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IN

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WILLIAM EMERSON RITTER

AND

CHARLES ATWOOD KOFOID

EDITORS

VOLUME 9

WITH 24 PLATES

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UNIVERSITY OF CALIFORNIA PUBLICATIONS

IN

ZOOLOGY

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THE HORNED LIZARDS OF CALIFORNIA
AND NEVADA OF THE GENERA
PHRYNOSOMA AND *ANOTA*

BY

HAROLD C. BRYANT



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THE HORNED LIZARDS OF CALIFORNIA
AND NEVADA OF THE GENERA
PHRYNOSOMA AND *ANOTA**

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HAROLD C. BRYANT

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* The present paper is the result of work carried on in the Department of Zoology of the University of California as partial fulfillment of the requirements for the master's degree, under the direction of Professor Charles A. Kofoid.

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INTRODUCTION

The paper here presented is the result of preliminary study of *Phrynosoma blainvillei* carried on at Pomona College during 1908 and a further study of the five species of *Phrynosoma* known to inhabit the states of California and Nevada, conducted at the University of California during the college year 1909-1910.

The material upon which this study is based consists of a good working collection of some sixty alcoholic specimens, representing ten of the known species of *Phrynosoma*, belonging to the Zoological Department of the University of California, and in addition a collection of over one hundred and fifty specimens, representing four of the species under consideration, belonging to the Museum of Vertebrate Zoology of the University of California. A cursory examination, which threw new light on the subject, was made of the collection in Leland Stanford Junior University. In all some three hundred specimens were examined. Observation of a large number of live specimens in the field and in the laboratory furnished the foundation for most of the habit notes.

To Professor C. A. Kofoid, under whose direction the work was done, Professor J. C. Merriam, Professor H. B. Torrey, and

Dr. J. A. Long of the University of California, Mr. Joseph Grinnell of the Museum of Vertebrate Zoology, and to Professor J. O. Snyder of Leland Stanford Junior University, the author is greatly indebted for use of material and for valuable suggestions. Thanks are also due Miss Elizabeth Heald for the text figures.

GENERAL DISCUSSION OF THE GENUS

GENERIC CHARACTERS

The southwestern part of the United States, with its warm, dry climate and great deserts, affords most favorable conditions for many of our reptiles. Among the Lacertilia to be found in this locality, no group is so unique and specialized as the genus *Phrynosoma*. The members of this genus are easily distinguished from the other lizards by their flat, oval bodies, covered with keeled, spiny scales, and by their circlet of horns upon the head. Their round pupils, numerous series of ventral scales not abruptly smaller than the laterals, notched tongue and femoral pores, place this genus among the Iguanidae. The presence of horns, however, widely separates the genus from the remainder of this family.

The members of the genus *Phrynosoma* are commonly known as "horned toads." The first part of this name describes these lizards very well, but the last is a misnomer for they bear no close relation to the batrachians. No doubt their sluggish habits and method of obtaining food by means of a viscid tongue, offer an explanation for this misnomer. From a scientific standpoint the name "horned lizard" is far more appropriate.

HISTORICAL DISCUSSION

Clavigero (1780), in his "Storio del Messico," describes and figures a Mexican horned lizard. He describes it thus, "It is remarkable for its shape, being perfectly round and cartilaginous; the body is six inches in diameter; the head is hard and spotted with various colors." His crude figure shows eight spines on the occiput and six transverse bands on the back. Hernandez (1790) also describes and figures a horned lizard from Mexico. Both of these men gave it the Mexican name, Tepajaxin. Later, several others (Barton, 1807?; Wood, 1871) used this term specifically.

Harlan (1825) was the first one to class the horned lizards in the genus *Agama*, his reason for so doing being the presence of femoral pores. He described the Texas horned lizard under the name *Agama cornuta*, calling attention to the fact that "It approaches nearest the *Agama orbicularis* Daudin (1802) or the *Lacerta orbicularis* Linnaeus (1787), the Tapayaxin of Seba, who has given three figures of the species." Four years later, Harlan (1829), in a synopsis of the reptiles of North America, describes but one species, *Agama cornuta* and gives its distribution as "transmississippi territories as far west as the plains of the Columbia River, and as far south as Arkansa [*sic!*]."

The Oregon horned lizard, *Phrynosoma douglassi*, was also placed in the genus *Agama* by Bell (1828). In the same year Wiegmann (1828) placed all of the known horned lizards in a new genus by themselves which he termed *Phrynosoma*. Girard (1858) divided this genus into four subgenera, *Tapaya*, *Batrachosoma*, *Phrynosoma*, and *Doliosaurus*. The subgeneric characters not being diagnostic, but few have used this classification. Cope (1898), instead of following the classification of Girard, divided the genus into two genera, *Phrynosoma* and *Anota*, basing the division on the character of the auricular aperture. This would seem to be the best division that could be made were it not for the numerous instances of intergradation to be found. Both *Phrynosoma platyrhinos* and *P. modestum*, two species grouped under the genus *Anota* in which the tympanum is concealed by a scaly integument, show wide variation in this respect, all gradations from an almost naked tympanum to one entirely concealed being found within each species.

One grouping used by Cope (1898) and Van Denburgh (1897) based on the position of the nostrils, divides the species into well defined groups, but those within each group are so unlike in other characteristics and in distribution that even this division is unsatisfactory.

The bases for generic and specific distinction among the horned lizards have not as yet been generally accepted owing to this difficulty experienced in finding dependable characters.

The working out of a key from a complete set of specimens of all the species might reveal the necessary characters for a revision of the genus. Until this can be done, the classification used by most of the recent writers (Gentry, 1885; Van Denburgh, 1897; Ditmars, 1907), grouping all of the species under the one genus *Phrynosoma*, is best used. One exception, that of *Anota maccalli* (*Phrynosoma maccalli*), should be made. It is here placed by itself in the genus *Anota*, the reasons being given in their proper place.

In the following table are given the recognized species and subspecies of the two genera with their distribution.

A LIST OF THE RECOGNIZED SPECIES AND SUBSPECIES OF THE
GENERA PHRYNOSOMA AND ANOTA

Species	Distribution
1. <i>Phrynosoma asio</i> Cope	Southwestern Mexico
2. <i>Phrynosoma blainvillei blainvillei</i> (Gray) Bryant	Southern California
3. <i>Phrynosoma blainvillei frontale</i> (Van Denburgh) Bryant	Central California
4. <i>Phrynosoma boucardi</i> Bocourt	Plateau of Mexico
5. <i>Phrynosoma braconnieri</i> Bocourt	Southern Mexico
6. <i>Phrynosoma cerroense</i> Stejneger	Cerros Island, Lower California
7. <i>Phrynosoma cornutum</i> Harlan	Kansas, Oklahoma, Texas, New Mexico and Northern Mexico
8. <i>Phrynosoma coronatum</i> Blainville	Lower California
9. <i>Phrynosoma ditmarsii</i> Stejneger	Sonora, Mexico
10. <i>Phrynosoma douglassi douglassi</i> (Bell) Stejneger	Northern part of Pacific Region
11. <i>Phrynosoma douglassi hernandesi</i> (Girard) Cope	Great Plains and Rocky Moun- tains
12. <i>Phrynosoma douglassi ornatissi- mum</i> (Girard) Cope	Painted Desert of Arizona
13. <i>Phrynosoma goodei</i> Stejneger	Sonora, Mexico
14. <i>Phrynosoma modestum</i> Girard	Texas, New Mexico, Utah, Ariz- ona and southwestern Mexico
15. <i>Phrynosoma orbiculare</i> Wiegmann	Plateaus of Mexico
16. <i>Phrynosoma platyrhinos</i> Girard	Lower Sonora and Deserts of the Great Basin from California to Utah
17. <i>Phrynosoma solare</i> Gray	Valleys of the Gila and Colorado rivers
18. <i>Phrynosoma taurus</i> Duges	Southeastern Mexico
19. <i>Anota maccalli</i> Hallowell	Deserts of the Gila and Colorado rivers

Genus **Phrynosoma** Wiegmann

Anota, Cope (1866), p. 310.

Tapaya Girard (1858), pp. 394-399, pl. 21, figs. 6-9.

Batrachosoma Girard (1858), pp. 354-365, pl. 20, figs. 10-13.

Doliosaurus Girard (1858), pp. 407-410.

Many good descriptions of the genus *Phrynosoma* are to be found, but all except Cope's (1898) are based solely on external characters. It is hoped that the addition here made of the more noticeable osteological characters will make the description more complete.

EXTERNAL CHARACTERISTICS

Diagnostic Characters: Head short, cordiform and elevated at the vertex; occipital and temporal regions bearing flattened and grooved spines which vary in length and number; cephalic plates small and polygonal; nostrils anterior or lateral; teeth small and bluntly conical; palatine teeth lacking; body short, suborbicular, greatly depressed and usually fringed by one or two rows of spinose scales; back covered with scales which vary greatly in size and shape; scales of ventral surface, smooth and equal sized; gular folds present; tail short, usually rounded and conical; limbs short, digit moderately developed; tympanum visible or covered more or less with scales; femoral pores present; preanal pores lacking; no dorsal or caudal crest (pl. 1).

Description: The body is broad, flat and oval, usually with a lateral fringe (pl. 1). Dorsally it is covered with keeled scales which are irregular in shape and size. Ventrally the scales are small and regular, giving an imbricated appearance. Larger keeled scales cover the front of the arm and thigh. The head is short and somewhat triangular in shape with a sharp projecting margin. The projecting superciliary regions overhang a groove from the occiput to the snout, in which the eye is situated. Small subequal scales cover the top of the head and a row of bony spines, variable in length and number, are to be found on the temporal and occipital region. The projecting superciliary regions bear posteriorly short, sharp scales. Protected by bony processes and just in front of the interoccipital region, is the

median pineal eye. The lower jaw is bordered by large projecting spinous plates. The neck is short, causing transverse gular folds which often cover the auditory aperture. The pentadactyl limbs are short and about equal in length, and the digits are moderately developed, the fourth being longest. The tail is short, conical, and covered dorsally with the same sort of scales as the back. Posteriorly the ventral scales are keeled. The tympanum may be naked or covered with scales. This character varies within species, however, and is not a good basis for dividing the genus as Cope (1898) has suggested. The nostrils are conspicuous and may be either on the line joining the superciliary region with the end of the snout or above this line (pl. 2). A row of femoral pores varying in number in the different species from seven to twenty, are found in both sexes on either thigh. Those in the male are the most highly developed. The presence of enlarged postanal scales in the male is a dependable character for determining sex. Anal pores are absent. Juveniles may be distinguished by their small size and poorly developed horns.

OSTEOLOGY

The following description of the osteology was made after a study of complete skeletons as enumerated below. The generic osteology given here is largely an amplification of Cope's (1898) work.

LIST OF SKELETONS

Species	Museum number	Locality	Collector
<i>Phrynosoma douglassi</i> <i>douglassi</i>	Zool. Dept.	Prescott, Arizona	G. W. Treadwell
<i>Phrynosoma blainvillei</i> <i>blainvillei</i>	272	Schain's Ranch, San Jacinto Mountains, California	Charles Camp
<i>Phrynosoma blainvillei</i> <i>frontale</i>	Zool. Dept.	Kern County, California	
<i>Phrynosoma platyrhinos</i>	1300	Big Creek Ranch, Humboldt County, Nevada	W. P. Taylor
<i>Phrynosoma platyrhinos</i>	1301	Pine Forest Mountains, Humboldt County, Nevada	Taylor and Richardson
<i>Phrynosoma cornutum</i>	4579		

LIST OF SKELETONS—(Continued)

Species	Museum number	Locality	Collector
<i>Anota maeccalli</i>	1006	Salton Lake, Imperial County, California	F. Stephens
<i>Phrynosoma modestum</i>	Zool. Dept.	Arizona	G. W. Treadwell
<i>Sceloporus occidentalis</i>	Zool. Dept.	Near San Leandro, Alameda County, California	E. P. Rankin
<i>Dipsosaurus dorsalis</i>	1878	Colorado River at Pilot Knob, California	J. Grinnell
<i>Crotaphytus wislizeni</i>	1467	Big Creek Ranch, Humboldt County, Nevada	C. H. Richardson, Jr

Diagnostic Characters: Parietal and supratemporal elements and often the jugal possessing spines; superciliary ridges formed by processes from the frontal and prefrontals present; post-orbital spines small and short; epipterygoids short, only reaching to the petrosal; pterygoid teeth absent; sternum broad with large fontanelle; no abdominal ribs; chevron bones lacking symphyses; postischial symphyseal cartilage well developed.

Description—Skull: The alveolar portion of the premaxillary is short and borders the nasal openings for a very short distance. The same openings are bordered laterally by processes arising at the middle of the maxillary elements. The nasals are distinct and form half or more of the arch over the nostrils. The unpaired frontal, narrowed anteriorly, where it articulates with the prefrontals, forms the superior arches over the orbital cavities. At the ends of the arches are small posterior, spiny processes and long, acute, anterior, superciliary processes extending forward over the orbits. The large prefrontals send processes posteriorly over the orbits forming, with the processes from the frontal, the superciliary ridges. These two processes vary in length in the different species, almost meeting in some (*Phrynosoma blainvillci blainvillci*, *P. b. frontale*) and widely separated in others (*P. platyrhinos*, *P. modestum*, *P. douglassi*). In *P. cornutum* they meet and partially ossify. The postfrontals are usually ossified. The lacrymals are small. The parietal overhangs the supra-occipital and supports several horns on its strong parieto-quadrate arch. The number of horns is usually two with a rudimentary third between, but in *P. solare* there are four well-

developed horns. The pineal foramen is usually at the coronal suture but may pierce the parietal alone. The paraoccipital is small and partially hidden by the occipital. The supraoccipital forms the superior part of the foramen magnum and articulates anteriorly with the parietal. The occipital condyle is formed by ossified processes from the basioccipital and lateral occipital elements. The sutures of the occipital elements are lacking. The postorbitals are slender but articulate broadly with the frontals and parietals above and the supratemporals and jugals below. The supratemporals and jugals are projecting and bear spiny tuberosities except in *P. douglassi* and *P. cornutum*, where they are lacking or reduced to mere tubercles on the jugals. The quadrates are at an angle to the vertical and present an external concave only, the inner surface being convex, whereas in all other iguanids except *Eublepharis* and *Celestus*, it is concave (Cope, 1898). The short vomers are separated by a narrow hiatus which broadens between the wide, toothless palatines and the pterygoids. The palatines possess processes which run forward and outward and join the vomers in front. The palatine foramina are small and vary in shape. The short, wide pterygoids run forward from the quadrates to the basi-ptyergoid processes of the sphenoid, then broaden out and articulate with the palatines. These elements are edentulate. The ectopterygoids are irregular in shape and articulate with the palatines for only a short distance. The petrosals are short and grooved inferiorly. The slender epipterygoids are peculiar in that they reach only to the petrosals. They originate just behind the ectopterygoid processes.

The Meckelian grooves may be open or partly closed by cartilage. The coronoids are situated just above the sutures between the angulars and the dentaries and articulate broadly on the interior surface of these two bones. The pleurodont teeth, one row on each dentary, are small and bluntly conical. The articulares are sometimes ossified with the surangulars.

The basihyal is wide and ossified. The rod-like anterior cornua are also ossified. The middle cornua are usually cartilaginous, very broad at the tip, and attached to the anterior

cornua at their middle and end. The posterior cornua are short and have their origin close to the middle cornua.

The orbital cavities are very large. A supratemporal opening is present in all of the species studied except *Anota maccalli*. The posterior temporal openings vary greatly in size and shape. The nasal openings may be anterior or lateral.

Vertebral Column: The procoelous vertebrae lack the zygosphenic articulation, although there are corresponding rudimentary processes. Only the cervical vertebrae possess intercentra. There are twenty pairs of ribs, the first pair and the last four or five pairs being short. The ribs from the second to the eighth vertebra articulate by cartilage to the sternal ribs. The two sacral vertebrae are partly fused. At least six to eight caudal vertebrae possess haemal arches, the remaining being rudimentary or vestigial. The neural spines are short but show in some species a tendency to form a dorsal crest. Chevron bones are present from the fourth or fifth caudal vertebra to near the end of the tail. These bones are peculiar in the lack of a symphysis.

Pectoral Girdle: The thin suprascapulas are nearly as long as the scapulas and extend well over the back. A proscapular process is present on each scapula. The episternum is only slightly curved and extends but a short distance beyond the sternum on each side. The sternum is broad and has a large fontanelle. Two or three sternal ribs may articulate with the sternum and the xiphoid rods are connected with but one rib. In *Phrynosoma platyrhinos* the third pair of sternal ribs have their origin on the xiphoid rods and only two ribs articulate with the sternum.

Pelvic Girdle: The ilia are stout and nearly vertical in position, whereas the pubes and ischia are slender and transverse, being separated by a large ischio-pubic foramen. At the symphysis the bones are connected by cartilage. Extending posteriorly from the symphysis and dorsally toward the vertebral column, is a slender rod-like cartilage. This cartilage, although not mentioned by Cope (1898), is found in each species. Not being able to find a name for it in literature it is here termed

the postischial symphyseal cartilage. In the different species it was found to vary in length and in the character of the tip. In some species (*Phrynosoma platyrhinos*, *Anota maccalli*) the tip is bifid. A tendency toward ossification was also found, the cartilage in *Phrynosoma blainvillei blainvillei* being ossified and that in *Anota maccalli* being partly ossified. The great difference in length and in the character of the tip, which may be found in the different species, is well illustrated in figures A and B.

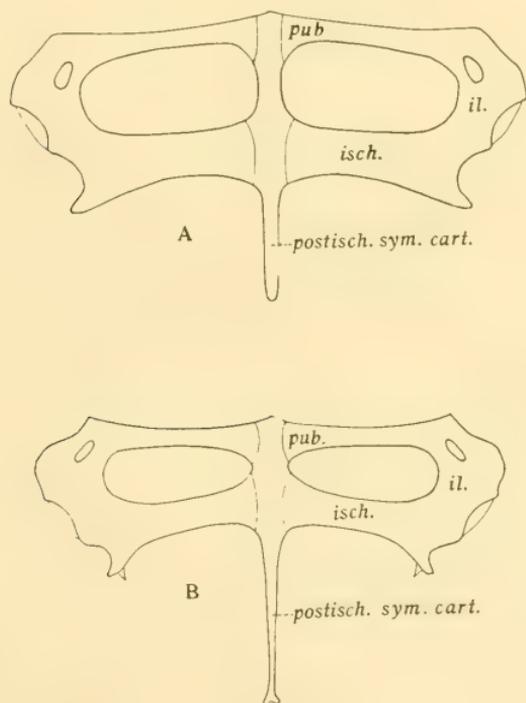


Fig. A. Pelvic girdle of *Phrynosoma blainvillei blainvillei* (Univ. Calif. Mus. Vert. Zool., no. 272). *pub.*, pubis; *il.*, ilium; *isch.*, ischium; *postisch. sym. cart.*, postischial symphyseal cartilage. $\times 2$.

Fig. B. Pelvic girdle of *Anota maccalli* (Univ. Calif. Mus. Vert. Zool., no. 1006). *pub.*, pubis; *il.*, ilium; *isch.*, ischium; *postisch. sym. cart.*, postischial symphyseal cartilage. $\times 2$.

The elongation of the symphyseal cartilage into a rod-like structure is found in other iguanids (*Dipsosaurus dorsalis*, *Sceloporus occidentalis*) but is developed to a less degree. The tendency to ossify appears to be peculiar to the genera *Phrynosoma* and *Anota*.

Limbs: The limbs are short but typically lacertilian. A pisiforme, ulnare, intermedium, radiale, centrale, and five carpalia compose the carpus, and five metacarpalia, the metacarpus. The tarsalia are partly united with the metatarsalia. A well-developed claw tips the digits.

INTEGUMENT

The integument of the horned lizards is much like that of other lizards except for a modification of the epidermis on the horns and the wide variation in size and shape of the dorsal scales.

On the horns and larger spinous scales the epidermis is modified into a cartilaginous cap. This cap is shed with the skin and is regenerated by the layer of epidermis which remains.

The rest of the epidermis is developed into horny plates or scales. The layer is continuous, the scales being formed by a thickening of the horny layer. The dorsal scales in this genus vary greatly in size and shape. Those of the back may be small and granular or large, keeled and tuberculated. Ventrally the scales are uniform in size and show a pavement-like arrangement. The plates of the head are usually small and regular in size but show variation in each species. Enlarged scales are found on the mandibles and periphery.

The horny epidermis is cast off periodically. This exuviation as shown by Bruner (1907), is caused by "a new growth of the stratum corneum beneath the old layer and a mechanical pushing off, of the old stratum which has been cut off from its supply of moisture and nourishment." This last part of the process is greatly aided by the growth of small prickles on the surface of the new layer. There is also a possibility that the formation of new capillaries may aid the process (Bruner, 1907). The molting process often causes the lizard a certain amount of incon-

venience. The skin usually loosens in patches and either falls off or is rubbed off. Pieces of skin two inches in diameter were found in the cage of some *P. b. blainvillei* which were molting in September.

Hay (1892) has suggested that the ejection of blood by the horned lizard is a protection at the time of molting. This is a possibility, but it is certain that the lizard can just as easily be induced to eject blood when it is not molting. Bruner (1907), in an interesting discussion, shows the use of the large blood sinuses of the head in aiding the molting process. The increased blood pressure in the sinuses in a measure explains the ejection of blood from the eye at such a time.

Located beneath the horny layer, in the dermis, are numerous pigmented cells situated in a layer of cells containing scattered yellow pigment granules. These cells constitute the mechanism by which the lizard is enabled to change its color. In *Phrynosoma*, the color change is slow, Coues (1875) stating that the change takes place in from twenty-four to forty-eight hours. The manner in which the change in color is accomplished is not far different from that found in the chameleon and *Anolis* except that the mechanism in the latter instances is more complex. Although it is impossible to see the change take place, yet the cells involved can be easily studied under the microscope. A piece of skin from a juvenile *P. b. blainvillei* when fixed in Erlicki's fluid and sectioned, showed large round cells filled with black pigment situated in the dermis below the scutes. In my material the pigmentation was best shown in unstained sections. The melanophores possessed many branches leading toward the epidermis, each branch dividing and redividing forming a network. In most instances the branches were filled with the black pigment. Between the melanophores and scattered through the dermis was a yellowish pigment constituting the ochrophore layer. The migration of the pigment outward or inward through these branches accounts for a dark or a light color, and is governed by the nervous system. Carleton (1903) has shown it to be the sympathetic system in the case of *Anolis*, whereas Brücke (1851) and Keller (1895) have shown it to be the cerebro-spinal

system in the chameleon. Light and heat rather than moisture probably have the most effect on the nervous system (Parker, 1904). In *Phrynosoma* light causes an inward migration of the pigment and dark, an outward migration. This is true in *Varanus*, *Agama* and several other lizards, but the opposite is true in *Anolis* (Carleton, 1903).

For the reason that the coloration varies so widely with the substratum, the color characters are omitted from the diagnoses. In the case of *P. douglassi douglassi* the distinctive features of the coloration are inserted in the key because the color characters are important in distinguishing subspecies.

On the ventral sides of the thighs, there is developed a row of glands, the so-called femoral glands. The ducts, which open on a row of enlarged scales, are formed from the stratum corneum and are filled with a mass of yellowish secretion (Shaefer, 1902). The glands are supposed to function in coition (Edwards, 1896).

REPRODUCTION

Reproduction in this genus is both oviparous and viviparous. Among the oviparous species are *Phrynosoma cornutum* and *P. blainvillei*. The former is known to dig a hole in the earth, deposit its eggs and cover them with sand (Edwards, 1896). Several days are needed for incubation. With *P. blainvillei*, however, the young hatch a few hours after the eggs are laid. The eggs are from fifteen to twenty millimeters in length and are covered by a tough, semi-transparent membrane. They vary in number from six to fourteen. *P. douglassi*, on the other hand, gives birth to numerous young which are able to take care of themselves a few hours after they are born (Ditmars, 1907). Young are usually produced late in the summer, although a specimen of *P. blainvillei blainvillei* kept in captivity laid its eggs the last of June. Specimens of the same species were seen in the act of coition in the latter part of April and in May. The period of gestation is not known.

HABITS

Phrynosoma is the most distinctly terrestrial genus of all the iguanids, in form and structure being ill adapted to climbing.

Most of the species are found in a dry, sunny climate, and usually where there is sandy soil and very little vegetation. A well known exception is that of *P. blainvillei frontale* which occurs in the forest belt of the Coast Range in California. Such an environment provides these lizards with an abundance of insect food,—ants, beetles, flies, etc.

The horned lizard presents a fine example of protective resemblance. Wherever its home, it resembles the color of the substratum so closely that it is practically invisible except when in motion. Specimens from the white sand of the desert are very light in color, those from the black lava belt are almost black, whereas those from the vari-colored mountain districts show red and even bluish markings. How quickly a change in environment would bring about a change in color is not definitely known, although Coues (1875) states that the change takes place in from twenty-four to forty-eight hours. Several specimens of *P. blainvillei blainvillei* from Pasadena when kept in captivity on dark soil in the moister climate of Berkeley, on shedding their skin, showed a much darker color. This may have been due partly, however, to their being kept indoors, for Parker (1904) has proved that both light and temperature influence color change.

The most distinctive thing about horned lizards is the circlet of horns which crowns the head. Any one who has seen a horned lizard on the defensive cannot doubt the value of these horns as a protection to the animal. With its head lowered so as to receive any blow on the horns and the large scales of the back elevated, it presents a very formidable appearance. In fact, the lizard seems to depend almost entirely on the ability to frighten its enemies, for aside from the horns it has no means of defense, as it seldom attempts to bite and is not a swift runner. As most of the species are represented by large numbers of individuals, the protection appears to have been adequate.

The two greatest enemies of the horned lizard are the road runner (*Geococcyx californicus*) and the rattlesnake (*Crotalus*). A tradition existing among the Indians that a horned lizard is able to burrow its way out of a snake's stomach seems to have some foundation in fact, for rattlesnakes have been found with

the head of a horned lizard protruding through the body wall. Mr. Newhall witnessed such a phenomenon in the Yosemite Valley. Rattlesnakes have also been found with the horns of a *Phrynosoma* caught in the throat (Cope, 1898). With the coming of civilization the domestic cat becomes a formidable enemy second only to the curio collector, who has practically exterminated the horned lizards in some localities.

A *Phrynosoma* is slow and sluggish in its movements. If moving leisurely along, it drags its body on the ground, but when running stands well on its legs. When frightened, it usually tries to seek shelter in a nearby bush or buries itself in the sand. The latter operation is very interesting, for it is so widely different from the method used by other burrowing animals. The chisel-shaped head is the principal tool, the legs being used almost solely for forcing the head forward. A wriggling motion of the head and body serves to drive the head beneath the sand and soon covers the body completely with earth. A little shake of the tail flings the dirt over that appendage and the lizard becomes entirely hidden. The nostrils are kept either at the surface of the ground or near enough to the surface so that breathing is possible.

The members of this genus, like most of the Lacertilia, are such lovers of sunshine and heat that they are seldom found in winter or on cold or rainy days. The winter months are spent in hibernation in rodent holes or buried beneath the soil. A specimen of *P. blainvillei blainvillei*, plowed out on December 15, 1909, was found to be in a state of hibernation. The eyes were tightly closed and the lizard could not be induced to open them; the muscles were set, the animal often lying in a very awkward position. The breathing was slow and erratic, intervals of several minutes intervening between inspirations. The external temperature of the body was about that of the air (15° to 18° C.). Some ten minutes after placing the lizard in the sun, it showed signs of renewed energy and was ready to run at anyone's approach.

Ants, beetles, flies, and other insects form the principal diet, although Bell (1828) states that *P. douglassi* is somewhat herbivorous. Unless very hungry, live insects alone satisfy a

Phrynosoma. In fact, their eyes seem unable to distinguish an insect unless it moves, so that this may largely govern the feeding habit. On seeing its prey, a *Phrynosoma* has a habit of raising and lowering itself on its front legs much as a lizard does when sunning itself on a rock. Always when feeding it raises itself well on its legs, seemingly to avoid being bitten. The moment the insect moves, the horned lizard darts for it, catches it on the end of its viscid tongue, swallows it alive and backs off again. Why the animal is never bothered by being stung internally by the ants it eats, seems hard to explain. Certainly the lining of the mouth and stomach must be particularly adapted to withstand the poisonous sting of insects, for when stung externally, the lizard shows no little discomfiture.

The dewdrops on the vegetation may sometimes serve as the water supply. Although horned lizards go for long periods of time without water, yet they are known to drink greedily at times.

A peculiar habit of "playing possum" is often seen, the lizard remaining perfectly still, as if dead, but darting away at the first opportunity for escape.

An interesting reaction is seen in the hypnotic effect produced by rubbing the animal on top of the head and between the eyes. Under such treatment the lizard turns its head down, closes its eyes and apparently goes into a hypnotic stupor. Pinching it with a tweezers or placing it on its back, a treatment which it highly resents in a normal state, fails to awaken it. In some cases specimens remain in such a stupor for five or ten minutes. The first sign of awakening is usually evidenced by the slow opening of the eyes. This habit may be simply a "playing possum," but is probably more in the nature of hypnosis such as is produced on birds when held for a time on their backs. This phenomenon offers a field for further study.

DISTRIBUTION

Phrynosoma is distinctly a North American genus, ranging from Canada to southern Mexico and from the Mississippi to the Pacific coast. The southwestern United States and Mexico have the largest number of representatives, due probably to the

especial fitness of the soil and climate. Of nineteen recognized species and subspecies, all but eight are found in the United States, these eight being distinctly Mexican species. The Texas horned lizard, *Phrynosoma cornutum*, is perhaps the best known and most widely distributed of any of the species, being found from southern Kansas and Colorado to the Gulf of Mexico and into Mexico as far as Monterey, and from New Mexico to Arizona. Other species, as for instance *P. modestum*, have a more limited distribution.

In California and Nevada are found four representatives of the genus *Phrynosoma*, *P. blainvillei blainvillei*, *P. blainvillei frontale*, *P. douglassi douglassi*, *P. platyrhinos*, and one representative of the genus *Anota*, *A. maccalli* (*P. maccalli*). A fifth *Phrynosoma*, *P. coronatum*, has been reported from San Diego, California (Cope, 1898). No California specimens of *P. coronatum* have been available in this study, although plenty of *Phrynosomas* from this locality were at hand. Specimens of this species in the collection at Leland Stanford Junior University were taken at San Telmo, Ensenada, San Jose del Cabo, and Santa Anita, Lower California. The majority of the known specimens are from the type locality, Cape San Lucas, Lower California. A number of specimens from San Diego County near the Mexican line (San Diego, National City, Campo, Dulzura), which were examined, are distinctly *P. blainvillei blainvillei*. If *P. coronatum* is found within the state it certainly is not of common occurrence. The fact that *P. coronatum* has often been used to include several species (Girard, 1858; Gentry, 1885; Ditmars, 1907) leaves the occurrence of this species in this state still in question. The two species *coronatum* and *blainvillei blainvillei* are separated by several distinct characters, so that they are easily identified.

Some doubt also centers around the occurrence of the pigmy horned lizard *P. douglassi douglassi* in northern California. But a single definite record, that of Charles H. Townsend (1887), from the western base of Mt. Shasta, is known. The type locality being the Des Chutes River, Oregon, its occurrence along the northern border of the state seems probable. An attempt to obtain specimens from the vicinity of Mt. Shasta failed, as did

also one to secure them from across the line in Oregon, where it was stated they had been seen. Several people living at Sisson, a town on the southwestern base of the mountain, stated that they had never seen a horned lizard in that locality. No distinctly California specimens being at hand, the discussion of this species has necessarily been abbreviated.

The type locality of *Phrynosoma blainvillei* was originally given as "California" without specification of locality. Since the division of the species into *P. blainvillei* and *P. frontale* by Dr. Van Denburgh (1903), the distribution of *P. blainvillei* should be restricted to southern California. An examination of a large number of specimens of these two species showed an intergradation of the diagnostic characters used by Van Denburgh. This fact, as well as others, indicate that these lizards belong to races rather than species. Cope (1898) has already suggested this. The two have therefore been reduced to subspecific rank and are referred to as *Phrynosoma blainvillei blainvillei* and *Phrynosoma blainvillei frontale*. A discussion of the intergradation and the reasons for the reduction can be found on page 35.

Blainville's horned lizard, *Phrynosoma blainvillei blainvillei*, is the common horned lizard of southern California, being found on the coastal slope from Los Angeles County southward to the Mexican line. Specimens from San Diego County are considered most typical. An intergradation with *Phrynosoma blainvillei frontale* takes place in northern Los Angeles County (see page 35).

The California horned lizard, *P. blainvillei frontale*, is found principally in the San Joaquin basin, although there are many records of its occurrence in the counties along the coast from San Mateo County southward. The most northern record is from Colfax, Placer County, and the most southern of individuals showing distinctly *P. b. frontale* characteristics, from Matilija, Ventura County. The type specimen in the collection of the Leland Stanford Junior University is from Bear Valley, San Benito County, California.

The three remaining species are limited to desert regions. *P. platyrhinos*, the desert horned lizard, occurs abundantly in

Nevada, the Mojave Desert, and the northern part of the Colorado Desert of California. There are also records from Arizona. The hottest and most arid parts of the deserts seem to be the most attractive for this lizard. The type specimen was obtained from the basin of Great Salt Lake.

A single specimen of a horned lizard collected in Death Valley, Inyo County, California, was described by Cope (1896) as a new species, *Anota calidiarum* (*Phrynosoma calidiarum*). The type being the only specimen known, and the differences from *P. platyrhinos* being very slight, there is some doubt as to the validity of the species.

The flat-tailed horned lizard, *Anota maccalli*, the other desert species, is rare and found only on the Colorado Desert of Imperial County, California, the Gila Desert, and Sonora, Mexico. The type specimen was taken between Vallecito and Camp Yuma, about 160 miles from San Diego. Van Denburgh (1897) gives this as the only California record of *A. maccalli*, the other three specimens belonging to the U. S. National Museum being from Fort Yuma, Arizona. Of this rare species there are at present in the Museum of Vertebrate Zoology of the University of California eight specimens, four from Mecca, three from Salton Lake, and one from Coyote Well. Several specimens of *P. platyrhinos* were taken at Mecca at the same time that *Anota maccalli* was collected, which would show an overlapping of the areas of distribution of the two species at this point.

Another overlapping of areas of distribution is to be noticed in the case of *Phrynosoma blainvillei frontale* and *P. platyrhinos*, for specimens of both species have been taken in Walker Pass, along the Kern River near Chimney Creek, and on the west slope of the divide, at an altitude of 5500 feet, in Kern County, by members of the Mt. Whitney Expedition of 1911 of the Museum of Vertebrate Zoology of the University of California. Doubtless the same intermingling of species takes place at other points in the Sierras, for, although this range of mountains forms the western boundary for *P. platyrhinos* and the eastern boundary for *P. blainvillei frontale*, it in no way forms an insurmountable barrier for these lizards.

There are no records of any species of *Phrynosoma* from the islands off the California coast, although some of the other lizards, as, for example, *Sceloporus* and *Uta*, are abundant there. *P. cerroense* is found only on Cerros Island off the coast of Lower California.

The appended map (pl. 8) shows clearly the distribution of the five species of horned lizards inhabiting California and Nevada. In the preparation of the map only reliable records were used. In no case were records incorporated where the subspecies could not be differentiated.

As the map shows, each species inhabits a rather well defined region and there is little overlapping of areas of distribution. Generally speaking, the distribution of these species conforms fairly well to the faunal areas proposed by Van Denburgh (1897). According to his analysis, the Colorado and Mohave deserts comprise the Desert Fauna; the southern end of the state, comprising San Diego (including what is now Imperial), Orange, Riverside, San Bernardino, and Los Angeles counties, constitutes the San Diego region; the western slope of the Sierra Nevadas westward to the ocean, the Californian; a strip along the coast, north of Monterey, the Pacific; and the mountainous region of the Sierra Nevada, the Sierra Nevadan. Thus, *P. platyrhinos* and *A. maccalli* would belong to the desert fauna, *P. b. blainvillei* to the San Diegan, *P. b. frontale* to the Californian, Pacific, and possibly the Sierra Nevadan, and *P. d. douglassi* to the Pacific and Sierra Nevadan.

As might be expected, the desert species, *Phrynosoma platyrhinos* and *Anota maccalli* show some special modifications which may be related to their environment. The most noticeable one is the reduction of the enlarged keeled scales of the back. Compared with *P. b. blainvillei* and *P. b. frontale*, these species present a rather smooth skin made up of small scales of unequal sizes and irregular distribution with the spiny scales reduced in size. In the ear opening we find the most characteristic modification, a characteristic which Cope (1898) has used in dividing the species into the genera *Phrynosoma* and *Anota*. In *A. maccalli* we find the ear opening entirely closed and in *P. platyrhinos* it is covered completely or partially by

scales. In the former, even a depression is scarcely discernible. The latter, however, shows clearly the location of the opening. That this unusual modification is some particular adaptation to environment would seem to be proved by its prevalence among all truly desert species of horned lizards. None of the other iguanids except *Holbrookia* show this adaptation, however. A slight reduction in size in *P. platyrhinos* and a greater reduction for *A. maccalli* is also to be noted in this connection.

KEY TO GENERA AND SPECIES

[Based in part on that of Van Denburgh (1907)]

- A. Horns flattened and grooved; one or two rows of peripheral spines; tail rounded; supratemporal openings present *Phrynosoma*
- a. Nostrils on the line joining the superciliary ridge with the end of the snout.
- b. One row of peripheral spines; occipital horns rudimentary; no rows of enlarged gular scales *P. douglassi*
- c. Size small (70-90 mm.); horns mere tubercles; snout blunt; coloration inconspicuous *P. douglassi douglassi*
- bb. Two rows of peripheral spines; occipital horns well developed; three rows of enlarged gular scales *P. blainvillei*
- d. Head shields convex and almost smooth, centrally located ones largest *P. blainvillei blainvillei*
- dd. Head shields flat, with numerous ridges and granulations, size uniform *P. blainvillei frontale*
- aa. Nostrils above the line joining the superciliary ridge with the end of the snout.
- c. Horns short (4-8 mm.); one row of peripheral spines; six to twelve femoral pores *P. platyrhinos*
- AA. Horns long (8-12 mm.), smooth and conical; three rows of closely-set, peripheral spines; tail flat; supratemporal openings absent *Anota*
- f. Nostrils anterior; sixteen to twenty femoral pores *A. maccalli*

***Phrynosoma douglassi douglassi* (Bell) Stejneger**

Pigmy Horned Lizard

Agama Douglassi Bell (1828), pp. 105-107, 1 pl.*Phrynosoma douglassi* Girard (1853), pp. 361-362, pl. 7, figs. 6-10.*Tapaya douglassi* Girard (1858), pp. 397-399, pl. 21, figs. 1-5.*Phrynosoma douglassi pygmaea* Yarrow (1882), p. 443.

EXTERNAL CHARACTERISTICS

Diagnostic Characters: Head broader than long; nostrils at the end of the supereiliary ridge; occipital horns very short, being in some cases mere tubercles; supratemporal horns projecting farther posteriorly than the occipital; head plates irregular in size and shape, and usually convex and granulated; sublabials not much larger than infralabials, the last three or four

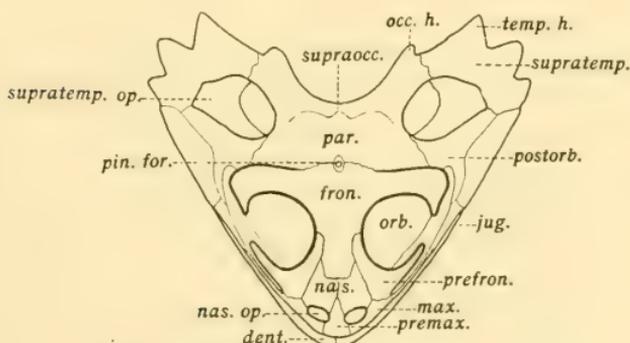


Fig. C. Skull of *Phrynosoma douglassi douglassi* (Zool. Dept.). *dent.*, dentary; *fron.*, frontal; *jug.*, jugal; *max.*, maxillary; *nas.*, nasal; *nasal op.*, nasal opening; *occ. h.*, occipital horn; *orb.*, orbit; *par.*, parietal; *pin. for.*, pineal foramen; *prefron.*, prefrontal; *premax.*, premaxillary; *postorb.*, postorbital; *supraocc.*, supraoccipital; *supratemp.*, supratemporal; *supratemp. op.*, supratemporal opening; *temp. h.*, temporal horn. $\times 2$.

enlarged and pointed; a conical rictal scale present; gular scales small and equal in size; body with one row of peripheral spines; back and tail with several rows of large, keeled, spiny scales set among smaller scales and granules; abdominal scales small and smooth; tail slender and rounded toward tip; tympanum usually visible but sometimes covered with scales; femoral pores in long series almost meeting medially.

Description: The horns are very rudimentary, reduced to blunt, conical tubercles, and flattened and grooved, those of the supratemporal elements projecting beyond those of the occipital region (pl. 3, fig. 7). The two occipital spines are widely separated at the base. An enlarged scale alone gives evidence of

an interoccipital. A series of four or five temporal horns are found on each side. One row of peripheral spines fringes the small body. The tail is enlarged near its base and then narrows suddenly into a short cylindrical part. It is fringed by a row of conical scales and is covered dorsally and ventrally by the same sort of scales as are found on the back and belly. The nostrils are situated on the line joining the superciliary ridge with the end of the snout. The muzzle is almost vertical. The gular scales are of equal size (pl. 3, fig. 8). The head is obtusely triangular, broader than long, and the superciliary region is strongly marked. Scales of the row on the margin of the superciliary ridge are enlarged, the central one acting as a keystone. The infralabial scales are larger than the supralabials, the last four to six being enlarged and pointed, forming a row of subrials. At the rictus is situated an enlarged, conical scale. The limbs are short. The enlarged dorsal scales are arranged in several rows but are not conspicuous. They are not surrounded at their base by a rosette. The abdominal scales are smooth and acute. Long series (usually sixteen) of conspicuous femoral pores approach the median line invading the preanal region. Males usually have enlarged postanal plates. See table of measurements for dimensions and proportions of the lizard.

The coloration varies greatly, the commonest being ashy to brown with several rows of dark blotches. The neck patches are narrow and widely separated (pl. 1, fig. 1). The tail and limbs are obscurely cross-banded. A faint, central white line runs from the occiput to the tail. The ventral surface is usually spotted as is also the gular region. For general color pattern see plate 3, figure 7.

OSTEOLOGY

Diagnostic Characters: Horns of occipital region rudimentary and widely separated; supratemporal horns extending posteriorly to them; nasals with short, obtuse processes over nostrils; spines on jugal elements lacking; postorbitals with broad articulating processes furred at right angles to each other; quadrates long with deep conchs; the epipterygoids run along the petrosal

for two millimeters; postischial symphyseal cartilage short (3 mm.) and not bifid.

Description: The alveolar portion of the premaxillary (*premax.*, fig. A) does not border the nostrils (*nas. op.*). The nasals (*nas.*) have a short obtuse process directly over the nasal opening. The superciliary processes from the frontal (*fron.*) are short and sharp; those from the prefrontals (*prefron.*) end in a sharp point above the middle of the orbit (*orb.*). The two rudimentary occipital horns (*occ. h.*) are widely separated. An interoccipital spine is represented by an enlarged, obtusely pointed scale. The horns on each supratemporal element (*supratemp. h.*) are three in number and the posterior ones extend farther back than the occipital horns. The pineal foramen (*pin. for.*) is at the coronal suture. The postorbitals (*postorb.*) have very broad articulations with the supratemporals (*supratemp.*) and jugals (*jug.*) and less broad ones with the frontal and parietal (*par.*). The broad processes for the latter articulations are turned at right angles to the processes for articulation with the former. There are no spinous processes on the jugals. The nearly vertical quadrates are long and narrow with deep conchs. The palatine foramen is long (3-4 mm.) and narrow. The upper part of the epipterygoids runs along the petrosal for about two millimeters.

All of the elements making up the inferior mandible are thick and heavy. Meckel's groove is short. Cope (1898) states that the surangular is ossified to the articular in this species, but the writer's specimen showed a well-defined suture.

The supratemporal openings (*supratemp. op.*) are large. The nasal apertures (*nas. op.*) are lateral (pl. 2, fig. 2).

There is no evidence of a dorsal crest, the neural spines being very nearly equal in size. The transverse processes of the caudal vertebrae are short and are absent on the last five or six vertebrae. The first pair is only a little shorter than the second and third pair. Three sternal ribs articulate with the sternum (pl. 8, fig. 17). The postischial symphyseal cartilage is three millimeters long and is not bifid.

Phrynosoma douglassi, which is the smallest of the horned lizards, has three recognized subspecies, *P. douglassi douglassi*

(*P. douglassi pygmaca*), *P. douglassi hernandesi* and *P. douglassi ornatissimum*. The first is found only in the North Pacific district, the second only through the central district, the Rocky Mountains and Great Basin, and the third, the desert species, only on the deserts east of the Sierra Nevada. *P. douglassi douglassi* is much smaller than the other subspecies and may be distinguished also by its very blunt snout, its very rudimentary horns and its inconspicuous color. Cope (1898) suggests that the characters define races which do not seem to be sufficiently distinct to represent subspecies.

The first description of this species was made by Bell (1828) from a specimen collected in Washington by H. W. Henshaw. Yarrow (1882, 1887) gave specimens from the same locality the subspecific name of *pygmaca* on account of their small size. This name, however, had to give way to that of *douglassi* when the subspecies were fully worked out by Stejneger (1890) and Cope (1898).

HABITS

Bell (1828) states that these horned lizards are always found in the immediate vicinity of water. If this be true, *P. douglassi douglassi* is different from other members of the genus, for most Phrynosomas depend upon the drops of dew on the vegetation for their water. It is also stated by the same author that this subspecies lives partly on the surrounding vegetation. This would seem another exception to the general rule, for all the species studied were found to be strictly insectivorous. These two observations need verification.

The protective coloration assumed by this species is very interesting. All shades and colors from the obscure gray skin of *P. douglassi douglassi* to the brightly spotted skin of *P. douglassi ornatissimum* are to be found. Indeed the character of the coloration is so modified by the environment that it is found constant enough to act as one of the characters for distinguishing subspecies. The large *P. douglassi ornatissimum* resembles the vari-colored rocks of the Painted Desert of Arizona where it is found, whereas *P. douglassi douglassi* resembles the gray uni-colored soil on which it occurs.

DISTRIBUTION

P. douglassi douglassi is of common occurrence in Washington, Oregon, Idaho and Utah. Bell (1828) in first describing it, gave its distribution as the banks of the Columbia River. C. H. Townsend (1887) records it from the western base (quoted in Van Denburgh, 1897, as northern) of Mt. Shasta, California. No other record of its occurrence in California is known, but it seems possible that it may range south from Oregon into the northern part of the state. It has been recorded from the following localities: Mt. Shasta, Shasta County, California; Des Chutes River, Grants, Willamette Valley, and between Warner's and Goose lakes, Oregon; Fort Steilacoom, Fort Walla Walla, North Yakima, and Spokane, Washington; near head of Birch Creek, desert at sink of Big Lost River, Clear Water River, Lewiston, Arco, American Falls, Snake River, Pocatella, Shoshone, Conaut, Cottonwood Creek, and Big Butte, Idaho.

Measurements: Measurements in the tables are in millimeters and were taken as follows:

Total length: from tip of snout to tip of tail.

Width of head: greatest width, across parietal region from tip to tip of temporal horns.

Snout to ear: from tip of snout to auricular aperture.

Occipital horns: from junction of horns to occipital bone to tip of horn.

Fore limb: from axilla to tip of longest toe on right fore limb.

Hind limb: from axilla to tip of longest toe on right hind limb.

Base of fifth to end of fourth toe: from base of fifth to tip of fourth toe on right hind limb.

TABLE OF MEASUREMENTS
Phrynosoma douglassi douglassi

Museum number	Sex	Locality	Total length	Length of tail	Width of head	Snout to ear	Length of occ. horns	Length of fore limb	Length of hind limb	Base of 5th to end of 4th toe	Ratios to total length			Ratios to width of head		
											Tail	Width of head	Snout to ear	Hind limb	Occ. horns	Snout to ear
2842	♀	Arco, Alturas Co., Idaho	85.0	28.0	17.0	14.0	1.5	26.0	34.0	10.0	33.5	20.0	16.5	40.0	8.25	88.5
2816	♀	Cottonwood Cr., Cassia Co., Idaho	83.0	25.5	16.5	12.5	1.0	25.0	31.5	10.0	31.0	19.9	15.0	38.0	7.58	60.5
2801	♀	Conant, Cassia Co., Idaho	89.0	29.0	17.5	14.0	1.5	26.0	33.0	10.0	33.0	19.7	15.7	37.0	8.00	86.0
1951	♀	Spokane, Washington	93.0	32.0	21.0	15.0	3.0	31.0	42.0	13.0	34.4	22.3	16.1	45.2	7.15	43.0
1951	♂	North Yakima, Washington	72.0	27.0	12.5	10.5	0.5	21.0	29.0	9.0	37.4	17.3	14.6	40.5	8.40	47.5
2840	♂	Arco, Alturas Co., Idaho	71.0	25.0	14.0	10.5	1.0	21.0	29.0	9.0	35.2	19.7	14.8	40.8	7.50	71.5
1944	♂	Pocatello, Idaho	69.0	24.0	14.0	10.5	1.0	21.0	29.0	9.5	34.8	20.1	15.2	42.0	7.50	71.5
		Average of males	87.5	28.6	18.0	13.8	1.7	27.0	35.1	10.7	32.9	20.4	15.8	40.0	7.74	69.0
		Average of females	70.6	28.0	13.5	10.5	0.8	21.0	29.0	9.1	35.8	19.0	14.8	41.1	7.80	63.5
		Average	79.0	28.3	15.7	12.1	1.2	24.0	32.0	9.0	34.3	19.7	15.3	40.5	7.77	66.2

¹ In the collection of the Department of Zoology of the University of California. The other specimens are in the collection of the Leland Stanford Junior University.

Phrynosoma blainvillei blainvillei (Gray) Bryant

Blainville's Horned Lizard

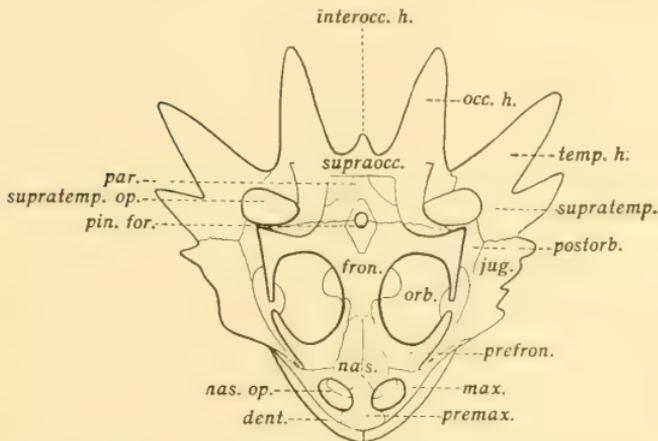
Agama coronatum Blainville (1835), p. 284, pl. 25, fig. 1.*Phrynosoma coronata*, Dumeril and Bibron (1837), p. 318.*Batrachosoma coronatum* Girard (1858), pp. 400-402, pl. 20, figs. 10-13.*Phrynosoma Blainvillii* Gray (1839), p. 96, pl. 29, fig. 1.

Fig. D. Skull of *Phrynosoma blainvillei blainvillei* (Univ. Calif. Mus. Vert. Zool., no. 272). *dent.*, dentary; *fron.*, frontal; *jug.*, jugal; *interocc. h.*, interoccipital horn; *max.*, maxillary; *nas.*, nasal; *nas. op.*, nasal opening; *occ. h.*, occipital horn; *orb.*, orbit; *par.*, parietal; *pin. for.*, pineal foramen; *prefron.*, prefrontal; *premax.*, premaxillary; *postorb.*, postorbital; *supraocc.*, supraoccipital; *supratemp.*, supratemporal; *supratemp. op.*, supratemporal opening; *temp. h.*, temporal horn. $\times 2$.

EXTERNAL CHARACTERISTICS

Diagnostic Characters: Head short and thick; snout not separated from frontal region by a prominent angle; nostrils on the line joining the superciliary ridges with the end of the snout; occipital horns large, flattened and grooved; interoccipital horn small (1-2 mm.), supratemporal horns three to six on each side; head plates convex and almost smooth; sublabials spinose, five to six in number and continued posteriorly with smaller plates;

below the rictus a large broad infrarictal spine followed by a smaller conical one; enlarged gular scales, in three or more double rows; peripheral spines in two widely separated rows, the upper being the largest; back and tail covered with large scattered scales which are strongly keeled and tubercular, set among smaller scales and granules; ventral scales smooth; tail conical and fringed by a row of widely separated trihedral spines; tympanum not covered by scales; femoral pores in long series (12-18).

Description: The two occipital horns are strongly developed, flattened and grooved (pl. 4, fig. 9). A small (1-2 mm.) inter-occipital spine is present. The horns of the occipital region are raised above those of the temporal region. The nostrils are on the lines joining the superciliary ridge with the end of the snout which is not separated from the frontal region by a prominent angle. There are two widely separated rows of peripheral spines, the upper being the largest. Three or more longitudinal rows of pointed gular scales, the inner rows being the smallest, are to be found on each side of the gular region. These rows form an apex at the front of the jaw and continue posteriorly onto the gular folds (pl. 4, fig. 10). The head shields are convex and almost smooth, some of the centrally situated ones being the largest. Four or more bony tuberosities are to be found on the parietal region in front of the occipital spines. The temporal horns are four to six in number on each side. The posterior one is much the largest. The postorbital spine is well developed. The temporal scales are ridged in the general direction of the temporal horns. A series of five or six large sublabial spines is continued posteriorly by several smaller scales. At the corner of the mouth is a large, flattened scale below which is a large and very broad infrarictal spine followed by a smaller conical one.

The back is covered with large, scattered scales which are somewhat elevated, keeled and tubercular and set among smaller scales and granules (pl. 4, fig. 9). The ventral scales are smooth and of equal size. Dorsally the tail is covered with the same sort of scales as those found on the back; ventrally the small equal-sized scales become keeled on the terminal portion. A

small group of conical spines is found on the tail just behind the thigh. This group of spines is situated just below the beginning of the one row of widely separated lateral spines which fringe the tail. The scales on the anterior surface of the limbs are large, pointed, and keeled. The tympanum is not covered with scales. A long series (12-18) of femoral pores is present on the anterior surface of the thigh (pl. 4, fig. 10). The males have enlarged postanal plates. See table of measurements for dimensions and proportions of the lizard.

The color above is gray to brownish with undulate cross bands or irregular blotches of dark brown. Two large, dark brown patches are situated on each side of the neck, the upper edge being the darker. These patches give the appearance of shadows made by the horns (pl. 1, fig. 1; pl. 4, fig. 9). The head scales are usually yellowish or slate and the horns reddish or brown. Below the color is yellowish to white and usually irregularly spotted with small dark patches (pl. 4, fig. 10). Young specimens are usually more brightly colored and show more distinct markings. For general color pattern see plate 4, figure 9.

OSTEOLOGY

Diagnostic Characters: Horns of occipital region well developed, flattened and grooved; interoccipital horn small and sharp; supratemporal horns usually two on each element, the posterior the largest; jugals presenting three or four tuberosities each; postorbitals well developed; four bony tuberosities present in front of the occipital horns on the parietal region; mandibles forming acute angles at their symphyses; lower mandible with no bony tuberosities; quadrates long (6 mm.); coronoids heavy; basiptyergoid processes strong; six or seven enlarged neural spines showing evidence of a rudimentary dorsal crest; xiphoid rods widely separated from third pair of sternal ribs; post temporal openings large.

Description: The alveolar portion of the premaxillary (*pre-max.*, fig. D) borders the nostrils (*nas. op.*) for a short distance. The nasals (*nas.*) form but part of the arches over the same openings. The superciliary processes of the prefrontals (*pre-fron.*) are but little longer than those of the frontal (*fron.*) and

do not meet the latter. The two occipital horns (*occ. h.*) are large, flattened and grooved. The interoccipital horn (*interocc. h.*) is small and sharp. Four bony tuberosities are found on the parietal region (*par.*) just in front of the occipital horns. The pineal foramen (*pin. for.*) pierces the parietal only, in the specimen examined. Usually but two horns are developed on each of the supratemporal elements (*supratemp. h.*), but there may be a smaller third one. The posterior ones on each side are always the largest. Each jugal (*jug.*) presents three or four tuberosities. The postorbital (*postorb.*) ridges of the frontal possess small tuberosities directly back of the orbit. The quadrates are long (5-7 mm.). The epipterygoids just reach the petrosal.

The Meckelian groove is open posteriorly. The coronoids are heavy. The surangular is not completely ossified to the articular. There are no bony tuberosities on the lower mandible (pl. 2, fig. 4).

Six or seven enlarged neural spines show evidence of a rudimentary dorsal crest. The transverse processes of the sacral vertebrae are heavy and strong, those of the first caudal vertebrae about as long as those of the second and third. The chevron bones are well developed. The xiphoid rods are widely separated from the three sternal ribs (pl. 8, fig. 18). The ossified postischial symphyseal cartilage is four to five millimeters long and is not bifid (fig. A).

The name *P. coronatum* has sometimes been used to include two species (Boulenger, 1885; Gentry, 1885; Ditmars, 1907), one of which presents at least two distinct subspecies. Although in general outward appearance *P. blainvillei* and *P. coronatum* are much alike, yet the latter is easily distinguished by its long, sharp, occipital horns, its well-developed interoccipital, its four well-developed supratemporal horns and by the lack of a conical spine behind the infrarietal, the presence of two rows of peripheral spines on the tail, and the dark-colored, equal-sized head plates which are outlined with light-colored lines at the sutures.

P. coronatum is distinctly a Lower California species, yet it ranges far north of its type locality, Cape St. Lucas, Lower California, and has even been reported from San Diego (Cope,

1898). As has already been noted (p. 18), its occurrence so far north, however, is somewhat doubtful and certainly rare.

HABITS

P. blainvillei blainvillei, next to *P. cornutum*, the Texas horned lizard, is perhaps the best known member of the genus, for this is the one largely used by the curio dealer. Then, too, it is easily domesticated and can be kept in captivity for a long time, if properly fed.

It is from this species that most of the knowledge in regard to the ejection of blood from the eyes has been derived. This habit was early discovered by the Mexicans, who called this lizard the "sacred toad" because it wept tears of blood. Nearly every small boy in the region where this species is common knows of the phenomenon and can usually cite definite instances when a horned lizard has "spit blood."

The writer has several times witnessed this strange habit. The first indication of the phenomenon to be noticed is a swelling of the eyelids to two or three times their natural size, so that they bulge from the head. During this procedure the eyes are tightly closed and the animal remains perfectly quiet. Suddenly a fine stream of blood shoots up from beneath the upper eyelid, usually with force enough to send it six or eight inches before dividing into fine drops. In one instance the blood was squirted about fifteen inches. Sometimes the blood is ejected so suddenly that the first indication of it is its contact with the observer's skin or a few drops left on the eye of the lizard. Dr. Hay (1892) states that in a specimen of *P. blainvillei frontale* the phenomenon was repeated several times. In the writer's experience a specimen could not be induced to eject blood again from the same eye, at least, until some time had elapsed.

Miss Myrtle Johnson, carrying on some experiments with *Phrynosoma blainvillei blainvillei* at San Diego during the early part of July, 1911, induced a specimen to eject blood. The first indication noticed was the presence of blood on the hand. A juvenile not more than one and one-half inches long was brought to her by a small boy with the report that it had "spit blood." Circumstantial evidence in the form of blood on the eye seemed

to prove the boy's statement. If the fact can be verified that a juvenile can eject blood as well as an adult, the theory that it is a habit only used during the breeding season would seem to be disproved.

A few generalizations on this habit may be of interest. Although cases are not rare where the lizard ejects blood on being caught, yet in two cases when success attended the experiment, the lizards were awakened from the stupor brought on by the night. The eyelids, on being sectioned, were found to be highly vascular and to contain large blood sinuses. Especially was this true of the upper lids. No duct was found and it seems probable that the blood is forced out by the rupturing of a vessel. H. L. Bruner (1907), in a paper on the "Cephalic Veins and Sinuses of Reptiles," gives the best explanation yet advanced. He says, in speaking of *Phrynosoma*, "It is not improbable in this case that the mechanism for elevating the blood-pressure is used as a fright mechanism. Such a function, however, is not sufficient to explain the wide distribution of the mechanism. On the contrary, it is probable that the flooding of the cephalic sinuses for frightening enemies is at best only a secondary use which has been acquired by relatively few forms."

These lizards show great aversion to dogs. When angered by one, the lizard presents a very bristling appearance by elevating the enlarged scales of the back, opens its mouth and gives a hissing noise by quickly expelling the air from the lungs. At such times it stands well upon its legs and puffs itself up to nearly twice its natural size. A *blainvillei*, when first caught, often hisses at any moving object.

At the sight of a snake, however, instead of standing its ground and attempting to frighten the intruder, it generally seeks to escape. A small California ring-neck snake (*Diadophis amabilis*) when placed in a cage containing several of these lizards, created no little excitement. When the excitement had somewhat quieted down, two of the lizards became courageous enough to take a nip at its tail. This would in a measure seem to corroborate the statement that has been made that these animals attack a snake when cornered.

The food consists principally of ants, although the smaller

beetles and flies seem to be eaten with relish. Even a large Jerusalem cricket does not daunt one of these lizards, for it seizes it by the head and, not being able to swallow it directly, either rubs it to pieces on the earth or works itself around it much as a snake does. A few drops of milk placed in the cage seemed to be enjoyed by old and young alike.

DISTRIBUTION

Dr. Van Denburgh (1894) placed the horned lizards inhabiting central California in a distinct species, under the name of *Phrynosoma frontalis*, basing his division on the character of the head scales. In a later work (Van Denburgh, 1897) the same division is made, using the specific name *frontale*. In this work he suggests that an intergradation between the two species *P. blainvillei* and *P. frontale* may take place in Santa Barbara or Ventura counties. The evidence at hand would seem to show that this intergradation takes place in Los Angeles County. All Santa Barbara and Ventura County specimens examined have equal sized, ridged and granulated head plates, showing them to be *P. frontale* and all from San Bernardino, Riverside, Orange and San Diego counties have smooth, convex head plates, the centrally located ones being the largest, characters of *P. blainvillei*, whereas specimens from Los Angeles County show characteristics of both, the head plates being unequal in size and showing a tendency to be ridged and granulated. The fact that there is an intergradation in a rather well defined locality, tends to prove that the two species are merely geographical subspecies.

All of the other species of horned lizards, at least in the United States, have well-defined characters. Since these two forms, *P. blainvillei* and *P. frontale*, are separated by such subordinate characters and show an intergradation, they have been reduced to subspecific rank. Further study may show that the intergrades have enough distinct characters and occupy such a definite locality that they too can be described as subspecies. Sufficient material is not at hand to justify such a division here.

P. blainvillei blainvillei occurs only on the coastal slope between San Diego and Pasadena. It is especially common in the valleys at the base of the San Gabriel, San Bernardino and San

Jacinto mountains. In some places, as Cajon Pass, San Bernardino County, and Warner's Pass, San Diego County, it crosses the divide onto the desert. In altitude it ranges from just above sea-level to over five thousand feet. In a series of some thirty specimens from the San Jacinto Mountains, from localities ranging in altitude from 1500 to 5000 feet, no differentiation according to altitude could be discovered. The color of the soil, however, could readily be determined by the coloration of the lizards.

A study was made of specimens collected at the following localities: Campo, Dulzura, Warner's Pass, National City, San Diego, and Escondido, in San Diego County; Oak Springs, Schain's Ranch, Fuller's Mill, Poppet Flat, Vandeventer Flat, Kenworthy, and Hall Grade, near Cabazon, in the San Jacinto Mountains, and Cabazon, Banning, and Riverside, in Riverside County; Santa Ana, in Orange County; Sanvenoska, Clarke's Ranch, and Santa Ana Cañon, in the San Bernardino Mountains, and Colton, Grapeland, and Ontario, in San Bernardino County; and Claremont, mouth of San Gabriel Cañon, and Sierra Madre, in Los Angeles County.

A list of specimens showing an intergradation with *P. blainvillei frontale* follows:

LIST OF SPECIMENS SHOWING AN INTERGRADATION BETWEEN *Phrynosoma blainvillei blainvillei* AND *Phrynosoma blainvillei frontale*

Museum number	Sex	Locality	Collector
851	♀	Pasadena, Los Angeles County, California	J. Grinnell
852	♀	Aroyo Seco, Pasadena, California	J. Grinnell
853	♀	Pasadena, Los Angeles County, California	J. Grinnell
2412	♀	Pasadena, Los Angeles County, California	H. L. Bryant
2413	♂ jun.	Pasadena, Los Angeles County, California	H. L. Bryant
2478	♂ jun.	East Pasadena, Los Angeles County, California	H. L. Bryant
2479	♂ jun.	East Pasadena, Los Angeles County, California	H. L. Bryant
2480	♀	East Pasadena, Los Angeles County, California	F. Davis
	♀	East Pasadena, Los Angeles County, California	R. N. Bryant
	♀ jun.	East Pasadena, Los Angeles County, California	R. N. Bryant
	♂	Milliard's Cañon, near Pasadena, Los Angeles County, California	R. N. Bryant
855	♂	Tubunga Valley, Los Angeles County, California	J. Grinnell
	♂	Sierra Madre, Los Angeles County, California	C. Camp

V. TABLE OF MEASUREMENTS
Phrynosoma blattveiteli blattveiteli

Museum number	Sex	Locality	Total length	Length of tail	Width of head	Snout to ear	Length of occ. horns	Length of fore limb	Length of hind limb	Base of 5th to end of 4th toe	Ratios to total length			Ratios to width of head		
											Tail	Hind limb	Snout to ear	Width of head	Length of horns	Snout to ear
24	♂	Reche Cañon, near Colton, Calif.	134.0	48.0	30.0	19.0	10.5	40.0	52.0	16.0	35.5	38.8	14.1	22.4	35.0	63.3
102	♂	Banning, Riverside Co., Calif.	132.0	41.0	30.0	18.0	11.0	41.0	52.0	15.0	31.5	39.4	13.7	22.5	36.6	60.0
274	♂	Shains Ranch, San Jacinto Mts., Calif.	120.0	37.0	26.0	15.0	9.0	40.0	51.0	17.0	31.0	42.5	12.5	21.5	34.6	57.8
856	♂	San Gabriel Cañon, Azusa, Calif.	133.0	45.0	32.0	18.0	13.0	41.0	51.0	17.0	33.5	38.4	13.5	24.0	35.3	56.5
382	♂	Dulzura, San Diego Co., Calif.	113.0	42.0	25.5	16.0	7.0	36.0	46.0	14.0	36.5	40.7	14.1	22.5	27.5	62.7
59	♀	Reche Cañon, near Colton, Calif.	122.0	38.0	31.0	18.0	11.0	37.0	49.0	14.0	31.5	40.1	14.8	25.4	35.5	58.0
275	♀	Shains Ranch, San Jacinto Mts., Calif.	118.0	35.0	26.0	16.0	9.5	37.0	46.0	16.0	35.0	39.0	13.6	22.0	36.6	61.5
872	♀	Escondido, San Diego Co., Calif.	124.0	36.0	27.5	17.0	9.0	41.0	52.0	17.0	29.0	42.0	13.7	22.2	32.7	61.9
1041	♀	Warner Pass, San Diego Co., Calif.	144.0	48.0	31.5	17.0	11.0	45.0	55.0	17.0	33.0	38.1	11.8	21.9	34.9	54.0
..... ¹	♀	San Diego, Calif.	148.0	47.0	33.0	19.0	12.0	45.0	54.0	17.0	31.5	36.5	12.8	22.3	36.4	57.5
		Average of males	126.4	42.6	28.7	17.2	10.1	39.6	50.4	15.8	33.6	39.9	13.5	22.5	33.8	60.0
		Average of females	131.2	40.8	29.8	17.4	10.5	41.0	51.2	16.2	32.0	39.1	13.2	22.7	35.2	62.5
		Average	128.8	41.7	29.2	17.3	10.3	40.3	50.8	16.0	32.8	39.5	13.3	22.6	34.0	61.2

¹In the collection of the Department of Zoology of the University of California. The other specimens are in the Museum of Vertebrate Zoology of the same institution.

Phrynosoma blainvillei frontale (Van Denburgh) Bryant

California Horned Lizard

Phrynosoma blainvillei Gray (1839), p. 96, pl. 29, fig. 1.

Phrynosoma coronata Holbrook (1842), pp. 97-100, pl. 13.

Phrynosoma frontalis Van Denburgh (1894), pp. 296-298.

Phrynosoma frontale Van Denburgh (1897), pp. 93-98.

EXTERNAL CHARACTERISTICS

Diagnostic Characters: Head spines usually smaller and narrower than those of *P. blainvillei blainvillei* and very much grooved; small interoccipital spine present; nostrils on the line joining the superciliary ridge with the end of the snout; snout not separated from frontal region by a prominent angle; temporal spines three to six on each side; head plates nearly equal-sized, flat, and covered with numerous ridges and granulations; sublabials, spinose and continued posteriorly by small plates; below the rictus a large, broad infrarictal spine followed by a smaller conical one; enlarged gular scales in three or more double rows with apices pointing outward; peripheral spines in two widely separated rows, the upper being the largest; back and tail covered with large scattered scales, which are strongly keeled and tubercular, set among smaller scales and granules; ventral scales smooth; tail conical and fringed by a row of widely separated trihedral spines; tympanum not covered with scales; femoral pores in long series (12-18).

Description: The two occipital horns and the interoccipital are usually narrower and smaller than those of *P. b. blainvillei* and the former are very much grooved (pl. 5, fig. 11). The horns of the occipital region are on a higher level than those of the supratemporal region. The nostrils are on the line joining the superciliary ridge with the end of the snout. The snout is separated from the frontal region by a very obtuse angle. Two rows of peripheral spines surround the body, the smaller lower row being separated from the upper by several rows of scales. Three longitudinal rows of enlarged, pointed scales with apices outward, the inner rows being the smallest, are to be found on each side

of the gular region (pl. 5, fig. 11). These rows form an apex at the front of the jaw and continue posteriorly onto the gular folds. The head shields are flat, nearly equal-sized, with numerous ridges and dark-colored granulations (pl. 5, fig. 11). Four or more bony tuberosities are to be found on the parietal region in front of the occipital spines. The temporal horns are four to six in number on each side, the posterior ones being much the largest. The large spinose sublabials number five or six on each side. Below the rictus is a large broad spine followed by a smaller conical one. On each side of the neck are two groups of spines. The lower group is slightly the larger.

The back and tail are covered with large scattered scales which are elevated, keeled, and tubercular, and set among smaller scales and granules. The ventral scales are smooth and equal-sized except on the terminal part of the tail, where they become keeled. A single row of lateral trihedral spines fringes the tail, which possesses a small group of slender spines just behind the thigh. On the anterior portion of the arm and thigh the scales are large, pointed, and keeled. The tympanum is not covered with scales. A long series (12-18) of femoral pores is present. Males have enlarged postanal plates (pl. 5, fig. 12). See table of measurements for dimensions and proportions of the lizard.

The coloration is usually gray or slate to brown, rarely to red. A large brown patch on each side of the neck is darker around the upper edges (pl. 5, fig. 11). Large dark brown cross-bands, posteriorly edged with a light band, usually eight in number, are found on the back and tail. The keels of the enlarged tubercular scales of the back are generally dark brown in color. The head is yellowish white or slaty gray. On the ventral surface the prevailing color is yellow or yellowish white with irregular black blotches (pl. 5, fig. 11). For general color pattern see plate 5, figure 11.

The sole character on which Van Denburgh (1897) based his description of this form as a new species, was upon the appearance of the head plates, those of *blainvillei* being convex and almost smooth, whereas those of *frontale*, are flat, ridged, and granulated. In addition I have found that several enlarged

scales are present on the central part of the forehead in *blainvillei*, whereas the scales of this region are about equal in size in *frontale*. These characters are all very superficial and can hardly be considered sufficient to separate species. They indicate rather, a differentiation due to geographical location and are therefore better classed as subspecies, under the names *P. blainvillei blainvillei* and *P. blainvillei frontale*. The fact that these two forms intergrade along the line of their contact greatly strengthens this idea.

OSTEOLOGY

But two minor differences from the osteology as described under *Phrynosoma blainvillei blainvillei* were found in this subspecies. In *frontale* the occipital horns are usually narrower and oftentimes more erect. In the skull studied, the pineal foramen, instead of piercing the parietal, is at the coronal suture. Both of these characters vary so widely that they cannot be considered diagnostic. The pineal foramen in *blainvillei* is separated from the coronal suture by only a very narrow strip of bone. As the lizard grows older and the bones become more strongly ossified this differentiation may take place.

HABITS

Several articles on the ability of this horned lizard to "eject blood" have been written. Vernon Bailey, collecting one of these lizards at Kernville, California, had it eject blood from each of its eyes (Stejneger, 1893). Later the same specimen became the subject of an article by O. P. Hay (1892). Dr. Van Denburgh (1897) has recorded the experience of a Mr. Denton with a *P. blainvillei frontale*, and adds that he has twice witnessed the strange performance.

P. b. frontale is the only known horned lizard which inhabits the forest belt. In the vicinity of Pacific Grove, Monterey County, it has been found within the forest shade, closely imitating in color the carpet of pine needles.

DISTRIBUTION

Van Denburgh (1897), in describing this form, suggested an intergradation with *P. b. blainvillei* in Santa Barbara or Ventura counties. In my material this intergradation would seem to take place in Los Angeles County. A series of specimens from the northern counties of the state shows distinctly *frontale* characteristics until Los Angeles County is reached. Two specimens from the northern part of this county (San Francisquito Cañon, Tuhunga Valley) have equal-sized head scales, very much ridged and granulated, which would show them to be *frontale*. Specimens from eastern Los Angeles County (Claremont) and San Bernardino County are plainly *blainvillei*, having smooth, convex, head scales, those centrally located being the largest. All available specimens from the vicinity of Pasadena, Los Angeles County, however, appear to be intergrades, for the head scales are convex, those centrally located being the largest, characters of *blainvillei*, but the scales are ridged and granulated, characters of *frontale*. Sufficient material is not at hand to determine what are the limits of this area of distribution in which these subspecies intergrade or to what degree the intergradation prevails.

This subspecies is found commonly all through the San Joaquin and Sacramento basins and on the western slope of the Sierra Nevada. It doubtless crosses over the divide into the territory occupied by *Phrynosoma platyrhinos* in some of the lower passes in this range. Specimens of both species have been taken on the south fork of the Kern River in Kern County. The most northern record for the California horned lizard is from Placer County. It meets *P. b. blainvillei* in Los Angeles County. No specimens have been recorded from the coastal region north of San Francisco, but southward from this point the species is abundant. The type specimen was collected at Bear Valley, San Benito County.

The specimens studied were taken at the following localities: Tuhunga Valley, San Francisquito Cañon, in Los Angeles County; Matilija, Mt. Pinos, in Ventura County; Santa Maria,

in Santa Barbara County; Fort Tejon, Bakersfield, Walker Pass, Kernville, Walkers Basin, Weldon, Onyx, Bodfish, south fork Kern River near Chimney Creek, and McKittrick, in Kern County; Earlimart, and Tipton, in Tulare County; Livingston, and Los Banos, in Merced County; Ripon, in Stanislaus County; Lemoore, in Kings County; Pacific Grove, in Monterey County; Bear Valley, in San Benito County; Canada Valley, Gilroy, Coyote Creek, Los Gatos, Morgan Hill, Santa Clara, and Mayfield, in Santa Clara County; Searsville, in San Mateo County; Tracy, and Lathrop, in San Joaquin County; Livermore, in Alameda County; Placerville, in El Dorado County, and Colfax, and Forest Hill, in Placer County.

TABLE OF MEASUREMENTS
Phrynosoma blainvilliei frontale

Museum number	Sex	Locality	Total length	Length of tail	Width of head	Snout to ear	Length of occ. horns	Length of fore limb	Length of hind limb	Base of 5th to end of 4th toe	Ratios to total length				Ratios to width of head	
											Tail	Hind limb	Snout to ear	Width of head	Length of horns	Snout to ear
93	♂	Bear Valley, San Benito Co., Calif.	137.0	52.0	26.0	19.5	6.0	41.0	54.0	18.0	38.0	39.4	14.2	19.0	23.0	71.0
..... ¹	♂	Mt. Hamilton, Calif.	121.0	40.0	26.0	17.0	8.0	48.0	52.0	16.0	32.5	43.2	14.1	21.5	30.8	67.5
..... ¹	♂	Mt. Hamilton, Calif.	113.0	39.0	23.5	14.5	7.0	35.0	47.0	14.0	34.0	41.6	12.8	20.8	31.1	61.8
1006	♂	Bakersfield, Kern Co., Calif.	116.0	40.0	26.0	16.1	9.0	38.0	47.0	14.0	34.0	40.5	13.8	22.4	34.6	61.5
1211	♂	Matilija, Ventura Co., Calif.	95.0	29.0	22.0	14.0	6.5	32.0	41.0	12.0	30.0	42.2	14.7	23.1	29.5	63.8
1002	♀	Bakersfield, Kern Co., Calif.	120.0	31.0	27.0	17.0	9.0	37.0	47.0	16.0	26.0	39.2	14.1	22.5	33.2	63.0
..... ¹	♀	Pajaro Road, Calif.	124.0	37.0	27.0	16.5	7.0	42.0	53.0	17.0	29.5	42.7	13.3	21.8	26.0	61.1
875	♀	Mt. Pinos, Ventura Co., Calif.	131.0	40.0	27.5	17.0	9.0	40.0	50.0	15.0	30.5	38.2	13.0	21.0	32.7	62.0
1210	♀	Matilija, Ventura Co., Calif.	114.0	36.0	26.0	17.5	9.0	38.0	48.0	15.0	31.0	42.1	12.5	22.8	34.6	67.3
1212	♀	Matilija, Ventura Co., Calif.	134.0	42.0	28.5	18.0	8.0	43.0	53.0	17.0	31.5	39.6	13.4	21.3	28.0	63.2
		Average of males	116.4	40.0	24.7	16.2	7.2	37.8	48.2	14.8	33.7	41.3	13.9	21.3	29.8	64.7
		Average of females	124.6	37.2	27.2	17.2	8.4	40.0	50.2	16.0	29.7	40.3	13.2	21.8	30.9	63.3
		Average	120.5	38.6	25.9	16.7	7.8	38.9	49.2	15.4	31.7	40.8	13.5	21.5	30.3	64.0

¹ In the collection of the Department of Zoology of the University of California. The other specimens are in the Museum of Vertebrate Zoology of the same institution.

Phrynosoma platyrhinus Girard

Desert Horned Lizard

Doliosaurus platyrhinus Girard (1858), p. 409.

Phrynosoma platyrhinum Cope (1883), pp. 15, 18.

Phrynosoma platyrhinus Boulenger (1885), p. 247.

Anota platyrhina Cope (1898), pp. 443-447, fig. 81.

Anota calidiarum Cope (1896), pp. 833-836.

Phrynosoma calidiarum Ditmars (1907), p. 157.

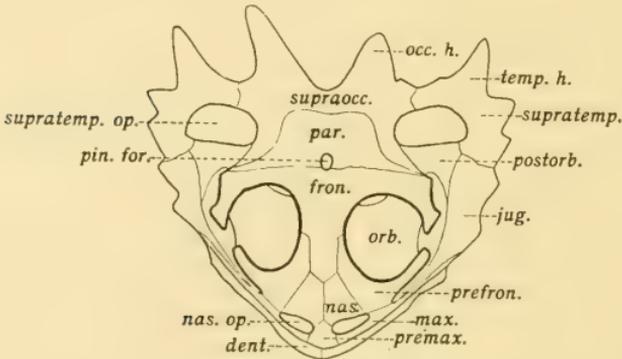


Fig. E. Skull of *Phrynosoma platyrhinus* (Univ. Calif. Mus. Vert. Zool., no. 1301). *dent.*, dentary; *fron.*, frontal; *jug.*, jugal; *max.*, maxillary; *nas.*, nasal; *nas. op.*, nasal opening; *occ. h.*, occipital horn; *orb.*, orbit; *par.*, parietal; *pin. for.*, pineal foramen; *prefron.*, prefrontal; *premax.*, premaxillary; *postorb.*, postorbital; *supraocc.*, supraoccipital; *supratemp.*, supratemporal; *supratemp. op.*, supratemporal opening; *temp. h.*, temporal horn. $\times 2$.

EXTERNAL CHARACTERISTICS

Diagnostic Characters.—Head short and wide; occipital horns of medium size (4-9 mm.), flattened and grooved and but little longer than the temporals; interoccipital represented by an enlarged scale; nostrils above the line joining the superciliary ridge with the end of the snout; temporal horns five to seven on each side, the larger posterior ones pointing in almost the same direction as the occipitals; head plates grooved and ridged and nearly equal sized, except for three enlarged scales in front of the occipital horns; sublabials large and spinose, increasing in size posteriorly; no enlarged infrarietial spine; usually one row of enlarged gular scales on each side, distant from the

median line; peripheral spines in one row, disappearing posteriorly; back and tail with several rows of enlarged, weakly keeled, spinose scales set among finer scales and granules; ventral scales smooth; tail conical and attenuated and fringed with a row of conical scales; tympanum usually entirely covered with scales; femoral pores few (7-8).

Description.—The short wide head is somewhat smaller than is found in the other species (pl. 6, fig. 13). The two occipital horns are of medium size (4-9 mm.), flattened and grooved. An interoccipital is represented by an enlarged scale. The nostrils are situated above the lines joining the superciliary ridge with the end of the snout. The series of temporal horns numbers five to seven on each side. The posterior two or three are the best developed, the others being mere tubercles. The posterior ones point almost in the same direction as the occipitals. The head shields are small and flat, with the exception of three enlarged scales in front of the occipital horns, and are roughened by granules and ridges. The suprarorbital regions are swollen. The infralabials are nearly equal in size and are acutely angular. Below them and separated from them by a row or two of small scales is a series of large, spinose, sublabial plates which increase in size posteriorly (pl. 6, fig. 14). No enlarged subrietal spine is present. But one row of peripheral spines fringes the body. One row of enlarged gular scales, distant from the median line, is present (pl. 6, fig. 14). There are two groups of enlarged scales on each side of the neck, the lower being the larger. The back and tail are covered with several rows of large, weakly keeled, spinose scales, set among finer scales and granules. A rosette of scales surrounds these larger ones. The ventral scales are smooth. The conical tail is attenuated and is fringed by a row of widely separated, conical spines. The limbs are long in comparison with those of other species, and the arm and thigh are fringed anteriorly by a row of enlarged, keeled scales. The tympanum is usually covered with scales, but this character is not constant. A row of widely separated, conspicuous femoral pores, seven to ten on each side, invades the preanal region. Males have enlarged postanal plates (pl. 5, fig. 14). See table of measurements for dimensions and proportions of the lizard.

The general color above is white, gray, or yellow, marbled with brown to black, with oftentimes red markings. The neck patches nearly meet on the median line near the occiput, are short and wide, and often faded in the older specimens. Obscure cross-bands are to be found on the limbs and tail. The head is usually dotted with black, brown, or red. The lower surface is whitish to yellow and usually spotted with black. For general color pattern see plate 5, figure 13.

OSTEOLOGY

Diagnostic Characters.—Horns of occipital region medium sized (5–7 mm.), flattened and grooved; interoccipital horn a small tuberosity; supratemporal horns, three on each element, posterior ones pointing in almost the same direction as the occipitals; jugals with four or five tuberosities; parietal region with three bony tuberosities, in the shape of a triangle, back of the pineal foramen; the edge of the frontal forming the arch over the orbits with elevated plate-like processes; superciliary processes from prefrontals and frontals about equal in length and not meeting; quadrates short and wide (4 x 2 mm.); two to five bony processes on each side of the lower mandible; articulars partly ossified to surangulars; slight evidence of dorsal crest; third sternal ribs attached to xiphoid rods near their base; post-temporal openings small; supratemporal openings about twice as wide as long.

Description.—The alveolar portion of the premaxillary (*premax.*, fig. E) borders the orbit for only a very short distance. The superciliary processes from the prefrontals (*prefron.*) and frontal (*fron.*) are of about equal length and do not meet. A number of raised plate-like processes are to be found on the edge of the frontal bordering the posterior part of the orbit (*orb.*). The occipital horns (*occ. h.*) have their origins close together and are medium in size, flattened, and grooved. The interoccipital horn (*interocc. h.*) is represented by a small tuberosity. The supratemporal horns (*supratemp. h.*) are three in number on each side. The posterior ones are the best developed and point in almost the same direction as the occipitals. Three to five tuberosities are found on each jugal (*jug.*). The vomers

articulate for nearly their whole length, leaving the hiatus to run between them for a proportionally short distance. The basipterygoid processes are long (3-4 mm.). The slender epipterygoids reach the sharp anterior edge of the petrosal. The quadrates are short (4 by 2 mm.).

The lower mandible presents several spinose tuberosities on each side (pl. 2, fig. 5). The coronoids are small and thin. The Meckelian groove is nearly closed with cartilage. The articulares are partly fused to the surangulans, leaving but a faint suture.

A few enlarged neural spines just back of the pectoral girdle show the rudiments of a dorsal crest. The second pair of transverse processes from the sacral vertebrae are small and slender. The well ossified postischial symphyseal cartilage is six millimeters in length and is bifid at its tip. The slender transverse processes of the caudal vertebrae are present to near the end of the tail. The transverse processes of the first caudal vertebra are nearly as long as those of the second or third and curve posteriorly, so that their tips almost touch the second pair of processes.

In the skeleton of this species one peculiarity, that of the joining of the third pair of sternal ribs to the xiphoid rods, is interesting (pl. 8, fig. 19). Every other species studied showed the xiphoid rods widely separated from the third pair of sternal ribs. If there were a marked lengthening of the body so that a strengthening of the floating ribs would be of value, this migration of the third pair of ribs could well be understood. The ratio of length to width in *Phrynosoma platyrhinos* is very nearly the same as in the other species, so that this explanation hardly seems sufficient. This character being unique, at least among the five species and subspecies studied, it can well be used as diagnostic of this form. This species and *A. maccalli* alone among the species examined showed a postischial symphyseal cartilage with a bifid tip.

HABITS

Phrynosoma platyrhinos is truly a desert species and is found in the most arid and barren places. During the heat of the day it usually keeps in the shade or buries itself beneath the sand,

but in the late afternoon it is seen scurrying across the sand hunting for its insect food.

Specimens of this species show the brightest coloration of any of the horned lizards under discussion. Several specimens from Nevada have bright red markings. As is the case with the other species of the genus, the ground color varies with the surroundings. Mt. Stejneger (1893), in his notes on the reptiles collected on the Death Valley expedition, says: "The specimens collected by the expedition vary from a very pale, in some nearly whitish, drab gray to a vivid brick-red. At Ash Meadows in the Amargosa Desert a very white form was found living on the white alkali soil."

DISTRIBUTION

P. platyrhinos inhabits the Lower Sonoran deserts of the Great Basin from California to Utah. The type locality is Great Salt Lake, Utah. In the mountains it often ranges a short distance into the Upper Sonoran Zone, for it has been taken at an altitude of 5700 feet in the Argus, Funeral, and Panamint mountains. This is the common horned lizard of Nevada and of the Colorado and Mohave deserts of California. No record of its occurrence in northern California is known, but it doubtless does occur in Lassen and Modoc counties, for it is common just across the line in Nevada. In Imperial County, California, this species overlaps the territory occupied by *Anota macalli*, both species having been taken at Mecca. This locality probably marks its southern limit. Specimens of *P. platyrhinos* and *P. blainvillei frontale* have been taken in Walker Pass and on the south fork of the Kern River, indicating that an overlapping of distribution areas takes place in this region.

The type locality (Death Valley, California) of a horned lizard described by Cope (1896) under the name *Anota calidiarum* lies within the territory occupied by *P. platyrhinos*. The diagnostic characters used by Cope in his description show *P. calidiarum* (*Anota calidiarum*) to be very closely allied to *P. platyrhinos*. He says: "This species is nearest to the *A. platyrhina* Girard, from which it differs in various respects. The general proportions of all the parts and the coloration are about

as in that species, the difference chiefly appearing in the squamation and the horns. The scales of the head are more subdivided, and the presence of accessory horns is unique in the genus. The simplicity of the lateral fringe is also characteristic, as is also the rudimental character of the rosette on the neck (Cope, 1898).” Ditmars (1907) describes this species as *Phrynosoma calidiarum*, and says that he has received a specimen from the Gila Desert of Arizona. He calls attention to the erect position of the occipital horns. The photograph which accompanies the description, however, appears to be a *platyrhinos*. Van Denburgh (1897) does not describe this species, but marks it “uncertain.”

The type specimen in the U. S. National Museum is the only known example of the species except for the one mentioned by Mr. Ditmars. No material, therefore, is at hand for examination. A study of the figures given by Cope (1898) and his descriptions of the species has convinced me that this is a doubtful form. Dr. Leonard Stejneger, to whom the matter was referred, regards *Phrynosoma calidiarum* as a synonym of *Phrynosoma platyrhinos*.

Specimens of *Phrynosoma platyrhinos* have been recorded from the following localities in California: Coyote Wells, in Imperial County; Mecca, and Palm Springs, in Riverside County; Needles, and Coyote Holes, twenty miles northeast of Daggett, in San Bernardino County; Antelope Valley, in Los Angeles County; Coso Valley, Coso, Ash Creek, ten miles north of Bishop, Independence, head of Borax Flat, and Wild Rose Spring, in Inyo County; and south fork of Kern River near Chimney Creek, Walker Pass, and head of Kelso Valley, in Kern County. In Nevada, specimens have been taken at Vegas Valley, and Indian Spring, in Clark County; Pahrump Valley, Pahrnagat Valley, and Panaca, in Lincoln County; Grapevine Mountains, in Esmeralda County; Virginia City, in Storey County; Pyramid Lake, in Washoe County; and head of Humboldt River, Amos, Quinn River Crossing, Pine Forest Mountains, Thousand Creek Ranch, and Leonard Creek, Alder Creek, and Big Creek Ranch, in the Pine Forest Mountains, in Humboldt County.

TABLE OF MEASUREMENTS
Phrynosoma platyrhinos

Museum number	Sex	Locality	Total length	Length of tail	Width of head	Snout to ear	Length of occipital horns	Length of fore limb	Length of hind limb	Base of 5th to end of 4th toe	Ratios to total length			Ratios to width of head		
											Tail	Hind limb	Snout to ear	Width of head	Horns	Snout to ear
1289 ¹	♂	Pine Forest Mts., Humboldt Co., Nev.	120.0	45.0	24.0	12.5	6.5	38.0	48.0	15.0	38.0	40.0	10.4	20.0	27.0	52.0
1306	♂	Big Creek Ranch, Humboldt Co., Nev.	113.0	42.0	24.0	14.0	9.0	36.0	46.0	14.0	37.0	41.3	12.4	19.5	34.0	58.5
1283	♂	Quinn River Crossing, Humboldt Co., Nev.	105.0	38.0	21.0	15.0	7.0	38.0	47.0	15.0	35.5	44.8	14.3	20.0	33.2	71.5
1104	♂	Needles, San Bernardino Co., Calif.	122.0	40.0	22.0	13.5	7.5	38.0	50.0	18.0	33.0	41.0	11.1	18.1	34.0	61.4
412	♂	Mecca, Riverside Co., Calif.	122.0	46.0	23.0	14.0	8.0	39.0	56.0	19.0	38.0	45.9	11.5	18.8	34.8	61.0
1200	♀	Pine Forest Mts., Humboldt Co., Nev.	117.0	40.0	22.0	14.0	7.0	37.0	49.0	17.0	34.5	42.0	11.9	18.8	31.8	63.5
1292	♀	Pine Forest Mts., Humboldt Co., Nev.	112.0	38.0	20.0	14.0	4.0	38.0	44.0	14.0	34.0	39.2	12.5	17.8	20.0	70.0
1286	♀	Leonard Creek, Humboldt Co., Nev.	108.0	38.0	20.0	14.0	6.0	33.0	45.0	16.0	34.5	41.6	12.9	18.5	30.0	70.0
1227	♀	Thousand Creek Ranch, Humboldt Co., Nev.	118.0	38.0	21.5	14.0	7.0	40.0	49.0	16.0	32.0	41.5	11.8	17.8	33.3	65.2
1295	♀	Big Creek Ranch, Humboldt Co., Nev.	104.0	33.0	20.0	13.5	4.0	36.0	46.0	14.0	32.0	44.2	12.9	19.2	20.0	67.5
		Average of males	116.4	42.5	22.8	13.8	7.6	38.2	49.4	16.2	36.3	42.6	11.9	19.2	32.6	66.8
		Average of females	111.8	37.4	20.7	13.9	5.6	36.8	48.6	15.4	33.4	41.7	12.6	18.4	27.0	67.2
		Average	114.1	39.9	21.7	13.8	6.6	37.5	49.0	15.8	34.8	42.1	12.2	18.8	29.8	64.0

¹ All of the above specimens are in the Museum of Vertebrate Zoology of the University of California.

Genus *Anota* Hallowell emend.*Doliosaurus* Girard (1858), pp. 407-408.*Phrynosoma*, Cope (1866), p. 310.

Diagnostic Characters.—Head short and abbreviated; occipital and temporal regions bearing long, smooth spines; cephalic plates small and polygonal; nostrils anterior; sublabial spines large and acute; gular scales small; upper surface of body comparatively smooth, the numerous spinose scales of *Phrynosoma* being greatly reduced in size; body fringed with a triple row of peripheral spines; tail flat; auricular apertures usually concealed by scales; supratemporal openings absent; well-developed transverse processes on the caudal vertebrae.

Description.—Hallowell (1852) recognized in the species *maccalli* a form which differed widely from any horned lizard known at that time, and so placed it in a new genus which he termed *Anota*. He based the division primarily on the character of the auricular aperture, the opening being concealed by scales. This character not being diagnostic, many subsequent writers have classed the type of *Anota* (*Anota maccalli*) in the genus *Phrynosoma* (Cope, 1866; Boulenger, 1885; Van Denburgh, 1897; Ditmars, 1907). Cope (1898), using the single character of the ear opening, included in this genus the species *modestum*, *calidiarum*, *goodei*, and *platyrhinus*. The present study has shown the character of the ear opening to vary greatly in the species named, some specimens showing the opening entirely closed, whereas others show it to be but partly closed. Even should this character be considered valid, yet the species *maccalli* shows such distinct characters that it should be separated from all other forms of horned lizards found in the United States. The subgeneric name proposed by Girard (1858) includes with *maccalli* the species *platyrhinus* and *modestum*, but his rejection of the name *Anota*, simply because it described a structure as developed in one of the species only, cannot be supported. The grouping together of the desert species as proposed by Girard and Cope would make an admirable division did these species

not show such wide differences in structure. In recognition of the distinct characters of *maccalli* the genus *Anota* is here emended to include this species only, the other species classed by Cope under this genus, being referred to *Phrynosoma* because of their intimate relations to the species of that genus.

The genus *Phrynosoma* is so absolutely distinct from the other iguanids and in turn from all of the Lacertilia that any species with the horns, the enlarged tubercular scales of the back, and the peculiarly shaped head characteristic of the horned lizards, is naturally referred to this genus. It is interesting, therefore, that within such a specialized group one species alone should show such divergent specialization as to call for a separate genus. The closure of the supratemporal openings alone seems to justify generic rather than subgeneric separation from the other horned lizards, for this character is without parallel among the Lacertilia. Osborn (1903) considered the presence of the supratemporal fenestra so constant that he used it as a character in dividing Reptilia into the subclasses, Synapsida and Diapsida. He says: "The contrast between the elongate cranium and large supratemporal fenestra and the abbreviate cranium and short supratemporal fenestra is one of the striking differences between the Synapsida and Diapsida." Although he does not discuss the presence of the opening in Lacertilia, its presence is inferred to be constant in that the Lacertilia are grouped under Diapsida.

A thorough examination of all of the horned lizards of the United States showed the presence of the opening. Several of the rarer Mexican species have not been available, but these show close resemblance to other species which possess the supratemporal opening.

An examination of young specimens showed a very small opening, about the size of a pinpoint, to be present, which would lead one to believe that the opening is closed during the period of growth. In adult specimens the opening is entirely roofed over with bone, a suture being left between the parietal and supratemporal elements.

It seems difficult to account for the closure of an opening

that is found in every other species in a class (Diapsida) as far as is known. The intense heat of the desert fails to account for it, for *Phrynosoma platyrhinos*, a co-inhabitant of the same desert, and *P. modestum*, a near neighbor on the east, both show well-developed supratemporal openings. *P. modestum*, although a smaller lizard, presents by far the largest openings. The full development of the horns in *Anota maccalli* might call for a strengthening of the parietal and temporal region. The closure of the opening gives fully four millimeters more of suture in the adult, thus undoubtedly strengthening the horns to a considerable extent. The skull of *A. maccalli* is far more delicate in structure than that in any of the other species. *Phrynosoma blainvillei blainvillei* develops horns just as long as those of *maccalli*, but their ratio to the width of the head is much less (see tables of measurements). Then, too, *blainvillei* has very heavy parietal bones, so that the need of strengthening the horns by means of a longer suture is not so apparent. It seems reasonable to believe, therefore, that in the evolution of this peculiar form there has taken place a strengthening of the horns through a closure of the supratemporal openings by the fusion of the surrounding bony elements.

Several other osteological characters, such as the well-developed spines of the lower mandible and the dome-shaped parietal region, separate the type *maccalli* from other species of horned lizards, but are best not definitely regarded as purely generic characters.

One of the most distinctive external characteristics is the flat tail. No other known species of horned lizards shows this peculiarity. As this flattening of the tail is accompanied by an associated osteological character, well-developed transverse processes on each of the caudal vertebrae, this character can well be considered diagnostic of this genus. Flat-tailed horned lizards as distinguished from other horned lizards would make a well defined group.

***Anota maccalli* Hallowell**

Flat-tailed Horned Lizard

Anota M'Callii Hallowell (1852), p. 182.*Doliosaurus mc'calli* Girard (1858), pp. 408-409.*Phrynosoma maccallii* Cope (1866), p. 310.*Phrynosoma m'calli* Van Denburgh (1897), pp. 100-101.

Diagnostic Characters.—Head small; occipital horns long, smooth, and conical; interoccipital horn lacking; nostrils above the line joining the superciliary ridges with the end of the snout;

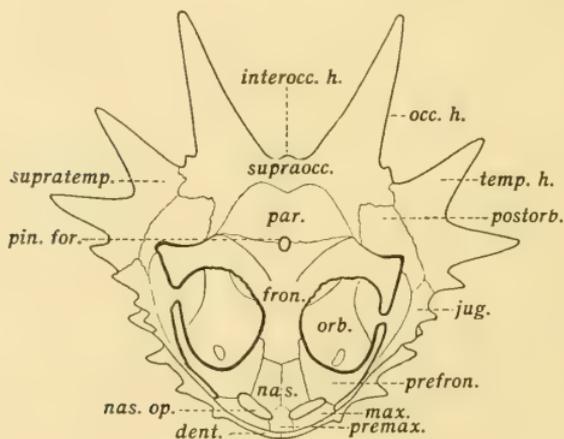


Fig. F. Skull of *Anota maccalli* (Univ. Calif. Mus. Vert. Zool., no. 1006). *dent.*, dentary; *fron.*, frontal; *jug.*, jugal; *interocc. h.*, interoccipital horn; *max.*, maxillary; *nas.*, nasal; *nas. op.*, nasal opening; *occ. h.*, occipital horn; *orb.*, orbit; *par.*, parietal; *pin. for.*, pineal foramen; *prefron.*, prefrontal; *premax.*, premaxillary; *postorb.*, postorbital; *supraocc.*, supraoccipital; *supratemp.*, supratemporal; *supratemp. op.*, supratemporal opening; *temp. h.*, temporal horn. $\times 2$.

temporal horns five or six on each side, the two posterior sharp and of about equal length; head plates irregular in size and shape; two enlarged plates just back of the pineal eye and one between the occipitals; sublabials large and acute, the middle ones the broadest and longest; no enlarged infrarictal spine; one row of slightly enlarged gulars on each side; the small peripheral spines in three closely set rows, the middle row being the largest;

back and tail with several rows of large, weakly keeled, spinose scales set among fine granule-like scales; ventral scales smooth; tail flat, acute and bordered by a single row of conical spines, every second spine being of smaller size; tympanum entirely concealed with scales; femoral pores in long rows (17-20 on each side) invading the preanal region.

Description.—The head is somewhat smaller than is found in other species (pl. 7, fig. 15). The snout is separated from the frontal region by a very prominent angle. The two occipital horns are long, smooth and conical, and are set close together. The nostrils are above the line joining the superciliary ridge with the end of the snout. There are five or six temporal horns on each side. The two posterior on each side are sharp and of about equal length. The head plates are polygonal, irregular in size and shape, with two enlarged plates just back of the pineal eye and one large one between the occipital horns. A group of enlarged scales is found on the front of the head at the angle with the snout. The supraorbital regions are swollen. The supralabials are somewhat spinose, giving a serrate appearance. The infralabials are small and flat; the sublabials large and acutely spinose (pl. 7, fig. 16). Those in the middle of the rows are usually the broadest and longest. No enlarged subrietal spine is present. One row of slightly enlarged gular scales, not reaching to the apex of the jaw, is found on each side of the gular region (pl. 7, fig. 16). Two small groups of conical spines are situated on each side of the neck. The back and tail present a much smoother appearance than that found in the other species. Several rows of large, weakly keeled, spinose scales are set among small granule-like scales. The enlarged scales are surrounded by a rosette of smaller ones (pl. 7, fig. 15). The ventral scales are smooth. The tail is very flat and tapers gradually to the tip. It is fringed by a row of conical spines, every second one of which is smaller than the preceding one. A short row is also formed on the tail just behind the thigh. The arm and thigh are bordered anteriorly with a row of enlarged keeled scales. The tympanum is entirely covered with scales. The femoral pores are numerous (17-20) and the rows nearly meet medially (pl. 7, fig. 16). Males have enlarged

postanal plates. See table of measurements for dimensions and proportions of the lizard.

The ground color is usually ashy gray or yellowish. Two rows of round, dark brown spots containing a paler center, centered with a brown dot, are arranged on either side of the median line (pl. 7, fig. 15). The neck patches are pale and inconspicuous. A narrow brownish median line leads from the occiput to the tail. Ventrally the color is silvery or yellowish white (pl. 7, fig. 16). The head is unspotted and the horns but little darker in color. Although this description of the coloration will fit many specimens, yet it is by no means the only type, for there are great variations in color. For general color pattern see plate 7, figure 15.

OSTEOLOGY

Diagnostic Characters.—Horns of occipital region long, smooth, and conical; interoccipital horn lacking; supratemporal horns three in number on each element, the posterior two sharp and of about equal length; jugal with three tuberosities on a line above the row of supratemporals; superciliary processes from premaxillaries twice as long as those from frontal; parietal region dome-shaped; postorbitals meeting parietal and supratemporals, thus closing the supratemporal opening; quadrates short (4 mm. in length) and narrow; lower mandible with six spinose tuberosities on each side, the two anterior ones on each side rudimentary; epipterygoids articulating in a depression of the petrosal; articulars not ossified to surangulars; all the caudal vertebrae with well-developed transverse processes.

Description.—The alveolar portion of the premaxillary (*premax.*, fig. F) element is very little wider than the element itself and does not appreciably border the nasal opening (*nas. op.*). The supramaxillary processes are wide and heavy, and articulate with processes from the palatines. The frontal (*fron.*) shows elevations for the enlarged scales bordering the orbit (*orb.*). The prefrontal (*prefron.*) superciliary processes are long (3.5 mm.), arching the orbits for two-thirds of the distance. The frontal superciliary processes are short (1–2 mm.). Small post-orbital spines are situated at the lateral angles of the frontal. The parietal (*par.*) region is dome-shaped; the pineal foramen

(*pin. for.*) is at the coronal suture. The two occipital horns (*occ. h.*) are long, smooth, and conical with a small tuberosity at the base of each. They are closely set together, an interoccipital being absent. The postorbitals (*postorb.*) meet the parietal, entirely closing the supratemporal opening. On each of the supratemporal (*supratemp.*) elements are two sharp, recurved horns with a third smaller anterior one. The marked upward curvature of the temporal horns is a characteristic of this species only. The posterior temporal horns are sharp and about equal in length. Each jugal (*jug.*) presents three tuberosities. The occipital condyle is trilobate in shape. The quadrates are small and narrow. The vomers slant back and up and are separated for over half their length by a wide hiatus. The processes from the basiptyergoids are slender. The short epiptyergoids fit into depressions on the petrosal.

Meckel's groove is long and narrow. Each angular presents three, almost equal sized, conical spines and each dentary (*dent.*) three, the two anterior of which are rudimentary. The articulares project downward and are not ossified to the surangulars.

The supporting of the spiny scales on the mandibles by bony tuberosities is peculiar to this species and to *Phrynosoma platyrhinos*. In this character we find a fine example of a purely dermal structure becoming more deep-seated and a bony support being developed. In *P. d. douglassi* and *P. b. blainvillei* no spinose ossifications are to be found on the lower mandible. However, well-developed spinose scales are present. In *P. platyrhinos* and *A. maccalli* the scales present the same appearance exteriorly, but are supported by a bony spine. The same can be noted on the jugal and supraorbital regions (pl. 2). There is, therefore, a growing tendency in some species to support the dermal scales by bony spines. That the occipital spines were developed by the same stages seems probable. The bony spines appear to be simply processes from the bone itself and not small ossifications inside the scale which secondarily fuse with the bone.

The orbital opening (*orb.*) is oval in shape. The supratemporal openings are completely roofed with bone by the meeting of the parietal (*par.*), supratemporal (*supratemp.*), and post-

orbital (*postorb.*) elements. The posttemporal openings are small. The nasal openings (pl. 2, fig. 6) are anterior.

All of the neural spines are small and about equal in size. The partially ossified postischial symphyseal cartilage is bifid at its tip and very nearly reaches to the caudal vertebrae (fig. B). Each caudal vertebra is supplied with well-developed transverse processes. The first pair of processes are short and curve posteriorly. The second and third pair are longest.

Comparison.—Yarrow and Henshaw (1878) record several specimens of this species from the Mohave Desert. Cope (1898), however, places specimens in the U. S. National Museum, bearing the same number and locality, under *platyrhinos*, and notes but three specimens of *maccalli*, all of which are from eastern San Diego County (Imperial County). Thus it appears that *P. platyrhinos* was mistaken by some former authors for the rarer species, *A. maccalli*. The two lizards are very different, as can be seen by the following table of the more striking differences (pl. 6, pl. 7; pl. 2, figs. 5, 6; figs. E, F).

COMPARISON OF *Phrynosoma platyrhinos* AND *Anota maccalli*

<i>Phrynosoma platyrhinos</i>	<i>Anota maccalli</i>
1. Horns grooved and short.	Horns smooth and long.
2. Two or three well-developed temporal horns.	Five or six well-developed temporal horns.
3. One row of peripheral spines.	Three closely-set rows of peripheral spines.
4. Tail rounded.	Tail flat.
5. Femoral pores 7-12 on each side.	Femoral pores 17-20 on each side.
6. No dark median dorsal line.	Dark median dorsal line.
7. Supratemporal openings present.	Supratemporal openings absent.
8. Third sternal ribs attached to xiphoid rods.	Third sternal ribs attached to sternum.

HABITS

Whether this species has any characteristic habits is not known. The stomach of a specimen was found to contain red ants and quite a little sand, which had probably been picked up with the insects. The coloration is of a light shade, closely imitating the light coloration of the desert sand and alkali soil.

DISTRIBUTION

The type locality of *Anota maccalli* is the Great Desert of the Colorado between Vallecito and Camp Yuma about 160 miles east of San Diego. All of the specimens in the Museum of Vertebrate Zoology are from the same general locality. One specimen in the collection of the Department of Zoology from Sonora, Mexico, indicates its occurrence over the border in Mexico. A list of the specimens studied follows:

LIST OF SPECIMENS OF *Anota maccalli*

Museum number	Sex	Locality	Date	Collector
1001	♀	Coyote Well, Imperial County, California	March 30, 1909	F. Stephens
1007	♀	Salton Lake, Imperial County, California	April 24, 1909	F. Stevens
1019	♀	Salton Lake, Imperial County, California	April 27, 1909	F. Stephens
449	♀	Mecca, Riverside County, California	March 31, 1908	C. H. Richardson, Jr.
450	♀	Mecca, Riverside County, California	March 25, 1908	C. H. Richardson, Jr.
447	♂	Mecca, Riverside County, California	March 31, 1908	W. P. Taylor
448	♂	Mecca, Riverside County, California	March 31, 1908	W. P. Taylor
Dept. Zool.	♀?	Sonora, Mexico		C. E. Hays

TABLE OF MEASUREMENTS

Museum number	Sex	Locality	Total length	Length of tail	Width of head	Snout to ear	Length of occipital horns	Length of fore limb	Length of hind limb	Base of 5th toe	Ratios to total length			Ratios to width of head		
											Tail	Hind limb	Snout to ear	Width of head	Horns	Snout to ear
1007	♀	Salton Lake, Imperial Co., Calif.	128.0	47.0	30.5	14.0	12.0	37.0	50.0	16.0	37.0	39.0	10.9	23.8	37.6	37.3
1001	♀	Coyote Well, Imperial Co., Calif.	100.0	36.0	24.0	12.0	10.0	33.0	38.0	14.0	36.0	38.0	12.0	24.0	41.7	50.0
1019	♀	Salton Lake, Imperial Co., Calif.	84.0	30.0	21.0	10.0	8.0	27.0	37.0	12.0	35.5	44.0	10.9	25.0	38.0	47.5
449	♀	Mecca, Riverside Co., Calif.	69.0	20.5	19.0	8.5	7.0	24.0	30.0	10.0	30.0	43.8	12.3	27.4	36.8	44.6
450	♀	Mecca, Riverside Co., Calif.	95.0	34.5	22.0	11.0	8.5	30.0	39.0	14.0	36.0	41.0	11.5	23.2	38.6	50.0
447	♂	Mecca, Riverside Co., Calif.	78.0	25.5	21.0	9.0	7.5	26.0	33.0	10.5	32.5	42.3	11.5	27.0	35.8	42.9
448	♂	Mecca, Riverside Co., Calif.	85.0	29.0	23.0	11.0	10.5	27.0	36.0	11.5	35.0	42.3	12.9	27.1	45.5	47.8
	♀	Sonora, Mexico	91.0	32.5	21.0	10.0	8.0	29.0	29.0	11.0	36.0	31.8	10.9	23.1	38.1	47.5
		Average of males	81.5	27.2	22.0	10.0	9.0	26.5	34.5	11.0	33.7	42.3	12.2	27.5	40.6	45.3
		Average of females	94.5	33.4	22.9	10.9	8.9	30.0	37.1	12.8	35.0	39.6	11.3	24.4	38.4	46.1
		Average	88.0	30.3	22.4	10.4	8.9	28.2	35.8	11.9	34.4	40.9	11.7	25.9	39.5	45.7

¹ In the collection of the Department of Zoology of the University of California. The others are in the collection of the Museum of Vertebrate Zoology of the same institution.

SUMMARY

1. The bases for generic and specific distinction among the horned lizards have not as yet been generally accepted owing to the difficulty experienced in finding dependable characters. This study of the horned lizards of California and Nevada shows that there are diagnostic osteological characters which in addition to the characters now separating the species might, by the working out of a key from a complete set of specimens of all the species, furnish the necessary characters for a revision of the genus.

2. A study of the osteology of the different species inhabiting California and Nevada was productive of at least four interesting features. (a) The closure of the supratemporal openings by the meeting of the postorbital, supratemporal, and parietal elements in *Anota maccalli*, a character heretofore unknown among the Lacertilia. (b) The attachment of the third sternal ribs to the xiphoid rods, a peculiarity of *Phrynosoma platyrhinos*. (c) A supporting of epidermal sublabial spines by bony processes from the lower mandibles in *Phrynosoma platyrhinos* and *Anota maccalli*. (d) The presence in all of the species of a well-developed postischial symphyseal cartilage which, in some species, showed a tendency to ossify.

3. A contribution to the slight knowledge of the "ejection of blood" by horned lizards was afforded by certain experiments carried on by the writer. A few notes on the hibernation of a horned lizard adds something to the limited knowledge of this habit.

4. Five species and subspecies of horned lizards inhabit the states of California and Nevada, each species and subspecies occupying an area fairly well defined. An overlapping of these areas of distribution takes place in at least three localities.

5. The species known as *Phrynosoma blainvillei* and *Phrynosoma frontale* are separated by very subordinate characters (characters much less diagnostic than those separating other species of horned lizards) and show an intergradation at the line of contact of their areas of distribution. They are therefore but geographical races and are reduced to subspecific rank

under the names *Phrynosoma blainvillei blainvillei* and *Phrynosoma blainvillei frontale*.

6. The horned lizard, *Anota maccalli* (*Phrynosoma maccalli*), is distinct from all other horned lizards. The closure of the supratemporal openings is unknown in any other lacertilian. In recognition of this and its many other differences the genus in which it was originally described has been emended to include this species only.

7. A comparison of the tables of measurements shows that the subspecies differ very little in size, whereas the species differ widely in this respect.

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PLATE 1

Fig. 1. Side view of a living specimen of Blainville's horned lizard, *Phrynosoma blainvillei blainvillei*. Note the horns of the occipital and temporal regions; the postorbital spines; the sublabial spines; the gular folds; the large, keeled, tubercular spines of the back; the small granular scales of the back; the smooth, equal-sized scales of the ventral surface; the two widely separated rows of peripheral spines; the row of enlarged scales on the anterior surfaces of arm and thigh; and the neck patch. Approximately life size.



PLATE 2

Fig. 2. Skull of *Phrynosoma douglassi douglassi* (Zool. Dept.). Note the rudimentary occipital horns; the lack of spines on the jugal elements; the large supratemporal openings; and the position of the nasal openings. $\times 1\frac{1}{2}$.

Fig. 3. Skull of *Phrynosoma blainvillei frontale* (Zool. Dept.). Note the well-developed occipital and temporal horns; the interoccipital horn; the spines on the jugal elements; the supratemporal openings; the position of the pineal foramen; and the position of the nasal openings. $\times 1\frac{1}{2}$.

Fig. 4. Skull of *Phrynosoma blainvillei blainvillei* (Univ. Calif. Mus. Vert. Zool., no. 272). Note the well-developed occipital and temporal horns; the interoccipital horn; the spines on the jugal elements; the supratemporal openings; the position of the pineal foramen; and the position of the nasal openings. $\times 1\frac{1}{2}$.

Fig. 5. Skull of *Phrynosoma platyrhinos* (Univ. Calif. Mus. Vert. Zool., no. 1301). Note the short occipital and temporal horns; the spines of the jugal elements; the rudimentary spines of the maxillaries; the supratemporal openings; and the position of the nasal openings. $\times 1\frac{1}{2}$.

Fig. 6. Skull of *Anota maccalli* (Univ. Calif. Mus. Vert. Zool., no. 1006). Note the long, conical occipital horns; the well developed second temporal horns; the spines of the jugal elements; the well developed spines of the maxillaries; the closure of the supratemporal openings; the dome-shaped parietal region; and the position of the nasal openings. $\times 1\frac{1}{2}$.



PLATE 3

Fig. 7. Dorsal view of ♀ *Phrynosoma douglassi douglassi* (Dept. Zool.). Note the small size; the rudimentary occipital horns; the temporal horns which project farther posteriorly than the occipitals; the scalation of the head; the attenuated tail; the single row of peripheral spines; and the color pattern. Approximately life size.

Fig. 8. Ventral view of ♀ *Phrynosoma douglassi douglassi* (Dept. Zool.). Note the small sublabials; the equal-sized gular scales; and the long series of femoral pores. Approximately life size.



PLATE 4

Fig. 9. Dorsal view of ♀ *Phrynosoma blainvillei blainvillei* (Univ. Calif. Mus. Vert. Zool., no. 60). Note the flattened, grooved occipital horns; the temporal horns; the smooth, convex head shields, those in the center being the largest; the double row of peripheral spines; and the color pattern. Approximately life size.

Fig. 10. Ventral view of ♀ *Phrynosoma blainvillei blainvillei* (Univ. Calif. Mus. Vert. Zool., no. 60). Note the large sublabial plates; the three rows of enlarged gular scales; the widely separated rows of peripheral spines; and the femoral pores. Approximately life size.

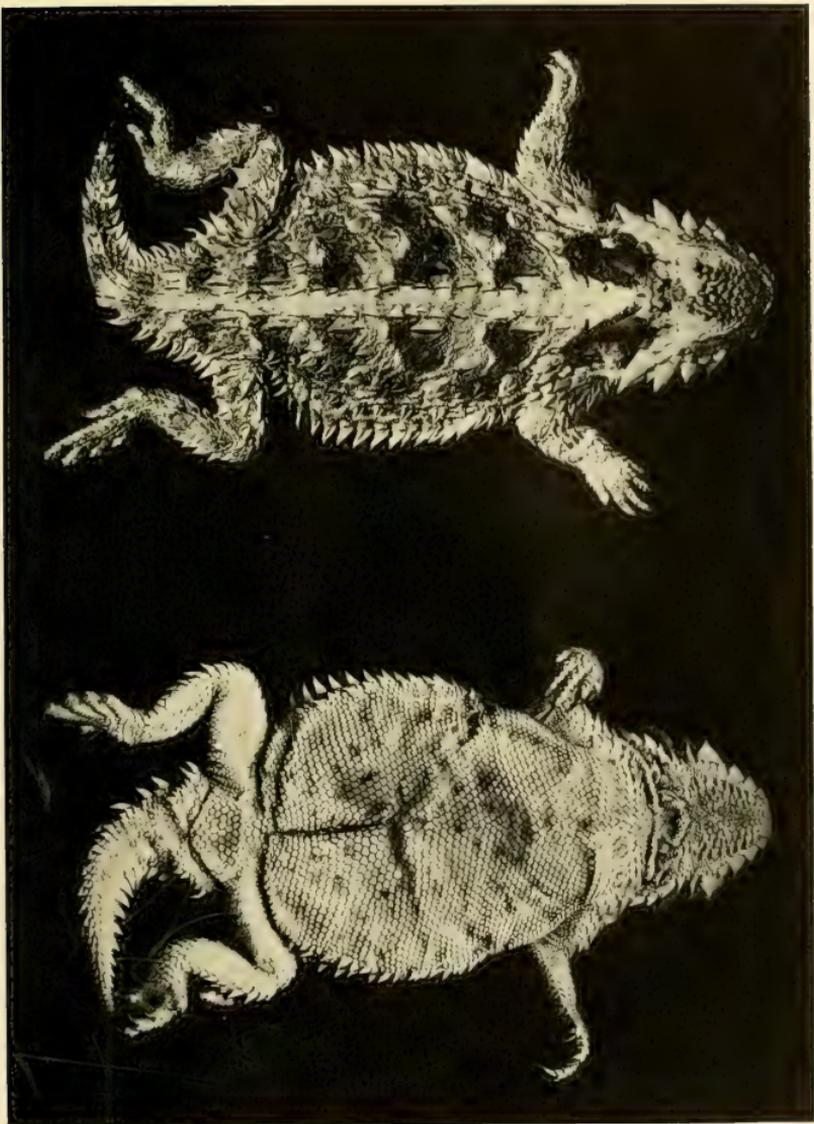


PLATE 5

Fig. 11. Dorsal view of ♂ *Phrynosoma blainvillei frontale* (Dept. Zool.). Note the narrow occipital horns; the temporal horns; the ridged and granulated, equal-sized head shields; the double row of peripheral spines; and the color pattern. Approximately life size.

Fig. 12. Ventral view of ♂ *Phrynosoma blainvillei frontale* (Dept. Zool.). Note the large sublabial plates; the three rows of enlarged gular scales; the femoral pores; and the enlarged postanal plates. Approximately life size.

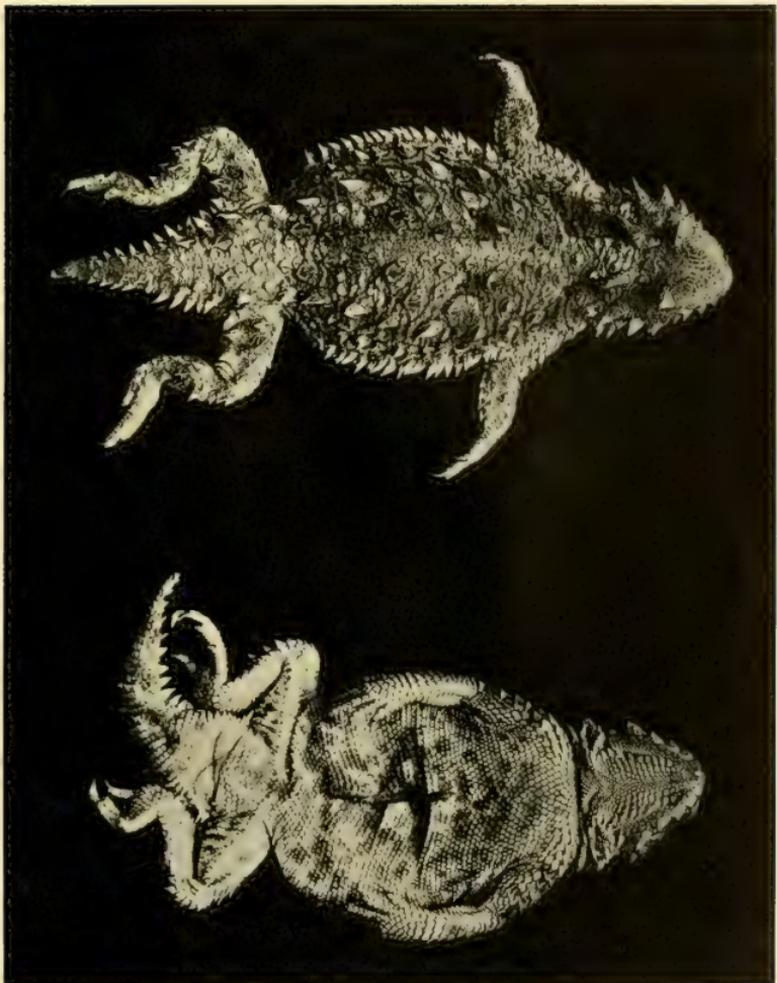


PLATE 6

Fig. 13. Dorsal view of ♂ *Phrynosoma platyrhinos* (Univ. Calif. Mus. Vert. Zool., no. 1311). Note the short occipital horns; the temporal horns; the small equal-sized head shields; the single row of peripheral spines; and the color pattern. Approximately life size.

Fig. 14. Ventral view of ♂ *Phrynosoma platyrhinos* (Univ. Calif. Mus. Vert. Zool., no. 1311). Note the large sublabial plates; the equal-sized gular scales; the single row of peripheral spines; the femoral pores and the enlarged postanal plates. Approximately life size.

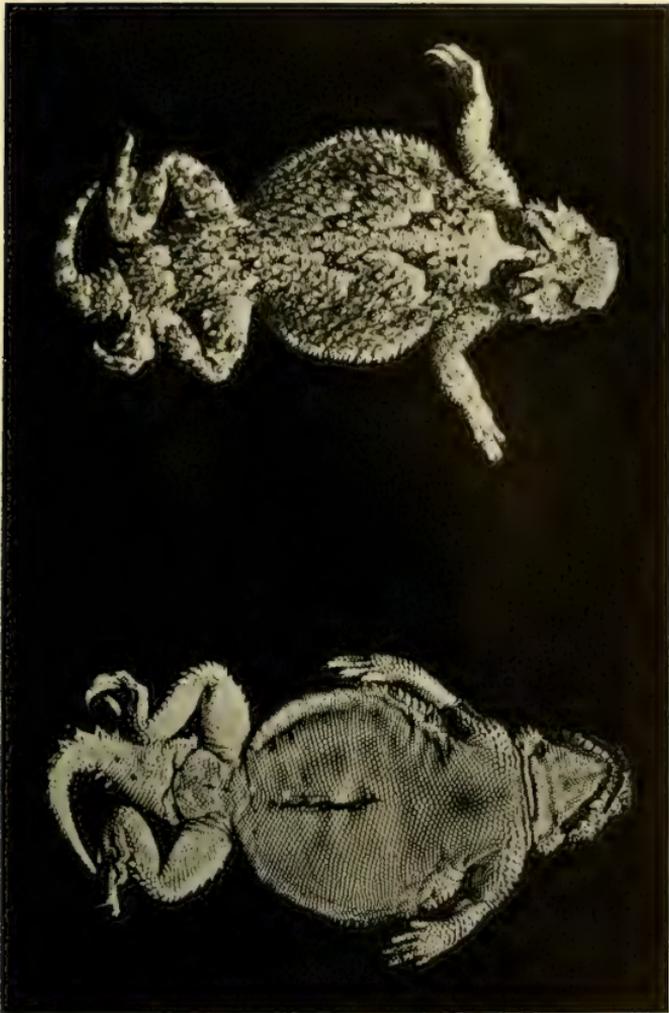


PLATE 7

Fig. 15. Dorsal view of ♀ *Anota maccalli* (Univ. Calif. Mus. Vert. Zool., no. 1007). Note the long, smooth occipital horns; the recurved temporal horns; the enlarged head shields of the parietal region; the reduced scales of the back; the flattened tail; the triple row of peripheral spines; and the color pattern. Approximately life size.

Fig. 16. Ventral view of ♀ *Anota maccalli* (Univ. Calif. Mus. Vert. Zool., no. 1007). Note the large, spinose sublabials; the single row of enlarged gular scales; the triple row of peripheral spines; the flattened tail; and the long series of femoral pores. Approximately life size.

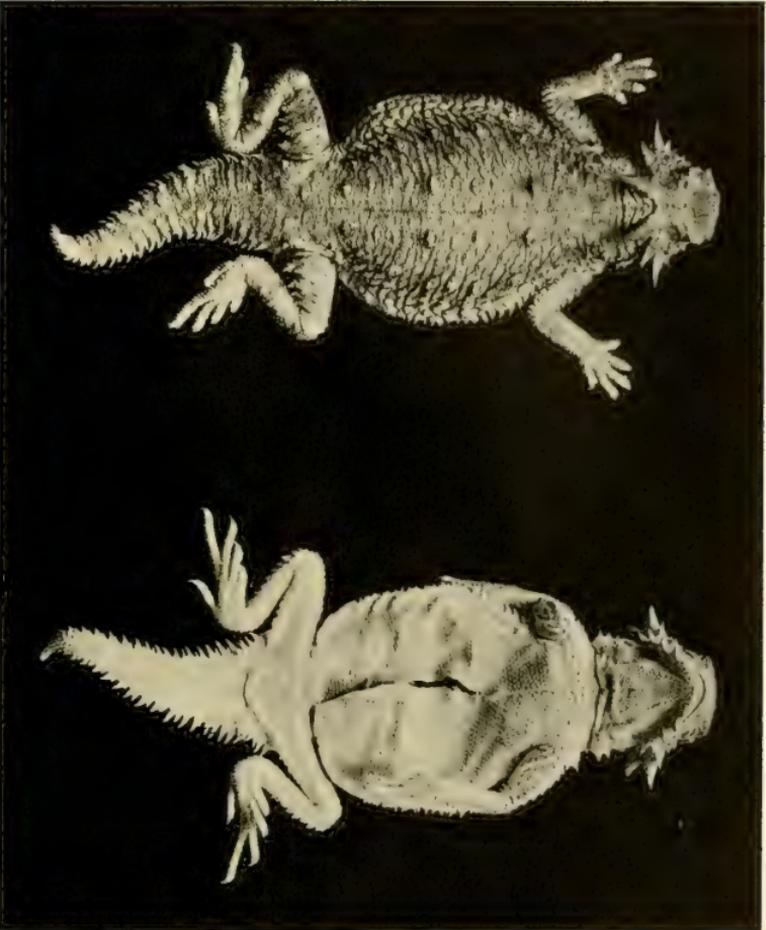


PLATE 8

Fig. 17. Sternum of *Phrynosoma douglassi douglassi* (Dept. Zool.).
× 1½.

Fig. 18. Sternum of *Phrynosoma blainvillei blainvillei* (Univ. Calif.
Mus. Vert. Zool., no. 272). × 1½.

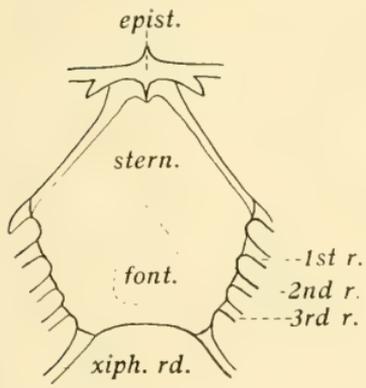
Fig. 19. Sternum of *Phrynosoma platyrhinos* (Univ. Calif. Mus. Vert.
Zool., no. 1301). × 1½.

Fig. 20. Sternum of *Anota maccalli* (Univ. Calif. Mus. Vert. Zool.,
no. 1006). × 1½.

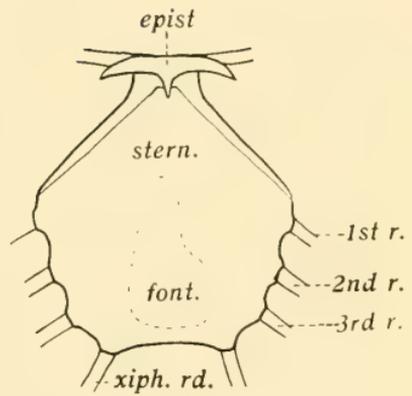
ABBREVIATIONS

1st r., first rib.
2nd r., second rib.
3rd r., third rib.
epist., episternum.

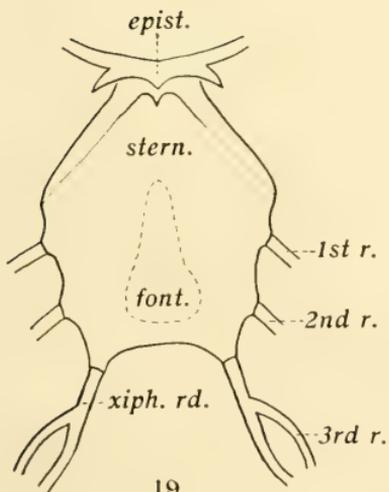
font., fontanelle.
stern., sternum.
xiph. rd., xiphoid rod.



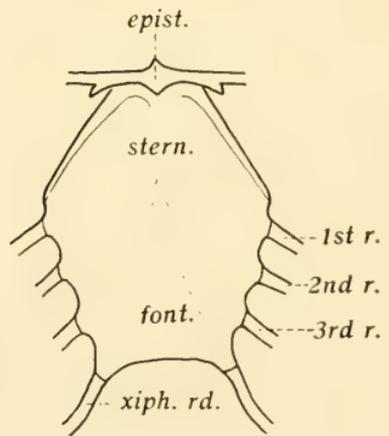
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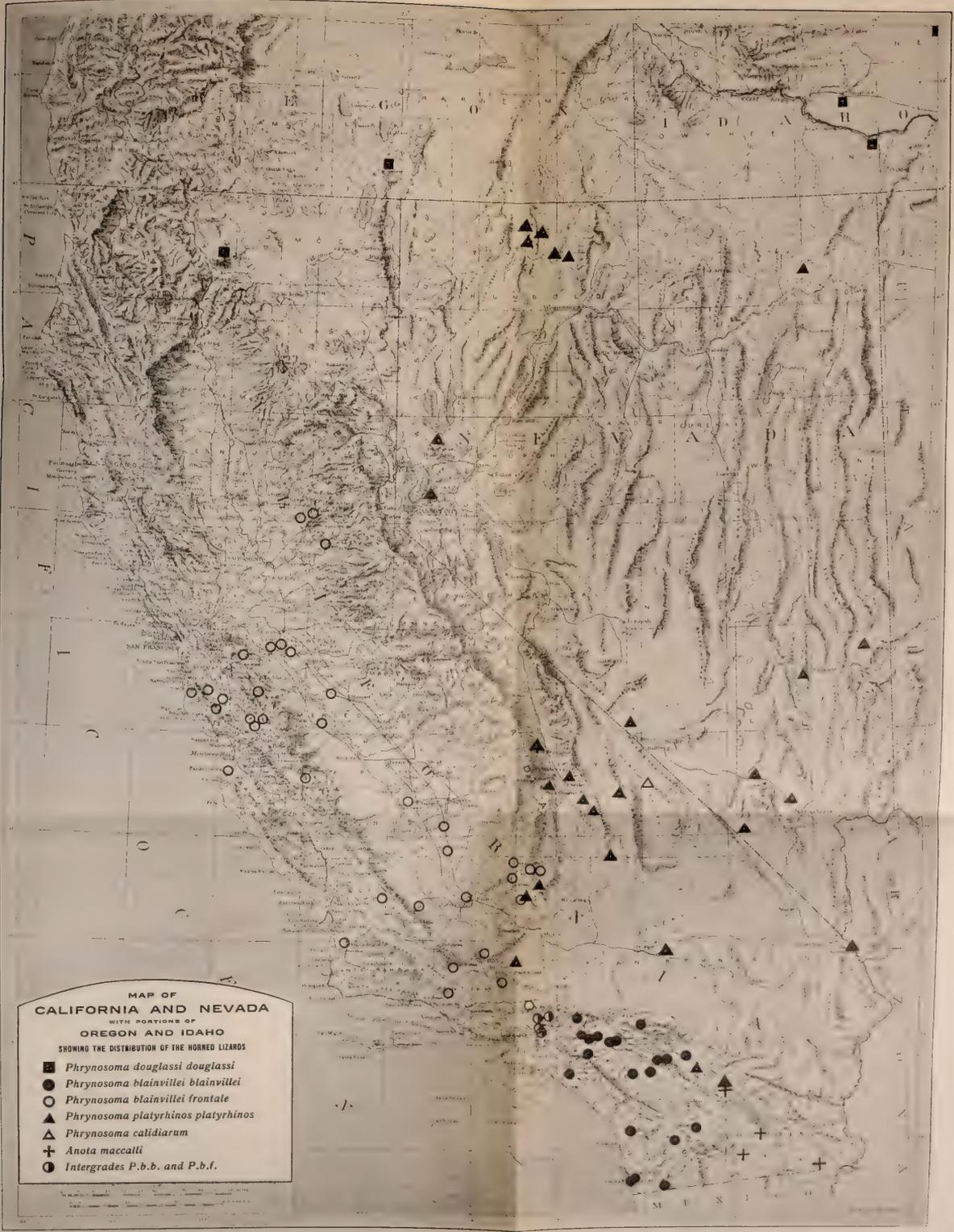


19



20





MAP OF CALIFORNIA AND NEVADA WITH PORTIONS OF OREGON AND IDAHO SHOWING THE DISTRIBUTION OF THE HORNED LIZARDS

- *Phrynosoma douglassi douglassi*
- *Phrynosoma blainvilliei blainvilliei*
- *Phrynosoma blainvilliei frontale*
- ▲ *Phrynosoma platyrhinos platyrhinos*
- △ *Phrynosoma calidiarum*
- ✚ *Anota maccalli*
- (with dot) Intergrades *P.b.b.* and *P.b.f.*

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IN

ZOOLOGY

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ON A LYMPHOID STRUCTURE LYING
OVER THE MYELENCEPHALON
OF *LEPISOSTEUS*

BY

ASA C. CHANDLER

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ON A LYMPHOID STRUCTURE LYING
OVER THE MYELENCEPHALON
OF *LEPISOSTEUS*

BY

ASA C. CHANDLER

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INTRODUCTION

The present paper is a preliminary report on a peculiar gland-like, lymphoid structure discovered over the myelencephalon of *Lepisosteus* while dissecting out the brain in the laboratory of Professor B. G. Wilder, at Cornell University, during the fall of 1910. The work was begun in Cornell University during the college year 1910-11, and later carried on in the Zoological Laboratory at the University of California.

Grateful acknowledgments are here made to Professors C. A. Kofoid and J. Frank Daniel, of the University of California.

and to Professors H. D. Reed, B. F. Kingsbury and W. A. Hilton, of Cornell University, for their supervision and assistance, as well as for the material used, and to Professor B. G. Wilder for his helpful advice and the free use which he allowed of the specimens in his neurological collection.

The structure here described, which I shall provisionally call the myelencephalic gland, was discovered while dissecting out the brain of a long-nosed gar, *Lepisosteus osseus*. While dissecting away the cartilage bit by bit in the region of the hind brain, there was noted a deeply pigmented mass of tissue lying over the myelencephalon, and directly behind the cerebellum. The first inclination was to tear this off with the cartilage and dura mater as merely a pigmented mass of connective tissue, such as often fills the subdural space in teleosts (see Wiedersheim, 1909, fig. 200, p. 294). Since, however, it was seen to have a rather definite form, and to be in closer relation to the brain than to any other part of the head, it was left in position, and carefully dissected out with the brain, to the pial covering of which it was firmly attached.

Though many eminent and competent scientists have worked over the brain of *Lepisosteus*, the myelencephalic gland seems almost universally to have been overlooked. The only reference to it which could be found in the literature on the brain of the ganoids is by Herrick (1891). In his plate 13, figure 9, he figures the dorsal aspect of the brain of *Lepisosteus osseus*, showing the structure in question lying over the myelencephalon. No reference is made to it in the text, and in the description of the figure he merely says: "The bilobed mass lying behind the cerebellum is not of a nervous character." But, as pointed out by Wilder (1891), the membranous parieties of the brain are an important morphological feature of the organ, and should be considered in any treatment of the brain as a whole. As will be shown later, the "bilobed mass" of Herrick is in direct connection with the parieties of the brain, and therefore should not be omitted from a morphological study of the brain because it is not of nervous tissue.

Parker and Balfour (1882) carefully worked out the brain of the adult *Lepisosteus*, and demonstrated the delicate thin-

walled "vesicle of the thalamencephalon," which had previously escaped notice and is readily destroyed in dissection, yet they make no reference to any gland-like structure lying over the myelencephalon, and the usual opening into the fourth ventricle is shown in their figure. They also made sections of the entire head of embryos up to the 26 mm. stage in working out the development of the brain, but, since the gland is not recognizable, as such, up to that stage, it escaped their notice again.

In tearing off the gland in a dissection of the brain, it is impossible not to tear off the posterior medullary velum with it, which accounts for the foramen of Magendie usually shown in figures of the brain of *Lepisosteus*, as seen in the figures of Busch (1848), Mayer (1864), Owen (1868, vol. 1, fig. 174), Huxley (1872, fig. 38), Wilder (1875, pl. 2, fig. 7), Parker and Balfour (1882, pl. 25, fig. 47B), and Allen (1907, pl. 6, figs. 11 and 12). Kingsbury (1897, pl. 6, fig. 5) has a diagrammatic sketch of a cross-section of the myelencephalon in which he shows the roof of the fourth ventricle undisturbed, but without the gland.

OCCURRENCE AND HOMOLOGY

The possibility that this gland might be an abnormal development presented itself, and to determine this point two other specimens of *Lepisosteus osseus* were dissected. The same structure was found in each of them, and was of the same size and shape. It was also found in *Lepisosteus platystomus*, only one specimen of which was available. No example of *L. tristacchus*, or alligator gar, could be obtained for dissection, but on account of the similarity of this species to *L. platystomus* in other respects, and also because of the very close similarity of the gland in the two more divergent species examined, it is probable that this organ will be found in the third species.

It was thought that some such development would be found in other types of ganoid fishes, and in the hope of finding something at least suggestive of it, numerous specimens of ganoid brains in the collection of Dr. Wilder were examined, including examples of *Acipenser*, *Scaphirhynchus*, *Polyodon*, and *Amia*. In none of these, however, could any indication of it be found.

though the possibility exists that in some it may have been present, and have been torn off in dissection. *Polyodon* has a very deeply pigmented pial covering of the brain, but it remains thin and membranous over the fourth ventricle. I myself exposed several brains of *Amia* with the myelencephalic gland especially in mind and found no trace of such a gland there. This was unexpected, since *Amia* is without doubt the form nearest allied to *Lepisosteus*.

In an article on the central nervous system of *Protopterus annectens*, only the preliminary report of which was accessible to me, Burckhardt (1892) figures the dorsum of this dipnoan brain with a structure possessing numerous diverticula lying over the hind-brain, which he calls the "saccus endolymphaticus." This figure is reproduced by Wiedersheim (1909, fig. 201A, p. 296). In a longitudinal section of the same brain (fig. 202B in Wiedersheim) this "saccus" has seemingly been removed, as the myelencephalon is covered only by the much folded choroid plexus. Whether or not Burckhardt's "saccus endolymphaticus" of *Protopterus* is in any way related to the myelencephalic gland in *Lepisosteus*, I am unable to say at the present time, but judging from the name and its appearance in the figure, it is highly improbable. If this should be found to be homologous, it is all the more strange that it does not appear in *Amia*.

GENERAL MORPHOLOGY

The general form of the gland in *Lepisosteus osscus* is not bilobed as described by Herrick (1891), but it is trilobed. The main body of the gland is slightly wider than long, and is thickened just cephalad of the middle, sloping off towards the front and back, and with a pronounced median sulcus caudally, causing the posterior border to be emarginate. From the anterolateral angles there projects on either side an ear-like lobe, very definite and constant in shape and size, connected with the main body by a rather slender neck (fig. A). These ear-like projections are entirely surrounded by cartilage, making their dissection rather difficult, although they readily hold their shape and position when freed from the cartilage.

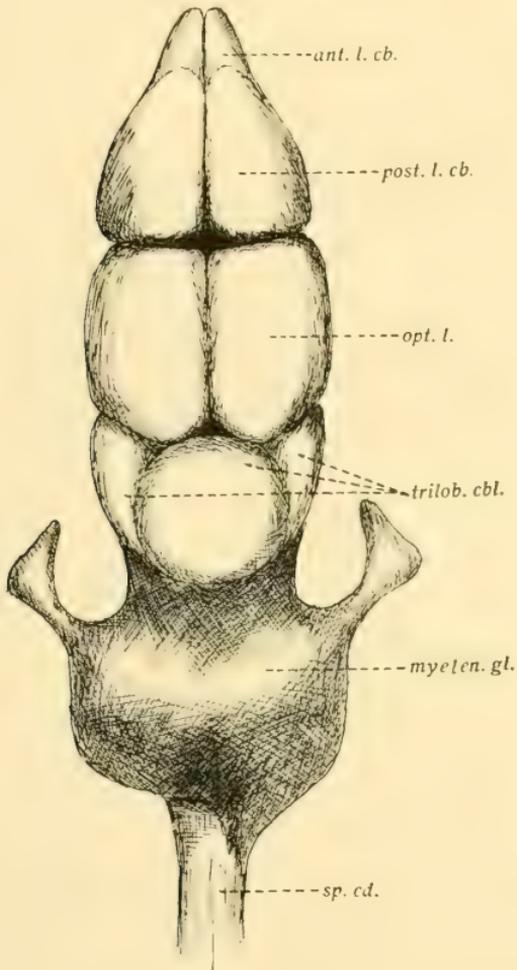


Fig. A. Dorsal aspect of brain of *Lepisosteus osseus*, with myelencephalic gland in situ. $\times 10$. *ant. l. cb.*, anterior lobe of cerebrum; *post. l. cb.*, posterior lobe of cerebrum; *opt. l.*, optic lobe; *trilob. cbl.*, trilobed cerebellum; *myelen. gl.*, myelencephalic gland; *sp. cd.*, spinal cord.

In *Lepisosteus platystomus* the gland is almost identical in form to that in *L. osseus*, but the ear-like projections are relatively shorter and stouter than in any specimen of the latter species which I have examined.

The size of the gland as compared with the rest of the brain is considerable. The width of the main body in a 25 cm. specimen is slightly greater than the width of the optic lobes, which form the widest dimensions of the brain, while the width from tip to tip of the lateral lobes is more than twice that of the cerebrum at its greatest width. Its length is approximately that of the cerebellum, and its thickness such that it attains the level of the dorsum of the cerebellum. In adults the size of the gland as compared with the rest of the brain is even greater than this.

The entire brain of *Lepisosteus* is covered by a deeply pigmented membrane which has a peculiar metallic appearance, in which the enormous pigment cells appear under the binocular microscope as a sprinkling of pepper. This covering membrane seems to be directly continuous with the covering of the myelencephalic gland, or with the gland itself, since in microscopic section there is no distinctly differentiated outer covering. In other words, the structure seems to be a very highly developed and enlarged portion of the pigmented covering of the brain.

HISTOLOGY

In order to determine the histological structure of the myelencephalic gland, the best specimen available was fixed in formalin, imbedded in paraffin, and cut in sections 12 microns in thickness. The sections were then stained in Delafield's haematoxylin, and counter-stained with eosin or with picro-fuchsin.

When placed under the microscope, it became at once apparent that the structure under study was not of nervous tissue, but appeared as an enormous development of the pial covering of the brain. In some of the sections there appeared to be a cavity, but this proved to be nothing more than a very large central blood vessel or sinus. In the section drawn (pl. 10, fig. 1) the true pia mater is indistinctly differentiated from the gland across the dorsum of the fourth ventricle and is fused with it. Where the pia mater curves down over the side of the

medulla, however, the tissue of the gland is continued into it as shown in the region marked "A" in plate 10. As stated above, there is no apparent differentiated covering of the gland.

Of the various histological elements present, the most conspicuous are the extremely large and irregular, black pigment cells, scattered irregularly throughout the whole organ. These cells are similar to those in the pigmented covering of the brain, except that they are not so flattened, and send their branches freely in all directions. Under the high power of the microscope, they show the typical granular structure of melanin pigment cells, and the granules are often somewhat scattered at the periphery, where the cell has been cut. Some of these pigment cells measure fully eighty microns from tip to tip of their branches.

In the middle of the dorsal part of the gland there is an open reticulum of connective tissue which is gradually encroached upon by the more solid substance (pl. 10, fig. 1). From the microscopical appearance of other parts of the gland, there is much evidence that this reticulum forms the framework for the entire structure, the other elements being netted in it. The appearance of this network in a "solid" part of the gland may be seen in plate 11, figure 2, which represents such a portion highly magnified. Farther cephalad than the region shown in plate 10, figure 1, which represents a section slightly in front of the middle, the network becomes more and more open, until, on the sides under the cerebellum, nothing is left but the reticular connective tissue with a few pigment cells in it. Blood vessels are of frequent occurrence, running in all directions, and ranging from very large ones visible to the naked eye to very minute capillaries. Even in the open network of connective tissue surrounding the hinder part of the cerebellum, and constituting the cephalic portion of the structure in question, blood vessels ramify quite freely. The pia mater on the sides of the medulla, and surrounding the cerebellum, is almost a solid mass of blood vessels, which are densely crowded with corpuseles, so crowded, in fact, that they appear as solid masses of tissue, and their identity was for some time in doubt. Caudally, the open network of connective tissue is lost entirely, and the gland appears solid throughout, and denser than the portion drawn (pl. 11, fig. 2).

The histological elements found in the connective tissue network of the gland, in addition to pigment cells, are of three kinds: (1) large, clear cells with small, deeply staining nuclei (pl. 11, fig. 2, *eryth.*); (2) large cells more or less deeply clouded with blue in material stained in haemotoxylin, and showing evidence of reticular chromatin network (pl. 11, fig. 2, *leuc.*); and (3) cells filled with masses of granules staining deep red with eosin, and yellow with picro-fuchsin (pl. 11, fig. 2, *gran. m.*).

The first cells above mentioned seem to be erythrocytes, as they have precisely the same appearance as those filling the vessels in the pia mater, where they are associated with fairly numerous leucocytes. They are scattered freely throughout the gland, entirely independent of vessels of any sort. This is very remarkable for an animal which has a closed blood system, and no explanation for such a phenomenon, if they really be erythrocytes, has yet been found. These cells range from eight to ten microns in diameter, are clear and transparent, with small, round, deeply-staining nuclei, and are irregular in outline, though this may be due to slight shrinkage or contact with other cells.

The second cells above described have much the appearance of large leucocytes. They are very uniformly round in outline, and vary from seven to nine microns in diameter.

The most peculiar and characteristic element present, however, are the numerous cells filled with granules. The granules are about one and a half microns in diameter, and are very nearly the same in size as the melanin granules in the pigment cells. Where a pigment cell and a mass of granules have been cut in close proximity and both types of granules slightly scattered, it is difficult to distinguish them except by color. As stated above, they stain a very deep red with eosin, suggesting eosinophile granules in leucocytes, but they are larger and occupy the cell more completely, as figured by Rawitz (1900). With picro-fuchsin, on the other hand, they stain a deep yellow, similar to the color given to muscle fibres. In many of the vessels of the gland, especially in the larger ones, there are areas filled with a substance which strongly suggests granules in process of disintegration, and occasional scattered granules still intact may be

found in these areas. It is further significant that the substance stains exactly the same as the granules, red with eosin, and yellow with picro-fuchsin. I cannot say that the granules do pass into the vessels and disintegrate, but there is no positive evidence against it, and there are some facts in favor of it. Although the granules appear to be normal, the possibility exists that they may be due to parasitism, or some other abnormality.

The masses of granules, from ten to twelve microns in diameter, are held together by some membrane, probably a very thin cell wall, but it is not evident in the sections. The granules are sometimes scattered somewhat when the mass is cut across just as are the melanin granules in the pigment cells. Associated with each mass there is a fairly large nucleus which shows much more plainly in some cases than in others (pl. 11, fig. 2). Due to the lighter coloring of the granules with picro-fuchsin, the nuclei show best with that stain. These granular masses are found in varying density throughout the gland, except in the open connective tissue network immediately behind and around the cerebellum. In the main body of the gland they are scattered in approximately the density shown in plate 11, figure 2, though possibly on an average slightly more numerous. In the ear-like projections, however, they are far more dense, so dense, in fact, as to obscure all the other kinds of cells, and to conceal the reticular network entirely.

DEVELOPMENT

Thinking that the origin and development of this gland-like structure might throw some more definite light on its nature and function, I sectioned a series of embryos ranging from 6 mm. to 22 mm. in length. The heads of these embryos were stained in toto in Delafield's haemotoxylin, imbedded in paraffin, and cut in sections 10 microns in thickness.

As the eosin counter-stain was the most effective with the adult, this was likewise used for the embryos.

Up to the 18 mm. stage there could be found no indication whatever of any structure lying over the myelencephalon, the ependymal lining of the brain cavity coming in close juxtaposition to the cartilaginous roof of the skull, or lying immediately

beneath the skin in the very young specimens in which the cartilaginous roof is not yet developed.

In the 18 mm. specimen was found the first indication of any tissue intervening between the brain covering and the roof of the skull, in the form of a blood sinus, a space across the dorsum of the myelencephalon filled with blood corpuscles. In the 21.5 and 22 mm. stages the condition is very similar except that the blood sinus is larger and more conspicuous. A typical section through the myelencephalon of the 21.5 mm. embryo is shown in plate 12, figure 3. Between the band of columnar endothelial cells covering the fourth ventricle, and the cartilaginous roof the skull, there is a space largely filled with blood corpuscles, and with a few strands of reticular connective tissue. A few scattered pigment cells may also be seen. Immediately beneath the skin, even in those embryos where the roof of the skull is not yet developed, there is a dense layer of pigment cells. As the cartilage grows over the dorsum, it is easy to see how some of the pigment cells might be pinched off and left inside, there to multiply and cause the apparently useless pigmentation of the covering of the brain. At any rate, it seems highly probable that the pigment cells found there are derived from the pigmented layer of the integument.

The next embryo available for study was a 55 mm. specimen which was cut in sections 10 microns in thickness and stained with Delafield's haemotoxylin and erythrosin. The condition there presented is extremely instructive, as it is in every way intermediate between the 22 mm. stage and the adult form. The space between the covering of the fourth ventricle and the skull is much widened, being at least as wide as the depth of the fourth ventricle. This space is largely empty, but is partially filled by a reticulum of connective tissue (pl. 12, fig. 4). In this reticulum are large blood sinuses, more or less densely crowded with corpuscles, and with a number of large, scattered pigment cells. The latter differ from those in the adult structure in that they are far more regular in outline, often nearly round, and without the dendritic branches displayed later. It will be noticed that in plate 12, figure 4, there are lateral outpocketings of the ependymal epithelium. Farther caudad these outpocket-

ings are larger and much more pronounced, curving forwards or backwards, so that in some sections they appear entirely separated from the ependyma, and look like cavities lined with epithelium and surrounded by the reticular connective tissue lying over the myelencephalon. Farther caudad than the region represented in plate 12, figure 4, also, the cavity over the brain is much extended laterally, and the lateral portions are largely filled in with embryonic connective tissue cells. These regions seem to be the centers of proliferation of the connective tissue, as here the cells are hardly differentiated, while towards the median line the reticular processes of the cells become more and more developed, and the cells themselves become fewer in number. At this stage the gland has not the definite outline which is apparent in the adult, and there is still no indication of the leucocytes or granular masses which form such a conspicuous part of the fully developed structure.

It has not been possible thus far to obtain a specimen intermediate between this 55 mm. stage, and a young adult of 250 mm., the brain of which is figured entire in figure A. This specimen has not yet been sectioned, but as it is adult in all characters except size, it is doubtful whether it will throw any more light on the development of the gland. It has, in this specimen, the characteristic shape, but is slightly smaller in proportion to the brain than in older individuals.

SUMMARY

1. A lymphoid, gland-like structure overlies the myelencephalon of *Lepisosteus*, and is closely associated with the pial covering of the fourth ventricle. Though large and conspicuous, it has been almost universally overlooked by workers on the brain of *Lepisosteus*.

2. The myelencephalic gland (provisionally so named) is present in both *Lepisosteus osseus* and *L. platystomus*, which are the only species of the genus examined by me. No indication of it has been found in other ganoids.

3. The size and form are very constant in all specimens dissected and are practically the same in both species. Topographically it seems to be a highly developed portion of the pia mater.

4. The microscopic structure is suggestive of a lymph gland. A reticulum of connective tissue underlies the whole, and in this a number of other histological elements are netted.

5. The most characteristic feature is the abundance of cells containing masses of granules staining deeply with eosin, of unknown nature, and resembling melanin granules in size and form.

6. There is some evidence that the granules mentioned above pass into the blood vessels and there disintegrate.

7. The earliest indication of the structure is in an 18 mm. embryo, where there is a blood sinus lying between the covering of the fourth ventricle and the cartilaginous roof of the skull. This sinus is larger and more conspicuous in embryos 21.5 and 22 mm. in length.

8. In a 55 mm. embryo the condition is directly intermediate between the 22 mm. stage and the adult. The connective tissue reticulum and pigment cells are well developed, and large blood sinuses are still present, but the granular masses so characteristic of the adult are not yet in evidence.

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EXPLANATION OF PLATE 10

Fig. 1. Cross-section of the myelencephalon and myelencephalic gland of a *Lepisosteus osseus*, 250 mm. in length. Section taken slightly cephalad of middle of gland, and cut farther cephalad on right than on left. $\times 12$.

ABBREVIATIONS

- A*.—region where tissue of gland extends into pia mater.
- 4th vent.*.—fourth ventricle.
- bl. ves.*.—blood vessel.
- col. c.*.—columnar epithelial cells.
- conn. tiss. n.*.—connective tissue network.
- d. gran. m.*.—region dense with granular masses.
- endol.*.—endolymph.
- fl. c.*.—flattened epithelial cells.
- inf. pl.*.—infolding of choroid plexus.
- med.*.—medulla oblongata.
- nerv.*.—nerve.
- pig.*.—pigment cell.
- p. m.*.—pia mater.

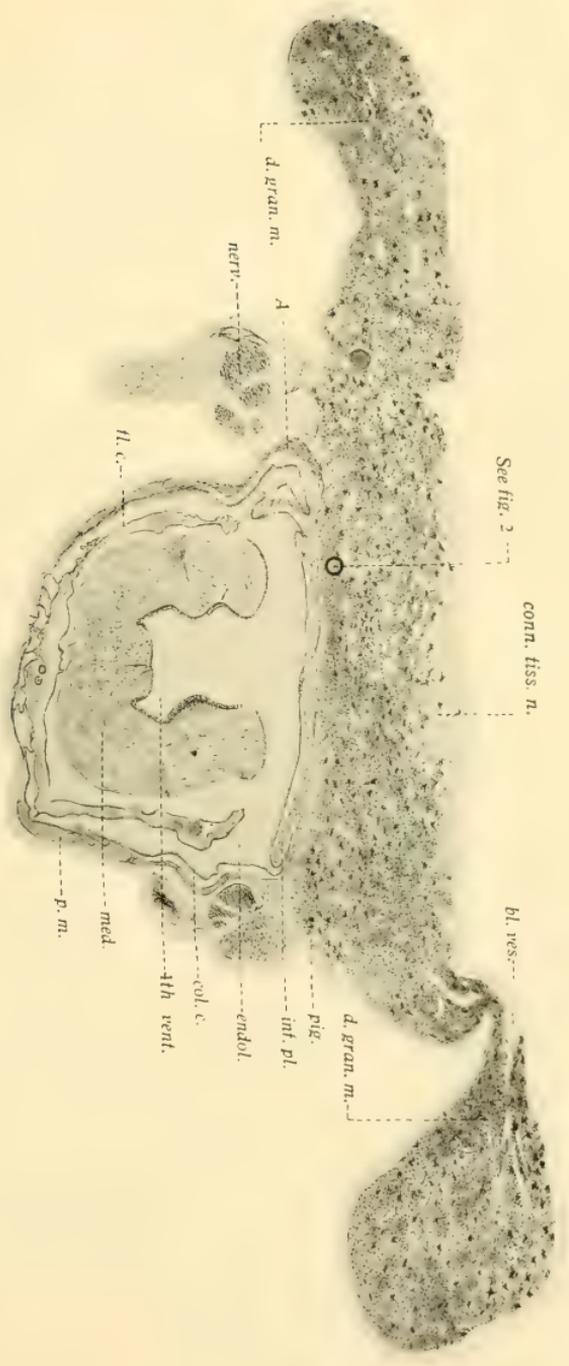


PLATE 11

Fig. 2. Highly magnified portion of myelencephalic gland of *Lepisteus osseus* from region marked with circle in figure 1. $\times 764$.

ABBREVIATIONS

conn. tiss. n.—connective tissue network.

eryth.—erythrocyte?

gran. m.—granular masses.

leuc.—leucocyte?

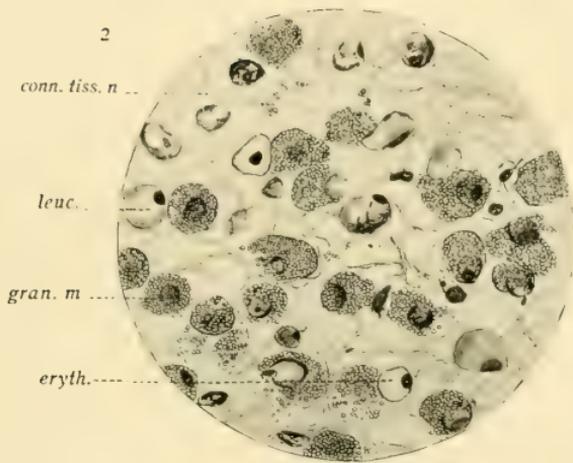


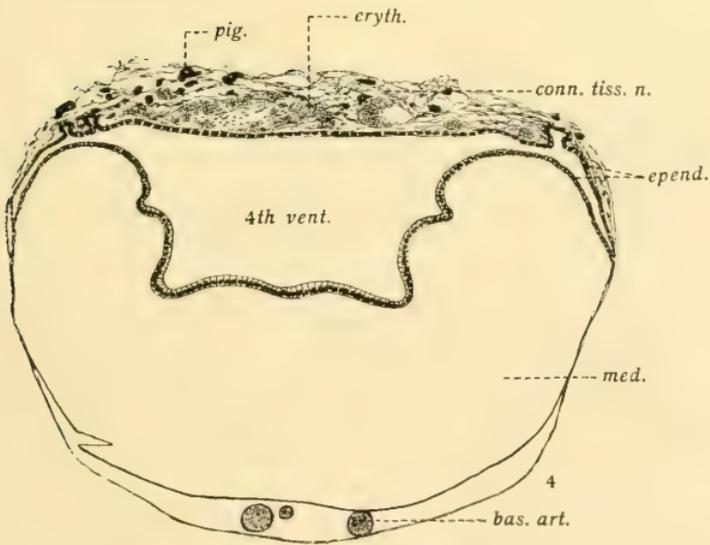
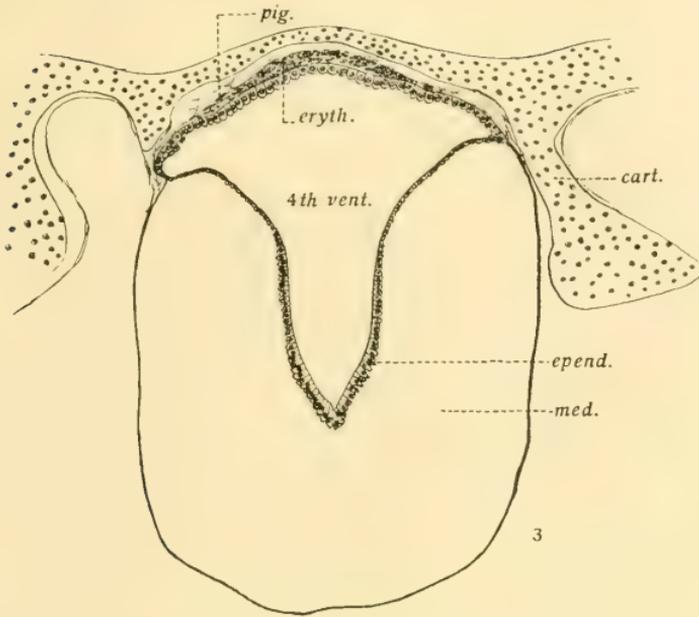
PLATE 12

Fig. 3. Cross-section of myelencephalon of 21.5 mm. embryo of *Lepisosteus osseus*, showing "anlage" of myelencephalic gland. $\times 112$.

Fig. 4. Cross-section of myelencephalon of 55 mm. embryo of *Lepisosteus osseus*, showing further development of myelencephalic gland. $\times 85$.

ABBREVIATIONS

- bas. art.*.—basilar artery.
bl. sin..—blood sinus.
cart..—cartilage.
conn. tiss. n..—connective tissue network.
epend..—ependyma.
eryth..—erythrocytes.
med..—medulla oblongata.
pig..—pigment cell.
4th vent..—fourth ventricle.



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IN RATS AND MICE. No. 3

BY
E. L. MARK AND J. A. LONG

THE LIVING EGGS OF RATS AND MICE
WITH A DESCRIPTION OF APPARATUS FOR
OBTAINING AND OBSERVING THEM

(Preliminary Paper)

BY
J. A. LONG

UNIVERSITY OF CALIFORNIA PRESS
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* No. 1 of these studies is Long and Mark, "The maturation of the egg of the mouse," Publ. Carnegie Inst. Wash., 1911. No. 2 is Mark and Long, "Die Reifung der Eier der Maus," Verh. 8, Intern. Zool. Kong., Graz, 1910.

INTRODUCTION

The solution of the complex problems of heredity, of transmission and of sex determination requires experimental studies as well as investigations of the normal events and conditions of reproduction. It was with this idea in mind that the writers undertook the present series of studies on mammalian sex cells, the first published results of which have already appeared (Long and Mark, 1911; see also Mark and Long, 1911). At present an attempt is being made to cross rats and mice, as well as to study the course of early development in each species, both under normal conditions and also under artificial conditions which simulate natural ones as closely as possible. It is believed that a comparison of the results thus obtained, both by hybridization and independently of it, will be instructive.

The following preliminary communication (No. 3 of these studies) is the outcome of an attempt to devise methods of manipulation which will enable the experimenter more successfully to control the material under investigation, and especially to enable him to follow in the living organism the changes which are inferred from the conditions in preserved material. Further communications on the results of artificial insemination and on other problems growing out of the whole undertaking are reserved for future papers.

The present paper is the result of work done in the Zoological Laboratory of the University of California, and is a continuation of investigations carried on in the Zoological Laboratory of Harvard University, some of the results of which have been published under the title "The Maturation of the Egg of the Mouse." It is published as a contribution from the Zoological Laboratory of the University of California and also as no. 225 of the *Contributions from the Zoological Laboratory of the Museum of Comparative Zoology at Harvard College*.

The running expenses of the work have been defrayed in part from grants made by the Carnegie Institution of Washington, and in part by funds furnished through the Zoological Laboratory of Harvard University; but the special equipment required

for the present work has been supplied by the Zoological Laboratory of the University of California.

Living eggs have been studied and artificially seminated under the microscope, having been carried as far as the formation of the second polar cell. This piece of work bears only on one aspect of the larger problem we have undertaken, and although the results are at present necessarily incomplete, they are set forth with the hope that especially the apparatus devised for the problem may be of value to investigators in related subjects.

The animals used in these experiments were the ordinary white rats and mice, the ancestry of which was mixed, partly white and partly colored individuals. All were normal and in good condition.

APPARATUS

In addition to new apparatus presently to be described, some improvements have been made in the appliances used in the earlier investigation (Long and Mark, 1911).

CAGES

The cages are now made entirely of metal (pl. 13, fig. 1). They are constructed of one piece of wire netting, one-fourth inch mesh, cut into the proper shape, bent over a wooden form, soldered at the angles, and reenforced by a frame of heavy wire. In the middle is soldered a partition of the same wire netting, in which there is a hole connecting the two chambers. In the bottom of each chamber is slipped a drawer-like tray of galvanized iron, which is partly filled with sawdust or shavings and forms the floor of the cage. A sloping lid is hinged at its upper edge as shown in the figure.

BIRTH-RECORDING APPARATUS

Advantage was taken of the method of timing the birth of litters which was described in the preceding paper (Long and Mark, 1911, pp. 7-10). The apparatus is now made on the same principle, but is somewhat simplified, and is fitted with electrical contacts and magnets for marking on the chronograph drum. Figures A-C and plates 13 to 15 illustrate the construction and operation.

It will be seen that by introducing the electrical connections it is possible to have each cage, or unit for the accommodation of one animal (mouse or rat), independent of the others and also to place it in any desired position with regard to the chronograph. Three cages have been arranged to make their records on one chronograph drum. A single cage and its connections with the chronograph drum are shown in plate 15.

The following description applies to each cage or unit. The wire sides and top of the cage are supported on two uprights (*up.*, pl. 14, fig. 4), and are independent of its floor. The floor consists of two parts, each made of sheet zinc, a smaller central and a larger marginal floor. They are shown at the right in plate 13, figure 2. The larger floor (*m. fl.*, fig. A, top surface exposed in pl. 13, fig. 2) has the center cut out to accommodate the smaller; at the edges the zinc is turned up, as clearly shown in figure 2. The smaller floor (under-surface exposed in fig. 2) also has the edges turned up, but to a less extent. The smaller part, which carries the nest, fits loosely within the opening of the larger one. These two floors instead of being suspended from levers above, as in the earlier model, are supported from *below* on levers of special construction (figs. A and B and pl. 13, fig. 2). Each lever consists of a transverse bar (*tr. br.*) at right angles to which are attached three parallel bars, one (*s. br.*) projecting beyond the cage, the other two (*p. br.*, *p. br.*) terminating under the middle of the cage. The two levers are so constructed that the smaller, carrying the nest floor, occupies a position inside the larger (see pl. 13, fig. 2). The fulcrum of each lever is formed of two slender wire nails (*ful. nl.* and *ful. nl.*), which fit into slots in the sheet-metal lever supports, as clearly shown at *br. sup.*, figure A and plates 14 and 15. The unpaired bar (*s. br.*) of each lever carries a counterweight (*wt.*); the paired bars support the appropriate floor. On the under side of each of the floors are two metal supports (fig. A, *fl. sup.*) similar to those on which the levers rest (see right hand of fig. 2, pl. 13, also pl. 14). In each support is a slot, which rides on a slender wire nail (*nl.*, fig. B) driven into the side of each of the paired bars near their free ends. Each floor thus rests on the ends of the paired bars of its lever. The floors are prevented from

tipping by means of the truss-like supports (*tr.*) attached to their under sides. To the angle of each truss is attached one end of a light bar (*lt. br.*), the other end of which is pivoted to the base board. The excursion which each lever may make is controlled by the adjustable block (*blk.*) at the end of the unpaired bar (*pl. 14, fig. 3*). By shifting the counterweights the

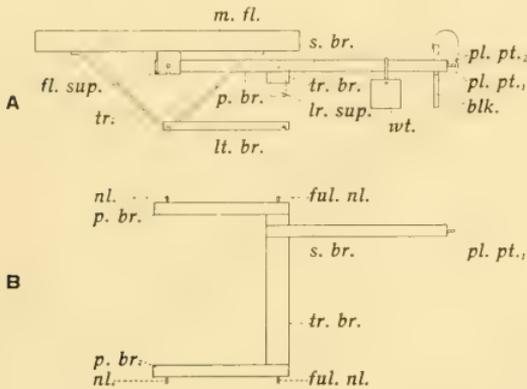


Fig. A. Diagram of side view of larger part of cage floor with its lever and accessories.

Fig. B. Plan (top view) of one lever shown in side view in figure A.

blk., adjustable block; *p. br.*, paired bars of lever; *ful. nl.*, fulcrum nail of lever; *fl. sup.*, floor support of metal attached to under side of floor and resting on slender nail (*nl.*) driven into the side of *p. br.*; *lr. sup.*, support for fulcrum of lever; *lt. br.*, light bar for steadying floor; *m. fl.*, main floor of cage; *nl.*, nail; *pl. pt.*, *pl. pt.*, platinum points which make an electrical contact with each excursion of the lever; *s. br.*, single bar of lever which carries the counterweight (*wt.*); *tr.*, truss-like frame attached to bottom of floor to prevent tipping of floor; *tr. br.*, transverse bar of lever; *wt.*, counterweight.

floors may each be so balanced that they will be moved by a very light weight.

The movements of the floors are recorded on the drum of a chronograph by electrical means. The marking apparatus consists of two small signal magnets (*fig. C*), which are adapted to the purpose by reversing the position of the parts in one and removing its supporting bar. The arrangement is shown in figure C and plate 15. One end of the wire of each coil is grounded in

the supporting frame; the other end terminates in a binding post. The armatures carry slender pointers (*p.*), which mark the smoked paper of the drum. The connections with the cages are simple. Each lever of a cage actuates one of the two magnets. Attached to the outer end of each unpaired bar (*s. br.*) of the lever is a platinum point (*pl. pt.₁*) which is connected by a wire (*wr.*, pl. 13, fig. 2) with one fulcrum-nail of the lever. A movable contact is thus made between the nail and the metal lever support (*lr. sup.*), which in turn is connected through a

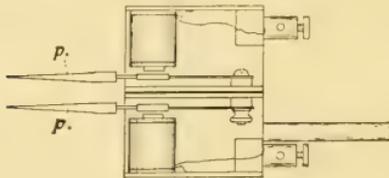


Fig. C. Signal magnets with attached pointers, which record on the chronograph drum the movements of the two parts of the floor of the cage.

binding post at *b. p.* (pls. 13 to 15) with one pole of a battery. With each excursion of the lever the platinum point at its end comes into temporary contact with another platinum point (*pl. pt.₂*) supported on the adjustable block (*blk.*). This second platinum point is connected with the binding post of the appropriate magnet (compare pl. 14, fig. 3; pl. 13, fig. 2, and pl. 15). The frame and support of the magnets is connected by a wire (*c. wr.*, pl. 15) with the other pole of the battery. Contact between the platinum points completes the circuit and the battery actuates the magnet, which pulls to itself the pointer (*p.*), and thus a vertical mark is made on the drum. Inspection of the figures will make clear these arrangements.

The working of the machine is nearly the same as in the one previously described, the important difference being that in the present machine it is possible to determine only the passage of the animal into and out of the nest, whether it be before or after a litter is born. For further details see Long and Mark, 1911.

For studying and experimenting on living eggs of mammals, apparently no suitable apparatus has ever been made. Several conditions must be fulfilled by a successful apparatus: the temperature of the microscope and accessory apparatus must be fairly constant; there must be some way of keeping the eggs that are under observation in suitable artificial media, of seminating them, and of removing the excess spermatozoa. To meet these requirements the writer has devised and constructed the two pieces of apparatus now to be described. They consist of a double-walled box, made of glass and wood, heated to a constant temperature by an automatically controlled electric current, and of a circulation slide, in which eggs can be placed for study and experimental treatment.

CONSTANT-TEMPERATURE BOX FOR MICROSCOPE

The box (figs. D to H, and pls. 16 and 17), which is large enough to contain two microscopes, a compound and a binocular, and also accessory apparatus and cultures, measures inside at the level of its floor about 30 by 18 inches, (76 by 45.5 cm.). The greatest inside height is about $11\frac{1}{2}$ inches (29 cm.). The box is supported on legs. The general appearance and shape is so well shown in the photographs (pls. 16 and 17) and in the vertical sectional view (fig. D) that only a brief explanation is necessary.

As can be seen in figure D, the upper part of the box, which is the part containing the microscopes, etc., is so shaped that the operator can work near the microscope with the least inconvenience, and so that the least light is cut off from the mirror, whether by reflection from the glass of the sloping front or by the lowness of the roof.

The walls of the upper part are of heavy glass (about $\frac{1}{5}$ inch, or 5 mm. thick) except the back and ends (pl. 16 and fig. D) which are of wood, and are double except at back, where there are holes through which the hands are passed in working. The end walls are covered inside with glass plates (fig. E and pl. 17), so that the box is lined with glass save for the back and floor. Where glass plate comes into contact with glass plate one or both edges are ground perfectly straight to ensure a tight joint. Details of the construction can be seen in figures D and E. The

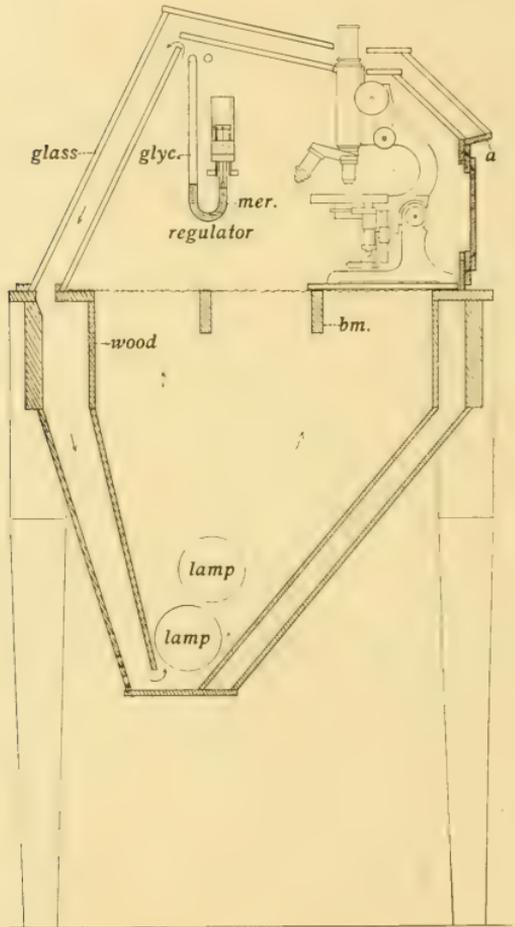


Fig. D. Transverse vertical sectional view of constant-temperature box for microscope. The regulator, which is at one end of the box and not opposite the microscope, is projected on the drawing. The air circulation is indicated by the arrows. *a*, place where cloth is attached; *bm.*, longitudinal supporting beam for wire netting floor; *glyc.*, glycerine-filled tube of regulator; *mer.*, mercury-filled U-bend of regulator. $\times \frac{1}{8}$.

three hand holes are large enough to permit the hand to pass easily. They are closed by small sliding doors; and the middle

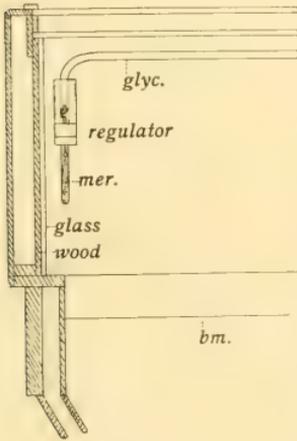


Fig. E. Longitudinal vertical sectional view of one end of the box shown in figure D. Letters as in figure D. $\times \frac{1}{8}$.

and right hand ones are cut in sliding doors, which in turn cover larger holes in the wooden back (see fig. D and pl. 16). This arrangement permits enough lateral and vertical motion of the wrists to enable the operator to reach all parts of the interior without appreciably affecting the temperature within. Several folds of cloth (omitted from the photographs for the sake of clearness), fastened along the top above the holes (*a*, fig. D) and hanging down over them, are very effective aids in keeping the temperature constant.

In figure D it can be seen that the microscope tubes pass through the glass where the edges of the roof plates meet. The holes in the glass are bored so that the glass fits snugly about the tubes of the microscope. Plate 17 shows how the wooden back, a part of the wooden end walls, and all of the glass back of the microscopes, can be removed in order to allow the microscopes to be put in place or to introduce large objects.

The floor on which the microscopes and apparatus rest consists of wire mosquito netting supported at the edges and by two longitudinal beams (*bm.*, figs. D and E) running through the middle. The microscopes rest on strips of heavy glass which lie on top of the netting, but are supported directly by the beams and at the edges. Smaller objects are most conveniently placed on pieces of glass large enough to reach from one wooden support to another.

The object of having a floor of netting is to allow the ascent of the air which is warmed in the lower part of the box below the floor. This lower part of double, wooden walls is shown in

figure D and plate 16. It has the form of an elongate, truncate pyramid, which is lined with heavy asbestos paper, and contains at its lower end the heating lamps. These are connected with a regulator to be described presently. The space between the double walls is filled with cotton, except at the front where the space communicates below with the chamber where the lamps are, and above with the space between the two plates of glass which form the front wall of the upper box. The latter space in turn is connected at the peak of the roof with the interior of the box. Consequently air warmed by the lamps rises, filters through the net floor, envelopes the apparatus, and passes out above, whence it descends between the front walls to the lamps. There is thus a constant circulation preventing the accumulation of hot air above and cold below.

The heating apparatus consists of four 32-candle power incandescent lamps arranged in two pairs. The members of each pair are connected in series. As a result they do not burn with maximum brightness and heat, and they therefore use less current. One pair is directly connected to the source of the current and burns constantly, the other pair is controlled by the regulator.

The regulator, which lies entirely within the box, is made on the plan devised by Mast (1907). The tube of the regulator is suspended at the highest part of the box. It runs lengthwise (figs. D and E and pls. 16 and 17), bending back on itself several times. At the left end (figs. D and E and pl. 17) the tube turns down, ending in a U-bend filled with mercury (*mer.*, figs. D to F). The greater part of the tube is filled with glycerine (*glyc.*), its escape being prevented by a cork stopper visible in plate 16, upper figure. The shape of the glycerine-filled part is immaterial. However, the longer it is, the thinner the glass, and the smaller the diameter, the more sensitive is the regulator. The rest of the regulator in its simplest form is shown in figure F.

On the free end of the mercury-filled U-tube is fitted a cork (*cork*). The cork is pierced by two heavy wires (*lr. wr.* and *ct. wr.*), at the lower ends of which are binding posts. The upper end of one (*lr. wr.*) is bent at right angles (figs. G and H) and passes through one end of a short lever (*lr.*) made of a piece of

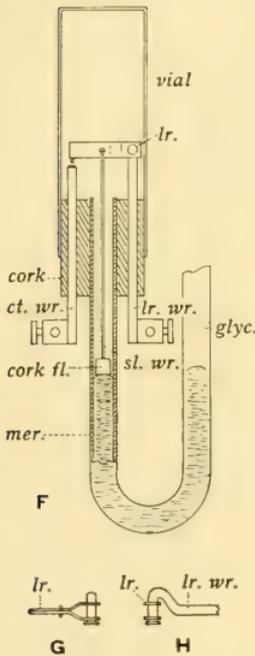


Fig. F. Diagram of thermo-electric regulator used in the constant-temperature box. Only a part of the glycerine-filled tube (*glyc.*) is shown, the rest may be seen in plates 16 and 17. $\times \frac{1}{2}$.

Figs. G and H. Top and end views, respectively, of the lever. $\times \frac{1}{2}$.

cork fl., cork float; *glyc.*, glycerine-filled tube; *lr.*, lever attached to upper end of *lr. wr.*; *sl. wr.*, slender wire between lever and float; *mer.*, mercury-filled U-tube; *lr. wr.*, *ct. wr.*, heavy wires carrying at their lower ends binding posts and at their upper ends the lever and platinum contacts respectively; *vial*, glass vial.

sheet copper shaped and bent as shown in figures F, G and H. At the free end of the lever is soldered a bit of platinum wire, which may touch a small plate of platinum soldered to the upper end of the other heavy wire (*ct. wr.*) and thus make an electric contact. At the middle point of the lever a small hole receives one end of a straight piece of slender wire (*sl. wr.*), which hangs down into the regulator tube. The wire terminates in a piece of cork, which fills the tube, but without sticking or binding, and rests on the surface of the mercury. The lever and opening into the regulator tube may be protected by an inverted shell vial (*vial*) fitted snugly over the cork (*cork*). The regulator is connected in series with one pair of lamps. It can easily be adjusted for a particular temperature by slipping the cork (*cork*) up or down on the tube. The operation of the regulator depends on the expansion of the glycerine when heated. It will easily be seen that when the glycerine expands the mercury is forced down one arm of the U and up the one containing the cork float, which is thus lifted; this breaks the contact at the platinum points, thereby shutting off the lamps.

There are a few precautions which should be observed. Too strong a current through the regulator is apt to cause the points to stick slightly, thus causing a variation in temperature. This can be avoided by using

a relay or similar apparatus for carrying the heavy current. Again, in filling the tube with glycerine care should be taken to prevent glycerine from entering the part of the bend where the cork float rests on the mercury, for it is exceedingly difficult thoroughly to dry the mercury if once wet. All rubber must be avoided in order to prevent tarnishing of metal and consequently poor contacts. With proper care and experiment it is possible to keep the temperature constant to within about one-tenth of a degree centigrade.

In a large box without artificial circulation the temperature in all parts is not exactly the same, though very nearly constant. The microscope is usually a degree or so colder, apparently because of radiation from the exposed part. Accordingly the upper exposed end should be insulated with a good non-conductor, as shown in the photographs. The covering was removed from the binocular in order to make the figure clearer.

Since a camera lucida cannot be used in the ordinary way, it was found practicable, and most convenient, to remove the mirror from the camera and to use instead a large mirror supported over a small shelf at one end of the box (pls. 16 and 17). Although the magnification is greater, because of the increased distance of projection, the method is still satisfactory.

CIRCULATION SLIDE

The circulation slide of glass, perhaps the most important piece of apparatus (now being made by the Spencer Lens Co., of Buffalo, N. Y.), is shown in detail in figures I to L and can also be seen in plates 16 and 17. The unassembled parts, placed however in their relative positions, are represented in figure I, the slide put together is seen in longitudinal section in figure J, and as set up on the stage in figure L.

The complete slide consists of several parts, shown in figure I. (1) A polished lower slide (*lr. sl.*) of glass, one inch by three, and about $\frac{1}{16}$ inch thick, is perforated by two bolt-holes (*bolt hl.*), which on the under side are countersunk to receive the heads of two short bolts. (2) A second polished upper slide (*up. sl.*), of the same dimensions as the lower and with corresponding bolt-holes is the most important part of the apparatus, being the one

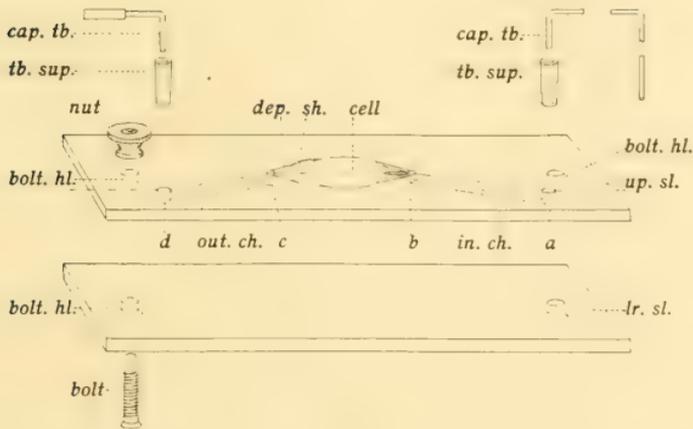


Fig. I. Assemblage of parts of circulation slide in position ready to be put together. $\times 1$.

a, d, holes which receive the tube supports (*tb. sup.*); *b, c*, holes which connect the incurrent and outcurrent channels with the cell on the upper side of the slide; *bolt hl.*, bolt hole; *cap. tb.*, capillary tube; *dep.*, depression; *in. ch.*, *out. ch.*, incurrent and outcurrent channels; *lr. sl.*, lower slide; *sh.*, shelf; *tb. sup.*, tube support; *up. sl.*, upper slide.

in which are ground and polished the cell in which the objects for study are placed, and the channels through which the fluids are conducted to and from the cell. The cell is a circular, flat-bottomed depression about 130 microns deep and 13 mm. in diameter, ground and polished in the center of the upper side of the slide. At its margin the floor is broadly rounded (figs. J and L). At one end of the cell a crescent-shaped area of the surface of the slide is ground down and polished so that it forms a shelf (figs. I, J and L, *sh.*) about 35 microns lower than the upper side of the slide and about 100 higher than the floor of

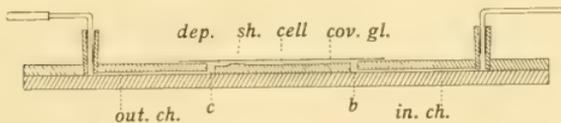


Fig. J. Longitudinal section of circulation slide taken along the dash line in figure I. $\times 1$.

cov. gl., cover-glass; other letters as in figure I.

the cell. Just outside the shelf a triangular deeper depression (*dep.*) is ground in the glass. At the outer angle of the depression a small hole (*c*), about 1 mm. in diameter, is bored through the glass and is connected by an outlet channel (*out. ch.*) or groove ground in the under side of the slide with another larger hole (*d*) leading to the upper side. At the opposite end of the cell three small grooves lead from the cell to a hole (*b*) which is connected by an inlet channel (*in. ch.*) with the hole *a*. The inlet and outlet channels on the under side of the slide are closed when the two slides are bolted together. Similarly the depression, shelf, cell and grooves on the upper side are closed when a cover-glass is placed in the position indicated by the coarse dotted line. Perfectly tight joints are ensured by thin films of vaseline encircling the inlet and outlet channels below and the cell and connected parts above. All parts are easily accessible for cleaning. (3) Fluid is conducted to the slide by means of glass capillary tubes (*cap. tb.*) and from it by both glass and rubber tubes. The capillary tubes are supported and connected with the slide by two tube-supporters (*tb. sup.*) made of short, thick-walled, tapering tubes of glass. The latter are ground into the holes *a* and *d* and fit firmly and tightly. As they do not extend entirely through the slide (see fig. J), they freely communicate with the inlet and outlet channels. All joints of the tubes, while very nearly tight, may be made completely so with bits of melted parafin.

The inlet capillary tube is dipped into a bottle, as shown at the right in figure K; the outlet tube is connected with a waste bottle by a small rubber tube which passes through a pinch-cock. The air of the waste bottle may be exhausted through another tube which passes out through a hole in the back of the box (pl. 16), and a current of fluid caused to flow through the cell. By having the waste bottle lower than the supply, the current once established becomes continuous, as a siphon, and may be accurately regulated by the pinch-cock. The glass must be chemically clean in order that the fluid may be started through without leaving air bubbles behind. Something of the arrangement of the slide and the accessory parts can be seen in plates 16 and 17.

It will easily be seen that fluid after entering the cell can

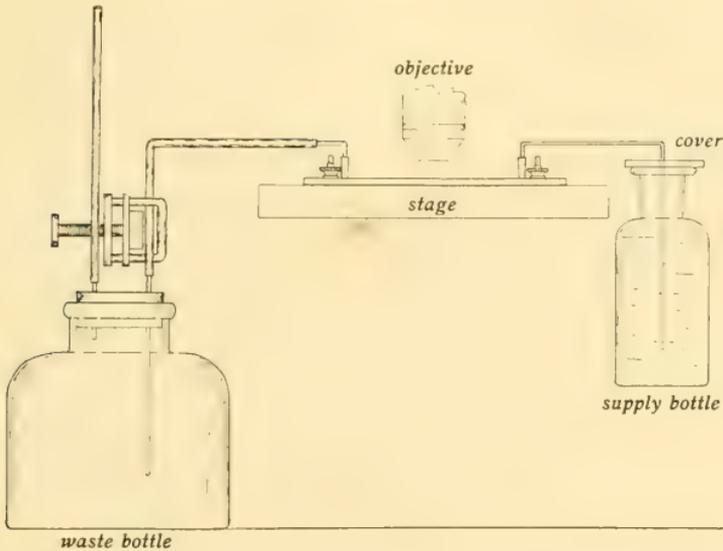


Fig. K. Circulation slide in position on stage of microscope under an objective and connected with supply and waste bottles. The supply bottle is covered by a perforated glass cap; it is supported on a circular disc shown in plates 16 and 17. $\times \frac{1}{2}$.

escape only through the narrow space above the shelf (*sh.*), which is shown in the enlarged sectional view of the outlet end of the cell (fig. L), while objects of large enough size are retained in the cell. Thus mammalian eggs are held back by coming into

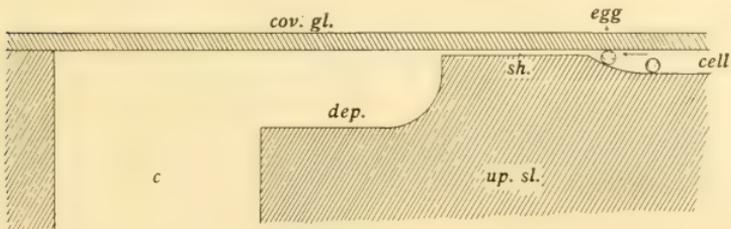


Fig. L. Semi-diagrammatic longitudinal section through part of the upper slide (*up. sl.*) at the outlet end of the cell; i.e., through part of the cell, the shelf (*sh.*), the depression (*dep.*) and hole (*c*) shown in the figures I and J. Cover-glass (*cov. gl.*) above. $\times 25$. It shows two eggs and the way in which one is being prevented from being washed away by the current which passes from right to left.

contact with the curved floor of the cell below and the cover-glass above. The current, if strong enough, causes a slight flattening of the eggs, but can be so regulated that the eggs are held without distortion against the under side of the cover-glass. Under such conditions they may be studied with an oil immersion lens.

A slide such as the one just described can easily be modified to make it available for many kinds of cultural and experimental work, whether with gases, fluids or electric currents. It can also be used for fixing and staining under the microscope.

For convenience in quickly changing the fluids to be passed through the slide a number of small glass stoppered bottles are supported (by having their necks let into slots) on the rim of a circular wooden disc, which may be both rotated about a vertical axis and also raised or lowered on the central shaft. Plates 16 and 17 show the bottles as they are used, and figure M is a vertical section showing the construction of the parts supporting the disc. The rod (*rd.*) has along one side a groove (*gr.*), in which a pin (*pin*) of the sleeve (*sl.*) fits. The sleeve has at its lower end a flange, which rests on a spiral spring and

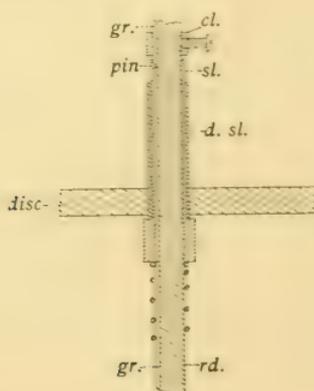


Fig. M. Section of metal supporting parts of the center of disc for holding reagent bottles. $\times \frac{1}{2}$.

cl., collar and set-screw; *disc*, wooden disc; *d. sl.*, metal sleeve to which disc is attached; *gr.*, groove; *pin*, pin; *rd.*, central supporting rod; *sl.*, sleeve resting on spiral spring and about which the sleeve (*d. sl.*) may rotate—it may move vertically, but is prevented from rotating by the pin.

in turn supports above a second tube or sleeve (*d. sl.*), to which the disc (*disc*) is attached. This arrangement allows free rotation of the disc and prevents any torsion in the spring being communicated to the sleeves. But for this, the disc might turn back and break the capillary tube which passes from the slide into the bottle. A collar (*cl.*) with set-screw determines the greatest height at which the disc is supported by the spring. In preparation for changing the fluid in the slide it is only necessary to depress the disc, rotate it until the desired bottle is in place, and then allow the spring to raise it so that the capillary tube passes into the bottle.

When one fluid is to be used for some time, evaporation from the bottle is greatly reduced by having the upper end of the neck ground perfectly flat and covering it with a piece of a polished glass slide (*cover*, fig. K). This cover is perforated by a hole just large enough to admit freely the capillary tube. As the slide on the stage of the microscope is moved about by the mechanical stage the cover slips over the polished surface of the neck.

OBSERVATIONS

Eggs for study were in all cases obtained from the oviducts. Knowing that in mice ovulation occurs fourteen or more hours after parturition, it is only necessary to know when a litter is born and to kill the female fourteen to seventeen hours later. Out of fifteen mice killed for live eggs, seven, killed on the average 16.2 hours, and two, killed 24 and 25 hours, respectively, after parturition, contained eggs in the oviducts. In two other cases the exact time was not known. In the four cases in which eggs were not found the average time was 19.9 hours. In successful cases the eggs were easily visible in a fold of the oviduct near the ovary. Previous work on fixed material demonstrated that soon after ovulation the eggs are in the above fold of the oviduct, where they lie in a cluster surrounded by corona or follicle cells, and that later, as they pass along the oviduct, they become separated and lose the enveloping follicle cells. Study of live material abundantly substantiates the earlier findings, for the cluster of eggs and follicle cells can be identified through the

thin transparent distended wall of that part of the oviduct. In the unsuccessful cases discharged follicles apparently were present in the ovary, but there were no eggs in a cluster in the oviduct. It is probable that they were isolated and naked and hence escaped observation. The search (for scattered eggs) is further made difficult by the secretions in the oviduct, the presence of follicle cells, some blood corpuscles and fat droplets, and also by the rapid drying of the minute oviducts.

Out of thirteen rats used for obtaining live eggs, ten, killed on the average 18.7 hours after parturition, furnished eggs in the oviduct. The other three, in which none could be found, averaged 20.2 hours. Failure can probably be explained here as a result of conditions as in the case of mice, although fixed material has not been studied. There is thus a comparatively very short period during which eggs are procurable. If the animal is killed too soon, the ova will not have had time to leave the ovary; if too late, the eggs will have passed on through the oviduct and escape even careful scrutiny.

In regard to ovulation in rats, it will be seen from the data just given that it must occur on the average less than eighteen hours after parturition.

In the case of both mice and rats the method of procuring eggs was as follows: the animal when killed (mice by breaking the neck, rats by cutting the spinal cord between the cranium and atlas) was quickly opened, one ovary and oviduct removed to the stage of the binocular in the constant-temperature box and placed on a clean, sterile cover-glass of the proper size. When the fold of the oviduct containing the eggs was found, it was moved to the middle of the cover-glass, cut, and the cluster of eggs allowed to flow out. The cluster is jelly-like and highly translucent. The eggs being protected by the follicle cells, the slight drying serves to make them adhere to the cover. A drop of Ringer's fluid, or in a few cases, blood serum, was placed over the eggs, and the cover-glass inverted over the cell of the slide. Up to this point the manipulations required from five to fifteen minutes. When the slide was connected by the glass tubes with the waste and reagent bottles, the chamber was easily filled with the desired fluid. With care nearly all air could be

driven out, for the eggs at first withstand a violent current without becoming detached.

Spermatozoa are easily introduced into the chamber after mixing them with a few drops of Ringer's fluid. Unfortunately for clear observation the eggs, especially those of the rat, are greatly obscured by the follicle cells, and thus far the penetration of the spermatozoon into the egg has not been observed.

The immediate effect of the spermatozoa is not quite the same in all cases. Mouse spermatozoa are exceedingly active in the salt solution. In one experiment they had within two minutes thrashed the follicle cells loose, and bared the eggs, which they then kept in rapid rotation. Usually the follicle cells are loosened less violently, becoming scattered within twenty to forty-five minutes. It is then possible to wash out the excess of spermatozoa and the follicle cells, leaving the eggs quite free in the chamber of the slide. By judiciously pinching the rubber tubing leading to the waste bottle the eggs may be moved about and freed from debris. While most of the spermatozoa when first introduced became attached to follicle cells and lashed the water violently, a number penetrated between the follicle cells and moved about with a slower sinuous motion, strikingly like that of a free-living nematode. The latter sort of motion is more effective, for the spermatozoa exhibiting it progress much more rapidly with the same amount of activity. Presumably this is the way they move up the uterus and oviduct.

At first scarcely anything can be observed of the zona pellicida. However, after the eggs are freed of the follicle cells in Ringer's solution, the zona is clearly visible as a highly transparent, thick envelope. In blood serum the zona is invisible. It is not closely applied to the egg, from which it is sometimes separated by a considerable space, especially in the region of the first polar cell. Sometimes the first polar cell seems hardly to touch the egg, again it lies in a slight depression in the surface of the egg.

The cytoplasm of the eggs of both mice and rats is beautifully transparent, so clear that it is possible to see distinctly granules at the lower pole. In both there is a granular ingredient, though it is different in the two ova. In eggs of mice

the granules are apparently single or in clusters of various sizes pretty uniformly distributed. They seem, under an oil immersion, to be more or less angular. In eggs of the rat, on the other hand, the granules are not so clean cut and brilliant, and before maturation is complete they are arranged irregularly. The egg has a somewhat mottled appearance, as though the granules formed a very coarse network. After the second polar cell is formed, this appearance is lost and the distribution of the granules is quite uniform.

Nothing whatever can be seen in the living egg of nuclear or spindle figures.

The eggs of both animals are approximately of the same size. Since salt solutions of slightly different density cause variations in the size of the eggs exact figures cannot now be given.

The first polar cell of the mouse egg was present in most of the eggs observed. It is large and very conspicuous and its cytoplasmic contents are very similar to the egg cytoplasm. It is more or less spherical, sometimes flattened, at times clearly amoeboid, lightly in contact with the egg or situated in a slight depression in the surface of the egg. The amoeboid condition may well account for the change in position described by several writers. When fixed, the zona is caused to contract quickly into contact with the cytoplasm and the polar cell to be rather deeply pressed into the egg. No second polar cell has so far been formed under the microscope, even when active spermatozoa are introduced into the artificial fluid.

In the rat the first polar cell is much less conspicuous. It is smaller and may easily be overlooked.

It has been possible to seminate rat eggs with rat spermatozoa and to observe the formation of the second polar cell. Fortunately the eggs always lie in such a position that the forming polar cell can be seen in profile. The formation, usually near the first polar cell, may begin within five minutes to two or more hours after the spermatozoa are introduced. The constriction may be finished three-fourths of an hour later. The process is strikingly like that described (Long and Mark, 1911) for the mouse egg as far as the external features are concerned. The first appearance is an elevation clearer than the rest of the

egg. The swelling becomes higher and at one side of the elevation there appears a depression which is the beginning of the constriction which presently encircles the whole swelling and cuts it off from the egg. The polar cell is at first clear, as in the mouse, and later becomes granular like the egg cytoplasm. There is at one side of the polar cell on the surface of the egg a temporary elevation, for which at present I have no explanation.

While the second polar cell is at first spherical, it becomes irregular and distinctly amoeboid, undergoing, perhaps amitotically, division into unequal parts. It seems to degenerate, growing smaller and more granular.

At present nothing can be said as to the changes which the chromatin undergoes after the spermatozoon has penetrated the egg.

The egg itself becomes more nearly spherical after the second polar cell is abstricted.

The eggs remain alive and apparently normal for about twelve hours, when they begin to degenerate, the outlines growing ragged, the granular contents becoming dull and contracted toward the center, leaving a clear peripheral zone. The causes are not at present determined. In some cases bacteria play a part.

No reason can at present be assigned for the failure of mouse eggs to produce a second polar cell; nor can the precise conditions under which it is formed in rat eggs be set down. Therefore a further discussion at present is not desirable.

Zoological Laboratory, University of California.

Transmitted July 28, 1911.

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EXPLANATION OF PLATES

PLATE 13

Fig. 1. All-metal cage for mice or rats.

Fig. 2. Top view of cage and apparatus for recording automatically the time of birth of litters of rats or mice. The floors are removed and are seen at the right, the larger from above, the smaller (which carries the nest, an inverted strawberry box, see pl. 14) from below.

ABBREVIATIONS

blk.—adjustable block.

b. p.—binding post through which the levers are connected to one pole of battery.

fl. sup.—metal support attached to under side of floor and resting on slender pin driven into side of lever bar (*p. br.*).

lr. sup.—metal support for fulcrum of lever.

p. br.—paired bars of lever.

s. br.—single bar of lever which carries the counterweight (*wt.*).

tr.—truss-like frame attached to floor to prevent tipping of latter.

tr. br.—transverse bar of lever

up.—upright posts which support the wire sides and top of the cage independent of floor.

wr.—wire connecting platinum contact (*pl. pt.*, fig. A) through the fulcrum nail (*ful. nl.*, fig. B) and one of the metal supports (*lr. sup.*) with the binding post (*b. p.*).

wt.—counterweight.

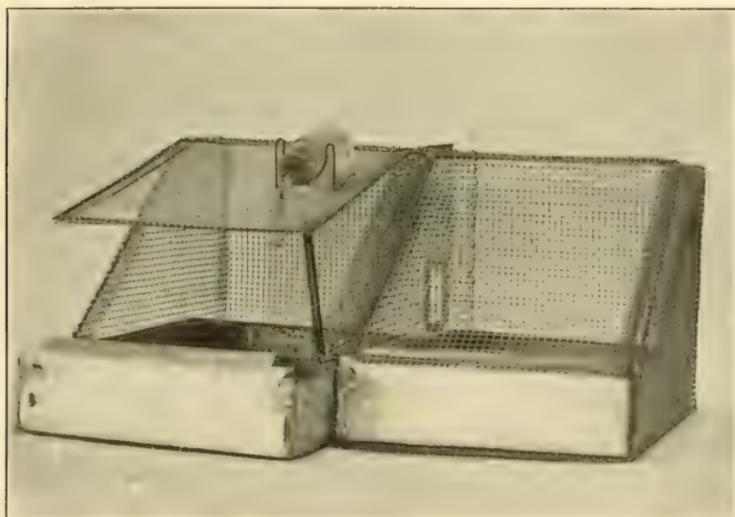


Fig. 1.

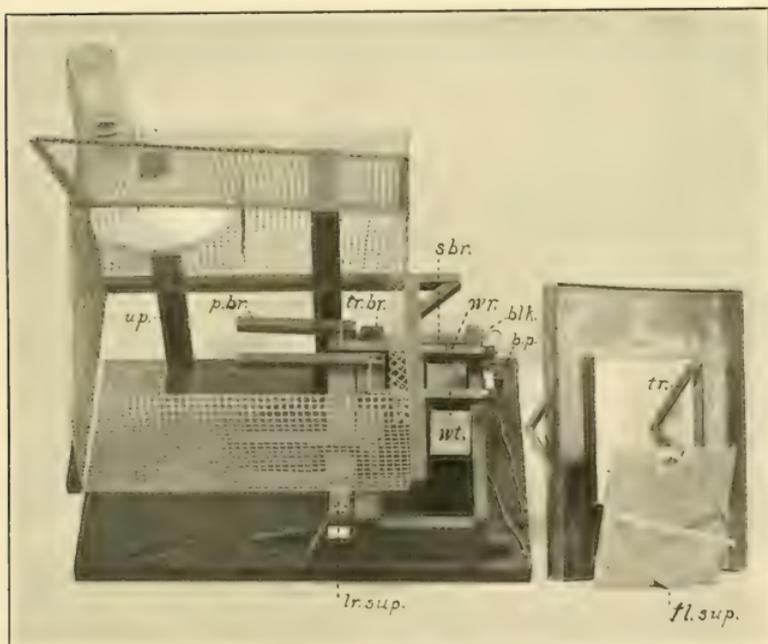


Fig. 2

PLATE 14

Figs. 3 and 4. Other views of cage and recording apparatus shown in plate 13.

ABBREVIATIONS

blk.—adjustable block.

b. p.—binding post through which the levers are connected with one pole of the battery.

fl. sup.—metal support attached to under side of floor and resting on slender pin driven into side of lever bar (*p. br.*, pl. 13).

tr. sup.—metal support for fulcrum of lever.

tr.—truss-like frame attached to floor to prevent tipping of latter.

up.—upright posts which support the wire sides and top of the cage independent of floor.

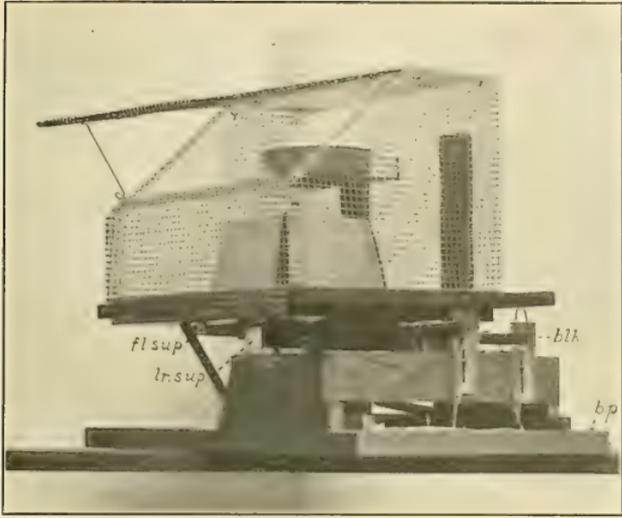


Fig. 3.

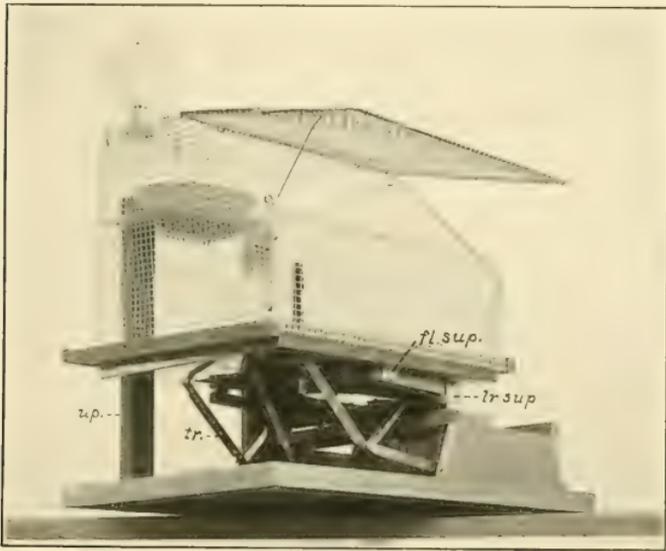


Fig. 4.

PLATE 15

One cage of recording apparatus showing connections with the signal magnets, the pointers of which mark the excursions of the floors on the smoked paper of the drum of the chronograph. Three such cages are arranged to make their records on one chronograph.

ABBREVIATIONS

blk.—adjustable block.

b. p.—binding post through which the levers are connected to one pole of battery.

c. wr.—wire connecting the supporting frame of signal magnets to other pole of battery.

tr. sup.—metal support for fulcrum of lever.

lt. br.—light bar which in connection with the frame (*tr.*) attached to the floor prevents the latter from tipping.

tr.—truss-like frame attached to floor.

wt.—counterweight.

Contact between the platinum points (*pl. pt.*₁, and *pl. pt.*₂, figs. A and B) completes the circuit, a part of which is formed by one of the coiled wires seen in plate 15. Each lever has its platinum contacts and is connected with one of the signal magnets by one of the coiled wires. (See description, pp. 109-110.)

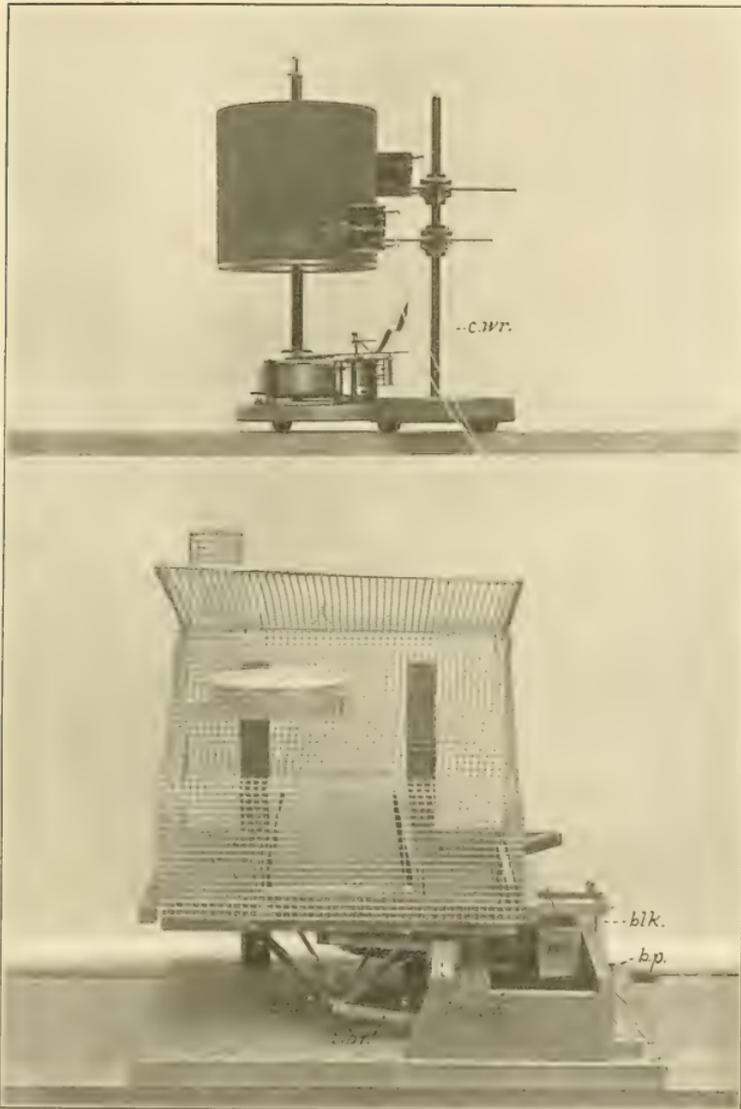


Fig. 5.

PLATE 16

Fig. 6. Front view (side away from the operator) of constant-temperature box for microscope. The glass front, which is invisible in the photograph, is in place and the apparatus inside is seen through the glass. A large 50-degree thermometer (white) is suspended from the glycerine-filled tube of the regulator. The bulb of another rests on the stage of the compound microscope in contact with the circulation slide.

Fig. 7. Rear view of the constant-temperature box. Between the microscopes lies the small (white) rubber tube through which the air of the waste bottle is exhausted and the current started in the slide. The drawing shelf and camera mirror are at the right.

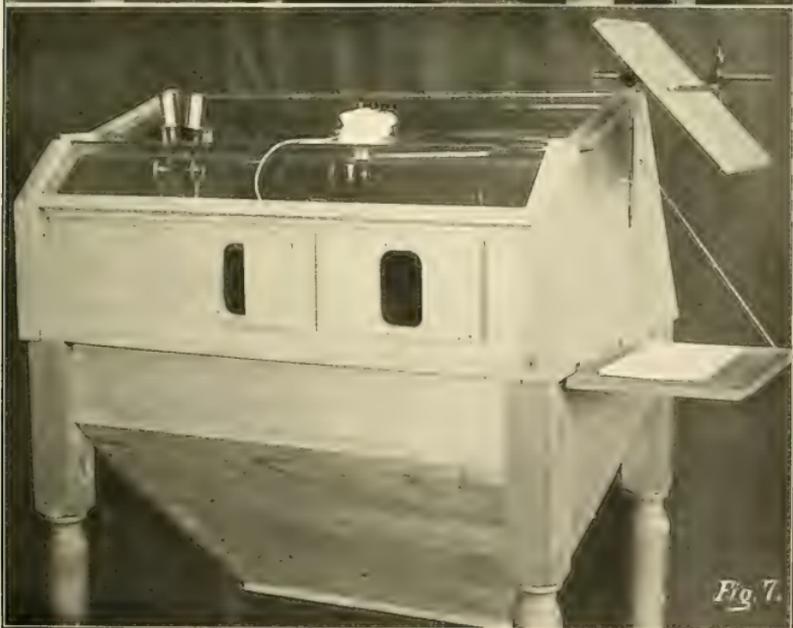
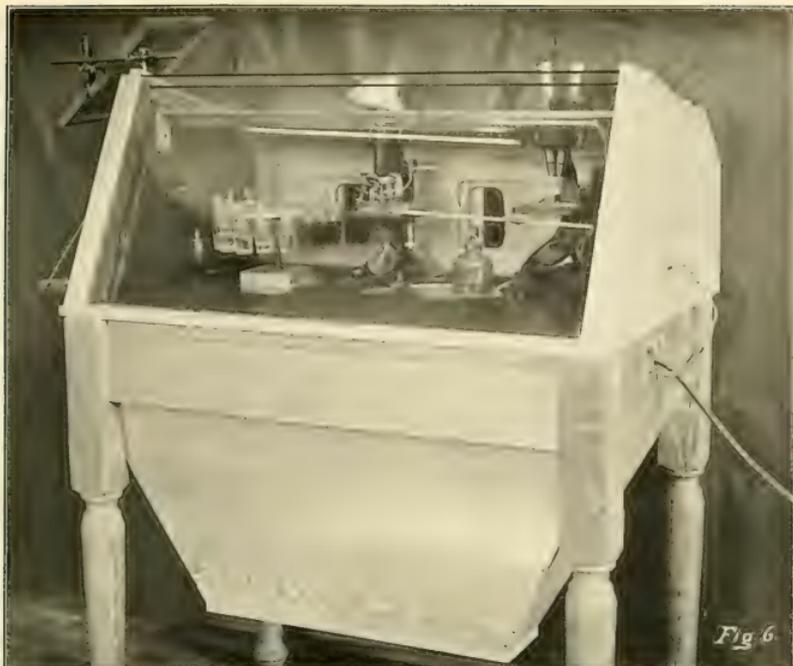


PLATE 17

Fig. 8. Interior of constant-temperature box as seen from behind after removal of the back. At the ends of the box the outer wooden and inner glass walls remain, while a part of the inner wooden is removed with the wooden back and glass top behind the microscopes. The two thermometers as in plate 16. The regulator, shown in figure F (p. 115), is at the left. The slide on the microscope stage is partly obscured by the mechanical stage, but the glass and rubber tubing, as shown in figure K, can be seen passing to one of the bottles at the right and to the waste bottle at the left. The exhaust rubber tube is withdrawn from the hole in the back of the box and is seen hanging over the glass roof and down in front.

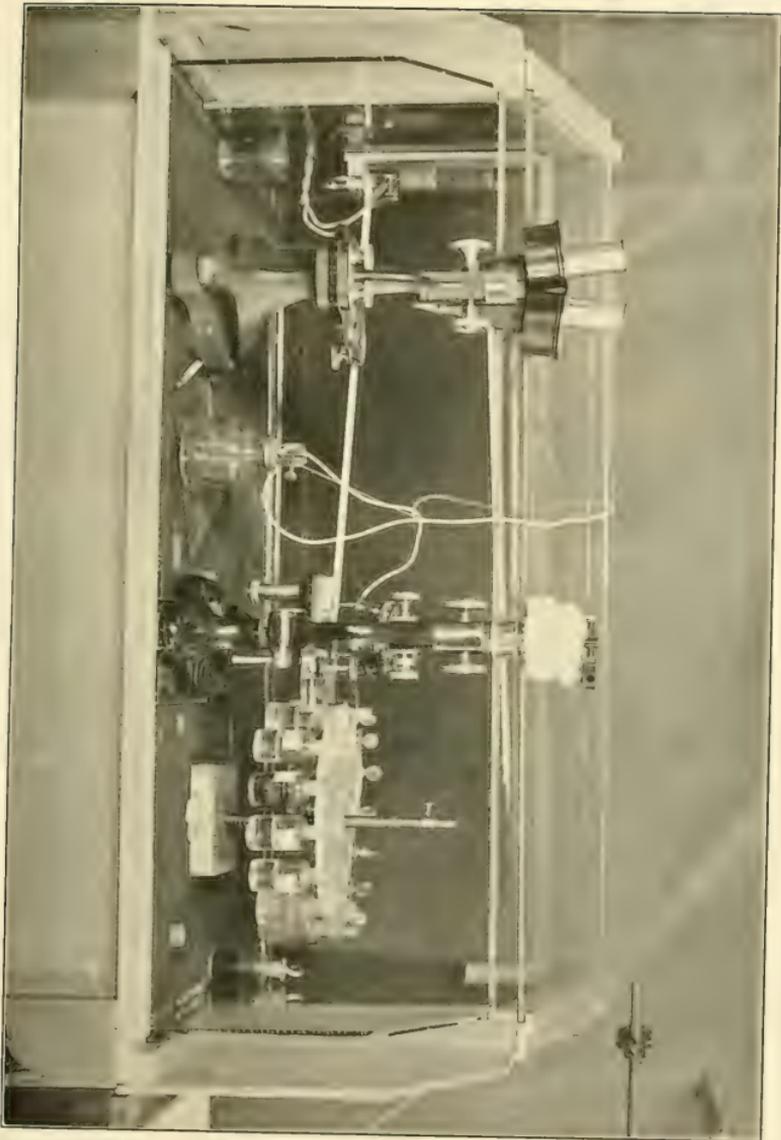


FIG. 5

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THE MARINE BIOLOGICAL STATION
OF SAN DIEGO

ITS HISTORY, PRESENT CONDITIONS,
ACHIEVEMENTS, AND AIMS

BY

WM. E. RITTER



UNIVERSITY OF CALIFORNIA PRESS
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ANNOUNCEMENT

While this report has been passing through the press, the transfer of the Station to The Regents of the University of California, as provided by the articles of incorporation (Appendix A), has been effected. The official designation under the new regime will be

THE SCRIPPS INSTITUTION FOR BIOLOGICAL RESEARCH
OF THE
UNIVERSITY OF CALIFORNIA

Although, as indicated by the change of name, an enlargement of activities is contemplated, no immediate alteration of policy or work will take place.

WILLIAM E. RITTER.
Scientific Director.

LA JOLLA, CALIFORNIA,
February 25, 1912.

THE MARINE BIOLOGICAL STATION OF SAN DIEGO

ITS HISTORY, PRESENT CONDITIONS, ACHIEVEMENTS, AND AIMS

BY

WM. E. RITTER

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B. INTRODUCTION

This year, 1911, is the twentieth anniversary of the first movements that led to the establishment of the Marine Biological Station of San Diego. It is also the tenth anniversary of the beginning of definite, continuous effort toward that end. The time is fitting, therefore, for a fuller general presentation of the institution's career, structure, accomplishments, and purposes than has yet been written. The account is not merely narrational and descriptive; it is a sort of confession of faith as to the larger meaning of science, of biology in particular. It has been prepared with the desire to make it informing and interesting to those immediately responsible for the life and work of the station, i.e., its patrons, business managers, and investigators; to those who are engaged in similar but wholly independent enterprises; and last but in no wise least, to earnest, inquiring people generally.

Sections B to G will be of interest mostly to the first two groups, in as much as these sections are a detailing of how an institution of research in pure science, starting with almost nothing in a material way and with almost no real friends, may yet grow to a state of considerable size and breadth of outlook. Sections E, G, and H ought to interest a number of persons in no way connected with or concerned about the station as such. Biologists and oceanographers especially should find items in sections F and G that would appeal to them. The concluding section has been put into the story for the reason that the desire to make the Station an instrument of general public enlightenment is embedded very fundamentally in the conceptions upon which the institution rests.

On glancing over the section headings the general reader will, presumably, be inclined to turn to the last two sections and read them first if not exclusively. To read this last part first would be in no wise objectionable; indeed such a course may be commended. But I would strongly urge that the sections "The Station as it is to-day" and "Scientific results already

achieved" be not passed by entirely. To do so would be to miss much of the real essence of any part. No one can hope to get more than a modicum of the good possible in general knowledge of the results of scientific research, without giving some attention to the methods by which the results are obtained. This consideration has led to the inclusion in the account of an amount of detail about the equipment and workings of the station's boat, the "Alexander Agassiz," that would otherwise probably have been left out.

Another matter of great moment for general, hardly less than for special information, is the vital way in which such enterprises are dependent upon the combined efforts of a number of persons. In any considerable undertaking the dependence of every one upon every other one is so commonplace a fact that the fundamentality of it is likely to be less reflected on than it ought to be. With the two-fold purpose of giving information as to who have been most active in the development of this particular institution, and of encouraging more general recognition of the fact that all such enterprises are in very essence partly individual and partly communal, I have aimed throughout to keep persons rather than inanimate things to the front, and have endeavored not to leave any one unmentioned who has contributed significantly to the results. The larger number of those who fall into this category are referred to under headings dealing with the particular work they have done. But a few individuals have been so intimately connected with many aspects of the station's growth and work that they must be spoken of here.

The operations of the "Agassiz" as set forth under the appropriate headings would have been impossible but for Mr. Ellis L. Michael and Captain W. C. Crandall, they having been responsible for most of the methods actually employed. By this I do not mean that these men and no others are competent for this work, but that the undertaking is such as to demand the combined efforts of several persons; that into their hands fell this important part of the programme; and that they proved equal to the task. Similarly into the general working plans of the station are woven the suggestions, the ideas, and the activities

of Professors C. A. Kofoid and H. B. Torrey in so intimate a way that surely without them the institution could not have been exactly what it is; indeed could not have been at all without services quite like theirs. To Professor Kofoid's extensive knowledge of laboratory plans, construction, and equipment, to his skill in working out details for such purposes, and to his ability in devising mechanical appliances, are largely due the laboratory building and some of the most important apparatus used on the "Agassiz." Professor Torrey also took an important part in planning the laboratory building and the "Agassiz"; while his special efforts have largely produced the library, not only as it now is but as it will be in its fuller development.

During the spring and summer of 1906 while the Scientific Director was absent from the United States, the conduct of affairs devolved upon Professor Kofoid as Assistant Director, and the period proved to be one of special importance for the station in that, largely through his initiative, three biologists, Professors E. L. Mark of Harvard University, E. B. Wilson of Columbia University, and H. S. Jennings of Johns Hopkins University, were invited to La Jolla at the expense of Mr. E. W. Scripps, primarily as advisors on certain matters of policy, particularly on the question then being considered, of locating on the land afterward acquired for the station's permanent site.

Moving on to still broader, more general aspects of the institution, it is not too much to say that the transference of the station from its precarious existence at San Pedro to its surer tenure of life at San Diego was a service due more to Dr. Fred Baker than to any other person. And from that day to this his constant thought and care and activity have contributed to making the institution what it is, to an extent that can be only partially specified. As concerns the routine business affairs since the formation of the Marine Biological Association of San Diego in 1904, what has been said of Dr. Baker's service is almost equally true of that of the other officials of the Board of Directors, Mr. Julius Wangenheim as treasurer and chairman of the building committee, Mr. H. L. Titus as vice-president and legal adviser, and Mr. F. W. Kelsey as secretary in the earlier days, and later Mr. W. C. Crandall in the same office. Nor

would the list of those whose labors have contributed most to the institutional upbuilding and operations of the station be in any wise complete without reference to the vicarious activities, official and scientific, of Mrs. William E. Ritter, wife of the scientific director.

Acknowledgment is also heartily made of the uniform courtesy and in several instances substantial help and encouragement given the station by persons acting in official capacity for the city of San Diego.

Finally, Miss Ellen B. Scripps and Mr. E. W. Scripps, the main financial supporters of the station, remain to be mentioned though only in general terms in this catalogue of acknowledgments. What these two have done in a monetary way is shown under other captions. The fact of fundamental importance to be brought out here is that whatever has been accomplished has been by earnest, thoughtful, sympathetic coöperation between those, on the one side, possessed of technical scientific knowledge and experience but no material resources; and on the other side, those possessed of large material resources but little of the technical knowledge and experience requisite for such an enterprise, the common meeting ground of the two parties being great faith in the efficacy of natural knowledge toward the highest good of mankind. By coöperation I do not mean that one party furnishes merely the money and the other party merely the technical experience. Such a conception is altogether too small for the sort of coöperation that is being practiced here. The truth is that one party furnishes the money primarily, and secondarily solicitude, sympathy and keen intelligence in the general development of the institution, while the other party furnishes technical knowledge and experience primarily, and secondarily thoughtfulness, care, and judgment in the business management.

Thus all along the line there is recognition both by givers and doers that in such an enterprise no one, however much material wealth or personal ability he may have, can accomplish anything alone. Success depends not only on individual but on communal efforts.

C. THE GENERAL IDEA—ITS INCEPTION AND DEVELOPMENT

The original ideas out of which the station grew though not lacking in positiveness were little differentiated. In 1891 when the scientific director took his place in the newly inaugurated subdepartment of biology in the University of California, the question of marine zoology at once presented itself. Imperfectly as had any of the fields of zoology of western America been cultivated, the least studied of all had been the teeming life of the great ocean on whose margin the University is located. This consideration was of itself a strong incentive to marine investigations. When in addition it was reflected that this field was not only practically virgin but was so set apart and unique in various ways as to warrant the expectation that it would yield richly in both new problems and new light on old problems, there was little hesitation in deciding that the chief effort in research should be in this domain. So it came about that most of the investigations carried on by the department of zoology from that day to this have pertained to the life of the Pacific Ocean.

Exactly what form the effort should take was not clearly indicated either from special familiarity with the most promising problems of marine biology nor from distinctly recognized expediency as to practicable undertakings. One thing was clear: no great headway, in a proper zoological sense, could be made without obtaining a far wider speaking acquaintance with the fauna of the region than any one had yet attained. A large amount of work in systematic zoology would have to be done at the outset.

The reasons that justified turning away from the great Bay of San Francisco, the very dooryard of the University, and finally choosing a location for the station six hundred miles distant, were partly recognized and partly not recognized. It is always instructive to look back upon any development and notice how, with whatever of deliberation it may have been carried

along, seen and unseen, even unforeseeable factors work together to produce the results actually reached.

The fact about San Francisco Bay that was recognized at once to be severely against it as headquarters for researches on marine biology was the absence from nearly all of its waters of the most characteristic oceanic animals and plants. This absence, which applies to the whole bay excepting the Golden Gate where the water runs with such fury at every change of the tide as to render working in it with small boats extremely difficult and hazardous, is due to the nearly land-locked nature of the bay and the discharge into it of the two large rivers, the Sacramento and the San Joaquin, with their heavy loads of sediment.

The circumstances that were destined to lead to greater and greater emphasis on problems essentially involving the life and physical conditions of the open ocean, which problems would in turn be so greatly favored by the conditions far to the south, were not at all clearly seen at the outset. Beyond the two early determinations that faunal studies must, at least at the beginning, play a large part in whatever might be our undertakings, and that a working place at some suitable point on the seashore proper would be essential, the main alternatives in policy and in method were but imperfectly seen. Assuming such a station assured, should its purpose be exclusively research, exclusively the formal instruction of elementary students, or a combination of the two? Should it aim at being a convenient work-place to which investigators from whatever source might go from time to time as individual needs might prompt, or should definitely correlated researches by the station as such, be aimed at? Should effort be confined to the shore life, or to the free-swimming and floating life, or should all, with no favors to any, be included in the programme? These and various other questions in the light of the meager experience to begin with could be but vaguely asked and more vaguely answered. Special local conditions and experiences gradually indicated the course which it seemed best to steer with reference to most of them.

Important as is the instruction of youth in biology, since provisions for this already existed in the two universities, in

the several colleges and normal and high schools of California, and for seaside work in the Timothy Hopkins Laboratory at Pacific Grove, it seemed that research ought to have the prior if not exclusive right, for it soon became apparent that with the facilities available or likely to be available any well carried out effort at elementary teaching must seriously interfere with research. Hence, after a few of the earlier summers, all thought of formal classes for beginners was put aside for the time being.

Two main considerations led gradually to the conviction that fairly definitely laid out investigations by the station, by teamwork as one might say, to be prosecuted by those naturalists more or less regularly and permanently connected with the enterprise, would be on the whole both more profitable and more practicable than an effort to develop a laboratory of general rendezvous for investigators of all sorts of interests and from all quarters. The two considerations were, first, the vast scope and possibilities in faunistic researches if only "faunistic" were to be taken in a broad sense, and the impossibility of doing much at such researches without coördinated and continuous effort. The second consideration lay in the remoteness of the Pacific Coast from the main centers of scientific activity of the world. The large cost in both time and money of reaching our shores would be prohibitive for the majority of investigators. The already established seaside laboratories of Europe and the Atlantic Coast of America, offering their splendid facilities, must for years to come be chiefly sought by students. The wisest course seemed to be to make a virtue of our disadvantages as far as possible: to concentrate our small energies and funds upon what it seemed might be done rather well by working in our own way, instead of dissipating them on what appeared highly probable we should not be able to do at all well.

So again by a process of natural selection and elimination the idea gained ground of a biological survey prosecuted as systematically, as continuously, as protractedly and as broadly, as facilities would permit. The natural and inevitable expansiveness of such an undertaking will be seen by any one who has even a meager acquaintance with the phenomena to be investigated and the methods that must be employed. The farther one

advances in experience and knowledge, the more does he become impressed with the vast scale on which things are done in the ocean and the literally infinite complexity of cause and law there in operation. Except for the gleams of light that early promise more light and the fascination there is in overcoming difficulties, one might welcome a pretext for turning back, once he has gone far enough in such an enterprise to see what is actually on his hands. Mere enthusiasm is too evanescent, and initial personal ambition has too many alternatives to hold one steady on such a course.

D. HISTORICAL SKETCH

I. PACIFIC GROVE, 1892

In the spring of 1892 a structure 16 x 24 feet, partly of wood and partly of canvas, and constructed with a view to being taken to pieces and moved about, was built for use as a seaside laboratory at Pacific Grove. The requisite funds, about \$200, were provided by the University, the department of zoology being permitted to expend the amount from its annual budget. This itinerant laboratory was set up for the summer vacation, the site selected being a small cove near the since departed Chinatown. The little apparatus provided, microscopes, glassware, etc., were borrowed from the University. All the water used, salt and fresh, was carried to the laboratory in buckets by hand.

The laboratory party consisted of about a dozen persons, mostly students and teachers but partly recreation seekers.

The first building of the Timothy Hopkins Laboratory belonging to Leland Stanford Junior University was erected and occupied for the first time during the same summer, and alongside that ample, well appointed laboratory our little tent-house made a sorry spectacle. Nothing on record shows any notable discoveries made that year, though a not inconsiderable amount of general collecting was done, both of information and specimens.

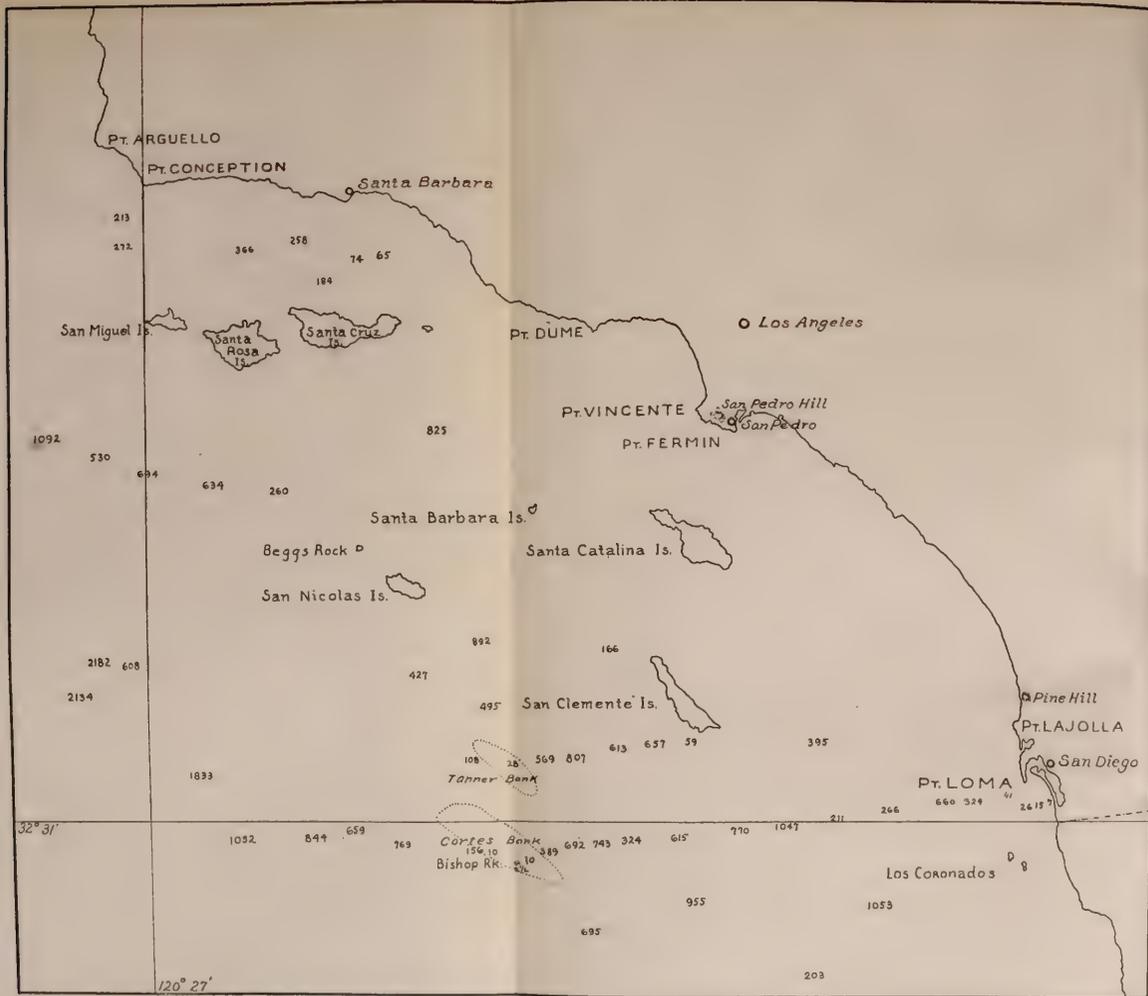
II. SANTA CATALINA ISLAND, 1893

A summer's work at Pacific Grove, supplemented by numerous collecting and observation trips to various points on the coast both south and north of the Golden Gate, having given us a glimpse of biological conditions on this portion of the seashore, a desire to see more of the southern coast was aroused. Accordingly for the summer of 1893 the piecemeal laboratory found itself re-erected on the shore of Avalon Bay, Santa Catalina Island. The biologically inclined portion of the company consisted chiefly of undergraduate students from the University, and general familiarity with sea-animals and the conditions

under which they live rather than rigorous special researches was the scientific fruitage of the summer's undertaking.

From the experiences of this year two important advances were made toward a decision as to what portion of the coast would be best for the location of a permanent laboratory: That San Francisco Bay and the outside places immediately adjacent to it which had been considered as possibilities would better be abandoned; and that some point in southern California south of Santa Barbara, probably San Pedro as it then appeared, presented on the whole more natural attractions to the student of marine organisms than any other portion of the California coast. The counsel of Professor E. B. Wilson of Columbia University, who had been asked by the University of California to come to the Pacific Coast in the interest of the marine work, was greatly influential toward these conclusions. Concerning the natural factors that entered into the final determination of the site problem I speak more in detail a little later.

It is pleasant to recall the lively interest taken by several persons besides those participating in the work itself during these first years. President Martin Kellogg was sympathetic and ready to extend such help from the University, financial and other, as conditions would permit. Professor Joseph LeConte, under whose official headship matters zoological in the University then rested, was ever enthusiastically desirous of seeing a seaside laboratory strongly and permanently established, and to this end never failed to use his influence when occasion offered. Perhaps the most earnest, aggressive worker in the cause outside of those professionally entangled was Mr. Arthur Rodgers, an alumnus of the University and for many years one of its most devoted and efficient Regents. Nor would it do to leave unmentioned the great interest taken by Mr. Adolph Sutro of San Francisco in the establishment of a marine laboratory and aquarium in connection with his extensive developments at the famous Sutro Heights just outside the Golden Gate. Being a man of uncommon intelligence and breadth of interests, though in no sense a biologist, he was keenly alive to the scientific significance of researches in marine biology and to the possibilities of a marine aquarium as a source of public enlightenment and



MAP 1.—Showing the Area to be surveyed. Modified from United States Coast and Geodetic Survey Chart.

Compare with plate 24, figure 10.

recreation. But for financial difficulties that came on with the widespread business collapse of 1893, and the conclusion to which we on the scientific side were driven that an effective biological station at any point near the Golden Gate would be impracticable, it is highly probable that Mr. Sutro would have become a liberal patron of marine biology and oceanic exploration.

III. EXPEDITIONS, 1894-1900

Owing partly to the fact that the person who had thus far been responsible for directing the seaside work was absent in Europe during the summers of 1894 and 1895, the knock-down laboratory was not erected in those years. A significant collecting and reconnoitering expedition on the coast north of San Francisco was, however, made in 1894. The party constituting the expedition were Mr. S. J. Holmes, a recent graduate from the University and an assistant in zoology; Mr. Frank Baneroft and Mr. E. W. Horn, advanced undergraduate students.

Following up the intimations received by the glance at San Pedro Bay and vicinity while en route to Avalon in 1893, that this was an especially favorable spot for a marine laboratory, a party from the University spent several weeks there during the summer of 1895. Dr. H. P. Johnson was in charge. A cottage and a tent on Timm's Point in San Pedro Bay constituted the laboratory-dormitory facilities. This season's experience was of special significance in that it greatly strengthened the belief in the natural advantages of this region for a marine station.

Between 1896 and 1901 no organized parties were formed for marine work nor was a seaside laboratory maintained. However, numerous collecting excursions were made from time to time by various members of the department to many points on the coast, ranging from San Diego at the south to the Shumagin Islands, Alaska, at the north. The observations by the writer while a member of the Harriman Alaska Expedition in the summer of 1899 were of special service toward a general clarification of views regarding points on the Pacific Coast of North America favorable for the location of marine stations concerned with the various aspects of biology and oceanography.

The outcome of these rather extensive castings-about was a firm conviction shared by all who had participated in reconnoitering that San Pedro Bay would be by nature a particularly favorable *locus standi* for almost any sort of marine biological activity. So the ground was prepared for a determined effort to create a permanent, well supported seaside station, presumably to be located at San Pedro. This effort took definite shape in the summer of 1901.

Among the circumstances that contributed largely to the resolution for a more definite and permanent attempt to establish such a station, two only need be mentioned: Dr. C. A. Kofoid, who had come into the department of zoology of the University in 1900, had had much experience in marine and aquatic biology and so was an important addition to the working force available for such studies on the sea and its life as had been occupying us. The other circumstance was the coming to scientific manhood of two university students who had chosen to cast in their lots as biological investigators. These men were Dr. F. W. Bancroft and Dr. H. B. Torrey. The strength of these three enthusiastic biologists, added to that previously available, made a total working force that promised much, not only for the main aim, scientific achievement, but also in assurance that with the united effort of such varied interest the securing of needed funds and facilities would be possible.

IV. SAN PEDRO, 1901-02.

The form which the ideas of marine biological research and a marine station had taken by this time has been stated in various published utterances by the present writer and his co-workers during the last decade; nevertheless these ideas are not sufficiently familiar either to professional biologists or to the general public to make their restatement superfluous.

The report made to the President of the University of the efforts put forth during the summer of 1901 (Ritter, 1902a, p. 55) contains these words: "In view of the importance of the field and the meagerness of previous investigations in it, it seemed best to plan the summer's work as though it were to be the beginning of a detailed biological survey of the coast of

California, even though no assurance could be had of being able to continue the work beyond this season." Another publication of about the same date (Ritter, 1902e) has this: "Researches in the life of the sea have been prosecuted widely and with great energy in recent years. We have learned much, very much from them. Perhaps the most important thing we have learned is what to do next. Now it is exactly the thing that should be done next that we here in California are, by the grace of a beneficent Providence, specially commissioned to do. Detailed, comprehensive, continuous and long-continued *observation* and *experiment*—these are the two golden keys that will let us farthest into the mighty arcana of the life of the sea. . . . Who that is accustomed to the sea can fail to recognize that an ocean like that off southern California, where icy tempests never rage and where torrid heat never enervates, must be exactly the sort of ocean where observations and experiments of the kind specified could be best carried on? . . . The future marine station, particularly the California station, must be planned for physical, chemical, and hydrographic, as well as for strictly biological research. . . . The work must go on every hour of the day, and every day of the year."

There being no funds available for putting these large conceptions into execution, and no prospect of securing such beyond the limited amounts that might possibly be contributed by the University and a few well-to-do friends of science and of the University, only the smallest and crudest beginnings could be made. But even a beginning would be something, and confidence in the soundness and ultimate workableness of an idea gives a sort of magnitude and robustness to what is initially small and weak. After having gathered together such sums as we could we went at the undertaking buoyantly, saying: "For the rest, like Elijah of old, we 'stand before the Lord' hungry but full of trust, and therefore expecting the ravens laden with bread and meat to appear at any moment" (Ritter, 1902c).

A grand total of about \$2000 was guaranteed partly by the University, but chiefly by individuals in Los Angeles, for the summer's work in 1901. It was decided to begin work at sea as well as to continue the collection and study of shore life carried

on more or less interruptedly in previous years. In view of the meagerness of funds the plan was to limit operations on the biological side to dredging and trawling in depths not exceeding one hundred fathoms. On the hydrographic side no more than temperature and density determinations were attempted. The idea of making the investigations "continuous and long continued" was strongly entrenched in all our minds. It seemed that the particular locations at which collections and observations were made should be carefully determined and recorded. Persons competent by reason of training, knowledge and sympathy to look after the several scientific interests would be basal to success in such an undertaking. On the biological side there was the regular staff of the department of zoology and two graduate students, Miss Alice Robertson and Mr. C. O. Esterly, who while then at the beginning of their careers in biology have remained identified in one capacity and another with the station, and have contributed in no small way to its scientific accomplishments. Professor W. J. Raymond, of the department of physics, had charge of the hydrographic work and made himself doubly useful from his interest in and extensive knowledge of the conchiferous mollusca of the Pacific Coast.

For a laboratory building a little old bath-house on the sand spit separating San Pedro Bay from the sea was rented and reconstructed. An open gasoline launch, the "Elsie," forty feet long, with an engine of 15-horsepower, was hired for the work at sea. A hand-winch at which four men could work simultaneously was provided for hauling the dredge and trawl. A sounding machine and an apparatus for taking sub-surface samples of water were improvised, the funds not permitting the purchase of even the least expensive regularly manufactured articles. Two months' work, from May 15 to August 15, were done. The boat "Elsie" was very active during the whole period. A total of 85 stations were occupied, to many of these numerous visits being made. The chief localities explored were off San Pedro, around Catalina Island, and at San Diego. Although research was avowedly the primary aim, it was determined to offer a few courses of formal instruction for elementary students. Two considerations dictated this. One, the more weighty it must

be confessed, was the hope that the small fee charged would yield enough to meet the traveling expenses of the University instructors, whose meager regular salaries would have to be supplemented in some way to make it possible for them to participate in the work. The other consideration was the genuine belief that the advantages of so favorable a natural opportunity for instruction ought to be used. The plan was to conduct the school as a part of the summer session of the University, the term of which was six weeks. The teachers were to be paid on the same basis as the University of California men teaching in the summer school at Berkeley. A total of thirteen persons paid the fees, and this number was quite the limit for which there were laboratory accommodations.

Owing to the failure to get even as large a fund for the work during the summer of 1902, exploration at sea was not resumed the second year. The laboratory was operated on the same basis as the preceding year, instruction again being conducted as a part of the regular summer session of the University. Except for the absence of Professor Raymond the investigating personnel of the laboratory was essentially the same as in 1901. Perhaps the most significant effort made during the summer of 1902 was to place the station on a larger, more secure financial basis. Past experience, particularly of the last year, had removed any lingering doubt of the natural attractiveness of the San Pedro region for seaside work. Through the encouragement and active assistance of several prominent citizens of Los Angeles, a plan was devised for securing \$20,000 with which to erect and equip a permanent laboratory building and secure a boat adequate for at least as extensive explorations at sea as had been carried on by the "Elsie." The Los Angeles gentlemen most actively interested and who had contributed considerable sums to the work already done were Mr. J. A. Graves, Mr. H. W. O'Melveny, Mr. Jacob Baruch, and Mr. J. H. Shankland. The plan was to secure the amount, or as near it as possible, among the foremost business men and firms in the city, in sums of \$500, the canvass to be made by a committee of business men each working among his own business acquaintances and associates. The subscriptions were made contingent on nearly the whole

being raised. Considerable time was devoted to the effort during the summer, not only by some of the gentlemen of the committee but by the writer of this report. The attempt was unsuccessful, the subscriptions having reached only about one-third of the required amount. This experience furnished to the friends of the enterprise a lesson not to be ignored as to the extreme difficulty of raising a considerable sum of money for such a purpose by such a method.

Much attention was given to the question of where, in or near San Pedro harbor, a permanent laboratory should and could be located. The outcome of this was a disquieting recognition of the rapidly growing commercial importance of the harbor and of the probability that a large urban population would be gathered around the little bay in a few years. This realization was disquieting not from any hostility to commercial development, but from a prevision of the inevitable destruction of some of the best collecting grounds in and about the harbor; and of the contamination of the sea-water by sewage and other incidents of industrial activity. These considerations were weighty in determining the next move.

V. CORONADO, 1903-04

As already indicated, the "Elsie" had made a run to San Diego during the summer of 1901 and had done considerable work there. The trip was planned largely with a view to obtaining information concerning the general conditions of that locality from the standpoint of marine research. Report from trustworthy sources, strengthened by cursory observation by the writer in the summer of 1891, was to the effect that San Diego Bay and vicinity presented many natural advantages for such an enterprise as we were occupied with. To leave this region unvisited would be contrary to the original idea of making a reconnaissance of the California coast before settling anywhere permanently. Professor Kofoid, who had charge of the 1901 expedition to San Diego, returned to San Pedro enthusiastic over the biological merits of that more southern locality. Besides he had been interviewed by a citizen, Dr. Fred Baker, who insisted that the San Diego region was probably the proper place against all

others on the California coast for a laboratory. Correspondence was entered into with Dr. Baker, resulting in arrangements whereby a sufficient sum was guaranteed by San Diego citizens to insure the resumption of explorations at sea, not only for the summer of 1903 but for the Christmas holidays following. In addition a laboratory more commodious and well appointed than the one occupied at San Pedro was provided. With the enthusiastic and efficient assistance of Dr. Baker, who from his profession and his interest in conchology was something of a biologist, the removal of the equipment from San Pedro to San Diego was made, laboratory quarters fitted up in the boat-house of the Coronado Hotel Company at Coronado, a small schooner, the "Laura," was rented and outfitted with the meager apparatus in our possession, put in charge of an intelligent Portuguese fisherman, Manuel Cabral, and set to work for six weeks during June and July.

During the first summer at Coronado the business affairs of the laboratory were handled by the Chamber of Commerce of San Diego. This was, however, regarded as an arrangement for immediate exigencies only. Something more specific and workable would have to be devised without delay. Only two courses seemed open. One was to continue to treat the enterprise as part of the department of zoology of the University of California and transact the business through the office of the Board of Regents of the University. The other was to form a local organization of some sort. The difficulties in the way of the first course, arising from the remoteness of San Diego from Berkeley, were sufficiently manifest from past experience. A local organization was really the only alternative. Accordingly the Marine Biological Association of San Diego was created in the fall of 1903 and duly incorporated under the laws of the state soon thereafter. The association consists of a general membership with a board of directors elected annually. The articles of incorporation contain the provision that the station should later be transferred to the Regents of the University of California at the option of the association. (See Appendix A.) The first officers of the association were Mr. H. H. Peters, president; Dr. Fred Baker, vice-president; Mr. H. P. Wood, secretary;

Mr. Julius Wangenheim, treasurer; Professor William E. Ritter, scientific director; and Miss E. B. Scripps and Mr. E. W. Scripps, members of the board of directors. With the exception of the first president and secretary, who soon moved from San Diego, the personnel of the board of directors has remained the same, with Mr. F. W. Kelsey and Mr. W. C. Crandall as secretaries, and Mr. H. L. Titus as vice-president and counsel, Dr. Baker having been president since the second year.

The experiences of 1901 had shown that with such a limited boat equipment bottom and plankton work could not be well combined, and that on the whole collections of the swimming and floating organisms could be made more efficiently and no less profitably from the scientific standpoint. But since the entire realm was practically virgin and it was important that the little we could do should be made to produce as much as possible, it seemed best that plankton studies should mainly occupy us for the time being. It was soon seen, though in a rather shadowy way, how absorbing and indefinitely expansive the problems of this side of marine biology would become. Two summer and two winter periods of telling work were done from Coronado as the base of operations.

The importance of extending the work, particularly the collecting over a larger portion of the year, was coming to be more and more clearly seen. This desideratum was partially met in 1904 by arranging with Mr. Cabral, the fisherman-collector, to run his own fishing-boat, the "St. Joseph," three days a week during the entire summer period and at intervals during the remainder of the year; and by creating the position of Resident Naturalist, i. e., a post at the laboratory to be continuously held by a trained biologist. The first incumbent of the position was Mr. B. M. Davis, who was willing to accept it on the small salary that could be paid with the consideration that half his time might be devoted to his own studies. Mr. Davis was the naturalist for one year only, his incumbency terminating with regret on both sides from his having been called to a position of greater responsibility and compensation.

No formal courses of instruction were offered after the San Pedro period. This aspect of the enterprise was abandoned, not

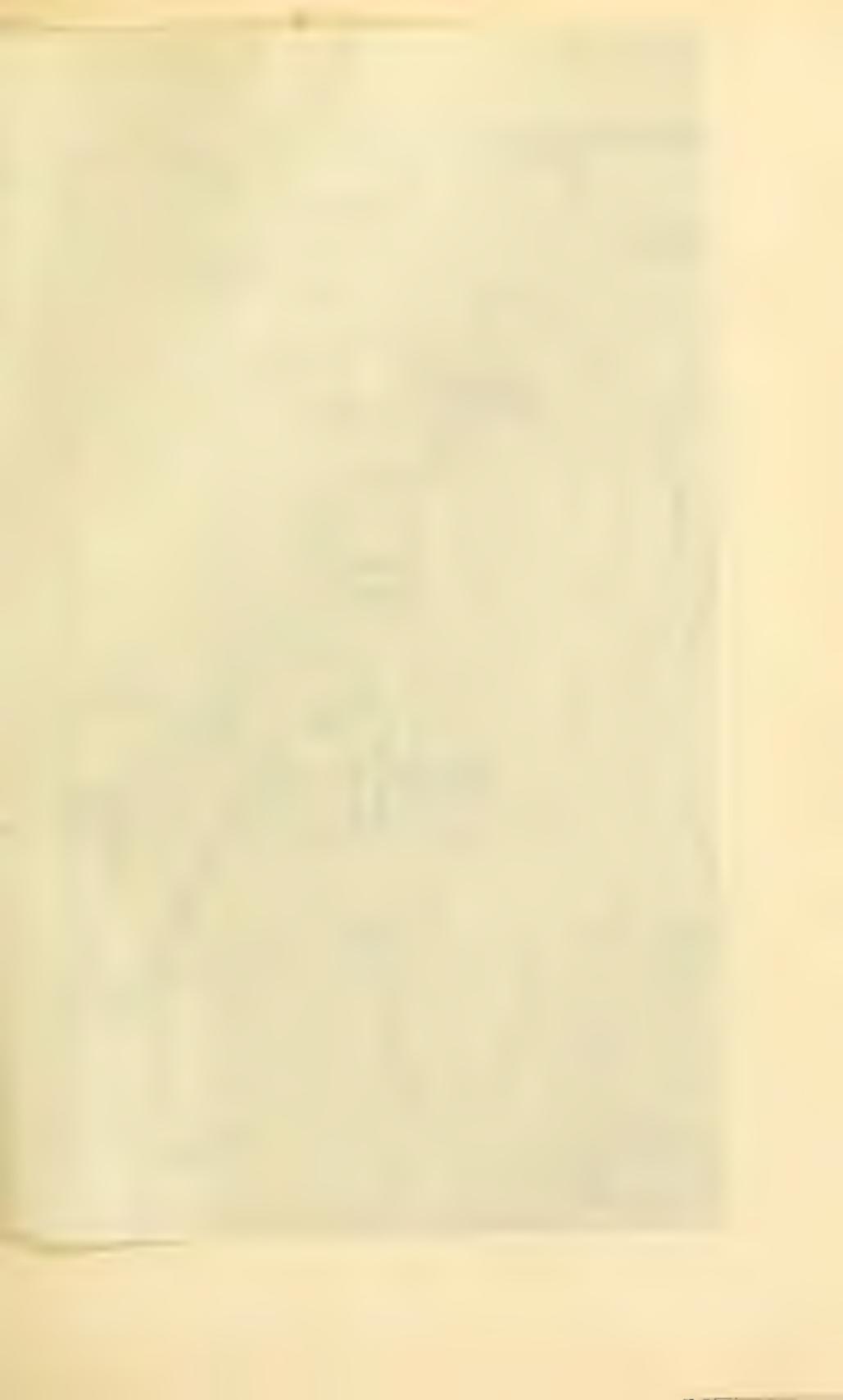
without regret, partly because of the growing absorption of the instructors in their investigations; partly because of relief from the necessity of depending on students' fees for paying the expenses of the investigators; and partly from the conviction that, all things considered, instruction was of less moment than investigation.

On the side of material support a matter of utmost importance in connection with the removal to San Diego was the keen, intelligent, and financially liberal interest taken in the station from the outset by Miss Ellen B. Scripps and Mr. E. W. Scripps. Although a considerable number of citizens of San Diego contributed well during the first two years, these two persons were the chief givers and soon became the exclusive patrons so far as money gifts were concerned.

In planning the laboratory at Coronado some of the serious difficulties that had been encountered at San Pedro soon came in sight. The location on the bay side of the long narrow sandspit that separates San Diego from the ocean was admirable in many ways. Boats could be landed and kept with great ease and safety; water for laboratory use could be dipped up and carried into the building so readily as to make a pump almost superfluous; and various species of marine organisms could be collected fresh, vigorous, and in quantity at our very door. But the water of the bay and so the organisms inhabiting it were very different from the water and the organisms of the open ocean; and the safe and easy landing was a good two hours' run with a motor-boat from the ocean. The more the problems of the biology of the ocean proper grew in clearness of definition and in interest, the more serious were seen to be the disadvantages of such a location. Consequently early in the Coronado period the idea of abandoning the attempt to find a satisfactory inside location and of turning to some point on the open coast where oceanic conditions prevail as near shore as possible began to be considered.

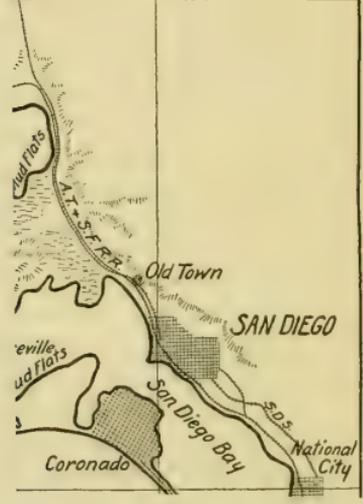
VI. LA JOLLA (VILLAGE), 1905-09

After studying the coast as carefully as possible, La Jolla, a suburb of San Diego situated on a point fifteen miles to the north, was selected as on the whole the most advantageous place.



117°10'

ine Hill
rey Pines
in Diego - Los Angeles Boulevard
Sea Cliffs
Land and
Buildings
of the M.B.A.S.D.
rad Hill

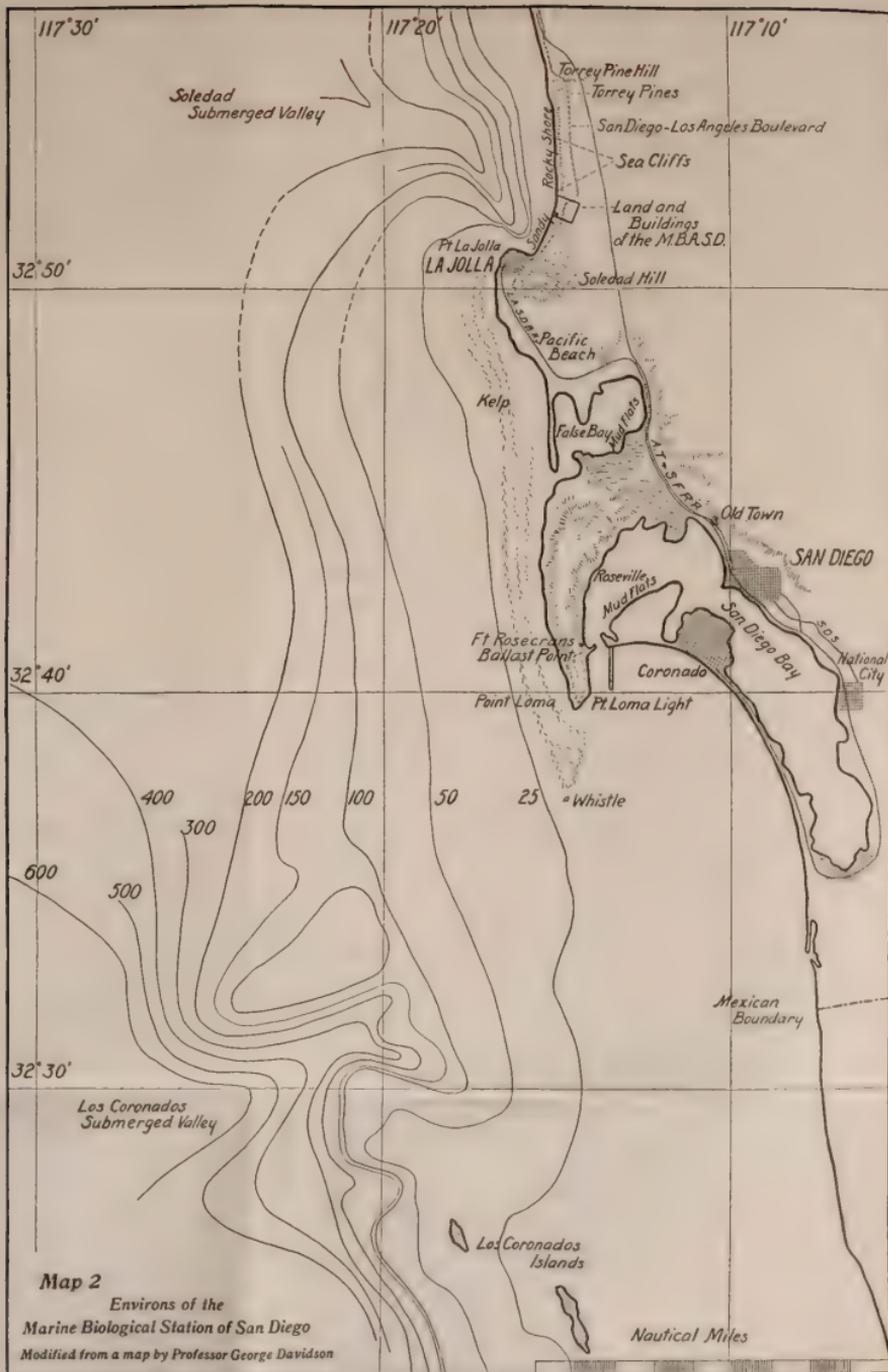


The question may be asked, Would it not have been possible to secure a site within the bay at some point near the entrance, so that the protection afforded by such a location could be had in combination with the requisite of good ocean water and ease of access to the open sea? As a matter of fact a site at Roseville or elsewhere on the lower bay was much talked about, and was favored by some members of the board of directors of the association. As a partial exhibit of the way the decision was reached, I appended a tabulation of advantages and disadvantages of the main claimants that was drawn up during the summer of 1904 (see Appendix E).

So it came about that preparations for the summer's work of 1905 were begun by transplanting the station from Coronado to the place in most ways unsurpassed in natural charm by any on the California coast. Here the station was first housed within walls of its own construction and possession. Under the leadership of Dr. Baker a local committee of La Jolla citizens raised by subscription the \$1000 necessary for erecting the laboratory building. Permission was gained from the City Council of San Diego to locate the laboratory on a piece of ground on the water front that had been given to the city for park purposes. The building was ready for occupancy on the arrival of the University party on June 19, 1905. Though the structure was small and simple, it was far superior to any residence the station had before occupied. For the first time the luxury of an abundance of running water, fresh and salt, was enjoyed.

The building was 60 feet long by 24 feet wide. It contained three laboratory rooms of equal size, 12 by 20 feet, on the north side; on the south side a small library room, a still smaller reagent room and a public aquarium-museum 45 feet long and 12 feet wide. In this room aquaria containing as ample a representation of the local marine fauna as our limited facilities could procure and accommodate were kept open to the public; also a fair exhibit of preserved specimens. A collection of mounted specimens of the local sea-weeds, the gift of Mrs. Snyder, a resident of La Jolla, was likewise for use by the public.

The scientific staff during the summer sessions averaged fifteen persons on the payroll and from four to six visiting inves-



tigators. A few of these visitors remained several months at a time. The winter sessions were irregular and brief with a much smaller attendance, as the University vacation was too short to permit many to make the trip to La Jolla. Each summer a series of free lectures on scientific subjects more or less popularized was given. For these not only our own staff but the visiting scientists were pressed into service.

This cheaply constructed laboratory was built in full confidence that it would have to serve only a few years before it would be replaced by a permanent, commodious one. The question consequently of a piece of land that should be the final resting place of the station after its long wanderings was taken up soon after the removal to La Jolla. For a time the little park already occupied seemed to be the most desirable. It was soon found, however, that while the city council was quite ready to grant the association certain privileges, it had no power to do so under the existing laws regarding park lands. This difficulty was overcome by securing from the state legislature an act enabling the city to grant the association the rights sought. By the time these were obtained questions had arisen as to the satisfactoriness of the location. Would there be room for such expansion as the institution might some time undergo? Would complications grow out of the relations between the station, whose primary purpose was scientific research, and the park, whose primary purpose was to serve as a recreation place for the public? Would the purity of the sea-water be more or less interfered with after a while by the sewage and other refuse of the growing population? Events and reflections made these questions more and more pressing as time went on, and the feeling grew that a more commodious, more unhampered site ought to be found if possible.

VII. THE FINAL LOCATION

To Mr. E. W. Scripps belongs the credit of proposing what at first flush seemed an extravagant if not an altogether impracticable solution of the problem. The city of San Diego is a large landowner, its possessions being a heritage from the Mexican regime before California became a part of the United States.

The land is situated in the extreme northern portion of the city, several of the 'pueblos' fronting on the ocean. The southernmost of these water-front pueblos is about two miles from the northern confines of the village of La Jolla and another quarter of a mile from the nearest railroad service. Mr. Scripps' plan was to secure this pueblo "No. 1289," consisting of nearly one hundred and seventy acres, as a site for the station. The tract has an ocean front of approximately one-half mile, of which about one-third is available for any buildings, piers, breakwaters and so forth, that the station might need. The remainder of the frontage being a sheer cliff of from fifty to two hundred feet could not be used as a site for station buildings proper, but a considerable area of rocky shore at the foot, including a fine trap-dyke reef, would be a valuable asset as a collecting ground and as a source of rock for building purposes.

In spite of the obvious difficulties that would attach to such a situation because of distance from sources of supply of both domestic and laboratory materials, after much deliberation it was resolved to take the step, provided the land could be secured. The city authorities were found to be well disposed toward the station, as indeed they had been at all times when occasion had arisen to seek aid from them. Willingness was expressed to give the tract to the association could this be done under the law. Since no way of alienating the land was allowed by the city charter other than by selling it at public auction to the highest bidder, such an auction was arranged for by the city council, the understanding being that a bid by the Biological Association at a nominal figure would be acceptable to the city. This course could be legitimately taken because of the right of the municipality to reject all bids. The project having been well discussed before the city council, in the newspapers, and with the dealers in real estate, very generously no bidders other than the association appeared at the auction. Thus this fine tract of land came into possession of the association nominally for \$1000, but with the understanding that Miss Scripps would expend \$10,000 in building a public roadway through this land and other lands belonging to the city. The deed of trust is without restriction, the city officials placing full confidence in the association for the

performance of its duties as a trustee of public property. The transaction was closed in August, 1907.

The tract was made accessible during the same summer by the construction of the boulevard which was a part of what later became the main highway between San Diego and Los Angeles. This piece of road, built by Mr. E. W. Scripps mostly at the expense of Miss E. B. Scripps, as above mentioned, was of far greater significance to the station than the mere furnishing of an easy access from the village of La Jolla. Opening up as it did the whole ocean-side area between La Jolla at the south and Del Mar at the north, and passing through the unique and much favored Torrey Pine Grove, it has been a great factor in bringing to public attention the beauty of the region and the natural productiveness and utilizability of the lands. Furthermore, the ascent from sea level to the three hundred-foot elevation of the mesa being through the station's tract, the necessary tortuousness of the road causes it to reach a large portion of the land.

Thus was settled the long and earnestly considered question of just where on the face of the earth the final home of this biological enterprise should be. But the home itself was still far from an accomplished fact, though a long, sure step toward it had been taken some time before when Miss Scripps had notified the board of directors during the fall of 1905 of her decision to place \$50,000 at its disposal, chiefly for building purposes, but also for whatever use the best interests of the station might demand. The main building was to be a memorial to a deceased brother, George H. Scripps. Soon after the settlement of the site question, planning for the first permanent building was turned to afresh.

The difficulties in the way of actually looking after the affairs of the station, incident to the fact that none of the scientific staff upon whom fell the chief responsibility could be at La Jolla more than a few weeks or at best months at a time each year, were becoming more and more apparent to all, but to none more than to Miss Scripps and Mr. Scripps. Nothing had so strongly emphasized the need of the constant presence at the scene of operations of a responsible scientific head as the preparations for

building. To meet the needs Miss Scripps decided early in 1909 to so endow the station that its affairs could have most of if not the whole time and energy of the scientific director. Accordingly Dr. Ritter took up his residence at La Jolla on June 1, 1909, the arrangement between the Biological Association and the University being that he return to Berkeley each year to give one or more brief, concentrated courses of instruction, the station paying two-thirds and the University one-third of his salary.

A supply of fresh water being an indispensable prerequisite to development of any kind on the new possessions, the city was again appealed to and readily undertook to lay a four-inch pipe from La Jolla to the building site. Construction of the first building began in the early summer of 1909 and was so far completed during the next twelve months that soon after the director's return in June, 1910, from his first year's engagement at the University under the new regime, it could be occupied. As a makeshift settlement of the domestic problem involved in the remoteness of the laboratory from the village, it was decided that the director's family should domicile itself for the present on the second floor of the laboratory building, the first floor furnishing ample space for the scientific work then being done, and the director's wife being equal to the task of transforming the laboratory rooms into quarters not only possible but comfortable for human habitation. So far as the transportation problem was settled, it was settled by an automobile for the director, bicycles for those of the staff who must still live in the village, and two good feet for every one who upon occasion should by choice revert to nature's first solution of the problem of locomotion for man.

VIII. WORK AT SEA

For the sake of consecutiveness in narration nothing has been said about the portion of the station that lives at sea since note was made of the earlier provision for this at the beginning of the San Diego period. During the summer of 1904 Mr. E. W. Scripps had placed his pleasure yacht "Loma" at the service of the station, and in the fall of the same year he gave the vessel

to the association, accompanying his gift with another of \$1500 toward fitting her with a propelling engine and scientific gear. She was taken to San Francisco, refitted and returned to San Diego in time for the summer's work of 1905. This was the largest, most efficient boat that had thus far been in the service, and the first one owned by the station.

The "Loma" was originally built for a pilot boat and therefore was sturdy and suited to dredging and trawling as well as being seaworthy for considerable distances from shore. Our area for work being outlined roughly by Point Conception on the north and the Santa Catalina, San Clemente, and Coronado islands on the west, stations for repeated observations were established at many points within this area. A more detailed account of these and how the work at sea is carried on will be given in another place. The "Loma" was wrecked near the lighthouse on Point Loma in July, 1906, while attempting to make the run from La Jolla to San Diego Bay between the shore and the kelp beds that skirt the coast. The mishap being due to striking a shore rock and not to a storm, the boat was completely dismantled and nearly everything saved.

The gift of \$50,000 by Miss Scripps being available for equipment at sea as well as on land, planning for a new boat was begun soon after the loss of the "Loma." Although construction of the new craft was commenced in what was supposed to be ample time to assure her readiness for the summer's work of 1907, delays in securing material put off the launching until August 16. Resort was had, consequently, to Captain Cabral and his fishing boat, the "St. Joseph," for sea work that year. The description of the new boat, the "Alexander Agassiz," is furnished by her present master, Captain W. C. Crandall.

E. FUNDS AND GENERAL RESOURCES

It is not proposed to deal with the finances after the manner of a treasurer's report. Rather the aim is to give an outline of the station's business career in such fashion as to make this tell as much as possible about the progress and policies of the enterprise. Likewise as to general resources, in some cases only estimated values are given and in a few none at all, even though it seems desirable that the articles themselves should be mentioned. It is particularly difficult to treat the library on a strictly financial basis.

The headings under which a presentation having such an end in view may best be made are: (1) Sources from which funds and appliances have come; (2) The main items of expenditure; (3) The present valuation of the station's holdings; (4) The present income.

1. Sources and amounts:

(a) University of California—		
Money for general expenses, 1892-1901	\$2,000	
Publication, 1902 to date	8,000	
		\$10,000
(b) San Pedro period, 1901-02—		
Citizens of Los Angeles	\$1,570	
Students' fees	350	
Mrs. Phoebe A. Hearst	500	
		2,420
(c) Coronado and early La Jolla period, 1903-06—		
Citizens of San Diego and La Jolla (exclusive of Mr. E. W. Scripps and Miss E. B. Scripps)	\$1,750	
		1,750
(d) E. W. Scripps—		
Cash, 1903 to 1911	\$13,000	
Yacht "Loma" (estimated)	2,000	
		15,000
(e) Miss Ellen Browning Scripps, cash, from 1903 to 1911		67,000
(f) Mr. Alexander Agassiz, nets and apparatus, 1905		1,000
Total		\$97,570

(g) Gifts to Library—

United States Government about 300 volumes from National Museum and Smithsonian Institution, Department of Agriculture, Treasury Department, Department of Commerce and Labor.	
American Association for the Advancement of Science, 60 volumes	\$90
Alexander Agassiz, Memoirs of Museum of Comparative Zoology, 15 volumes	150
William E. Ritter, scientific journals, 104 volumes	400
University of California, set of Challenger Expedition Reports, 45 volumes (indefinite loan)	550
Walter Lieber, Encyclopedia Britannica, 9th edition, 28 volumes	90
Total	\$1,190

2. Main items of expenditure:

(a) Professional service	\$22,000
(b) Boats, building and repairs	21,300
(c) Boat labor, crew and scientists	6,000
(d) Expense of running boat	3,500
(e) Buildings	25,000
(f) Publication	8,000
(g) Land	1,000
(h) Scientific apparatus (laboratory and boat)	2,500
(i) Non-professional labor	1,600
(j) General expense	2,600
(k) Library (journals, binding and purchases)	1,100
	\$95,000

3. Present valuation of properties:

(a) Land (estimated)	\$100,000
(b) Buildings	24,000
(c) Boat, "Alexander Agassiz"	10,000
(d) Scientific apparatus	2,500
(e) Library	3,000
	\$139,500

4. Present income:

Miss E. B. Scripps, 6 per cent interest on \$150,000 legacy	\$9,000
E. W. Scripps, annual contribution	1,500
	\$10,500

F. THE STATION AS IT IS TO-DAY

I. LAND

The considerations that most influenced the board of directors to endure the present disadvantages of isolation of the new location were the certainty for all time of ocean water uncontaminated by human habitations, and the ample elbow-room assured whatever developments might take place. Not much less weighty with some of the board was the belief that at no distant future time the land not actually used by the station would become a rich income-producing endowment. This belief would appear chimerical to a sober-minded person who should contemplate it without taking into account the nature and extent of the demand, as evidenced by events of the last decade and a half, for seaside lands on the coast of southern California. The recent rapid increase in population and wealth that has taken place at various points along the coast, particularly in the vicinity of Los Angeles, can be interpreted in no other way than by assuming that the climatic and other natural conditions of the region are as positively a material and business asset as the prairies of the upper Mississippi Valley and the Great Lakes are an asset of Chicago, and as New York Bay and the Hudson River are an asset of New York City. Once this is seen, it becomes clear that the country tributary to this region in a business sense, that is, available for natural exploitation, is nearly the whole United States. The general fact of the demand for homes in this region because of climatic conditions, taken along with the special ones that the station's property is certainly not surpassed in natural attractiveness by any on the whole coast, and that the developments of the San Diego region are assuring ready accessibility and the many other advantages that appertain to a large concentrated population, constitute the chief basis of the belief.

Looking at the situation in the broadest way, taking account of physical, industrial, social, and intellectual tendencies and possibilities, as well as of the scientific purposes of the station,

it may be confidently held that every dollar put into the upbuilding of the institution as an instrument for scientific research and general enlightenment may be made to count also as investment for enlarging the income applicable to the scientific work.

II. BUILDINGS

The first permanent building, known as the George H. Scripps Memorial Building (pl. 18, fig. 1), situated sixty feet from the edge of a fifteen-foot sea-cliff, is a plain rectangular two-story structure of reinforced concrete, 26 feet high, 75 feet long and 50 feet wide. Its long axis is perpendicular to the water front and runs east and west. The flat, parapeted roof carries two large iron-framed skylights, one over the corridor, the other over the museum and lecture room. The only other buildings so far erected are a tank-house located about twenty-five feet north of the northwest corner of the laboratory, and a small frame building (20 by 30 feet) which serves in part as a store-room for miscellaneous bulky material, and in part for housing an automobile.

On the ground floor of the laboratory is a corridor 12 feet wide running from the east to the west entrance. Along the north side of this corridor are six rooms (12 by 17 feet each) for investigators. These rooms occupy the entire length of the building. South of the corridor is an aquarium room (17 by 37 feet) occupying the southwest corner; a dark-room (8 by 8 feet) which opens from the east end of the aquarium room; a shop (12 by 8 feet) also opening from the east end of the aquarium room as well as from the corridor and men's toilet; a store-room for reagents and glassware (15 by 16 feet); the janitor's room (9 by 10 feet) occupying the southeast corner, and between this and the east entrance a lavatory for women. Ten feet west of the east entrance concrete stairs ascend from the lower corridor to the second floor leading directly into another corridor (12 by 37 feet), along the north side of which are three investigators' rooms exactly similar to those of the ground floor. At the west end of this corridor is a museum and lecture room (32 by 37 feet), along the north side of which are three more investigators' rooms. South of the corridor and occupying the southeast corner

of the building is the library (17 by 25 feet); while adjacent to it and opening from the corridor at the head of the stairs is an apparatus and glassware room (12 by 17 feet).

The furniture of the investigators' rooms is simple. It includes a U-shaped table running across the north and half way down the east and west walls, two and a half feet wide and provided in the middle with a chest of five drawers, and with one drawer on each wing. On the east and west walls are a set of book shelves, a large specimen case, a cloak locker, and a "wood stone" table 2 feet 2 inches by 6 feet 3 inches adjacent to a sink, and a two-story aquarium on the south side. These rooms, in common with the rest of the building, are supplied with gas, fresh water, and electric lights. At present they are heated with stoves, although provision is made for gas grates. While thus simply equipped these rooms were planned to yield the greatest convenience and satisfaction as scientific workshops. The common difficulty in controlling, for microscopic purposes, the extreme variations in light intensity is overcome by the very simple device of admitting only north light to the microscope's reflector through three large windows (2 feet 6 inches by 5 feet 8 inches each). Again the usual awkward and troublesome manner of filing and caring for one's working collections is, we believe, satisfactorily overcome by the construction and arrangement of the specimen cases. Similarly the salt-water aquarium is constructed and arranged to allow ease of observation and experimentation as well as illumination from all sides.

The specimen case, constructed of well-seasoned Oregon pine, is 7 feet 3 inches high, 3 feet wide, and 2 feet deep. The insides of its lateral walls are provided with cleats and upon these cleats moveable shelves 1 inch thick are placed, the distance from one shelf to the next varying according to convenience. Upon each shelf rest two trays 15 by 21 inches, in which the bottles of specimens are kept. This arrangement is advantageous from two points of view, (1) bottles of any size may be filed by merely readjusting the distance to the shelf above, and (2) in having two trays instead of one on each shelf, thereby making them lighter and easier to handle. The case is rendered dust proof by a glazed hinged door, which is locked by

two circular window catches, one a third the distance from the top and the other a third the distance from the bottom of the door.

The aquarium (pl. 21, fig. 4), after plans by Professor Kofoid, in each investigator's room consists of two stories. The upper one is rectangular, with inside measurements of 37 inches in length by 17 in width and 13 in depth, and is elevated so that its base is 4 feet 9 inches above the floor. Its walls consist of half-inch plate glass 10 inches high and 35 and 14 inches wide at the sides and ends respectively, which glass is supported in a reinforced concrete frame 2.5 inches thick. The lower aquarium, rectangular in shape and constructed entirely of reinforced concrete 2.5 inches thick, is of the same length and depth as the other aquarium, but about nine inches wider. A wooden shelf resting upon concrete cleats is located intermediate between the two aquaria and the salt-water system is so arranged that small moveable aquaria may be operated thereon. At the front base of the upper aquarium is another smaller shelf, supported upon iron cleats, which may be used for glassware or experimental apparatus whenever desired. It is noteworthy that the plate glass of the upper aquarium is set directly into the concrete walls, thereby eliminating all metal rods and bolts. Another important feature is that the upper aquarium backs against frosted glass windows, thus making it possible to illuminate the aquarium from any desired direction. The salt-water supply pipes are of soft lead with vulcanite cut-offs and delivery cocks. Every main angle is provided with a clean-out plug. The waste aquarium water is carried away by a system of open drains in the cement floor.

The method of circulation within the aquarium is based upon the siphon principle, as follows (pl. 21, fig. 4): From a $1\frac{3}{8}$ -inch soft lead supply pipe (*s*) the water enters through a vulcanite stopcock into the aquarium inlet (*i*), which is merely a channel $\frac{7}{8}$ inch in diameter, in the concrete wall. As the water fills the aquarium it also ascends the outlet (*o*), which like the inlet is a $\frac{7}{8}$ -inch channel in the concrete wall, until it reaches an overflow level (*l*) about three inches below the aquarium top. This brings the siphon into action, and the water passing through

the descending end of the siphon (*d*), also a channel in the concrete, enters the lower aquarium. As the lower aquarium fills, the water after passing through a screen fitting in the slots (*sl.*) ascends an outlet (*e*) similar to that in the upper aquarium. After reaching an overflow level about two inches below the top of the lower aquarium, the water flows downward through the descending stem of the siphon (*f*) into the floor gutter (*g*). This gutter is 3¼ inches wide and, beginning in the most easterly investigators' room, runs in a straight line through the other five rooms, and conducts the water down a gentle slope through an exit at the west end of the building into the ocean. The gutter is installed only on the ground floor, the plan for the second story not being completed as yet. This scheme of circulation very simply and effectively solves many difficulties. The water enters and leaves at the base of each aquarium; the pipes when clogged can be readily cleaned through their orifices (*m*). Overflow is not likely to occur except in case of stoppage of outlets and absence of the investigator from the room. Even if, in an extreme case, water should overflow onto the floor, no damage would be done, for the cement floor is constructed like the deck of a ship, so as to slope toward the gutter. With this system a constant level of water is maintained in the aquaria in such manner as to afford adequate circulation and simplicity in cleaning.

The excellently lighted aquarium room is supplied with two floor tanks used as aquaria for large animals. Each may be partitioned into two, in which case the water enters one compartment by flowing over the partition from the other. The smaller tank is 5 feet 2 inches long, 3 feet 4 inches wide, and 5 feet deep. The larger is 9 feet 3 inches long, 6 feet wide, and 5 feet deep. The bottom in both is 16 inches below the floor and both are concrete, with walls 4½ inches thick. In addition to these floor tanks the aquarium room is provided with four tables for serial aquaria. Each table is supplied with five or more rectangular aquaria 31 inches long and 21 inches wide, arranged in succession according to height, the highest being 15 inches, the next adjacent being 2 inches lower, and so on. They are made of half-inch plate glass supported by galvanized

iron frames, and rest upon either concrete or soft lead bases. Each aquarium is provided with an inlet pipe and bottom outlet. Each may therefore be used as a unit, or by plugging the outlet and siphoning from one aquarium to the next, serial circulation may be maintained. The outlet in either unit or serial arrangement leads into a concrete floor tank beneath the table. This tank extends the entire length of the table, but is constructed so that it may be partitioned into five compartments in which serial circulation may be maintained by allowing the water to flow from one compartment over the partition into the next. The final outlet is similar to that in the investigators' rooms, the water flowing by siphons into gutters and thence out of the building.

The remaining rooms need scarcely more than a passing word. The dark-room is supplied with sink, running fresh water, electric lights, and the usual equipment pertaining thereto, the walls and ceiling being black. The reagent and glassware rooms afford ample space for storage. They are equipped with numerous lockers, some with glass and some with wooden doors so arranged as to yield the most space compatible with convenience. The museum-lecture room is not yet equipped, and the library room is used as such only temporarily until more adequate quarters may be obtained. It is provided with adjustable wall shelves utilizing all the space not taken up by windows, the door and a fireplace.

The tank for the salt-water supply to the laboratory aquaria is a cylindrical structure of concrete reinforced by the so-called "high-rib" steel framework of the Kahn system. It is 16 feet high and 16 feet in diameter, and has a capacity of 20,000 gallons. It is partitioned into halves, either one of which may be used independently of the other. In addition to the usual outlet pipe the tank is provided with another to permit drainage and cleaning. The tank is supported by an octagonal, two-story reinforced concrete building 24 feet high, intended to house the pumping plant when installed.

Great difficulty was experienced in making the tank watertight. The contract was let on the assumption that the concrete walls would be strictly impervious. Whether from faulty design,

construction, or material is uncertain, but the tank leaked badly at first and no way was found of remedying the trouble except by resort to asphaltum for an inside dressing. This was applied by the membrane method, i.e., by alternating layers of asphaltum and burlap. Leakage was entirely stopped in this way. Whether sea-water in contact with these substances will become noxious to the sensitive organisms of the plankton remains to be determined, but there are good grounds for hoping it will not.

In the light of what we now know, apparently it would have been better had the building of the tank been deferred for a year or two.

III. SCIENTIFIC EQUIPMENT OF THE LABORATORY, AND LABORATORY METHODS

Mention has already been made of the fact that from the beginning the station has depended to a considerable extent on the department of zoology of the University of California for apparatus. This has been particularly true as regards microscopes. Gradually as finances have permitted, this dependence has been and is being overcome. Passing by the instruments, glassware, reagents and so on common to every biological laboratory, reference need be made only to such things as are of interest because of the special work done and methods employed.

On the biological side mention should be made of the importance of the Zeiss-Greenough binocular microscope in identifying, sorting and enumerating the vast numbers of organisms too small for the unaided eye or ordinary simple microscope, and too large for the compound microscope. Reference ought also to be made, though details are impossible, to the various devices employed in counting, measuring, and weighing organisms, and in recording data in the laboratory work. To a considerable extent these have been described in the several technical papers setting forth the researches in which they have been employed. They are spoken of here but without details to impress upon the reader the great but still subordinate importance of these aids to research.

The equipment and methods used in the laboratory work on

the hydrographic side being much less common, especially in the United States, than are those on the biological side, may be spoken of in somewhat more detail. The apparatus in use comprises:

1. One Ainsworth balance accurate to a tenth of a milligram, primarily for weighing water samples;
2. Three Knudsen burettes and three Knudsen pipettes for chlorine determination by titration;
3. One set of fourteen Aräometers, from R. Kuchler, Elmenau, graded readings from 1000-1007 to 1024-1031, for specific gravity determinations;
4. One set of weighing bottles, Guy-Lussac model, for weighing water samples;
5. One Fox gas analysis apparatus for extracting the gases from sea water.

It will be seen by this list of apparatus that the laboratory is prepared to determine the density of the water by three methods. All of these are used more or less, partly for checking one another as to accuracy and partly for facilitating labor. Where thousands of determinations are made, as in this case, rapidity and inexpensiveness are important as well as is reliability. After much comparing the weighing method has come to be most used, it being undoubtedly the most trustworthy. The original cost of the apparatus aside, it is less expensive and almost as rapid as the titration method. The hydrometer method, though most rapid and least expensive of the three, is also least reliable. Reports have come to us from some of the European laboratories of twenty-five determinations an hour by the chlorine method. We have not been able to reach such a speed. The best we have attained is about fifteen per hour, and this rate can be reached in weighing quite as well as in titrating.

The problem of the gaseous content of sea water is undoubtedly very complex both actually and manipulatively. In the opinion of competent chemists the Fox method of extracting and measuring the several gases is probably the most effective so far devised. The apparatus used is however rather complicated, and although Mr. Burbridge, who alone has thus far manipulated

it, has seemingly made it do as good work as it is capable of doing, exactly how valuable the results will be from the biological standpoint is yet to be seen.

IV. THE "ALEXANDER AGASSIZ," ITS SCIENTIFIC EQUIPMENT AND METHODS OF WORK

1. THE BOAT ITSELF

The loss of the station's first boat, the "Loma," in 1906, necessitated the building of another. A prime aim in designing the new craft was to make her capable of working in the shallow waters of the bays and close-in-shore areas, as well as in any part of the Pacific Ocean that had been roughly laid off as the "San Diego Region." It is shown in an earlier publication (Ritter, 1905) that this area is a triangle having a shore line boundary of about two hundred and eighty miles from Point Conception at the north to the limits of California and the United States at the south; a west side boundary in the open ocean of about one hundred and twenty miles; and a south side boundary, also entirely in the ocean, of about two hundred miles. The tract contains approximately twelve thousand square miles and is nearly coextensive with the continental shelf of this part of the coast. The west and south limits, being entirely arbitrary so far as the sea bottom is concerned, have to be extended somewhat in order that two very important features belonging to the shelf, namely Los Coronados Islands and Cortez Bank, may be included. Within the area occur depths of nearly eleven hundred fathoms which must be explored if anything like a comprehensive study of the whole is to be made. This indication of the duties that would devolve upon the boat makes it obvious that she would have to be of considerable capacity, not only for strictly scientific work but also for carrying men and supplies. She would have to be good for cruises of at least a week's duration, and the programme laid out would make it impossible for her wholly to escape heavy seas and rough weather.

After much discussion among ourselves and conferring with seamen experienced in work more or less similar to that upon

which we were engaged, it was decided that the boat should be wide and shallow in proportion to length, should be fitted for sailing as well as for motoring, should have a center-board instead of a deep keel, two driving engines instead of one, and plenty of stern overhang to insure the safety of the collecting lines and nets from the propeller blades. The plans presented by L. Jensen, a San Diego boat builder, were accepted and the contract let to him.

The "Agassiz" (pl. 22, figs. 5 and 6) is 85 feet long over all, is of 26 foot beam, and draws 5 feet of water. She is schooner-rigged, and as originally built was a "ketch," that is, a boat with deck area forward of the mainmast large and unencumbered, the wheel being placed behind the rear mast. Her foremast was at first 65 feet high, carrying a boom and large mainsail, and her mizzen-mast 39 feet, rigged with a boom. She has a spoon bow and a 15-foot overhang. As launched the deck was without superstructures except the two-foot decking of the cabin and engine house, these being separated by a narrow passage way. Below the main deck the space was apportioned as follows: The forecastle contained the galley, the chain locker, and a 110-gallon water tank. Immediately behind the forecastle came the cabin area divided in the middle lengthwise by the center-board box, into a captain's cabin forward on the starboard side, and a stateroom aft; and on the port side the mess cabin and lavatory. Separated from the cabins by a bulkhead is the engine room containing the two propelling engines, the main hoisting engine, and the reeling drum for the dredging cable. Behind the engine room is a lazaretto containing two distillate tanks of 460 and 230 gallons capacity and a 100-gallon gasoline tank.

The "Agassiz" began work in June, 1908, and the first season made it clear that her rigging was too heavy; that the wheel should be forward; that the scientific work should have better accommodations on the after deck; and that the galley was too small. Consequently the following year the mainmast was cut down 15 feet and reduced in diameter; both main and mizzen-sails were made lighter by changing them to the leg-of-mutton pattern; the wheel was placed in a pilot house immedi-

ately aft the mainmast; a naturalist's house was built on the deck behind the mizzen-mast; and the galley was enlarged by partitioning off a portion of the messroom. These changes greatly improved the vessel not only in sea-worthiness but in comfort and in facilities for scientific work. As now arranged the "Agassiz" has sleeping accommodations for nine persons, there being two berths in the forecabin, two "Pullman" berths in the messroom, two berths in the stateroom, one in the captain's room, and two in the engine room.

The twin driving engines are gasoline, 30 horse-power each, and were built by the Western Standard Engine Company of San Francisco. The main hoisting engine is a five horse-power gasoline built by the Union Gas Engine Company of San Francisco. The large reeling drum and its spooling apparatus were designed by Mr. T. W. Ransom of San Francisco, a mechanical engineer, and were built by the Union Gas Engine Company. These three engines and the hoist are in the engine room. Recently a combination hoist and sounding machine run by a three horse-power gasoline engine designed by Mr. Robert Baker, machinist, of San Diego, has been added. This is placed in the naturalist's house on the rear deck. Unfortunately it is not available for work at this writing.

2. HANDLING THE BOAT AND HEAVY GEAR

All scientific work requiring engine power is done aft. The sounding wire proper is paid out on the port side and is independent of the collecting gear, so that soundings may be taken while other work is in progress. The collecting cables are attached to the boom of the mizzen-mast and are run out over the stern. While this arrangement has the decided advantage of bringing together the scientific gear and the naturalist's quarters on the rear deck where there is most available space, it is not best for the handling of the vessel. The disadvantage, probably considerable for any type of boat, is specially accentuated with the "Agassiz." From her shallowness and shape of bow, her "foot-hold" on the water, as a land-lubber might say, is insecure. As a result, if not at anchor, she slips around badly when she attempts to lift or pull much else than her own weight.

especially when, as is the case with the scientific gear, the weight is attached at a point considerably above the water line. These disadvantages are particularly in evidence when work is being done in rough weather or in a heavy sea-way.

Again the excessive stern overhang, while of undoubted advantage as regards the end in view which gave her this characteristic, namely, the protection of the cables and nets from the propeller blades, is far from advantageous in another way. In even a moderately rough sea when the boat comes to a standstill or to slow headway, as she always must to do her scientific work, the waves strike under the stern with a force that is surprising to one who has not considered the possibilities in such a case, and which becomes a rather serious obstacle to the operations. While admirably adapted to work in smooth and shallow water, at least as far as general design is concerned, she has not the right style of hull for open-sea, deep-water exploration. The truth is, a diversity of requirements, practically unrealizable in any one boat, was attempted in planning the "Agassiz." Experience has proved that while it might be possible to design a satisfactory open-sea boat that would answer rather well for shallow, smooth water, the most desirable craft for work of the last mentioned sort cannot be made that will operate most effectively in the open ocean. Since on the whole our enterprise is more concerned with oceanic problems than with those of land-locked and in-shore waters, we would have done better had we built a boat with greater draught, a keel instead of a center-board, and a somewhat different form of bow and stern. The increased storage room that would have been secured by the deeper hull would have been an important gain, since as our problems define themselves with the progress of the investigation, it becomes clear that occasional cruises to greater distances from the home port and hence of longer duration, than was seriously contemplated at first, will be necessary.

It is not to be understood that the "Agassiz" is wholly unsuited to her task. A moment's reflection on what she really has accomplished and is all the time accomplishing is sufficient proof that such is not the case. She has two features that may be mentioned as particularly advantageous—her twin propelling

engines and the slight elevation of her deck above the water. For the frequent turning about required, for overcoming drift, for holding slow headway, and for various other reasons, the two-engine plan is of great importance. Nearness of the deck to the water is advantageous not merely because it facilitates the putting out and hauling in of the heavy gear, the using of hand-nets, the launching of small boats, and so on, but because it makes possible many observations on organisms in the sea that would be precluded by greater elevation. This is of more consequence than at first thought would be supposed—more in fact than one would appreciate who had not had experience in such work on both high and low boats.

3. SCIENTIFIC EQUIPMENT

In addition to the hoisting engines and drums already mentioned, the scientific equipment contains the following:

1. 1200 fathoms of $\frac{3}{8}$ -inch hemp steel cable for dredging and other heavy work.
2. 1080 fathoms of 3 mm. 28-strand galvanized wire for sounding and carrying the serial reversing water bottles.
3. 1200 fathoms piano wire for Thompson sounding machine.
4. One patent Thompson sounding machine, run by a friction wheel on the fly-wheel of the main hoisting engine.
5. One Kofoid horizontal closing net.
6. One small Nansen vertical closing net.
7. One large Nansen vertical closing net.
8. One Peterson vertical closing net.
9. One Kofoid five-gallon water bottle.
10. An ample supply of surface tow-nets of millers' bolting silk, mesh numbers 20, 12, 10, 9, and 000.
11. Numerous dredges and trawls of various sizes.
12. Six combined reversing water bottles and self-registering thermometers, Ekman model.
13. One propeller current-meter, Ekman model.
14. One meter-wheel.

15. One hundred water-sample bottles for gas analysis, with cases.
16. Three hundred water-sample bottles with patent closure, with cases.
17. One electric lighted photometer for measuring the intensity of daylight.
18. A large supply of glass jars and carboys as containers of biological specimens and water samples.

Items 2, 6, 7, 12, 13, 14, 15, and 16 are the apparatus used in the international researches on the oceanic areas of northern Europe, and were purchased through the Central Laboratory of the International Commission at Christiana. Items 5, 9, 10, 11, and 17 were designed and constructed in San Diego and Berkeley. Items 1, 3, 4, and 18 are commercial articles and purchasable from dealers in such things. Item 8 was made for Mr. Alexander Agassiz, and given by him to the station.

4. METHOD OF PROCEDURE

Experience gained during the earlier years of general exploration of the San Diego region demonstrated that correlations between organisms and their environment are by far too complex to be revealed from data obtained by the usual methods of collecting. Variations in light and in currents, temperature, density, and gas-content of the water, as well as in many other factors, largely determine the vertical and horizontal movements of organisms and likewise their abundance at any particular depth at any particular time and place. Consequently a very careful plan of collecting would be required if the data obtained were to yield the information sought.

In preparing such a plan two fundamentally important considerations are involved. First, the plan must be workable from the standpoint of available equipment, for a plan admirably adapted to a large boat like the "Albatross" for example, would scarcely suit the "Agassiz." Not only must the size of the boat and the number of the crew be considered, but its speed, draft, and in fact its entire design must be taken into account. Again the need of accurate positions while collecting requires that

locations be selected as far as possible, which can be fixed by accurate sextant observations on points of land. Second, the plan must be made with reference to some particular correlation problem or small group of closely interdependent problems, for it is obvious that all such problems cannot be investigated at the same time. The problems fall into a natural sequence so that those which are selected for investigation at a given time will depend upon work already accomplished.

Suppose we choose variation with respect to season as our problem. Obviously to compare the data obtained from one locality during the summer with those obtained from another locality during the spring, fall or winter, would come short of the best scientific procedure. Were comparison thus made, the variations observed in the kinds and abundance of organisms might be due to differences in locality and not to the effects of season. The first point of importance then, is to confine investigation to the same localities during all the seasons. Again, data obtained during daylight in summer would not reveal seasonal effect with certainty if compared with those obtained during twilight or darkness in the other seasons, because the variations noted might be due entirely to variations in light. Consequently collecting at one season must be done under approximately the same daylight conditions each day for all the other seasons. Similar remarks apply to problems of variation with temperature, currents, density, gas-content, and other hydrographic factors, as well as to a number of meteorological factors such as clouds, fog, rain, etc. However an important difference exists, namely, that while we can confine collecting to definite localities and times of day we cannot control or even foresee, except in a general way, what the hydrographic and meteorological conditions will be. Nevertheless it is necessary to eliminate the vitiating effect of the numerous variable factors if we are to determine the effects of season. This can be accomplished only by repetition of the observations under the same conditions, so far as the means of observing are concerned. To be adequate then, our plan must provide for frequently repeated collecting with the same apparatus, in the same depths, at the same localities, and at the corresponding time of day during all the seasons.

From the information that had been secured by work done previous to making the plans here described, it seemed best to concentrate still more on the effect of season upon the kinds and abundance of organisms. Three localities were selected on a line extending approximately west of the south end of South Coronado Island. These three localities were taken for the following reasons. First, because of the ease with which sextant observations may be made in almost any kind of weather. Second, because of the bottom topography and its consequent hydrographic and biological interest, especially as affording opportunity for testing Ekman's theory of oceanic currents, and of determining the effect of upwelling water on the organisms. Third, because little time would be consumed in running from station to station, and from station to good anchorage, the farthest station, although in water having a depth of 700 fathoms, being within ten miles of the island.

The locality settled, the question of the time of day when work should be done was next considered. It was certain from observations already made that some organisms accumulate at the surface during morning and evening twilight, and occur in deeper water during daylight and darkness. Work ought to be done consequently during these four parts of the day. The "Agassiz" not being capable of accommodating two crews, work could not proceed more than twelve hours each day. Which, then, should be the period of work, from noon till midnight or from midnight till noon? It was decided to take first the part of the day that includes morning twilight mainly from practical reasons, such as the disinclination of most crews to run for an anchorage during darkness, and the fact that the ocean in this vicinity is usually much smoother from midnight to noon than after noon. Further considerations concerning the time consumed in handling the apparatus made it impracticable to work each station from surface to bottom, so that either deep water or shallow water collecting would have to be left out of this particular programme. Resorting again to experience and data already secured, it seemed best to work mainly in the upper one hundred fathoms.

An example may now be given of actual work in accordance with these general considerations, which has been for some time and is still being, carried on.

On arriving at the station, which of course is "picked up" by sextant observation, a series of water samples and temperatures is first taken (see description of this operation, p. 189), this series corresponding in general with the depths at which the biological collections are to be made. In the programme here presented the depths are from 75-50, 50-40, 40-30, 30-25, 25-20, 20-15, 15-10, 10-5, and 5-0 fathoms. The biological collections are made and immediately thereafter a second series of water samples and temperatures is taken similar to the first, and sextant observations taken to make sure of the position at the end of the operations. The "Agassiz" then returns to the station and the observations are repeated. Three complete series on the same station can usually be secured between midnight and noon; one for darkness or very early morning twilight; one for twilight; and one for daylight. Although as previously stated seasonal distribution is made the central problem or point of departure in the programme, the operations yield in addition information as to the abundance and movements of organisms as affected by variations of (1) light, (2) temperature, (3) density of water, (4) topography of the sea bottom, and (5) the gaseous content of the water. One of the three stations having been thus worked, the next day another is occupied and the operations repeated as exactly as possible. The third day the remaining station is investigated. These three stations having been gone over, what shall be done next will depend on circumstances. Three more days may be spent on the same stations, taking them in the same or in a different order; stations in some other locality may be visited for the same kind of work; somewhat different work may be done; or the cruise may have been planned for going once over these three stations and no more.

A copy of the log-book for one day, rearranged for convenience of reading, will be instructive. The day, selected at random, is June 15, 1911.

5. THE LOG-BOOK FOR ONE DAY

- 12:35 A.M. Lift anchor South Coronado Island and start for Station 2.
1:25 A.M. Arrive at Station 2, latitude $32^{\circ} 22'7''$ N, longitude $117^{\circ} 19'2''$ W.
1:30 A.M. Surface nets out; surface water-samples taken.
1:32 A.M. Water-bottle series and temperatures from 75, 50, 7 and 4 fathoms.
2:00 A.M. Water-bottle series and temperatures from 60, 40, 25, and 15 fathoms.
2:10 A.M. Nansen net down to 75 fathoms.
2:20 A.M. Surface nets in; surface water-sample taken.
2:23 A.M. Nansen net closed at 50 fathoms and hauled up.
2:25 A.M. Surface nets out; surface water-sample taken.
2:25 A.M. Nansen net down to 50 fathoms.
2:35 A.M. Nansen net closed at 40 fathoms and hauled up.
2:37 A.M. Nansen net down to 40 fathoms.
2:43 A.M. Nansen net closed at 30 fathoms and hauled up.
2:45 A.M. Nansen net down to 30 fathoms.
2:52 A.M. Nansen net closed at 25 fathoms and hauled up.
2:55 A.M. Nansen net down to 25 fathoms.
3:00 A.M. Nansen net closed at 20 fathoms and hauled up.
3:02 A.M. Nansen net down to 20 fathoms.
3:05 A.M. Nansen net closed at 15 fathoms and hauled up.
3:06 A.M. Nansen net down to 15 fathoms.
3:08 A.M. Nansen net closed at 10 fathoms and hauled up.
3:09 A.M. Nansen net down to 10 fathoms.
3:10 A.M. Nansen net closed at 5 fathoms and hauled up.
3:11 A.M. Nansen net down to 5 fathoms.
3:12 A.M. Nansen net closed at surface and hauled up.
3:20 A.M. Water-bottle and temperature series from 45, 30, 12, 10 fathoms.
3:25 A.M. Surface nets in; surface water-samples taken.
3:35 A.M. Water-bottle series from 25, 20, 9, 5 fathoms.
3:55 A.M. Water-bottle series from 35, 20, 6, 3 fathoms.
4:00 A.M. Accurate position determined; lat. $32^{\circ} 23'6''$ N; long. $117^{\circ} 18'9''$ W.
4:10 A.M. Under way for Station 2 again.
4:20 A.M. Arrive at Station 2.
4:23 A.M. Surface nets out; surface water-samples taken.
4:25 A.M. Water-bottle series from 75, 50, 7, and 4 fathoms.
4:40 A.M. Water-bottle series from 60, 50, 25, and 15 fathoms.
4:50 A.M. Nansen net down to 75 fathoms.
5:03 A.M. Nansen net closed at 50 fathoms and hauled up.
5:05 A.M. Nansen net down to 50 fathoms.
5:07 A.M. Surface nets in; surface water-samples taken.
5:10 A.M. Nansen net closed at 40 fathoms and hauled up.
5:11 A.M. Surface nets out; surface water-samples taken.
5:15 A.M. Nansen net down to 40 fathoms.

- 5:20 A.M. Nansen net closed at 30 fathoms and hauled up.
 5:22 A.M. Nansen net down to 30 fathoms.
 5:26 A.M. Nansen net closed at 25 fathoms and hauled up.
 5:28 A.M. Nansen net down to 25 fathoms.
 5:30 A.M. Nansen net closed at 20 fathoms and hauled up.
 5:33 A.M. Nansen net down to 20 fathoms.
 5:35 A.M. Nansen net closed at 15 fathoms and hauled up.
 5:37 A.M. Nansen net down to 15 fathoms.
 5:39 A.M. Nansen net closed at 10 fathoms and hauled up.
 5:41 A.M. Nansen net down to 10 fathoms.
 5:42 A.M. Nansen net closed at 5 fathoms and hauled up.
 5:44 A.M. Nansen net down to 5 fathoms.
 5:45 A.M. Nansen net closed at surface and hauled up.
 5:50 A.M. Water-bottle series from 45, 30, 12, 10 fathoms.
 6:00 A.M. Water-bottle series from 50, 25, 9, 5 fathoms.
 6:15 A.M. Water-bottle series from 35, 20, 6, 3 fathoms.
 6:25 A.M. Surface nets in; surface water-samples taken.
 6:30 A.M. Accurate position determined; lat. $32^{\circ} 23' 5''$ N; long. $117^{\circ} 18' 5''$ W.
 6:30 A.M. Under way for Station 2 once more.
 7:05 A.M. Arrive at Station 2 again.
 7:06 A.M. Surface nets out; surface water-sample taken.
 7:10 A.M. Upon attempting to lower water-bottles the signal bells failed to work. Time consumed in putting them in commission, 25 minutes. Fourth water-bottle out of commission.
 7:35 A.M. Water-bottle series from 75, 50, and 7 fathoms.
 7:55 A.M. Water-bottle series from 45, 30, and 4 fathoms.
 8:00 A.M. Nansen net down to 75 fathoms.
 8:05 A.M. Surface nets in; surface water-sample taken.
 8:10 A.M. Nansen net closed at 50 fathoms and hauled up.
 8:15 A.M. Nansen net down to 50 fathoms.
 8:20 A.M. Surface nets out; surface water-sample taken.
 8:22 A.M. Nansen net closed at 40 fathoms and hauled up.
 8:23 A.M. Nansen net down to 40 fathoms.
 8:27 A.M. Nansen net closed at 30 fathoms and hauled up. Cable caught in sheave, 8 minutes consumed in releasing it.
 8:35 A.M. Nansen net down to 30 fathoms.
 8:40 A.M. Nansen net closed at 25 fathoms and hauled up.
 8:41 A.M. Nansen net down to 25 fathoms.
 8:45 A.M. Nansen net closed at 20 fathoms and hauled up.
 8:46 A.M. Nansen net down to 20 fathoms.
 8:48 A.M. Nansen net closed at 15 fathoms and hauled up. Cable caught in sheave again; time lost, 4 minutes.
 8:52 A.M. Nansen net down to 15 fathoms.
 8:54 A.M. Nansen net closed at 10 fathoms and hauled up.
 8:56 A.M. Nansen net down to 10 fathoms.
 8:58 A.M. Nansen net closed at 5 fathoms and hauled up.
 9:00 A.M. Nansen net down to 5 fathoms.
 9:01 A.M. Nansen net closed at surface and hauled up.

- 9:05 A.M. Water-bottle series from 25, 10, 3 fathoms.
 9:12 A.M. Water-bottle series from 45, 35, 6 fathoms.
 9:20 A.M. Water-sample series from 20, 9, 5 fathoms.
 9:25 A.M. Surface nets in; surface water-sample taken.
 9:25 A.M. Accurate position determined; lat. $32^{\circ} 23'2''$ N; long.
 $117^{\circ} 18'6''$ W.

Owing to a smooth sea and the fact that a minimum of accidents occurred, the regular plan as given above was completed from an hour to an hour and a half earlier than usual. The remaining time from 9:30 A.M. to 11:25 A.M. was employed in testing V. K. Ekman's theory of oceanic currents as follows:

- 9:50 A.M. Arrive at latitude $32^{\circ} 23'2''$ N; longitude $117^{\circ} 17'4''$ W.
 9:50 A.M. Water-bottle series from 55, 35, 15 feet.
 9:55 A.M. Water-bottle series from 65, 40, 25 feet.
 9:55 A.M. Surface water-sample taken.
 10:15 A.M. Arrive at latitude $32^{\circ} 23'2''$ N; longitude $117^{\circ} 16'2''$ W.
 10:15 A.M. Water-bottle series from 55, 35, 15 feet.
 10:20 A.M. Water-bottle series from 65, 40, 25 feet.
 10:20 A.M. Surface water-sample taken.
 10:40 A.M. Arrive at latitude $32^{\circ} 23'2''$ N; longitude $117^{\circ} 15'5''$ W.
 10:40 A.M. Water-bottle series from 55, 35, 15 feet.
 10:45 A.M. Water-bottle series from 65, 40, 25 feet.
 10:45 A.M. Surface water-sample taken.
 11:00 A.M. Arrive at latitude $32^{\circ} 23'2''$ N; longitude $117^{\circ} 14'9''$ W.
 11:00 A.M. Water-bottle series from 55, 35, 15 feet.
 11:05 A.M. Water-bottle series from 65, 40, 25 feet.
 11:05 A.M. Surface water-sample taken.
 11:20 A.M. Arrive at latitude $32^{\circ} 23'1''$ N; longitude $117^{\circ} 14'1''$ W.
 11:20 A.M. Water-bottle series from 55, 35, 15 feet.
 11:25 A.M. Water-bottle series from 65, 40, 25 feet.
 11:25 A.M. Surface water-sample taken.
 12:25 P.M. Arrive at anchorage on South Coronado Island.

The following record of weather and light conditions were made while the regular collecting was being done:

- 2:23 to 4:00 A.M. Too dark for photometer reading. Ocean smooth, weather foggy and dismal. Barometer remained at 30 throughout entire day. Photometer readings for the day were as follows:
- | | | | | |
|-----------|----|---|----------------|----------------|
| 4:28 A.M. | 13 | Hood open. | | |
| 4:30 A.M. | 12 | Hood open. | | |
| 4:45 A.M. | 5 | Hood open. | | |
| 4:58 A.M. | 39 | Hood covered. Fog lifting, partly cloudy. | | |
| 5:00 A.M. | 35 | Hood covered for remainder of observations. | | |
| 5:02 A.M. | 32 | | 5:32 A.M. 10.0 | 6:06 A.M. 10.0 |
| 5:04 A.M. | 29 | | 5:34 A.M. 15.0 | 6:08 A.M. 9.5 |

5:06 A.M.	26		5:36 A.M.	14.5	6:10 A.M.	9.0
5:08 A.M.	24.5		5:38 A.M.	14.5	6:18 A.M.	9.0
5:10 A.M.	24.5		5:40 A.M.	14.5	6:20 A.M.	8.5
5:12 A.M.	22.5		5:42 A.M.	14.0	6:28 A.M.	8.5
5:14 A.M.	22.5		5:44 A.M.	15.5	6:30 A.M.	8.0
5:16 A.M.	21.0		5:46 A.M.	13.5	7:02 A.M.	7.5
5:18 A.M.	21.5	Floating clouds.	5:48 A.M.	15.0	7:12 A.M.	6.0
5:20 A.M.	21.0		5:50 A.M.	13.5	7:18 A.M.	6.0
5:22 A.M.	19.5		5:52 A.M.	12.5	7:25 A.M.	6.5
5:24 A.M.	21.0		5:54 A.M.	12.5	7:50 A.M.	6.0
5:26 A.M.	18.5		6:00 A.M.	11.5	7:58 A.M.	6.0
5:28 A.M.	17.0		6:02 A.M.	10.0	8:10 A.M.	5.0
5:30 A.M.	17.5		6:04 A.M.	10.0		

After 8:10 the light was too bright to detect its intensity with the photometer.

6. HANDLING THE APPARATUS

(a) *The Surface Nets.* When according to the judgment of the scientist in charge the surface nets should be used he calls: "Surface nets out," and two sailors detailed for this service put them over. The large 000 net is fastened to the end of a heavy rope about two hundred feet long, and to its rim is attached an air-tight five-gallon can or carboy to serve as a float. The net is then thrown over the rail at either side of the boat's stern, depending upon the direction of the drift. At a distance of about fifteen feet from the 000 net the next smaller net, mesh no. 9, 10 or 12 as the case may be, is attached to the rope, and about fifteen feet from that one the third net, usually mesh no. 20, is likewise attached. The nets are then allowed to drift until the rope becomes taut, when it is made secure. After the nets have been out long enough the scientist calls "Surface nets in" and the sailors haul them in, detach the two smaller ones and lift the large one on deck. The nets are then washed with surface water to prevent any of the organisms from adhering to the netting and the contents of the bucket are transferred to containers which consist of pint or quart sure-seal fruit jars, or if the catch is unusually large, into pails. About five minutes are consumed in hauling in, detaching and washing the nets, transferring the catch and putting the nets out again.

(b) *The Nansen Net.* To operate this net requires the combined labor of an engineer, a man to read the meter, another to

stand by the bells, and two sailors to handle the net itself. When ready to be lowered the ring from which the net is suspended is fastened to the trip which has previously been made secure to the cable. The man at the bell, usually the captain or scientist, signals the engineer to lower. Just before the net has descended far enough, say seventy-five fathoms, he signals a second time and the man at the bell passes the signal to the engineer who stops the cable. A second signal tells the engineer to raise the cable, the man at the meter gives notice when it has risen far enough, say fifty fathoms, and the man at the bell signals the engineer to stop. The sailors then send the messenger down the cable which strikes the trip and closes the net. A haul has thus been made from 75 to 50 fathoms, and the net is brought to the surface as quickly as possible. When it reaches the surface it is hoisted high enough to avoid the railing, then lowered on the deck and washed. In all hauls made below the surface the water used for washing is filtered through netting of finer mesh than that of the net, thereby preventing contamination by surface organisms. After washing, the catch is transferred to containers as in the case of surface nets, and while one sailor is transferring the catch the other is removing the messenger and adjusting the net for its next haul. The cable may be raised or lowered at any speed but during the interval of each haul the speed is constant, thus insuring a uniform rate of filtration. About one minute elapses between the time the net reaches the deck and its descent for the next haul.

(c) *The Kofoid Net*. This is operated in almost the same way as the Nansen, although its great weight makes the handling more difficult, and impossible on the "Agassiz" in rough weather. Being constructed to make horizontal instead of vertical hauls, two messengers are used, the first one to open and the second to close the jaws. An interval of fifteen minutes or more usually elapses between the sending down of the two messengers. Owing to its weight the net tends to act as a sea anchor. This is overcome by steaming ahead with one engine while the net is making the catch. For a full description of this net see Kofoid, 1911c.

(d) *The Ekman Reversing Water Bottles*. If it is desired to take water-samples and temperature in say 75, 50, 45, and 10

fathoms, the terminal bottle is attached to the end of the cable and lowered to 25 fathoms. The second bottle is then clamped to the cable and lowered to a depth of fifteen fathoms, when the third is attached and lowered to a depth of 35 fathoms, after which the fourth is attached and lowered to 10 fathoms. This brings the terminal bottle into 75, the second into 50, the third into 45, and the fourth into 10 fathoms as desired. After waiting about a minute to insure the setting of the thermometers, a messenger is sent down which reverses the first bottle, thereby freeing a second messenger which reverses the second bottle, and so on. After all the bottles have been reversed (which can be detected by feeling the cable), the cable is elevated until the first bottle reaches the deck. The bottle is then detached from the cable and handed over to the scientist who notes the temperature and places the instrument in a specially made rack which allows the water to run out into a container. By this means as soon as the water has been removed from the terminal bottle everything is in readiness for a second series. In case gas samples are taken the water must be removed more carefully, so as to preclude the possibility of admixture with air. The gas analysis sample being secured the bottle is then placed in the rack as before. There is no necessity to hurry in removing the water from these bottles, for the first one to arrive on deck is the last one needed in the next series. The cable is operated in exactly the same way as when working with the Nansen and Kofoid nets.

(e) *The Other Apparatus.* The Kofoid water bottle, the trawl and dredges are operated in much the same manner as the instruments already mentioned.

(f) *Methods of Recording.* Even though the best apparatus, the best methods of operating, and the most expert crew in the world were employed, the data would be worthless for the main purpose of the investigations unless properly recorded. A double-entry plan of recording is used on the "Agassiz." After the hauls and water-samples are transferred to containers, the recorder labels each one. For this purpose he is provided with haul and water-sample books consisting of tags about one and one-half inches square, made of the best linen paper. Printed along the left margin of each tag are the following items:

Haul No.	Water-Sample No.
Apparatus	Haul No.
Date	Date
Position	Position
Depth	Depth
Bottom	
Water Sample No.	Temperature
Temperature	
Haul-Book Tag	Water-Sample Book Tag

The recorder enters on each tag the information called for, using a soft lead pencil except in the case of haul numbers, which being in sequence irrespective of the nature of the haul, are written in India ink previous to sailing. However, to provide against loss of tags, a few tag-books are carried in duplicate in which the haul number is not designated. When a tag is properly filled out it is placed inside the jar containing the haul, and formaline (about 10 per cent) is added, or when practicable the hauls are carried to the laboratory without killing. In addition to the tags a log-book is kept in which is also entered the same data for each haul and water sample, together with the details of operating the apparatus, accidents, weather conditions, and in fact anything that might have the remotest bearing on the results. Upon completion of the day's work the recorder checks the entries in his book against those the captain has kept. As soon as possible after the material has reached the laboratory the data for each haul and water sample are typewritten in triplicate upon accession sheets. Each accession sheet for hauls is 17 by 14 inches in size and ruled into columns having the following headings: haul number, character of haul, apparatus used, date, time of day, station, position, depth of haul, nature of bottom, water-sample number, temperature (during haul, at surface, in air), remarks. The accession sheet for water-samples is of the same size and bears the following headings: water sample number, date, time of day, haul number, position, depth, temperature, and many other headings for entries of density, chlorine content, salinity, etc.

Experience has taught that the recorder should not attempt anything else than his particular task when thus engaged. Hauls

and water-samples come in so fast at times that it is exceedingly easy to make mistakes in reading and recording. Any attempt to hurry means error, and should the recorder fail to enter a single catch the entire day's work would probably be vitiated, because of the difficulty of determining where the error occurred. There is no one thing upon which success of the work depends more than on trustworthy recording.

5. THE LIBRARY

Although a library is so vital an adjunct of any institution of scientific research, that of the Marine Biological Station at La Jolla is unfortunately but meagerly developed. The main reliance thus far has been on the library of the University of California. The supply of books proper consists of something less than five hundred bound volumes, but these are supplemented by a much larger number of pamphlets and reprints, and by the considerable library of the director. The cards of the Concilium Bibliographicum are provided, and the pamphlets are arranged in accordance with the system employed by that institution. The subscription list of journals contains only fifteen of the great number that would be requisite to make a really adequate working library for such an enterprise. No department of the station is in sorer need of enlargement than this.

G. SCIENTIFIC RESULTS ALREADY ACHIEVED

I. BIOLOGICAL

1. WHAT HAS BEEN DONE TOWARD A "SPEAKING ACQUAINTANCE"
WITH THE FAUNA

A "Biological Survey of the Waters of the Pacific adjacent to the Coast of Southern California"¹ having been adopted as a general statement of the station's scientific program, the first thing was to describe and record as many as possible of the kinds of organisms inhabiting the region.

So far the groups of organisms listed in table 1 have been dealt with to some extent. To make this table as truthful and at the same time as useful as possible, no little puzzling has been done on the question of what should and what should not be included. As it stands it aims to contain all the species of the "San Diego Region" to the study of which our work from the beginning has contributed. It shows (*a*) the groups of the organisms that have been studied and the results published; (*b*) the number of new species described in each group; (*c*) the total number of species so far found in the area; and (*d*) the persons doing the work.

TABLE I

<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>
Group	New species	Total no. species	Investigator
Unicellular Organisms—			
Peridinia	37	195	Kofoid
Ciliates	7	7	Kofoid
Coelenterata—			
Hydromedusae	32	57	Torrey
Actinaria	0	1	Torrey
Ctenophora	1	3	Torrey
Aleyonaria	8	23	Nutting

¹ See for example Appendix C, the By-laws of the Association, and "A general statement of the ideas and present aims and status of the Marine Biological Association of San Diego" (Ritter, 1905a).

TABLE I—(Continued)

<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>
Group	New species	Total no. species	Investigator
Asteroides—			
Serpent Stars	5	20	McClendon
Flat-Worms—			
Endoparasites	1	2	Watson
Chaetognatha	0	10	Michael
Nemertea	10	37	Coe
Bryozoa	21	70	Robertson
Mollusea—			
Cephalopods	0	4	Berry
Naked Opisthobranchs	7	0	Cockerell
Shell-bearing Gastropods	4	0	Raymond
Shell-bearing Gastropods	6	21	Dall and Bartsch
Crustacea—			
Copepoda	43	113	Esterly
Ostracoda	6	17	Juday
Cladocera	0	1	Juday
Amphipoda	16	0	Holmes
Stalk-eyed	14	?	Holmes
Enteropneusta	3	3	Ritter and Davis
Tunicata	13	25	Ritter
Fishes	3	253	Starks, Davis and Mann
Total	328	862	

While the chief value attached to the describing and recording of species lies in their being the first steps toward a deeper knowledge of the organisms, there is a firm conviction in the minds of most of those who have participated in the work that a genuine and high intrinsic value pertains to such knowledge. The difference between the attitude of civilized and savage man with reference to nature consists to a considerable degree in the difference between a comprehensive and accurate knowledge of what actually exists in nature, and a restricted and at many points inaccurate knowledge. The starting place, consciously or unconsciously, of all knowledge of nature is description. So that were the enterprise to go no farther than the mere characterizing, arranging, and cataloguing of the kinds of organisms,

it would still be justified. When, however, there is an understanding that the primary object is to lay the foundation for a superstructure of still more significant knowledge, the task is pursued with added zest, and special emphasis on this view relative to "systematic" zoology and botany is justified by the rapidly growing body of evidence to the effect that no matter what biological problems are made the subject of investigation, whether in the morphological, the physiological, or the developmental aspects of organic beings, these problems essentially involve the question of kinds. That is, it looks as though we are being driven to recognize that all qualities whatever, be they anatomical or physiological, will if studied closely enough, furnish taxonomic characters. To state the matter from a different angle, it appears that no biological generalization is fully stated until it is stated in reference to particular kinds of organisms. For example, a vast range of living beings possess the property of response to light; but do any two kinds, or even individuals, respond in quite the same way?

Such studies as those by Michael on the structural features and movements of the chaetognaths, by Kofoid on the dinoflagellates, and by Ritter and Johnson on the asexual propagation of the salps, to say nothing of studies by many other biologists on many other groups, make it certain that researches must be carried on in full light of the probability of a negative answer to the question.

2. WHAT HAS BEEN DONE TOWARD A DEEPER KNOWLEDGE OF THE ORGANISMS

While it is not possible to present in tabular form, as was done under the preceding head, what has been accomplished here, the more significant results may be briefly stated.

(a) *Abundance and Mode of Life*

Mr. Michael's work on the chaetognatha or "bristle-jawed" worms, representing as it does the most advanced point yet reached on the ecological side of the station programme, is noticed first.

The mere statement (see table) that ten species of the group

occur in the area, would give a very imperfect picture of the population as it actually exists. Thus of the nearly 79,000 specimens collected during the five-year period, 1904-1909, covered by his report, about 51,600 were of one species, *Sagitta bipunctata*. Over 10,000 of the remaining 17,400 belonged to one other species, *S. enflata*, and nearly half of the balance to another, *S. serratodentata*. One species, *S. draco*, was represented by a single specimen.

Thus it appears that much the same rule prevails respecting abundance of different kinds in this group of oceanic organisms as that with which we are familiar in many groups of land plants and animals. By far the larger part of all the grass in almost any naturally grass-grown region will be of one species, and so with forested regions. Most of the trees belong to one or to a very few species, though several species may be represented in comparatively small numbers.

So far as the evidence goes, it indicates that none of these species lives chiefly on the surface of the sea; that all make bi-daily excursions, more or less extensive, up and down; that each has, within rather wide limits, its own most favored stratum or "center of migration" as Mr. Michaels terms it; and that this center and the movements from it depend upon several factors. Thus *S. bipunctata* occurs most abundantly on the surface twice each day, namely within an hour after sunrise, and within an hour after sunset. From fifteen to twenty fathoms seems to be the most favorable depth for this species. The evidence tends to show that its movements are influenced by light, by temperature, and probably by density of the water. Since these three are the only environmental factors considered in the investigation, it is not known whether others are operative. Contrary to what might have been expected, the data do not reveal correlation between abundance and different seasons of the year.

The group in which the next best headway has been made in finding how abundant the different kinds are, and how and where the creatures pass their time, is the copepods or "oar-footed" crustaceans. Dr. Esterly has published two preliminary papers on this phase of his work, and has a third, much more extensive, nearly ready for the press.

From the results so far obtained it appears that as regards up-and-down migration, these animals behave quite differently from the chaetognaths. For example, *Calanus finmarchicus*, one of the most abundant species, comes to the surface in greatest numbers between 7 and 8 P.M. (during June and July) and begins to descend about midnight, appearing to be nearly gone by four o'clock in the morning. No second return to the surface occurs the same day. Dr. Esterly points out that this confirms the conclusions reached by several other observers that some other factor or factors than light must come into play in determining the movements. What these are remains to be ascertained. The animals descend to 200 fathoms in great numbers, but do not seem to go much deeper. As would be expected, it is during the day that they are found in the extreme depths.

Another species, *Eucalanus elongatus*, "does not exhibit any well-marked diurnal migration," and though very abundant at from 200 to 250 fathoms is never abundant on the surface. No cause has been definitely discovered for the failure of this species to make the customary daily excursions, but Dr. Esterly calls attention to the fact that the animals are particularly transparent, more so perhaps than those of any other species, and suggests that this may partially explain their peculiarity of habit.

The larvae of the enteropneusts or "intestine-gilled" worms are the only other animals upon which anything has been published from this standpoint. Ritter and Davis (1904) point out that one species, *Tornaria ritteri*, almost never occurs on the surface, but at certain times and certain localities occurs in considerable abundance at depths from 25 to 100 fathoms. This conclusion was based on work done before closing-nets were used, and was not founded on a very great amount of data statistically treated. It nevertheless seems reliable. Although a quantitative study of the vertical distribution of the animals in relation to daylight was not made, laboratory experiments were performed to determine whether or not they react to light. The results were negative; and no explanation other than the structural and functional constitution of the larvae were found for the phenomenon of a pelagic period in the life of the species. Interesting relations were made out between stage of development, bulk, specific gravity, and power of swimming of the larvae.

But the programme of the station specifically in hand, that of studying the occurrence and ecology of the pelagic fauna and flora, by no means comprehends all that has been accomplished in the way of answering those larger questions of the living world that are particularly approachable through the life of this locality.

(b) *Morphological and Physiological Studies*

Torrey and Martin (1906) describe an instance of sex differences among hydroids that amounts almost to secondary sexual characters even so far down in the animal scale as this. The highly modified branches, called corbulae, which carry the sex elements in the Plumularian genus *Aglaophenia* are quite distinctly different in the species examined.

Dr. Watson's extensive study (Watson, 1911) of the fish parasite *Gyrocotyle*, though carried on largely in the zoological department of the University of California, Berkeley, was based on material much of which was collected at the station, and some of the work was done here. The investigation was undertaken primarily with the hope of settling the debated question of which end of this animal should be regarded as the head. Much of the creature's structure, both gross and microscopic, was examined and the movements of the living animal were studied to a considerable extent in their bearing on the main question. The conclusion is that the end bearing the acetabulum or adhesive cup is the true anterior end. This is based partly on the fact that the animal crawls, so far as it crawls at all, with this end foremost; and partly on morphological evidence, particularly in connection with the nervous system. Another point, seemingly not specially contemplated at the beginning of the study, turned out to be one of the most significant of all, namely, that of the bearing of the conclusions above indicated on the question of which is the anterior or "head" end of the tapeworm. Cogent reasons are brought forward in support of the view that the attached end, or scolex of this latter parasite, which is commonly called the head, is really the tail end, the "head" having been lost. A rather interesting detail is the fact that there is "no trace in any tissue of the body of an epithelial layer of cells."

Bancroft and Esterly (1903) reëxamined the reversal in direction of heart-beat in the ascidian *Ciona intestinalis*. Their work is a good illustration of the seeming inexhaustibleness as a subject of research of almost any biological phenomenon. Despite the large amount of study that has been bestowed upon this matter, a striking fact, hitherto unobserved, was brought to light: "Not only does the direction of the contractions remain fixed while a part of the heart is connected with only one of its ends, but in some way a change is effected in the heart tissue so that the direction of the contractions still remains fixed after the part has been isolated from the end which was instrumental in producing the fixation."

The "set" of a beat, as it might be called, in either one direction or the other, the authors speak of as physiological polarization. Comparison of the phenomenon with the "habit" acquirement by the arms of the star-fish observed by Jennings, and to be mentioned farther on, is instructive.

(c) *Reproduction and Development*

Kofoïd (1908a) has shown that in one group of unicellular organisms (*Ceratium*) the cellulose shell of the organisms is normally shed and renewed from time to time; that the three outgrowths of horns characteristic of the genus exhibit, in some instances at least, alternating periods of growth and rest; and that self-amputation followed by regeneration of the horns occurs. In these unicellular organisms, therefore, phenomena of growth and development occur that are quite comparable with such phenomena in many higher organisms. This similarity seems to be exhibited again in the clinging together for a time (how long is not known) of the individuals which arise from one another by division. A detailed study of the members of these series, both qualitatively and quantitatively, might throw light on the important general question of the relation among the individuals of a lineal generation of cells. But the author did not have sufficient material of this particular sort to enable him to attack the question.

Dr. Torrey's work on the hydroids and anemones has touched a considerable range of developmental phenomena. From studies

partly descriptive but chiefly experimental (Torrey, 1905a) he concludes that the facts "appear to give strong support to the view that the stem [of the hydroid *Clytia bakeri*] instead of retaining unmodified its regenerative capacity, actually loses with age its ability to produce structures which formerly characterized it; and that this is owing to a modification of conditions *within* the organism, which govern its behavior without being necessarily a part of it." And further that "the resemblance of the phenomena of colonial differentiation in *C. bakeri* to the phenomena of senescence is so strong as to suggest a similar interpretation for both."

Of his series of studies upon the fine large hydroid *Corymorpha palma*, Dr. Torrey has devoted one (1910c) to the much investigated phenomena of heteromorphosis and of polarity. Complete reversal of polarity of pieces cut from the stem was observed, and a considerable measure of control was effected over the phenomena, both as to occurrence itself and as to the rate of growth. For example it was shown that by inserting the distal end of a section of the column into a capped glass tube, a hydranth promptly develops at the free or proximal end of the piece, but not at the end in the tube; whereas a similar piece not enclosed in glass develops distal but not proximal hydranths. The author believes exclusion of oxygen by the glass tube explains the difference in results.

Torrey and Mery (1904) have considerably enlarged our information about asexual propagation in the anemones, three rather distinct modes of fission having been observed in the same species. In the species studied another instance of heteromorphosis is recorded for the group, of which until now comparatively little has been known.

Number II of Torrey's studies on *Corymorpha* (1907a) is devoted to the embryonic development of the animal. This species appears to be peculiar in its genus in that the egg-carrying medusae do not become detached from the hydroid. Egg-laying occurred in May, June, July, August, September, December, and January, no observations having been made in the remaining months of the year. From this standpoint as well as from several others, the animal is well fitted for biological

studies. Extruded eggs undergo marked amoeboid movements before fertilization. The larvae have no free-swimming stage, and this fact, together with the absence of free medusae, would seem to leave the species with little ability to scatter about widely. The later development is described somewhat more fully than the earlier. The great plasticity of the organism from beginning to end of its developmental career is specially noticed, particular attention being given to the extent to which the differentiation both of larger morphological features and of cellular details is more or less dependent upon activities of the organism and external conditions. Attention is called to the close resemblance between the tentacles and the hold-fasts, or frustules, abundantly present on the lower part of the stem in the early stages of development. The attractiveness of this species for biological study, while strong from the accessibility and size of the animals, is made doubly so by the number of further inquiries suggested by this initial research.

An important contribution to the reproductive habits and embryonic development of the enteropneusta was made by Dr. B. M. Davis (1908). A fuller account of egg-laying is given for the species studied than has been recorded for any other of the group. Although not sufficient material was secured to make possible anything like a complete description of the earliest stages of development, enough was observed to impress the author with the resemblance of the embryo in the stages studied to the corresponding stages of *Amphioxus*. This species is the second enteropneust known in which no true tornaria stage occurs. By far the most important contribution made by Dr. Davis to the development of the group was the conclusion reached, on very strong evidence, that the middle and posterior body-cavities arise entirely differently from the way in which they are currently supposed to arise. He found them to originate by backward growth of and constriction from the first, or anterior cavity, and not by separate outpocketings from the enteron. While there is not sufficient ground in all the germane phenomena for attaching as much theoretical importance to the particular question of fact here involved, as was done some years ago, the matter is nevertheless one of real interest and it

is to be hoped that this investigation may be followed up in the not distant future.

In the study of enteropneust larvae by Ritter and Davis, already noticed, three quite distinct stages in the larval development were recognized and correlated with different habit-of-life periods of the larva. This class of studies, that of tracing in detail the relation between structural features in pelagic larvae and modes of life in nature at different periods, has yielded instructive results wherever pursued and so promises well for future work.

The four papers, Ritter and Bailey (1908), Ritter (1909b), Johnson (1910), and Ritter and Johnson (1911), are concerned with a common developmental problem notwithstanding the wide diversity in title and special topics. The problem may be stated thus: To what extent do the members of the repetitive growth series so obvious and widely prevalent in organic beings fall into groups of such sort that each member is a function, in the mathematical sense, of the position it occupies in the series to which it belongs? Stated in another way the problem is: How far are the periodic phenomena so common in organisms expressible in terms of systematic quantitative difference for different parts of the observed periods? It will be noticed that the problem involves not only one of fact as regards organic phenomena, but also for its solution, one of method, that of systematic quantitative determination within the confines of individual organisms.

The second paper mentioned (Ritter, 1909b) contains an account of the initial attack upon the problem. The results, so far as they pertain to this problem, are summarized in the following quotations: "An approximately exhaustive study of one of the animals finds it to contain a manifolding of similar parts to an extent that is surprising in view of the slight prevalence of such parts recognized by cursory observation. Comparison of many individuals of various sizes and ages . . . reveals the fact that to a large extent, the measure of which is not known, these manifolded parts have arisen (*a*) as lineally genetic series . . . from a few initial ancestral organs; while others have arisen (*b*) as repeated productions from common original substrata, or menstrua. Attention to these repetitive series makes

it quite certain that many of them . . . not only are subject to definite schemes as to positional arrangement and time of origin, but also as to mass relations. Otherwise stated, the repetitive series which obviously constitute so large a part of the whole animal are to a great extent disposed in mathematically treatable order." Although the systematically graded quantitative relation among repeated parts was definitely recognized in this study, no attempt was made to measure the quantities.

The first effort toward dealing with the problem quantitatively was made by Miss Johnson (1910). Her most immediate results were that "the salpa chain presents an obvious periodicity," the so-called "blocks" of zooids making the periods; and that the zooids at the ends of the block are much smaller than the intermediate ones, those of maximum size being nearer the distal end in the younger blocks, and nearer the proximal end in the older blocks. Attention was called to the resemblance of the size-scheme of zooids in the blocks to the well-known phenomenon of "grand period of growth" exhibited by many plants.

Ritter and Johnson (1911) found that in the wheel-shaped groups characterizing the chain of another species of salpa, the size gradation of the zooids is more generally distributed in the groups than in the species previously studied, the graphs made from plotting the measurements approaching more closely the normal probability curve. In this species, though the size-scheme is very clearly revealed by quantitative study, the differences among the zooids are so small relatively to the whole animal as to be unrecognizable to the eye. Consideration of such environmental and physiological influences as might conceivably bring about the observed gradation among the zooids led to negative conclusions, leaving no other recognizable explanation of the phenomenon than that growth itself proceeds in that way.

The paper by Ritter and Bailey (1908) records a preliminary attack on the same general problem in quite a different and more fundamental quarter, but a quarter where the difficulties of manipulation are much greater; that is, in the realm of cell division as this manifests itself in the developing egg. The method of quantitative determination was that of weighing. So far as the problem itself is concerned, the meager results were

of doubtful value, but the manipulative experience was of decided value as suggestive of future effort in this same direction.

(d) *The Adaptations of Organisms*

This problem has been touched in several researches besides those occupied expressly with ecology which, in its very essence, is to a large extent the problem of adaptation.

Considering the question of adaptiveness of the specific characters of the flagellate infusorian *Triposolenia*, Kofoid (1906c) reaches the conclusion that "while it is not probable that all of the species are all equally well adapted to survive, it is evident that they have been and are *sufficiently* well adapted to maintain themselves." In this study, as the quotation indicates, the author makes use of the important principle that the question of adaptation receives much more illumination by treating it from the standpoint of the relative adaptiveness of several species belonging to a single group, than by giving attention to one species alone. Reference will be made to this principle in connection with another study.

In his work on *Ceratium*, already noticed, Kofoid (1908a) goes extensively into the question of the adaptiveness of the phenomena primarily dealt with (the shedding of the test and self-amputation and regrowth of the horns) to various environmental conditions. He brings forward good reasons for the conclusion that the phenomena mentioned "assist in the adjustment of the specific surface and possibly also of the specific gravity to changing conditions of flotation, especially as effected by temperature."

Dr. Torrey studied the habits and movements of a species of anemone in detail (1904b) and recognized some of the activities to be clearly adaptive, while others "appear to have no adaptive value whatever." For example certain movements of the tentacles are very definitely in the interest of securing and using food, while others seem to have no purpose either in this way or any other.

In dealing with our common shore anemone, *Bunodactis xanthogrammica*, this author (1906a), though not concerned directly with the problem of adaptation, points out that the same

species lives along the whole western coast of North America from Panama at the south to Unalaska at the north. This is certainly a remarkable case of the adaptation of the same species to a great variety of environmental conditions.

Although the extensive study of Jennings (1907) falls properly under the heading of animal behavior, noticed later, the question of adaptiveness of this behavior to natural conditions under which the animal lives, received considerable attention. The results bearing on this may be summarized by saying that of the large number of reactions and activities of the starfish studied, every one is probably to some extent advantageous to the individual animal. At least it is not suggested that any activity studied is without significance for some particular aspect of the creature's existence.

(c) *The Doctrine of Natural Selection*

Kofoed (1906c) and Ritter (1909b) have dealt specifically with this subject to some extent.

Studying the species-characters of the dinoflagellate already referred to, Kofoed concludes that "in assigning natural selection as the cause of the species characters in *Triposolenia* we are at once confronted by the difficulty of finding any evidence of the *differential* survival value of any of the characters in question." "It is," he says, "impossible to establish the fact of any advantage accruing to one of these species over its nearest allies by reason of its structural distinctions and difficult to find any satisfactory basis for a logical inference or conclusion to that effect."

Ritter carried the idea of coördinating the differences between two closely related species with the differences between their environments well toward a quantitative determination, with the result summarized in the following: "So far as the present inquiry has gone, the attempt to find a causal relation, or a necessary correlation, between the character differentials of the two species (*Halocynthia johnsoni* and *H. haustor*) and their environmental differentials, has produced negative results. In other words, the results do not enable us to affirm anything more definite about the adaptation of *H. johnsoni* to its environment

than that in a general way it is so adapted; that is, that it is sufficiently adapted to enable the individual animals to live and maintain their specific identity in a considerable range of environmental conditions."

(f) *Animal Behavior*

This term has come to have a very definite meaning in recent biology and as such to stand for one of the most important subjects of investigation. It has been dealt with by Dr. Torrey in several studies (Torrey, 1904b, 1905b, and 1906a), and by Dr. H. S. Jennings (1907).

Torrey's work on *Corymorpha* (1905b) brought out, among other things, the interesting result that the pronounced geotropic movements of the animal appear to depend not on the muscles of the body, although these are well developed, but on the axial cells which are not at all muscular. The action of these cells is, it seems, due to their changing turgidity. If this interpretation be right, the author says, "*Corymorpha* stands alone among the metazoa in possessing a tropic mechanism distinct from the body musculature." Such a conclusion naturally leads to reflection on the similarity of these movements of the animal to the negative geotropism of plant seedlings. "I know of no animal," Torrey says, "which more closely approximates the plant in structure and tropic response. If the behavior of the one be explicable on the basis of direct reactions to stimuli, of the reflex type, I do not see how the behavior of the other can be excluded from a similar interpretation."

Study of the tentacular and ciliary movements in the anemone *Sagartia* (1904b) under various chemical and mechanical stimulations extended our knowledge of these phenomena in several directions. For instance the question that has been raised as to whether reversal in direction of ciliary action could be induced by mechanical as it can by chemical stimulation was definitely answered in the affirmative. Special emphasis was laid on the fact that polyps act more or less definitely and vigorously in various food-taking operations, depending on how hungry they are.

In all of Jennings's long series of studies on animal behavior

it is doubtful if any single one contains a greater number of important observations or more interesting reflections than the one here noticed. Reading carefully through the whole one hundred and thirty pages which constitute the paper, with a view to summarizing the most significant facts, I am so impressed with the difficulty of making such a summary as to be impelled to quote the author's own words: "The foregoing account," he says, "is intended as a storehouse of objective facts, for reference when information concerning the behavior of the starfish is required in order that there may be no farther excuse for theories that leave out of account the facts. It is therefore not practicable to make a summary that will really represent the results set forth in the paper. To form an idea of the matters treated, reference should be made to the table of contents." But Jennings has given an appraisal of his work as follows: "Perhaps the most important thing developed in the paper is the demonstration of the variability, modifiability, unity and adaptiveness in the main features of the behavior of the starfish. The movements are shown to depend on the varying physiological conditions of the animal, and the numerous factors which demonstrably modify the physiological condition, and therefore the behavior, are set forth in detail. Habit formation is demonstrated and discussed in full." From this enumeration I select the item of *unity* for a little further remark, not however, with the implication that it is foremost in importance among them all, but because it is less usually dwelt upon by most investigators than are the other items. "It is clear," says Jennings, "that the behavior under the righting impulse tends toward the accomplishment of a general turning of the starfish as a whole, and that given parts sacrifice their own more direct turning, or even reverse it, in the interest of the general result. The behavior shows what can be hardly characterized otherwise [than?] as a general 'plan,' each part doing what will assist (often very indirectly) to bring about the result." The fact that this unity is in some instances incomplete; that occasionally "the action is discordant," is emphasized as important in "forming a theory of the matter." *The unity of action is, it seems, a development.* In connection with the extremely interesting results on

habit formation, worthy of special notice, is the fact that "the behavior of young specimens is more readily modifiable than that of old ones."

Jennings also makes clear what, in general outline, is his position as to the deeper meaning of the facts observed. "Conversation with investigators," he says, "leads me to believe that a large proportion of them would welcome a distinctly 'vital' explanation as readily as any other if they could see that it helped them in understanding and controlling the activities of organisms. But such a view as that of Driesch merely transfers the problems to the Entelechy, where they are less attackable than before." On the other hand, "Investigators may hold with Driesch, as the present writer does, that most of the simple chemical and physical explanations that have recently been given are superficial and quite inadequate to account for the regulatory activities of organisms." We are not, he thinks, obliged to enroll under either flag, but "can hold, in preference to either of these views, that our present analysis is incomplete, and that there will be something for investigators to work out in these fields during the next ten thousand years or so."

Several researches carried on at the station have been the basis, wholly or partly, of memoirs that cannot be claimed as part of the station's output, since nothing more was contributed to the work than granting to the investigators the privilege of occupying the laboratory and using some of its appliances.

Under this head come papers by Mr. W. C. Adler-Mereschkowsky of Russia, on sessile diatoms; by Miss Sarah P. Monks of Los Angeles, on variation and the self-amputation and regrowth of the arms of the starfish *Linkia columbiae*; by Professor W. R. Coe of Yale University, on the nemertians of the region; by Professor T. D. A. Cockerell of Colorado College, on the opisthobranch molluscs; by Professor T. H. Morgan of Columbia University, on the problem of self-fertilization in the ascidian *Cione intestinalis*; by Dr. A. J. Carlson of the University of Chicago, on the electrical stimulation of the heart in several marine invertebrates; two reports by Professor C. C. Nutting of Iowa University, on alcyonarian polyps for the United States Bureau of Fisheries; one or more papers by Mr. M. B.

Nichols of the University of California, on the calcareous seaweeds of the coast of southern California; four by Dr. C. M. Child of the University of Chicago, on "form regulation" in the sand anemone *Harenactis attenuatis*; and studies well advanced on endoparasites of fishes by Mr. W. E. Allen of the University of Illinois; on the circulatory system of annelids by Dr. H. R. Linville of Jamaica, N. Y.; on the so-called pyloric gland of ascidians by Dr. H. S. Colton of the University of Pennsylvania; on the problem of accessory chromosomes in chaetognaths by Dr. Nettie M. Stevens of Bryn Mawr; and on the endostyle of ascidians and amphioxus by Dr. David Marine of Western Reserve University, Medical Department.

Since these investigations cannot be held to represent activities of the station as these are now carried on, no resume of the results is given here. I cannot, however, refrain from mentioning Child's observations and reflections on "polarity" and correlation, particularly in connection with the development of what he calls "rings" from pieces cut out of the body of the anemone studied; nor from calling attention to Morgan's proposal to make use of the repugnance to self-fertilization manifested by the ascidian under observation, for getting at the chemical basis of individuality. The brief paper by Miss Monks must also have something more than a mere mention. The remarkable variability of the starfish studied, and the unquestioned ability of its amputated arms to produce a complete animal even though the plane of severance is some distance from the disc, are facts of unusual interest and strongly invite further examination.

II. HYDROGRAPHIC

Although as was stated in another connection, study of the water was from the outset counted as an essential part of the enterprise, little has yet been published of the very considerable amount of data collected.

The preliminary paper by Dr. G. F. McEwen (1910) contains a brief statement of the methods used, a very general summary of water temperatures and densities observed up to 1909, and by way of generalization, a short discussion of the probable significance of colder in-shore surface water along this coast.

The particular thing brought out in this discussion is the applicability of V. W. Ekman's theory of oceanic circulation to the facts observed.

While this is all that has been published on hydrography as such, the extent and importance of the hydrographic work as an adjunct to the biological investigations are indicated by the use made of this data in the papers of Michael and Esterly.

The earlier data collected but not yet published should be referred to. During the summer of 1901 a series of temperature and density determinations were made by Professor W. J. Raymond of the Physics Department, University of California. From 1903 to 1906 considerable work was done in this way, particularly on the San Diego Bay and in-shore water by Mr. W. T. Skilling, teacher of physics and chemistry of the State Normal School at San Diego. Mr. Skilling also began work on the chemistry of the water.

Under this head reference should be made to the modeled topographic map (pl. 24, fig. 10) of the continental shelf and adjacent land area of Southern California constructed in 1906 by Professor R. S. Holway of the Department of Geography, University of California. This was constructed partly on the basis of soundings taken by the station's boats, though more from the work of the United States Coast and Geodetic Survey and other departments of the national government. This map is very useful in several ways for the operations at sea.

H. THE FUTURE

I. THE STATION'S PROGRAMME PROPER

Turning from the past and present to the future, it is desirable to remind ourselves of the general idea upon which our whole enterprise immediately rests, namely, that of a "Biological Survey of the Waters of the Pacific adjacent to the Coast of Southern California." An earlier statement (Ritter, 1905a) will furnish a useful introduction to what is to follow. "While there is no reason for attempting a rigorously laid out attack on the numerous problems, a natural sequence within certain limits will establish an order; and where practical administrative conditions conveniently adapt themselves to such sequence this order will be followed. For example, the species representing a given pelagic group having been gotten well in hand, a natural second step would be the determination of the seasonal distribution of the group. . . . Following close upon the treatment of seasonal distribution would come that of horizontal and vertical distribution, the chorology; and inseparably linked with these would be the problems of food and reproduction; and these again would lead to problems of migration, with their intimate dependence upon temperature and other environmental factors. And here, completeness of knowledge being ever the watchword, the demand would arise for applying experimental and statistical methods in the effort to get at the deeper significance of the facts observed, and generalizations reached from the observational investigations. The chain of questions hanging one to another is endless and, of course, completeness of knowledge in a literal sense is an unattainable ideal."

This quotation is made partly to emphasize the general view which has from the beginning guided the station's work and development; and partly to show that when the statement was written six years ago even a rough outline of the course then proposed was only approximately that which has actually been followed. For instance, experience has proved that such a severance of problems of vertical migration from those of vertical

distribution as was suggested, is impracticable. Other discrepancies between the programme indicated and that actually carried out will be seen by anyone who studies Michael's work, particularly. With this reference to what the past teaches concerning both the value and the limitations of laying out work for the future, we may pass to a consideration, in barest outline only, of what now appears the next thing to be done.

II. NECESSITY OF CLOSER CO-OPERATION BETWEEN FIELD WORK AND LABORATORY WORK

Looking at the matter from the standpoint of both the present stage of the scientific work and the actual conditions of the station as a means of prosecuting this work still further, two things are quite clear. These are the desirability of continuing the collection of data at sea in much the same way as this has been in progress during the last three years especially, though increased in amount of work done and in refinement of method; and of taking up in earnest laboratory experimentation to supplement the field operations. The sharpness of definition which these two things have taken on with experience, brings up so concretely the much discussed question of the relative merits of the experimental as against the observational and descriptive method of research in biology, that I cannot forbear some remarks on the subject.

The view to which one is irresistibly led in carrying forward an enterprise like ours is that both field observation and laboratory experimentation are wholly indispensable, since each furnishes ways of entrance into the problems presented that the other cannot possibly furnish. There is no more ground for holding either the one or the other as *the* method, as being the more important or more promising, than there is for holding either the father or the mother to be the more important or more promising in the begetting of offspring among the higher animals. If, for example, it is desirable to know how many kinds of fishes there are in the sea, there is no way of finding out except to go a-fishing and keep at it until no more fish can be caught; or if the question is raised whether or not the deepest depths of the ocean are inhabited by living beings, it can be answered in no

other way than by devising and using some means of capturing organisms in these depths if they occur there. On the other hand, if it is desirable to know whether eggs that develop naturally in sea-water will develop at all, or in some modified way, in water that contains only one of the minerals found in normal sea-water, there is one possibility and only one of finding out, and that is to place undeveloped eggs in the particular kind of water about which the question is asked and see if they develop.

One method leads to knowledge of one sort, another to knowledge of another sort, generally speaking. Apparently the question of the greater importance of one method as against another could arise only as a sequel to a judgment already reached that one kind of knowledge is more important than another. If the object of biological research is held to be "to know, to understand organic things" (Ritter, 1908), if a particular biological undertaking has the end in view of getting as much knowledge as is possible about the organisms in a restricted area of the earth, there can be no partiality shown for one method over another. Each and every known method will be invoked as far as practicable and prized without stint for the particular thing it can do.

As a matter of fact the sharp distinction frequently made between the experimental and the descriptive methods in biology has less scientific validity and less practical utility than the distinction between field, or out-in-nature methods and laboratory methods. Observation is surely essential in laboratory investigations no less than in field investigations. And no one can give an intelligible account of what he has accomplished either in laboratory or field, without description of some sort. Experiment is likewise resorted to almost if not quite always in work done with sufficient care and intelligence to meet the requirements of modern biology, in field studies no less than in laboratory studies. The testing of different kinds of closing nets, for instance, in the effort to find at what depth a particular species of pelagic organism occurs in greatest abundance, is as certainly an experiment as is the testing in a laboratory of the effect of light of different intensities on the same species. But there comes to view a distinction between out-in-nature

experimenting and observing, and laboratory experimenting and observing that is far-reaching, not only as to application but as to scientific conceptions in the largest sense.

Much stress has recently been put upon the element of control in research. By some biologists this is held to be almost if not quite the end and aim of such research, because according to the view of these persons, control not only constitutes the essence of our understanding of living beings, but also because the highest level of utilitarian interest in organisms is reached in this way. There can be no doubt about the importance of control, and it stands forth in particularly large and bold outline when seen from the vantage ground of research of such scope as that in marine biology, where it presents itself under two very distinct aspects. First in the field work there is the complex and exceedingly difficult matter of controlling, that is, restraining and determining, everything concerned in the investigation *except the organisms themselves*. The object is to find what organisms there are in existence, exactly where they are, and what they are doing under the conditions imposed upon them by nature alone. Control over them is what is *not* wanted even were such a thing possible, since knowledge of their mode of life *in nature* is exactly what is sought. By judicious and long-continued experimenting with the means of collecting and observing we find that very extensive information and understanding can be obtained in this way. At the same time the farther we go on this track the more numerous and the more clearly defined become problems not to be reached by these means—problems whose solutions, so far as solutions are possible, must be reached through a shift from controlling the *means* of observation to controlling the *objects* of observation, i. e., the organisms themselves. Such control can generally be exercised far more effectively and advantageously in the laboratory than anywhere else. As illustrative of the binary method demanded for handling problems of marine biology, attention may be called to Esterly's work on the vertical distribution of the copepod *Eucalanus elongatus*. So far the field results indicate an absence of a regular up-and-down migration of this species. Assuming these results to be correct, the question naturally

arises, Why the absence of such movement when other related species perform daily excursions? Noticing the unusual transparency of the animals, Dr. Esterly makes the suggestion that their relative invisibility affords them a protection not enjoyed by less transparent species and so does away with a need for migration which the others have. How is such a hypothesis to be tested? Obviously in no other way than by laboratory experiments. Again, Miss Johnson and myself have learned a number of interesting things about the asexual propagation of certain species of salpa by studies for the most part on preserved specimens. But these studies have brought to light a number of questions which, so far as we can see, cannot be answered without keeping living, growing animals under observations for considerable periods of time. But such observation is impossible without the best of aquarium facilities—and the aquarium is only one part of a laboratory.

The mutually supplementary relation between field work and laboratory work in such an enterprise is so obvious as to make dwelling upon it seem superfluous. Actual conditions and practices, and to some extent views, do nevertheless justify insistence upon the point. For one thing the great cost and difficulty of bringing together, duly balanced, the two kinds of work are serious obstacles in many cases to the realization of the ideal. An obstacle still more unfortunate in some ways is the well-defined notion rather widely held, that field studies are of quite subordinate importance. I believe, however, that an open-minded review of past and contemporaneous biology will convince anyone of the danger that lurks in overconfidence in any *single method* of research. Possibly there are nooks of science somewhere in which one method is enough; but if so they have escaped my notice. The admonitions of experience as to exactly where monomethodic research tends, are useful. Field observation alone unquestionably encourages illy supported and more or less sentimentally colored generalization. Unsupplemented description, whether of organisms as wholes or of parts of organisms, produces results that savor more of the collector and cataloguer than of the whole-hearted student of animate nature. The laboratory too singly confided in has still greater danger

because a danger more pervasive and subtle. There can be no question that laboratory biology may have much the stamp of museum anthropology, of library sociology, of scholastic philosophy, and of cloister theology. We must undoubtedly take many, probably most biological problems, into our laboratories for study. But the idea of learning biology proper in a laboratory or a museum is as preposterous as the idea of learning navigation from a toy ship on a mill pond. Valuable as may be the "selected types" method of elementary instruction in biology when used with discretion, its possibility for evil when allowed to gain a full mastery over independent thinking is enormous. Recognition of the direful tendencies of the method was forced upon me some years ago by reading in an exhortatory tract written by an enthusiastic teacher for his classes in zoology this well-turned, assuring epigram: "When you have dissected a fish you have dissected the whole animal kingdom." The mischievousness of such teaching would, I suppose, be admitted by most biologists to-day so far as concerns gross structure. The real magnitude of the evil is appreciated only when one sees clearly that the epigram would almost certainly be just as false if made with reference to minute structure, to physiological or psychological activity, or to chemical composition. The living world is illimitably vast, complex, and changing, and cannot be forced into a few ossific formulations by all methods of work combined, much less by some one or a few methods.

From what has been said, experimentation, particularly laboratory experimentation, would seem to play a part supplementary to observation-in-nature in only the restricted sense of assisting observation toward the solution of problems raised by the latter and found to be unmanageable by it. In addition to this important role experiment has another more independent and still higher, namely that of discovering attributes of organisms that could not have been suspected to belong to them by inspecting the organisms in their natural environment alone; or otherwise expressed, attributes that could be revealed only by bringing the organisms into relations and conditions to which they have never before been subject. For example, the fact that an animal has the attribute of behaving in a particular manner

when subjected to a chemical environment radically different from anything either it or any of its ancestors were ever subjected to, is of the greatest significance to philosophical biology, but could be discovered by no other means than experiment. This sort of discovery is not restricted to laboratory experimentation though undoubtedly some of the most startling, most definite results have been and will continue to be reached by this method. The transference of a plant from a desert interior to a seaside is obviously much the same kind of experiment as that of the transference of an aquatic plant from water holding one chemical substance in solution to water holding another substance.

By whatever method either the form or the behavior of an organism be modified through experiment, a *sine qua non* to sound interpretation of the new form or behavior is extensive and exact comparison with the form or behavior of the same organism under natural conditions; and such comparison is impossible without extensive and exact description of the organisms both as they occur in nature and under the new conditions. So we are forced back even from a consideration of this higher use of experimentation to the demand for the most extensive and the most exact studies possible of organisms not only as they have developed and lived their lives in nature, but *while* they are developing and living their lives in nature.

These general and special considerations as to method taken together with a consideration of the problems now in hand and of the resources of the station, indicate very definitely not only what ought to be done in the near future but also what may be aimed at with prospects of a good measure of success.

As to field work the foremost desideratum is that it should be *made more continuous*. This means practically that the "Agassiz" should be kept in constant commission though not necessarily at sea all the time. The main point is not so much to increase the volume and scope of the operations, though this would result, as to complete what is already in progress. Great gaps exist in the data so far secured, and consequently most of the conclusions as to daily, yearly, and vertical distribution and

movements of the organisms are more or less tentative. In other words, the laws governing in these matters are only partly made out. On the laboratory side the experimental work urgently calls for the completion of the salt-water circulatory system and the building of a wharf as the two most important items. The details that would be involved in these extensions need not be entered into here. It is enough to say that increase to the extent indicated, with no curtailment of what is being done, would necessitate an increase of yearly expenditure of not less than \$5000 over what is now available.

Reference should be made to the involvement in the question of future policy and development of two kinds of work which though in a sense only subsidiary to biology, are yet very important. They are research in hydrography and oceanography, and the application of mathematics to biological problems.

As to hydrography, investigations not only at this station but at several European stations have gone far enough to make it positive that as a supplement to biology the study of environment (for such hydrography as thus treated really is) must not only be kept up but must be perfected and extended if anything like sound biological advance is to be made in the directions thus far followed. There can be no hesitancy about this. The question is, Are not some of the oceanographic problems so interesting and important in themselves, that is, independent of their relation to biology, as to justify according them an independent place in the station's aims and programme? There is certainly some temptation, not to say tendency to do this. My present view is, however, that it ought not to be done *except there be special and additional funds* provided for the purpose. My belief is that although oceanographic problems are of undoubted importance, and although pursuit of them on their own merits would frequently be quite different from what it would be with oceanography held strictly subordinate to biology, important hydrographic results may still be reached without the least departure from or impairment of the original intent.

III. THE INDISPENSABILITY OF MATHEMATICS FOR THE
SOLUTION OF SUCH BIOLOGICAL PROBLEMS AS
THE STATION IS ENGAGED UPON.

The question of the place of mathematics in the station's future work, although quite different methodologically from that just considered, is administratively much the same. It is obvious from a cursory examination of our latest publications that there is hardly a phase of the biological research constituting the main programme that does not even now demand constant resort to quantitative treatment involving considerable proficiency in mathematics. If the investigations continue in the course marked out, this demand will surely become more insistent. Two main and rather widely separated lines of mathematical dealing are clearly entered upon. One includes the array of problems involving the correlation between the organisms numerically treated, and environmental factors mensuratively treated. Success depends and will more and more depend on the resourcefulness and skill with which data can be segregated, coefficients of correlation computed, and so on.

The other demand upon mathematics grows out of the nature of the individual organism and depends on the fact of rhythm or periodicity, so familiar and so deep-seated in apparently all organic beings. Age in almost if not quite all organisms, man as well as the rest, with which we are concerned in practical life, is of such obviously great importance that its wide neglect by biology itself except in the most general way is truly remarkable. It would appear that science must before long take due heed of the great extent to which a given organism's morphology and physiological capacity at a given time in its life are mathematical functions of the life-career taken as a whole. Once this is duly recognized, quantitative valuation of a particular structure or activity at each particular age, relative to the value of the same part or function at various other ages extending over as great a part of the whole life as possible, will be seen to be imperatively demanded by rigorous biology. This will make the measuring rule and the balance as indispensable to the biological laboratory as they are to the chemical and physical laboratory

and the astronomical observatory. And seemingly the labor of selecting and managing the proper material for study, of measuring, weighing and recording, segregating and computing data, will be greater than that involved in chemical and astronomical research in much the ratio that biology is greater in complexity than chemistry and astronomy.

The important administrative question arises, How is all this labor to be done? Undoubtedly much of it will be rather formal and routine and will not demand the highest ability in either biology or mathematics. At the same time, certain it is that the best results biologically would be missed without the constant maintenance, and that on a high plane, of the biological standpoint. It seems as though the demand for mathematical cleverness may be greater than the biologist is likely to possess. Sooner or later it will probably be found necessary for the somewhat mathematical biologist and the somewhat biological mathematician to join forces avowedly and regularly. Dr. Karl Pearson is furnishing a splendid example of how useful to biology the biologically inclined mathematician may be, and at the same time how disastrous it would be to the science to leave the quantitative aspects of it to workers whose chief training was mathematical rather than biological. On the other hand, among biologists, Dr. Raymond Pearl² particularly is showing that mathematics called to the service of biology and kept strictly in its place as an assistant, is not only enormously important, but for many of the deepest problems absolutely indispensable.

Probably these same organizational and administrative difficulties have been and are being felt by all the sciences that have passed from the descriptive and qualitative to the exact and quantitative stage; and probably, too, they will seem somewhat less formidable to biology as they are more closely approached than they do seen at a distance—just as appears to have been the case with the older sciences.

² Pearl more than anyone else among the considerable number of biologists who are now applying mathematics to biological problems with true insight and effectiveness, seems to me to deserve being mentioned because of his general discussions, especially that entitled "Biometric ideas and methods in biology, their significance and limitations (*Scientia*, 10, 101-119). So far as I have read, nothing approaching this paper in general grasp of the subject has appeared.

IV. RESEARCHES NOT YET UNDERTAKEN BUT ESPECIALLY INVITING BECAUSE OF NATURAL ADVANTAGES

So far the consideration of future work has had in view the restricted programme of the station which is being actually carried out. However a general forecast such as that now occupying us would be too narrow if reference were not made to scientific desirabilities and possibilities lying beyond the present programme.

1. *The migration of water birds and other phenomena of their life.* cursory observation of the water birds of the locality suggests that various problems of migration, feeding and breeding, might be taken up to excellent advantage. An ornithologist accompanying the "Agassiz" on her cruises could undoubtedly gain much information with little increase of expense beyond the salary and outfitting of the observer.

2. *The life of pelagic fishes.* The pelagic fishes offer innumerable problems that fall within the station's aims, and while under existing conditions these cannot be touched they should be kept constantly in view. Undoubtedly a combination of field and laboratory studies would be necessary for handling many of the problems, and keeping them in mind is likely to result in an attack upon them sooner or later.

3. *Animals that live on the sea-bottom.* Although expediency has led to the relinquishment for the present of work on the bottom-dwelling organisms, it would be a great misfortune to lose sight of the fact that researches in this vast field are quite as fundamentally part of the station's purpose as are investigations on the free-moving organisms. Nor should it be the design to hold aloof from this until the problems of pelagic life have all been taken up. The two domains touch each other at so many points and so intimately that it will probably be better to turn to certain questions of bottom life before many years, even though this can be done only by curtailing work on pelagic problems.

4. *The ultra-minute organisms of the sea.* Probably the most important field still untouched by the station, though particu-

larly within its ambitions, is that of the nannoplankton³ or dwarf plankton, in familiar terms the floating organisms of ultra-minute size. Under this head would come, at least as I am now using it, the bacteriology of the sea in the large sense, as well as the treatment of any other organisms or stages in the life-cycle of organisms that are so minute as to escape ordinary methods of capture and observation.

One of the main questions that arises in this domain is, if there be such a thing as a smallest species of organism in the sea, what are its characteristics, especially those of size, mode or nourishment, and of resistance to the destructive tendencies of its environment? This question, or rather series of questions, is not only legitimate from the standpoint of observational science, but is one the answering of which marine biology is now advanced to the position for attacking. And there are several easily recognizable points of attack: What may be found in sea-water by the extreme concentration of its floating particles through subjecting it to the centrifuge? What is there in the way of organic beings in the meshes of the finest filtering media through which water will pass, after large quantities of it have been filtered? What is there in the digestive tracts of animals which though themselves minute, live on others vastly more minute? What do many small pelagic animals feed upon, the digestive organs of which have so far furnished little or no evidence of food having been taken? What causes the patches of "slicky" or "greasy" water noticed by everybody familiar with the sea? What of the putrefactive bacteria of the carcasses of marine animals? Are living organisms of any kind taken ashore in the spray that is blown inland, often to considerable distances, on nearly all seacoasts almost all the time? If such transportations do occur, what is the fate of the organisms transported?

These are all questions not only of great interest in themselves but of still greater interest because of the illimitable vistas

³ For the introduction of this term (Greek *nannos*, dwarf) see H. Lohmann (*Internat. Revue d. ges. Hydrobiol. u. Hydrographie*, 4, 1-38). It may be doubted whether an appropriate name has been chosen for it, but Lohmann more perhaps than any other single investigator has made it clear that a great realm of biology exists here, the exploration of which has so far extended along its very margins only.

they open to the scientific imagination. For instance, what better experimental approach to the panspermia hypothesis advocated by Lord Kelvin, Professor Arrhenius and others, can be suggested than is here presented? If organic "germs"—better minute organisms—are carried about through all space, starting from and lodging upon the great bodies of the universe, here, there, everywhere, and all the time, what more promising place to hunt for those that may land on and pass from our earth, than the vast expanses of the sea which for eons have surely been both the germinating and the conserving beds of myriads upon myriads of organic beings?

Only a few years ago the notion of such universal dissemination of organisms could have had no standing outside the realm of poetic fancy. Now, however, that it is backed up by weighty scientific observation and deduction, and can be given a place in a soberly laid out programme of scientific investigation, one can hardly avoid stopping for a moment to ask, What after all is the difference between poetic imagination and scientific imagination? Is it not chiefly that the first runs on with a minimum of conscious reference to past objective experience and, rightly enough, neither asks nor cares much about future testing by the same sort of experience; while the latter demands a basis of considerable well-attested observations to start with, and looks forward to much rigorous testing by that same means? The interesting thing about this view of imagination is that according to it we are not dealing with two wholly distinct imaginations, but rather with one imagination used in two radically different ways. Science finds itself in a favorable position to realize the truth of this view when on rare occasions of which the present would seem to be one, it moves well to the front in some of its largest provinces. Incidentally it is wholesome to be led to see definitely that poetry and science, though so far asunder in their parts most remote from each other, really interblend in their nearest parts. Poetry has its truth primarily in man's imaginative and subjective nature and only secondarily in his objectively experiential nature; while science has its truth primarily in his objectively experiential and rational existence, and only secondarily in his imaginative and subjective existence.

V. THE QUESTION OF MAKING THE STATION AVAILABLE TO VISITING INVESTIGATORS

This is of great importance. Even though the idea upon which the institution immediately rests does not require us to consider it, yet the larger aims of biology will not allow it to go unheeded. From a strictly business standpoint the course we have followed and are following is nothing less than absurd. Unquestionably the work done by Child on the growth-capacity of the anemone *Harenactis*, and by Jennings on the activity capacities of the starfish *Asterias*, is not surpassed in scientific value by any yet done at the station. Yet when comparison is made between the cost of these investigations dealing with creatures than can be picked up on the shore with almost no effort, and others of approximately equal scope carried out as part of the station's regular oceanic-survey programme, the discrepancy against the programme work is seen to be so great as to make one fairly gasp when looking at the case from the business point of view. And the gasping is not likely to be alleviated by the reflection that in all probability, had the original aim been to promote work on the basis on which Child's and particularly Jennings's was done, the total output might have been increased in nearly the proportion that the cost of the programme work bears to the cost of independent work, the expenditure remaining what it has actually been. There is one way of justifying such a financially absurd situation that most men (men of science at any rate) would readily accept as sufficient, namely, by insisting that the valuation of knowledge of nature in terms of money is only one way, and that the least important, of estimating its worth. But this justification does not fully reach the present case. How justify the expenditure of large sums on a particular kind of scientific research when even less expenditure on another rather closely related kind, of no less intrinsic importance, will produce much larger returns? Justification in this case must be found by considerations that lie wholly within the realms of knowledge values; that is, that disregard money as a measuring stick. The justification comes easy and ample, according to my view, in the proposition that the widest gen-

eralizations which any science is capable of reaching never can be reached until the whole range of phenomena touched by such generalizations has been examined. I have expressed essentially the same conception but in a special application of it, in another place (1908) as follows: "No phenomenon essential to the life-career of any organism can be pronounced as fully explained so long as any other phenomenon likewise essential to that same life-career is entirely unknown or entirely ignored."

Brought down to an expression that fits the case in hand, this would say that the breadth and depth of biological philosophy which all biologists confidently believe possible, can never be obtained without the expansion of observational and experimental research to include, along with expansion in many other directions, just such knowledge of marine organisms as we are here obtaining and trying to obtain. In other words the practical, the business question is not, "In what field can we get the largest, quickest returns on the money invested?" but "What field is open to us and tillable by us that has been least cultivated and is least likely for various reasons to be cultivated by other instrumentalities?" Right or wrong, the course to which we are committed is that of turning such resources as we have to the supplementing of work already well in hand by other similar undertakings in various parts of the world. There are at least a half-dozen other marine biological stations in the United States, to say nothing of the much greater number in Europe, quite as well located and some of them at least much better appointed than is this station for the prosecution of such researches as the two above specified. But no other one in our country is in position, all things considered, to enable a biologist to carry out such researches as those, for instance, by Mr. Michael and Dr. Esterly.

But—and here is the important practical point—does the policy to which the station is committed rigidly exclude promotion, especially through the direct expenditure of money, of work of this independent, more generally provided-for sort? By no means. The truth is, within limits rather readily determinable in actual administration, such research may be furthered to a very considerable extent to the advantage of all interests

concerned, particularly those of the station, without in the least hampering the programme work.

VI. THE STATION'S ATTITUDE TOWARD INDUSTRIAL PROBLEMS CONNECTED WITH MARINE ORGANISMS

I cannot, perhaps, better state what I conceive to be the wisest course for the station in this behalf, than I have already done elsewhere (Ritter, 1911). Speaking of the coöperation of the station with the State Game and Fish Commission in studying the lobster problem, and with the Bureau of Soils of the national government in a survey of the kelp beds of this southern coast, both entered upon during the past summer, the following words were used: "These industrial undertakings are at present aside from the main aims of the station. This however is in no wise due to lack of sympathy on the part of the chief patrons and officials of the Biological Association with such undertakings, but entirely to the circumstance that under the present limitations of income it seems wisest to make research the primary object. Consequently whenever, as in these cases, it happens that equipment and experience can be made to serve industrial ends without considerable interference with research, the management is more than glad thus to extend the station's usefulness."

It is wiser for us now to make research primary and loaves-and-fishes problems secondary for the simple and very practical reason that the community—the state, the nation—to which this institution belongs, is in far greater need of intellectual, spiritual sustenance than it is of loaves and fishes. The time may come when this will not be true, when physical needs will be more pressing with our people than spiritual needs. But it is surely not so at present. Should that time come it would probably be wise to reverse the order of emphasis, to make industrial aims primary and research secondary. But it is greatly to be hoped that still further support and development of institutions of applied science, already so admirable among us, will do their full share toward putting off indefinitely the day when actual want of the means of physical well-being shall be so urgent as to hamper seriously the procurement of the wherewithal for spiritual well-being.

I. THE DUTIES TO THE PUBLIC OF RESEARCH INSTITUTIONS IN PURE SCIENCE

The reader will have recognized that although the station has up to the present devoted itself almost exclusively to research, an undoubted tendency has manifested itself to depart from this straight and narrow way. Elementary instruction was given to young people several summers; an aquarium and museum, open to the public free of charge, were maintained a number of years; from time to time popular lectures and demonstrations have been given by the investigators connected with the laboratory; recently relations have been entered into with the California State Game and Fish Commission and with the United States Bureau of Soils for the investigation of industrial problems pertaining to the sea; and in various less obvious ways efforts have been made to be of service outside the realm of pure science.

It seems desirable to place on record more fully than has hitherto been done the ideas held by the present scientific director touching the duties to the public of institutions for research in science generally and of this station particularly.

As a point of departure for what is to be said we take the assertion that science "for its own sake" as frequently understood is a false and unrealizable ideal. Science "for its own sake," art "for its own sake," wealth or anything else "for its own sake," if held without fundamental qualification, bears the germs of its own degradation if not of its death. Science can no more live "to itself alone" than can a human being. The fallacy prevalent here is in reasoning that because science and because art each has an exalted *intrinsic* nature and worth, it therefore has a nature and worth *quite apart from* its relation to other things and to men. Somehow it seems difficult to grasp the truth that the worth of science is in deepest essence *partly intrinsic* or resident and *partly extrinsic* and relative. However, that its essential worth is thus two-fold becomes obvious upon reflection.

On the one hand science has a nature of its very own. It is

not anything else whatever. It is not religion, it is not philosophy, it is not art of any kind, it is not mathematics, it is not commerce. At the same time, equally true is it that science never has existed nor can it be conceived wholly apart from the world of *other* interests. For instance, science simply could not be without objects of nature to operate on, and appliances such as instruments and chemicals and literature to work with. And more interesting still from the standpoint of method, verification and confirmation (almost always by more than one worker) are entirely essential to science. Science is as certainly communal as it is individual.

The communal functions of science on the material side are sufficiently recognized in what is known as Modern Civilization. The incalculable worth of "applied science," commonly so-called, for human life under this type of culture is questioned to only a negligible extent. There is no need of either exposition or apologetic on behalf of this aspect of science.

Not so with science in its relation to the higher, the spiritual life of man. Looked at from this standpoint it is truly surprising that the value attached to science should be so largely that of physical utility. To be sure, there is a rather general recognition that science, or certain aspects of it, is valuable for mental discipline, especially of the powers of observation. It is allowed, too, that science has an important function in delivering men from superstition. Beyond this little is claimed for science as a contributor to the higher needs and life of humanity. All along the line, educators, publicists, clergymen, politicians, journalists, and, surprisingly, scientific men themselves, appear to take it for granted that the office of science is primarily to minister to man's bodily needs, and secondarily to sharpen his wits. If anything beyond this comes from it, so current opinion holds, this is wholly incidental and secondary.

My belief is that science must justify its right to live and flourish, not alone in its ministrations to physical well-being, but also to the higher and highest reaches of man's nature. While I do not for a moment subscribe to the view held by a few, that science is everything, that by-and-by it will supplant religion, philosophy, ethics, art, and the rest, I am fully persuaded that

as civilization advances, it must become ever more and more an underpinning and ally of all these.

The distinction between an institution of applied science and one of pure science might be stated thus: The former is one the primary aim of which is to use certain more or less well-established truths and principles of science to the answering of man's needs and desires in certain well-defined directions. For example, the Bureau of soils of the United States Department of Agriculture is for the purpose of applying chemistry, physics, and geology to the end of increasing the productivity of the land of the United States. The Liverpool School of Tropical Medicine is for the "perfection of physicians in tropical hygiene" and for "investigations in tropical diseases." An institution of pure science, on the other hand, should be one the primary aim of which is to extend the bounds of man's knowledge of nature in a specified field, *and* to show something of the significance of the new knowledge for the higher life of mankind. To be more definite, an institution of research in biology or in astronomy could justify its existence, in a democratic country like ours, only by making considerable additions to knowledge and then by showing, in language comprehensible to the generally but non-technically educated members of the community, something of the meaning of this knowledge for human beings in both the physical and the spiritual aspects of their natures.⁴

I now mention certain biological discoveries and generalizations which have, as I believe, very great importance to civilized men but which are by no means as widely known as they ought to be and might be, and which can become thus known *only through the efforts of professional biologists*.

The significance of *omne vivum ex vivo* (*all life from preceding life*) not only for philosophic biology but for the attitude of thoughtful people generally toward the problems of practical

⁴The soundness of this view is dependent upon the soundness of two assumptions which cannot be argued here but which may be briefly stated: 1. The person of average natural endowment and education in the United States is capable of understanding the most essential things in any scientific discovery that has ever been made or is likely to be made for many years to come. 2. It does "matter" enormously not only to the individuals but to the nation as a whole, whether or not those who are capable of this much understanding have an opportunity to get it.

living, should be more clearly and firmly grasped than it has been. That the dictum is solely an expression of the summed-up results of technical science and practical experience; that so far it has not encountered the crucial "one exception" and hence ranks with gravitation as one of the best established of nature's laws; and that its unescapable implication is that the succession of living beings in nature was without beginning, that is to say, has come from an infinite past, are matters readily susceptible of popular presentation and may be counted on greatly to interest many people, were the subject to be presented by the biologist who himself had fully grasped the problems and clearly seen their significance for human life and conduct.

The generalization, based on an enormous range of observations, that *all organic beings, including humans, are subject in all aspects of their natures, to the principle of evolution*, needs to be and may be far more widely and firmly implanted in popular intelligence than it is; and its bearings on general ideas of progress, social and other, and on popular estimates of perfection and imperfection, are very important.

That biology has been forced through its own advances, to recognize that the *struggle-survival doctrine*, upon which she earlier staked so much as the cause of evolution, is *really of very subordinate importance in this way*, needs to be set forth to the general public far more emphatically and convincingly than it has been. Undoubtedly this strictly biological doctrine has been used to justify much cruel, destructive practice particularly in the industrial world, and now that biology herself has found the doctrine to be so largely erroneous, it would seem the bounden duty of biology to rectify as far as may be the harm that has been done.

The conception of "*the reign of law*"³ in the organic world

³ Were I pressed to say which of the "biological discoveries and generalizations" here mentioned is uppermost in the interest and effort of the present programme of the San Diego Station, I should almost certainly select this one of disseminating knowledge concerning the reign of law in the organic world. To learn more than we know about the laws that prevail in the wealth of life of the great oceans seems to me an object of the greatest importance for the general higher welfare of mankind. So slight is our knowledge in this domain relative to what future generations will possess, that all of us, professional biologists and the generally informed alike, look out upon the expanse of the sea with an impression concerning its inhabitants

ought to be much more widely and concretely established than it is in the public mind. Under stress of the necessity of dethroning notions of supernaturalism from living nature, biologists have up to now been so occupied with explaining phenomena in terms of *natural causation* that the *orderliness* of organic phenomena has had to take a back seat both in research and in speculation.

The well-established truth that apparently all organic beings have in nearly if not quite all their parts and functions *capacities far beyond those needed for ordinary life*, frequently far beyond what are ever used excepting under very unusual circumstances, is of great significance for a general theory of life. But being so comparatively recent a discovery, and standing in sharp contradiction to the widely prevalent views about the "economy of nature," and to the utilitarianism of the Darwinian theory of natural selection, it has as yet found little place in either the learned or the popular theories of life. The general enlightenment needed on this matter might come partly from teachers, secular and religious, partly from psychologists, but most basally from biologists.

The conception of "*the organism as a whole*" that has been forcing itself into biology, particularly from the side of embryology, is destined to have a far-reaching, elevating influence on general beliefs, attitudes and practices. There is no likelihood that the idea will be brought into the full light of day in any other way than at the hands of biologists. Poets and poetical humanists in all ages have had much to say about "the whole man," but the idea appears never to have germinated to the extent of greatly influencing the every-day lives of ordinary mortals. Biologists must be the original culturists here as they have been in so many other realms of things germinal.

(so far as we think of these at all) that is very vague and therefore meaningless and uninteresting. We conceive this vast wealth of life *en masse* as one may say; that is, our knowledge and thoughts about it are undifferentiated and chaotic. We take for granted in a hazy kind of fashion that some sort of order prevails. Such knowledge has little power for good, either practical or theoretical. Knowledge as to what this order is must be explicit before it can be very significant and interesting. It is just this sort of definite information that the San Diego Station is striving after.

The hypothesis that all phenomena of organic beings, including those pertaining to the very highest aspects of human nature, *are correlated with chemicophysical phenomena*, though not yet rigorously demonstrated in most of the subtler psychic and aesthetic provinces, is securely established over so wide a range of life phenomena and has thus far so well withstood rigorous efforts of disproof, that without doubt it has already greatly influenced general thought and attitude toward the deep problems of human life, and will more and more influence them. In a matter so vital, and one about which general intelligence is bound to be so widely astir for such information as can be had, it is of the greatest moment that information from the best sources should be readily available.

The laws of heredity, particularly those discovered by Mendel, have been tested to such an extent as to make them of positive moment to human life. The eugenics idea, started in England by Francis Galton, aims at a practical application of the known principles of inheritance to the good of the human race. In view of the wide theoretic interest attached to these laws, and to the possible good that may come from their application to the propagation of man himself, the intelligent, thoughtful members of the community could undoubtedly be far better instructed than they are. Not only the possibilities but the limitations of eugenics as a practical programme ought to be and might be presented in simple, readable language.

That *imperium in imperio* of human concerns, *the problem of the relation between the sexes* is calling almost frantically to the biologist for help at certain points where it is coming to see dimly that he alone can help. A few investigators are doing splendid things in this way, though what has been done is but as molecule to mountain relative to what remains undone.

Finally, without a doubt, *innumerable bald, unphilosophized facts of living nature that would entertain and instruct, and consequently keenly interest thousands upon thousands of generally intelligent persons, are buried in the technical language of biological narration and description beyond the possibility of extraction for such purposes except at the hands of biologists themselves.*

And undoubtedly many, perhaps not all, professional biologists are abundantly endowed by nature with the ability to do this extracting and preparing for general consumption. Acquiring the knack to do it is dependent first and foremost on being convinced that it ought to be done. The fact that many biologists develop splendidly the talent for graphic art in response to the need of illustrating the organisms and organs with which they deal, is proof positive that the art instinct is not wanting in them; and there is every reason to believe that this instinct would come out as literary skill here and there, as well as in the form of skill in delineation, were the need felt as keenly in the one case as in the other.

Assuming the contention to be sound that biological knowledge ought to be more widely disseminated than it is, and that so far as concerns the capabilities and desires of people such dissemination is possible, the familiar question arises, "What are you going to do about it?" "The schools!" Nine out of ten, I suppose, of those who would assent to my contention would turn automatically in this direction.

To forestall doubt about my just appraisal of the schools, the college, the university, in educating the young, I refer to an article ("Feeling in the interpretation of nature," *Pop. Sci. Mo.*, **79**, 1911) in which I have taken the ground that these instruments ought to and could, do vastly more than they do toward making the people appreciative of and intelligent toward nature. Here I would insist that no matter how efficiently and broadly the tasks of institutional instruction might be performed, they would still have to be extensively supplemented before the real saving power of knowledge could be realized. This supplementing would have to be done in two places particularly: In the home for young children before school age is reached; and for grown-ups after the school period is passed.

Our eyes must be opened in some way to the fact that education taken in the full sweep of its meaning, is too life-and-death a matter for us as a nation to be left to the formalities of the schoolroom, the university lecture hall and the laboratory, even though these be excellent beyond the possibility of improvement. This truth is being forced upon us at a few points. As one

instance, it is becoming clear that wider instruction on sex matters is imperative, and that parents and the home primarily, and the school secondarily, must be looked to for the broader, better knowledge. Again, the simply incalculable power of the press and the speaker's platform for educating and influencing the voting part of the population are recognized and resorted to upon occasion.

I may now state my views summarily: Biological science, as now developed, contains numerous facts and generalizations of very great moment to the higher intellectual and spiritual life of the people generally. The essence of all these can be stated in language readily comprehensible to persons of average intelligence and education. Most if not all these facts and generalizations are of such nature as to make their strongest appeal to the majority of people only from their bearings on problems of personal experience, so that in the nature of the case they can be of living interest and significance to such persons only after the period of formal schooling is past and the business of actual living is on. Instruction concerning them must, consequently, be given by other means than the school. Some of the most important instrumentalities for such instruction are the botanical and zoological garden, the natural history museum, the aquarium, the library, the lecture platform, and in some ways most important of all, the public press.

And now for the culminating point: In the main the instruction given through all these instrumentalities must be by *professional biologists*. It will never be done well, that is, in a manner at the same time vivacious, convincing, and dependable, by persons who have merely "read up" on biology with nothing but an elementary training to start from. Only persons constantly occupied with the first-hand gathering of data, with the making and testing of hypotheses, and with the submitting of results and conclusions to fellow-workers for criticism and verification, can do the safest teaching in these ways.

Here comes not only the opportunity but the obligation of those whose vocation is in research institutions. The university teacher may generally be considered to have done his share when in addition to his research work he has instructed his

regular classes. Those, on the other hand, whose lots are cast in institutions of research, being relieved of the round of duties incident to the university professorship, would seem to be marked as the ones to use such instruments of general education as are most suitable for reaching the great public outside the schools and colleges. The press, as already said, is probably the most available and powerful of all such instrumentalities.

I would not be understood to mean that every person regularly employed by institutions of research in non-industrial science should be held responsible for a certain amount of popular writing or lecturing or arranging of collections or the like. Such an idea put into practice would undoubtedly carry disaster in its train not alone to the institutions but to the cause designed to be promoted. My view is that these institutions, as *institutions*, ought to hold themselves obliged, from time to time, to give out in a form readily accessible to and comprehensible by the rank and file, the results of their most significant achievements. Indeed, I am willing to go a step farther and say that such institutions might well be held to something of the sort by their boards of administration. I am persuaded that such a course would be, in the long run, not only not obstructive but actually promotive, of the work of investigation itself.

It is true something in this way is being done by some, possibly all, of the research foundations of the country. But in very few if any, so far as I can judge, is the doing accepted as a weighty obligation and as a set policy. So it happens that what is done is an exceedingly small fraction of what ought to be and might be done.

Under its present management, the Marine Biological Station of San Diego holds duties in this direction to be as incumbent upon it as are those of making discoveries about the Pacific Ocean and the things that live in it.

Submitted December 28, 1911.

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APPENDIX A

ARTICLES OF INCORPORATION OF THE MARINE BIOLOGICAL
ASSOCIATION OF SAN DIEGO

KNOW ALL MEN BY THESE PRESENTS, that we, the undersigned, a majority being citizens and residents of the State of California, have this day voluntarily associated ourselves together for the purpose of forming a corporation under the laws of the State of California, and we hereby certify:

1. That the name of said corporation is the "MARINE BIOLOGICAL ASSOCIATION OF SAN DIEGO."

2. That the purposes for which said corporation is formed are:

(a) To succeed to all the rights, property, and privileges held by the Association designated the "Marine Biological Association of San Diego."

(b) To carry on a biological and hydrographic survey of the waters of the Pacific Ocean, adjacent to the coast of Southern California; to build and maintain a public aquarium and museum; and to prosecute such other kindred undertakings as the Board of Directors of said corporation may, from time to time, deem it wise to enter upon.

(c) To transfer the whole or any part of the properties, rights, and privileges of said corporation to the Regents of the University of California, the same to become a department of the said University, coördinate with its already existing departments, and to affiliate with said University.

(d) To acquire by purchase, gift, or otherwise, and to hold and dispose of all kinds of properties, both real and personal.

3. That the place where the principal business of said corporation is to be transacted is in the City of San Diego, County of San Diego, State of California.

4. That the time for which said corporation is to exist is fifty years from and after the date of its incorporation.

5. That the number of directors of said corporation shall be seven, and the names and residences of the directors, who are hereby appointed and elected for the first year to serve until their successors are elected and qualified, are as follows, to wit:

Names	Residences
Homer H. Peters	San Diego, California.
Ellen B. Scripps	San Diego, California.
W. E. Ritter	Berkeley, California.
Julius Wengenheim	San Diego, California.
Fred Baker	San Diego, California.
E. W. Scripps	West Chester, Ohio.
Jas. MacMullen	San Diego, California.

6. That the above named directors were duly elected at a meeting of the members of said Association, duly convened and held in the room of the Chamber of Commerce of San Diego, County of San Diego, State of California, on the 3rd day of May, 1904, for the purpose of forming this corporation; and of electing directors to take charge of, and the management of its property and affairs, and to form this corporation; that a majority of the members of said Association were then and there present and voted at said meeting and election for the above-named directors; and as a result of said election, the above-named persons were unanimously elected directors of said corporation.

7. That this corporation is not formed for the purpose of pecuniary profit; that there are no shares, no capital stock, and no subscription to stock or shares by any person.

IN WITNESS WHEREOF, we have hereunto set our hands and seals this 5th day of May, 1904.

ELLEN B. SCRIPPS
E. W. SCRIPPS
JULIUS WANGENHEIM
W. E. RITTER
JAS. MACMULLEN
FRED BAKER
HOMER H. PETERS

APPENDIX B

BY-LAWS OF MARINE BIOLOGICAL ASSOCIATION OF SAN DIEGO, A CORPORATION

I

The name and purpose of this corporation are those set out in its Articles of Incorporation.

II

The officers of this corporation shall be a President, Vice-President, Scientific Director, Secretary and Treasurer.

III

The officers of this corporation shall be elected at its regular annual meeting, which shall be held on the second Tuesday of July of each year, at ten o'clock A.M.; and it shall not be necessary to give any notice of such annual meeting.

The officers shall hold office for one year and until their successors shall have been duly elected.

IV

The Board of Directors shall have power to fill vacancies in the offices, arising from any cause. It shall be their duty to carry out the purpose of this corporation. They shall have full control of all funds of the corporation, and the management of the institution. They shall

make a full report of all moneys received and disbursed and of the affairs of the institution at each annual meeting. They shall have power to elect new members of the corporation, a majority of the directors being requisite for such election.

The President and Vice-President, or any three members of the Board shall have the power to call a special meeting of the Board, or of the corporation at any time, by depositing in the United States Postoffice at San Diego, a notice addressed to each member of the Board or of the corporation, postage thereon being prepaid, two days before said meeting; and special meetings of the members of the corporation may be called on the written request of one-half of the members of the Association, and like notice of said meeting shall be given.

V

The Board of Directors may, at any time, fix a limit to the number of members of the corporation, provided, however, that this limit shall never be less than twenty-five (25).

VI

These by-laws may be amended by two-thirds vote at any regular or special meeting of the members of the corporation, notice of the proposed amendment having been mailed to each member of the corporation at least fifteen (15) days before the meeting at which a vote on said amendment is to be taken, or in the manner provided by the general laws of the State of California.

The foregoing by-laws are hereby adopted and approved this 23rd day of May, 1904.

 APPENDIX C

 RESOLUTION RELATING TO THE PURPOSES OF THE MARINE
 BIOLOGICAL ASSOCIATION

At the annual meeting of the Marine Biological Association of San Diego held July 20, 1907, the following resolutions, presented in substance by Mr. E. W. Scripps, were unanimously adopted:

Whereas this Association desires to acquire pueblo lot 1298 containing about 160 acres, now owned by the City of San Diego, and

Whereas some explanation may be due to the City Council and public of San Diego as to the Association's need for so large a tract of naked land,

Therefore be it resolved, That this Association set forth its plans and intentions with reference to the future development of the Biological Station as follows:

1. It is declared that said land would be owned by and for the exclusive use of the Biological Association, until such time as the ownership and management of this as of all the belongings of the Association shall pass to the Board of Regents of the University of California in

accordance with a provision in the articles of incorporation of the Association.

2. It is proposed to erect for the scientific work of the station a commodious, imposing structure, one section of which will be built at once at a cost of about twenty thousand dollars. This will give some idea of the nature of the structure when finally completed, and its need for adequate setting.

3. The next step will be the erection of cottages for the accommodation of the various attaches, including a number of University of California professors.

4. The erection of other buildings for the housing and accommodation of visiting naturalists and scientists who will engage in the work here at various seasons.

5. It is proposed not to restrict biological research at the station to marine organisms as has thus far been done, but to extend it to land plants and animals as well. This would necessitate the creation of experimental culture plots, propagation grounds and houses, animal paddocks and run-ways, herbarium and museum buildings, and various other instrumentalities usual to such investigations, all of which require much ground space.

Briefly, it is the intent of these resolutions to inform the public that while at present the Association has not sufficient funds to enable it to carry out all its designs, it is its purpose to create on this foundation an institution of biological research the bounds for the expansion of which shall have no limits except those of biological science itself, and such as may be set by limitation of means and facilities.

APPENDIX D

LIST OF INVESTIGATORS WHO HAVE WORKED AT THE STATION

Ackert, J. E.	University of Illinois.
Allen, Dr. Bennet M.	University of Wisconsin.
Allen, W. E.	University of Nebraska.
Bailey, S. E.	University of California.
Bancroft, F. W.	University of California.
Billinghurst, B. D.	Prescott, Arizona (Sup't of Public Schools).
Bovard, J. F.	University of Oregon.
Burbridge, W. C.	Stanford University.
Carlson, A. J.	Stanford University.
Child, Dr. C. M.	University of Chicago.
Cockerell, Dr. T. D. A.	Las Vegas, New Mexico.
Coe, Dr. Wesley R.	Yale University.
Colton, Dr. Harold S.	University of Pennsylvania.
Congdon, Edna	University of California.
Cort, W. W.	University of Illinois.
Crandall, W. C.	San Diego State Normal School.

Crocker, Gulielma R.	University of California.
Davis, Dr. B. M.	Los Angeles State Normal School.
Davis, D. W.	University of California.
Esterly, Dr. C. O.	Occidental College.
Evans, Herbert M.	University of California.
Foote, Ethelwyn	Pasadena, California.
Gutberlet, J. E.	University of Illinois.
Henderson, Margaret	University of California.
Hindle, Dr. Edward	School of Tropical Medicine, Liverpool, Eng.
Hubbard, Marian	Wellesley College.
Jennings, Dr. H. S.	Johns Hopkins University.
Johnson, Dr. H. P.	University of California.
Johnson, Myrtle	University of California.
Johnson, Riley O.	Chico State Normal School.
Juday, Dr. Chancey	University of Wisconsin.
Kleeberger, Frank	University of California.
Kofoid, Dr. C. A.	University of California.
Linville, Dr. Henry R.	Jamaica High School, New York.
Long, Dr. J. A.	University of California.
Mark, Dr. E. L.	Harvard University.
Marine, Dr. David	Western Reserve University (Medical Dep't).
Martin, Ann	University of California.
McClendon, Dr. J. F.	Randolph Macon College, Virginia.
McEwen, Dr. G. F.	Stanford University.
Mereschkowsky, Dr. K. S.	University of Kasan, Russia.
Michael, Ellis L.	San Diego Marine Biological Station.
Miller, L. H.	Los Angeles State Normal School.
Monks, Sarah P.	Los Angeles State Normal School.
Moore, Fred	University of Iowa.
Morgan, Dr. T. H.	Columbia University.
Morris, B. L.	Stanford University.
Nichols, Maurice B.	University of California.
Nutting, Dr. C. C.	University of Iowa.
Oldroyd, Mrs. T. S.	Long Beach, California.
Paden, Agnes	University of California.
Powers, Dr. J. H.	University of Nebraska.
Raymond, Professor W. J.	University of California.
Reese, Dr. A. M.	University of West Virginia.
Rimmel, A. J.	University of California.
Richardson, Grace	Oceanside, California.
Rigden, E. Josephine	University of California.
Ritter, W. E.	San Diego Marine Biological Station and University of California.
Robertson, Dr. Alice	Wellesley College.
Shelford, Dr. V. E.	University of Chicago.
Starks, Dr. E. C.	Stanford University.
Stevens, Dr. Nettie M.	Bryn Mawr College.
Stokes, Susan	Orange, California.
Streedain, A. B.	University of California.

Stringer, Miss Caroline	Omaha High School.
Torrey, Dr. H. B.	University of California.
Toy, Susie M.	Oceanside, California.
Turrentine, R. J.	Mt. Vernon, Missouri.
Van Orden, Dorothea	University of California.
Von Geldern, C. E.	University of California.
Ward, Dr. Henry B.	University of Illinois.
Watson, Dr. Edna Earl	University of California.
Wells, Clarence W.	University of California.
Williams, Dr. R. D.	University of California.
Williamson, Mrs. Burton	Los Angeles, California.
Wilson, Dr. E. B.	Columbia University.
Young, Helen	University of California.

APPENDIX E

ADVANTAGES AND DISADVANTAGES OF THE POSSIBLE LOCATIONS CONSIDERED BEFORE THE DECISION WAS REACHED IN FAVOR OF LA JOLLA

CORONADO

<i>For</i>	<i>Against</i>
1. Accessibility.	1. Difficulty of getting good ocean water.
2. Living facilities.	2. Poor quality of bay water.
3. Safety of small boats.	3. Difficulty of landing large boats in ocean or bay.
4. Convenience for mud-flat collecting.	4. Remoteness of rocky collecting grounds.
5. Bay plankton.	5. Remoteness from oceanic conditions.

ROSEVILLE

1. Safety and convenience for all kinds of boats.	1. Inaccessibility.
2. Convenience to rocky collecting grounds.	2. Living facilities.
3. Convenience to mud-flat collecting grounds.	3. Remoteness from ocean water.

LA JOLLA

1. Accessibility to oceanic conditions, deep water, plankton, etc.	1. Unsafety of boats, small and large.
2. Good ocean water for aquaria.	2. Distance from mud-flat collecting.
3. Rocky collecting grounds.	
4. Accessibility.	
5. Living facilities.	

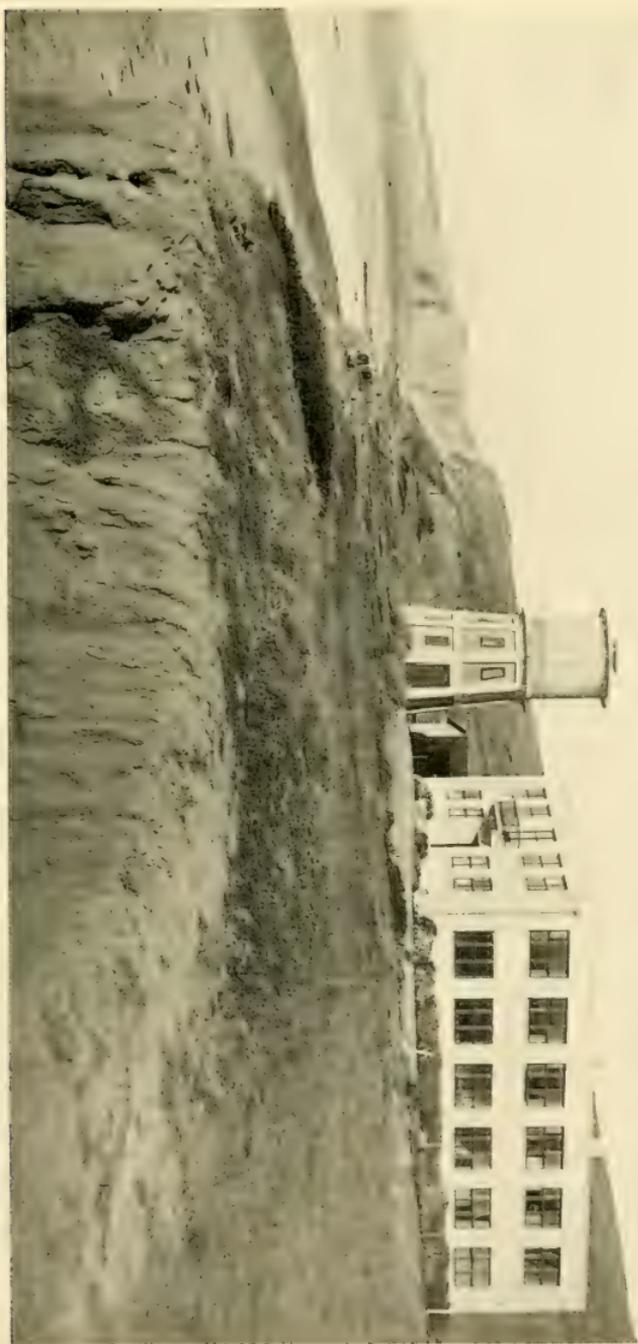


Fig. 1. Marine Biological Station at La Jolla, viewed from the south.

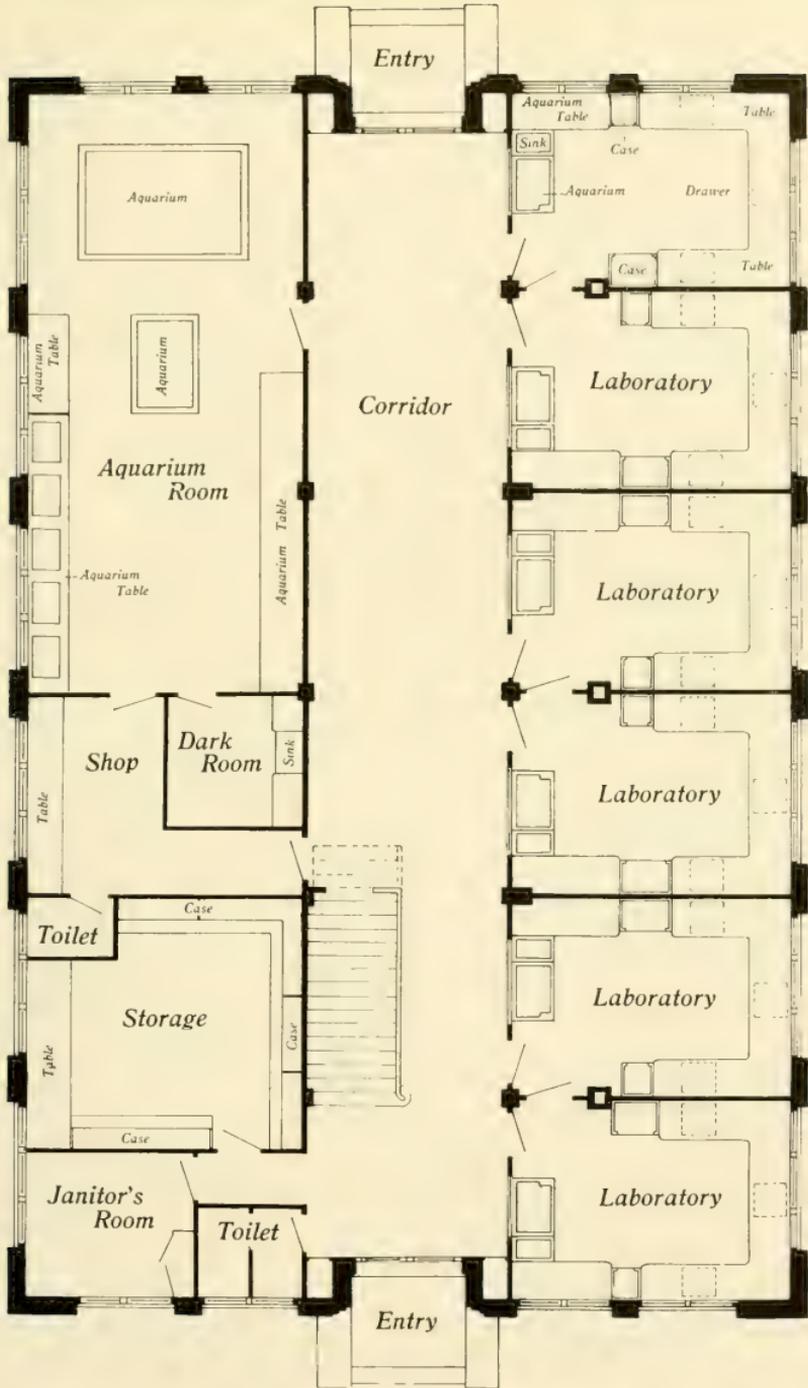


Fig. 2. Ground floor plan of Laboratory.

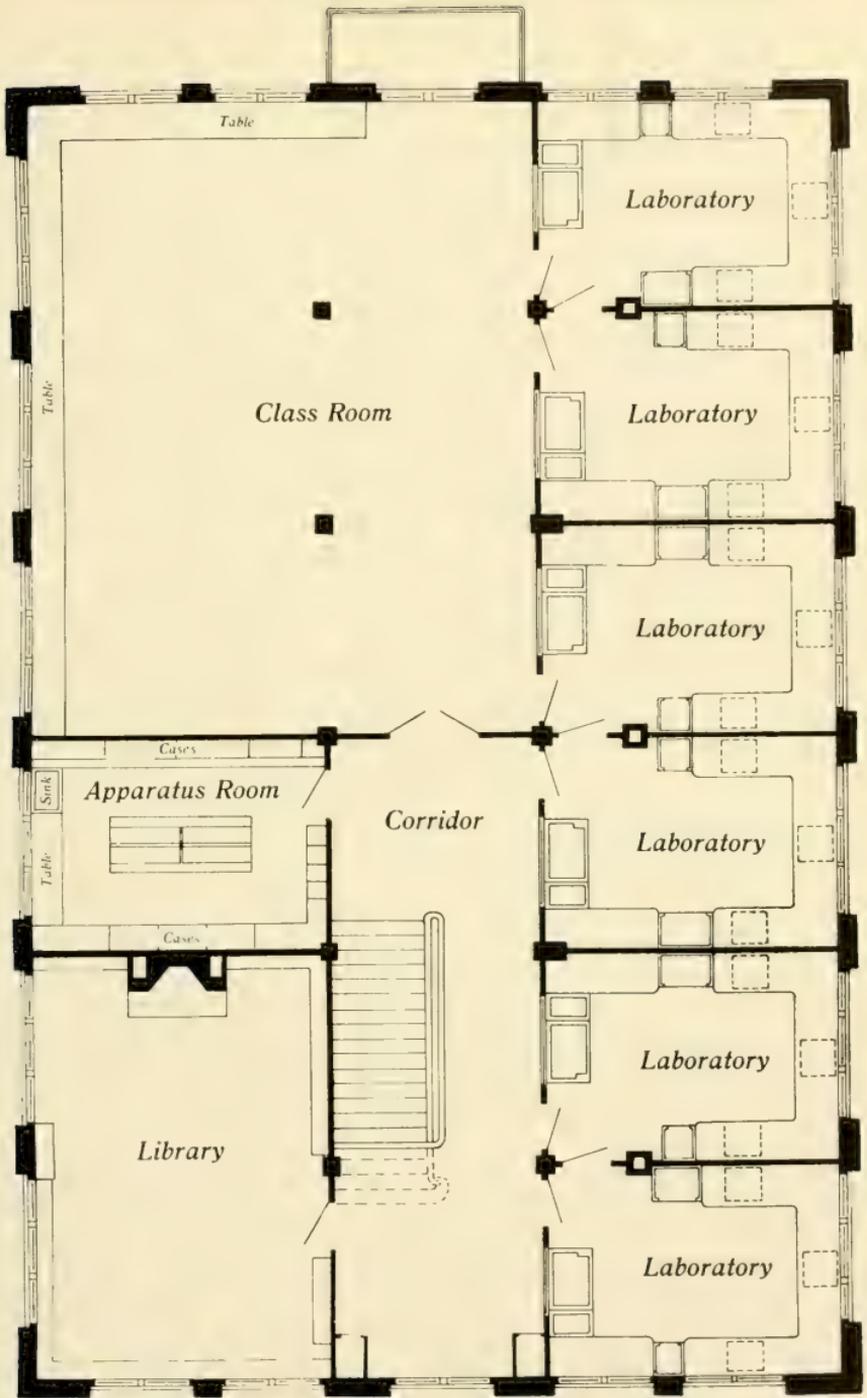


Fig. 3. Second floor plan.

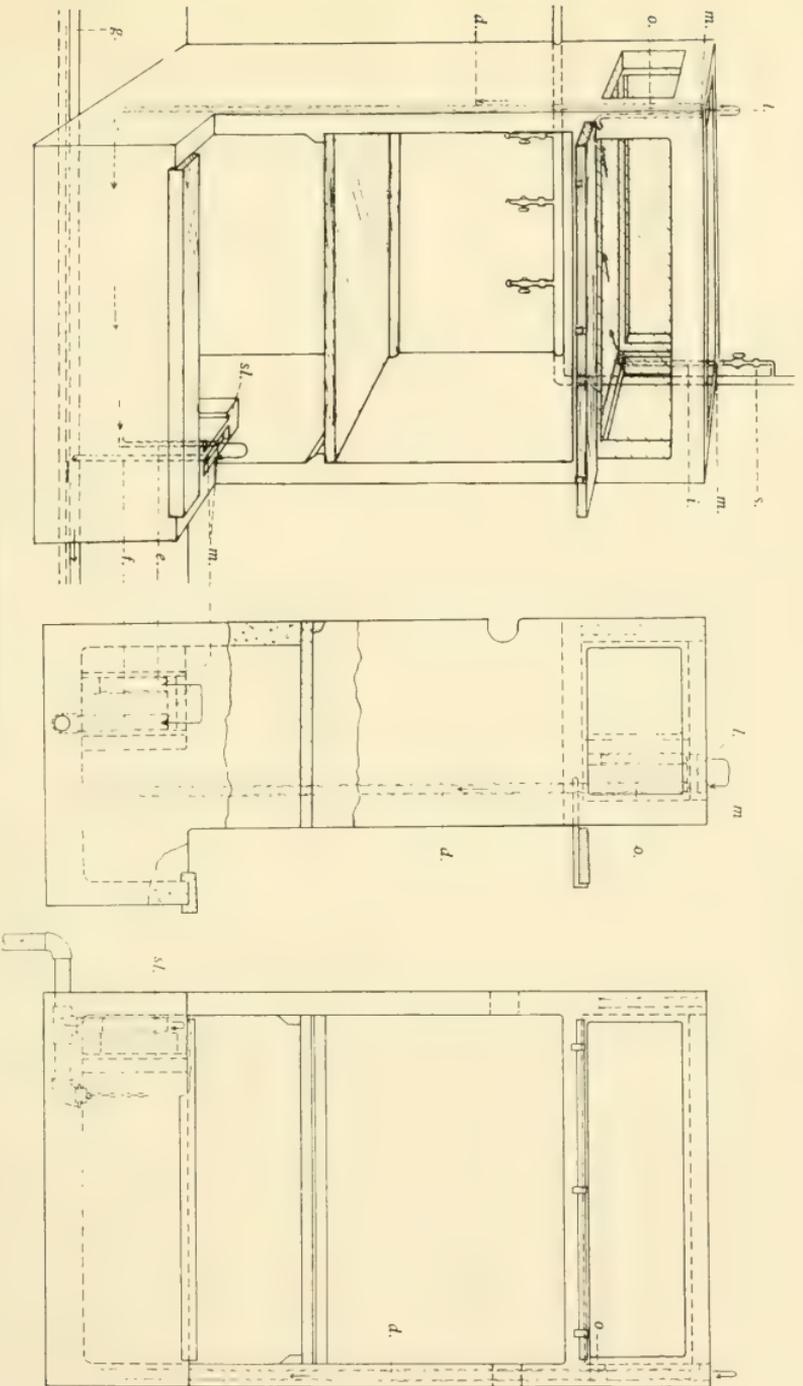


Fig. 1. Diagrams of private research aquarium. A, front; B, end; C, back.



Fig. 5. The "Alexander Agassiz" as she is now.



Fig. 6. Deck view of the "Alexander Agassiz" before she was remodeled.



Fig. 7. View of one corner of the Library.



Fig. 8. View of one corner of Reagent and Collection Room showing arrangement of general working plankton collections.



Fig. 9. Marine Biological Station viewed from the hillside to the northeast, showing La Jolla Point.



Fig. 10. Topographic map from Point Conception to Mexico, showing coast, islands and sea-bottom. Compare with Outline Map 1.

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May 29, 1912

OXYGEN AND POLARITY IN TUBULARIA

BY
HARRY BEAL TORREY



UNIVERSITY OF CALIFORNIA PRESS
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May 28, 1912

OXYGEN AND POLARITY IN TUBULARIA

BY
HARRY BEAL TORREY

It is a familiar fact to students of regeneration that in the regeneration of a segment cut from a stem of *Tubularia*, two hydranths are produced, one at each end of the piece (which is then termed heteromorphic), and that the distal hydranth appears earlier than the proximal. It is also well known that the development of the proximal hydranth can be accelerated by ligating the stem at almost any level.

According to Loeb (1904) this acceleration is connected causally with the diversion by the ligation of the currents circulating in the stem. I have attempted to show (1910), however, that it is due to quite another effect of the ligation, namely, the suppression of the regeneration of hydranths at the ligation on either side owing to an inadequate supply of oxygen at these points. The same proximal acceleration, associated with the same suppression of distal development, may be produced, as Loeb (1906) long ago pointed out, by burying the distal ends of the stem segments in sand. The proximal ends thereupon produce hydranths more rapidly than would have been the case had oxygen had free access to the distal ends. Loeb's surmise that "lack of oxygen is responsible for the fact that no polyp can be formed except at a free end of a stem, since the chitinous surface of the stem is very little permeable for oxygen," is clearly supported (see Torrey, 1910) by the following facts: (1) in *Corymorpha*, the stem is naked, and hydranths do develop *at the ligation*, that is, *immediately below it*; (2) in *Tubularia*, development can be suppressed at either end of the stem by slipping over

that end a glass cap, the suppression of the distal hydranth being coupled with an acceleration in the development of the proximal hydranth. The latter experiment is open to the possible objection that while preventing oxygen from diffusing inward, the glass cap might hinder the diffusion of gases from the stem outward.

A recent experiment, however (performed during a laboratory course in experimental zoology with the coöperation of several students) shows that this objection is not valid, and points conclusively to the supply of oxygen as the essential factor in determining the result.

The method employed consisted in separating by a partition two bodies of sea water that should differ only in the absence of oxygen from one of them, and then passing segments of *Tubularia* stems through perforations in the partition so that approximately equal lengths should project on either side of it, their distal ends being immersed in the deoxygenated water. The simple device used to obtain these conditions was composed of a small battery jar and, fitting snugly into it, a crystallizing dish whose bottom had been removed and a sheet of soft paraffine about 5 mm. thick substituted for it. A portion of water boiled a few minutes to remove the contained oxygen completely filled the battery jar below the paraffine plate. Another portion of the same boiled water, but aerated by pouring from one dish to another, almost filled the crystallizing dish above the paraffined plate. The *Tubularia* stems were so placed that their distal ends projected downward into the de-aerated water, their proximal ends upward into the aerated water. As a control, the previous conditions were duplicated with the difference that aerated water only was used.

Accordingly, two sets of nine pieces each, approximately 2 cm. long and equal in size and vigor, were arranged as described. Sixteen hours later the control pieces possessed six distal, but no proximal hydranths; the other pieces, on the contrary, possessed two proximal but no distal hydranths. Four hours later, seven distal hydranths and six proximal had appeared in the control; on the other pieces there were now five proximal, but still no sign of distal hydranths. Three hours later the control pieces were apparently in the same condition, while in the other dish a

sixth proximal hydranth had emerged and a seventh was emerging. In the same dish, sixteen hours later, all nine proximal hydranths were out, but still no distals; nor did distals show any sign of developing in the de-oxygenated water for two days longer, when the experiment terminated. The control pieces ultimately developed nine distal and seven proximal hydranths, two failing to develop proximally.

It is obvious from these brief records that not only was lack of oxygen hindering the development of the distal hydranths in one set of stems, but the proximal ends of these stems were developing more rapidly in consequence; and this when all possible influence of ligatures or contact stimuli had been removed.

Transmitted April 22, 1912.

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THE OCCURRENCE AND VERTICAL DIS-
TRIBUTION OF THE COPEPODA OF
THE SAN DIEGO REGION
WITH PARTICULAR REFERENCE TO NINETEEN
SPECIES

BY
CALVIN O. ESTERLY

UNIVERSITY OF CALIFORNIA PRESS
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This paper is the second from the Marine Biological Station at La Jolla dealing with the distribution of plankton animals. The first is that by Michael (1911) which contains data for certain hauls that will be used by later writers. It is proposed, accordingly, to refer to that paper when it gives the data for any hauls used in this one. Michael and I made no attempts to use the same hauls, and for various reasons our lists are somewhat different. In a good many cases, however, we worked over the same collections, and where that is true I have stated where the data for those hauls may be found in Michael's paper. On account of its earlier appearance, Michael's paper does not cover so many of the collections made by the station as does mine.

I have followed the plan originated by Michael and arranged the data in four sections, the surface hauls being tabulated first, those with the horizontal closing nets second, then the hauls with vertical closing nets and last those with open vertical nets. Temperatures and salinities are given for surface hauls only, but one may gain some idea of the general relation between depth, temperature and salinity from McEwen (1910).

The various nets used in collecting are referred to in the tables by letters, as follows:

- A. Surface net of 000 XX mesh silk bolting cloth; the orifice of the net being 97.5 cm. in diameter.
- B. The Kofoid horizontal closing net, the material the same as above, the orifice of the net being 37.5 cm. in diameter.
- C. The "small" Nansen net, of 1 XX silk bolting cloth, the orifice about 45 cm. in diameter.
- D. The "large" Nansen, of the same mesh as net C, but the orifice 109.5 cm. in diameter.
- E. A Nansen net of 0 XX bolting cloth, the orifice of the net 62.5 cm. in diameter.
- F. The "000" Nansen, of 000 XX bolting cloth and 62.5 cm. across the mouth.

It should be noted here that in Michael's paper there has been a slight error in not distinguishing between nets C and D of the list above. He designates both nets of No. 1 silk as net C in his list, when really some of the hauls in his Tables 30 and 32 were made with the large Nansen net (D above). Since reference is made from this paper to Michael's, the following in his

list of hauls with the horizontal closing nets (Tables 30 and 31) should be noted as made with the small Nansen net:

1668, 1677, 1708, 1725, 1770, 1785, 1788, 1789, 1792, 1793, 1793, 1794, 1797, 1798, 1801, 1802, 1805, 1806, 1827, 1827, 1833, 1841.

In Tables 32 and 33 (Michael) the following hauls were made with the small Nansen:

1989, 1990, 1994, 1995, 1996, 2013, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2100, 2104, 2108, 2112, 2113.

The first of the hauls I used were made in June, 1905, and the last in August, 1911; there are none in 1907. These include practically all the collections made by the station; a few hauls have been lost, some were omitted because of lack of data. Nearly all the hauls I used were made during June, July and August, though there are some in the spring, fall and winter months. The following arrangement shows how the collections are distributed with respect to season.

TABLE 1
Distribution of hauls through the year

Year	Month	Number of hauls			
		Surface	Horizontal Closing	Vertical Closing	Vertical Open
1905	June	.....	.....	.....	5
	July	.....	.....	.....	6
	December	.....	.....	.....	1
1906	June	6	.....	.....	14
	July	8	.....	.....	17
1908	June	16	.....	.....	5
	July	15	9	.....	5
	August	2	.....	.....	.....
1909	February	1	.....	.....	.....
	June	26	28	.....	.....
	July	26	.....	.....	.....
	August	.....	54	.....	.....
	September	6	7	.....	.....
1910	November	4	14	.....	.....
	February	5	.....	7	.....
1911	March	15	.....	34	.....
	April	5	.....	18	.....
	August	10	.....	.....	.....
	June	42	.....	172	.....
	August	18	.....	69	.....

In table 2, which follows, is a list of surface hauls (net A) and the data for them. These hauls were not used by Michael. The salinity is given wherever it is known. Temperatures are in degrees centigrade, and when two temperatures are given the first is that at the beginning of the haul, the second that at the end.

TABLE 2
Data for hauls with the surface net (Net A)

Haul Number	Date	Time of day	Duration minutes	Temperature of water	Salinity of water	North Latitude	West Longitude
1906							
1106	June 21	4:55- 5:20 a.m.	25	21°4	.....	32° 51'0	117° 19'0
1119	June 25	4:57- 5:22 a.m.	25	.....	.....	32° 51'6	117° 18'8
1125	June 26	4:15- 4:45 a.m.	30	21°1	.....	32° 53'4	117° 23'6
1137	June 27	4:50- 5:10 a.m.	20	21°4	.....	32° 51'5	117° 17'6
1158	June 29	5:15- 5:50 a.m.	35	19°9	.....	32° 51'7	117° 17'0
1168	June 29	6:00- 6:25 a.m.	25	20°4	.....	32° 51'6	117° 17'4
1180	July 2	6:10- 6:30 a.m.	20	20°9	.....	32° 52'3	117° 16'7
1190	July 3	5:10- 6:00 a.m.	50	20°4	.....	32° 52'6	117° 18'8
1210	July 6	6:15- 6:45 a.m.	30	29°4	.....	32° 51'2	117° 17'1
1224	July 6	7:00- 8:00 p.m.	60	.....	.....	About La Jolla	
1309	July 18	12:50- 1:15 p.m.	25	.....	.....	32° 50'9	117° 25'5
1321	July 19	2:20- 2:45 p.m.	25	.....	.....	32° 47'5	117° 25'0
1345	July 21	1:10- 1:35 p.m.	25	.....	.....	32° 52'5	117° 26'5
1357	July 23	11:35-12:00 a.m.	25	.....	.....	32° 52'8	117° 21'9
1908							
1488	June 25	8:25- 9:15 a.m.	50	18°6	33.630	32° 55'2	117° 21'4
1504	June 26	12:25-12:50 p.m.	25	20°0	33.617	32° 38'8	117° 29'9
1532	July 7	9:30-10:30 a.m.	60	19°1	.....	32° 52'8	117° 19'0
1910							
2204	Aug. 14	3:00- 3:30 p.m.	30	19°4	33.693	32° 46'6	118° 21'9
2207	Aug. 16	10:15-10:50 a.m.	35	20°6	33.603	32° 23'4	117° 24'2
2213	Aug. 16	5:29- 6:10 p.m.	41	20°4	33.621	32° 23'4	117° 24'2
2219	Aug. 16	6:20- 6:54 p.m.	34	20°3	33.630	32° 23'4	117° 24'2
2224	Aug. 16	6:58- 7:07 p.m.	9	20°3	33.630	32° 23'4	117° 24'2
2228	Aug. 16	8:05- 8:30 p.m.	25	20°2	33.589	32° 23'4	117° 21'9
2242	Aug. 17	11:54 a.m.-12:08 p.m.	14	20°2	33.613	32° 23'4	117° 18'2
2259	Aug. 17	6:56- 7:28 p.m.	32	20°1	33.567	32° 23'4	117° 24'2
2264	Aug. 17	7:30- 7:56 p.m.	26	20°0	33.540	32° 24'2	117° 24'2
2271	Aug. 17	8:52- 9:21 p.m.	29	19°9	33.585	32° 23'4	117° 21'3

TABLE 2—Continued

Haul Number	Date	Time of day	Duration minutes	Temperature of water	Salinity of water	North Latitude	West Longitude
2295	June 14	5:00- 5:40 a.m.	40	16°9	.....	32° 22'2	117° 21'6
2313	June 14	6:05- 7:55 a.m.	110	16°8	.....	32° 22'2	117° 21'6
2316	June 14	10:00-11:00 a.m.	60	17°0	.....	32° 22'4	117° 21'2
2328	June 14	11:00-12:00 a.m.	60	17°0	.....	32° 22'4	117° 21'2
2331	June 15	1:30- 2:20 a.m.	50	16°6	.....	32° 22'7	117° 19'2
2343	June 15	2:35- 3:25 a.m.	50	16°5	.....	32° 22'7	117° 19'2
2346	June 15	4:23- 5:07 a.m.	44	16°7	.....	32° 22'7	117° 19'2
2351	June 15	5:10- 6:25 a.m.	75	16°5	.....	32° 22'7	117° 19'2
2361	June 15	7:05- 8:05 a.m.	60	16°8	.....	32° 22'7	117° 19'2
2365	June 15	8:20- 9:25 a.m.	65	16°7	.....	32° 22'7	117° 19'2
2376	June 16	1:50- 2:30 a.m.	40	16°9-16°6	.....	32° 23'5	117° 18'0
2391	June 16	4:15- 4:45 a.m.	30	16°8	.....	32° 23'4	117° 18'0
2395	June 16	4:50- 5:45 a.m.	55	16°8-16°6	.....	32° 23'5	117° 18'0
2407	June 16	5:55- 6:20 a.m.	25	16°8	.....	32° 23'5	117° 18'0
2410	June 16	6:45- 7:30 a.m.	45	.....	.....	32° 23'5	117° 18'0
2415	June 16	8:25- 9:43 a.m.	78	17°0	.....	32° 23'5	117° 18'0
2427	June 17	1:45- 2:25 a.m.	40	17°2-17°1	.....	32° 22'4	117° 21'2
2431	June 17	2:30- 4:00 a.m.	90	17°1	.....	32° 22'4	117° 21'2
2442	June 17	4:35- 5:00 a.m.	25	17°1	.....	32° 22'4	117° 21'2
2446	June 17	5:05- 6:10 a.m.	65	17°0	.....	32° 22'4	117° 21'2
2457	June 17	6:55- 7:38 a.m.	43	16°9	.....	32° 22'4	117° 21'2
2461	June 17	7:45- 8:30 a.m.	45	16°9	.....	32° 22'4	117° 21'4
2473	June 17	8:55-10:00 a.m.	65	16°9	.....	32° 22'4	117° 21'2
2476	June 18	2:00- 2:35 a.m.	35	17°2-17°1	.....	32° 22'7	117° 19'2
2479	June 18	2:40- 3:35 a.m.	55	17°1-16°9	.....	32° 22'7	117° 19'2
2491	June 18	3:40- 3:55 a.m.	15	17°0	.....	32° 22'7	117° 19'2
2494	June 18	4:05- 4:35 a.m.	30	.....	.....	32° 22'7	117° 19'2
2497	June 18	4:38- 5:45 a.m.	67	17°0 17°5	.....	32° 22'7	117° 19'2
2511	June 18	6:25- 7:30 a.m.	65	17°1-17°3	.....	32° 22'7	117° 19'2
2523	June 18	4:35- 5:15 a.m.	40	17°2	.....	32° 23'5	117° 18'0
2526	June 18	5:20- 6:05 a.m.	45	17°0	.....	32° 23'5	117° 18'0
2539	June 18	6:10- 6:40 a.m.	30	16°9	.....	32° 23'5	117° 18'0
2542	June 18	7:05- 7:30 a.m.	25	17°1	.....	32° 23'5	117° 18'0
2545	June 18	7:45- 9:40 a.m.	115	17°5-17°3	.....	32° 23'5	117° 18'0
2557	June 18	10:15-10:40 a.m.	25	17°5	.....	32° 20'0	117° 17'4
2564	June 21	5:00- 7:00 a.m.	120	17°1-17°2	.....	32° 22'4	117° 21'2
2571	June 22	5:35- 5:50 a.m.	15	17°1	.....	32° 40'0	117° 32'0
2573	June 22	6:00- 7:18 a.m.	78	17°1	.....	32° 40'0	117° 32'0

TABLE 2—Continued

Haul Number	Date	Time of day	Duration minutes	Temperature of water	Salinity of water	North Latitude	West Longitude
1911							
2588	June 22	9:20-10:00 a.m.	40	17°5	.....	32° 52'0	117° 30'0
2594	June 24	3:45- 4:30 p.m.	45	18°6-18°5	.....	32° 50'0	118° 20'3
2607	June 26	4:00- 5:10 a.m.	70	17°9	.....	32° 22'7	117° 19'2
2620	June 26	5:45- 6:45 a.m.	60	18°-17°9	.....	32° 22'7	117° 19'2
2639	Aug. 8	4:05- 5:05 a.m.	60	.....	.....	32° 23'5	117° 18'0
2645	Aug. 8	5:10- 5:35 a.m.	25	.....	.....	32° 23'5	117° 18'0
2651	Aug. 8	6:05- 6:55 a.m.	50	19°4-19°7	.....	32° 23'5	117° 18'0
2674	Aug. 8	8:45- 9:55 a.m.	70	.....	.....	32° 23'5	117° 18'0
2679	Aug. 8	10:17-10:38 a.m.	21	20°4	.....	32° 23'5	117° 18'0
2680	Aug. 9	3:20- 4:23 a.m.	63	19°9-19°8	.....	32° 22'7	117° 19'0
2703	Aug. 9	6:06- 6:33 a.m.	27	20°0	.....	32° 22'4	117° 18'5
2714	Aug. 9	7:15- 8:10 a.m.	48	19°6-20°0	.....	32° 22'7	117° 19'0
2725	Aug. 9	8:35- 9:20 a.m.	45	20°1	.....	32° 22'3	117° 20'2
2736	Aug. 10	3:45- 4:53 a.m.	68	20°8-20°6	.....	32° 22'4	117° 21'2
2747	Aug. 10	5:06- 6:00 a.m.	54	20°7	.....	32° 22'4	117° 21'2
2749	Aug. 10	6:12- 7:55 a.m.	103	20°6	.....	32° 23'3	117° 20'0
2751	Aug. 10	8:45- 9:45 a.m.	60	20°1	.....	32° 18'2	117° 24'7
2753	Aug. 10	11:35-12:45 p.m.	70	19°8	.....	32° 18'2	117° 24'7
2755	Aug. 10	12:53- 1:45 p.m.	52	19°8	.....	32° 18'2	117° 24'7
2756	Aug. 11	5:50- 6:40 a.m.	50	20°4	.....	32° 20'9	117° 21'1
2760	Aug. 11	8:05- 9:12 a.m.	67	20°5	.....	32° 20'9	117° 21'1
2761	Aug. 11	10:45-11:57 a.m.	72	20°7	.....	32° 22'7	117° 20'2
2762	Aug. 11	12:46- 1:35 p.m.	51	20°1	.....	32° 20'0	117° 17'4

The following is a list of the surface hauls that I used, the data for which may be found in table 28, page 79 of Michael's (1911) paper:

1432, 1436, 1438, 1444, 1448, 1452, 1452, 1455, 1460, 1465, 1471, 1478, 1499, 1509, 1512, 1530, 1559, 1560, 1562, 1568, 1579, 1582, 1585, 1588, 1591, 1594, 1597, 1600, 1605, 1634, 1650, 1653, 1655, 1657, 1667, 1673, 1680, 1682, 1686, 1689, 1695, 1698, 1703, 1712, 1716, 1719, 1728, 1734, 1738, 1744, 1747, 1751, 1754, 1759, 1763, 1767, 1772, 1779, 1784, 1791, 1796, 1800, 1804, 1810, 1812, 1815, 1826, 1832, 1836, 1837, 1850, 1854, 1860, 1864, 1868, 1872, 1875, 1881, 1883, 1888, 1892, 1902, 1906, 1910, 1915, 1920, 1931, 1941, 1954, 1967, 1981, 1991, 1998, 1998, 2010, 2014, 2024, 2028, 2033, 2039, 2044, 2049, 2054, 2062, 2064, 2070, 2078, 2083, 2085, 2092, 2096, 2101, 2109, 2114, 2123, 2126, 2136.

The surface hauls given in the following list did not contain Copepoda and therefore do not appear in table 3, which gives the numbers of individuals of the different species:

1432, 1436, 1438, 1444, 1448, 1452, 1455, 1460, 1465, 1478, 1488, 1499, 1504, 1509, 1512, 1532, 1559, 1562, 1686, 1689, 1695, 1712, 1716, 1747, 1751, 1759, 1763, 1767, 1796, 1800, 1804, 1810, 1812, 1815, 1832, 1854, 1868, 1910, 1915, 1941, 1967, 2039, 2044, 2049, 2078, 2085, 2114, 2242, 2313, 2316, 2351, 2361, 2446, 2491, 2511, 2523, 2526, 2539, 2542, 2545, 2557, 2564, 2571, 2573, 2588, 2594, 2607, 2620, 2751.

In table 3 is a list of the surface hauls and the number of specimens of each species occurring in the hauls. The numbers of specimens as given were obtained by actual count in most cases, though there are some entries of estimated numbers, especially when the numbers are large. It is but fair to state, however, that in some cases I counted the entire catch when the number was over a thousand; this is generally true for numbers less than a thousand. Estimated numbers may be relied upon as fairly exact.

The following list contains the numbers of the hauls made with the horizontal closing nets that I used.

1542, 1550, 1557, 1567, 1572, 1575, 1576, 1578, 1603, 1620, 1621, 1668, 1683, 1684, 1688, 1690, 1691, 1699, 1700, 1701, 1704, 1708, 1714, 1725, 1726, 1729, 1732, 1733, 1736, 1739, 1745, 1748, 1752, 1753, 1756, 1757, 1760, 1761, 1764, 1770, 1785, 1788, 1789, 1792, 1793, 1794, 1797, 1798, 1801, 1802, 1805, 1807, 1808, 1813, 1816, 1817, 1820, 1821, 1824, 1827, 1828, 1830, 1833, 1834, 1839, 1840, 1841, 1842, 1843, 1844, 1845, 1846, 1851, 1852, 1855, 1856, 1857, 1858, 1861, 1862, 1865, 1866, 1869, 1870, 1873, 1876, 1877, 1878, 1879, 1884, 1885, 1886, 1889, 1909, 1923, 1926, 1927, 1928, 1929, 1930, 1944, 1946, 1947, 1948, 1963, 1964, 1965, 1966, 1976, 1977, 1978, 1979, 1980, 1984.

The data for the above hauls are given in table 30 of Michael's paper except for the two hauls in table 4 which follows.

TABLE 4

Data for hauls with horizontal closing nets not given in table 30 of Michael's paper

Haul number	Date 1909	Time of day	Duration minutes	Net	Depth in fathoms	North Latitude	West Longitude
1976	Nov. 5	9:45-10:00 a.m.	15	B	550	32° 40'6"	117° 30'3"
1977	Nov. 5	10:45-11:00 a.m.	15	B	400	32° 40'6"	117° 30'3"

In table 5 which follows, is given a list of the species occurring in all of the above collections. The hauls are arranged according to depths. The following hauls of the list given above did not contain Copepoda:

1542, 1572, 1575, 1621, 1725, 1797, 1798, 1801, 1805, 1807, 1808, 1820, 1821, 1827, 1828, 1833, 1839, 1840, 1841, 1842, 1856, 1862, 1886; 1909, 1944, 1946.

These do not appear in table 5.

I made use, in part, of the following hauls with the vertical closing nets; the data for the hauls will be found in tables 30 and 31 of Michael's paper:

1994, 1995, 1996, 1997, 2001, 2017, 2018, 2027, 2031, 2032, 2036, 2037, 2038, 2048, 2052, 2053, 2057, 2058, 2059, 2067, 2068, 2069, 2073, 2074, 2075, 2081, 2088, 2089, 2090, 2094, 2095, 2099, 2106, 2107, 2108, 2112, 2113, 2119, 2120, 2121, 2122, 2131, 2132, 2133, 2134, 2135, 2139, 2140, 2141, 2142, 2143, 2144.

These hauls all contained copepods except numbers 2027, 2037, 2140, 2141, and 2088, and in table 6, which follows, there are lists of species as they occurred in the hauls given above; in the table the hauls are arranged according to depths, the hauls in shallower water being put first. All of the foregoing collections were made before June, 1911.

The other hauls with the vertical closing nets form a group by themselves in that they were made in June and August, 1911, above 75 fathoms, and nearly everyone on some one of three stations located as follows:

	North Latitude	West Longitude
Station 1	32° 23'5	117° 18'0
Station 2	32° 22'7	117° 19'2
Station 3	32° 22'4	117° 21'2

A few hauls were made at a station in Ritter Deep, 32°40' north latitude, 117°32' west longitude; a few at a station off San Clemente Island in 32°50' north latitude and 118°20'3 west longitude; a station near La Jolla was covered a few times, 32°50' north latitude and 117°30' west longitude. In table 7 following, the six positions named above are referred to as Stations 1, 2, or 3 (as the case may be), Ritter Deep, Clemente and La Jolla. The list of hauls in table 7 is arranged according to depths as shown. It is not necessary to give duration of hauls, since the nets are drawn at the rate of two feet per second in every case.

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TABLE 7

Hauls made with the vertical closing net in June and August, 1911 (Net F),
with numbers of specimens of the more abundant species

Haul number	Date 1911	Time of day	Station	<i>Calanus finmarchicus</i>	<i>Eucalanus elongatus</i>	<i>Labidocera trispinosa</i>	<i>Metridia lucens</i>	<i>Pleuromma abdominalis</i>	<i>Pleuromma siphiae</i>	<i>Rhinocalanus hacketti</i>
A. Hauls 5-0 fathoms										
2303	June 14	6:35 a.m.	3	1	....	....	....	....	....	....
2342	June 15	11:58 a.m.	2	....	....	....	2	....	....	....
2390	June 16	3:20 p.m.	1	7	1	....	....	....	....	....
2650	Aug. 8	5:30 a.m.	1	15	3	....	....	....	....	....
2673	Aug. 8	8:24 a.m.	1	12	....	....	....	....	....	....
2691	Aug. 9	4:20 a.m.	2	1	1	7	....	....	....	....
2702	Aug. 9	5:36 a.m.	2	1	1	1	....	....	....	....
2713	Aug. 9	8:08 a.m.	2	....	....	3	....	....	....	....
2724	Aug. 9	9:17 a.m.	3	5	....	3	....	....	....	....
2735	Aug. 9	4:47 a.m.	3	1	....	....	....	....	....	....
2746	Aug. 9	5:52 a.m.	3	2	....	....	....	....	....	....
B. Hauls 10-5 fathoms										
2341	June 14	3:10 a.m.	2	....	1	....	4	....	....	....
2389	June 16	3:16 a.m.	1	27	1	....	....	....	....	....
2440	June 17	3:15 a.m.	3	1	1	....	....	....	....	....
2489	June 18	3:30 a.m.	2	....	1	....	....	....	....	....
2605	June 24	4:27 p.m.	Clemente	3	....	....	....	....	....	....
2618	June 26	5:02 a.m.	2	....	1	....	....	....	....	....
2649	Aug. 8	5:23 a.m.	1	3	2	....	....	....	....	....
2660	Aug. 8	8:21 a.m.	1	18	....	....	....	....	....	....
2672	Aug. 8	8:21 a.m.	1	3	1	....	....	....	....	....
2690	Aug. 9	4:16 a.m.	2	5	....	1	....	....	....	....
2701	Aug. 9	5:33 a.m.	2	....	1	....	....	....	....	....
2712	Aug. 9	8:05 a.m.	2	5	4	....	....	....	....	....
2722	Aug. 9	9:15 a.m.	3	3	....	....	....	....	....	....
2734	Aug. 9	4:43 a.m.	3	....	6	....	....	....	....	....
2745	Aug. 9	5:53 a.m.	3	13	3	1	....	....	....	....
C. Hauls 15-10 fathoms										
2302	June 14	6:30 a.m.	3	....	1	....	....	....	....	....
2310	June 14	7:40 a.m.	3	....	1	....	....	....	....	....
2340	June 15	3:07 a.m.	2	5	2	....	7	....	....	....
2373	June 15	8:54 a.m.	2	....	1	....	....	....	....	....
2388	June 16	3:11 a.m.	1	76	3	....	14	....	....	....

TABLE 7—Continued

Haul number	Date 1911	Time of day	Station	<i>Clanans humarchicus</i>	<i>Pucdanus longatus</i>	<i>Labidocera trispinosa</i>	<i>Melitidia lucens</i>	<i>Pleuromamma abdominalis</i>	<i>Pleuromamma tiphiaz</i>	<i>Rhinocdanus nasutus</i>
2404	June 16	5:30 a.m.	1	....	1	....	....	....	....	....
2424	June 16	9:15 a.m.	1	....	1	....	....	....	....	....
2439	June 17	3:11 a.m.	3	4	3	....	1	....	....	....
2488	June 18	3:25 a.m.	2	....	2	....	....	....	....	....
2604	June 24	5:25 p.m.	Clemente	24	....	....	....	....	....	....
2648	Aug. 8	5:10 a.m.	1	3	3	....	....	....	....	....
2659	Aug. 8	6:44 a.m.	1	3	....	....	....	....	....	....
2671	Aug. 8	8:15 a.m.	1	10	2	....	....	....	....	....
2700	Aug. 9	5:30 a.m.	2	1	1	....	....	....	....	....
2711	Aug. 9	8:00 a.m.	2	3	....	....	....	....	....	....
2722	Aug. 9	9:12 a.m.	3	2	....	....	....	....	....	....
2733	Aug. 9	4:37 a.m.	3	1	2	....	....	....	....	....
2744	Aug. 9	5:48 a.m.	3	9	1	....	....	....	....	....
D. Hauls 10-15 fathoms										
2301	June 14	6:27 a.m.	3	....	1	....	....	....	....	....
2309	June 14	7:32 a.m.	3	....	8	....	....	....	....	....
2339	June 15	3:02 p.m.	2	10	1	....	33	....	....	1
2357	June 15	5:35 a.m.	2	....	2	....	....	....	....	....
2387	June 16	3:08 a.m.	1	33	5	....	12	....	....	2
2403	June 16	5:20 a.m.	1	3	....	....	....	....	....	....
2423	June 16	9:07 a.m.	1	....	3	....	....	....	....	....
2438	June 17	3:07 a.m.	3	8	6	....	....	....	....	1
2453	June 17	5:42 a.m.	3	....	1	....	....	....	....	....
2487	June 18	3:22 a.m.	2	2	2	....	....	....	....	....
2506	June 18	5:17 a.m.	2	....	1	....	....	....	....	....
2534	June 20	5:52 a.m.	1	....	....	....	1	....	....	....
2603	June 24	4:20 p.m.	Clemente	15	1	....	....	....	....	....
2644	Aug. 8	4:55 a.m.	1	2	9	....	....	....	....	....
2658	Aug. 8	6:40 a.m.	1	....	4	....	....	....	....	....
2669	Aug. 8	7:15 a.m.	1	1	....	....	....	....	....	....
2688	Aug. 9	4:06 a.m.	2	2	2	....	4	....	....	....
2699	Aug. 9	5:25 a.m.	2	....	1	....	....	....	....	....
2710	Aug. 9	7:51 a.m.	2	1	....	....	....	....	....	....
2721	Aug. 9	9:00 a.m.	3	4	....	....	....	....	....	....
2732	Aug. 9	4:33 a.m.	3	6	....	....	....	....	....	....
2743	Aug. 9	5:45 a.m.	3	12	1	....	....	....	....	....

TABLE 7—Continued

Haul number	Date 1911	Time of day	Station	<i>Calanus finmarchicus</i>	<i>Eucalanus elongatus</i>	<i>Labidocera trispinosa</i>	<i>Metridia lucens</i>	<i>Pleuronamma abdominalis</i>	<i>Pleuronamma rhipias</i>	<i>Ethricalanus asiaticus</i>
E. Hauls 25-20 fathoms										
2300	June 14	6:20 a.m.	3	1	3	...	...	...	...	...
2308	June 14	7:25 a.m.	3	...	10	...	...	...	...	...
2323	June 14	11:40 a.m.	3	...	2	...	...	...	...	...
2338	June 15	2:58 a.m.	2	1	1	...	2	...	...	...
2356	June 15	5:30 a.m.	2	13	6	...	53	...	...	...
2371	June 15	8:45 a.m.	2	...	2	...	...	...	...	...
2386	June 16	3:04 a.m.	1	21	5	...	9	...	...	...
2402	June 16	5:15 a.m.	1	...	3	...	...	...	...	...
2422	June 16	9:05 a.m.	1	...	6	...	...	...	...	...
2437	June 17	3:00 a.m.	3	15	13	...	12	1	...	...
2452	June 17	5:38 a.m.	3	...	4	...	...	...	...	...
2467	June 17	8:10 a.m.	3	...	1	...	...	...	...	...
2518	June 18	6:55 a.m.	Clemente	...	3	...	...	...	...	...
2602	June 24	4:15 a.m.	2	1	...	...	...	...	...	...
2615	June 26	4:47 a.m.	1	1	3	...	...	...	...	...
2657	Aug. 8	6:35 a.m.	1	2	2	...	...	...	...	...
2668	Aug. 8	7:48 a.m.	1	3	1	...	...	...	...	...
2687	Aug. 9	4:00 a.m.	2	1	1	...	5	...	...	...
2698	Aug. 9	5:20 a.m.	2	1	4	...	...	...	...	...
2709	Aug. 9	7:53 a.m.	2	...	...	1	...	...	...	...
2720	Aug. 9	9:03 a.m.	3	3	2	...	...	...	...	...
2731	Aug. 9	4:27 a.m.	3	5	2	...	...	...	...	...
2742	Aug. 9	5:38 a.m.	3	14	2	1	...	...	...	...
F. Hauls 30-25 fathoms										
2299	June 14	6:12 a.m.	3	...	19	...	...	...	...	...
2307	June 14	7:15 a.m.	3	...	...	...	...	...	...	1
2322	June 14	11:34 a.m.	3	...	2	...	...	...	...	...
2337	June 15	2:54 a.m.	2	12	2	...	43	...	...	...
2355	June 15	5:26 a.m.	2	...	7	...	...	...	...	...
2371	June 15	8:40 a.m.	2	...	2	...	...	...	...	...
2385	June 16	2:59 a.m.	1	31	5	...	58	...	1	...
2401	June 16	5:10 a.m.	1	...	2	...	...	...	...	...
2421	June 16	8:55 a.m.	1	...	6	...	...	...	...	...
2436	June 17	2:55 a.m.	3	8	2	...	12	...	1	1
2451	June 17	5:35 a.m.	3	...	1	...	...	...	...	...

TABLE 7—Continued

Haul number	Date 1911	Time of day	Station	<i>Calanus</i> <i>nanarchicus</i>	<i>Eucalanus</i> <i>longatus</i>	<i>Labidocera</i> <i>trispinosa</i>	<i>Metridia</i> <i>lucens</i>	<i>Pleuromamma</i> <i>abdominalis</i>	<i>Pleuromamma</i> <i>tiphias</i>	<i>Rhinocalanus</i> <i>nasutus</i>
2466	June 17	8:04 a.m.	3	....	2	..	....	....	....	....
2485	June 18	3:15 a.m.	2	5	....	....	13	....	....	....
2503	June 18	5:05 a.m.	2	....	1	....	....	....	....	....
2517	June 18	6:50 a.m.	2	....	4	....	....	....	....	....
2551	June 20	8:35 a.m.	1	1	1	....	....	....	....	....
2562	June 20	10:35 a.m.	1	11	....	....	....	....	....	....
2601	June 24	4:12 p.m.	Clemente	7	1	....	....	....	....	....
2614	June 26	4:40 a.m.	2	2	2	....	....	....	....	....
2642	Aug. 8	4:15 a.m.	1	15	4	....	3	....	....	....
2656	Aug. 8	6:28 a.m.	1	7	..	....	....	....	....	....
2667	Aug. 8	7:37 a.m.	1	2	3	....	....	....	....	....
2686	Aug. 9	3:55 a.m.	2	2	....	....	5	....	....	....
2697	Aug. 9	5:14 a.m.	2	3	1	....	....	....	....	....
2708	Aug. 9	7:45 a.m.	2	1	5	....	....	....	....	....
2719	Aug. 9	8:57 a.m.	3	1	1	....	....	....	....	....
2730	Aug. 9	4:20 a.m.	3	9	1	....	....	1	....	....
2741	Aug. 9	5:32 a.m.	3	11	2	....	....	....	....	....
G. Hauls 40-30 fathoms										
2298	June 14	5:50 a.m.	3	1	1	....	1	....	....	....
2306	June 14	7:07 a.m.	3	....	5	..	..	....	....	....
2321	June 14	11:27 a.m.	3	....	7	..	..	....	....	....
2336	June 15	2:43 a.m.	2	13	6	....	53	....	....	....
2354	June 15	5:20 a.m.	2	1	4	....	....	....	....	....
2369	June 15	8:27 a.m.	2	....	1	....	....	....	....	....
2384	June 16	2:52 a.m.	1	10	3	....	30	....	....	....
2400	June 16	5:05 a.m.	1	2	7	....	....	....	....	....
2420	June 16	8:52 a.m.	1	1	4	....	....	....	....	....
2435	June 17	2:47 a.m.	3	1	1	....	9	1	....	....
2450	June 17	5:30 a.m.	3	....	3	....	....	....	....	....
2484	June 18	3:10 a.m.	2	1	2	....	9	1	....	....
2502	June 18	5:00 a.m.	2	....	2	....	....	....	....	....
2516	June 18	6:45 a.m.	2	....	8	....	....	....	....	....
2531	June 20	5:37 a.m.	1	5	7	....	....	....	....	....
2550	June 20	8:25 a.m.	1	2	2	....	....	....	....	....
2561	June 20	10:30 a.m.	1	19	4	....	....	..	....	....

TABLE 7—Continued

Haul number	Date 1911	Time of day	Station	<i>Calanox pinnacchicus</i>	<i>Eucalanx elongatus</i>	<i>Labidocera trespinoae</i>	<i>Metridia lucens</i>	<i>Pleurommaeta abdominalis</i>	<i>Pleurommaeta eriphus</i>	<i>Rhinocalanus coastalis</i>
2580	June 22	6:30 a.m.	Ritter Deep	...	1	...	...	...	...	...
2599	June 24	4:04 p.m.	Clemente	3	4	...	...	...	...	...
2612	June 26	4:25 a.m.	2	2	5	...	...	...	...	...
2638	Aug. 8	4:03 a.m.	1	5	...	...	...	...	...	...
2655	Aug. 8	6:22 a.m.	1	11	1	...	...	...	...	...
2666	Aug. 8	7:35 a.m.	1	2	...	...	...	...	...	...
2685	Aug. 9	3:47 a.m.	2	3	...	...	8	...	...	...
2707	Aug. 9	7:40 a.m.	2	2	4	...	...	...	...	...
2718	Aug. 9	8:53 a.m.	3	...	4	...	...	...	...	...
2740	Aug. 9	5:25 a.m.	3	8	2	1	...	...	...	...
H. Hauls 50-40 fathoms										
2294	June 14	5:35 a.m.	3	2	13	...	...	...	...	...
2305	June 14	7:00 a.m.	3	...	4	...	...	...	...	...
2320	June 14	11:20 a.m.	3	1	7	...	...	...	...	...
2335	June 15	2:35 a.m.	2	12	2	...	48	...	...	...
2350	June 15	5:10 a.m.	2	1	1	...	...	1	...	...
2368	June 15	8:22 a.m.	2	...	7	...	...	...	...	1
2383	June 16	2:45 a.m.	1	16	1	...	26	...	...	...
2399	June 16	5:00 a.m.	1	4	3	...	1	...	...	...
2419	June 16	8:45 a.m.	1	...	1	...	...	...	...	...
2434	June 17	2:40 a.m.	3	1	...	...	11	...	...	...
2449	June 17	5:12 a.m.	3	...	13	...	...	...	...	...
2464	June 17	7:50 a.m.	3	...	10	...	...	...	...	1
2483	June 18	3:02 a.m.	2	4	1	...	7	1	...	...
2501	June 18	4:50 a.m.	2	...	9	...	...	...	...	1
2515	June 18	6:38 a.m.	2	1	4	...	1	...	...	...
2530	June 20	5:30 a.m.	1	26	6	...	...	...	...	...
2549	June 20	8:15 a.m.	1	9	...	...	...	...	...	1
2560	June 20	10:20 a.m.	1	13	2	...	1	...	...	1
2593	June 22	1:00 a.m.	La Jolla	...	8	...	...	...	...	...
2598	June 24	3:56 p.m.	Clemente	21	4	...	...	...	...	...
2611	June 26	4:16 a.m.	2	10	1	...	...	...	...	...
2627	June 26	7:55 a.m.	3	...	3	...	...	...	...	...
2637	Aug. 8	3:50 a.m.	1	8	2	...	6	...	...	...
2654	Aug. 8	6:10 a.m.	1	2	1	...	...	...	...	...

TABLE 7—Continued

Haul number	Date 1911	Time of day	Station	<i>Calanus</i> <i>kumarehicus</i>	<i>Eucalanus</i> <i>elongatus</i>	<i>Labidocera</i> <i>trispinosa</i>	<i>Metridia</i> <i>lucens</i>	<i>Pteromamma</i> <i>abdominale</i>	<i>Pteromamma</i> <i>zeplios</i>	<i>Rhincalanus</i> <i>nasutus</i>
2665	Aug. 8	7:27 a.m.	1	1	1	....	....	....	....	....
2684	Aug. 8	3:38 a.m.	1	3	....	1	....	....	....	....
2695	Aug. 9	5:04 a.m.	2	1	2	....	2	....	....	....
2739	Aug. 9	5:15 a.m.	3	6	1	1	....	....	....	....
I. Hauls 75-50 fathoms										
2293	June 14	5:20 a.m.	3	19	13	....	....	....	....	....
2304	June 14	6:50 a.m.	3	....	10	....	....	....	....	....
2319	June 14	11:05 a.m.	3	....	16	....	....	....	....	....
2334	June 15	2:23 a.m.	2	8	7	....	42	....	1	....
2349	June 15	5:03 a.m.	2	13	8	....	1	....	....	....
2364	June 16	8:10 a.m.	1	....	15	....	2	....	....	....
2379	June 16	2:35 a.m.	1	27	....	....	20	....	....	....
2394	June 16	4:45 a.m.	1	45	....	....	5	....	....	....
2418	June 17	8:40 a.m.	3	1	1	....	2	....	....	....
2430	June 17	2:30 a.m.	3	2	1	....	4	....	....	....
2444	June 17	5:04 a.m.	2	1	....	....	....	....	....	....
2460	June 17	7:42 a.m.	2	....	5	....	....	....	....	....
2482	June 17	2:55 a.m.	2	4	1	....	8	....	....	....
2500	June 17	4:40 a.m.	2	4	5	....	6	....	....	2
2514	June 20	6:30 a.m.	1	1	7	....	7	....	....	....
2529	June 20	5:20 a.m.	1	184	4	....	7	....	....	1
2548	June 22	8:05 a.m.	Ritter Deep	41	4	....	9	....	....	....
2576	June 22	6:00 a.m.	La Jolla	2	3	....	....	....	....	....
2591	June 24	9:45 a.m.	Clemente	....	3	....	....	....	....	....
2597	June 26	3:47 p.m.	2	....	10	....	....	....	....	1
2610	June 26	4:01 a.m.	3	28	1	....	19	....	....	....
2626	June 26	7:40 a.m.	3	....	10	....	....	....	....	....
2694	Aug. 9	4:50 a.m.	2	1	2	....	8	....	....	1
2738	Aug. 9	5:10 a.m.	3	5	....	1	....	....	....	....

The list of species given in the above table comprises the more important ones, but the following should be added:

Haul number	Depth	Species	
2436	30-25	<i>Gaidius pungens</i>	1
2436	30-25	<i>Undeuchaeta bispinosa</i>	1
2686	30-25	<i>Euchirella curticauda</i>	1
2686	30-25	<i>Undeuchaeta bispinosa</i>	1
2384	40-30	<i>Euchirella rostrata</i>	1
2685	40-30	<i>Euchirella curticauda</i>	1
2368	50-40	<i>Euchirella rostrata</i>	1
2434	50-40	<i>Euchirella galeata</i>	1
2434	50-40	<i>Undeuchaeta bispinosa</i>	2
2501	50-40	<i>Euchirella rostrata</i>	2
2637	50-40	<i>Undeuchaeta bispinosa</i>	1
2684	50-40	<i>Pleuromamma gracilis</i>	1
2684	50-40	<i>Euchirella pulchra</i>	1
2684	50-40	<i>Undeuchaeta bispinosa</i>	1
2334	75-50	<i>Gaidius pungens</i>	1
2334	75-50	<i>Undeuchaeta bispinosa</i>	1
2430	75-50	<i>Gaidius pungens</i>	6
2430	75-50	<i>Scolecithrix frontalis</i>	1
2482	75-50	<i>Scolecithrix frontalis</i>	2
2576	75-50	<i>Gaidius pungens</i>	1

The following hauls (table 8) in the same group as those given in table 7 did not contain Copepoda.

TABLE 8

Data for hauls with vertical closing nets made in June and August, 1911, and containing no Copepoda. Net E.

A. Hauls 5-0 fathoms

Haul number	Date 1911	Time of day	Position
2312	June 14	7:50 a.m.	Station 3
2327	June 14	11:58 a.m.	Station 3
2360	June 15	5:45 a.m.	Station 2
2375	June 15	9:01 a.m.	Station 2
2406	June 16	5:35 a.m.	Station 1
2426	June 16	9:18 a.m.	Station 1
2441	June 17	3:20 a.m.	Station 3
2456	June 17	5:32 a.m.	Station 3

Haul number	Date 1911	Time of day	Position
2472	June 17	8:25 a.m.	Station 3
2490	June 18	3:32 a.m.	Station 2
2510	June 18	5:25 a.m.	Station 2
2522	June 18	7:10 a.m.	Station 2
2537	June 18	6:00 a.m.	Station 1
2556	June 18	8:55 a.m.	Station 1
2587	June 22	6:59 a.m.	Ritter Deep
2606	June 24	4.37 p.m.	Clemente
2619	June 26	5:07 a.m.	Station 2
2634	June 26	8:35 a.m.	Station 3

B. Hauls 10-5 fathoms

2311	June 14	7:46 a.m.	Station 3
2326	June 14	11:54 a.m.	Station 3
2359	June 15	5:42 a.m.	Station 2
2374	June 15	8:58 a.m.	Station 2
2405	June 16	5:33 a.m.	Station 1
2425	June 16	9:17 a.m.	Station 1
2455	June 17	5:49 a.m.	Station 3
2471	June 17	8:22 a.m.	Station 3
2508	June 18	5:23 a.m.	Station 2
2521	June 18	7:08 a.m.	Station 2
2536	June 20	5:58 a.m.	Station 1
2555	June 20	8:52 a.m.	Station 1
2586	June 22	6:57 a.m.	Ritter Deep
2633	June 26	8:32 a.m.	Station 3

C. Hauls 15-10 fathoms

2325	June 14	11:48 a.m.	Station 3
2358	June 15	5:39 a.m.	Station 2
2454	June 17	5:46 a.m.	Station 3
2470	June 17	8:20 a.m.	Station 3
2507	June 18	5:20 a.m.	Station 2
2520	June 18	7:04 a.m.	Station 2
2535	June 20	5:55 a.m.	Station 1
2554	June 20	8:50 a.m.	Station 1
2585	June 22	6:52 a.m.	Ritter Deep
2617	June 26	4:58 a.m.	Station 2
2632	June 26	8:30 a.m.	Station 3

D. Hauls 20-15 fathoms

Haul number	Date 1911	Time of day	Position
2324	June 14	11:44 a.m.	Station 3
2372	June 15	8:47 a.m.	Station 2
2468	June 17	8:18 a.m.	Station 3
2519	June 18	7:00 a.m.	Station 2
2553	June 20	8:45 a.m.	Station 1
2584	June 22	6:47 a.m.	Ritter Deep
2616	June 26	4:53 a.m.	Station 2
2631	June 26	8:20 a.m.	Station 3

E. Hauls 25-20 fathoms

2504	June 18	5:10 a.m.	Station 2
2533	June 20	5:48 a.m.	Station 1
2552	June 20	8:42 a.m.	Station 1
2583	June 22	6:44 a.m.	Ritter Deep
2630	June 26	8:15 a.m.	Station 2
2486	June 18	3:30 a.m.	Station 2

F. Hauls 30-25 fathoms

2532	June 20	5:42 a.m.	Station 1
2582	June 22	6:40 a.m.	Ritter Deep
2629	June 26	8:09 a.m.	Station 3

G. Hauls 40-30 fathoms

2628	June 26	8:03 a.m.	Station 2
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H. Hauls 50-40 fathoms

2579	June 22	6:20 a.m.	Ritter Deep
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Table 9, which follows, contains the data for the hauls with the open vertical net. The data for the following hauls will be found in table 34, p. 96 of Michael's paper:

1468, 1492, 1494, 1508, 1516, 1534, 1527, 1571, 1574.

These hauls, together with the ones listed in table 9, comprise all that I used.

TABLE 9

Data concerning hauls with the open vertical net. (Net A).

Haul number	Date	Time of day	Depth in fathoms	North Latitude	West Longitude
1109	June 21, 1906	6:00 a.m.	15-0	32° 51'50	117° 19'50
1171	June 29, 1906	6:40 a.m.	20-0	32° 51'17	117° 16'55
1161	June 29, 1906	5:30 a.m.	30-0	32° 51'56	117° 17'54
1099	June 20, 1906	5:40 a.m.	35 0	32° 51'57	117° 17'57
1128	June 26, 1906	5:15 a.m.	40-0	.....	.....
1207	July 5, 1906	7:00 a.m.	45-0	32° 51'17	117° 18'52
1087	June 19, 1906	5:30 a.m.	50-0	32° 52'22	117° 17'50
953	July 1, 1905	7:00 a.m.	55-0	32° 52'50	117° 18'57
1115	June 25, 1906	6:00 a.m.	60 0	32° 51'56	117° 18'58
1140	June 27, 1906	5:30 a.m.	60-0	32° 51'55	117° 17'56
1213	July 6, 1906	7:00 a.m.	60-0	32° 51'52	117° 17'51
1183	July 2, 1906	6:30 a.m.	65 0	32° 52'23	117° 16'57
1152	June 28, 1906	5:30 a.m.	70 0	32° 51'58	117° 16'57
886	June 21, 1905	.....	80-0	32° 52'50	117° 18'53
1193	July 3, 1906	6:30 a.m.	85-0	32° 52'56	117° 18'58
1237	July 7, 1906	6:00 a.m.	90-0	32° 51'50	117° 18'50
896	June 22, 1905	.....	100-0	32° 54'51	117° 20'50
928	June 28, 1905	4:00 p.m.	100-0	32° 53'50	117° 18'57
935	June 29, 1905	6:00 a.m.	100-0	32° 53'56	117° 21'51
939	June 30, 1905	5:00 a.m.	100-0	32° 52'53	117° 19'50
950	July 1, 1905	6:00 a.m.	100-0	32° 52'56	117° 18'58
979	July 8, 1905	6:00 a.m.	100-0	32° 51'59	117° 18'55
1094	June 19, 1906	3:30 p.m.	100-0	32° 52'22	117° 17'50
1267	July 13, 1906	10:30 a.m.	100-0	32° 48'51	117° 19'56
1354	July 23, 1906	11:00 a.m.	115-0	32° 52'58	117° 21'59
962	July 5, 1905	1:00 p.m.	118-0	32° 54'56	117° 22'52
1306	July 18, 1906	1:00 p.m.	150-0	32° 50'59	117° 25'55
1342	July 21, 1906	12:30 p.m.	150-0	32° 52'55	117° 26'55
1270	July 13, 1906	12:30 p.m.	155-0	32° 47'54	117° 20'58
1177	June 30, 1906	11:00 a.m.	160-0	32° 52'58	117° 18'51
1318	July 19, 1906	2:00 p.m.	170-0	32° 47'55	117° 25'50
1174	June 30, 1906	10:00 a.m.	185-0	32° 53'55	117° 17'57
1351	July 23, 1906	9:30 a.m.	215-0	32° 52'59	117° 22'52
1134	June 26, 1906	12:45 p.m.	285-0	32° 53'54	117° 23'56
1131	June 26, 1906	10:30 a.m.	275-0	32° 53'54	117° 23'56
1045	July 27, 1905	4:00 p.m.	300-0	32° 55'57	117° 24'59
1252	July 11, 1906	1:30 p.m.	310-0	32° 54'58	117° 23'50
1339	July 21, 1906	11:00 a.m.	310-0	32° 52'56	117° 28'52
1303	July 18, 1906	12:00 m.	315-0	32° 50'59	117° 25'55
1315	July 19, 1906	12:00 m.	320-0	32° 47'55	117° 25'50
1249	July 11, 1906	11:00 a.m.	325-0	32° 54'58	117° 23'50
1030	July 20, 1905	2:30 p.m.	400-0	San Clemente	
1528	July 2, 1908	11:45 a.m.	500-0	32° 58'53	118° 14'57
1075	Dec. 17, 1905	.....	600-0	San Clemente	

<i>Xanthocephalus</i> <i>similis</i>	Hant number
.....	1571
.....	1574
.....	1109
.....	1171
.....	1161
.....	1099
.....	1128
.....	1207
.....	1087
.....	953
.....	1115
.....	1140
.....	1213
.....	1183
.....	1152
.....	886
.....	1193
.....	1237
.....	896
.....	928
.....	935
.....	939
.....	950
.....	979
.....	1094
.....	1267
.....	1354
.....	962
.....	1306
.....	1342

The list of species as they occurred in the open vertical hauls is given in table 10, which follows.

No attempts have been made to standardise the catches of the different nets. It would be advisable to attempt this if we were studying the action of the types of nets used. But since we are primarily concerned with the biology of the copepods, and because certain facts are obtainable from our data without correlating, each sort of net is considered by itself. One cannot fail to notice that the catches of the horizontal and vertical closing nets do not always agree closely, particularly as to the location of the region of greatest abundance. Yet all the nets show a rather striking correspondence in regard to certain general features of the behavior of the Copepoda.

It does not seem that standardisation of net catches with each other would really be of much value in view of the results of hauling with similar nets at the same time and almost in the same place. The idea that such standardising is valuable doubtless grew out of the belief that plankton animals are uniformly distributed in the water. But such work as that of Herdman (1906), Herdman, Scott and Dakin (1909), or that of Michael (1911) has shown that distribution is irregular. Instances of this could be given almost without number in regard to the distribution of the copepods of this region. Standardisation would have to be based on factors that depend on the organisms themselves, that is on biological factors in cases where similar nets used at the same time and in as nearly the same manner as possible give very different results. It is likely, therefore, that attempting to adjust for different nets in regard to distance and rate of hauling, amount of water filtered, and like factors is at least unnecessary when the nets are used at different times and under different conditions. We may reasonably expect that, if we deal with a large number of hauls well distributed over several months and through the twenty-four hours, we shall obtain results of worth in regard to the relation of the organisms to their environment.

A possible method of standardising would be to allow for the difference in area of the mouths of nets. This was done in two earlier papers (Esterly, 1911a, 1911b), but my experience

has led me to believe that such a method is practically valueless. In this paper numbers of specimens taken with different nets are not adjusted to each other and allowance should be made for that fact. The effect of certain environmental conditions is plain even if we do not know, from the number of animals taken with a given net, the number that might have been expected under the same conditions but with another net. Accordingly, I have followed the plan of considering the distribution of various species as shown by each of the four sorts of nets used, the catches with the different vertical closing nets being combined.

Nineteen species have been chosen for a detailed study of distribution. The selection was based purely upon frequency of occurrence, for a form must be found reasonably often to make it profitable to study its distribution. It is believed that all of the species listed in table 11 were taken often enough to furnish a reliable basis for such a study. This table explains itself, but it should be noted that the lower numbers in each column and in lines 1-18 give the number of hauls in which the species was found.

TABLE 11

List of species studied singly, and their occurrence in different sorts of hauls

	A Surface	B Horiz. closing	C Vertical closing	D Vertical open	E Totals
Total number of hauls	203	114	310	53	680
Name of species	Numbers of animals and successful hauls				
1. <i>Calanus finmarchicus</i>	20480 117	1875 75	2927 171	57731 49	82013 412
2. <i>Eucalanus elongatus</i>	2427 55	1050 60	2049 193	179499 49	185026 357
3. <i>Euchaeta tonsa</i>	..... .....	11 4	16 5	72 15	99 24
4. <i>Euchirella galcata</i>	..... .....	4 3	26 10	72 15	102 28
5. <i>Euchirella pulchra</i>	18 7	33 10	107 17	135 18	293 52
6. <i>Euchirella rostrata</i>	.9 13	4 4	4 3	171 27	198 47
7. <i>Gaetanus unicornis</i>	..... .....	6 3	13 5	35 11	54 19
8. <i>Gaidius pungens</i>	4 3	148 12	786 26	83 13	1021 54
9. <i>Labidocera trispinosa</i>	3466 28	..... .....	21 11	11822 18	15309 57
10. <i>Metridia lucens</i>	38190 28	740 28	5974 80	104+ 4	45008 140
11. <i>Pleuromamma abdominalis</i>	372 19	114 14	110 28	70 15	666 76
12. <i>Pleuromamma gracilis</i>	213 7	1 1	316 6	1 1	531 15
13. <i>Pleuromamma quadrangulata</i>	3 2	56 16	276 21	166 18	501 57
14. <i>Pleuromamma xiphias</i>	..... .....	12 7	29 11	12 7	53 25
15. <i>Rhincalanus nasutus</i>	54 11	9 8	142 46	7+ 6	212 71
16. <i>Scolecithrix frontalis</i>	..... .....	12 5	46 13	25 12	83 30
17. <i>Scolecithrix magna</i>	..... .....	3 3	9 5	18 8	30 16
18. <i>Scolecithrix persecans</i>	3 2	20 10	551 27	127 17	701 56
19. <i>Undeuchaeta bispinosa</i>	25 5	36 11	85 14	116 20	262 50

In considering the distribution and movements of the species named in table 11, the data for the four styles of nets have been studied separately, and arranged so. In all other cases except hauls with vertical closing nets the number of animals has been reckoned on the basis of a haul one hour in length; such numbers are called hourly averages or number per hour and are obtained by dividing the total number of animals by the total number of hours. The term "haul frequency" means the percentage of *successful hauls*—the ratio between hauls in which the species was taken and the total number of hauls. "Time frequency" is the percentage of hours of successful hauling or the ratio between the time occupied by hauls in which the species was taken and the total time spent in hauling. Frequency has no reference to abundance of animals; the frequency would be the same for a given number of hauls whether one animal or a hundred were taken in each haul.

The whole day has been divided into twelve periods of two hours each and the time from 6 a.m. to 6 p.m. is referred to as "day," while that from 6 p.m. to 6 a.m. is called "night." These designations are more or less arbitrary since they have no necessary relation to sunrise or sunset.

DISTRIBUTION of *Calanus finmarchicus*.

According to the statements of Sars (1904, p. 11) this form should be referred to as *C. helgolandicus*. It seems to me, however, that there can be no doubt that the species is *C. finmarchicus*, and Wolfenden (1904, p. 126) is of the opinion that the factors on which Sars bases the distinction are too inconstant to be admissible.

This species was found in a larger proportion of all hauls than any other, being taken in 412 out of 680; the haul frequency is 61. I have discussed the vertical distribution of *Calanus* on a basis of 23 surface hauls and 73 hauls with the Kofoid closing net (Esterly, 1911b) and while there are 114 of the latter hauls available now it is unnecessary to repeat the discussion, since the additional number of hauls does not affect the conclusions arrived at before. This is also true of the surface hauls in a general way, but the larger number of hauls that can

be included in this study enables us to arrange the data in a much more useful manner than was done previously. Table 12, which follows, shows how *Calanus* is distributed at the surface according to the time of day.

TABLE 12

Distribution of *Calanus finmarchicus* at the surface, by two-hour periods through the day. Net A.

Time of Day	No. of hauls		No. of hours		No. of animals		Haul G	Frequency Time H
	Total A	Success. B	Total C	Success. D	Total E	Per hour F		
1. 6-8 a.m.	35	15	27.2	12.3	2491	91	43	41
2. 8-10	21	9	20.2	11.4	1640	80	43	51
3. 10-12	14	7	9.8	6.1	103	10	50	62
p.m.								
4. 12-2	14	8	9.0	6.0	92	10	57	66
5. 2-4	14	5	9.7	3.5	663	68.5	36	36
6. 4-6	13	6	9.9	5.0	900	69.2	46	51
7. 6-8	30	23	19.9	15.4	3643	175.0	74	73
8. 8-10	8	8	4.4	4.4	4285	973	100	100
9. 10-12	1	1	2.8	2.8	3825	1375	100	100
a.m.								
10. 12-2	3	3	2.6	2.6	151	58	100	100
11. 2-4	8	8	12.0	12.0	1177	97.2	100	100
12. 4-6	41	25	26.6	13.0	514	19.3	61	53

Table 13 is a summary of table 12, and is self-explanatory.

TABLE 13

Summary of table 12

	Day	Night
1. Total number of hauls	111	92
2. Number of successful hauls.....	50	67
3. Total number of hours.....	85.6	69.5
4. Number of successful hours.....	43.3	47.7
5. Total number of animals.....	5889	14574
6. Average per hour	6.6	218.0
7. Haul frequency.....	45	75
8. Time frequency.....	50	75

This table shows in a very striking manner the greater abundance and frequency at night (lines 5-8), though there are not so many night as day hauls, nor so many hours spent

in hauling at night. From table 12, lines 8 and 9, it is evident that *Calanus* is found in greatest abundance at the surface during the four hours preceding midnight; this is a fact without taking account of the possible factors that operate to produce the result observed. It seems very likely that this general condition is due to diurnal migrating. In column F of table 12 the lowest hourly averages are in lines 3 and 4, which include the two hours before and after midday. In the afternoon and evening up to midnight (lines 5-9) the averages increase, after which there is a sharp drop in the numbers per hour. It should be noted that the highest frequencies are obtained in night collecting (columns G, H, lines 7-11) during the hours when the animals are most abundant. The number of hauls from 8 a.m. to 4 p.m. is relatively small, but there is certainly some significance to the fact that every haul made during those hours took the animals. It is noticeable that when the hourly average is higher the frequencies may be lower and vice versa (cf. columns F, G and H, lines 4 and 6).

Michael (1911, p. 116) found this to be true, also, and has given a discussion of possible reasons for it. I cannot add to his discussion, but the general facts of distribution are beyond dispute both as regards *Sagitta bipunctata* and *Calanus finmarchicus*.

The following propositions may be regarded as well established by the data in tables 2 and 13:

1. As the light increases during the morning the averages per hour decrease.
2. As the light decreases toward evening the hourly averages increase up to a certain time, after which they decrease. (See fig. 1).

At this point it should be noted that following the night maximum the decrease in abundance begins before the light increases; this matter was brought out in a former paper (Esterly, 1911b) but is a good deal more evident now on the basis of a much larger number of hauls. The conclusion from this is, evidently, that an increase in the intensity of light is not the only cause of the downward movement from the surface.

The fact of diurnal migrating was clearly shown by hauls with the Kofoid net made in 1909. The discussion of those hauls, as already stated, is in a separate paper (Esterly, 1911b) and will not be repeated here. Table 14, which follows, is derived from the data obtained from hauls with the vertical closing nets. The hauls with these nets are not well distributed through the twenty-four hours: there are no hauls between

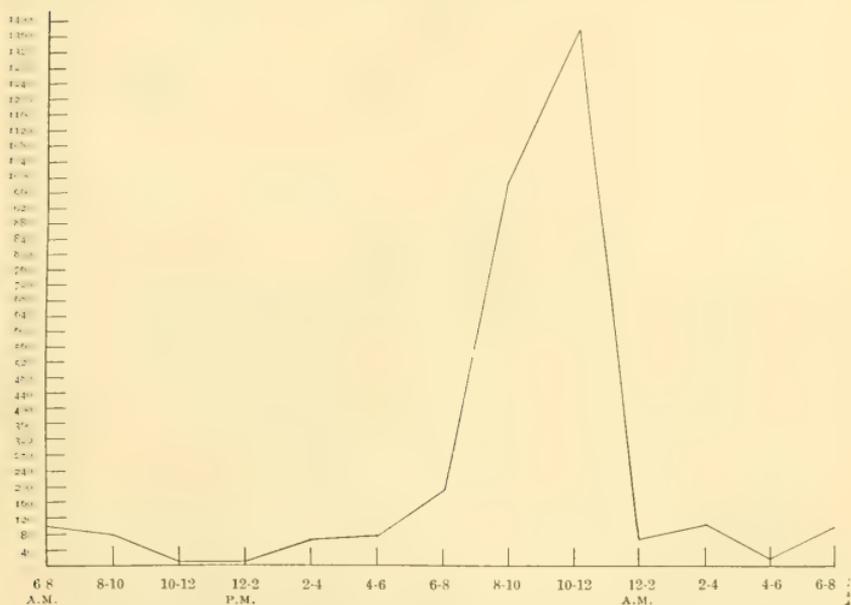


Fig. 1. *Calanus finmarchicus*. Variations in numbers per hour at surface according to time of day. Data in table 12.

8 p.m. and 2 a.m., and none between 6 and 8 p.m. above 50 fathoms; the day hauling was done between 6 and 12 a.m. and 4-6 p.m., there being no collections from 12 o'clock noon to 4 p.m. The frequencies in table 14 as in all others dealing with the vertical closing nets are "haul frequencies." "Hour frequency" would be practically meaningless, since the nets are drawn at the same rate in all hauls. The averages expressing abundance are "per fathom" for the same reasons.

TABLE 14

Distribution of *Calanus finmarchicus* as shown by vertical closing nets

Depth in fathoms	Day						Night				
	6-12 a.m., 4-6 p.m.		Animals		Freq.	2-6 a.m., 6-8 p.m.		(below 50 f.)		Freq.	
	Total Hauls	Success.	Total	Per fathom		Total Hauls	Success.	Total	Per fathom		
A	B	C	D	E	F	G	H	I	J		
1. 5-0	15	3	17	3.4	20	14	6	27	5.4	43	
2. 10-5	15	5	32	6.4	33	14	5	49	9.9	36	
3. 15-10	15	5	42	8.4	33	15	7	99	19.8	47	
4. 20-15	15	4	21	4.2	27	15	8	75	15.0	53	
5. 25-20	15	5	10	2.0	33	14	9	65	13.0	64	
6. 30-25	17	7	20	4.0	41	14	10	98	19.6	71	
7. 40-30	14	7	40	4.0	50	14	12	52	5.2	86	
8. 50-40	16	6	48	4.8	37	15	12	84	8.4	80	
9. 75-50	17	11	393	15.7	58	16	14	398	15.7	88	
10. 100-75	6	4	143	5.7	66	3	3	240	9.6	66	
11. 150-100	6	5	225	4.5	83	4	4	114	2.8	109	
12. 200-150	6	6	242	4.9	100	3	3	87	1.7	66	
13. 250-200	6	6	22	4.4	100	1	0	0	0.0	0	
14. 300-250	4	2	58	1.6	50	1	1	1	0.2	100	

This table shows that the region of greatest abundance during the day is between 50 and 75 fathoms (columns C and D, line 9). It is to be noted, however, that the greatest frequencies are between 150 and 250 fathoms (column E, lines 12 and 13), where the animals were taken in each of twelve hauls. It seems to me that this is a case where one must endeavor to estimate on the basis both of the abundance and the frequency.

During the night there appear to be two plurima, one at 10-15 fathoms and one at 30-25 (columns H and I, lines 3 and 6), but the abundance at 75-50 fathoms is close to the others.

Neither the day nor the night plurimum with the vertical closing nets corresponds to those found with the horizontal closing net. The latter appears to encounter the animals most abundantly at about 200 fathoms during the day, while the plurimum between 6 and 10 p.m. is at 100 fathoms, at midnight between 5 and 10 fathoms and from 4 to 6 a.m. it is at 100 fathoms again (Esterly, 1911b).

I am unable to reconcile the discrepancies between the action of the two sorts of nets. It seems certain that the Kofoid net will give more reliable results and it is possible that if the vertical hauls were distributed evenly through the day and night the results of using them would be more in agreement with those obtained by the horizontal nets. It may be said that the plurimum with the vertical nets between 6 and 8 p.m. is overwhelmingly between 75 and 100 fathoms (this is not shown in table 14), while between 4 and 6 a.m. the plurimum is plainly between 50 and 75 fathoms. These regions correspond fairly well with the plurima at the same times as shown by the Kofoid net (see preceding paragraph). Furthermore, in table 14, line 9, columns C and D, and H and I, it will be seen that the total number of animals and the number per fathom is the same for night and day hauls between 75 and 50 fathoms. It is noticeable that the vertical hauls at night were made in very early evening (6-8 p.m. or early morning 2-6 a.m.) and these are the times when the Kofoid net showed the maxima at 100 fathoms. It can at least be said that there is an indication in the data from the vertical nets of the same behavior on the part of the animals as is shown by the horizontal net.

Although the distribution of the vertical closing hauls as to time of day is not all that can be desired, the evidence points toward a diurnal migration of the organisms. Inspection of table 14 shows that above 50 fathoms the numbers of animals taken are smaller by day and larger by night (columns C, D, H, I, lines 1-8). Below 50 fathoms the day numbers are larger than above that level (columns C and D, lines 1-8, 9-12). Accordingly, we may take 50 fathoms as a sort of dividing line and arrange a table like that following, which is a summary of the data in table 14.

TABLE 15
Summary of results in table 14

	Specimens per fathom		Total hauls		Success. Hauls		Frequency	
	Day	Night	Day	Night	Day	Night	Day	Night
Between 0 and 50 fathoms	4.6	10.4	122	115	42	69	34	46
Between 50 and 200 fathoms	7.0	5.6	35	26	26	24	70	93

It is fair to conclude from table 15 that the vertical nets indicate that there is a movement away from the upper water during the day, and a movement away from deeper water at night. It is true that the differences between day and night hauls as shown in table 15 are not great but taken in connection with the results from surface and horizontal closing collections, they are suggestive. Emphasis should be laid on the fact that there are no vertical hauls above 50 fathoms and at night before 2 a.m., and that it is between 8 and 12 p.m. that the animals are obtained in greatest abundance with the surface net; and furthermore that during the same time and above 50 fathoms they were taken in largest numbers by the Kofoid net. It is to be expected that with these omissions the results of collecting with the vertical nets will not be so clear as with the others, and that the differences in abundance between day and night will not be so great. At any rate, judging from the data available at this time, there is evidence from all the nets that *Calanus* performs diurnal migrations. This conclusion should not be cast aside because the three types of nets do not agree in all respects, for a larger number of hauls more uniformly distributed as to time will probably smooth out the irregularities.

Distribution with regard to temperature.—In considering the relation between temperature and the occurrence of *Calanus*, I used 130 surface hauls made in June, July, August and September. These were chosen in order to do away with possible seasonal changes, for the temperatures in the months named run about the same. Temperatures for closing net hauls are not known.

The results reached are very irregular. As an indication of this table 16 has been constructed. It contains the ten hauls of the 130 that took the largest number of specimens; these are all night hauls in either June or July. The hauls were made between the hours in the column at the left.

TABLE 16

Two-hour period	Temperature	Number of animals per hour
6-8 p.m.	16°3	2900
2-4 a.m.	16°7	930
8-10 p.m.	17°6	1795
4-6 a.m.	18°7	1635
10-12 p.m.	19°0	1362
2-4 a.m.	19°2	66
6-8 p.m.	20°3	801
8-10 p.m.	20°5	1780
8-10 p.m.	20°5	4050
6-8 p.m.	22°2	1020

It is difficult to detect any relation between temperature and abundance in this table. Most of the large hauls were made before 10 p.m. but the temperatures at those times ranged from the lowest to the highest. In addition to the hauls in table 16, four others may be noted which were made in February of two different years: One haul, between 6 and 8 a.m. took 4600 per hour at a temperature of 14°2; another, between 2 and 4 p.m. took 404 per hour at 14°2; a third, made between 4 and 6 p.m. captured at the rate of 1300 per hour when the temperature was 13°8; the fourth, between 6 and 8 p.m. took 360 at a temperature of 13°8. These hauls show that at low temperatures there is about as much variation in abundance as at medium and high temperatures.

If all the surface hauls are arranged in a table there is no marked correlation between surface temperatures and number of specimens. Such a table is found in the one following (table 17). It is arranged on the same plan as table 14.

TABLE 17
Distribution of *Calanus* at surface with regard to temperature

	Temperature	No. of hauls		No. of hours		No. of animals		Frequency		
		Total 1	Success. 2	Total 3	Success. 4	Total 5	Per hour 6	Haul 7	Time 8	
A. 4-8 a.m.										
1.	16.0-17.0	10	9	10.5	5.9	152	12.7	56	56	
2.	17.1-18.0	15	3	14.0	3.7	11	.8	20	24	
3.	18.1-19.0	10	1	6.4	.3	546	124.2	10	4	
4.	19.1-21.5	14	10	8.1	5.2	162	54.0	71	64	
B. 8 a.m.-4 p.m.										
1.	16.0-17.0	10	3	8.1	2.0	3	.4	30	25	
2.	17.1-18.0	8	1	4.5	.3	8	1.8	12	6	
3.	18.1-19.0	6	1	2.5	.2	7	2.8	16	5	
4.	19.1-21.5	7	2	6.8	2.3	26	3.8	29	34	
C. 8-10 p.m.										
1.	16.0-17.0	1	1	.4	.4	1209	2900.0	100	100	
2.	17.1-18.0	6	4	5.6	3.6	1999	334.0	66	64	
3.	18.1-19.0	9	4	5.5	1.5	141	20.6	44	28	
4.	19.1-21.5	17	13	8.4	6.2	3279	390	77	74	
D. 10 p.m.-4 a.m.										
1.	16.0-17.0	4	4	3.4	3.4	757	210	100	100	
2.	17.1-18.0	3	3	2.7	2.7	133	49	100	100	
3.	18.1-19.0	3	3	4.7	4.7	3865	964	100	100	
4.	19.1-21.5	1	1	5.5	5.5	367	66	100	100	

A summary of this table is given in table 18, which will make it easier to bring together the results of table 17.

TABLE 18
Summary of table 17

	Temperature	No. of hauls		No. of hours		No. of animals		Frequency		
		Total A	Success. B	Total C	Success. D	Total E	Per hour F	Haul G	Time H	
1.	16°0-17°0	31	17	22.4	11.7	1571	70.6	55	47	
2.	17°1-18°0	32	11	27.8	10.0	2151	77.3	31	36	
3.	18°1-19°0	28	11	19.1	8.7	4559	238.0	39	46	
4.	19°1-21°5	39	26	29.8	19.2	3834	125.0	67	64	
Time of day										
5.	4 a.m.-8 a.m.	55	23	39.0	14.8	871	22.0	42	38	
6.	8 a.m.-4 p.m.	31	7	21.0	6.7	54	2.4	22	30	
7.	4-10 p.m.	33	24	19.0	13.7	6628	303.0	73	69	
8.	10 p.m.-4 a.m.	11	11	16.3	16.3	5122	305.0	100	100	

It is plain from table 18 that the highest hourly average is obtained at a temperature between 18:1 and 19° (column F, line 3), while the frequencies are highest for the highest temperatures (columns G and H, line 4). In table 17 the averages per hour are highest when the temperature is between 18:1 and 19° in two cases out of a possible four (column 6, line 3 in sections A and D; so far it may be said that there is an apparent correlation between abundance at the surface and that range of temperature. This holds for early morning (section A) and late night (section D). It is not easy to say whether or not the general lack of correspondence between abundance and frequency is significant. Michael (1911, p. 139) found that these correspond rather closely.

It would seem that if temperature is a very effective agent in determining distribution there would be some sort of regularity in the arrangement of hourly averages with respect to temperature; that is, in the present case, we should expect the highest average to be at the same temperature whatever the time of day. This is obviously not the case in table 17, where, in section B, columns 5 and 6, there is a regular series for the abundance from the lowest to the highest temperatures. The order of abundance in relation to temperature varies in all the sections of the table. If table 18 is considered from all points of view, it is very difficult to discover a constant relation between temperature and abundance; the conclusion is that this factor within the limits of surface variation revealed by our data has but a slight effect, if any, in determining the distribution of *Calanus*, and this conclusion is strengthened by the data in table 16.

It is true that table 18 shows the animals to be least abundant at a low temperature and that there is an increase in abundance to the maximum at 18:1–19° (columns E and F, lines 1–3). This table, however, summarises the distribution with regard to temperature without the possible effects of light. This is impossible under natural conditions and we know that the abundance is much greater at certain times of day than at others. It seems to me that the apparent relation pointed out between the temperatures 18:1–19° and abundance is really

misleading in that it does not clarify matters. The data concerning distribution and temperatures are given for what they are worth; they do not seem to show that temperature is important in determining the distribution of *Calanus* at the surface. There is doubtless a temperature that may be called usual at the region of maximum abundance during the day, but there is no evidence that *Calanus* seeks that depth because of the temperature. In view of the movements performed by the species, it is difficult to imagine the part that temperature really has in the life of these animals. The bulk of the population periodically leaves a region where the temperature is about 9 degrees on the average and moves into water where the average temperature is about 17 degrees. The temperature does not vary periodically or constantly enough to lead us to consider its changes as the causes of the migrations, and it is very probable that there is some other cause. The variations in the intensity of light are both constant and periodical, and it is my belief that light is the primary cause of the movements of this species and also the main factor in determining its vertical distribution.

Distribution with regard to salinity.—The salinity is known for 71 surface hauls made in June, July, August and September, and these hauls alone will be considered because of the desirability of eliminating seasonal changes. This number of hauls is rather small, but table 19 will give some idea of the abundance of animals at certain salinities and times of day.

TABLE 19

Distribution of *Calanus* at surface with regard to salinity

A. 4-8 a.m.									
Salinity	No. of hauls		No. of hours		No. of animals		Frequency		Time
	Total 1	Success. 2	Total 3	Success. 4	Total 5	Per hour 6	Haul 7	Time 8	
1. 33.604 or less	10	3	9.0	3.2	11	1.2	30	35	
2. 33.605-33.648	2	2	.8	.8	31	3.9	100	100	
3. 33.649 or more	11	5	6.4	3.8	689	108.0	45	59	
B. 8 a.m.-4 p. m.									
1. 33.604 or less	6	2	4.3	1.1	11	2.6	33	25	
2. 33.605-33.648	5	0	3.2	0.0	0	0.0	0	0	
3. 33.649 or more	9	3	7.0	2.3	37	5.3	33	33	
C. 4 p.m.-10 p.m.									
1. 33.604 or less	11	9	6.0	5.4	4669	778.1	82	90	
2. 33.605-33.648	8	5	4.2	3.0	954	226.0	62	71	
3. 33.649 or more	7	4	4.4	3.6	293	66.5	57	82	
D. 10 p.m.-4 a.m.									
1. 33.604 or less	0	0	0.0	0.0	0	0.0	0	0	
2. 33.605-33.648	1	1	2.8	2.8	3825	1368.0	100	100	
3. 33.649 or more	2	2	5.7	5.7	378	61.3	100	100	

TABLE 20

Summary of table 19

Salinity	No. of hauls		No. of hours		No. of animals		Frequency	
	Total A	Success. B	Total C	Success. D	Total E	Per hour F	Haul G	Time H
1. 33.604 or less	27	14	19.3	9.7	4691	271.0	82	50
2. 33.605-33.648	16	8	11.0	6.6	4810	437.2	50	60
3. 33.649 or more	29	14	23.5	18.6	397	16.7	48	81

In table 20, which deals with distribution in relation to salinity apart from time of day, we see that the highest hourly average (column F) is when the salinity is between 33.605 and 33.648 (line 2); the highest haul frequency is at a salinity 33.604 or less and the highest time frequency at a salinity of 33.649 or more.

In table 19 the greatest averages per hour (column 6) are at the highest densities in two cases out of four (line 3, sections A and B). In other words, the animals are most abundant during brightest daylight (8 a.m.—4 p.m.) and early morning (4 a.m.—8 a.m.) at a salinity of 33.649 or more. But they are most abundant and most frequent during twilight hauling when the salinity is lowest (section C, line 1), and during late night (section D, line 2) at a salinity of 33.605–33.648. It seems to me that such an erratic distribution of abundance in respect to salinity can only mean that that factor is negligible in the determination of distribution. Michael (1911, p. 139) found that *Sagitta bipunctata* is always most frequent and abundant at salinities between 33.605 and 33.648. There is no reason to expect that such a relation between abundance and salinity, in regard to consistent results at least, should be absent in the case of *Calanus* if salinity is a factor in distribution. It is of course possible that a relation between abundance and salinity would be established if a larger number of hauls were available, but as far as our data go at present we are hardly justified in claiming that there is such a relation. The animals are known to be mostly a long distance below the surface from 8 a.m. to 4 p.m., and the relation between abundance and salinity during these hours (as shown in table 19, section B), concerns a relatively small proportion of the population. When they are most abundant at the surface (4 p.m.—4 a.m.) the abundance is greatest at this salinity at one time and at that at another (table 19, sections C and D). On the whole, we are not warranted at present in forming a definite conclusion as to the effect of salinity on distribution.

Farran (1910, p. 83) has recently summarized the facts as to the distribution of *Calanus finmarchicus*, including under that name the species known as *helgolandicus* and *septentrionalis*. The form is designated as eurythermal and stenohaline, the temperature limits (p. 87) being from 16° at the surface to 13° at the bottom in the mouth of the English Channel; in the north it is found in waters of 0° or less. Cleve gives the temperature limits in the North Atlantic as 22° C to 0:2 C. (Farran 1910, p. 87). Farran states (p. 88) that the organisms

are found only in waters where the salinity is between 35:30 and 33:00. If that is true for this region also, we are not likely to find a correlation between salinity and abundance, since the salinities appear to be always within the limits mentioned by Farran.

DISTRIBUTION OF *Eucalanus elongatus*

The distribution of this copepod has been dealt with briefly in an earlier paper (Esterly, 1911a), but it seems desirable to make use of the larger number of hauls available now. In table 21, which follows, the occurrence at the surface is shown, the day being divided into twelve two-hour periods.

TABLE 21

Distribution of *Eucalanus elongatus* at the surface in two-hour periods

	Time of day	No. of hauls		No. of hours		No. of animals		Frequency	
		Total A	Success. B	Total C	Success. D	Total E	Per hour F	Haul G	Time H
1.	6-8	35	9	27.2	6.8	106	3.9	33	25
2.	8-10	21	2	20.2	1.3	24	1.2	9	6
3.	10-12	14	6	9.8	3.3	112	11.0	43	34
	p.m.								
4.	12-2	14	3	9.0	1.8	22	2.4	21	20
5.	2-4	14	2	9.7	0.6	263	27.1	6	14
6.	4-6	13	1	9.9	1.0	1	0.1	10	8
7.	6-8	30	8	19.9	3.3	403	20.2	26	16
8.	8-10	8	5	4.4	2.6	321	73.0	62	60
9.	10-12	1	0	2.8	0	0	0	0	0
	a.m.								
10.	12-2	3	1	2.6	0.87	6	2.3	38	33
11.	2-4	8	4	12.0	3.3	119	16.0	28	50
12.	4-6	41	14	26.6	8.3	1050	40.0	34	31

TABLE 22

Summary of table 21

1.	Total number of hauls	111	92.
2.	Number of successful hauls	23.0	33.0
3.	Total number of hours	85.8	68.3
4.	Number of successful hours	15.7	18.3
5.	Total number of animals	528	1899.
6.	Average per hour	6.2	27.8
7.	Haul frequency	21	36.
8.	Time frequency	18	27.

Inspection of table 22 will show that *Eucalanus* is both more abundant (lines 5 and 6) and more frequent (lines 7 and 8) by night than by day. In table 21 it is shown that the highest hourly average (column F) is obtained from about the middle to the end of evening twilight (line 8); the frequencies are also highest at that time (columns G and H). The curve of hourly averages at the surface for *Eucalanus* is in figure 2.

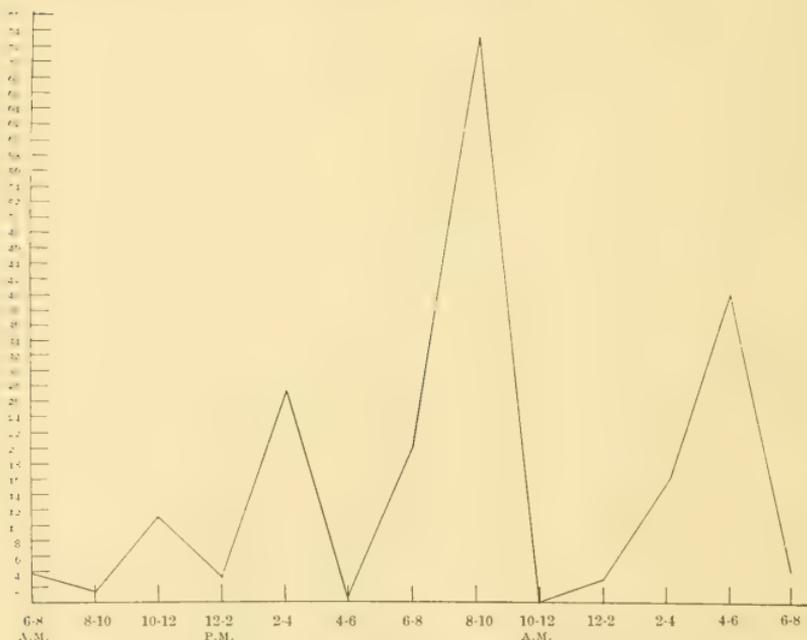


Fig. 2. *Eucalanus elongatus*. Variations in numbers per hour at the surface according to time of day. Data in table 21.

The occurrence of *Eucalanus* is much more irregular at the surface than that of *Calanus*, as can be seen by comparing the curves of the two species (figs. 1 and 2). It is also noticeable that the former species was taken in a much smaller proportion of hauls than the latter (cf. lines 7 and 8 in table 22 with those in table 13). Notwithstanding this, both species occur

most abundantly at the surface within the same four hours of the evening.

It is difficult to say whether the irregular occurrence of *Eucalanus* at the surface is due to lack of hauling at certain times or to the habit of the species. There is no reason to feel that the curve for *Eucalanus* must resemble that for *Calanus*, yet it might if more hauls were available. The afternoon, evening and morning maxima shown in figure 2 are probably of normal occurrence; they should be so considered at this time, at any rate.

The distribution of *Eucalanus* as shown by the horizontal closing nets will not be considered here, since that was done in another paper (Esterly, 1911a). There appears to be an extensive movement of the species below the surface, but it can hardly be called an upward migration such as is so evident for *Calanus*. The daylight plurimum of *Eucalanus* as shown by the horizontal nets is at 200 fathoms.

The occurrence of *Eucalanus* as shown by hauls with the vertical closing nets is given in table 23 which follows. It is similar to table 14 for *Calanus*.

TABLE 23

Distribution of *Eucalanus* as shown by the vertical closing nets

	Depth in fathoms	Day				Night					
		Hauls	6-12 a.m., 4-6 p.m.	Animals		Hauls	2-6 a.m., 6-8 p.m. (below 50 f.)	Animals			
	Total	Success.	Total	Per fath.	Freq.	Total	Success.	Total	Per fath.	Freq.	
1.	5-0	15	0	0	0.0	0	14	4	6	1.2	29
2.	10-5	15	3	11	2.0	20	14	8	11	2.2	52
3.	15-10	15	4	5	1.6	27	15	9	19	3.7	60
4.	20-15	15	5	18	3.6	33	15	12	21	4.2	80
5.	25-20	15	10	32	6.4	66	14	11	44	8.8	78
6.	30-25	17	11	46	9.3	65	14	13	30	6.0	93
7.	40-30	14	10	38	3.8	72	14	12	42	4.2	81
8.	50-40	16	12	52	2.6	66	15	13	65	6.5	82
9.	75-50	17	12	84	3.3	70	16	12	48	1.9	66
10.	100-75	6	4	10	0.4	66	3	1	4	0.16	33
11.	150-100	6	5	62	1.2	83	4	3	79	1.6	75
12.	200-150	6	6	398	8.0	100	3	3	20	0.4	100
13.	250-200	6	6	616	12.0	100	1	1	1	0.02	100
14.	300-250	4	3	286	5.7	75	1	1	1	0.02	100

TABLE 24

Summary of table 23

	Specimens per fathom		Total hauls		Successful hauls		Frequency	
	Day	Night	Day	Night	Day	Night	Day	Night
Between 0 and 50 fathoms	40.0	48.0	122	115	53	83	43	72
Between 50 and 250 fathoms	5.8	.8	41	27	33	20	80	74

We may gather from table 23 that the daylight plurimum is near 200 fathoms (lines 12 and 13) as was shown by the Kofoid net as well (Esterly 1911b). Though there is a plurimum at 30-25 fathoms nearly as large as that at 200 fathoms, the frequency for the former depth is 65, while for the latter it is 100. This probably means that the larger proportion of the animals is at 200 fathoms or thereabouts.

In table 24 it is plain that these animals are more abundant and more frequent above 50 fathoms by night than by day. The number per fathom at night below 50 fathoms is only about one-seventh of that during the day, and the night frequency is smaller. Since the vertical and horizontal nets both show that the hourly averages are smaller in deep water by day than by night, and since the surface net takes more at night, we are justified in assuming that the organisms move upward at night. There is no such clean-cut evidence of daily oscillation as was obtained for *Calanus* and, while more hauling might show such a condition for *Eucalanus*, there is no more reason at present for attributing its manner of distribution to the methods of collecting than to the organisms themselves.

Distribution with regard to temperature.—As in the case of *Calanus*, we are limited to surface hauls for evidence as to the effect of temperature on the distribution of *Eucalanus*. The species was obtained in 31 hauls out of the 130 for which the temperature is known. Table 25 is intended to show the distribution as regards temperature.

TABLE 25

Distribution of *Eucalanus* at surface with regard to temperature

Temperature	No. of hauls		No. of hours		No. of animals		Frequency	
	Total 1	Success. 2	Total 3	Success. 4	Total 5	Per hour 6	Haul 7	Time 8
A. 4-8 a.m.								
1. 16°0-17°0	16	3	11.0	1.2	5	0.45	19	9
2. 17°1-18°0	15	2	14.0	4.0	44	3.1	13	21
3. 18°1-19°0	10	1	6.4	0.35	6	0.93	10	5
4. 19°1-21°5	14	5	6.8	1.6	45	6.6	51	23
B. 8 a.m.-4 p.m.								
1. 16°0-17°0	10	0	0	0	0	0	0	0
2. 17°1-18°0	8	2	4.5	0.66	16	3.5	25	14
3. 18°1-19°0	6	0	3.2	0	0	0	0	0
4. 19°1-21°5	7	2	6.8	1.0	15	2.2	28	15
C. 4-10 p.m.								
1. 16°0-17°0	1	1	0.42	0.42	81	194.0	100	100
2. 17°1-18°0	6	3	5.6	4.4	3	0.5	50	79
3. 18°1-19°0	9	0	7.5	0	0	0	0	0
4. 19°1-21°5	17	7	8.3	4.1	372	44.8	41	49
D. 10 p.m.-4 a.m.								
1. 16°0-17°0	4	3	3.4	2.5	56	16.5	75	74
2. 17°1-18°0	3	1	2.9	0.58	57	19.6	33	20
3. 18°1-19°0	3	0	5.0	0	0	0	0	0
4. 19°1-21°5	1	0	1.0	0	0	0	0	0

The only conclusion that is justifiable from the above data is that the distribution of *Eucalanus* is unrelated to the surface temperature. For example, the highest average per hour in section A is at a temperature from 19°1 to 21°5; in section B the high average is obtained when the temperature varies from 17°1 to 18°. In other words, we find that the relation between temperature and abundance varies with the time of day. This should be taken to mean, in my opinion, that whatever the effective factor is in determining distribution, temperatures within the limits observed at the surface are practically negligible. It may be pointed out as a matter of interest that only one haul out of twenty-eight took *Eucalanus* when the temperature was 18°1-19° (table 25, line 3 of all the sections).

It may be that the animals really are less abundant at those temperatures than at the others as a rule, but we have hardly enough data for more than a suggestion to that effect.

The effect of salinity on the distribution of *Eucalanus* at the surface can be determined from only 14 hauls. More than half of these hauls were made between 4 and 10 p.m., this being the time when the animals are most abundant at the surface anyway. This small number of hauls does not show that there is any connection between the salinity of the water and abundance; the limits are 33.534 and 34.069. A larger number of collections ought to be available if we are to have a reasonable basis for any conclusion. Farran (1910, p. 93) gives a summary of the occurrence and distribution of *Eucalanus* as derived from the records of the International Council.

DISTRIBUTION OF *Metridia lucens*

This species is the third most abundant in the San Diego region. It was taken in a much smaller number of hauls than *Calanus* or *Eucalanus*, but certain facts about its distribution seem clear. The distribution of this species at the surface is shown in table 26, which follows.

TABLE 26

Distribution of *Metridia lucens* at the surface in two-hour periods

	Time of day a.m.	No. of hauls		No. of hours		No. of animals		Frequency	
		Total A	Success. B	Total C	Success. D	Total E	Per hour F	Haul G	Time H
1.	6-8	35	1	27.2	0.62	42	1.5	3	2
2.	8-10	21	2	20.2	2.3	2	0.1	9.6	11
3.	10-12	14	0	9.8	0.0	0	0.0	0	0
	p.m.								
4.	12-2	14	0	9.0	0.0	0	0.0	0	0
5.	2-4	14	0	11.1	0.0	0	0.0	0	0
6.	4-6	13	1	9.9	0.6	6	0.7	8	6
7.	6-8	30	1	20.0	0.7	1	0.05	3	3
8.	8-10	8	4	4.4	2.4	228	52.0	50	55
9.	10-12	1	1	2.8	2.8	31900	11380.0	100	100
	a.m.								
10.	12-2	3	3	2.6	2.6	3401	1310.0	100	100
11.	2-4	8	6	12.0	9.4	2124	177.0	75	78
12.	4-6	41	9	26.6	6.2	486	17.6	22	22

TABLE 27
Summary of table 26

	Day	Night
1. Total number of hauls	111.	92.
2. Number of successful hauls	4	24
3. Total number of hours	85.8	68.3
4. Number of successful hours	3.5	24.1
5. Total number of animals	50.	38140
6. Average per hour	0.6	573
7. Haul frequency	6	25
8. Time frequency	6	33

Table 26, columns E and F, lines 9 and 10, shows that *Metridia* is overwhelmingly more abundant and frequent on the surface between 10 p.m. and 2 a.m.; a noticeable increase is observable from 8 to 10 p.m. (line 9). The time of great abundance for this species at the surface corresponds with that for *Calanus* and *Eucalanus*. Beginning with line 7 in table 26 and following columns E, F, G and H through to line 12, it is noticeable that the numbers of animals and the frequencies increase to the amounts in line 9; after that the numbers decrease gradually to line 12, and the frequencies also, following line 10. The organisms are practically absent from the surface between 8 a.m. and 8 p.m. (lines 3-7). While this evidence of a diurnal migration is based on a comparatively small number of hauls, it is so clear that we can hardly doubt its reliability. Figure 3 shows the varying numbers per hour at the surface in a curve which is made up from the data in table 26.

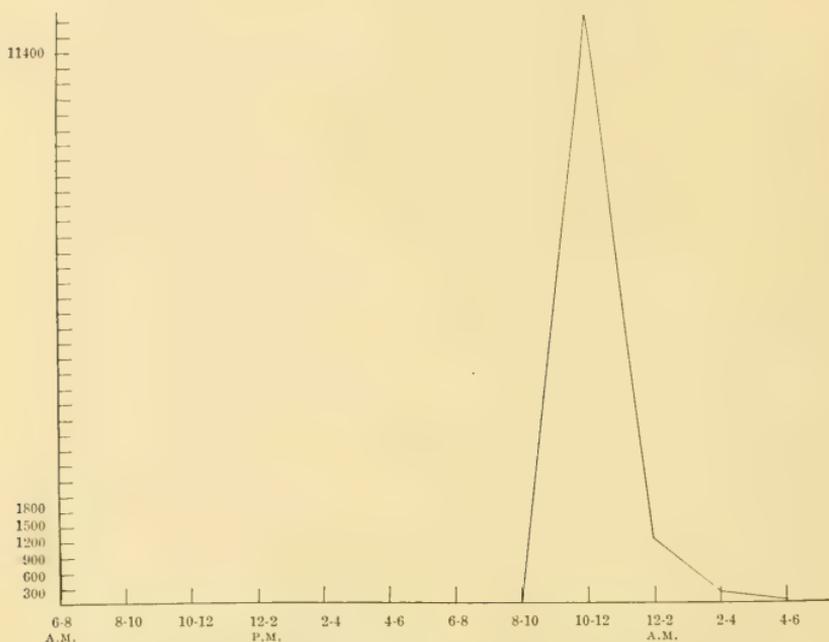


Fig. 3. *Metridia lucens*. Variations in numbers per hour at surface according to time of day. Data in table 26; as may be seen there, the numbers before 8 a.m. are so small that they do not appear on a plot of this scale.

In table 28 which follows, the data for 144 hauls with the horizontal closing nets are arranged to show the occurrence of *Metridia* at various depths at different times.

TABLE 28
Distribution of *Metridia* as shown by the horizontal closing nets

A. 6 a.m.—6 p.m.

Depth in fathoms	No. of hauls		No. of hours		No. of animals		Frequency	
	Total	Success.	Total	Success.	Total	Per hour	Haul	Time
	1	2	3	4	5	6	7	8
1. 4-6	5	0	1.6	0	0	0	0	0
2. 7-12	6	0	2.5	0	0	0	0	0
3. 15-20	8	2	2.1	.47	15	7.1	25	22
4. 25-35	10	0	2.6	0	0	0	0	0
5. 50-75	12	1	3.3	.13	3	.9	8	4
6. 100-160	8	2	2.7	.82	28	10.3	25	30
7. 200-250	9	3	3.2	.82	7	2.2	33	26
8. 300-550	7	2	3.3	.57	3	.9	29	29

TABLE 28 (Continued)

Depth in fathoms	No. of hauls		No. of hours		No. of animals Total	Per hour	Frequency	
	Total	Success.	Total	Success.			Haul	Time
	1	2	3	4	5	6	7	8
1. 4-6	3	1	.92	.17	5	.54	33	18
2. 7-12	4	2	1.8	.58	46	39.	50	32
3. 15-20	2	0	.5	0	0	0	0	0
4. 25-35	4	1	1.1	.20	2	.82	25	18
5. 50-75	5	2	1.9	.7	38	19.	40	37
6. 100-160	7	3	2.4	.82	19	7.9	43	38
7. 200-250	3	0	1.6	0	0	0	0	0

C. 10 p.m.-2 a.m.

1. 4-6	1	1	.17	.17	219	1314.	100	100
2. 7-12	1	1	.18	.18	284	1550.	100	100
3. 15-20	1	1	.17	.17	3	18.	100	100
4. 25-35	1	1	.25	.25	1	4.	100	100

D. 2-6 a.m.

1. 4-6	2	0	.6	0	0	0	0	0
2. 7-12	2	0	.5	0	0	0	0	0
3. 15-20	3	0	.7	0	0	0	0	0
4. 25-35	3	2	.8	.24	5	25.	66	33
5. 50-75	3	1	1.	.4	2	2.	33	40
6. 100-160	4	2	1.6	.5	60	37.	50	31

In table 29, which follows, there is a summary of table 28 by sections. It seems evident enough that there is a diurnal migration of *Metridia* if the number of hauls may be considered large enough to give a reliable basis for a conclusion.

TABLE 29

Summary of Table 28

	Section A 6 a.m.-6 p.m.	Section B 6-10 p.m.	Section C 10 p.m.-2 a.m.	Section D 2-6 a.m.
Total number of animals	56	110	507.	67
Average per hour for entire time	2.6	10.1	659.5	13
Highest average per hour	10.3	39.	1550	37
Depth of highest hourly average	100-160 f.	7-12 f.	10 f.	100-160 f.
Time frequency	13	24	100	22

The frequency, total number of animals and highest average per hour reach the minimum in Section A, that is, during daylight. It should be noted that the plurimum, according to these hauls, is at a depth of from 100 to 160 fathoms.

Section D is next to section A in all respects, and the depth at which the plurimum is located is within the same limits as for daylight hours.

Section B, including hauls made between 6 and 10 p.m., shows a marked rise in frequency with a greatly increased average for the whole time as well as a much greater plurimum. The plurimum was found between 7 and 12 fathoms.

The maximum in all respects is reached between 10 p.m. and 2 a.m. (section C), with the plurimum at 10 fathoms.

While it may be argued that the number of hauls is so small as to render it inadvisable to draw conclusions from the horizontal closing nets, the evidence for diurnal movements is so marked in tables 28 and 29 that one can hardly doubt that they actually take place. It is noticeable that the main results set forth in tables 28 and 29 check closely with those in tables 26 and 27 for the surface collections.

The results of hauling with the vertical closing nets are given in table 30, which follows.

TABLE 30
Distribution of *Metridia* as shown by the vertical closing nets

Depth in fathoms	No. of hauls	Day				Night					
		6-12 a.m.		4-6 p.m.		2-6 a.m.		6-8 p.m. (below 50 f.)			
		Total	Success.	Total	Per fath.	Total	Success.	Total	Per fath.	Success.	Per fath.
	A	B	C	D	E	F	G	H	I	J	
1. 5-0	15	1	2	0.4	7	14	1	2	0.2	7	
2. 10-5	15	0	0	0.0	0	14	1	4	0.8	7	
3. 15-10	15	0	0	0.0	0	15	3	22	4.4	25	
4. 20-15	15	0	0	0.0	0	15	4	50	10.0	27	
5. 25-20	15	0	0	0.0	0	14	5	81	16.2	36	
6. 30-25	17	0	0	0.0	0	14	6	134	26.8	43	
7. 40-30	14	0	0	0.0	0	14	6	110	11.0	43	
8. 50-40	16	2	2	2.0	12	15	7	101	10.1	47	
9. 75-50	17	6	485	19.4	35	16	11	175	7.0	69	
10. 100-75	6	2	201	8.0	33	3	1	1036	41.1	33	
11. 150-100	6	4	251	5.0	66	4	3	500	10.0	75	
12. 200-150	6	6	1467	29.3	100	3	2	34	0.7	66	
13. 250-200	6	6	828	16.5	100	1	0	0	0.0	0	
14. 300-250	4	3	489	9.8	75	1	0	0	0.0	0	

TABLE 31

Summary of table 30

	Specimens per fathom		Total hauls		Success. hauls		Frequency	
	Day	Night	Day	Night	Day	Night	Day	Night
Between 0 and 40 fathoms	0.5	10.1	106	100	1	26	0.9	26
Between 40 and 200 fathoms	23.2	13.1	51	41	20	24	40	58

The almost total absence of *Metridia* during the day above 40 fathoms is evident (table 30, columns A-E, lines 1-7). The daylight plurimum is at 200-150 fathoms, which checks roughly with the results from the horizontal nets (table 28, section A, column 6, line 6). As in the other species, a detailed comparison of vertical with horizontal closing nets is not possible because of the different times at which collecting was done in the two cases.

It is plain, however, from table 31 that *Metridia* is much more abundant by night than by day above 40 fathoms, and also more frequent; and that between 40 and 200 fathoms it is more abundant but not so frequent by day. These facts suggest that there is an upward migration at night, which was indicated from hauls with the surface and horizontal closing nets. A puzzling question arises in connection with table 31 as to why the catches by day below 40 fathoms should be larger than those at night though there are more successful hauls at night. There is no evidence available now to show why that condition should prevail. It is possibly due to the times at which the vertical closing hauls were made, but such results were not obtained in the case of *Calanus* (table 15) or of *Eucalanus* (table 23). In the case of *Metridia* the night collections below 40 fathoms are larger than the day collections above that level (table 31), but this does not hold for the other two species. These considerations suggest that we have to deal with a peculiarity of the species in table 31, but the matter should be left open until more collections are at hand.

There seems to be little room for doubt that *Metridia* as a whole is a good deal more abundant at night in the upper water than it is by day.

The hauls are so few (fifteen) for which temperatures are known where *Metridia* was taken, that it is useless to try to draw conclusions as to the effect of those factors in the distribution of the species. It may be stated, however, that it occurred at the surface when the temperatures ranged from 14:7 to 20:5, and at salinities from 33.577 to 33.856. As is the case with the two preceding species, I find it impossible to separate the temperature and light effects. The abundance varied from nearly 12,000 per hour at 19° between the hours of 10 and 12 p.m., to 8 per hour at a temperature of 19:2 between 4 and 6 a.m. Hauls 1875 to 1892 inclusive in table 3 form an interesting group if it is desired to note how abundance varies with the time of day while the temperature is practically stationary, there being a range of only 0:3.

Farran (1910, p. 67) gives the vertical range of *Metridia luccas* as from 0 to over 2000 meters, and mentions the marked tendency to swarm at night at the surface. The region of greatest abundance during the day is between 50 and 100 meters (about 27-55 fathoms). This is far above the depth of the daylight plurimum for this species according to our results. The difference is probably due to the different depth to which light penetrates in this region as compared with that covered by the International Council (see Hjort, 1910, p. 505, and the discussion at the end of this paper).

The other species found at the surface are listed in table 32 which gives their ranges in fathoms. Each of the ten species was more or less abundant at the surface, and since they are the less common ones they form a group which may conveniently be considered alone. The depths given for the vertical closing nets are upper and lower possible limits; the open vertical net did not take specimens in hauls that began *above* the indicated depths.

TABLE 32

	Horiz. closing	Vertical closing Range in fathoms	Open vertical
1. <i>Euchirella pulchra</i>	5-350	40-250	150
2. <i>Euchirella rostrata</i>	5-200	30-50	40
3. <i>Gaidius pungens</i>	50-350	25-350	150
4. <i>Labidocera trispinosa</i>	.....	0-75	15
5. <i>Pleuromamma abdominalis</i>	5-250	20-300	20
6. <i>Pleuromamma gracilis</i>	7.5	10-250	
7. <i>Pleuromamma quadrangulata</i>	5-350	100-300	150
8. <i>Rhincalanus nasutus</i>	15-350	15-300	60
9. <i>Scolecithrix persecaus</i>	25-300	50-300	150
10. <i>Undeuchaeta bispinosa</i>	5-350	20-300	100

The depths indicated for the horizontal closing nets are the more reliable, though it is noticeable that in several cases the range obtained from hauls with the vertical closing nets agrees closely with the other. In the case of *Euchirella rostrata*, for example, the lower limit at which the animals were taken with the vertical nets is far above that with the horizontal nets. Both sorts of nets agree, however, in showing that most of the species are wide-ranging.

Labidocera trispinosa.—This copepod was fourth in order of abundance at the surface and was taken in fairly large numbers in 28 hauls. Table 33 and figure 4 show the manner in which the animals occurred in relation to the time of day.

TABLE 33

Distribution of *Labidocera* at the surface in two-hour periods

Time of day	No. of hauls		No. of hours		No. of animals		Frequency	
	Total	Success.	Total	Success.	Total	Per hour	Haul	Time
	A	B	C	D	E	F	G	H
1. 6-8	35	3	27.2	1.8	6	0.2	8	4
2. 8-10	21	3	20.2	3.6	234	11.7	14	17
3. 10-12	14	1	9.8	1.2	2	0.2	7	12
p.m.								
4. 12-2	14	0	9.0	0.0	0	0.0	0	0
5. 2-4	14	1	11.1	0.5	1	0.9	7	4
6. 4-6	13	3	9.9	2.5	13	1.2	23	25
7. 6-8	30	5	20.0	3.8	2630	131.1	16	19
8. 8-10	8	2	4.4	1.1	3	0.6	25	23
9. 10-12	1	0	2.8	0.0	0	0.0	0	0
a.m.								
10. 12-2	3	0	2.6	0.0	0	0.0	0	0
11. 2-4	8	3	12.0	2.4	52	4.3	37	20
12. 4-6	41	7	26.6	4.4	527	21.2	17	16

TABLE 34

Summary of table 33

	Day	Night
1. Total number of hauls	111	92
2. Number of successful hauls	11	17
3. Total number of hours	85.8	68.3
4. Number of successful hours	9.6	15.7
5. Total number of animals	256	3212
6. Average per hour	3.0	470.2
7. Haul frequency	10	18
8. Time frequency	11	23

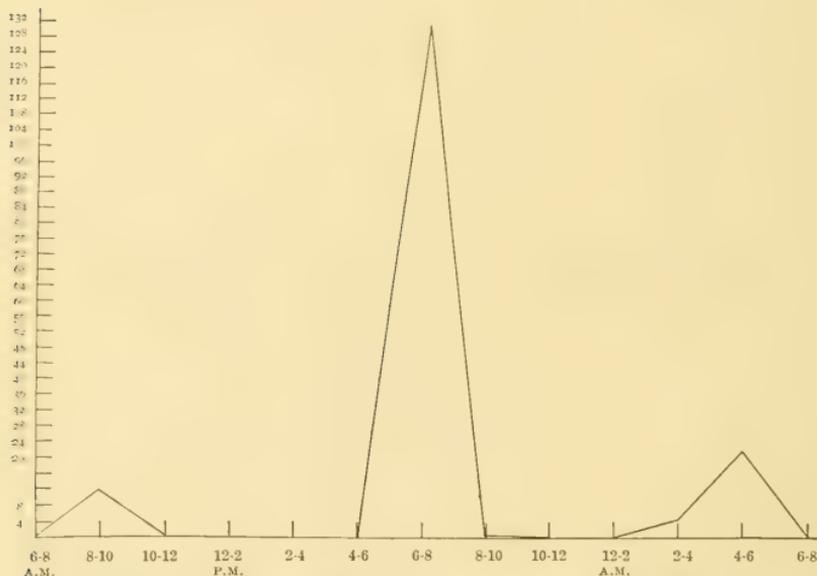


Fig. 4. *Labidocera trispinosa*. Variations in numbers per hour at the surface according to the time of day. Data in table 33.

The preponderance at night at the surface is marked (lines 5 and 6 of table 34). The night frequency is also somewhat greater (lines 7 and 8). The plurimum is reached between 6 and 8 p.m. (table 33, columns E and F, line 7), but the

frequencies are not so high then as at other times. The low frequencies throughout table 33 give some idea of the rarity of *Labidocera* at the surface, and on the whole the results of surface hauling are rather obscure except in the matters just pointed out.

Labidocera appears to be found only above 100 fathoms; it was not obtained in vertical closing hauls below 75 fathoms. There were 11 of these hauls and 21 animals were obtained, the majority (16) at night. In the absence of any successful hauls with the horizontal closing nets, it is difficult to say where the day plurimum is located; it is barely indicated by the vertical nets as between the surface and 5 fathoms.

The lowest and highest surface temperatures and salinities for *Labidocera* were, respectively, 13:1 and 22:3, and 33.563 and 33.704.

Euchirella pulchra was obtained at the surface in seven hauls which captured 17 animals. One day haul took one animal; the other 16 animals were obtained in six night hauls. The lowest temperature at the surface when this species was taken was 13:8, the highest 19:9; the lowest and highest salinities were, respectively, 33.536 and 33.648. Figure 5 shows the time of greatest abundance at the surface; the numbers of animals given in the figure are reckoned on the basis of one-hour hauls and then increased ten times.

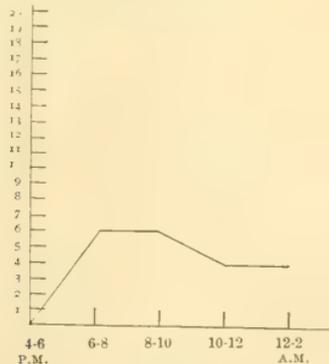


Fig. 5. *Euchirella pulchra*. Variations in numbers per ten hours of hauling at the surface during the night.

The distribution of this species as shown by the closing nets is indicated in tables 35 and 36 which follow. It is evident from both tables that the animals are most abundant during the day in deep water (table 35, column E, lines 3 and 4; table 36, column D, lines 3 and 4). Neither the horizontal nor vertical nets took the animals above 100 fathoms during the day, though some were taken there during the night. If allowance is made for differences in the action of the two sorts of nets, inspection of the tables under consideration shows that the organisms leave the deep water during the night and are found at much higher levels by night than by day. So far as this evidence goes, it indicates that there is an upward movement at night.

TABLE 35

Distribution of *Euchirella pulchra* as shown by hauls with the horizontal closing nets, day and night hauls compared

	Depth	A Total hauls		B Successful hauls		C Total hours		D Total animals		E Animals per 10-hr. haul		F Haul frequency	
		Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1.	4-35	29	27	0	2	8.8	7.8	0	4	0	5	0	7
2.	50-75	12	8	0	0	3.3	3.0	0	0	0	0	0	0
3.	100-160	8	11	2	1	2.7	4.0	12	2	41	5	25	9
4.	200-250	9	3	3	0	3.2	1.6	13	0	40	0	33	0
5.	300-350	7	0	2	0	3.3	0.0	2	0	6	0	28	0

TABLE 36

Distribution of *Euchirella pulchra* as shown by hauls with the vertical closing nets, day and night hauls compared

	Depth	A Total hauls		B Successful hauls		C Total animals		D Animals per 100-f. haul		E Haul frequency	
		Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1.	40-0	106	100	0	0	0	0	0	0	0	0
2.	100-40	39	34	0	2	0	13	0	21	0	6
3.	200-100	12	7	3	1	12	8	12	8	25	14
4.	250-200	6	1	6	0	47	0	94	0	100	0
5.	200-250	4	1	3	0	24	0	48	0	75	0

Euchirella rostrata.—Nineteen specimens were obtained in 13 surface hauls. The number in night hauls (16) is five times as great as that in day hauls (3), and there are three times as many successful night as day hauls. The lowest and highest temperatures and salinities for the surface hauls taking the species are, respectively, 16.9 and 20.9, and 35.534 and 33.670.

The center of migration (daylight plurimum) seems to be at about 200 fathoms, yet out of 8 hauls during the day at or below 100 fathoms, with the closing nets only one was successful, taking one animal; the other seven specimens were obtained above 100 fathoms, one by day and six by night, the latter being taken in six hauls. Evidently, the species moves upward at night if the numbers taken at the surface then as compared with those during the day can be taken as representative of the whole population.

Gaidius pungens.—This species is one of the commonest in the hauls with closing nets, but extremely rare at the surface. It was taken there in only three hauls, all of which were in daylight. It was obtained in 12 hauls with the horizontal closing nets and in 26 with the vertical nets; these took 148 and 777 specimens respectively. The distribution of these specimens at different depths and at various times as shown by the horizontal closing nets is indicated in table 37 which follows.

TABLE 37

Distribution of *Gaidius pungens* as shown by hauls with the horizontal closing nets, day and night hauls compared

Depth	A Total hauls		B Successful hauls		C Total hours		D Total animals		E Animals per 10-hr. haul		F Haul frequency	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1. 4-35	29	27	0	0	8.8	7.8	0	0	0	0	0	0
2. 50-75	12	8	1	1	3.3	3.0	1	2	3	6	8	12
3. 100-160	8	11	2	2	2.7	4.0	55	4	203	14	25	18
4. 200-250	9	3	5	0	3.2	1.6	81	0	506	0	55	0
5. 300-550	7	0	1	0	3.3	0.0	75	0	18	0	14	0

The region of greatest abundance is plainly between 200 and 250 fathoms during the day. This level is deserted at night, when the region of greatest abundance is between 100

and 160 fathoms. Specimens were taken both by day and by night between 50 and 75 fathoms, but the abundance and frequency are both greater at night. The table gives, on the whole, some evidence of an upward movement at night.

The vertical distribution of *Gaidius* as shown by hauls with the vertical closing nets appears in table 38 which follows. The evidence is similar to that in the preceding table, though much clearer as to the upward movement at night. The animals were not obtained above 100 fathoms except at night, nor below 200 fathoms except during the day; this evidently points to a movement toward the upper levels during the night.

TABLE 38

Distribution of *Gaidius pungens* as shown by hauls with the vertical closing nets, day and night hauls compared

	Depth	A Total hauls		B Successful hauls		C Total animals		D Animals per 100-f. haul		E Haul frequency	
		Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1.	40-0	106	100	0	4	0	9	0	22	0	4
2.	100-40	39	34	0	2	0	3	0	50	0	6
3.	200-100	12	7	5	6	55	58	55	58	41	85
4.	250-200	6	1	6	0	316	0	632	0	100	0
5.	300-250	4	1	3	0	345	0	690	0	75	0

Pleuromamma abdominalis.—As may be seen in table 11, this species was fairly abundant at the surface, ranking fifth in that respect. Two hauls at the surface during the day were successful, taking two animals; the discussion of surface distribution may therefore be limited to night hauls. Table 39 is arranged like a number that have preceded, but deals only with night hauls that obtained *P. abdominalis* at the surface. Figure 6 is derived from the data in table 39.

TABLE 39

Distribution of *Pleuromamma abdominalis* at the surface at night in two-hour periods

	Time of day	No. of hauls		No. of hours		No. of animals		Frequency	
		Total A	Success. B	Total C	Success. D	Total E	Per hour F	Haul G	Hour H
1.	6-8	30	2	20.0	2.4	45	2.2	7	12
2.	8-10	8	4	4.4	2.2	254	58.8	50	50
3.	10-12	1	1	2.8	2.8	14	5.0	100	100
	a.m.								
4.	12-2	3	3	2.6	2.6	39	15.0	100	100
5.	2-4	8	3	12.0	3.0	12	1.0	37	25
6.	4-6	41	4	26.6	1.4	6	0.22	10	5

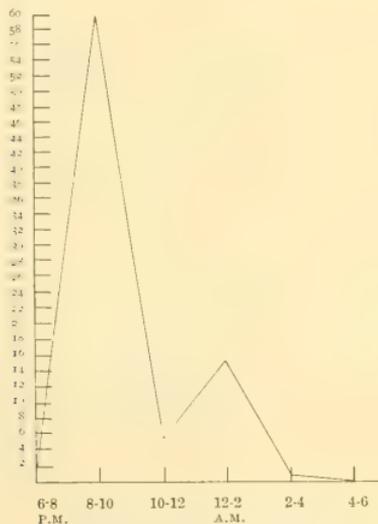


Fig. 6. *Pleuromamma abdominalis*. Variations in numbers per hour at the surface at night. Data in table 39.

The time of greatest abundance is from 8-10 p.m. (line 2), though the frequencies are greatest within the next four hours (lines 3 and 4). It seems that there is a sudden and marked rise to the maximum and a drop that is almost as abrupt. This species was found at the surface at temperatures ranging from

13:8 to 20:5, and at salinities from 33.539 to 33.762. As in the case of other species, it is not possible here to separate the possible effects of temperature from the more evident effect of light.

The hauls in which *P. abdominalis* was taken with the horizontal closing nets are summarized in table 40 which follows. It is scarcely necessary to point out the greater abundance between 4 and 35 fathoms (line 1) at night, or the smaller numbers taken at night as compared with the day catches between 100 and 160 fathoms (line 3).

TABLE 40

Distribution of *Pleuromamma abdominalis* as shown by hauls with the horizontal closing nets, day and night hauls compared

Depth	A Total hauls		B Successful hauls		C Total hours		D Total animals		E Animals per 10-hr. haul		F Haul frequency	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1. 4-35	29	27	0	3	8.8	7.8	0	45	0	57	0	11
2. 50-75	12	8	1	1	3.3	3.0	1	1	3	3	8	12
3. 100-160	8	11	2	3	2.7	4.0	17	10	60	25	25	27
4. 100-250	9	3	2	1	3.2	1.6	34	1	10	6	22	33
5. 300-550	7	0	1	0	3.3	0.0	1	0	3	0	14	0

The collections with the vertical closing nets (table 41) show that there is apparently an upward movement at night. The region of greatest abundance is below 200 fathoms (lines 4 and 5) during the day, but this region is deserted at night. The animals were not taken above 100 fathoms except at night.

TABLE 41

Distribution of *Pleuromamma abdominalis* as shown by hauls with the vertical closing nets, day and night hauls compared

Depth	A Total hauls		B Successful hauls		C Total animals		D Animals per 100-f. haul		E Haul frequency	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1. 40-0	106	100	0	4	0	4	0	10	0	4
2. 100-40	39	34	0	4	0	5	0	8	0	11
3. 200-100	12	7	7	4	27	7	27	7	58	57
4. 250-200	6	1	6	0	29	0	58	0	100	0
5. 300-250	4	1	3	0	28	0	56	0	75	0

Pleuromamma gracilis.—This species was taken in seven surface hauls, all of which were at night and took 213 animals. The largest number of animals was 165 between 8 and 10 p.m. The horizontal closing nets took *P. gracilis* but once, a haul between 6 and 8 p.m. at 7.5 fathoms containing one animal. Six hauls with the vertical closing nets obtained 316 animals. One of these (no. 2053) contained 253 specimens; this haul was from 200 to 150 fathoms in the middle of the afternoon. None of the animals was taken above 150 fathoms with the closing nets except at night, and the center of migration may be taken as 150 fathoms.

The lowest and highest surface temperatures at which *P. gracilis* was taken are 13.8 and 20.2 respectively; the salinities range from 33.578 to 33.603.

This species was taken in only one haul with the horizontal closing net. The results of collections with the vertical nets are shown in table 42. The center of migration is at 100–200 fathoms (line 3), but there is little evidence of an upward migration except in the fact that that region is deserted at night.

TABLE 42

Distribution of *Pleuromamma gracilis* as shown by hauls with the vertical closing nets, day and night hauls compared

Depth	A Total hauls		B Successful hauls		C Total animals		D Animals per 100-f. haul		E Haul frequency	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1. 40–0	106	100	0	0	0	0	0	0	0	0
2. 100–40	39	34	0	1	0	1	0	1	0	3
3. 200–100	12	7	4	0	303	0	303	0	33	0
4. 250–200	6	1	1	0	2	0	4	0	16	0
5. 300–250	4	1	0	0	0	0	0	0	0	0

Pleuromamma quadrangulata.—This is a very rare form at the surface, for it was obtained in only two day hauls which contained three animals.

The closing nets obtained the animals in much larger numbers, and both sorts of nets agree in that the day plurimum is at 200–250 fathoms. The results of hauling with the horizontal closing nets are shown in table 43. The region of the day

plurimum is between 200 and 250 fathoms (line 4). This is also the location of the region of greatest abundance at night (column E), but the number of animals is much smaller at night; moreover, the animals were taken above 100 fathoms (line 1) only at night.

TABLE 43

Distribution of *Pleuromamma quadrangulata* as shown by hauls with the horizontal closing nets, day and night hauls compared

	Depth	A Total hauls		B Successful hauls		C Total hours		D Total animals		E Animals per 10-hr. haul		F Haul frequency	
		Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1.	4-35	29	27	0	3	8.8	7.8	0	6	0	7	0	11
2.	50-75	12	8	0	0	3.3	3.0	0	0	0	0	0	0
3.	100-160	8	11	2	1	2.7	4.0	8	4	29	10	25	9
4.	200-250	9	3	5	1	3.2	1.6	28	2	80	12	55	33
5.	300-550	7	0	3	0	3.2	1.6	6	0	18	0	43	0

The vertical closing hauls (table 44) did not take the animals above 100 fathoms (lines 1 and 2), and there is a marked reduction in the numbers taken below 100 fathoms at night as compared with day. This is some indication of an upward migration at night, but it is difficult to say in what degree the scarcity in deep water at night is due to lack of hauling.

TABLE 44

Distribution of *Pleuromamma quadrangulata* as shown by hauls with the vertical closing nets, day and night hauls compared

	Depth	A Total hauls		B Successful hauls		C Total animals		D Animals per 100-f. haul		E Haul frequency	
		Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1.	40-0	106	100	0	0	0	0	0	0	0	0
2.	100-40	39	34	0	0	0	0	0	0	0	0
3.	200-100	12	7	5	4	27	13	27	13	41	57
4.	250-200	6	1	6	1	154	1	208	2	100	100
5.	300-250	4	1	3	1	75	1	150	2	75	100

Rhincalanus nasutus.—These copepods appeared in eleven surface hauls, of which nine were made during the night and contained 46 animals out of a total of 54. The maximum abundance

and frequency occurred between 8 and 10 p.m., as is shown in figure 7. The temperature and salinities ranged from 13:8 to 20:4, and from 33.539 to 33.704.

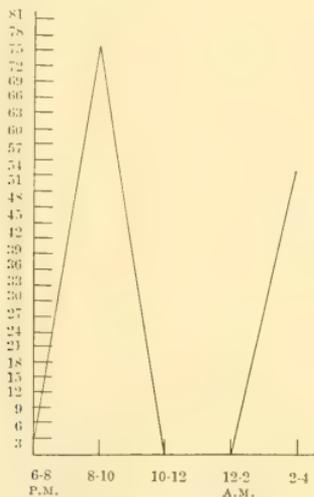


Fig. 7. *Rhincalanus nasutus*. Variations in numbers per ten hours of hauling at the surface at night up to 4 a.m.

The results of hauls made with the horizontal closing nets is shown in table 45. The abundance at 50-75 and at 200-250 fathoms is the same during the day, but the frequency at the latter depth is greater (compare lines 2 and 4); it seems likely, therefore, that the center of migration is located between 200 and 250 fathoms. There is very little evidence of an upward migration at night unless the desertion of the 200-250 fathoms level at night may be so considered.

TABLE 45

Distribution of *Rhincalanus nasutus* as shown by hauls with the horizontal closing nets, day and night hauls compared

Depth	A Total hauls		B Successful hauls		C Total hours		D Total animals		E Animals per 10-hr. haul		F Haul frequency	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1. 4-35	29	27	1	1	8.8	7.8	1	1	1	1	3	3
2. 50-75	12	8	1	0	3.3	3.0	2	0	6	0	8	0
3. 100-160	8	11	1	1	2.7	4.0	1	1	3	2	12	9
4. 200-250	9	3	2	0	3.2	1.6	2	0	6	0	22	0
5. 300-550	7	0	1	0	3.3	0.0	1	0	3	0	14	0

Table 46 which follows deals with the vertical closing hauls. Considering both number of animals and frequency, the region of the plurimum during the day is between 100 and 200 fathoms, though the abundance at 200-250 is a little greater (lines 3 and 4). It is noticeable that above 40 fathoms (line 1) the abundance by night is greater than by day.

TABLE 46

Distribution of *Rhincalanus nasutus* as shown by hauls with the vertical closing nets, day and night hauls compared

	Depth	A Total hauls		B Successful hauls		C Total animals		D Animals per 100-f. haul		E Haul frequency	
		Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1.	40-0	106	100	1	6	1	8	2	15	0.9	6
2.	100-40	39	34	7	6	12	10	20	16	18	16
3.	200-100	12	7	10	6	51	13	51	13	84	85
4.	250-200	6	1	5	0	26	0	52	0	16	0
5.	300-250	4	1	3	0	17	0	34	0	25	0

The result in tables 45 and 46, in connection with those of the surface hauls, are indicative of a movement of the greater portion of the individuals from the neighborhood of 200 fathoms upward to above 100 fathoms at night.

Scolecithrix persecans.—Two day hauls at the surface obtained three specimens. The species as a whole appears to be a resident of deep water during the day; it is rather common in the closing hauls, and an idea of its occurrence in hauls with the horizontal nets may be obtained from table 47, which follows. The table shows the plurimum is located between 200 and 250 fathoms during the day (line 4), and that that region is deserted during the night; on the other hand the animals were taken between 4 and 75 fathoms only at night (lines 1 and 2). This indicates that there is an upward movement at night.

TABLE 47

Distribution of *Scolecithrix persecans* as shown by hauls with the horizontal closing nets, day and night hauls compared

	Depth	A Total hauls		B Successful hauls		C Total hours		D Total animals		E Animals per 10-hr. haul		F Haul frequency	
		Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1.	4-35	29	27	0	1	8.8	7.8	0	1	0	1	0	4
2.	50-75	12	8	0	1	3.3	3.0	0	2	0	6	0	8
3.	100-160	8	11	2	2	2.7	4.0	4	6	14	16	25	18
4.	200-250	9	3	3	0	3.2	1.6	6	0	18	0	33	0
5.	300-500	7	0	1	0	3.3	0.0	1	0	3	0	14	0

Table 48, which follows, deals with the vertical closing hauls. It will be seen that, as in the preceding table, the day plurimum is between 200 and 250 fathoms (line 4) and that this region and the level below (line 5) are deserted at night. The animals are more abundant above 100 fathoms by night, but the results are not particularly clear.

TABLE 48

Distribution of *Scotectithrix persekans* as shown by hauls with the vertical closing nets, day and night hauls compared

Depth	A Total hauls		B Successful hauls		C Total animals		D Animals per 100-f. haul		E Haul frequency	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1. 40-0	106	100	1	0	1	0	2	0	0.9	0
2. 100-40	39	34	0	5	0	53	0	8	0	14
3. 200-100	12	7	9	5	184	37	184	37	75	71
4. 250-200	6	1	5	0	203	0	406	0	81	0
5. 300-250	4	1	3	0	74	0	148	0	75	0

Undeuchaeta bispinosa.—This species was taken at the surface only at night, when there were five successful hauls containing 25 animals; 21 of these were taken between 8 and 10 p.m., and two between 10 and 12. The temperatures for these hauls range from 18:9 to 20:2 and the salinities from 33.539 to 33.762. This is the only species which occurs at the surface consistently at any temperature (high in this case), there being a range of 1:3. In other cases the range is as much as six degrees. The hauls that contained *Undeuchaeta* are so few that its occurrence with reference to temperature is only suggested, but the available data are certainly exceptional merely in indicating conclusions as to the effect of that factor in determining the distribution of the species.

The distribution of this species as shown by the horizontal closing nets is set forth in table 49 which follows. The day plurimum is between 200 and 250 fathoms (line 4); this region is deserted during the night but the animals were taken between 4 and 75 fathoms only at night. These facts are evidences of an upward movement at night.

TABLE 49

Distribution of *Undeuchaeta bispinosa* as shown by hauls with the horizontal closing nets, day and night hauls compared

Depth	A Total hauls		B Successful hauls		C Total hours		D Total animals		E Animals per 10-hr. haul		F Haul frequency	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1. 4-35	29	27	0	2	8.8	7.8	0	3	0	3	0	8
2. 50-75	12	8	0	1	3.3	3.0	0	13	0	43	0	12
3. 100-160	8	11	0	0	2.7	4.0	0	0	0	0	0	0
4. 200-250	9	3	4	0	3.2	1.6	12	0	37	0	44	0
5. 300-550	7	0	4	0	3.3	0.0	8	0	23	0	57	0

The vertical closing hauls are dealt with in table 50 which follows. The results are practically the same as for the horizontal closing hauls (preceding table) and need no further comment.

TABLE 50

Distribution of *Undeuchaeta bispinosa* as shown by hauls with the vertical closing nets, day and night hauls compared

Depth	A Total hauls		B Successful hauls		C Total animals		D Animals per 100-f. haul		E Haul frequency	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
1. 40-0	106	100	0	2	0	2	0	5	0	2
2. 100-40	39	34	0	5	0	8	0	13	0	14
3. 200-100	12	7	1	2	1	2	1	2	8	28
4. 250-200	6	1	3	0	44	0	88	0	50	0
5. 300-250	4	1	3	0	29	0	58	0	25	0

The evidence of all the nets is indicative of an upward movement of the animals at night.

DISTRIBUTION OF *Euchaeta tonsa*, *Euchirella galeata*, *Gaetanus unicornis*, *Pleuromamma xiphias*, *Scolecithrix frontalis* AND *S. magna*

These six species were not taken at the surface in any of the hauls. For that reason I have considered them together. Table 51 shows the range of each of the species, but in the case of the vertical closing nets it is to be understood that "range" means

that the depths given are only *possible* limits. The number of each species and the number of successful hauls is given in table 13. The animals were not taken in hauls with the open vertical net starting above the depths given in table 32.

TABLE 51

Vertical ranges of six species that did not occur at the surface

Character of haul	Horizontal closing	Vertical closing Range in fathoms	Vertical open
<i>Euchaeta tonsa</i>	160-300	200-300	150
<i>Euchirella galeata</i>	200-350	75-300	160
<i>Gaetanus unicornis</i>	220-350	150-350	250
<i>Pleuromamma xiphias</i>	10-350	40-350	100
<i>Scolecithrix frontalis</i>	100-350	50-300	150
<i>Scolecithrix magna</i>	250-350	100-300	290

In table 52 I have attempted to show how these species are distributed at different depths by day and night in the horizontal closing hauls. The actual numbers of animals for each species are given in the column at the left in columns C-II, and the species are designated by using the first letter of the generic and specific names. In the right-hand columns (C-II) are the numbers of specimens to be expected in ten hours of hauling; this avoids the use of numbers smaller than 1.

TABLE 52

Distribution of the six species that did not occur at the surface, as shown by the horizontal closing nets, day and night hauls compared

I. 6 a.m.-6 p.m.

Depth	A Total hauls	B Total hours	C		D		E		F		G		H	
			<i>E. t.</i>	<i>E. g.</i>	<i>G. u.</i>	<i>P. x.</i>	<i>S. f.</i>	<i>S. m.</i>						
1. 4-35	29	8.8	0	0	0	0	0	0	0	0	0	0	0	0
2. 50-75	12	3.3	0	0	0	0	0	0	0	0	0	0	0	0
3. 100-160	8	2.7	0	0	0	0	0	0	1	3	1	3	0	0
4. 200-250	9	3.2	3	9	3	9	1	3	7	21	4	12	1	3
5. 300-550	7	3.3	7	21	1	3	3	9	4	12	6	18	2	6

II. 6 p.m.-6 a.m.

1. 4-35	27	7.8	0	0	0	0	0	0	3	3	0	0	0	0
2. 50-75	8	3.0	0	0	0	0	0	0	0	0	0	0	0	0
3. 100-160	11	4.0	1	4	0	0	0	0	0	0	0	0	0	0
4. 200-250	3	1.6	0	0	0	0	2	6	0	0	1	3	0	0

Table 53 which follows deals with the vertical closing hauls. It is similar to table 52, but the numbers in the right-hand columns (B-G) represent the numbers of animals per 100 fathom hauls.

TABLE 53

Distribution of the six species that did not occur at the surface, as shown by the vertical closing nets, day and night hauls compared

I. 6-12 a.m., 4-6 p.m.														
	Depth	A Total hauls	B		C		D		E		F		G	
			<i>E. t.</i>		<i>E. p.</i>		<i>G. u.</i>		<i>P. x.</i>		<i>S. f.</i>		<i>S. m.</i>	
1.	40-0	106	0	0	0	0	0	0	0	0	0	0	0	0
2.	100-40	39	0	0	0	0	0	0	0	0	0	0	0	0
3.	200-100	12	0	0	1	1	1	1	0	0	1	1	0	0
4.	250-200	6	5	10	8	16	6	12	16	32	18	36	3	6
5.	300-250	4	11	22	12	24	6	12	7	14	6	12	4	8
II. 2-6 a.m., 6-8 p.m. (below 50 f.)														
6.	40-0	100	0	0	0	0	0	0	0	0	0	0	0	0
7.	100-40	34	0	0	0	0	0	0	1	2	15	25	0	0
8.	200-100	7	0	0	5	5	0	0	1	1	6	6	2	2
9.	250-200	1	0	0	0	0	0	0	0	0	0	0	0	0
10.	300-250	1	0	0	0	0	0	0	0	0	0	0	0	0

Consideration of tables 52 and 53 will show that there is some evidence of an upward movement at night on the part of these species which are all below 100 fathoms during the day. It is true that not all of the species were taken above 100 fathoms at night, but the general fact of decreased numbers below 100 fathoms at night in all cases and of increased numbers by day above 100 fathoms in some cases is suggestive. The number of all closing hauls above 100 fathoms during the day is many times greater than the number of night hauls, yet no animals were taken during the day above 100 fathoms. This evidence, it must be admitted, is unsatisfactory, yet tables 52 and 53 taken together at least suggest that the species which never came to the surface are found in deeper water by day than by night.

Our knowledge of the usual conditions under which these species live during the day is so slight that there is not even a suggestion to offer as to why they do not come to the surface.

GENERAL CONSIDERATIONS.

In the preceding study of the distribution of nineteen species of copepods in as much detail as the data allow, the fact of greater abundance at night in the upper water has been prominent in the case of every species. From collections with closing nets we are able to locate the day plurimum or center of migration with a reasonable degree of accuracy, and this is never at the same depth for daylight hauls that it is for collections made during the night. The obvious conclusion is that there is an upward migration from the region of greatest abundance during the day to that during the night. For this reason the term "center of migration" as first used by Michael (1911) is particularly appropriate in referring to the region of the day plurimum.

The possible effect of the lack of as many night as day hauls in deep water in modifying this conclusion has been mentioned several times in the course of the paper, but it seems impossible that the widespread occurrence of the upward movement at night can be due to excess of day hauling. It is exceedingly desirable, nevertheless, to have more hauls with the closing nets at depths of 200 fathoms and below, and during the night especially.

The matter of upward migration at night is most evident in table 54 which deals with surface and closing net hauls, all separated into day and night and the latter into those above 100 fathoms or at this level and below.

TABLE 54

Numbers of animals at the surface, and above and below 100 fathoms, day and night hauls compared; horizontal and vertical closing nets considered separately

	No. of animals per 10-hr. haul in surface hauls		No. of animals per 10-hr. haul in horizontal closing hauls		No. of animals per 10-hr. haul in vertical closing hauls	
	Day	Night	Day	Night	Day	Night
1. <i>Calanus finmarchicus</i>	68.0	2099.0	330.0	740.0	296	1187
2. <i>Eucalvus elongatus</i>	61.0	270.0	310.0	120.0	296	290
3. <i>Euchaeta tonsa</i>	0.0	0.0	0.0	0.0	0	0
4. <i>Euchirella galecta</i>	0.0	0.0	0.0	0.0	0	0
5. <i>Euchirella pulchra</i>	0.1	2.3	0.0	5.0	0	21
6. <i>Euchirella rostrata</i>	0.3	2.3	0.0	0.9	1	2
7. <i>Gaetanus unicoloris</i>	0.0	0.0	0.0	3.0	0	0
8. <i>Gaidius pungens</i>	0.4	0.0	3.0	6.0	0	77
9. <i>Labidocera trispinosa</i>	28.0	462.0				
10. <i>Metridia lucens</i>	5.0	5487.0	150.0	560.0	690	1715
11. <i>Pleuromamma abdominalis</i>	0.1	54.0	3.0	60.0	0	18
12. <i>Pleuromamma gracilis</i>	0.0	30.0	0.9	0.0	0	1
13. <i>Pleuromamma quadrangulata</i>	0.3	0.0	0.0	7.0	0	0
14. <i>Pleuromamma zephias</i>	0.0	0.0	0.0	2.0	0	2
15. <i>Rhinocalanus nasutus</i>	0.9	6.0	7.0	1.0	22	31
16. <i>Scolecithrix frontalis</i>	0.0	0.0	0.0	0.0	0	25
17. <i>Scolecithrix magna</i>	0.0	0.0	0.0	0.0	0	0
18. <i>Scolecithrix persecanis</i>	0.9	0.0	0.0	7.0	2	8
19. <i>Undeuchaeta bispinosa</i>	0.0	3.0	0.0	46.0	0	18
Totals	165.1	8865.6	796.9	1557.0	1787	3405
Total number of hauls	111	92	31	35	145	22
Total number of hours	85.6	69.5	12.1	10.8	9.2	5.6

It can be seen in the preceding table that there are only three exceptions to the rule that the abundance at the surface is greater at night; these are, *Gaidius pungens*, *Pleuromamma quadrungulata* and *Scolecithrix persecans*. There are only nine animals involved for the three species and they are evidently individual exceptions, for each species is typically resident in deep water. *Eucalanus elongatus* in both sorts of closing nets and *Rhincalanus nasutus* and *Pleuromamma gracilis* in the horizontal nets were found less abundantly by night than by day above 100 fathoms; the other sixteen species were more abundant by night in the epiplankton. The species occurring at all below 100 fathoms were much more abundant there by day than by night, with the exception of *Metridia lucens* in the hauls with the horizontal closing nets.

It may be pointed out that, though the number of night hauls at the surface and above 100 fathoms is smaller than the number of day hauls, the number of animals is much larger at night at both levels. This makes it unlikely that the larger number of animals during the day at or below 100 fathoms is due to the larger number of day hauls.

The Copepoda appear to behave as do the Ostracoda as shown by Fowler (1909). He found that out of about fifteen species, nine showed an increase in the epiplankton at night, and three were never taken at or above 100 fathoms by day; one species was taken there once, another was taken twice. Six species did not show such a variation by day and night. Table 54 shows that out of nineteen species of copepods, six were never taken at the surface nor above 100 fathoms by day. There are fewer exceptions among the copepods to the rule of increased numbers in the epiplankton at night.

The facts regarding vertical distribution of the copepods of the San Diego region show, I believe, that each species is in a state of chronic movement as claimed for the ostracods by Fowler (1909, p. 299). The reasonable explanation of increased abundance at night above 100 fathoms is that the population is actually augmented by specimens coming up from below, especially since there is a decrease in the numbers of animals taken below 100 fathoms at night. The idea that we have to deal with

the oscillations of a confined swarm is without foundation, considering the length of time and the area over which our observations extend (Fowler, 1909, p. 304). Damas et Kofoed note (1905, p. 410) conditions among the copepoda, similar to those observed here.

Franz (1911b, p. 10) states that it is doubtful if vertical migration occurs regularly; the catches may be larger at night because the animals can not see the nets and are taken in larger numbers than during the day when the nets are visible. He says that if nets are constructed that tend to prevent the escape of the organisms the difference between the day and night catches diminishes.

The possibility that the animals see the nets and avoid them during the day should not be ignored, but it can not apply in the case of such organisms as the Halocypridae among the Ostracoda, which have no eyes (Fowler, 1909, p. 302). The fact of diurnal migrations is so well established for the Chaetognatha (Michael, 1911) and Copepoda of this region, and the Ostracoda of the Biscayan region (Fowler, 1909) that it is needless to more than mention those instances to indicate the extent to which such movements appear to occur.

Franz also (1911b, pp. 8 and 9) states, on the basis of his experimental work, that we may assume that copepods in their natural surroundings do not react phototactically, and he uses this, apparently, as an argument against the occurrence of diurnal migrations. On the contrary, he says the movements observed in nature take place because of unrest for short periods. Furthermore, he claims (p. 12) that his laboratory experiments have shown for a number of animals (among them certain pelagic copepods) that movements toward or away from a source of light do not take place because of unequal illumination, but because of the unusual and abnormal stimulation produced when the animals are put into the vessel.

In another paper this author states his views concisely (Franz, 1911a, p. 10), where he says: "Wenn die freibeweglichen Tiere beim Laboratoriumsversuch phototaktisch reagieren, so tun sie für eine etwas längere Zeitsdauer das, was im Freileben das Flichen vor ungünstigen Einflüssen oder das Aufsuchen geeigneter Aufenthalts ist. Die Lichtsverhältnisse sind für die

Tiere im Freileben wichtige Wegweiser bei ihren Fluchtbewegungen, und deshalb dirigieren sie auch die Fluchtreflexe der Tiere im Laboratorium."

"Die Phototaxis ist bei den untersuchten Tieren also nur als ein kleiner Ausschnitt aus den Lebensgewohnheiten zu verstehen."

The author is justified in his claim that phototactic reactions are not in themselves vertical migrations. There can be hardly any doubt that the migrations take place, but it has been pointed out in the course of this paper, and elsewhere (e.g., Esterly, 1911b), that a negative reaction to light does not seem to explain *downward* movements. Reactions to light are, as stated by Franz (1911a, p. 10), only a part (possibly not small) of the habits of the organisms, but it is difficult to avoid the conclusion that a reaction to light is the primary cause of the upward movement. The results in table 55 appear to show that the copepods follow a waning light in their upward migration. We may assume that the optimum intensity of light is low, judging from the depth at which the plurimum of most species is located during the day, and that the animals follow the optimum, so to speak.

TABLE 55.

Total numbers of animals and numbers per hour in ten species at surface during different periods of the night; totals at left, averages per hour at right in each column; bold face indicates plurima. When the average falls below 1, it is not entered.

	6-8 p.m.		Number of specimens				12 p.m.-6 a.m.	
			8-10 p.m.		10-12 p.m.			
<i>Calanus finmarchicus</i>	3643	182.1	4285	973.7	3825	136	1842	44.7
<i>Eucalanus elongatus</i>	403	20.1	321	73.2	0		1175	28.2
<i>Euchirella pulchra</i>	12		3		1		1	
<i>Euchirella rostrata</i>	9		2		0		5	
<i>Labidocera trispinosa</i>	2630	131.5	3		0		569	13.8
<i>Metridia lucens</i>	1		228	52.0	31900	11390	6011	145.8
<i>Pleuromamma abdominalis</i>	45	2.2	254	57.7	14	5	57	1.3
<i>Pleuromamma gracilis</i>	1		165	37.5	15	5.4	32	
<i>Rhincalanus nasutus</i>	5		14	3.2	0		6	
<i>Undeuchaeta bispinosa</i>	1		21	4.8	2		1	
Totals	6750		5296		35757		9699	
Total hours of hauling	20		4.4		2.8		41.2	
Number of animals								
per hour haul	328.5		1203.6		12770		230.3	

There is only one case (*Eucalanus elongatus*) where the two plurima do not coincide.

Table 55 shows that three species were at their plurimum between 6 and 8 p.m., five between 8 and 10 p.m., one between 10 and 12 p.m., and one between 12 p.m. and 6 a.m. As to totals, the period from 10 to 12 p.m. is overwhelmingly predominant owing to one haul of *Metridia lucens* that contained 32,000 specimens. The number of hours of hauling between 8 and 10 p.m. and 10 and 12 p.m. are small compared to the time from 6 to 8 p.m. or from 12 p.m. to 6 a.m., but the numbers of animals per hour are much larger for the shorter times. This is to be expected, but the totals of those times are so high that it is to be presumed that the averages would be at least relatively as large if there had been more hauls.

All species do not have the same time of maximum abundance at the surface as shown by table 55, but in eight cases out of ten it occurs between 6 and 10 p.m. On the whole, there is no reason to doubt that table 55 gives an approximately correct idea of the time of greatest abundance at the surface for the species considered.

I have been unable to find that there is any clear relation between the distribution of the Copepoda of this region and temperature and salinity of the water. It may be said that the expectation was that such a relation would appear, especially in view of the results of Michael with the Chaetognatha. This investigator is of the opinion (1911, p. 160) that a species is a species as much from the physical environment in which it is normally found as from its morphological characters. Hjort, also (1910, p. 371), states that each of many forms in the same area of the sea has its own area of distribution, mode of life and habitat, and that a species may be defined by certain conditions of existence as well as by its structure. "These conditions characterize a given species quite as much as any morphological description, and in fact for a proper conception of the species both methods of investigation are supplementary."

The available data for the Copepoda of this region lend plausibility to these views, at least to the extent of showing that a species is not characterized by structural features alone. No

two kinds of copepods so far as can be determined, have the same behavior, as is shown by the fact that the curves in figures 1-7 are all different. While the amount of data is small in some cases, it shows that a species may be recognized by its behavior as well as by its structure. We do not know enough about the conditions under which these forms live to be able to state, as Hjort does in the passage mentioned, that each has its own area of distribution, but we can say that the character of a species is shown by something else than its morphology.

There is another point that should be mentioned here. If we start with the species as defined by *structural characters*, can it be shown that, on such a basis, the range of the form is limited by definite hydrographic conditions? In other words, is there any evidence that each species has its own area of distribution or not?

There is some tendency to argue that if a certain form is found within a given area we may *expect* to find morphological characters that distinguish these forms from others. For example, Nordgaard (1905, p. 243) cites instances of the division of a species into two or more because of "more exact morphological investigation" (the morphological investigation apparently being subsequent to hydrographic studies) so that "instead of one species distributed over nearly every sea we now get three species with a comparatively limited distribution." The species referred to in the quotation is *Calanus finmarchicus*, and I have already mentioned that there is some difference of opinion regarding the validity, on morphological grounds, of one of its derivatives. The question here, however, is whether or not within such an area as that under investigation by this station each species, or even a group of species, may be said to have a physical environment of its own.

So far as the study of the copepods in the San Diego region has gone, there is no evidence that they form "hydrographic" species. *Calanus finmarchicus* has been taken at the surface in as great numbers when the temperature is as low as it gets, as at the highest temperatures and those between the extremes. This species, like all the others, has a plurimum or center of migration for the day and also for the night, but there is no reason to

claim that a given temperature or salinity of the region most frequented during the day is any more of an optimum (so far as those physical factors are concerned) than is the temperature of the region of most abundance during the night. In other words, a species like *Calanus finmarchicus*, in its extensive diurnal migrations probably passes back and forth through as many different physical conditions as would be encountered in a horizontal journey of many miles at a given level.

As our knowledge of the temperature and salinity conditions of the waters of this region increases, it may be that we shall find that there are regions for certain species with bounds that are definite, within which the species may be said to be isolated. It seems to me, however, that the body of facts presented here concerning vertical migrations is no small indication that the boundaries are not temperature or salinity lines, even if it shall be found that boundaries of some kind actually exist.

It is true that maps have been made showing the distribution of certain species of copepods. Damas (1905) has done this for the larvae and adults of *Calanus finmarchicus* and Farran (1910) for a number of species. Both these investigators have dealt with region which are affected by great ocean currents, where there are, accordingly, barriers due to abrupt changes in temperature. It is possible, therefore, to delimit the regions occupied by given species more or less sharply. The San Diego region, however, seems not to present such conditions, and, as far as we know, changes in temperature and salinity are gradual. Six species of copepods were never taken at the surface, but there is no evidence that they avoid the surface because of the temperatures or salinity there. We know that each of these species appears to execute diurnal migrations, and in so doing it is presumable that they encounter changes of temperature and salinity. We do not know how great the changes are. It must be admitted that there are temperatures or salinities which would act as barriers, but so far as our investigations have gone they do not seem to occur in this region. The probable reason that temperature has no apparent effect in such a case as that of *Calanus* is that a variation of from 16°–20° at the surface is too small to cause an appreciable reaction when an organism

encounters, during vertical migrations, a range from 7° or less to 20° or more. The same sort of statement applies to salinity.

At the present stage of our investigation (so far as the Copepoda are concerned) it seems that differences in temperature and salinity must be either more considerable or more abrupt than we have yet found, if we are to be able to speak of "copepod provinces" in this region. On the other hand, changes in light intensity are periodic as well as gradual, and it seems that those are the changes which influence the distribution of the copepods. We cannot claim that the temperature changes with the time of day (to any important extent, at least) and I feel more strongly than ever that light is the main determining factor in the vertical distribution of these organisms. It is only too plain that this is not the whole of the matter, but it is certain that, through the widespread occurrence of day and night oscillations, we have recognized a factor that is important. In view of our results at this station statements as to the depth limits of copepods should be based upon day or night hauls separately. That is, if a species is not found above 100 fathoms during an expedition when collecting at that level is done only during the day, it does not follow that the usual hydrographic conditions at or below that level are the optimum conditions for the species. The same form would probably be found at night above 100 fathoms where the hydrographic conditions are almost certain to be different from those met with during the day hauling.

The foregoing discussion should be regarded as more in the line of suggestion than exposition. It is based entirely on the results of studying collections as embodied in this paper, and is not intended as a criticism of the views of others. That would be warranted only when our collections are much more numerous and especially when we know the sub-surface temperature and salinity conditions under which a large series of hauls with the Kofoid horizontal closing net were made.

Our results hardly warrant more than the mention of their apparent bearing on the question of coincident distribution of related species. The hauls, especially with the Kofoid net, in which "couplets" of species occurred are so few that I can cite only a few *instances* (which are notorious for proving anything).

The general trend of the data concerning the distribution of the Copepoda is in line with the discussion in the papers of Kofoid (1907a, 1907b). He shows for a number of plankton animals that in general the species which are more closely related structurally have a coincident instead of a contiguous distribution. This might also be inferred as true of the pelagic Copepoda, since so many of them are found at the same depths during the day. As particular examples may be mentioned *Gaetanus unicornis* and *G. secundus*, which, structurally, form a very closely related pair of species; *secundus* was taken in but one haul with the Kofoid net, but then it was in company with a specimen of *unicornis*. *Euchirella galcata* and *E. pulchra* form a couplet: the former was taken in but three hauls with the Kofoid net, always with *pulchra*. *Scolicithrix magna* appeared in but three hauls of this character, two of which contained *S. frontalis*, a rather closely related species. The four species of *Pleuromamma* found in this region occurred together repeatedly in the closing nets and *P. abdominalis* and *gracilis* were taken together in the seven hauls that contained *gracilis*. It is hard to say how much these examples mean until we know more about breeding ranges and seasons as well as the general hydrographic conditions in deep water, where all of the species mentioned are found in greatest abundance during the day.

It is important to note again, however, that, even with our lack of knowledge concerning the conditions under which the Copepoda live, the forms we know most about show differential characters in other respects than structure. The species grouped in the "couplets" mentioned above are so placed because of morphological characters. If our knowledge of them in other matters were as extensive we might find that they are examples of species that are quite *different* from each other but with a similar distribution. That is, if the behavior, for example, of one species of *Gaetanus* should prove to be markedly unlike that of the other, there would be justification for the view that these are distantly related forms; and even if they should always be taken in the same hauls with the Kofoid net, it would at least be a matter for argument if they were not examples of the coincident distribution of distantly related species. That would depend on

what conditions are held to be the more important in the characterization of species. As a matter of fact the species mentioned in the above speculation are two that we know practically nothing about (except as to structure), yet they may be used to illustrate the different points of view that are possible in the matter of "coincident *versus* contiguous distribution."

The interesting matter of color of marine animals and the depths at which they occur has recently been discussed by Hjort (1911). It was found on the "Michael Sars" expedition that black and red forms predominate among animals from greatest depths (Hjort, 1911, pp. 503, 504), and in certain cases all the specimens of fishes caught above 150 m. were taken at night (p. 505). Hjort states (p. 505) that the rays of light will have passed through the same distance to reach a depth of 500 meters in 50° N, that they will pass through to reach 650 meters in 33° N, or 300 meters in 67° N. The visible depth in the open sea is given as 50 meters in 33° N, 40 meters in 50° N, and 25 meters in 67° N. As to the intensity (p. 506), it will be the same from rectilinear rays in 33° N at about 200 meters, at 50° N at about 500 meters, and at 67° N at about 200 meters. The red and black forms therefore have an upper limit in different waters which corresponds everywhere with the same intensity of light. The upper limit for the red crustacea at about 50° N was 500 meters below the surface, while for the same forms at 33° N it was from 200 to 300 meters deeper.

The distribution of the copepods of this region is in general line with the observations of Hjort. Many of the typically deep water forms are characterized by red or orange in the body as a whole or merely in localized regions. Such are the species of *Euchaeta* like *tonsa*; of *Euchirella* such as *galeata*, *pulchra*, *simplex*, *propria*, *truncata*; *Pleuromamma quadrangulata*; others might be given as examples of deep water forms that have red or orange-red pigment. On the other hand there are species with a similar range which are exceedingly transparent, such as *Augaptilus lucidus* or *pyramidalis*; the former has a brown spot around the mouth while the latter is entirely without pigment. It is hardly necessary to mention *Calanus finmarchicus* or *Eucalanus clongatus* which have been taken as deep as 400 fathoms with the

Kofoïd net, the latter even appearing in a haul at 550 fathoms; these species, however are not as thoroughly characteristic of deep water as the others, nor do they possess as much red pigment. There is only one black copepod known from this region, *Metridia atra*, which was taken with the Kofoïd net at 550 fathoms.

Hjort (p. 507) evidently inclines to the opinion that red animals are protected by the color in deep water, for the red rays were not found at 500 meters by means of the Helland-Hansen photometer, and red animals at that depth must be as invisible as black ones.

The available data concerning the distribution of the Copepoda of this region are not extensive enough to make a discussion of this question advisable. It may be pointed out, however, that the upper limit for red animals as given by Hjort for this latitude (700-800 meters or about 435 fathoms) seems to be farther down than our data would lead us to believe. The extreme limits within which the largest numbers of individuals are taken are 200 and 400 fathoms, but horizontal closing hauls below 350 fathoms are greatly needed to determine this point more satisfactorily. The general fact of the red forms being taken at much higher levels during the night than during the day is most evident, as shown also by Hjort (1911, pp. 503 and 504). He states, however, (p. 509) that out of 3600 transparent larvae and young fishes, 90 per cent were taken between the surface and 150 meters. We find that transparent copepods (such as *Eucalanus*) are obtained at practically all depths, and it certainly seems that a transparent form would be as invisible at 400 fathoms as anywhere else. This whole matter is an exceedingly important and interesting one and well worth further study; at this time such suggestions as have been given above and elsewhere (Esterly, 1911a) are all that are warranted.

I have not found that our data indicate that there is a relation between the locality in which a haul at the surface is made and the abundance of any of the species. Likewise, there is nothing to be noted as to the seasonal distribution. Possibly this is because the greater portion of our collecting was done in June, July, and August.

In conclusion, I do not wish to be understood as having

advanced any views that I regard as more than tentative, although the data as analyzed lend strong support to the suggestions that have been made. Michael has well expressed my feelings in his concluding paragraph (p. 160) as to proving conclusions. I feel as he does, also, in regard to the necessity of improving our methods of collecting, especially as to the use of similar nets at all depths. From my experience up to this point, I feel that one successful haul with the Kofoid net is more valuable than many with the vertical nets. We need, also, more hauls of that sort at night and especially between 25 and 150 fathoms; day and night hauls at 200 fathoms and below would also tend to clear up some obscure points.

I wish to express my appreciation of the many favors extended to me by Professor W. E. Ritter, Director of the La Jolla station, and by Mr. E. L. Michael, the Resident Naturalist, and particularly of the friendly and helpful conversations with them. My wife has patiently helped in the tiresome drudgery of making tables and checking results; hers is no small part in that portion of the work.

SUMMARY

1. The Copepoda as a group are found mainly in deep water during the day, the upper limit being not above 150 fathoms; the region of greatest abundance on the whole is probably about 250 fathoms.

2. It is the rule, practically without exception, that the abundance is greater at higher levels during the night than during the day, and that such deep water forms as come to the surface do so mostly at night. In other words the epiplankton is more populous at night, the mesoplankton during the day.

3. Thus there seems to be a constant oscillation of these Crustacea, there being a day and a night plurimum or "center of migration." If we may take it for granted that the region of greatest abundance is located where the largest number of optimum conditions are found, the fact of diurnal movement suggests that the optimum is a rather indefinite term since it changes with the time of day.

4. This fact of constant change appears to make it doubtful if there are regions in which species may be said to be isolated. At any rate the data available from the records of this station do not show that the abundance of any of the species is related to temperature or salinity. These have been taken for the surface hauls only, as yet, and the species of Copepoda that we know most about reach the plurimum at the surface at night regardless of the temperature or salinity within the limits known for the region.

5. On the other hand, no two of the curves of distribution at the surface with regard to time are the same, so far as the more abundant species are concerned. This fact suggests that, just as there are structural differences between the forms, there are also other characters that mark a species as a definite kind. It is also to be suggested that, though two forms may be closely allied structurally (so far as we can judge), and taken repeatedly in the same area, the other differential characters will show that the forms in question occur coincidentally as widely separated species.

6. Ten species have been taken at the surface in large enough numbers for judging as to when during the night they reach their maximum abundance. Three species do so between 6 and 8 p.m., five between 8 and 10 p.m., one between 10 and 12 p.m., and one between midnight and 6 a.m. (table 55).

7. *Calanus finmarchicus* is the commonest species in the San Diego region. The following conclusions as to its distribution and behavior appear to be well grounded:

(a) With the surface nets (tables 12 and 13 and fig. 1) we found that it is most abundant during the night, between 10 and 12 p.m., though there is a very marked increase in abundance beginning at 6 p.m. After midnight there is a great decrease in the size of the hourly averages.

(b) With the Kofoid closing net we found (Esterly, 1911b, tables 4 and 5) that the day plurimum is at 200 fathoms; that the evening plurimum is at 100 fathoms; that at midnight the plurimum is at 5-10 fathoms; and that from 4 to 6 a.m. the plurimum is again at 100 fathoms.

(c) With the vertical closing nets, we found (tables 14 and

15) that the plurimum is at 75-50 fathoms for the day, though the animals were taken in a few more than half of the hauls at that level, while from 150-250 fathoms all of the twelve hauls were successful. At night there are two plurima, at 10-15 and at 30-25 fathoms.

(d) All the nets agree in indicating that there is an upward migration at night, though this is shown more clearly with the surface and horizontal closing nets.

(e) The animals appear to leave the surface before the light increases at all in intensity. This suggests that decreasing light is not the cause of the downward movement. A more complete discussion of this question will be found in my paper mentioned in (b) above.

8. In regard to the distribution of *Eucalanus elongatus*, the next most abundant species, we found:

(a) With the surface net (tables 21 and 22 and fig. 2) that the animals are more abundant at night; that the highest average per hour for any two-hour period is between 8 and 10 p.m., though the number per hour for the six hours of the night before midnight is much smaller than for the six hours after midnight; that there are three plurima for the occurrence of the species on the surface (fig. 2), in the afternoon, evening and morning. On the whole, the occurrence of *Eucalanus* is erratic, as compared with that of *Calanus*.

(b) With the Kofoid horizontal closing net we found that there is an extensive movement of the species from a day plurimum at 200 fathoms, which does not seem to come under the class of diurnal migrations (Esterly, 1911a).

(c) With the vertical closing nets we found (tables 23 and 24) that the day plurimum is probably at 200 fathoms as an average depth; that the abundance and frequency above 50 fathoms are greater by night than by day, while below 50 fathoms the reverse is the case.

9. The distribution of *Metridia lucens* shows the following features:

(a) With the surface net (tables 26 and 27) the greatest abundance and frequency is between 10 p.m. and 2 a.m.; that the hourly average is enormously larger between 10 and 12 p.m.,

though shown by only one haul; that, allowing for this condition, there is clear evidence of a regular diurnal migration.

(b) With the horizontal closing nets (tables 28 and 29) the day plurimum is shown to be at 100–160 fathoms; from 6 p.m. to 2 a.m. it does not go lower than 12 fathoms, but between 2 and 6 a.m. it is at 100–160 fathoms.

(c) With the vertical closing nets we found (tables 30 and 31) that there is evidence of diurnal migration, the day plurimum being between 200 and 150 fathoms, while at night it is at 100–75 fathoms.

10. The following species did not come to the surface: *Euchaeta tonsa*, *Euchirella galcata*, *Gaetanus unicornis*, *Pleuromamma abdominalis*, *Scolecithrix frontalis*, *Scolecithrix magna*. As a group, these six species are most abundant below 200 fathoms during the day and above 200 fathoms during the night (tables 52 and 53).

11. The other ten species (*Euchirella pulchra* and *E. rostrata*, *Gaidius pungens*, *Labidocera trispinosa*, *Pleuromamma abdominalis*, *P. gracilis* and *P. quadrangulata*, *Rhincalanus nasutus*, *Scolecithrix persecans*, *Undeuchaeta bispinosa*) were taken at the surface, but in so few hauls that an extensive analysis of them is not practicable. So far as the evidence goes, they are, with three exceptions more abundant at the surface at night, as can be seen in table 55. The exceptions are nine animals belonging to three species and there is nothing whatever to show why they should be found at the surface. The hauls with the closing nets show that these species, like the others, move upward during the night, as may be seen in summary in table 54.

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OCCIDENTAL COLLEGE,
LOS ANGELES, CALIFORNIA.

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OBSERVATIONS ON THE SUCKLING
PERIOD IN THE GUINEA-PIG

BY

J. MARION READ

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OBSERVATIONS ON THE SUCKLING
PERIOD IN THE GUINEA-PIG

BY

J. MARION READ

While carrying on some experiments upon the period of gestation in the guinea-pig (*Cavia cobaya*) it became desirable to determine how long after birth the young are entirely dependent upon the mother's milk for nourishment.

It is a well-known fact that the young of this animal are born in a very mature state. The guinea-pig, quite in contrast to mice, rats and rabbits, comes into the world with the eyes open, incisor teeth well developed and a heavy coat of permanent fur. They are strong and able to run about at once. During the second or third day most young guinea-pigs begin to take solid nourishment.

Abderhalden (1908, p. 371), in discussing the length of time that different animals require in which to double their weight after birth, says of guinea-pigs: "According to their development they scarcely belong in the ranks of mammalia; by eating green food shortly after birth they rapidly increase in weight. At birth they are already remarkably developed. Even then they are able to eat the same food as that of the mother. . . . The female of this animal possesses only two mammary glands, situated in the groin, and milk plays but a subordinate part in the nourishment of the new born guinea-pig."

G. Bunge (1902, p. 108), in considering the composition of the milk of this animal says: "From the first day of birth the

guinea-pig picks up its own food by the mother's side. The milk in this case plays but a secondary part therefore in its nutrition and only supplies a welcome addition to the vegetable food so deficient in fat."

Only in one instance have I observed a young guinea-pig eat vegetable food during the first day after birth. This animal ate hay when about eighteen hours old. Upon two other occasions I observed the young eat hay when forty-six and forty-eight hours old.

Let us consider at this point the composition of the milk of this animal, and its probable relation to early weaning. In doing this a comparison of the milk of the guinea-pig with that of the rabbit is helpful. From table I (Bunge, 1902, table pp. 104-105) we observe that rabbit's milk is higher in protein, sugar and inorganic salts (ash) than the milk of the guinea-pig. These tissue- and bone-forming foods are needed by the young rabbit after birth in order to reach a stage of growth which is attained by the guinea-pig *in utero*. These same foods are supplied by the mother to the latter animal before parturition.

TABLE I

One hundred parts of Milk contain:

	Human	Dog	Rabbit	Guinea-pig	Elephant	Horse	Goat	Reindeer	Camel	Porpoise
Casein	1.2	5.2	.....	.....	.....	1.2	3.2	8.4	.....	.....
Albumin	0.5	1.9	.....	.....	.....	0.8	1.1	2.0	.....	.....
Total Proteids	1.7	7.1	15.5	11.2	3.1	2.0	4.3	10.4	4.0	7.6
Fat	3.8	12.5	10.5	45.8	19.6	1.2	4.8	17.1	3.1	43.8
Sugar of Milk	6.0	3.5	2.0	1.3	8.8	5.7	4.5	2.8	5.6	.....
Ash	0.2	1.3	2.6	0.6	0.7	0.4	0.9	1.5	0.8	0.5

The most striking comparison, however, is between the proportions of fat which the milks of the two rodents contain. The milk of the guinea-pig contains, in 100 parts, 45.8 parts of fat, while that of the rabbit has only 10.5 parts of fat. The table shows further that the milk of the porpoise has 43.8 parts of fat, this marine mammal ranking below the guinea-pig in the fat-content of its milk.

It is thus observed that the fat-content of the guinea-pig's milk is very high. The reason for this may be explained as follows:

As previously stated, the young guinea-pig is but very slightly dependent upon the mother's milk after the third or fourth day, for at this age it begins to eat the same food as the adult. There is one food, however, of which it has more need in proportion to its size than the adult. This food is fat, which has as its chief function the supplying of heat to the body. The loss of heat from the body-surface of a small animal is greater in proportion than that from the body of an adult, because the proportion of surface to volume is greater in a small than a large body (i.e., surface increases as the square, and volume as the cube of the linear dimension).

Recognizing this fact then, it is clear that the young guinea-pig must get more fat than is contained in the solid food which it eats. This same food contains all the fat which the adult needs. In fact it seems to contain more than is ordinarily required to maintain body temperature, for in no other way can the following phenomenon be accounted for.

Guinea-pigs as well as human beings accumulate a reserve store of fat during pregnancy. This is used up during lactation, as can be shown by the rapid loss of weight which a nursing guinea-pig undergoes. Table II (C. S. Minot, 1891, p. 144) shows that on an average 63.8 grams were lost by the animals under observation during the normal nursing period.

TABLE II

Alterations of weight of female guinea-pigs during lactation

Days after delivery	Number of observations	Average weight	Daily per cent increase
0	24	613.6	.....
1-5	55	575.6	-1.2
6-10	51	556.2	-0.7
11-15	36	581.5	0.9
16-20	36	572.1	-0.3
21-25	28	549.8	-0.8

The great loss of weight leads us to believe that the high percentage of fat in the guinea-pig's milk comes from the fat stored up in the tissues during pregnancy.

It has already been shown that the percentage of fat in the guinea-pig's milk is high, but this does not necessarily prove that the young receive a great amount of fat, for the amount of milk might be small. From the above table, however, it is quite evident that each young one in a litter of two receives about 30 grams of fat from the mother's milk, if, as we assume, all the accumulated fat leaves the body in the milk. Besides this it gets fat from the same source which supplies the fatty food utilized by the mother. So the relative amount of fat received by the nursing guinea-pig is much greater than that received by an adult.

It remains to be shown why the young guinea-pig needs more fat than the young of such animals, for example, as the rabbit.

Rabbits, rats, and mice are born in large litters and so the young help to keep each other warm. These animals also build nests in which the mother, for purposes of suckling the young, stays a large part of the time. On the other hand the guinea-pig is rarely born in litters of more than two or three and quite frequently there is only one. The young are provided with a coat of fur at birth and run about at once, the mother building no nest before they are born. They derive little heat from the body of the mother, for they spend a very small portion of the time suckling, but the milk which they do get is almost half fat, a food of "high calorific value."

Another point in which guinea-pigs differ from most mammals is pointed out by Minot (1891, p. 118) who says "Male guinea-pigs lose weight as do new-born children for a variable period of a few days after birth." Females do not lose weight, as may be observed by inspection of table III, giving the average weights of male and female guinea-pigs for the first three weeks.

TABLE III

	Number of observations	0 days	1 day	2 days	3 days
Males	15	76.6 gm.	75.0 gm.	76.6 gm.	79.8 gm.
Females	13	68.0 gm.	71.3 gm.	75.0 gm.	76.7 gm.

It may be said that there are cases in which the male does not lose weight after birth; indeed I have seen individual cases in which there was an actual gain in the weight of the male.

The weights of Bb and Be given in table IV, columns five and six, show that these two animals suffered no loss of weight.

So it is observed that there are cases which do not conform to the rule. But there is in all mammals a post-natal retardation of growth while the newly born animal is adapting itself to its new environment. The point to be borne in mind is that this retardation is very slight in the case of the guinea-pig and amounts to an actual loss of weight in the case of the males only.

Minot further observed that "Birth retards growth from two to five days." This being the case, a young guinea-pig, especially a male (which actually loses weight), would be at considerable disadvantage if weaned within this period of retardation, or even shortly after it.

The normal time at which mice, rabbits, and guinea-pigs should be weaned is about three weeks. With the last-named animal, however, there is considerable variation in this respect. I have observed a mother which allowed a young one to suckle when it was four or five weeks old. Another animal was seen to kick the young away and refuse to let them suckle at sixteen days. My animals, except those considered in detail in this paper, were weaned at twenty-one days. For future comparison I will add that a suckling guinea-pig doubles its weight in about eighteen days after birth.

In view of the fact that the young begin to eat solid food when three or four days old and that there seems to be no definite time at which the mother weans them, it was decided to determine how soon after birth the young could be weaned and live.

The first young one studied (known as W) was a normal animal weighing at birth 77 grams, which is two grams above the average. Its weight upon successive days is shown in the second column of table IV. It was taken away from the mother at the end of ten days. Two days after weaning it had lost 2.4 per cent of its weight, but four days after weaning it was 3 grams (2.4 per cent) heavier than when first separated from the mother.

TABLE IV

Age in days	Number of observations	Average weaned at 21 days		W ♀. Weaned at 10 days		Cb ♀. Weaned at 9 days		Ca ♀. Weaned at 7 days		Bb ♂. Weaned at 6 days		Bc ♂. weaned at 4 days	
		Weight in grams	Per cent increase	Weight in grams	Per cent increase	Weight in grams	Per cent increase	Weight in grams	Per cent increase	Weight in grams	Per cent increase	Weight in grams	Per cent increase
		0	28	74.8	77	57	94	75	.....	79	.....
1	28	73.3	-1.7	79	2.5	56	-1.7	93	-1.0	75	0.0	79	0.0
2	28	76	3.6	82	3.8	61	8.9	95	2.1	77	2.6	82	3.8
3	28	78.4	3.2	89	8.5	61	0.0	99	4.2	85	10.3	90	9.8
4	27	82.4	5.1	91	2.2	67	9.8	102	3.0	89	4.7	91	1.1
5	25	86.5	4.9	97	6.6	69	3.0	108	5.8	96	7.8	83	-8.7
6	22	90.6	4.7	102	5.1	71	2.9	109	0.9	100	4.1	84	1.2
7	16	95	4.8	.....	.....	75	5.6	111	1.8	95	-5.0	91	8.3
8	24	100	5.2	112	10.0	84	12.0	107	-3.6	99	4.2	100	9.9
9	.....	.....	.....	.....	.....	82	-2.3	108	0.9	104	5.0	102	2.0
10	21	107.2	7.3	115	11.6	82	0.0	114	5.5	107	2.8	103	1.0
11	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
12	13	117.1	9.1	122	-2.4	75	-8.5	106	-7.0	108	0.9	105	1.9
13	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
14	20	126.6	8.1	128	4.9	82	9.3	122	15.0	125	15.7	105	0.0
15	.....	.....	.....	.....	.....	.....	.....	.....	.....	132	4.8	112	6.6
16	21	136.3	7.6	137	7.0	89	8.5	142	16.4	.....	.....	.....	.....
17	.....	.....	.....	.....	.....	89	0.0	135	-4.9	134	1.5	118	5.3
18	20	145.1	6.4	133	-2.1	.....	.....	.....	.....	.....	.....	.....	.....
19	.....	.....	.....	.....	.....	88	-1.1	148	9.6	162	21.1	138	17.0
20	13	151.5	4.4	135	1.5	.....	.....	.....	.....	158	-2.4	138	0.0
21	.....	.....	.....	.....	.....	102	16.0	167	12.8	.....	.....	.....	.....
22	18	160	5.6	131	-3.0	.....	.....	.....	.....	172	8.9	150	8.7
23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
24	13	171.4	7.1	131	0.0	100	-2.0	172	3.0	171	0.5	145	-3.3
25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
26	12	181.3	5.7	147	12.2	108	8.0	194	12.8	171	0.0	136	-6.2
27	.....	.....	.....	145	-1.3	.....	.....	.....	.....	.....	.....	.....	.....
28	10	190.4	5.0	.....	.....	110	1.7	190	-3.0	192	12.2	163	19.8
29	.....	.....	.....	150	3.4	.....	.....	.....	.....	.....	.....	.....	.....
30	8	198.4	4.2	.....	.....	125	13.6	.....	.....	195	1.5	170	4.2

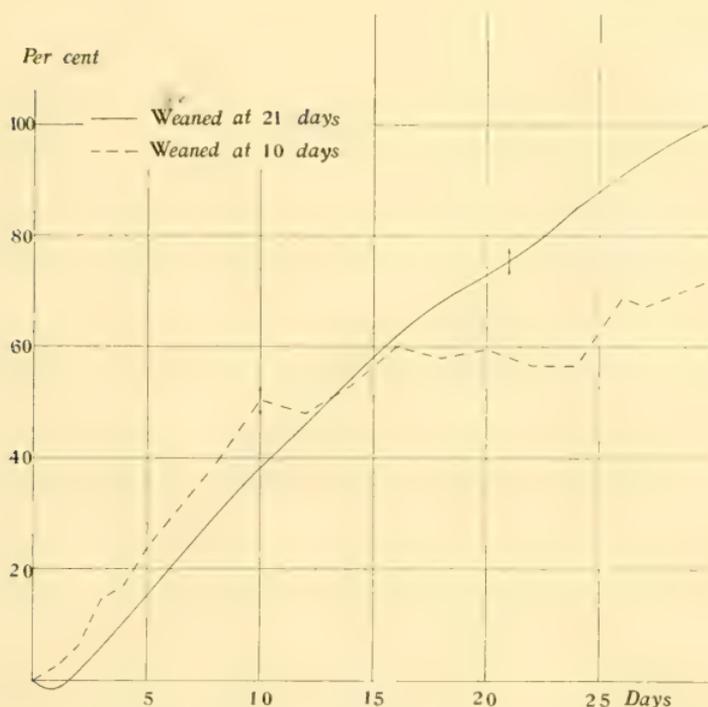


Fig. 1. Solid line shows the average growth of guinea-pigs weaned at twenty-one days, based on twenty-eight observations. The broken line shows the growth of W (♀) weaned at ten days. The arrows on each line mark the termination of the suckling period. Data taken from table four, columns one and two.

In a litter of three there were two animals which were the heaviest and lightest I have yet seen, weighing at birth respectively 94 and 57 grams. These two animals were selected for early weaning.

The larger one (Ca) was weaned at the end of six days and nineteen hours (seven days). It lost 3.6 per cent of its weight by the end of the second day. But at the end of the third day it began to regain its weight, as is shown in column four, table IV. It required about twenty-seven days in which to double its weight.

An attempt was made to wean the smaller animal (Cb) at seven days, but it returned to the mother. It was successfully weaned, however, at the end of nine days and suffered no ill effects therefrom. Its changes in weight are to be found in the third column of table IV.

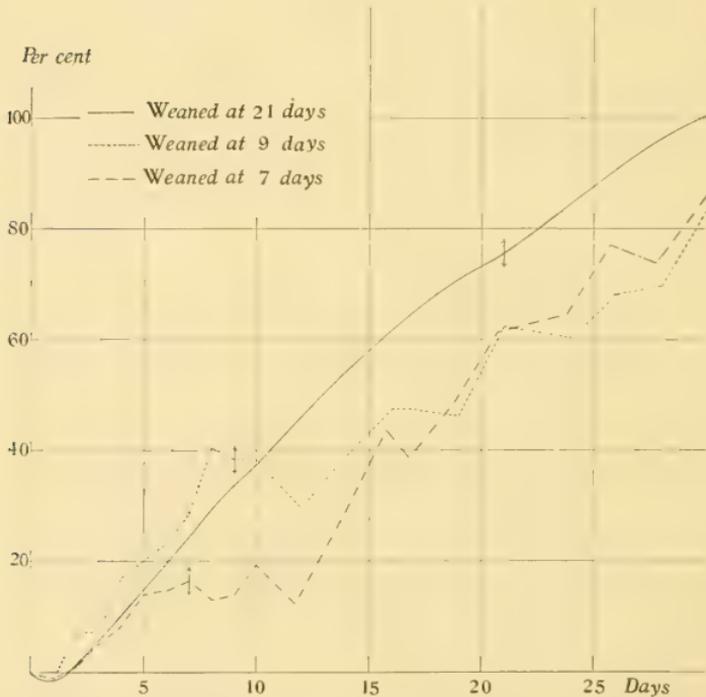


Fig. 2. Solid line shows the average growth of guinea-pigs weaned at twenty-one days, based on twenty-eight observations. The broken line shows the growth of Cb (♀) weaned at nine days. The dotted line is the growth curve for Ca (♀) weaned at seven days. On all three lines the arrows mark the termination of the suckling period. Data taken from table 4, columns one, three and four.

The next young one (Bb) experimented upon was taken from the mother when just six days old. It lost 5 grams the first day, but regained four by the end of the second day. Its weights are given in column five, table IV. The time required in which to

double the weight was eighteen days. Inspection of the growth curve in figure 3 shows that it follows the average curve very closely.

Another animal (Be) which was born in the same litter with (Bb) was weaned at the end of the fourth day. The first day it lost 8 grams but at once began to gain, and on the third day after weaning its weight was the same as when taken from the mother. Its weights are given in the sixth column of table IV. Twenty-seven days after birth its weight had been doubled.

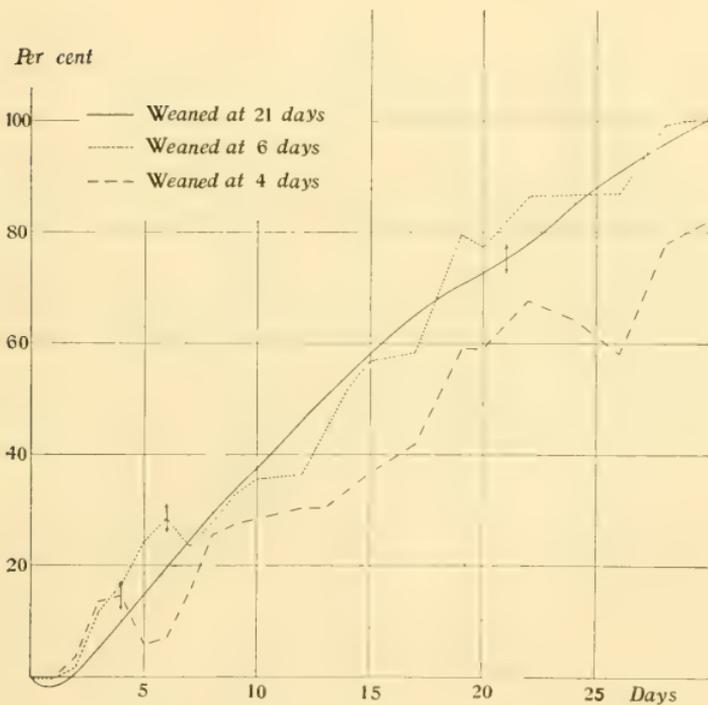


Fig. 3. Solid line shows the average growth of guinea-pigs weaned at twenty-one days, based on twenty-eight observations. The broken line shows the growth Bb (σ) weaned at six days. The dotted line marks the growth curve of Ba (σ) weaned at four days. The arrows on the three lines mark the termination of the suckling period. Data taken from table 4, columns one, five and six.

Our attention may now be directed to the fact that the data (and the curve constructed from them) giving the general average of weights for young weaned at twenty-one days show that no loss of weight took place at weaning. This indicates that the young have not been dependent upon milk for their growth.

The method used in calculating the percentage increments brings out this point to best advantage. Each change is shown by the percentage of the weight at the *previous weighing* which has been gained or lost in the interval between weighings.

The cases of Bc, Bb and Ca show that the earlier the animal is weaned the greater is the percentage of weight lost. These percentages are 8.7, 5, and 3.6 respectively, and the ages at which they are weaned are 4, 6, and 7 days respectively.

The food given the young ones after they were separated from the mother was the same as that given to the young weaned at twenty-one days and to the adults. It consisted of hay, barley, lettuce, cabbage, grass and water. The animals weaned at the times stated above were given a larger proportion of freshly cut grass, which they ate more readily than any other food given to them.

No attempt was made to supply heat. The young guinea-pig weaned at four days spent the first night away from the mother in a temperature of almost 40° F. During the day, however, its box was placed in the sunlight.

In these experiments an attempt was made to have conditions the same for the animals weaned early as for all the others. No milk was given them at all, the only difference in diet being the larger proportion of green food given the animals weaned before twenty-one days.

SUMMARY

The guinea-pig is born in a very mature state and begins to eat solid food very early. An examination of the mother's milk shows it to be very low in proteins, carbohydrates and inorganic salts, so we conclude that a large part of these foods needed by it is obtained from the solid food it eats. The percentage of fat (45.8) in the guinea-pigs' milk is very high. Since the young

get some fat from the solid food which supplies all the fat the adults require, we are led to believe that the young require more fat in proportion to their size than do adults. The reason for this greater need of fat we see when we consider the high heat-value of this food. The loss of heat by radiation from the body of a small animal is *greater* in proportion than that from the body of a larger one, hence *more fat* is needed to make good the loss. The high content of fat and low content of the other constituents of the milk indicate that the young guinea-pig is fitted to subsist upon other food than milk. That the young begin to eat solid food very early is shown by the observed fact that an animal ate hay when eighteen hours old.

The post-natal retardation of growth characteristic of "all mammals so far studied" is but very slight in the case of the guinea-pig.

In view of the facts set forth in this paper the following conclusions seem justifiable:

1. A guinea-pig can be successfully weaned as early as the fourth day.
2. Providing that the animal is healthy, its size and weight have little or nothing to do with the result in early weaning.
3. The percentage of weight lost the first day by the young (previously considered) guinea-pigs weaned before the usual time bears an inverse ratio to the age of the animals at the time of weaning.

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ZOOLOGICAL LABORATORY,

UNIVERSITY OF CALIFORNIA, BERKELEY.

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September 14, 1912

HAECKEL'S *SETHOCEPHALUS EUCECRY-*
PHALUS (RADIOLARIA) A MARINE
CILIATE

BY
CHARLES ATWOOD KOFOID

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HAECKEL'S *SETHOCEPHALUS EUCECRY-*
PHALUS (RADIOLARIA) A MARINE
CILIATE

BY

CHARLES ATWOOD KOFOID

(Contribution from the Scripps Institution for Biological Research)

In his *Prodromus* (1881) Haeckel proposed the genus *Platy-cryphalus* for a radiolarian with a bicamerate fenestrated shell with a transverse stricture separating it into a primary chamber, or cephalis, and a secondary basal one, or thorax. The shell was without ribs, open, with obtusely rounded, smooth, non-spinous cephalis and spreading, open, almost disk-like thorax. No species was mentioned in this article and naturally no type species is available. However, in his *Report on the Radiolaria* (1887, p. 1298) Haeckel quotes "*Platycryphalus sethodiscus*, Haeckel, 1881, *Prodromus*, p. 430" as a synonym of his *Sethocephalus platycryphalus* n. sp., though no such species appears on this page, or elsewhere, in the article quoted.

The location in the system assigned to this organism is as follows: Class Radiolaria, Order Monopylaria, family Cystida, subfamily "Dyocyrtida," tribe Sethocorida, genus *Platycryphalus*.

In the corresponding location in his *Challenger Report* he (1887) proposes the genus *Sethocephalus* with the definition "Sethocorida (vel Dyeyrtida eradiata aperta) with discoidal, flatly expanded thorax. Cephalis large, without horn." He describes in this genus two species, *Sethocephalus eucecryphalus*, which he figures (pl. 56, fig. 13), and *S. platycryphalus*, to

which he assigns *Platycryphalus sethodiscus* as a synonym, but does not figure the second species.

The species figured appears strangely out of place among the trieyrtid Radiolaria with which it is grouped, and one is surprised that neither Haeckel nor his artist, Mr. Adolph Giltseh, was led to question this allocation of the organism, especially since Haeckel himself had previously (1873) described *Dictyocysta cassis* (= *Cyttarocyliis cassis* (Haeckel) Bdt.) a tintinnid ciliate most nearly related to the organism in question. The lack of clear evidence as to the differentiation of typical cephalis and thorax lead Haeckel (1887, p. 1298), to speculate, however, as to the origin of this unusual genus as follows: "It is possible that this peculiar genus has been derived from a Trieyrtid (*Theocalyptra?*) by loss of the original cephalis, and that the apparent large cephalis is the original thorax."

The organism in question is represented in Haeckel's (1887) figure by the skeleton only. It is drawn as a fenestrated cone with rounded apex and narrow, flaring collar. The mesh of the cone (cephalis) is made up of somewhat uniform, rounded elements with traces of angulation or polygonal form in places, but with much less of the polygonal effect than in the Radiolaria to which Haeckel supposes it to be nearly related. The mesh of the rim or collar is less uniform and has scattered, irregular elements of larger size and irregular form.

The species in question, *Sethocephalus eucecryphalus*, has not since been reported.

In December of the same year in which Haeckel (1887) published this species, Daday (1887) in his *Monographie der Familie der Tintinnodeen* described as *Cyttarocyliis cassis* Haeckel var. *plagiostoma* n. var. the same organism, but does not refer to Haeckel's figure, nor does any subsequent investigator of the Tintinnodea make such reference.

The differences between the descriptions and figures of the two organisms as given by Haeckel and Daday are no greater than the variation found by monographers (Daday, 1887, Brandt, 1907) within the individual species of *Cyttarocyliis*. The dimensions and proportions are very similar and become more so if one takes the measurements of Haeckel's figure (pl. 56, fig.

13) rather than his statements of dimensions in text. The comparison is made in the following table:

TABLE OF MEASUREMENTS (in microns.)

	<i>Sethocephalus cuccecyphalus</i>	<i>Cyttarocyelis cassis</i> Haeckel var. <i>plagiostoma</i> Daday
	Haeckel (1887, p. 1298)	Haeckel (1887, pl. 56, fig. 13) Entz (1887, p. 581).
Total length	140	115
Length of bowl	120	105
Length of collar	20	10
Width of bowl	120	110
Width of aperture	90	95
		108

The meshwork as figured by Daday (1887) is more angular, and there is less contrast between that of the bowl and that of the collar; in fact, the elements of the collar are smaller than those of the bowl, rather than larger as in Haeckel's figure, and the apex is slightly pointed. Daday also correctly figures the wall as a meshwork whose openings are filled with a ground substance, wholly omitted in Haeckel's figure. These are considerable differences, and, if they stood alone without further evidence, might well obscure the close relationships or identity of the two organisms.

The publication of Brandt's (1906, 1907) exhaustive monograph on the Tintinnodea of the "Plankton Expedition" has, however, revealed (1) that *Cyttarocyelis cassis* var. *plagiostoma* Daday is in reality specifically distinct from *C. cassis*, being a small species of more rotund form, more sharply set-off collar, and different proportions, and (2) that the range of variation within the species is very great. Brandt distinguishes three varieties, one of which, var. c (as represented in his pl. 36, figs. 3 and 6) most closely resembles the organism figured by Haeckel. This variety has, moreover, the broadly rounded apex, the rounded meshwork, the coarser, less regular mesh in the collar which characterize Haeckel's figure, and its dimensions (length 115-140 μ) fall within those given by Haeckel. Brandt also reports this variety from South Pacific waters (off Sidney) whence came Haeckel's material (Challenger Station 285, 32° 36' S., 137° 43' W.).

A comparison of the figures in question will convince anyone familiar with pelagic organisms that Haeckel (1887) and Brandt (1906-1907) are dealing with the same species and an inspection of Brandt's beautiful plates will be equally convincing that the organism in question is not a radiolarian but the tintinnid which Brandt names *Cyttarocyelis plagiotoma* Haeckel var. *e.* Bdt.

In connection with the examination of the plankton at San Diego I have seen this species a number of times and am convinced that it is a shell of a tintinnid. It has the filled mesh-work as figured by Brandt and not the open net as in Haeckel's figure. I have recorded the species, in connection with *Cyttarocyelis cassis* Haeckel, from collection No. 862, vertical haul with No. 20 silk net from 85 fathoms on Cabral's Banks, about ten miles off shore at San Diego, January 4, 1904. The catch containing this species was of mixed neritic and typical oceanic material, containing besides a small number of tricyrtid Radiolaria, *Tintinnus lusus undae*, *Ceratium candelebrum* var. *dilatatum*, *C. gibberum*, *C. gallicum*, *C. claviger*, *C. inflexum*, *Amphisolenia palmatum*, and *Planktonicella sol.* The facies of the collection was distinctly semi-tropical.

Brandt (1907) also reports the species from the Florida Current, Gulf Stream, Sargasso Sea, the Northeast Trades, South Equatorial, and the Indo-Pacific region. It has a predominantly tropical distribution.

The nomenclatural status of the organism is modified by the discovery that Haeckel's description is applicable. This antedates Daday's (1887) paper of the same year, and Haeckel's name *cucceryphalus* therefore takes precedence over *plagiotoma* as the specific name of the organism, and Entz's *Cyttarocyelis cassis* var. *plagiotoma*, and Brandt's *C. plagiotoma* fall into its synonymy.

Haeckel includes one other species in his genus, to wit, *Sethoccephalus platycryphalus*. This is not figured and is described as having a thorax (= collar, if a tintinnid) three to four times as broad as the cephalis (= bowl, if a tintinnid). This wide expansion of the collar is unknown among the Tintinnodea except in the insufficiently known genus *Fungella* described by

Cleve (1899), which Brandt rejects as doubtfully a ciliate. There is nothing in Haeckel's (1887) brief description which makes it possible to determine either the radiolarian or tintinnid relationships of this species. The "square pores" are suggestive of radiolarian affinities but the absence of collar beams and radial ribs strongly militates against this view. It has no resemblance in shape to any other known species of the Tintinnodea. Pending the re-examination of material, *Sethocephalus platycryphalus* must therefore be left in the list of species *incertae sedis*. But the possibility of its ultimate allocation among the Tintinnodea should remain open.

Transmitted, June 18, 1912.

ZOOLOGICAL LABORATORY,
UNIVERSITY OF CALIFORNIA, BERKELEY.

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ERRATA

- Page 87, line 26, for *tristaechus* read *tristoechus*.
Page 186, line 11, for V. K. Ekman read V. W. Ekman.
Page 192, line 26, for *Peridinia* read "*Dinoflagellata*"
Page 195, line 21, for *Michaels* read *Michael*.
Page 209, line 2, for V. K. Ekman read V. W. Ekman.
Page 247, for K. S. Mereschkowsky read W. C. Adler-Mereschkowsky.
Page 322, line 11 from the bottom, for *day* (last word) read *night*.
Page 344, line 30, for *weeks* read *days*.
Page 349, line 3 from bottom, for *Ba* read *Bc*.
Page 354, line 8, for *Cyttarocylis* read *Cyttarocylis*.
Page 354, line 11, for *lead* Haeckel (1887, p. 1298), read *leads* Haeckel (1887, p. 1298).
Page 356, lines 12, 13, for *Cytarocylis* read *Cyttarocylis*.
Page 356, line 19, for "*and*" read "*and.*"

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