Family *Amphiuridae*
Genus *Amphiodia* Verrill
Amphiodia occidentalis (Lyman)

Amphiura occidentalis Lyman, 1860, p. 194.
Amphioda occidentalis Verrill, 1899, p. 313. (Clark, 1911)

Two specimens of this species were found by screening sand from among the *Zostera* roots at Station 5. Since these two came from a 45-inch circle, careful screening would undoubtedly uncover more.

Family *Ophiothricidae*
Genus *Ophiothrix* Müller and Troschel
Ophiothrix spiculata LeConte

Ophiothrix spiculata LeConte, 1851, p. 318.

This species was found at Stations 1 and 4 under the rocks.

Class ECHINOIDEA
Order EXOCYCLOIDA
Family *Scutellidae*
Dendraster excentricus (Eschscholtz)

Scutella excentrica Eschscholtz, 1831, p. 19.
Dendraster excentricus Agassiz and Desor, 1847, p. 135. (Clark, 1925)

This sand dollar is very plentiful at Station 2. A dozen specimens can often be found within a radius of a few feet.

During the summer of 1926 many small specimens ranging from 3 to 13 mm. in diameter were screened from the sand at Stations 3 and 5. At Station 2 they may be found in abundance in all sizes up to between 30 and 40 mm., and it is probable that an age curve could be made for this species.

This species is exceedingly abundant in Monterey Bay just outside the Slough, where it is found in a narrow zone just beyond the surf line. Large specimens are often washed up on the beach outside the Slough. Many of these have barnacles *(Balanus tintinnabulum californicus)* growing on the aboral surface.

Dendraster moves about just under the sand; its presence is usually indicated by slight elevations in the sand.

Although many of the *Dendraster* in the Slough are small and sexually immature, the larger ones are ripe in the spring. Those in Monterey Bay are ripe in the spring and early summer, the majority being completely spawned out by the latter part of July or the first part of August.

Class HOLOTHUROIDEA
Order MOLPADONIA
Family *Caudinidae*
Genus *Caudina* Stimpson
Caudina chilensis (J. Müller)

Molpadia chilensis, J. Müller, 1850, p. 129.
Caudina chilensis Clark, 1908, p. 175, figs. 9-13.

One specimen of this species was found in July, 1927, on a small island at Station 2, near the east side of the Slough.

The tentacles of this *Caudina* were at the surface, and the body extended vertically into the sand for about 7 inches. Its body was a beautiful transluscent purple, with the five longitudinal lines indicated by a lighter shade tinged with yellow. The purple color faded considerably in the few days during which the animal was lying in an aquarium at the laboratory.

This species has been found in Chile, the Aleutian Islands, and at Asamushi, Japan, being very abundant in the latter locality. The specimens from each of these localities were given different names, but it is now evident that about the only reason for assigning them to different species is the wide distribution of the ones that have thus far been found. The discovery of *Caudina* at Elkhorn Slough helps to bridge the gap between Chile and the Aleutian Islands, and the fact that the spicules of the Elkhorn Slough specimen are the same as those of the Japanese form leaves little doubt as to the identity of the northern, southern and Japanese forms. It is probable that careful digging or dredging will reveal this animal in other localities between Monterey and Chile, or between Monterey and the Aleutian Islands.

Order APODA
Family *Synaptidae*
Genus *Leptosynapta* Verrill
Leptosynapta albicans (Selenka)

Synapta albicans Selenka, 1867, p. 363.
Leptosynapta inhaerens Clark, 1908, p. 88 (partim).
Leptosynapta albicans Heding, 1928, p. 208.

During this entire investigation only one specimen of this species was found at the Slough, and that was taken at Station 2 in the sandy region which is inhabited by the sand anemone, *Harenactis attenuata*.

This species is abundant along the bay shore and along the ocean beach outside Pacific Grove.

ARTHROPODA

Class CRUSTACEA

This is one of the best represented groups at the Slough, and also one of the most interesting. The entrances to the burrows of the orange mud shrimp, *Callianassa californiensis*, are in evidence almost everywhere. Along the banks, especially at Stations 1 and 4, and among the *Zostera* the burrows of the blue mud shrimp, *Upogebia pugettensis*, may be seen. The burrows of these two crustacea and of the echiurid worm, *Urechis*, afford an excellent habitat for the commensal crabs. Three of the six genera of the *Pinnotheridae* and six of the eleven species of the genus *Pinnixa* listed for the coast of California were found at the Slough. In all, eight of the twenty species of *Pinnotheridae* listed for California are represented there.

The Cancer crabs are represented by seven of the nine species recorded for California, namely: *Cancer antennarius, C. anthonyi, C. gracilis, C. productus, C. magister, C. jordani,* and *C. gibbosulus*. The first four species are the most plentiful, although young specimens of *C. magister* about an inch in width are numerous at certain times of the year. Although *C. anthonyi* has not been reported north of Long Beach before (MacGinitie, 1930), many specimens were found at Elkhorn Slough during the eight and one half years this study was carried on. The Cancer crabs are taken in considerable numbers by the campers, the favorite being *C. magister*. The proprietor of the camp ground on the north side of the highway bridge states that he measured one which was 13 inches across the carapace. None of the specimens which I collected approach this, 9 inches being the maximum. Some of the Cancer crabs seem to be more plentiful at certain times of the year, at least they are more in evidence, and I believe that they migrate in and out of the Slough.

The shore crabs are plentiful along the banks; *Pachygrapsus crassipes* may be obtained in large numbers. *Hemigrapsus oregonensis* may be obtained in almost any quantity from the ditch leading back from the large pump at the salt works. *Hemigrapsus nudus* is most plentiful along the shore and among the rocks at Station 4, but it is not nearly so plentiful as the two preceding species.

The *Zostera* beds yield rare species of Isopods, Copepods, and Amphipods. The appearance of the parasitic forms, *Argulus melanostictus* and *Livoneca vulgaris,* in a free swimming state was of interest from a distributional point of view. Of the five species of copepods taken four were new. Copepods and Amphipods were not collected intensively, so much remains to be done with these two groups. As yet very little work has been done on the Amphipods of the west coast of North America.

Order AMPHIPODA
Suborder GAMMARIDEA
Family *Ampithoidae*
Genus *Ampithoe* Leach
Ampithoe lacertosa (Bate)

Amphithoe lacertosa Bate, 1858, p. 362.

One juvenile specimen of this species was found at Station 7 in August, 1926. (U. S. N. M. Cat. No. 60100)

This is the first record of this species from the west coast.

Family *Gammaridae*
Genus *Gammarus* Fabricius
Gammarus confervicolus (Stimpson)

Maera confervicola Stimpson, 1857a, p. 90.
Gammarus convervicolus Stimpson, 1857b, p. 520.

This amphipod was first found among the rocks at Station 1. Later, on the night of November 28, 1930, numbers of them were found on *Enteromorpha,* mating.

Family *Corophiidae*
Genus *Corophium* Latreille
Corophium salmonis Stimpson

Corophium salmonis Stimpson, 1857b, p. 514.

This *Corophium,* which is characterized by its very long antennae, is common on the rocks at Station 1.

Corophium salmonis has not been reported from this locality before.

Corophium spinicorne Stimpson

Corophium spinicorne Stimpson, 1857b, p. 514.

This species, which resembles *Corophium salmonis* except for its much shorter antennae, lives among the burrows of the shipworms, *Teredo diegensis* and *Bankia setacea.* This is a new locality.

Ovigerous females were found in August.

Family *Aoridae*

Aoroides columbiae Walker

Aoroides columbiae Walker, 1898, p. 285.

A single female of this species was found at the Slough in June, 1930. This species has not been reported from this locality before.

Suborder CAPRELLIDEA

Family *Caprellidae*

Caprella scaura Templeton

Caprella scaura Templeton, 1836, p. 191, pl. 20, fig. 6.

This large caprellid is abundant at the Slough, where it may be found clinging to the *Zostera*. The *Zostera* on the west side of Station 3 was especially rich with *Caprella scaura*. All the specimens taken were the color of a dead stick.

E. F. Rickets reports having taken this species on colonies of *Aglaophenia* at depths of 60 fms., mud bottom.

Caprella aequilibra Say

Caprella aequilibra Say, 1817, p. 391.

This species is common among the hydroids, hence, is found chiefly at Stations 4, 7 and 8. The color ranges from white to brown and reddish.

Caprella acutifrons Latreille

Caprella acutifrons Latreille, 1825, p. 277.

This species was found among hydroids at Station 4. It has not been reported from this locality before.

Order CIRRIPEDIA

Suborder THORACICA

Family *Lepadidae*

Genus *Lepas* Linnaeus

Lepas hilli Darwin

Lepas hilli Darwin, 1854, p. 77.

This species occurs but rarely at the Slough, although occasionally colonies, usually of young specimens, are found attached to some floating stick or seaweed.

Family *Balanidae*

Genus *Balanus* Linnaeus

Balanus tintinnabulum californicus Pilsbry

Balanus tintinnabulum californicus Pilsbry, 1916, p. 65, pl. 14, figs. 1-3, pl. 15, fig. 4.

This barnacle occurs sparingly at Stations 1 and 4, where it is attached to rocks. Specimens are not very large.

Cross fertilization of this and other species of barnacles is accomplished by one individual extending its penis and inserting it into the oviduct of another individual which may be two or more inches distant. If cross fertilization is to take place the barnacles must be numerous enough for the penis of one to reach the oviduct of another. This distance varies with the size of the species, but in no case can it exceed 3 inches.

Mating occurs during spring and summer. In Southern California I have seen this species mating in December and January.

Balanus nubilis Darwin

Balanus nubilis Darwin, 1854, p. 253, pl. 6, figs. 2a-2c.

This is the most abundant barnacle at the Slough, for it occurs at all stations and grows anywhere it can find attachment.

Suborder RHIZOCEPHALA
Family *Sacculinidae*
Genus *Sacculina* Thompson
Sacculina sp. (undescribed)

This cirripede is frequently found on the kelp crab, *Pugettia producta* On July 29, 1929 a small *Sacculina* was found on a *Pugettia* at Station 5, and on April 21, 1930 a specimen was found on each of two male *Pugettia*.

Order COPEPODA
Suborder BRANCHIURA
Family *Argulidae*
Genus *Argulus* O. F. Müller
Argulus melanostictus Wilson

Argulus melanostictus Wilson, 1935, p. 776.

Two specimens of this parasitic copepod were found swimming free at Station 7 on August 17, 1926. Ordinarily this copepod is an ectoparasite on certain fishes.

When this copepod is distributed it swims only a few centimeters before coming to rest. It can crawl rapidly over a glass surface, just as it does on the surface of a fish, by moving the suckers one at a time. It moves in any direction, but prinicipally ahead or obliquely to one side. A current of water is kept up by a continual and very rapid movement of the swimming legs. The swimming legs are also used for brushing the under side of the carapace.

Suborder CYCLOPOIDA
Family *Clausidiidae*
Genus *Hemicyclops* Boeck
Hemicyclops thysanotus Wilson

Hemicyclops thysanotus Wilson, 1935, p. 783.

Great numbers of these small copepods are to be found crawling over the surface of *Hermissenda crassicornis* and on the egg masses of *Callianassa californiensis*.

None of these copepods have ever been found on male *Callianassa* or on non-ovigerous females. They crawl about over the eggs of the ovigerous females, probably eating the debris that collects on them, empty egg cases, or eggs that become injured or spoiled. It is doubtful if they eat good eggs, and probably do the *Callianassa* no harm. It is even possible that they may be beneficial to the latter in helping to keep the egg masses clean.

As is true of nearly all copepods, females of this species may be found with eggs at any time.

Hemicyclops callianassae Wilson

Hemicyclops callianassae Wilson, 1935, p. 782.

This species of *Hemicyclops* is nearly always present in the gill regions of *Callianassa californiensis.*

Family?

Modiolicola gracilis Wilson

Modiolicola gracilis Wilson, 1935, p. 781.

This copepod is quite abundant on the gills of *Mytilus edulis.*

Trebius caudatus Kröyer

Trebius caudatus Kröyer, 1837.

This small copepod was frequently taken from the surface of the sting ray, *Myliobatis californicus.* It travels over the surface of the fish at will, attaching itself on any portion of the surface, but is most plentiful in the more tender places, such as the posterior bases of the fins and around the anal and oral openings.

Order ISOPODA

Family *Cymothoidae*

Genus *Livoneca* Leach

Livoneca vulgaris Stimpson

Livoneca vulgaris Stimpson, 1857b, p. 508, pl. 22, fig. 9. (Richardson, 1905)

A juvenile specimen of this isopod was found at Station 5, swimming freely in an opening among the *Zostera.* The adults are parasitic in the gills of flatfish.

Family *Limnoriidae*

Genus *Limnoria* Leach

Limnoria lignorum (Rathke)

Cymothoa lignorum Rathke, 1799, p. 101, pl. 3, fig. 14.
Limnoria lignorum White, 1857, p. 227, pl. 12, fig. 5. (Richardson, 1905)

This small isopod is found associated with the shipworms, *Teredo diegensis* and *Bankia setacea,* and is found in all parts of the Slough where there is wood into which it can bore, hence it is more abundant at Stations 4, 7, and 8.

This species does much damage to piling, eating away the surface just above the 0.0 tide level. (Miller, 1926a)

It has been stated that *Limnoria lignorum* has no free swimming larval stage (Kofoid, 1921), but this must be an error, for any stake or piling that is driven into the mud becomes infected within a very short time.

Family *Idotheidae*

Genus *Pentidotea* Richardson

Pentidotea resecata (Stimpson)

Idotea resecata Stimpson, 1857b, p. 504, pl. 22, fig. 7.
Pentidotea resecata Richardson, 1905, p. 369.

At the Slough this isopod lives among the *Zostera* (Stations 4, 5, 7), orienting itself lengthwise on the blades. If disturbed it immediately orients itself again. This habit, together with its green color, makes it difficult to see one of the creatures even when looking especially for them.

All the individuals taken at the Slough were the color of the *Zostera* upon which they lived, but in other places where they occur on kelp they are the brownish color of the kelp. Still others which were found among coralline algae were either the color of the algae or had pinkish splotches which nearly concealed the original brownish coloration.

This is a very hardy species. Little is known of its food, but I have seen it eating dead worms.

Ovigerous females were found at Elkhorn Slough during the first part of April.

Family *Bopyridae*
Genus *Phyllodurus* Stimpson
Phyllodurus abdominalis Stimpson

Phyllodurus abdominalis Stimpson, 1857b, pp. 511-513. (Richardson, 1905)

This isopod is found in pairs lying across the abdomen of the blue mud shrimp, *Upogebia pugettensis*, just anterior to the pleopods. Only two pairs were found on *Upogebia* at Elkhorn Slough. This is rather interesting in view of the fact that it is common in San Francisco Bay (Lockington, 1878) and that "almost every specimen collected in Tomales Bay, in the month of May, bore. . . either. . . *Phyllodurus abdominalis* or . . . . *Pseudopythina rugifera*. . . ." Lockington also states that the smaller individuals were usually accompanied by a pair of isopods and that the larger shrimps were free of the isopod, but often bore the mollusc. This may account for the scarcity of the isopod at the Slough, for nearly all the *Upogebia* found there are exceptionally large ones. The two pairs of isopods which were found at the Slough were from medium sized *Upogebia*.

Phyllodurus abdominalis has not previously been reported from south of San Francisco Bay.

At Tomales Bay I took ovigerous *Phyllodurus* from *Upogebia* in August, 1930. The female of the pair taken at Elkhorn Slough in June of the same year was not ovigerous. A pair was taken at the Slough on May 6, 1931; the following day the female laid eggs at the laboratory. This female was kept until the eggs hatched. The larvae are very hardy.

Order DECAPODA
Family *Hippolytidae*
Genus *Hippolyte* Leach
Hippolyte californiensis Holmes

Hippolyte californiensis Holmes, 1895, p. 576, figs. 21-26. (Schmitt, 1921)

This shrimp is usually found among the *Zostera*, which it resembles in color, and is often found clinging lengthwise on the blades of the grass. It was also found occasionally among the rocks at Station 4.

Ovigerous females were found in April, July, and November. In November the ovigerous females were three times as numerous as the non-ovigerous ones. Ovigerous females were found at Morro Bay in February and July, and at Anaheim Slough they have been taken in October.

Genus *Spirontocaris* Bate

Spirontocaris paludicola (Holmes)

Heptacarpus paludicola Holmes, 1900, p. 201, pl. 3, figs. 56, 57.
Spirontocaris paludicola Rathbun, 1904, p. 101. (Schmitt, 1921)

This shrimp is very abundant among the rocks at Stations 1 and 4, being especially plentiful in the spring of the year.

The color varies; sometimes the entire body is a transparent green with reddish brown oblique lines, and sometimes only the thorax is traversed by the oblique lines, the abdomen being a uniform light green.

Individuals of this species may be kept readily in an aquarium where their interesting habits may be observed. They are scavengers, and walk about over the mud and rocks picking up with their first two pair of legs every little particle they can find. These particles are passed to the mouth, but perhaps only one in twenty-five proves edible, the undesirable ones being discarded almost immediately. From this it might seem that the sense of taste is located only in the mouth parts. However, they very quickly sense particles of clam or fish flesh which are dropped into the water, and gather around the particles in considerable numbers, apparently appearing from nowhere. The gobies, *Clevelandia ios*, gather at the feast to pick up particles as they are being torn off, and they occasionally disrupt the proceedings by giving a particle a shake while it is still attached to the main piece of flesh.

Many ovigerous females of *Spirontocaris paludicola* were found at the Slough from March to June, inclusive.

Spirontocaris picta (Stimpson)

Hippolyte picta Stimpson, 1871, p. 125.
Spirontocaris picta Rathbun, 1904, p. 101. (Schmitt, 1921).

This species is much less common at the Slough than the one above. It was found almost exclusively in the *Zostera* regions.

The specimens from the Slough were difficult to distinguish from the preceding species, for the coloring was the same, and the antennal acicle of *S. paludicola* was never so long as that described for the type. However, the other specific differences were evident.

The scarcity of this *Spirontocaris* at the Slough prevented securing any data on the breeding season, but ovigerous females have been found in Monterey Bay and along the Pacific Grove coast from March to August, inclusive. At Ensenada, Mexico, ovigerous females have been found in January.

Family *Crangonidae*

Genus *Betaeus* Dana

Betaeus longidactylus Lockington

Betaeus longidactylus Lockington, 1877, p. 35. (Rathbun, 1904; Schmitt, 1921)

In August, 1927, one specimen of this shrimp was found at Station 4 in an *Urechis* burrow. This was the first record of its being found north of San Pedro, California (MacGinitie, 1930b). In April, 1930, more were found among the rocks at Station 4, and still later another was found in an *Urechis* burrow.

I also found this species in ocean beach tidepools at Pacific Grove, and at Morro Bay I found it in the burrows of *Upogebia*. At Newport Bay I have also found it in pairs in the burrows of *Urechis*.

The specimen found at Elkhorn Slough in August was an ovigerous female. The eggs, which are bright green, began hatching after being in the laboratory for a month. The larvae escape in the mysis stage. At Newport Bay ovigerous females are plentiful in January.

Family *Cragonidae*
Genus *Crago* Lamarck
Crago nigricauda (Stimpson)

Crangon nigricauda Stimpson, 1856, p. 97.
Crago nigricauda Schmitt, 1921, p. 84, fig. 56.

Specimens of this species were found at the Slough in March, July and November, usually among the *Zostera* at Stations 4 and 5, but on one occasion they were found among the rocks at Station 4.

The specific name of this shrimp seems rather unfortunate, for of all the specimens seen at Elkhorn Slough only two had black tails at the time they were collected. I have taken thousands of these shrimps from Monterey Bay, and in every case practically all of them had tails with the same sandy effect of coloration as the body. However, when they were disturbed by taking them from the water and putting them in a bucket of seaweed their tails turned black or very dark. In the laboratory they often turn to black-tailed shrimps upon being transferred from one fingerbowl to another. This coloration disappears within a short time. I have observed this same phenomenon in *Crago nigromaculata*. On the other hand, all the specimens of *Crago stylirostris* which I have collected had black tails which remained black. The tails of *Crago nigricauda* often become black when the animals are placed in alcohol.

At Elkhorn Slough ovigerous *Crago nigricauda* were taken in March. It is probable that it is ovigerous here at other times, for ovigerous females were dredged from Monterey Bay in June and August also.

Family *Callianassidae*
Genus *Upogebia* Leach
Upogebia pugettensis (Dana)

Gebia pugettensis Dana, 1852, p. 19.
Upogebia pugettensis Holmes, 1900, p. 157. (Schmitt, 1921)

This shrimp (Fig. 13) is found at Stations 1, 4, 5 and 6. It was studied in the field, and at the laboratory by using limoria and burrows made of glass tubing, with "turn-arounds" blown at suitable places.

In the Slough *Upogebia* builds burrows in the mud or sandy mud, being more abundant where the soil contains considerable clay. In such soil individuals often attain a length of 5 or 6 inches. Along bowlder strewn beaches at

Hunter's Point (San Francisco Bay) and at Newport Beach in Southern California they are much smaller, averaging little more than 2.5 inches in length. At the latter places they are much more aboundant than at Elkhorn Slough.

In the mud at Elkhorn Slough it was possible, although difficult, to trace the burrows of *Upogebia*, which incline downward from the surface for from 18 to 24 inches, extend horizontally for several feet, and then come to the surface again.. From the horizontal portion two or more branches lead off and eventually open to the surface. *Upogebia* always live in pairs, and this

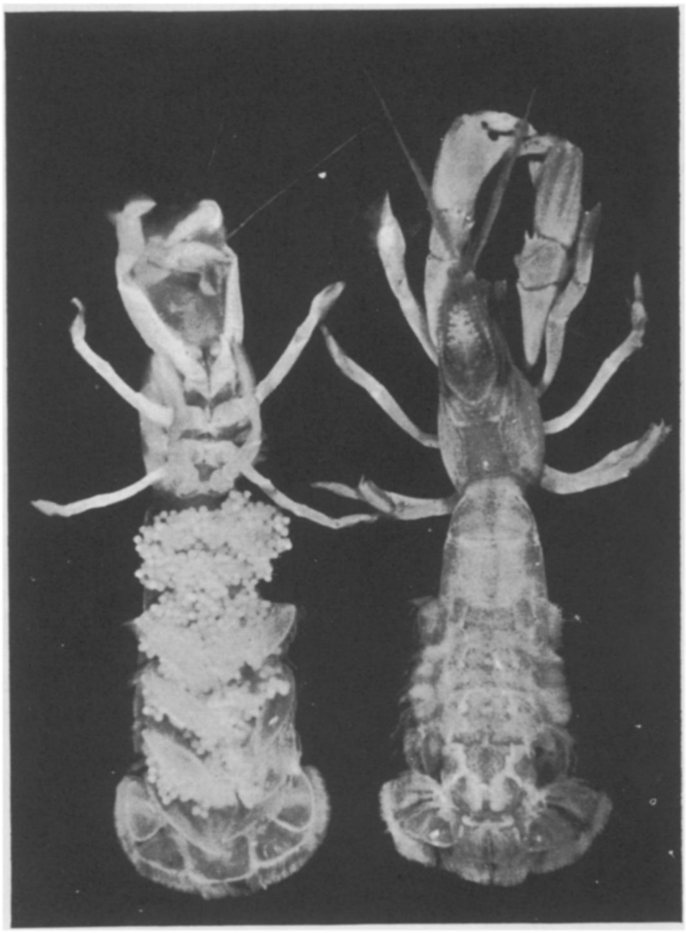


Fig. 13. Male and female *Upogebia pugettensis*. Note the fringe of hairs on the lower edges of the first pair of walking legs (ventral view) which serve to strain food from the current of water pumped through the burrow. Natural size.

accounts for the necessity for more than two entrances to the burrow. The openings of the burrows, three or four in number, are about one centimeter in diameter, but at a depth of 3 cm. below the surface the burrow enlarges to a size to accommodate the body of the animal. At various places along the burrow, and especially at points of branching, there are enlarged semi-globular places where the animals can turn around. The walls of the burrow are smooth from the rubbing by the bodies of the animals, and also from some adhesive material secreted and applied by the animal while building the tunnel.

The first two pairs of legs of the animal have long growths of hair on their anterior and posterior edges. These hairs serve a dual purpose: they form a mud basket for transporting mud to the surface when digging a burrow, and they serve as collectors of food. When *Upogebia* is digging, the soil is first loosened with the chelae of the first legs and the dactyls of the second legs. Then the hair-fringed legs gather up the loosened material much as one scoops up sand with the hands. The mud is then carried in this receptacle to the entrance and pushed outside with the chelae, or, if the burrow is in need of repair the soil is carried to the damaged portion of the tunnel and carefully worked into the sides with smoothing and tamping movements of the movable fingers of the chelae. When taking a load of mud to the entrance the animal first backs to the nearest enlargement in the burrow, turns over in much the same manner as a boy turns a somersault, then proceeds forward. On the return trip the animal backs to enlargement, turns over and then goes forward to the place of excavation.

Upogebia is a successful detritus feeder. When it is feeding it approaches one of the entrances of the burrow, and spreads its first and second walking legs against the side of the burrow. Then, by fanning with the pleopods, or swimmerets, a current of water is created which strains through the hairy borders of the legs, and these intercept the detritus. At intervals the third maxillipeds, which are equipped with brushes for the purpose, alternately sweep outward and downward to remove the collected detritus. This detritus is then taken from the third maxillipeds by the second maxillipeds, and thence finds its way to the mouth.

The fourth pair of legs of both *Upogebia* and *Callianassa* turn up and out against the sides of the burrow and serve to balance the animals as they move along. Only the third and fifth legs are used in walking.[5]

Upogebia has the following commensals: *Scleroplax granulata, Pinnixa franciscana, Hesperonoe* sp., *Phyllodurus abdominalis, Cryptomya californica,* and *Betaeus longidactylus.*

Upogebia has a definite breeding season. Females are ovigerous during January, February, and part of March. The eggs are carried on the single

5 The above acccount is condensed from Ann. Mag. Nat. Hist. (MacGinitie, 1930a).

pair of egg carriers and on the inner rami of the first three pairs of swimmerets.

Genus *Callianassa* Leach

Callianassa californiensis Dana

Callianassa californiensis Dana, 1854, p. 175. (Schmitt, 1921)

This shrimp is found at all stations, but most abudantly at Stations 3 and 5.[6] It is most abundant in tidal regions of from 0.0 to 1.0 foot. It is restricted to a soil of mixed sand and mud of a consistency to allow the construction of fairly permanent burrows. It is one of the most abundant animals in Elkhorn Slough. Perhaps no animal exerts more influence on mudflat associations than does this shrimp.

Callianassa californiensis (Fig. 14) has been reported from Mutiny Bay, Bay, Alaska, to the mouth of the Tia Juana River in San Diego County, California, but I have taken it as far south as El Estuario de Punta Banda, Lower California.

Adult individuals are from 2 to 3.5 inches in length, and vary from whitish yellow to orange-red. One cheliped, which may be either the right or the left, is exceedingly large, especially in the males.

Callianassa may be kept for observation in limoria at the laboratory. The limoria which I used were frames holding two plates of glass about threequaters of an inch apart, filled three-quarters full of mud and submerged in aquaria. Artificial burrows of glass tubing were also used, but for the study of *Callianassa* these are not so satisfactory as limoria, for the shrimps cannot carry on their natural activities in tubing.

Callianassa uses the third, fourth, and fifth pairs of legs for walking, the fourth pair being elevated and extended laterally to support and brace the animal against the walls of the burrow. The large cheliped, besides being a weapon of offence and defense in the ordinary manner, can also be used as a shield for the carapace. The second and third pairs of legs function like shovels in digging. Ovigerous females spend much time manipulating the eggs with the chelae of the fifth legs for purposes of aeration and cleaning. While *Callianassa* is resting or cleaning itself the swimmerets keep water circulating through the burrow for respiratory purposes.

The hairs or setae of *Callianassa* are of vital importance since it is through them that the animal comes in contact with its environment. They function mainly for obtaining food, for cleaning, for creating currents, for carrying eggs, and for receiving stimuli. There are many different types of hairs, with various combinations, and degrees of coarseness and fineness.

The abundance and activity of *Callianassa* make it an important animal in the Slough, and it no doubt does for the bottom soil of estuaries what the earthworm does for the field. It makes possible the existence of certain other

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6 For a detailed account of this shrimp see Amer. Midl. Nat. (MacGinitie, 1934a).

animals in that its burrows, which often extend downward as far as any other life exists, supply the deeper soil with fresh water.

Callianassa californiensis is a detritus feeder, but, unlike its relative *Upogebia,* it secures this detritus by sifting it out of the sand. When feeding, the shrimp takes sand from the face of the tunnel and sifts it by means of the hairs on the dactyls of the second and third legs. The hairs take out the desired material and allow most of the sand to slip through. The fine material which has been retained by the hairs of the legs is scraped off by the hairs of the third maxillipeds and passed into the mouth by a series of movements of the mouth parts. The discarded sand is picked up, carried to the entrance and pushed outside. (See Fig. 10, p. 683)

In a period of 24 hours a *Callianassa* works over and carries to the outside from 20 to 50 cc. of sand. Although burrows often extend downward to a depth of 30 inches the main activity is within the upper 18 inches of soil, for this is the richest part. The surface of the bottoms of sloughs, with its layer of detritus is thus continually being covered and worked deeper by the feeding and burrowing activities of these animals. The upper 18 or 20 inches of soil could be entirely turned over within a few months. No sand is brought to the surface while the entrances of the burrows are exposed at low tide, hence feeding is carried on only when the entrances are submerged. If an area containing a thriving colony of *Callianassa* is built up by drifting sand so that it is left exposed for long periods the amount of detritus deposited on the surface becomes much less, and the soil finally becomes so poor that the *Callianassa* can not obtain enough food for subsistence. If many individuals starve the few that remain will eventually die because their activities are not sufficient to bury enough detritus, and the soil becomes so sterile that they can not work over enough sand between tides to obtain a sufficient amount of food. As regions become unsuitable for *Callianassa* others are being made suitable. When a region is built up by currents until surface algae, such as *Enteromorpha,* can grow upon it, such growth not only aids the deposition of sand, but furnishes detritus and makes the soil firmer. In time the region becomes rich enough to support *Callianassa,* and in time the activities of these animals prevent the growth of *Enteromorpha.* The region continues to build up and finally becomes exposed at low tide too long to support *Callianassa.* This sterile soil is acted upon by wind and currents until it is again lowered to a depth that will support *Enteromorpha,* and the cycle is repeated. Because of variation in factors such cycles are not uniform, and several years are required to complete a cycle, especially in the regions more remote from the entrance where changes take place slowly. I have seen this entire cycle take place at Station 3, and I have pieced it out from other localities and in other estuaries along the coast.

The following commensals are found with *Callianassa californiensis* at Elkhorn Slough: *Scleroplax granulata, Pinnixa franciscana, Hesperonoe complanata, Cryptomya californica,* and two species of *Hemicyclops* (one from the egg masses, the other from the gills).

Some ovigerous female *Callianassa* may be found at any time during the year, but are much more numerous during the latter part of June and July. The eggs are carried on the first two abdominal appendages, and not on the swimmerets. The larvae, which hatch in the zoea stage, soon settle to the bottom—the majority to fall prey to the surface feeders. Juvenile specimens of *Callianassa* are seldom found, those over three-fourths of an inch averaging less than one in a hundred. Indications point to longevity for this animal. If conditions remain favorable, individuals probably live for at least 10 years.

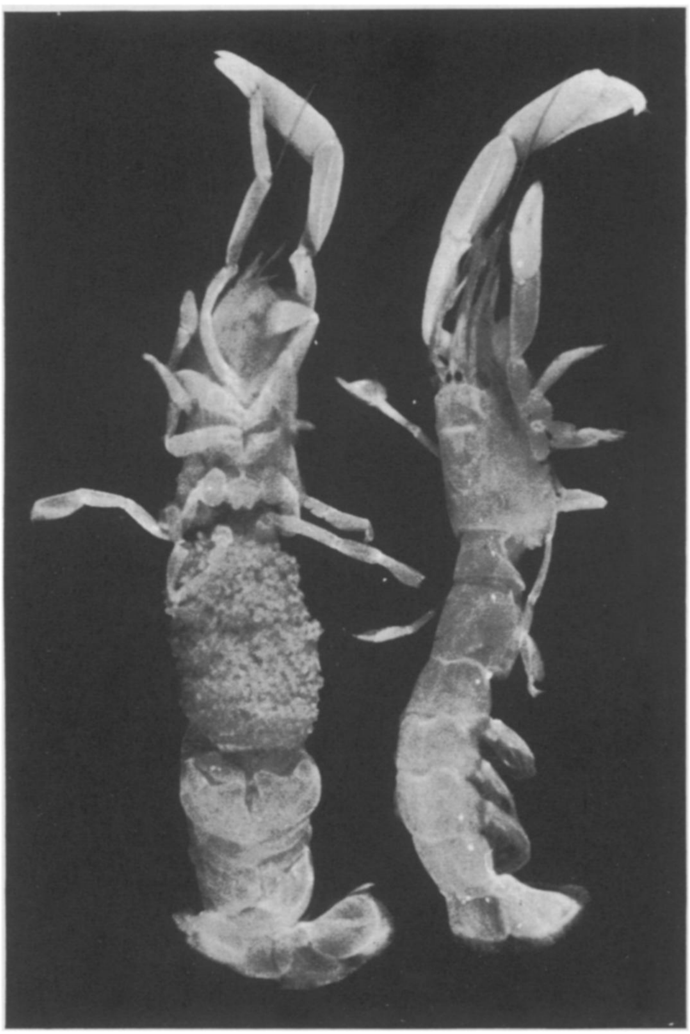

Fig. 14. Male and female *Callianassa californiensis*. Natural size.

Callianassa gigas Dana

Callianassa gigas Dana, 1852, p. 19.
Callianassa longimana Stimpson, 1857b, p. 86.
Callianassa gigas Stevens, 1928, p. 325. (Schmitt, 1921)

This species is rare at the Slough, but was taken from Stations 1, 4, 5 and 6.

A male and female taken from a burrow in the *Zostera* region at Station 5 measured 108 mm. and 104 mm., respectively. Other specimens ranged from 52 to 110 mm. in length. A female which was collected at Humboldt Bay was 134 mm. in length.

A large female which was taken on April 6 had just lost its berries. The female taken at Humboldt Bay the last of December had also just lost its berries.

Family *Paguridae*

Genus *Pagurus* Fabricius

Pagurus hirsutiusculus (Dana)

Bernhardus hirsutiusculus Dana, 1851, p. 70.
Pagurus hirsutiusculus Holmes, 1900, p. 143. (Schmitt, 1921)

This hermit crab is not common at the Slough, but it is found occasionally, especially at Station 5 in the eelgrass. Adults inhabit *Nassa fossata* shells and smaller specimens were found in shells of *Olivella biplicata* and *Littorina scutulata*.

All pagurids are scavengers, or detritus or plankton feeders, but they will take any living prey they are able to handle. (Orton, 1927; Nicol, 1932)

On July 11 an ovigerous *P. hirsutiusculus* was found, and on August 19 a female which had just lost its berries was taken.

During mating a male pagurid carries a female about, holding her shell at the aperture by means of his large chela. Actual mating is very quickly performed, both crabs emerging nearly outside their shells. The male may carry the female about for several days before mating. When a male is carrying a female it is often attacked by another male, and then a battle royal ensues.

Pagurus samuelis (Stimpson)

Eupagurus samuelis Stimpson, 1857b, p. 86.
Pagurus samuelis Holmes, 1900, p. 144. (Schmitt, 1921)

Specimens of this hermit crab were found in shells of *Tegula funebrale* and *Acanthina spirata* among the rocks at Stations 1 and 4. Like so many of the crabs at the Slough, the legs of some of these hermits were extremely hairy and were covered with hydroids and detritus.

The scarcity of specimens of this species prevented securing information about its breeding season, but ovigerous females were found on the ocean beach at Pacific Grove in August, and females which had just lost their berries were found in early March.

Family *Porcellanidae*

Genus *Pachycheles* Stimpson

Pachycheles rudis Stimpson

Pachycheles rudis Stimpson, 1859 (1860), p. 76, pl. 1. fig. 5. (Schmitt, 1921)

This small crab, which is a plankton or detritus feeder, is abundant among the rocks at Station 4.

Ovigerous females were found in August. Along the ocean beach ovigerous females were found from March until August, inclusive, and at Ensenada, Mexico, they were found in December. A male and female live together in pairs.

Genus *Petrolisthes* Stimpson

Petrolisthes cinctipes (Randall)

Porcellana cinctipes Randall, 1839, p. 136.
Petrolisthes cinctipes Holmes, 1900, p. 107. (Rathbun, 1904; Schmitt, 1921)

This species may also be found among the rocks at Station 4, but it is not nearly so plentiful as the above species, and the specimens are rather small. This crab feeds on plankton or detritus exclusively.

Ovigerous females were seen from January until July, inclusive.

Family *Inachidae*

Genus *Pugettia* Dana

Pugettia producta (Randall)

Epialtus productus Randall, 1839, p. 110.
Pugettia producta Rathbun, 1925.

This crab is quite plentiful among the *Enteromorpha,* but seems to prefer the beds of *Zostera.*

At night, like the shore crab, *Hemigrapsus oregonensis,* it has the trait of pulling *Zostera* blades together to buoy itself up as it moves about feeding, but it does not feed so near the surface as does the shore crab. It is a vegetarian, using the algal growth on the *Zostera* for food.

In July, 1929, a *Pugettia* which was taken at Station 5 was parasitized by a small *Sacculina.* Two males taken in April, 1930, were likewise parasitized, but with larger *Sacculina.*

Large numbers of ovigerous females were found in February, March, and July.

Family *Cancridae*

Genus *Cancer* Linnaeus

Cancer productus Randall

Cancer productus Randall, 1839, p. 116. (Rathbun, 1930; Schmitt, 1921)

This crab may be found at the Slough throughout the year, usually at Stations 1 to 4, inclusive, but it is found less frequently at all stations. The Cancer crabs are scavengers.

Although *Cancer productus* may be found during any month of the year it is most abundant during July and August, during which time many pairs are found mating. The female is usually soft shelled while mating. The males are larger than the females, and during mating the female is clasped for from one to several days.

Although adult *Cancer productus* are so plentiful, young ones are rarely seen in the Slough. However, in March, August and November several young males and females, with carapaces measuring from 12 to 13 mm. in width, were found.

Cancer antennarius Stimpson

Cancer antennarius Stimpson, 1856, p. 96. (Rathbun, 1930; Schmitt, 1921)

This is one of the most common Cancer crabs at the Slough. Like the above it may be found at all stations, but is most plentiful at Stations 3 and 4.

Also like the above species, it may be found at any time throughout the year, but is most plentiful during the spring and early summer. The specimens found at the Slough usually ranged from 90 to 150 mm. across the carapace. In August a male with a carapace 29 mm. wide was taken.

Ovigerous females were found in December.

Cancer anthonyi Rathbun

Cancer anthonyi Rathbun, 1897, p. 111. (Rathbun, 1930; Schmitt, 1921)

This species was found from Stations 1 to 4, inclusive. Prior to this *Cancer anthonyi* had not been reported from north of Long Beach (MacGinitie, 1930b).

Although specimens of this species were seen in March, June, July, August and November, they were much more abundant during July. They ranged in size from 38 to 150 mm. across the carapace, the majority of them being over 50 mm. wide.

Mating pairs were seen in June, and in July both males and females are numerous.

Cancer magister Dana

Cancer magister Dana, 1852, p. 73. (Rathbun, 1930; Schmitt, 1921)

This species is not particularly abundant, but it is found throughout the year at Stations 1 and 2, being most plentiful at the latter station.

Individuals with carapaces ranging from 25 to 225 mm. in width were taken, but adult specimens are very rare in the Slough, no doubt due to their desirability as food for man. A resident near the Slough says that large specimens of *Cancer magister* were formerly taken from the Slough, but that they have been fished out in recent years.

A mating pair was seen in March. The carapace of the female was 87 mm. long and 129 mm. wide, and that of the male was 130 mm. long and 189 mm. wide.

Cancer gracilis Dana

Cancer gracilis Dana, 1852, p. 73. (Rathbun, 1930, Schmitt, 1921)

This Cancer was found from Stations 1 to 5 inclusive.

During the summers of 1926 and 1927 only two individuals of this species, a male and a female, were found. But in November, 1930, they were so numerous that it was the most common Cancer at the Slough. In general they are quite abundant.

Ovigerous females were seen at the Slough in July and August. Many mating pairs were found in November.

Cancer gibbosulus (De Haan)

Corystes (Trichocera) gibbosula De Haan, 1835, p. 45, pl. 2, fig. 4; pl. 13, fig. 3.
Cancer gibbosulus Rathbun, 1898, p. 581. (Rathbun, 1930; Schmitt, 1921)

One immature female was taken at Station 1 in September, 1927. The carapace was 17 mm. long and 23 mm. wide.

Cancer jordani Rathbun

Cancer jordani Rathbun, 1900, p. 133. (Rathbun, 1930; Schmitt, 1921)

One male specimen of this species was taken at Station 1 in August, 1927. The carapace was 19.3 mm. long and 26.4 mm. wide.

Ovigerous females were taken from Monterey Bay in October.

Family *Pinnotheridae*
Genus *Pinnixa* White
Pinnixa faba White

Pinnotheres faba Dana, 1851, p. 253.
Pinnixa faba Holmes, 1900, p. 93. (Rathbun, 1918; Schmitt, 1921)

This crab is commensal in the gaper clam, *Schizothaerus nuttallii,* which is found at all stations in the Slough.

Pinnixa faba has previously been reported from Alaska to Humboldt Bay. I have taken it not only at Elkhorn Slough (MacGinitie, 1930b), but at Morro Bay and as far south as Newport Bay. In nearly every case the host is *Schizothaerus*. At Humboldt Bay practically every *Schizothaerus* taken (in the month of January) contained a pair of these crabs, but at Elkhorn Slough less than half the *Schizothaerus* contained a crab.

At Elkhorn Slough ovigerous females were found in July, August and March. In two instances a male and female were found in the same clam. Both of the females were ovigerous. At Humboldt Bay these crabs were, with one exception, found in pairs during the month of January. Out of 19 females 9 were ovigerous and 10 were non-ovigerous.

Pinnixa franciscana Rathbun

Pinnixa franciscana Rathbun, 1918, p. 161, fig. 100; pl. 35, figs. 1-4. (Rathbun, 1918; Schmitt, 1921)

Prior to the finding of this crab at Elkhorn Slough (MacGinitie, 1930b) only twelve specimens had been reported, nine females and three males, the latter without chelipeds. These were taken in dredge hauls in San Francisco Bay (Rathbun, 1918) at depths of from 9.5 to 13.5 fms. The habitat of the species was not determined.

At Elkhorn Slough so many specimens of this species were found that a record was not kept of them after 50 had been taken. They occur most frequently in the burrows of *Urechis caupo,* but ten were taken from the burrows of *Callianassa californiensis* and one was found in an *Upogebia* burrow. Six of those found with *Callianassa* (in August) had carapaces less than 5 mm. in width. The specimens from the Slough ranged from 2.8 mm. in length by 5.4 mm. in width to 11 mm. in length by 22 mm. in width.

Since taking these crabs at Elkhorn Slough I have subsequently found them at Morro Bay in the burrows of *Urechis* and of *Callianassa,* and at Newport Bay in the sand in a *Upogebia* bed. Mr. S. A. Glassell has taken over a dozen of these crabs from *Upogebia* beds at Newport Bay, but did not actually find them in the burrows. All of these specimens were small compared with those from Elkhorn Slough.

Pinnixa franciscana screens detritus, by means of its second maxillipeds, from the current of water passing through the burrows of its hosts; and it will also feed on particles of worms, clams, etc. During the latter part of June several individuals were observed molting.

At Elkhorn Slough the majority of the females are ovigerous in March. At Morro Bay three ovigerous females were taken in March and one in July.

Pinnixa longipes (Lockington)

Tubicola longipes Lockington, 1876 (1877), p. 55.
Pinnixa longipes Holmes, 1894 (1895), p. 573, pl. 20, figs. 19-20. Rathbun, 1918; Schmitt, 1921)

This minute crab was found at Stations 4 and 5 commensal in the tubes of *Pectinaria auricoma*. Two large males were also found in the burrows of *Urechis caupo*.

On the ocean beach at Pacific Grove, as well as in Tomales Bay, I have found this crab in the tubes of *Pista elongata*. At Morro Bay and Newport Bay it is found in tubes of *Clymenella rubrocincta*. With the exception of the latter, these represent new habitats.

Ovigerous females were found in July and August.

Pinnixa schmitti Rathbun

Pinnixa occidentalis Rathbun, 1904, p. 187.
Pinnixa schmitti Rathbun, 1918, p. 162, fig. 101; pl. 35, figs. 6, 7, and 9. (Rathbun, 1918; Schmitt, 1921)

One juvenile male of this species was found at Station 5 in a tube of *Pista elongata*.

This was the first record (MacGinitie, 1930b) of *Pinnixa schmitti* being found south of San Francisco Bay, but I have also taken it as far south as Morro Bay. In the latter place it was commensal with *Upogebia pugettensis* and *Callianassa californiensis*. At Humboldt Bay I found it in the mantle cavity of *Macoma secta*. Wells (1928) found *P. schmitti* in burrows of *Upogebia* at Puget Sound, but with this exception the habitats given above are all new.

Pinnixa tomentosa Lockington

Pinnixa tomentosa Lockington, 1876, (1877), p. 156. (Rathbun, 1918; Schmitt, 1921)

One female of this species was taken in August at Station 5 in a tube of *Pista elongata*. Prior to this none had been reported (MacGinitie, 1930b) from north of San Clemente Island, California. No habitats have been recorded.

At Corona Del Mar, California, I have taken this species at depths of from 10 to 66 fms. in tubes of *Chaetopterus variopedatus*. One specimen was a male, taken in February, 1933. No males have yet been recorded, but Mr. Glassell has taken several since, and is now describing them.

The female taken at Elkhorn Slough was not ovigerous; one taken at Corona Del Mar in March was carrying eggs.

Pinnixa tubicola Holmes

Pinnixa tubicola Holmes, 1894 (1895), p. 569, pl. 20, figs. 17-18. (Rathbun, 1918; Schmitt, 1921)

One male *Pinnixa tubicola* was found free at Station 5 in July. Among the Pinnotheridae the males are usually smaller than the females, and mating depends upon the males going to the females, which are often permanently located.

Ovigerous females were taken in Monterey Bay in June and August.

Genus *Scleroplax* Rathbun

Scleroplax granulata Rathbun

Scleroplax granulata Rathbun, 1893, p. 251. (Rathbun, 1918; Schmitt, 1921)

This pinnotherid, although found at all stations, is very abundant at Station 4. It was first found in July, 1926.

Scleroplax granulata is commensal with *Urechis caupo* (Fisher and MacGinitie, 1928b), *Upogebia pugettensis* (MacGinitie, 1930a), and *Callianassa californiensis* (MacGinitie, 1934a). Wells (1928) found it in *Upogebia* burrows at Puget Sound. Way (1917) reported a male and a female from the mantle cavity of *Mya arenaria* at Friday Harbor, but after having collected several hundred *Scleroplax* from Humboldt Bay, California, to Ensenada, Lower California, and after studying its habits and adaptations over a period of several years I do not believe that the mantle cavity of a clam is the normal habitat of this crab. It is probable that the clam served as a temporary refuge. The anatomical structure of this crab, as well as its feeding habits, fit it for life in a burrow.

The food of *Scleroplax* consists of particles which wash into the burrows of *Upogebia, Urechis* and *Callianassa,* and of particles which the latter uncovers while digging. Most pinnotherids can supplement their diet by fanning plankton. *Scleroplax* was never observed doing so, however.

It is not uncommon to find more than one *Scleroplax* in the same burrow. On one occasion I took six *Scleroplax* from one *Urechis* burrow, and on another occasion three ovigerous females were taken from one burrow. On a third occasion a male and two ovigerous females were taken from one *Urechis* burrow. A male and a female are often found together in a burrow, and frequently two females are in one burrow. On one occasion an ovigerous female was found in a burrow with an ovigerous *Pinnixa franciscana,* and in another burrow a male *Scleroplax* and a male *P. franciscana* were found.

The carapaces of male *Scleroplax* from Elkhorn Slough ranged from 3.0 mm. in length by 3.9 mm. in width to 8.5 mm. in length by 12.4 mm. in width; of the females from 2.4 by 3.1 mm. to 9.0 by 13.1. mm. In several instances ecdysis took place in June.

Scleroplax has the habit, when disturbed, of playing possum, and will remain rigid for a few seconds or even for one or two minutes.

Although a few ovigerous females were found in June, July and August, by far the greater number are ovigerous in February, March and April. Out of 75 females taken between March 6 and March 24 (of the same month), 70 were ovigerous. Toward the latter part of April of the same year only 26 out of 44 were ovigerous. Ovigerous females, with a carapace measuring 3.7 mm. long by 4.9 mm. wide, were found with the abdomen still immature. The female abdomen is often immature in specimens with a carapace 4.2 mm. long by 5.7 mm. wide, but it begins to differentiate in specimens only 2.4 mm. across the carapace.

Genus *Opisthopus* Rathbun

Opisthopus transversus Rathbun

Opisthopus transversus Rathbun, 1893, p. 252. (Rathbun, 1918; Schmitt, 1921)

Only one specimen of this ubiquitous pinnotherid was found at the Slough and that was taken from the mantle cavity of a *Sanguinolaria nuttallii* from Station 2. The crab was a male.

Family *Grapsidae*

Genus *Pachygrapsus* Randall

Pachygrapsus crassipes Randall

Pachygrapsus crassipes Randall, 1839, p. 126, pl. 5, fig. 4 (Rathbun, 1918; Schmitt, 1921)

This shore crab is very numerous in burrows along the entire east bank, and among the rocks at Stations 1 and 4, and around the pilings and rocks at Station 7.

Many individuals of this species are covered with barnacles, bryozoa, etc. One had so many barnacles that it could not move one of its eyestalks and one leg. The other eyestalk, as well as one chela and first leg, was missing, and a small *Mytilus edulis* was growing near the missing eyestalk and another at the base of the missing leg.

These crabs may be seen at the mouths of their burrows along the bank, but they usually vanish if one approaches near them. Sometimes they perch outside their burrows and "blow bubbles," the continued respiratory movements causing the entire forward portions of the creatures to be surrounded by foam. Specimens may be obtained by locating a burrow along the bank, then pushing a shovel blade down back of the entrance, and then, as the crab runs out of the burrow when the shovel handle is lowered it may be caught with a net.

Pachygrapsus crassipes is a scavenger as an adult, but juveniles pick algal growth by means of their chelae and eat it. One adult was found holding a living young *Cancer anthonyi* and eating it piecemeal. The mouth parts had been partly eaten and the shore crab was very reluctant to release its victim.

Genus *Hemigrapsus* Dana

Hemigrapsus nudus Dana

Pseudograpsus nudus Dana, 1851, p. 249.
Hemigrapsus nudus Rathbun, 1904, p. 189. (Rathbun, 1918; Schmitt, 1921)

This species is common among the rocks at Stations 4 and 7. Unlike the other shore crabs, its range at the Slough is extremely limited, and, unlike the above species, it does not inhabit burrows along the bank.

Hemigrapsus oregonensis (Dana)

Pseudograpsus oregonensis Dana, 1851, p. 248.
Hemigrapsus oregonensis Rathbun, 1904, p. 189.

This shore crab is the most plentiful of all the crabs at the Slough and is found at all stations. Although it prefers beds of *Zostera* or algae, such as *Enteromorpha* or *Polysiphonia,* as places of refuge, many individuals are found on the open bottom. Small specimens often scuttle into the burrows of *Callianassa, Upogebia* and *Urechis* for temporary places of refuge. Great numbers collect in the ditch above the highway bridge where the pump of the salt works lifts water from the Slough and empties it into a ditch leading to the evaporating works.

When the tide is out *Hemigrapsus* has a curious habit of collecting in considerable numbers on small exposed areas, such as mounds of *Enteromorpha* or of mud left by clam diggers, and exposing themselves to the air.

This crab feeds mostly at night, and by the aid of a flashlight one may see individuals buoyed up on several blades of *Zostera* which they hold together with the legs. As they move about they reach out and draw in new blades before releasing the others. One crab was found tightly grasping a hermit crab, which it probably devoured.

MOLLUSCA

Because of the many different conditions of bottom soil represented at the Slough the molluscs are plentiful both in species and individuals, and they offer one of the best examples of adaptive deployment to be found. Some adhere strictly to one kind of bottom; whereas others apparently try to adjust themselves to all.

Schizothaerus nuttallii is an example of the latter, and *Zirfaea gabbi* of the former. *Zirfaea gabbi* is a borer and requires hard soil such as that at the northeast end of Station 1. *Schizothaerus nuttallii* attempts to use it, but the resulting clam is dwarfed and rounded, giving a clew to the development of boring clams. Being practically sessile, but having no boring apparatus, *S. nuttallii* develops best in a soil that is not too firm, and so it is found at its best in the loose sand at Station 2. Farther inland among the *Zostera* and where the soil is more compact *S. nuttallii* shows an intermediate state or just average development. The same thing is true of *Macoma nasuta.*

The general attitude of biologists toward clams is that they are an uninteresting group except when prepared for the table. Nevertheless their adaptations and activities are of considerable interest and furnish much food for thought, particularly along evolutionary lines. It seems to me that they offer exceptional opportunity for study, especially for physiologists. Although molluscs have no striated muscle, they give responses which are typical of it. Kymograph records made from clam muscles also show curves typical of striated muscle.

One could list the clams at Elkhorn Slough in a complete series according to their degree of activity. This list would begin with *Solen sicarius,* which is able to swim either backward or forward, jump out of a pan, and move up and down its burrow very rapidly; and would end with *Zirfaea gabbi* or *Pholadidea penita,* whose movements are extremely slow. The life activities of the latter species consist only of pumping currents of water for respiration and feeding, and of reproducing.

Clams have a decided economic importance, but because of a lack of knowledge on the part of those entrusted with the making of laws governing their use commercially, they have been depleted to the extent that this importance has become practically nil.

The gasteropods have also been a source of considerable interest. The beauty of the nudibranchs is unsurpassed. Both these and the tectibranchs have a great variety of interesting methods of egg-laying. The feeding activities of others, as described later, could not fail to attract the attention of anyone who is interested in living creatures.

Class PELECYPODA
Family *Ostreidae*
Genus *Ostrea* Linnaeus, 1758
Ostrea lurida Carpenter

Ostrea lurida Carpenter, 1863, p. 645.

This oyster is very plentiful in all parts of the Slough where there are rocks or pilings to which it can attach, hence at Stations 1, 4 and 7. It is also found abundantly at the railway bridge five miles up from the mouth of the Slough. *Ostrea lurida* attaches to anything solid. It must be kept free from mud, i.e., be up off muddy bottoms, otherwise it is smothered. It seems to be especially partial to iron as a place of attachment. (Fig. 15)

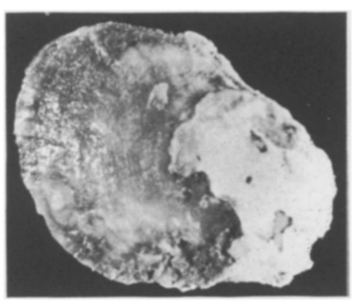

Fig. 15. *Ostrea lurida.* x 2/3.

Although *Ostrea lurida* is commercially propagated in the northern waters of our west coast, this has not yet been attempted at Elkhorn Slough, but the wild stock has been gathered and sold from there. I believe that this oyster will in time be the only one propagated on the west coast, an opinion also held by Dr. Galtsoff and Dr. Hopkins, who have charge of the oyster investigation for the Bureau of Fisheries on this coast.

As specimens of this oyster develop they are first male and then female. The eggs are brooded and larvae are given off in spring and summer.

Ostrea elongata Solander

Ostrea elongata Solander, 1786, p. 151.
(= *Ostrea virginica* Gmelin, 1792, p. 3336, sp. No. 113.)

This oyster has been introduced into Elkhorn Slough many times, but, because of the low temperature, it will not reproduce there. There are large beds at Station 8 and above the highway bridge.

Planted spat grows very rapidly, and the marketable oysters are of good size and fine flavor. The Japanese oyster, *Ostrea giganteus,* has also been planted at the Slough, but because of the black edge of the mantle and the report that people have become ill from eating this oyster raw, it has not been commercially profitable.

Family *Pectinidae*
Genus *Pecten* Müller, 1776
Pecten hindsii Carpenter

Pecten hindsii Carpenter, 1864, p. 645.

A few specimens of this pecten were found among the rocks at Station 4.

Genus *Hinnites* DeFrance, 1821
Hinnites giganteus Gray

Hinnites giganteus Gray, 1825, p. 103.

Since this pecten becomes sessile, the lower or right valve attaching firmly to rock, it is found at the Slough only at Stations 1, 4 and 7.

A specimen from the Slough spawned profusely on April 21.

Family *Anomidae*
Genus *Pododesmus* Philippi, 1837
Pododesmus macroschisma (Deshayes)

Monia macroschisma Deshayes, 1839, p. 359.
Pododesmus macroschisma Dall, 1898a, p. 780.

Occasional specimens of this rock oyster were found attached to the rocks at Stations 1, 4 and 7. They attach directly to a rock by means of the adductor muscle which passes through a hole in the lower valve.

Family *Mytilidae*
Genus *Mytilus* Linnaeus, 1758
Mytilus edulis Linnaeus

Mytilus edulis Linnaeus, 1758, p. 705.

This mussel grows everywhere at the Slough that it can find a place of attachment, being especially abundant on the rocks at Station 1, and on the pilings at Stations 4, 7 and 8. At Station 8 the shells are so overgrown with hydroids that they are scarcely recognizable. One was found growing under the abdomen of a kelp crab, *Pugettia producta,* and others (one of which was 68 mm. in length) were growing attached to the siphon plates of the gaper clam, *Schizothaerus nuttallii.* At Tomales Bay this species attaches itself to little rocks and gravel all over the sand.

Mytilus edulis spawns at intervals from the beginning of spring to early fall.

Genus *Modiolus* Lamarck, 1799

Modiolus rectus (Conrad)

Modiola recta Conrad, 1837, p. 243, pl. 19, fig. 1.
Modiolus rectus Arnold, R., 1903, p. 120.

Although this solitary mussell is rare at the Slough, a specimen is occasionally found at Stations 3, 5, 6 and 7.

It lies at an angle with two thirds of the shell buried in the sand, and the portion which extends above the surface is covered with algae and hydroids.

Modiolus capax Conrad

Modiolus capax Conrad, 1837, p. 242.

A few half-grown specimens of this mussel were found at Station 4.

Genus *Botula* Mörch, 1853

Botula diegensis Dall

Modiolus diegensis Dall, 1911, p. 110.
Botula (Adula) diegensis Dall, 1916, p. 18.

This tiny bivalve is quite abundant on the under side of rocks at Stations 1 and 4, where it seeks protection by attaching with its byssus threads in crevices of rocks or in empty barnacle shells.

Genus *Lithophaga* Bolten, 1798

Lithophaga plumula Hanley

Lithodomus plumula Hanley, 1844, p. 17.
Lithophaga plumula Dall, 1898a, p. 799.

This mussel is found in burrows in the marble rocks at Station 7 at the southern end of the bridge.

This is the only boring mollusc known to secrete acid to dissolve a burrow. Harmful effects to its own shell are prevented by its extra heavy periostracum.

Lithophaga plumula spawns in January and February. Larvae raised in the laboratory metamorphosed to the bivalve stage in ten days. They evidently fed on bacteria and protozoa developing in the dish.

Family *Chamidae*

Genus *Pseudochama* Odhner, 1917

Pseudochama exogyra (Conrad)

Chama exogyra Conrad, 1837, p. 256.
Pseudochama exogyra Dall, 1921, p. 33.

This species is found sparingly at Stations 1 and 4

Family *Leptonidae*

Genus *Kellia* Turton, 1822

Kellia laperousii (Deshayes)

Chironia laperousii Deshayes, 1839, p. 357.
Kellia laperousii Carpenter, 1864, p. 643.

This small clam is quite abundant at Station 1, where it inhabits old barnacle shells, and at Station 4, where it is found not only in old barnacle shells, but also in the rocks in old burrows of *Pholadidea.* Ten *Kellia,* ranging from 2 to 19 mm. in length, were found in a group in one old shell in a rock.

The foot of *Kellia* is very extensible and is sticky on the distal end so that the animal is able to move about quite easily. There is but one siphon, which is incurrent, and the opening posterior to the foot is used as an excurrent siphon.

Genus *Pseudopythina* Fischer, 1884

Pseudopythina rugifera (Carpenter)

Pythina rugifera Carpenter, 1864, p. 643.
Pseudopythina rugifera Dall, 1916, p. 29.

In April, 1930, four of these clams, all about 10 mm. in length, were found loose in a burrow of *Upogebia.*

This species has previously been reported from Puget Sound and Tomales Bay, where it was found on the abdomen of *Upogebia.* It occurs in Monterey Bay attached to the foot of the sea mouse, *Aphrodite.* It is my belief that these clams attach and detach themselves at will.

Pseudopythina compressa Dall

Erycina (Pseudopythina) compressa Dall, 1899, p. 888, pl. 87, figs. 1, 8.
Pseudopythina compressa Dall, 1899. (Dall, 1916, p. 29)

One large specimen only of this clam was found, and that was attached to the abdomen of a large *Upogebia* which was taken at Station 4, in March, 1930. The clam was attached to the shrimp just anterior to the pleopods.

Family *Cardiidae*

Genus *Cardium* Linnaeus, 1758

Cardium corbis (Martyn)

Pectunculus corbis Martyn, 1784, pl. 28, fig. 2.
Cardium corbis Carpenter, 1863, p. 642.

This cockle, which is fairly plentiful, is found in the sandy regions at all stations. It has been collected and eaten by Japanese and Italians until it is becoming rare.

Since the siphon of this clam projects just beyond the shell, the clam lies either partly exposed or buried so that the siphon is just at the surface. The clam is rather active, and can move a considerable distance in a day. It usually remains where the bottom is not exposed at low tide. But if an exceptionally low tide occurs, especially after a period in which there have been no low tides for several weeks, it will be found out on the exposed flats, where it has migrated during the high water.

One specimen was found with a loosened mantle in the right valve, and a nestler, *Saxicava arctica* (length 17 mm.), and six *Phoronopsis* had taken up their abode within the valve. Judging from the growth of the shell beyond the point of injury to the mantle, and by the apparent age of the *Saxicava,* the phoronids and nestler had been within the *Cardium* for about a year.

Family *Veneridae*
Genus *Tivela* Link, 1807
Tivela stultorum (Mawe)

Donax stultorum Mawe, 1823, p. 37, pl. 9, fig. 7.
Tivela stultorum Dall, 1903a, p. 386.

This clam is strictly a beach form, but several times it was found at Station 2, and on one day as many as nine clams, ranging from 24 to 124 mm. in length, were counted. The bottom conditions at Station 2 are somewhat like those of the open beach. However, the periostracum of these clams was rather badly discolored by the mud.

Since *Tivela* has a very heavy shell and can close so tightly that it is able to remain out of water for a long time, it is admirably suited to commercial purposes. One which was taken to the laboratory remained tightly closed and was apparently uninjured after being out of water for a week.

Genus *Saxidomus* Conrad, 1837
Saxidomus nuttallii Conrad

Saxidomus nuttallii Conrad, 1837, p. 249, pl. 19, fig. 12.

This large clam is found in limited numbers at Stations 2, 3, 4, 5 and 6. (Fig. 16)

Fig. 16. *Saxidomus nuttallii*. Natural size, small specimen.

Because of its value as a food clam it is being rapidly exterminated by the Italians and Japanese who have taken it by the sacksful. This is one of the few larger clams at the Slough which has neither parasite nor commensal.

Genus *Paphia* Bolten, 1798
Paphia tenerrima (Carpenter)

Tapes tenerrima Carpenter, 1856, p. 200.
Paphia tennerima Dall, 1903a, p. 399.

Although this cockle is very rare at the Slough, a few specimens were found at Stations 3, 5 and 6, and during the summer of 1927 six young ones were found at Station 2.

Paphia staminea (Conrad)

Venus staminea Conrad, 1837, p. 250, pl. 19, fig. 15.
Tapes staminea Carpenter, 1863, p. 641.

This rock cockle is common at any station, but the greatest number are found among the rocks at Station 4. The scattered individuals at the other Stations are usually found among the *Zostera* roots.

Family *Petricolidae*
Genus *Petricola* Lamarck, 1801
Petricola carditoides (Conrad)

Saxicava carditoides Conrad, 1837, p. 255, pl. 20, fig. 8.
Petricola carditoides Arnold, R., 1903, p. 154.

This clam is very rare. The one live specimen found was in an empty borer clam burrow in a rock at Station 4.

Family *Tellinidae*
Genus *Tellina* (L.) Lamarck, 1799
Tellina buttoni Dall

Tellina buttoni Dall, 1900, p. 324, pl. 4, figs. 12, 13.

This small *Tellina* was found at Station 2 under the same conditions as *T. bodegensis*, but was not nearly so plentiful as the latter.

Tellina bodegensis Hinds

Tellina bodegensis Hinds, 1844, p. 67, pl. 21, fig. 2.

Many specimens of this clam, ranging from 25 to 37 mm. in length, were found at Station 2 in the summer of 1927, and have been found sparingly there since.

Tellina bodegensis has split siphons which are very long in proportion to the size of the clam, the incurrent siphon being much longer than the excurrent. One clam with an incurrent siphon of 102 mm. had an excurrent siphon 48 mm. long, and in another case the incurrent siphon was over three times as long as the excurrent. Portions of the siphons are often autotomized when the clam is disturbed.

If clams of this species are left exposed too long at low tide they come to the surface in search of water, and then remain lying on the sand. Their habits give one the impression that they are not yet adapted to slough conditions.

Genus *Macoma* Leach, 1819
Macoma inquinata (Deshayes)

Tellina inquinata Deshayes, 1854, p. 357.
Macoma inquinata Carpenter, 1864, p. 525, 611, 639, 682.

Several varieties of this species are found at the Slough at all stations and in considerable numbers, although they occur scatteringly. They average from 30 to 35 mm. in length and are found at depths not exceeding 6 inches.

Macoma nasuta (Conrad)

Tellina nasuta Conrad, 1837, p. 258.
Macoma nasuta Carpenter, 1863, p. 639.

This bent-nosed *Macoma,* which derives its name from the fact that the valves are turned to the right on the siphon end, is the most common clam at the Slough. A shovelful of mud in a *Zostera* bed may bring up from 10 to 20 of these clams. Two hundred seventy-seven were taken from a 45-inch circle in an eelgrass region.

Macoma lies in the mud on its left side, with the bent portion of the shell turned upward, and may be found anywhere in the upper foot of soil. If one is placed on the surface of the sand it rapidly buries itself. The foot is first worked into the sand, then the tip of the foot is enlarged, and, with this as an anchor the body of the clam is drawn into the sand by sawing the shell back and forth.

Macoma nasuta (Fig. 17) varies in size and shape according to the nature of the soil in which it is buried. In the hard clay at Station 1 specimens are much thicker, and are not buried so deeply as they are in loose sand. In very loose sand they are thinner and attain a much greater size than those found elsewhere.

That *Macoma nasuta* is so successful may be explained by the fact that its unique method of feeding upon detritus is very efficient. The incurrent siphon is extended out of the sand for a distance of one or two centimeters. Then the tip is rotated or waved back and forth over the surface of the sand, sucking up any detritus that is deposited upon it. After two or three minutes of sucking up the detritus in this manner the siphon is retracted even with the surface of the sand, and soon the clam blows out through this same siphon the sand and other inedible materials taken in. This process is repeated several times, then the siphon is drawn down and extended in another place 3 or 4 inches away, where feeding is again resumed. The excurrent siphon is small and does not reach the surface.

This species spawns in summer.

Macoma secta (Conrad)

Tellina secta Conrad, 1837, p. 257.
Macoma secta Arnold, R., 1903, p. 164, pl. 16, fig. 5.

This species is found occasionally at Stations 2 and 3, and rarely at Stations 5 and 6. It prefers loose sand, and is very sensitive to unfavorable conditions, for it succumbs to exposure quicker than any other clam at the Slough.

M. secta is easily located by the two holes made by its incurrent and excurrent siphons. For an average specimen at the Slough (50 mm. long) these holes are from 1 to 2 inches apart. They may be confused with the siphon holes of *Sanguinolaria nuttallii,* which are similar.

Family *Psammobiidae*
Genus *Sanguinolaria* Lamarck, 1799
Sanguinolaria nuttallii Conrad

Sanguinolaria nuttallii Conrad, 1837, p. 230, pl. 17, fig. 6.

One specimen of this clam was found at Station 5, in 1926, but no more were located until the following year, when a dozen or more were found at Station 2.

S. nuttallii prefers sand so loose that it is very difficult to dig, for it lives at a depth of about 18 inches. Specimens may be located by finding the siphon holes, which are about 2.5 inches apart.

Prior to the finding of *Sanguinolaria nuttallii* at Elkhorn Slough (Mac Ginitie, 1930b) it had not been reported from north of San Pedro.

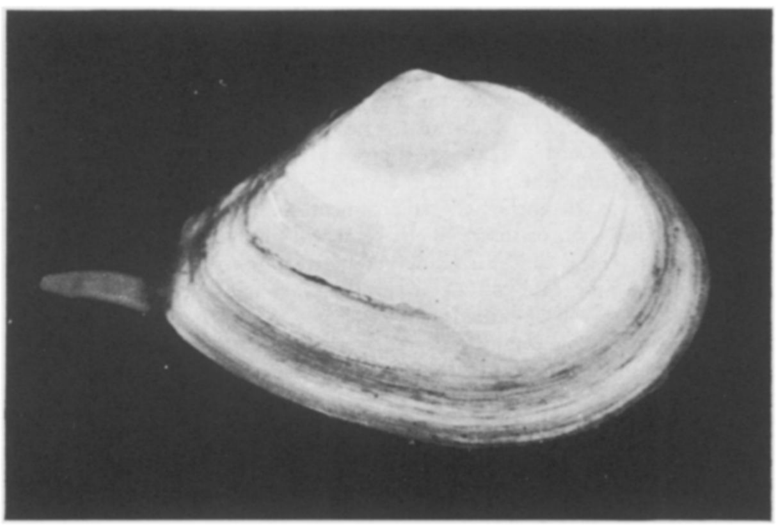

Fig. 17. *Macoma nasuta*, the bent-nosed clam. x 1.5. Note the larger size of the incurrent siphon.

Genus *Tagelus* Gray, 1847
Tagelus californianus (Conrad)

Solicurtis (Cultellus) californianus Conrad, 1837, p. 233, pl. 18, fig. 3.

Tagelus californianus Dall, 1898b, p. 59.

This jackknife clam does not live in the stations studied at the Slough, but it does occur abundantly about 2 miles inland from Station 7.

This species has not previously been reported north of Santa Barbara.

Family *Solenidae*
Genus *Solen* (L.) Scopoli, 1777
Solen sicarius Gould

Solen sicarius Gould, 1849b, p. 214.

Although an occasional young *Solen* may be found at almost any station, I have never found adult specimens outside of *Zostera* beds. Fifteen of these jackknife clams were found in an area of 40 sq. ft. where *Zostera* was growing. However, one may dig an equal area in apparently as favorable a spot in the same locality and perhaps not find a single specimen.

Solen digs a smooth-lined, permanent burrow in which it moves quickly up and down at will. The burrows are generally from 12 to 14 inches deep, and the clams begin to go deeper when disturbed, but their progress beyond the permanent burrow is not so rapid.

This is the most active of the clams at the Slough. It is able to swim by two methods: first, by expelling water forcibly from the siphons; second, by expelling water from the mantle cavity through an opening around the foot. The latter method which is aided by a flip of the extended foot, is the customary method, as well as the more efficient of the two. *Solen sicarius* can also jump vertically several inches.

This clam is capable of digging very rapidly. The foot becomes pointed and rapidly works its way into the sand, then the end swells until a disklike bulb is formed. This bulb then serves as an anchor while the body is being drawn downward. The entire process is then repeated, four or five repetitions being sufficient to bury the clam. When the foot is enlarged at the tip to serve as an anchor the enlargement is disk-shaped at right angles to the line of the foot, or direction the clam will go. The digging movement of the pointed foot is at the rate of about two strokes per second, and the traction pulls at the rate of one in every six seconds. In thirty seconds, therefore, the clam will be buried.

The siphons of this clam are united, and, when disturbed, the clam often constricts the siphon in bands and then autotomizes at the points of constriction.

Genus *Siliqua* von Mühlfeld, 1811
Siliqua lucida (Conrad)

Solicurtis lucidus Conrad, 1837, p. 231, pl. 17, fig. 8.
Siliqua lucida Dall, 1871, p. 141.

This razor clam is found at Station 2, and less abundantly at Stations 3, 4 and 5. The largest specimen was 44 mm. long.

S. lucida lives near the surface in very loose, sandy soil. It is supposed to be strictly an ocean beach form, but I have found it not only at Elkhorn Slough, but also at Anaheim Slough. It is almost as active as *Solen sicarius*, but lacks some of the versatility of the latter.

Family *Mactridae*
Genus *Mactra* Linnaeus, 1758
Mactra dolabriformis (Conrad)

Spisula dolabriformis Conrad, 1867a, p. 193.
Mactra dolabriformis Dall, 1894, p. 138, pl. 5, fig. 1.

During the early summer of 1927 considerable change took place in some parts of Station 2, and several spits were built up that were uncovered at low tide. About an hour after these spits were exposed *Mactra dolabriformis* would come out on the surface in considerable numbers. Often these clams would be lying 6 or 8 inches from the place where they had come out of the sand, having jumped that distance when they came out. Some of them would start to dig in again after they had left one place. They averaged from 40 to 50 mm. in length, but occasionally larger ones were found. Like *Tellina bodegensis,* this clam does not seem to be thoroughly adapted to slough conditions.

Genus *Schizothaerus Conrad,* 1853
Schizothaerus nuttallii (Conrad)

Lutraria (Cryptodon) nuttallii Conrad, 1837, p. 235, pl. 18, fig. 1.
Schizothaerus nutallii Carpenter, 1863, p. 640.

Of the large clams at the Slough this is the most plentiful one. It occurs at all stations but is most abundant at Stations 2, 4, 5 and 6.

At Station 1 the soil is hard clay, and gapers which grow there tend to become rounded in form and remain much smaller than those of the same age which grow in looser soil. They attain their greatest size at Station 2 where the sand is loose and water saturated. The depth to which they burrow is not proportionate to their size, the smaller clams being deeper for their size than are the larger ones. The majority of them are found at depths of 18 inches or more.

Schizothaerus (Fig. 18) may usually be located by the large size of the

Fig. 18. *Schizothaerus nuttallii.* One half natural size. Note the siphon plates on the ends of the siphon.

hole through which the siphon comes to the surface. If the siphon is extended the clam may be identified by the hard chitinous siphon plates, which are unique for the genus.

Schizothaerus is an edible clam, but the gaping of the valves makes it unsuited for shipping or market sale. At the Slough this clam is always infected with the larvae of a tetraphyllid cestode, the primary host of which is the Sting Ray, *Myliobatis californicus*. One hundred forty cysts of this cestode were taken from one clam, and each cyst may contain from one to five larvae. A law intending to restrict the taking of *Saxidomus nuttallii* was passed by the State legislature of California, but the technical name *Schizothaerus nuttallii* was used, so this tough-necked, undesirable clam was protected and *Saxidomus nuttallii* is being exterminated.

At the Slough *Schizothaerus nuttallii* has spawned in April, and well-filled gonads have been noted during the first of June.

Family *Myacidae*
Genus *Mya* (L.) Lamarck, 1799
Mya arenaria Linnaeus

Mya arenaria Linnaeus, 1758, p. 670.

This soft-shelled clam thrives best where the sand is somewhat loose and where there is some fresh water seepage. Although small specimens are found at all stations, the adults are found only on the east side of Stations 7 and 8, south from the highway bridge, where the soil is sandy and loose. Adults may also be found in certain loose sandy regions farther inland in the unmapped areas. In such places they receive fresh water seepage from the shore, which may have something to do with their location, for along the Oregon coast they often live in mud flats of river mouths where the winter supply of fresh water must lessen the salinity of the salt water tides considerably.

The siphon tubes of *Mya arenaria* project just to the surface or a little beyond, so that the clams are easily located, and, since they live only about 8 to 12 inches below the surface, they can be dug with the hands. A large *Mya* from the Slough is about 80 mm. long, which is much smaller than this species grows in its northern range.

Genus *Cryptomya* Conrad, 1837
Cryptomya californica (Conrad)

Sphaenia californica Conrad, 1837, p. 234, pl. 17, fig. 11.
Cryptomya californica Carpenter, 1863, p. 637.

This small (22 to 30 mm.), inequivalved clam is found frequently at all stations, but is most abundant in beds of *Callianassa, Urechis* and *Upogebia* at Stations 3, 4 and 5.

This clam has very short siphons, which at first seemed incompatible with the fact that it is often found as deep as 20 inches, and usually much deeper than its short siphons would permit of contact with the surface. The explanation for its ability to live so deeply was quite evident when it was found that it lives with its siphons projecting into the burrows of *Upogebia, Urechis*, and *Callianassa* (MacGinitie, 1934a). It is most plentiful in *Callianassa* beds. *Cryptomya*, therefore, must obtain its food from the water which circulates through the burrows of these animals. The fact that *Urechis* and *Upogebia* are efficient plankton strainers may also have some influence on the relative numbers of *Cryptomya* to be found around their burrows and those of *Callianassa*.

Genus *Platyodon* Conrad

Platyodon cancellatus (Conrad)

Mya cancellata Conrad, 1837, p. 236, pl. 18, fig. 2.
Platyodon cancellatus Carpenter, 1863, p. 637.

Occasional specimens of this clam are found among the *Zirfaea* in the blue clay at the northeast end of Station 1. A great many old shells are found in the same locality, and, without exception, these shells and the holes to the surface above contain a number of *Phoronopsis* tubes.

A *Platyodon* burrow may be distinguished from a *Zirfaea* burrow because the hole around the siphon of the former is always sandy, whereas around that of *Zirfaea* it is clayey.

Family *Saxicavidae*

Genus *Panope* Ménard

Panope generosa Gould

Panopaea generosa Gould, 1849b, p. 215.

While this clam is quite plentiful in its northern range, and also to the south at Morro Bay, it is very rare at Elkhorn Slough. A few specimens were found at Station 2. They are exceedingly difficult to dig, for the end of the shell is often 36 inches below the surface of the sand, and they prefer a substratum of loose texture.

This clam has the longest and largest siphon of any clam I know, and the siphon constitutes at least one half the weight of the clam, including the shell. The shell is relatively small in comparison with clam shells in general.

Both here and in its northern range this clam is called a Geoduck (pronounced Go′ e duck) by clam diggers, a name which was given to it by the Indians.

Genus *Saxicava* Fleuriau, 1802

Saxicava arctica (Linnaeus)

Mya arctica Linnaeus, 1767, p. 1113.
Saxicava arctica Carpenter, 1863, p. 637.

This nestler clam was found in the hard blue mud of Station 1, as well as in old barnacle shells, burrows of boring clams, and crevices of rocks at Stations 1, 4 and 7. A specimen 23 mm. long was also found in the loose sand at Station 5. Another was living within the mantle cavity of a cockle, *Cardium corbis,* where injury had caused the mantle to loosen from the shell.

Family *Pholadidae*

Genus *Zirfaea* (Leach) Gray, 1847

Zirfaea gabbi Tryon

Zirphaea gabbi Tryon, 1862, p. 144, pl. 1, fig. 1.

This boring clam is found abundantly in many places along the east side of the Slough, especially at the northeast end of Station 1. It is also found along the north bank of the Slough above the highway bridge. Another small area of *Zirfaea* is located in the sand at the east side of Station 2, but the clams themselves are in rather hard clay, only the siphons extending up through the layer of loose sand 6 inches or more in thickness, which is on top of the firmer soil.

Zirfaea (Fig. 19) has a very thin shell which is easily broken, and is not the kind of equipment one would expect in a borer. The shell seems to lack the nacreous layer, and for this reason lacks the pearly appearance of most bivalves, but instead it has the dull limy appearance of pure calcium carbonate. On the outside, especially near the anterior end, are many rather sharp spines with which the animal scrapes material loose from the sides and ends of the burrow. The siphon is double and very extensible, and the openings are usually held about even with the surface. The lower end of the burrow is from 12 to 14 inches below the surface.

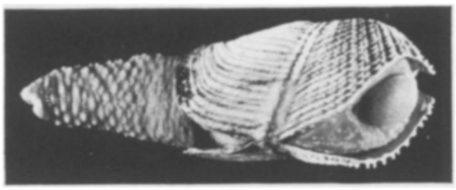

Fig. 19. *Zirfaea gabbi.* x ½.

The burrow is shaped to fit the animal closely when the siphon is extended. As the clam sometimes reaches a diameter of 50 mm. at the anterior end and is club -shaped, tapering gradually to the end of the siphon, the burrow for a large specimen will approximate 15 mm. at the top and gradually enlarge to over 100 mm. at the lower end. In some of the *Zirfaea* beds, e.g., the northeast end of Station 1, the burrows are as thick as they can be without opening into one another at the lower end.

A curious trait of this clam is that at times many of them in a bed may extend their siphons far out of the burrow. Here and there a white "neck" will protrude from 6 to 8 inches. Since the clam is always extended to about its limit, this protrusion naturally means that the whole animal has moved up in its burrow, which was proved by grasping the siphons of two or three and lifting the specimens entirely out of their burrows. This same phenomenon has been observed at Anaheim Slough and Newport Bay also. There is surely some reason for this trait, for in such a position the clams would be easy prey for fish, and since they make good bait, no fish would miss the opportunity to feed on them should it happen by at such a time. Necks were seen extending from the burrow where the tide was low and but six inches of water covered them; however, others which were farther from shore where the necks were still coverd by six feet of water were also extended, so the position cannot be other than dangerous to the clams. Perhaps the clams come up to enlarge the diameter of the burrow; for, since the small borers extend nearly as deeply as do larger ones, this would undoubtedly have to be done occasionally. One might think that selection would have developed in the clam an instinct to shorten its siphon when it comes up in the burrow; but, as will be seen later, the siphon must be extended while the clam is digging. Perhaps this trait will be explained later, perhaps never; but it is given mainly as an example of the many interesting problems that confront one when investigating almost any species of animal.

A *Zirfaea* was taken to the laboratory and placed in a small jar with some of the hard blue clay from the east side of the Slough. In about ten days the animal began its boring movements. These were watched, and later the clam was moved to a large round-bottomed test tube. The boring movements were continued in this tube and every movement could be seen clearly.

The boring movements of *Z. gabbi* are exceedingly slow and methodical. The foot of this species is modified into a sucking disk, and this disk forms the anchorage so that the spines of the shell may be scraped against the clay. The disk is firmly attached to the clay, the foot moving so slowly that it can not be seen to move; but since it is attached a little out of line to one side in the direction the animal will turn, the fact that it moves becomes discernible by comparing its position from time to time with the edges of the valves. By this is meant that one detects the movement of the foot by comparing its position with the non-moving parts of the clam in much the same way that one compares the position of an hour hand of a clock with minute marks to discern the movement of the hour hand.

After the disk is attached the following movements always take place and always occur in the order given: (1) The portion of the foot back of the disk grows smaller in diameter by contracting; (2) the mantle, which usually fits tightly about the foot, is drawn back; (3) the body is expanded, forcing the valves against the sides of the burrow; (4) the valves are then raised and lowered once; (5) the body is contracted; and (6) the whole clam then rotates in the direction the foot is attached. From this it will be seen that the real boring movements are mainly the up and down movements of the valves and not the rotating movement. The drawing back of the mantle allows the loose material from previous movements to be sucked into the mantle cavity, and between about every three or four rotating movements this material is blown from the incurrent siphon a considerable distance into the water above by a sudden contraction of the body. In this way the clay is loosened and removed. While it was in the glass tube the clam made no movements for blowing out material, so this shows that the stimulus of collected material within the mantle cavity is necessary to a blowing movement. It takes about thirty-two turns for the clam to make one complete rotation, and the quickest rotation observed was made in the glass tube in 70 minutes.

The following table gives the times for turning movements for one half hour. During this time (from 9:16 to 9:45:50 a.m.) a little over a quarter turn was made. The times marked with an asterisk are not times of turning movements but times when material was blown from the incurrent siphon. Between the time preceding (which is a time for a turning movement) and the time marked with an asterisk the clam was perfectly still, perhaps preparing for the expulsion of material from the mantle cavity.

9:16:00	*9:30:45
*9:17:35	9:32:50
9:19:00	9:34:30
9:20:20	*9:37:15
*9:23:40	9:38:25
9:24:20	9:42:10
9:26:20	9:45:50

As viewed from above all movements were clockwise. At 11:15 a.m. the clam reversed and went anti-clockwise, and at 12:50 p.m. it went clockwise again. These times were taken while the animal was in the jar containing mud.

The boring movements of other rock borers are quite similar to those of *Zirfaea gabbi.* I am of the opinion that the main factor concerned with the enlargement of the burrows of any of these boring clams is not the mechanical abrasion of the material by the shell of the clam, but rather that the clam keeps the inside of the burrow clean, which allows the dissolving action of the ocean water to be the actual agent which removes the material. Rocks on the open coast, even granite rocks, would erode much more rapidly than they do if it were not that they are supplied with a protective covering of algal and animal growths, and chemical compounds. The chemical action of ocean water on a new surface of the burrow of a boring clam would be relatively rapid for a short time. Hence, if the surface of the burrow is always kept clean so that the action of the ocean water upon it is continuous, it seems that this could easily account for the removal of a sufficient amount of material to accommodate the body of a clam in the course of the years which it takes to grow to adult size.

The excretion of carbon dioxide from the body of a clam has been suggested as a factor in enlarging burrows in rocks, but when it is remembered that a clam is fairly well covered on its exterior surface by its periostracum, and that practically all of the gas exchange takes place within the mantle cavity and is carried to the outside of the burrow by the excurrent siphon, I feel that this factor is of very slight importance. The fact must be kept in mind that any acid strong enough to have an appreciable effect on the walls of the burrow would also dissolve the shell of the animal. The shell may, of course, be built up from the inside, but with a clam like *Zirfaea,* or *Pholadidea,* which has spines or tubercles on the outside entirely removed from the influence of the mantle, it is evident that the shell is not worn away and replenished to any great extent.

From the slowness of the boring movements described above, it will be seen that for *Zirfaea gabbi* to once become removed from its burrow in its natural environment means death. It can not begin a burrow when lying horizontally on the clay, and in any event it would fall a prey to crabs or fish long before it could even commence a burrow were this possible. Specimens which are dug out of the clay soon die if left to lie flat in an aquarium, but they seem to live indefinitely if placed in a test tube.

The shells of *Zirfaea* indicate that it lives to be seven or eight years old, certainly not less. This means that the life existence of this clam consists of boring a burrow 14 inches deep and 2 inches in diameter at the lower end in blue sticky clay, keeping a continual current of water flowing in at one siphon and out another, and producing eggs and sperm annually.

It is interesting to note here that a clam like the jacknife, *Solen sicarius,* while so active and efficient in its movements, is not nearly so plentiful as *Zirfaea gabbi.* Perhaps this is due to the latter being more secure in its hard clay, or perhaps it is due to some more fatal spot in the life cycle of the *Solen* or perhaps because the *Solen* lives where there are more natural enemies; as J. Arthur Thompson has said in his Natural History, perhaps and perhaps and perhaps.

Genus *Pholadidea* Turton, 1819
Pholadidea penita (Conrad)

Pholas penita Conrad, 1837, p. 237, pl. 18, fig. 7.
Pholadidea penita Wood and Raymond, 1891, p. 55.

This boring clam is found in the rocks at Stations 4 and 7.

The boring movements of this species and of *P. ovoidea* are quite similar to those of *Zirfaea gabbi,* which are described above. But when *Pholadidea* attains a certain size the anterior end is covered over with shell, and from this time on the clam is strictly sessile within the rock.

Pholadidea ovoidea (Gould)

Pholas ovoidea Gould, 1851, p. 87.
Pholadidea ovoidea Tryon, 1862, p. 213.

This species, like the above, is found in solid granite rocks at Stations 4 and 7, but it is not so plentiful as *P. penita.*

Family *Terediдae*
Genus *Bankia* Gray, 1842
Bankia setacea Tryon

Bankia setacea Tryon, 1863, p. 144, pl. 1, figs. 2, 3.

This large shipworm is quite common in pilings, timbers, or stakes which have been driven into the mud for boat or skiff moorings; hence chieflly at Stations 4, 7 and 8.

Bankia and its activities are well described by Miller (1926a). Under favorable conditions its burrows may be 4 mm. in diameter and nearly one meter long. It is, therefore, a very destructive wood borer. It actually uses ingested wood for food (Miller, 1926b).

Genus *Teredo* Linnaeus, 1758
Teredo diegensis Bartsch

Teredo diegensis Bartsch, 1916, p. 48.

Teredo diegensis was found in old boxes and mooring stakes at Stations 7 and 8. At Station 7 it was found in the same wood with *Bankia setacea.*

In comparison with *Bankia* this shipworm is quite small. Its burrows are about 6 mm. in diameter and not over 100 mm. long.

T. diegensis may found with brood during July.

Class GASTEROPODA
Order OPISTHOBRANCHIATA
Suborder TECTIBRANCHIATA
Family *Akeridae*

Genus *Haminoea* Turton, 1830
Haminoea vesicula (Gould)

———*vesicula* Gould, 1855, app. p. 334.

This is the only bubble shell found at the Slough, but it is by far the most abundant gasteropod there. During the summer months hundreds of individuals may be found wherever there is *Enteromorpha* or *Polysiphonia*, to which they attach their eggs. In the latter part of March great numbers of small specimens were found at Station 5.

Adults are exceedingly abundant during the first part of July, when they are mating and laying eggs, but by the first of August most of them have gone and only a few of those which remain are still laying eggs. However, eggs have been found from March until late fall.

The eggs are laid in thick ribbons about 10 mm. wide and from 125 to 200 mm. long, which are attached to algae or, occasionally, *Zostera*. The eggs, which are yellow, are not in capsules or compartments but are embedded in the jelly in semicircular sheets, or layers.

Family *Philinidae*
Genus *Philine* Ascanius, 1772
Philine (sp. nov.?)

No species of *Philine* has been recorded before from south of Nanaimo or north of South Coronado Island.

Philine was seen at the Slough from January until September, so it is probably a permanent resident. The greatest numbers were found in January and August, but they were more plentiful in August, when they were mating and laying eggs.

As the animal moves about through the water it secretes a slimy covering which practically envelops its body. This sheet of slime evidently forms continuously, and particles in the water adhere to it, causing the animal to pass through a protective slime tube covered with foreign material. The edges of the foot are usually folded up over the sides of the animal, but at times they are laid out flat, making a large circular foot, with the lateral edges somewhat turned up like the wings of a devilfish. When the animal moves without the foot being extended, only the anterior and posterior ends are in contact with the surface, the middle portion of the foot forming an arch between. When *Philine* moves rapidly the entire ventral surface of the foot is in contact with the surface, and the posterior portion ends in a circular opening notched on the dorsal side. The respiratory current goes anteroposteriorly and out through this opening.

Philine is hardy, being able to remain out of water for some time, and also to endure the admixture of considerable fresh water with the ocean water. Its ability to remain out of water is due to the slimy covering which envelops it.

Eggs of *Philine* were found in August. The eggs are white and are laid in globular masses of soft transparent jelly which are attached to *Enteromorpha*. These egg masses are as large as or larger than the animal itself.

Family *Aglajidae*
Genus *Navanax* Pilsbry, 1895
Navanax inermis (Cooper)

——— *inermis* Cooper, 1862, p. 202.

In July, 1927, one specimen of this tectibranch was found on the sand at Station 2. Prior to this (MacGinitie, 1930b) it had not been reported from north of San Diego or Santa Catalina. In July, 1928, two more specimens were found at Stations 2 and 3. Two more specimens were found at Station 3 in April, 1930, and a single specimen 6 inches in length was found at this same station in July.

Although only six *Navanax* were found, the fact that they were found over a period of three years indicates that their occurrence at Elkhorn Slough is not a matter of chance.

At the Slough *Navanax* eggs were found in July at Station 7. Two *Navanax* taken to the laboratory in July mated shortly after being placed in an aquarium, and during the night laid two large skeins of eggs. At Newport Bay and Anaheim Slough, in Southern California, eggs of *Navanax* may be found during the entire year. The eggs, which are white, are laid in a long coiled string embedded in a skein of transparent jelly which is about 4 inches long.

Family *Aplysiidae*
Genus *Tethys* Linnaeus, 1758
Tethys californicus (Cooper)

Aplysia californica Cooper, 1863, p. 57, fig. 14.

On the coast of California there are two species of sea hares, whose ranges may be separated roughly by Point Conception. The descriptions of these animals are very poor, for mulluscan taxonomists on the whole seem to be afraid to take into consideration anatomical structure rather than shell shape, and Tethys has only a vestigial shell, which is internal. Actually, the description of *Tethys californicus* fits the southern form better, and that of *Tethys ritteri* fits neither. However, since a discussion and description of the two animals is out of place here, the northern sea hare, or the one found in Elkhorn Slough, will be called *Tethys californicus* (Fig. 20), as this is the name applied to it by the marine personnel of the Hopkins Marine Station.

The northern species reaches a weight of 15 pounds, and one, while crawling in an aquarium, measured 480 mm. long, 260 mm. high, and 170 mm. broad.

This species may occur very abundantly at the Slough at certain times, and at other times be conspicuous by its absence. In the summer of 1926 none at all were seen, in spite of special effort to find them, but during the summer of 1927 fifty-nine specimens were counted. Specimens were found in January, February, April, July, August and November. On the night of November 28, 1930, when there was an exceptionally low tide, hundreds of the sea hares, including many small-sized ones, were found. Dozens of them had been left stranded by the low tide. Some were mating, and both fresh and old eggs were found.

Although on the outside beach *Tethys* eats seaweed, while in the Slough it feeds on *Zostera*. It consumes vegetation in great quantities. This is rather surprising for a marine animal, for most of them feed sparingly, at least as compared with land animals. The indications are that the sea hares live to be two years old, spawning the second year.

At Elkhorn Slough mating sea hares were found in July, August and November. Eggs, which are produced in enormous quantities, are laid in

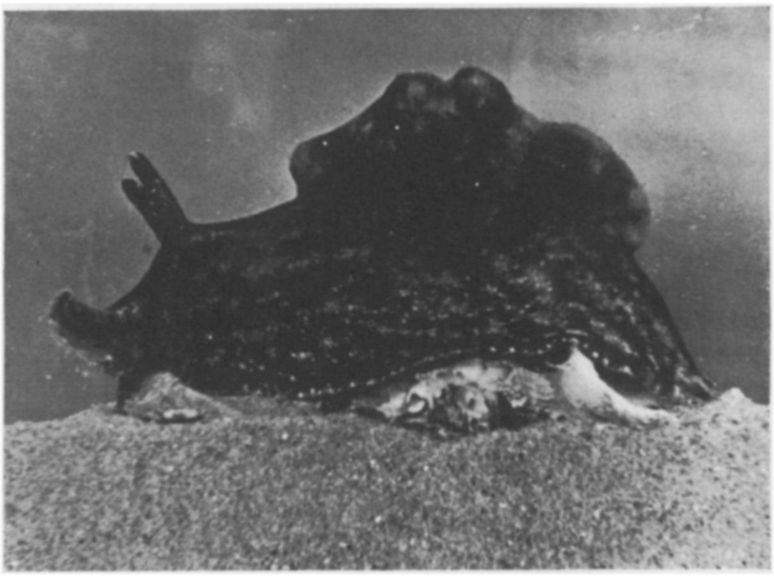

Fig. 20. *Tethys californicus*. One third natural size.

a mass which resembles a tangled bunch of coarse, yellow wool yarn. Within the gelatinous string the eggs are separated into capsules, each containing about 150 eggs, which are arranged spirally along the strand, four to each turn. One sea hare laid a mass of eggs which weighed 1937 grams, was 612.15 cm. in length, and contained a total of 83 million eggs. Before egg-laying the animals copulate to exchange sperm, and the eggs are fertilized when laid. From two to fifteen sea hares have been seen copulating in chains, all but the first and last giving and receiving sperm. In one instance eight were seen copulating in a ring, all giving and receiving sperm (MacGinitie, 1934b). The mass of eggs mentioned above was kept at the laboratory, and, although conditions were somewhat adverse, all the eggs hatched. The larvae escape as veligers, and the period of mortality is undoubtedly at the time they metamorphose and settle to the bottom, for apparently these tectibranchs are not fed upon by other animals after they are once well started.

In contrast to the above statements in regard to *Tethys californicus* at Elkhorn Slough it may be noted that the southern form laid 478 million eggs in four months and one week, in a total of 27 layings (MacGinitie, 1934b). I am quite sure that the northern form does not lay more than twice, and I think, in general, only once. The southern form, at least, dies after the completion of egg-laying the second year, and I believe that the northern form does likewise, although I am not sure of this latter point.

The potential space required for the third or fourth generation of offspring of either the northern or southern form (the southern not exceeding 6 pounds in weight) may furnish amusement and recreation for those who care to make such computations.

Family?
Genus *Phyllaplysia* Fischer, 1872
Phyllaplysia taylori Dall

Phyllaplysia taylori Dall, 1900.

This tectibranch is found quite abundantly on *Zostera* at Stations 5 and 7 (MacGinitie, 1930b). This species had previously been reported only from Nanaimo, British Columbia. Since this time I have found it abundant at Tomales Bay, at Newport Bay and Anaheim Slough, and extremely abundant at Humboldt Bay.

Phyllaplysia is found among the *Zostera,* on the blades of which it lives and deposits its eggs. It orients itself lengthwise with the blade and, since it is practically the same color as the *Zostera,* it is not easily detected.

The eggs are laid in a very firm transparent jelly about 1 mm. thick and from 5 to 25 mm. in length. The mass, which is about the same width as a blade of *Zostera,* adheres firmly to it. Each egg is in a separate compartment along with an oil droplet, which is not attached to the egg, and which is about one half the diameter of the egg. Egg masses that are freshly laid appear green from the color of the *Zostera* showing through the transparent jelly. Later the masses have a brownish color from the detritus that has gathered on them.

Eggs were found at Elkhorn Slough the year round. At Anaheim Slough and Newport Bay the height of the egg-laying season seems to be in November, but the animals have been observed mating and laying eggs throughout the year. At Humboldt Bay in January, 1931, there were thousands of Phyllaplysia and their eggs, both fresh and old masses, as well as thousands of young animals from 2 to 10 mm. in length.

Suborder NUDIBRANCHIATA
Tribe HOLOHEPATICA

The only dorid found at the Slough was a black and white specimen found on the sand at Station 2, June 6, 1927. This dorid was given to Dr. MacFarland, of Stanford University, for identification. The name will appear in a forthcoming paper of his.[7]

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[7] Dr. MacFarland has specimens of all Elkhorn Slough nudibranchs.

Tribe CLADOHEPATICA
Family *Dendronotidae*
Genus *Dendronotus* Alder and Hancock
Dendronotus . . . . MacFarland (sp. nov.)

This eolid was found at Station 4 on *Obelia* and among the rocks. It was also found on hydroids at Stations 3 and 5, but always in limited numbers. Specimens were given to Dr. MacFarland for identification in 1928.

Family *Aeolididae*
Genus *Aeolidia* Cuvier
Aeolidia papillosa (Linnaeus)?

Three specimens of this species were found at Station 4, and one at Station 3.

Genus *Coryphella* Gray
Coryphella . . . . MacFarland (sp. nov.)

One specimen of this eolid was found among the *Zostera* at Station 5.

Galvina . . . . MacFarland (sp. nov.)

This new species of *Galvina* was found on *Obelia* which was taken from the bridge piling at Station 7.

Hermissenda crassicornis (Eschscholtz)

During the summer months Elkhorn Slough is an excellent place for collecting this eolid, for exceptionally large ones, in great numbers, many 60 mm. or more in length, are found at Stations 2, 3, 4, 5 and 6.

The eggs, which are attached to *Enteromorpha* and *Zostera*, are white, and are arranged in groups of loosely coiled masses in a regular order. In appearance they resemble a tangled string of tiny white beads embedded in a gelatinous mass. Eggs are most abundant in July and August, although they have been seen from March to November, inclusive.

Family *Dotonidae*
Genus *Doto* Oken
Doto . . . . MacFarland (sp. nov.)

This species was found among hydroids at Stations 4 and 7.

Order STREPTONEURA
Family *Olividae*
Genus *Olivella* Swainson, 1840
Olivella biplicata Sowerby

Olivella biplicata Sowerby, 1825, p. 33.

This snail is usually found on bare, sandy bottoms (Stations 1, 2, 3, 6), where it ploughs along through the soil, either with its foot below and shell partly above the surface, or with its entire body just below the surface. A small furrow is left behind as it ploughs along, and, where there are not too many, one can follow the furrow and dig out a snail at the end.

Olivella is a scavenger, and in the laboratory it would accept any kind of clam or fish flesh, seeming to prefer it in a state of decomposition.

Family *Nassidae*
Genus *Nassa Lamarck,*
Nassa fossata (Gould)

Buccinum fossatum Gould, 1849a, p. 152.
Nassa fossata Tryon, 1882, p. 55, pl. 17, figs. 316, 318.

Nassa fossata was found at Stations 3, 5 and 6. It was seen at Elkhorn Slough in July, February and April. (Fig. 21).

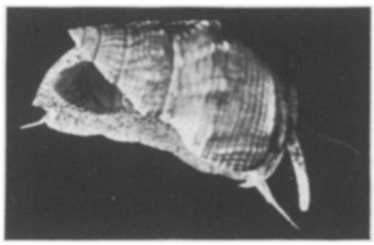

Fig. 21. *Nassa fossata*. Large specimen, natural size. The organ between the tentacles is the siphon.

As a rule this snail is not very plentiful at the Slough, but when it is found it is usually fairly numerous. It is exceedingly sensitive to fresh or decaying flesh, and will go to it in almost a direct line from a considerable distance. At Morro Bay I saw a dead fish lying in a channel where the tide was running out, and *Nassa* were coming in a continual stream from a distance of 100 feet or more below it. I kept several *Nassa* in a battery jar at the laboratory for several months. Whenever a piece of clam meat was held at the top of the jar these snails would rapidly crawl to the top and reach for the meat with their radulaphores, which can be extended for a distance of 50 mm. Even when the flesh was held in the air above the jar the snails would reach through the screen and wave their radulaphores around until they located the food. If any snail was given a piece of meat about 10 mm. in diameter it would turn over and lie with its shell downward and its foot held high and wrapped tightly about the meat, completely hiding it while it was being eaten. The other snails, scenting the meat, would crawl actively about on the bottom, but were seldom able to locate it.

Nassa lays its eggs in capsules which are usually attached to blades of *Zostera*.[8] A satisfactory spot is first located with the siphon, and then this spot is cleaned by making about fifteen forward strokes with the radula. Then a fold is thrown in the right portion of the foot so as to form a tube or tunnel from the genital pore to the pedal gland, which is centrally located in the anterior portion of the foot. A fluid egg-mass then passes from the genital pore, through the tunnel, and into the pedal gland. The peristome of the pedal gland then presses against the surface where the egg-capsule is to be

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8 This account of the egg-laying of *Nassa fossata* is condensed from Ann. Mag. Nat. Hist. (MacGinitie, 1931).

attached and is held there for about 9.5 minutes. When the eggs enter the pedal gland the infolded tunnel disappears, and then a water chamber with incurrent and excurrent funnels is formed around the pedal gland by raising the foot posterior to the gland and throwing a fold in the lateral edges of the foot on each side of the gland. During the 9.5 minute interval the body of the snail and the shell slowly oscillate from side to side, possibly to maintain a current of water through the water chamber, or it may be that this movement has something to do with the functioning of the pedal gland. At the end of this period the egg capsule is cemented to the place where it is being attached, hence, when the foot is lifted upward and backward the completed capsule pulls out of the pedal gland. Another area is then cleaned just ahead of this capsule and the entire process is repeated.

It requires 12.5 minutes to clean an area and deposit a completed capsule. An average capsule measures 3.8 mm. in width, 5.5 mm. in length, and is 1.1 mm. thick. The margins are bordered by rows of points, and the anterior face is crossed by six or seven ridges armed with points. The capsules are attached in imbricated rows, the base of one being contiguous with the base of the next, each capsule requiring about 1.3 mm. of space. As many as forty-five capsules have been observed in a string.

Egg capsules of *Nassa fossata* were found at Elkhorn Slough in February. They were also seen in Morro Bay in February. Several *Nassa* from Morro Bay were placed in an aquarium at the Kerckhoff Marine Laboratory on June 25. Two days later they began laying eggs and continued laying for several days. On July 15 the aquarium was full of *Nassa larvae* that had escaped from the egg capsules. *Nassa* eggs have also been found in February at Anaheim Slough, Southern California.

Genus *Acanthina* Fischer, 1807

Acanthina spirata (Blainville)

Purpura spirata Blainville, 1832, p. 252, pl. 12, fig. 8.
Acanthina spirata Dall, 1921, p. 112.

This species of snail is plentiful among the rocks at Station 4. Its number is restricted by the limited extent of a suitable habitat. *Acanthina spirata* feeds on mussels and barnacles.

This snail lays eggs in July. The eggs are incased in urn-like capsules which are attached to the rocks in groups of about 20.

Family *Littorinidae*

Genus *Littorina* Ferussac, 1822

Littorina scutulata Gould

Littorina scutulata Gould, 1848, p. 83.

This small gastropod is restricted to the rocks at Station 1, but is fairly plentiful there. It lives well above low tide and is active but a small portion of a 24-hour period.

Family *Lacunidae*

Genus *Lacuna* Turton, 1827

Lacuna porrecta Carpenter

Lacuna porrecta Carpenter, 1863, p. 656.

This tiny snail may be obtained in considerable numbers by screening the soil at the bases of *Zostera,* and it is often seen crawling on the blades of the plant.

Lacuna porrecta presents an amusing spectacle as it moves along, for it moves first one side of the foot and then the other, which gives it the appearance of waddling like a duck.

In summmer small masses of the eggs of this snail are often found attached to the shell, sometimes as many as six coils on one shell.

Lacuna unifasciata Carpenter

Lacuna unifasciata Carpenter, 1856, p. 205.

This *Lacuna,* which is somewhat larger than the preceding species, is nearly always found in the screening pan with it, and is likewise found on the *Zostera*. But, unlike the above species, it has the characteristic snail-like motion of other gasteropods.

Eggs of *L. unifasciata* were never observed on its shell, but were found on *Zostera* in summer.

Family *Naticidae*
Genus *Polinices* Montfort, 1810
Polinices draconis (Dall)

Lunatia draconis Dall, 1903b, p. 174.

This large predaceous snail is found only occasionally along the edges of the deeper channels. It apparently is a visitor and does not take up a permanent residence within the Slough. It is quite plentiful on the ocean floor outside.

Polinices lewisi (Gould)

Natica lewisii Gould, 1847, p. 239.
Polynices lewisii Arnold, R., 1903, p. 315. pl. 10, fig. 4.

Two specimens of this snail were found at the Slough in April, 1930.

Both this species and the one above are drills, and feed mainly on clams. A circular hole is drilled through the shell at any place, usually near the umbo, and the body of the clam is rasped and sucked out through this hole.

Polinices lays eggs in a matrix of slime and sand in the shape of a collar. These collars are about 6 inches in diameter and 2.5 inches high.

Family *Crepidulidae*
Genus *Crepidula* Lamarck, 1801
Crepidula nivea C. B. Adams

Crepidula nivea Adams, C. B., 1852, p. 234.

This species was found on rocks at Station 4. It is not abundant.

Family *Acmaeidae*
Genus *Acmaea* Eschscholtz, 1830
Acmaea limatula (Carpenter)

Acmaea scabra limatula Carpenter, 1864, p. 340.
Acmaea limatula Dall, 1914, p. 14.

This limpet is common on the rocks at Stations 1 and 4.

Acmaea scabra Gould

Acmaea scabra Gould, 1846b, p. 152.

This species is quite abundant although it is restricted to Stations 1 and 4. Although there are a few rocks at Station 7, it apparently has not become established so far inland.

This limpet lives above low tide level. Each individual has a certain place to stay when the tide is out, and its shell grows to fit the particular depression in the rock thus used.

Acmaea persona Eschscholtz

Acmaea persona Eschscholtz, 1829-1833, p. 20, pl. 24, figs. 1, 2.

This limpet is restricted to the same areas as the above species, but it is much less abundant. It lives at low tide level and above.

Family *Trochidae*
Genus *Tegula* Lesson, 1832
Tegula funebrale (A. Adams)

Chlorostoma funebrale Adams, A., 1854, p. 316.
Tegula funebrale Keep, 1911, p. 235.

This black turban is found only rarely among the rocks at Station 1. It prefers the brown seaweed pools of rocky ocean beach.

Family *Fissurellidae*
Genus *Diodora* Gray, 1821
Diodora aspera (Eschscholtz)

Fissurella aspera Eschscholtz, 1829-33, p. 21, pl. 23, fig. 5.
Diodora aspera Dall, 1921, p. 185.

A few specimens of this keyhole limpet were found on the rocks at Station 4 during the latter part of this investigation.

Class AMPHINEURA
Family *Ischnochitonidae*
Genus *Ischnochiton* Gray, 1847
Ischnochiton cooperi Carpenter

Ischnochiton cooperi Carpenter, Pilsbry, 1892-93, p. 127.

A few adult specimens of this chiton were found at Station 4.

Family *Lepidochitonidae*
Genus *Lepidochitona* Gray, 1821
Lepidochitona raymondi (Pilsbry)

Trachydermon raymondi Pilsbry, 1894, p. 46.
Lepidochitona raymondi Dall, 1921, p. 189.

This chiton was also found only at Station 4.

Family *Mopaliidae*
Genus *Mopalia* Gray, 1847
Mopalia ciliata (Sowerby)

Chiton ciliatus Sowerby, 1840, p. 289.
Mopalia ciliata Wood and Raymond, 1891, p. 58.

A few specimens of this species were found on the rocks and piling at Station 4.

Mopalia muscosa (Gould)

Chiton muscosus Gould, 1846a, p. 145.
Mopalia muscosa Carpenter, 1863, p. 648.

This chiton is found in limited numbers on the rocks at Station 1, and on the rocks and pilings at Stations 4 and 7.

Mopalia muscosa hindsii (Reeve)

Chiton hindsii Reeve, 1847, pl. 12, fig. 67 a-b.
Mopalia muscosa hindsii (Sowb.) Pilsbry, 1892, p. 296.

This species is also found at Stations 1, 4 and 7. It is the most abundant chiton at the Slough.

This chiton reaches a length of 88 mm. and is often so overgrown with algae, hydroids, etc. that it is difficult to distinguish.

The following is a partial list of the animals and plants which were growing on two specimens:

Animals	Plants
Protozoa	Diatoms
Campanularia sp.	*Ectocarpus* sp.
Opercularella lacerata	*Griffithsia* sp.
Nematodes	*Polysiphonia* sp.
Barentsia gracilis	*Bryopsis* sp.
Caprella aequilibra	
Balanus nubilis	
Halosydna insignis	
Small annelids.	

Class Cephalopoda
Order Dibranchiata
Family *Polypodidae*
Genus *Paroctopus* Naef, 1923
Paroctopus apollyon (Berry)

Octopus punctatus Gabb, 1862 (name preoccupied)
Polypus hongkongensis Berry, 1911, p. 302.
Polypus appolyon Berry, 1912, p. 284.
Paroctopus apollyon Robson, 1929, p. 202, fig. 82.

This octopus was found among the rocks at Station 1, and a single specimen about one foot in length was found at Station 2.

During June and July this octopus lays eggs which it attaches to a rock in clusters resembling grapes. The mother octopus remains with the eggs, guarding and cleaning them until they hatch. (Fisher, 1923, 1925)

TUNICATA

Order ASCIDIACEA

Suborder ASCIDIAE SIMPLICES

Halocynthia johnsoni Ritter

Halocynthia johnsoni Ritter, 1907.

This tunicate occurs on the rocks at Stations 1 and 4. This and one other unidentified species are the only tunicates found at the Slough.

VERTEBRATA

Class PISCES

No attempt was made to list all the species of fish inhabiting the Slough. Only those directly connected with the associations sudied are given here. Some, for example, the goby, *Clevelandia ios,* and the sting ray, *Myliobatis californicus,* are an integral part of the life at Elkhorn Slough.

Family *Myliobatidae*

Genus *Myliobatis* Dumeril

Myliobatis californicus Gill

Myliobatis californicus Gill, 1865, p. 137.

This fish is commonly called Stingaree or Bat Fish by the fishermen. It is often caught on hook and line by bass fishermen at the Slough. It is more plentiful above the highway bridge than below it.

The stomachs of several Sting Rays were examined and were found to contain clams, shore crabs, *Pectinaria,* and sardines which had been used by fishermen for bait. The Sting Ray digs for clams by flapping out holes with its "wings." It may dig a channel 2 or 3 feet wide, 20 inches deep, and 15 feet long in one night. Instead of teeth, the mouth of *Myliobatus* is equipped with two heavy crushing plates which are very effective in breaking clam shells.

This fish harbors a great many parasites: three trematodes *(Probolitrema* . . . . , *Udonella* . . . . . , *Epibdella* . . . . .), a cestode *(Phyllobothrium* ? sp.), a leech *(Branchellion* sp.), and a copepod *(Trebius caudatus).*

Family *Serranidae*

Genus *Roccus* Mitchell

Roccus saxatilis (Walbaum)

Perca saxatilis Walbaum, 1792, p. 330.
Roccus saxatilis Jordan, Evermann and Clark, 1930, p. 307.

Roccus saxatilis, commonly called Striped Bass, is rightly considered a visitant, for most of those that come into the Slough come in with the tide and leave as it goes out. High water is considered the most favorable time for fishing, although some are caught between tides. When they are plentiful on the beach fishing is usually good in the Slough. I am of the opinion that this fish does not form schools but is attracted by food supply.

Roccus feeds on sand crabs *(Emerita analoga),* which are sometimes successfully used for bait; but from its preference for sardines it is probable that other fish is its favorite food. It is primarily a surf feeder; in the Slough it feeds largely on shore crabs.

Family *Atherinidae*
Genus *Atherinopsis* Girard
Atherinopsis californiensis Girard

Atherinopsis californiensis Girard, 1854-55 (1856b), p. 134.

On March 22, 1927, myriads of small fry of this species were swimming about near the surface of the water, especially at Station 1. These jack smelt come into the Slough in the spring to spawn, and are often caught by fishermen at this time.

Genus *Atherinops* Steindachner
Atherinops affinis (Ayres)

Atherinopsis affinis Ayres, 1860, p. 73.
Atherinops affinis Jordan and Gilbert, 1883, p. 409.

Schools of these small smelt are abundant during the summer months. They come in and go out with the tide. Pelicans fish for them at the mouth of the Slough, and Striped Bass may often be seen feeding on them. They are also fed upon by terns, cormorants, loons, and grebes.

An interesting fact was noticed when visiting the Slough at night. If the direct rays of a flashligh were turned on one of these smelt it would remain perfectly quiet and could be lifted out of the water with a small hand net.

Family *Cottidae*
Genus *Leptocottus* Girard
Leptocottus armatus Girard

Leptocottus armatus Girard, 1854-55 (1856b), p. 131.

This fish, which is sometimes called the Smooth Cabezon, is quite numerous at the Slough, but it is of no importance as a food fish. It is a source of irritation to fishermen because of its numbers and its propensities for stealing bait. Its preopercular spines are very effective weapons. It averages from 3 to 5 inches in length.

When disturbed, *Leptocottus* rushes rapidly to a new place and buries itself, leaving only the eyes exposed. It forms a favorite food of the great blue heron, which must account for the destruction of great numbers of the fish. It also forms a large portion of the diet of the loons and cormorants which fish in the Slough.

Family *Syngnathidae*
Genus *Syngnathus* Linnaeus
Syngnathus californiensis Storer

Syngnathus californiensis Storer, 1848, p. 73.

This relative of the sea horse is quite common among the *Zostera*. It is very difficult to see in the water because it stands upright. This habit makes it look almost like a blade of *Zostera,* for it, too, is greenish in color.

The male pipefish have a brood pouch in which they carry the eggs until hatched. They may be found with brood during June, July and early August.

Family *Gobiidae*

Genus *Clevelandia* Eigenmann and Eigenmann

Clevelandia ios (Jordan and Gilbert)

Gobiosoma ios Jordan and Gilbert, 1882, p. 437.
Clevelandia ios Jordan and Starks, 1895, p. 839, pl. 100.

This small, active fish lives both free and commensally in the burrows of *Callianassa, Urechis,* and *Upogebia*. It does not migrate to deeper water at low tide, but remains in pools or in the entrances of burrows. It is more abundant in eelgrass regions which are not uncovered at low tide. One hundred twenty *Clevelandia* were collected from a 45-inch circle among the *Zostera*. A series of over 400 *Clevelandia* (which were sent to Dr. Carl Hubbs of the University of Michigan) were obtained from a pool 3 feet wide and 7 feet long which formed when the tide went out. It is evident that it would be difficult to overestimate the numbers of this small goby.

The coloration of *Clevelandia* makes it very inconspicuous, and it is quick to sense danger and dig out of sight when a burrow is not handy. This species is a source of food for terns and kingfishers and larger fish.

Several *Clevelandia ios* were taken to the laboratory and placed in a limorium for the purpose of studying their habits. They use their operculi but little, and it is probable that they respire mainly through the integument. *Clevelandia* goes down a burrow head first, and it can turn around in a burrow which is no larger around than a lead pencil. It can also go backward fairly rapidly in places where the burrow is too small for turning. By means of its pectoral fins it is able to cling to the side of the glass in an aquarium.

Clevelandia picks up food from the bottom by throwing the head sideways or in a straight front attack. It prefers moving material for food, and it undoubtedly eats great numbers of the larvae of *Callianassa*, *Urechis*, annelids worms, etc. as they settle to the bottom.

Clevelandia lays eggs in the spring, fifteen to twenty-five eggs at a laying. The eggs, which are laid singly, are allowed to settle to the bottom, where they adhere to the sand. The eggs are 735μ long and 570μ wide; the yolk is 645μ long and the same width as the whole egg.

Genus *Gillichthys* Cooper

Gillichthys mirabilis Cooper

Gillichthys mirabilis Cooper, 1863, p. 109.

This little fish, known as the long-jawed goby, is not very common at the Slough. Elsewhere reference is made to a 45-inch circle from which 121 gobies were taken. Only one was *G. mirabilis,* and all the others were *Clevelandia ios*. In another collection of over 400 gobies four were *Gillichthys* and the remainder *Clevelandia*. This makes the proportion about one *Gillichthys* to one hundred *Clevelandia*. In its southern range *Gillichthys* is much more abundant.

The habits of *Gillichthys* are much the same as those of *Clevelandia*.

Family *Batrachoididae*
Genus *Porichthys* Girard
Porichthys notatus Girard

Porichthys notatus Girard, 1854-55 (1856a), p. 141.

During the late spring and summer this fish is found nesting under the rocks at Stations 1 and 4. When the females are preparing their nests they work out the sand with their pectoral fins until they have a considerable cavity under the rock, and then, after attaching their eggs to the rock, they lie in this hole and keep watch over the nest until the young become free. At the Slough it is easy to tell under which rocks the *Porichthys* are nesting because the surface of the bottom is covered with a layer of gray detritus, and as the fish digs under the rock it throws out the darker soil from beneath.

As the embryos develop the little fish form on the yolk sac and hang from its lower side. In this position they are able to wriggle quite early, but are unable to leave the rock until the yolk sac is entirely absorbed, which does not occur until the young fish are an inch or more in length. The persistence of this species undoubtedly depends upon the habit of the parent guarding the nest, for otherwise the little fish would be entirely at the mercy of all the neighboring carnivorous species, particularly the shore crabs. The little fish become freed from the rocks in July and August.

When a *Porichthys* is picked up or disturbed it usually makes a grunting sound which can be heard for quite a distance. Because of this trait local residents refer to this fish as a "grunter" or "talking fish."

Family *Pleuronectidae*
Genus *Platichthys* Girard
Platichthys stellatus (Pallas)

Pleuronectes stellatus Pallas, 1811, p. 416.
Platichthys stellatus Lockington, 1878-79, p. 43.

Flounders are quite plentiful in the Slough, and fishermen catch considerable numbers of them. This species is commonly known as the Starry Flounder.

Flounders show great adaptive colorations, for when lying on the sand they so closely resemble it that they are almost invisible. They lie thus waiting for food, and when a fish swims over them they make a quick dart upward and gulp it down. When disturbed they swim rapidly for several yards, leaving a muddy trail behind them, and again come to rest partly buried. If one approaches them carefully when they are partly buried they may be captured by stepping on them.

Those caught within the Slough average from one half to one pound, although some weighing 3 pounds and over have been taken.

Class AVES

Tide flats are always a favorite feeding ground for shore and sea birds; therefore, the area dealt with in this paper has its quota of birds which are representative of such localities. The daily feeding of the great number of birds which one sees at the Slough (and which are listed below), can not fail to have a considerable effect on the animal life there and I believe that this paper would be incomplete without this list of birds and something of their feeding habits.

Of all the birds the gulls, which are represented mainly by the Western Gull and the Ring-billed Gull, are the most numerous. In the summer time the gulls nest on rocks off shore or farther north along the coast and inland. While nesting their food consists mainly of eggs of sea birds, which the gulls obtain by robbing other nests, and of fish which they obtain by robbing other sea birds as the latter bring food to their nestlings. But there are always a considerable number of gulls which seem to be permanent residents at the Slough during the summer, no doubt because, for some reason, they have not mated. After the nesting season the gulls appear in thousands, and often in the fall of the year one of the tide flats may be covered with these birds. Within the reaches of the Slough the gulls fed upon anything they can obtain in the way of flesh, living or dead. They scour the tide flats at low tide, picking up any stranded life and taking considerable toll of the young clams which have the habit of coming to the surface when exposed by the tide.

Next in importance, from the point of view of their demand upon the life of the Slough for food, are the California Brown Pelicans. As far as can be determined, these birds live entirely upon fish, which they take from the water by diving for them. Most of their activities are carried on at the mouth of the Slough, and at any time considerable numbers of them may be found there, fishing or resting upon the spits. It is an interesting sight to see one of these great birds suddenly fold its wings and drop like an arrow, striking the water with a great splash. Seldom do these birds miss their prey, and one can always tell whether or not they obtain the fish they were after. As they strike the water the beak is opened and water rushes in and distends the pouch. This inrush of water carries the fish with it. The water is then removed by straining it out the edges of the beak while the latter is held under water up to the eyes. When this is finished the head is lifted and the fish swallowed by awkward gobbling motions. When the bird is unsuccessful, which happens only on rare occasions, the head is immediately withdrawn from the water after the dive and shaken to dry it.

The Great Blue Heron follows the Pelican in importance as a feeder on animal life at the Slough. A considerable number of these great birds nest in the Eucalyptus grove on the south side of the Slough just above the highway bridge. Except during the nesting season, when they may be seen feeding at any time, these birds feed mainly early in the morning or late in the evening.

Following the Great Blue Heron in importance comes Least Tern, several pairs of which nest on the dunes west of Station 2. These birds, although small, are tireless fishers, and from six to a dozen may be seen at any time flying about near the surface in search of fish. When they sight a fish they usually flutter above it for a moment and then fall like a plummet, sometimes going completely out of sight under the water. They become quite tame and often drop into the water within a few feet of a boat or a person. On one occasion a young tern which was learning to fly alighted on a tide flat within a few feet of me, and the parent birds were observed as they brought food to the young bird and fed it.

In addition to the birds discussed above, Scoters, Loons, and Cormorants fish to some extent in the Slough. The Scoters are important because they feed on small crabs as well as on fish.

The shore birds are very numerous from the latter part of August until the following spring. Their food consists mainly of worms and small crustacea. Thus, judging by their numbers, they are of considerable importance in the food chain. The following is a representative list of the birds common at Elkhorn Slough in the fall. Those marked with an asterisk are abundant the entire year.

Herrmann's Gull
Herring Gull
Ring-billed Gull
*Western Gull
Forster's Tern
Least Tern
Brandt's Cormorant
Common Loon
Pacific Loon
Pied-billed Grebe
Western Grebe
Eared Grebe
*California Pelican
White Pelican (not numerous).
*American Coot
Red-breasted Merganser
Surf Scoter
*California Great Blue Heron
Night Heron
Dowitcher
Marbled Godwit
Knot (not common)
Western Willet
Least Sandpiper
Wilson's Phalarope
Greater Yellow Legs
Kingfisher.

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