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Foolfish, or filefish, from Hawaii. By Stephen Haweis

COLD-BLOODED VERTEBRATES

PART I

FISHES

By

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Director, United States Fisheries Biological Station
Beaufort, North Carolina

PARTS II AND III

AMPHIBIANS AND REPTILES

By

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VOLUME EIGHT

OF THE

SMITHSONIAN SCIENTIFIC SERIES

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PART I

FISHES

By

SAMUEL F. HILDEBRAND

Director, United States Fisheries Biological Station
Beaufort, North Carolina

CHAPTER I

THE FIRST BACKBONES

THE first backboned animal was a fish. Before mammals, before the birds, the reptiles, the amphibians, came the fishes; and paleontologists and zoologists generally agree that all these vertebrate animals, high and low, can trace their ancestry back to the marine creature who first incased his spinal cord in a hard protective covering which gave his body rigidity with suppleness. We may appreciate the importance of these qualities if we think of man trying to walk erect without them. Also, without the backbone no skull would probably ever have developed and, consequently, no brains as we now know them. Every human embryo passes through a fish phase in its development, for each at a certain stage possesses several pairs of unmistakable gill slits. As the embryo develops, all these gill slits disappear except one pair, which form the Eustachian tubes, connecting the middle ears with the throat.

There exist to this day living forms which are believed to closely resemble this ancestral vertebrate who lived so many millions of years ago that we hesitate to count them. These are the lowly lancelets.

In the other direction it is not a long stride from fishes to the next higher group of vertebrates, the amphibians. These animals are distinguished from fishes because they generally possess paired limbs provided with toes, instead of having fins. Some of them live in water throughout life and breathe by means of gills, whereas others, such as the frogs and toads, are truly aquatic only during the larval stages, later becoming air-breathing and terrestrial. It is evident, therefore, that the relationship between the more primitive forms of amphibians and fishes is close and it does not require a far fling of the imagination to find evidence that fishes are distant ancestors of the amphibians.

Similarly a close relationship links the amphibians with the reptiles. Thus relationships may be pointed out between the successive groups, from the lowest and most primitive vertebrates, namely fishes, to the most recent and highly developed forms, such as mammals. These structural relationships, as already stated, have led to the belief that all land-dwelling vertebrates may have arisen from the lowly fish.

In spite of their great antiquity, fishes still form one of the largest and most widely distributed groups of vertebrate animals. In fact there are certainly more of them than of all other classes of vertebrates. This is to be expected, as they represent the most perfect adaptation achieved by any creatures to life in the water. There exist but few bodies of water, such as the Great Salt Lake which is too salt for fish life, that are not inhabited by some members of the class; and as water covers three-fourths of the earth's surface, the reason for the wide distribution of fishes becomes obvious.

We find some forms such as the trout occupying fresh water only, and dying in salt water; others like the mackerel that can not live in fresh water; and still others like the eel and salmon which pass indiscriminately from one medium to the other. Again, while brook trout can not live in water above a medium temperature, catfish endure water disagreeably warm to the human hand. Some lungfishes (*Protopterus* and *Lepidosiren*) live in mud cocoons for months at a time when the pools dry up; certain deep-sea fishes can exist only at depths far below the range of light; while others must keep to the shallows or they die.

As the environment varies, the animals that inhabit it must vary. The many adaptations necessary to meet the diverse conditions in the waters have given rise to thousands upon thousands of fish species. Close to 30,000 species, living and fossil, have been described, and new species come to light continually. Variations in form, structure, and size are exceedingly great. The smallest living fish that has been found is a goby (*Mistichthys luzonius*) of the Philippine Islands which measures a little less than one-half inch (males 7.5 to 9, and females 10 to 11 millimeters) in length. This pygmy goby also has the distinction of being the smallest living vertebrate. In spite of its size it is so abundant that it has become an important article of food in Luzon. The largest present-day fish known is the whale shark (*Rhineodon typicus*), of which specimens fifty feet long have been reliably reported, although rumor has it that they reach a length as great as seventy feet (see Plate 26). If a smaller fish than the Philippine goby ever lived, it has not yet been found. However, certain fossilized teeth suggest that some of the ancient sharks greatly exceeded the modern whale shark in size; for it is estimated that the possessors of teeth bearing cusps three, four, and five inches long must have attained a length of upward of one hundred and twenty feet.

And yet all this variety amounts to little when compared with that attained by land-living animals. Naturalists agree that evolution in fishes has proceeded much less rapidly than among terrestrial vertebrates. They explain this by the fact that conditions in the sea in comparison with the land have remained throughout all the ages essentially stable. Geology and paleontology reveal to us that at times in the earth's history polar conditions have existed well down in the temperate zones while almost tropical conditions have existed at the poles. When changes of such magnitude have occurred, whole groups of land animals have been wiped out. But the sea has known no such great modifications; and although conditions through the ages have varied sufficiently to render extinct many species of fish, the number thus extinguished is small compared to the extinct species of land animals.

This theory of stability of marine conditions and slow evolution of fishes gains support from the fact that some of the living fish forms, such as the bullhead sharks and the gar pikes, existed in their present form many ages ago, as their fossil remains prove.

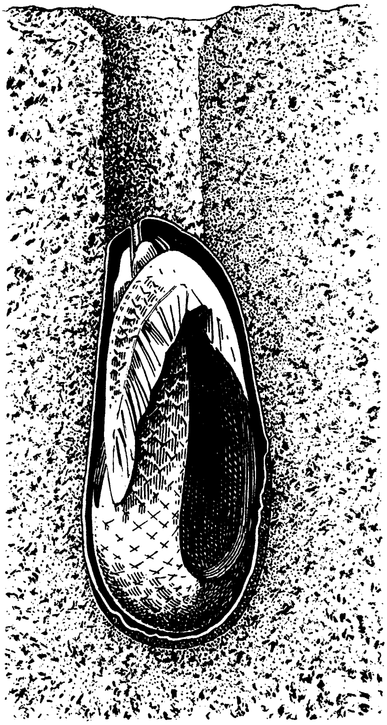


FIG. 1. African lungfish, *Protopterus*, aestivating in its cocoon of mucus. Note funnel by which air passes to mouth. After Newton Parker

But what is a fish? It is customary to call by this name all animals that live in water, especially if they have a commercial value. The mere fact that an animal lives in the water, however, is insufficient to make it a fish, just as not all animals that fly are birds.

For present purposes a true fish may be defined as a cold-blooded animal with a backbone, with arms and legs represented by fins or rudiments of fins, and living in the water in which it breathes by means of gills. Whales and porpoises and their allies often are spoken of as fish. They are excluded, however, because they possess lungs and do not breathe by means of gills. Our definition also excludes the so-called shellfish—oysters and clams, crabs and shrimps—for none of these animals possesses a backbone. For the same and many other reasons, starfishes and jellyfishes are not true fishes.

It would simplify matters greatly if we could distinguish a fish by its shape. But the members of the class vary so much in this respect that it is utterly impossible to define them by the form of the body. Some are long and slender, resembling worms, others are very deep, short, and narrow, while still others are very flat and broad. The factors that determine form are generally the conditions under which the fish lives and obtains its food, and as these conditions vary, shapes vary.

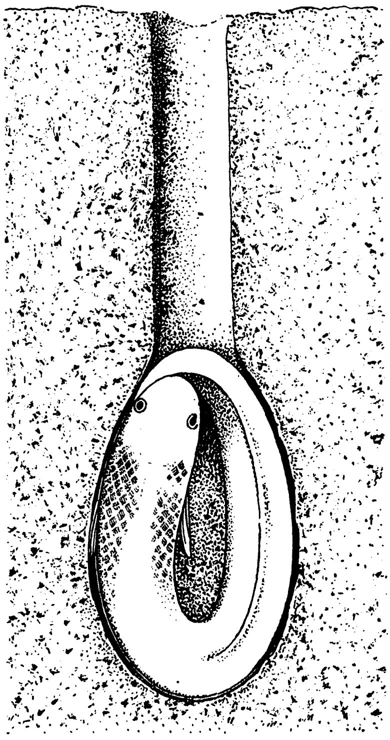


Fig. 2. South American lungfish, *Lepidosiren*, aestivating in deep burrow, mouth of which is plugged by a piece of perforated clay

Lampreys or cyclostomes, of which examples occur both in salt and fresh water, illustrate the wormlike type of fish, a form which is readily understood when their mode of life is known, for they are parasitic on other fish during at least a part of their existence. In fact the head is not even definitely distinct from the body. Nor does the lamprey possess jaws, for the mouth is a sort of funnel-shaped sucking disk, provided with large rasping teeth (Fig. 3). With its sucking disklike mouth this eel attaches itself to another fish and it obliges the animal of its "choice" to provide free transportation while the rider rasps away at the very flesh and blood of its host with its large teeth. Sometimes the host fish is killed outright. Again the lamprey eel abandons its victim with large gaping sores which are attacked by disease, causing a slow and torturous death. Some of the hosts survive, however, but the deep healed-over scars tell their own story of hardship and suffering. Lampreys vary in length from several inches to several feet.

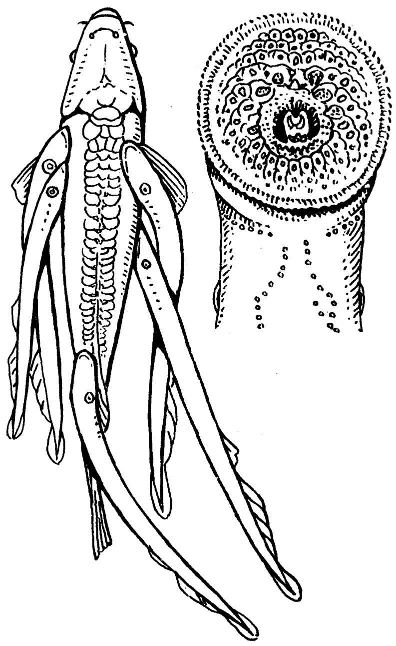


FIG. 3. Left, young lake lampreys attacking a fish; right, mouth of lake lamprey showing rasping teeth. After Gage

The spadefishes and their allies offer examples of very short and narrow fishes. They often are quite as deep as long and always strongly *compressed.* Many of these fishes feed chiefly on plants and often on algae and other growths attached to plant stems, sticks, and piling. The narrow, compressed body obviously permits them to pass with little resistance between closely set plant stems or pilings and through other narrow spaces, while in search of food.

The skates and rays typify fishes that are thin, or narrow in the opposite direction from the spadefishes, for they are very strongly *depressed.* Some of the species, as for example the butterfly rays, are broader than long. These animals generally live on the floor of the waters they occupy, seeking their food on the bottom. Their broad, flat bodies are admirably adapted to the life they live.

The examples mentioned are extremes in form. Thousands of intermediate shapes exist, each fish being adapted to the life it leads. It is evident, then, that a fish can not be defined by the shape of the body. Neither can a general definition of a fish be based upon the presence of scales, for not all fishes possess scales. More permanent and constant characters than these must be sought. These characters, as we have said, include cold bloodedness and the possession of a backbone and of fins, or rudiments of fins, in place of arms or legs. Furthermore, the animal must live in the water, in which it breathes by means of gills.. Unless an animal meets all of these specifications it is not a fish.

CHAPTER II

PEDIGREE AND KINSHIPS

EVERYBODY is interested in the beginning of things. All the more so when the beginning in question is not only that of fishes but of all vertebrates. Although interrogated from various angles as to what the first fish was like, nature has given no definite answer. The history of extinct animals, if indeed there exists any history, is "written in the rocks." But this is inadequate at best. The soft parts of primitive animals are not preserved. The remains that are found generally consist of bones, spines, teeth, and other hard parts. If the earliest or most primitive vertebrate did not possess real bones, and we cannot believe that it did, its remains most probably failed of preservation and man will never know precisely what it was like.

When paleontology fails, only one other clue to primitive structures and characters remains, and that is found in the embryological and larval development of living things. Long-lost characters of the adult often appear in the embryo. It is from the study of embryology that we learn of the several pairs of gill slits possessed by the human embryo. In the early stages of development of the embryo fish we find it a mere string upon the yolk, with no heart or limbs. It is apparently a mere worm. The lowest living fish form, the lancelet, is just about this sort of creature. If the embryo repeats the history of the race, we have here a striking indication of what the first fish was like.

The most primitive living vertebrate, the lancelet (*Branchiostoma lanceolatum*), generally classed among the

Atlantic spadefish, *Chaetodipterus faber*, a narrow, compressed fish feeding largely on inshore plants.
By Stephen Haweis

fishes although not a true fish, usually reaches a length of only a couple of inches (Fig. 4). It has no jaws, the mouth consisting of a lengthwise slit. True vertebrae are likewise lacking, as the "backbone" is a continuous cartilaginous rod. The median fins, both dorsal and ventral, consist of folds of skin. Of paired fins there are none; hence, no hard parts are present. It seems quite probable that the ancestral vertebrate similarly lacked

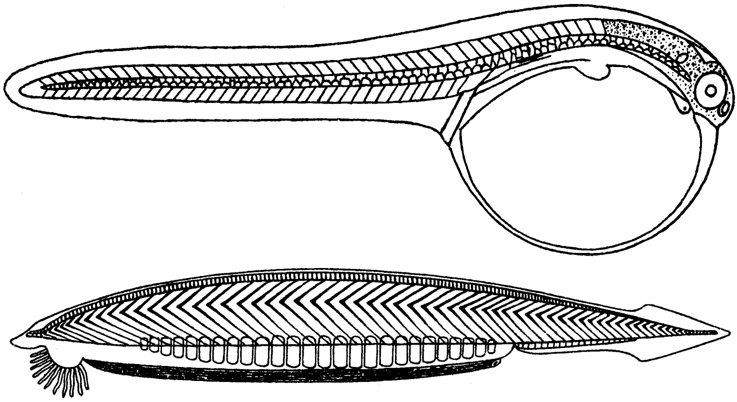


FIG. 4. Upper, larval stage of plaice (enlarged fourteen times) attached to yolk and without limbs, compared with (lower) the lancelet, natural size, the lowest fish form, without limbs, head, or spinal column

hard parts so that we may have little hope of finding any of its remains preserved in the rocks.

Taking a considerable step upward from the lancelet, we come upon the next class of fishlike vertebrates, namely the lampreys (*Hyperoartia*) and hagfishes (*Hyperotreta*). These animals are eel-shaped, wormlike creatures, some of the species reaching a length as great as three feet. They have a cartilaginous skull, a brain, and a heart, but no limbs and no armor. Their mouths are round or oval, suctorial, and provided with teeth, but without jaws. No species of lampreys have been found among the fossils. Theoretically, the earliest fishlike animal would be lancelet-like and would naturally be followed by the lampreys. However, lampreys have no hard parts (exclusive of the teeth) and, therefore, appear to have left no trace in the sedimentary deposits. Lampreys and hagfishes today stand, structurally, between the lancelets and the sharks, but nothing is known of their origin nor of their ancestors.

The earliest traces of fish life which the rocks have yet yielded have been found in the Rocky Mountains of Canada. These date back to the Paleozoic era and the Cambrian period—that is, almost back to the beginning of life on earth. The time in years, of course, is not known but it is variously estimated. A recent writer would have us believe that the first fish lived at the almost incredible period of something like 400 million years ago.

These oldest remains are so fragmentary that it is not possible to determine what the animals were like. That they are fish remains, however, is certain. Apparently few calcified parts were present, and no armor or anything that resembled limbs. Presumably these early fishes were active muscular bodies, able to swim through the water in a definite direction. Further than that the naturalist is not yet able to go.

The earliest recognizable fishlike remains are called ostracoderms because of the dorsal and ventral dermal plates which protect the head and anterior part of the body. Usually the rest of the body is covered with small platelike scales. This structure is quite peculiar and no transitional forms are known leading to sharks or other fishes. There appears no trace of an internal skeleton, as that was probably cartilaginous and so disappeared. Of these small armored creatures Doctor Dean writes:

"In their simpler forms they occur in the Upper Silurian; they flower out in a variety of types in the Devonian, and shortly become extinct." One of these old forms, *Cephalaspis*, curiously resembles in its armature a small armored catfish, *Callichthys*, inhabiting rivers of South America today (Fig. 5). The anterior outline of the head of this extinct form is strikingly like a saddler's knife in shape. The creature, like most of the others of this group, has no side fins or limbs, and the fossil remains show no trace of jaws. It must have had a mouth, of course, but what that was like can only be guessed.

Another member of the extinct ostracoderms was the wingfish, *Pterichthys*, a small, quaint, armored creature, once thought to be a crab and again described as a beetle. This animal had bony, jointed arms attached to the head, giving it the appearance to the untrained eye of some

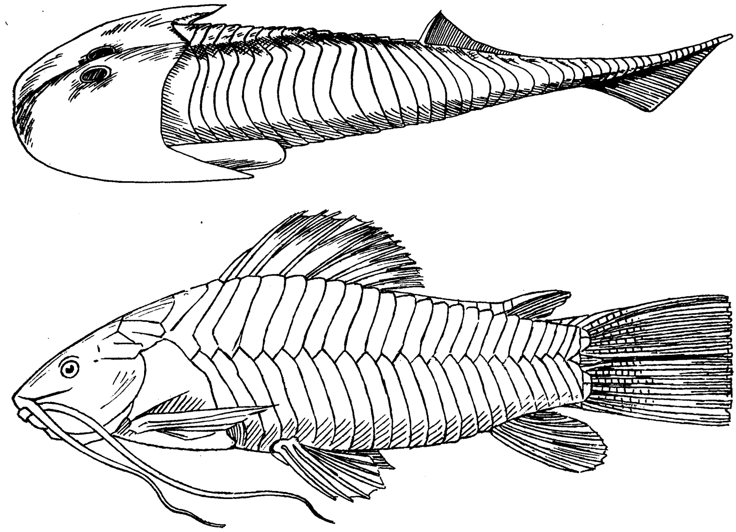


FIG. 5. Upper, a small extinct ostracoderm of the Devonian, ***Cephalaspis***, showing same type of body armor as (lower) a catfish, *Callichthys*, of South America. Each about six inches long

crawling creature rather than that of a fish. Writers tell us that the "wings", or paddlelike structures, probably were not real limbs but merely jointed appendages to the headplate. In this creature, as in all others of the group, nothing in the fossil remains suggests a mouth.

These fishlike creatures and their allies appear at one time to have been the dominant type of life, for in places their protective shields, jumbled together, are said to form great deposits. Some students estimate their abundance as so great that the oil from their decomposing bodies helped to consolidate portions of the strata of the English Old Red Sandstone. They seem to have lived in troublous times, for regardless of their extensive armor, they perished utterly, leaving no progeny at all closely related in form or structure.

Much larger and more formidable fishes succeeded the vanished ostracoderms. These animals, whose remains are preserved in the Devonian strata, are likewise known chiefly from the armor with which they were clad, for the endoskeleton consisted of cartilage and generally was not preserved. The armor covered the head and anterior part of the body. The "box" was not continuous, however, for there was a sort of hinge at the neck so that the fish could nod their heads. It is from this hinge that these animals of the past receive their name, Arthrodires, meaning "jointed neck."

Unlike their smaller predecessors, the Arthrodires possessed large, powerful jaws. Likewise they boasted of pelvic limbs, small though they were. They attained a length of ten to eighteen feet and the largest species had a mouth fully four feet wide, probably large enough to devour any other animal of the time. All these characteristics probably made them the rulers of the waters in their day. But time and changing conditions were against them. They met disaster and, like their small predecessors, they lost their dominance and eventually became extinct, leaving no close relatives.

Although it is not the earliest recognized in the rocks, the shark type is believed to be the most primitive of the existing true fishes and the forerunner of all other subsequent groups. We find the principal reasons for this belief in the apparently more primitive character of the shark's body covering, the simple gill slits, and the primitive shape of the tail. In these animals the upper lobe of the forked tail is longer and larger than the lower one and the backbone is bent upward posteriorly and enters the larger lobe of the tail fin (see Fig. 30). This is a condition through which the so-called higher fishes, namely the true bony fishes, pass in their early larval development (see Fig. 18), although later in life the spinal column does not

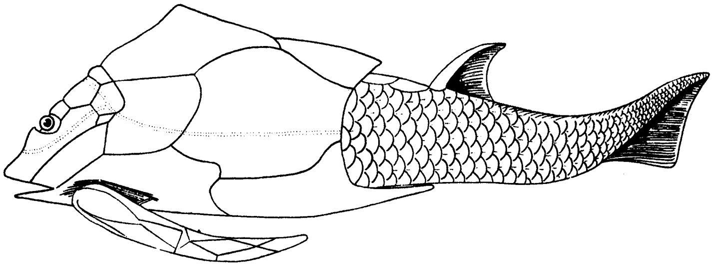


FIG. 6. Extinct wingfish, *Pterichthys*, showing limblike appendage to the head

enter the upper part of the tail fin. This condition of the tail in the larval bony fishes is interpreted by naturalists as indicating the type of tail their ancestors (sharks?) possessed.

Small fish spines, doubtfully referred to a primitive shark, occur in rocks of a very early period, but it is not till we come to the Carboniferous that we find remains complete enough to be definitely identified as those of a primitive shark. These oldest sharks were of relatively small size possibly only two to six feet in length, yet the shape appears clearly to have been that of a modern shark. The skin was covered with hard, bony points, and the teeth bore a large central cusp with smaller cusps on the broad, expanded base, very much as in certain modern sharks.

Succeeding the sharklike creatures of Carboniferous times came a host of other sharks, known principally from their teeth and fin spines. Nearly all of these old forms perished, giving place to others better adapted to the changed conditions brought about by time. One family, the Port Jackson or bullhead sharks (Heterodontidae), however, appears to have survived. The living species, of which there are four, are found only in the Pacific, the Port Jackson shark of Australia being known the longest. These sharks, like other old ones, have a spine in front of each dorsal fin. The lateral teeth are padlike, ridged or rounded, and arranged in many rows, and differ from the anterior pointed teeth. The surviving members suggest a bottom-dwelling form with teeth adapted for crushing hard objects. This family, although probably older, has not been traced earlier than the Mesozoic period, sometimes estimated at something like fifty million years ago.

As the Eocene and Miocene epochs were reached, the warmer oceans seem to have teemed with sharks. Some were small, but others reached monstrous proportions, apparently much greater than any living animal of today. However, they are known mostly only from their teeth, as their skeletons were cartilaginous and do not appear to have been preserved. It has been estimated from a comparison of the teeth of living sharks with those of extinct forms, which reached three, four, and even five inches in length, that some of the giants of the past attained a length of a hundred and twenty feet, which is longer than any modern whale. They appear to have swarmed everywhere throughout the warmer seas, for their teeth occur in the Tertiary strata in many parts of the world, and dredgings made in the deep sea have brought up their teeth by scores. Eventually, however, these huge wolves of the sea perished. The reason is not known. It is sometimes thought that they may have devoured everything throughout their habitat and then fallen to eating each other. In any case it is certain that they perished while some of the smaller sharks survived and still live, showing that victory does not always belong to the largest.

Among the latest sharks to appear are the great man-eating *Carcharodon carcharias* and its nearest allies, remains of which have been recognized only in the Tertiary formations.

A second group of important fishes, known as chimaeroids, sharklike in character, appeared early in geological time, certainly as early as the middle Silurian, which greatly antedates the Carboniferous. These animals, having several living representatives, variously known as spookfishes, ratfishes, and elephant fishes, are generally

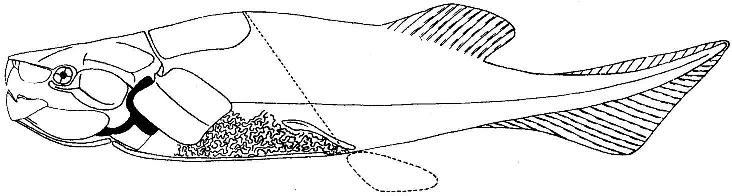


FIG. 7. One of the extinct Arthrodira, with heavy armor hinged at the neck. Ten to eighteen feet long

believed to have diverged from the sharks, although the association is not very close. A thick, round head which tapers gradually toward the pointed or filamentous tail usually distinguishes them. The skin is smooth and the paired fins are somewhat sharklike in character. The fin on the back has a long spine and the skeleton is cartilaginous, both characteristics suggestive of the sharks. The cranium is a highly compact structure. The upper jaw is immovably fused with the cranium and the lower one is directly articulated with it, differing sharply in these respects both from the sharks and the bony fishes. The teeth are represented by dental plates, closely fused with the jaws and studded with sharp points.

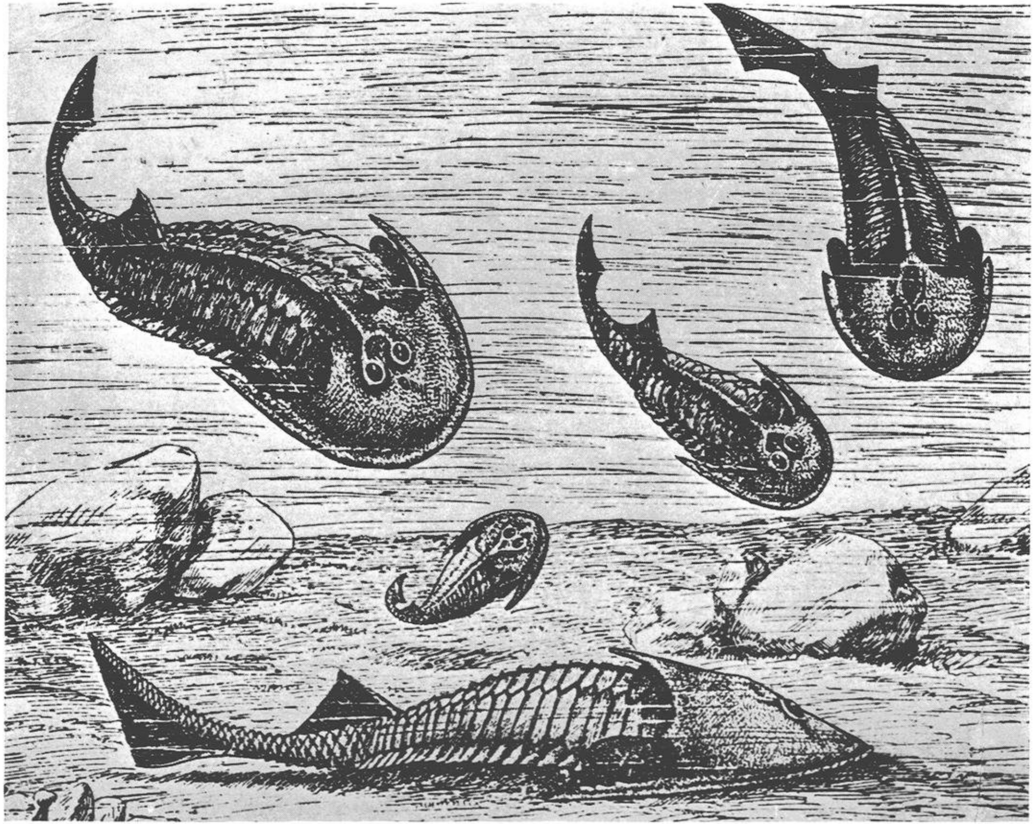
Chimaeroids, like the sharks, are very imperfectly represented in the rocks, probably because their skeletons were cartilaginous and decomposed before they could become covered and preserved. Little more than their dental plates and fin spines have been found. The structure of the ancient chimaeroids, however, appears to have differed little from the living representatives. These modern chimaeroids inhabit the cold and cooler seas and the depths of the ocean. The elephant fish, the best-known species of this group, lives in shallow water, of ten to twenty fathoms, from Sitka, Alaska, to San Diego, California. It is brown in color, with whitish spots, and reaches a length of two and a half feet. It is harmless and worthless, except for the oil in its liver, but always of great interest to the naturalist.

We come now to the remaining groups of fishes, living and fossil, which are all combined by Dr. David Starr Jordan under one class, Teleostomi, meaning "true mouth." In these fishes the lower jaw generally is not attached directly to the skull but is joined with intermediate bones. They possess, typically, an air bladder, or a modification thereof; their skeletons are at least partly ossified, and they have membrane bones, such as the opercle and suborbitals, on the head; one or two pairs of limbs are developed; and a single gill opening leads to the gill arches.

To this large class belong the vast majority of recent fishes and also a large percentage of the known fossil forms. It may be divided into three major subclasses—the fringe-fins, the lungfishes, and the ray-fins. The ray-fins include the ganoids, represented among living forms by the gar pikes, sturgeons, paddlefish, and bowfin, and the bony fishes or the true teleosts, including from ninety to ninety-five per cent of all living fishes.

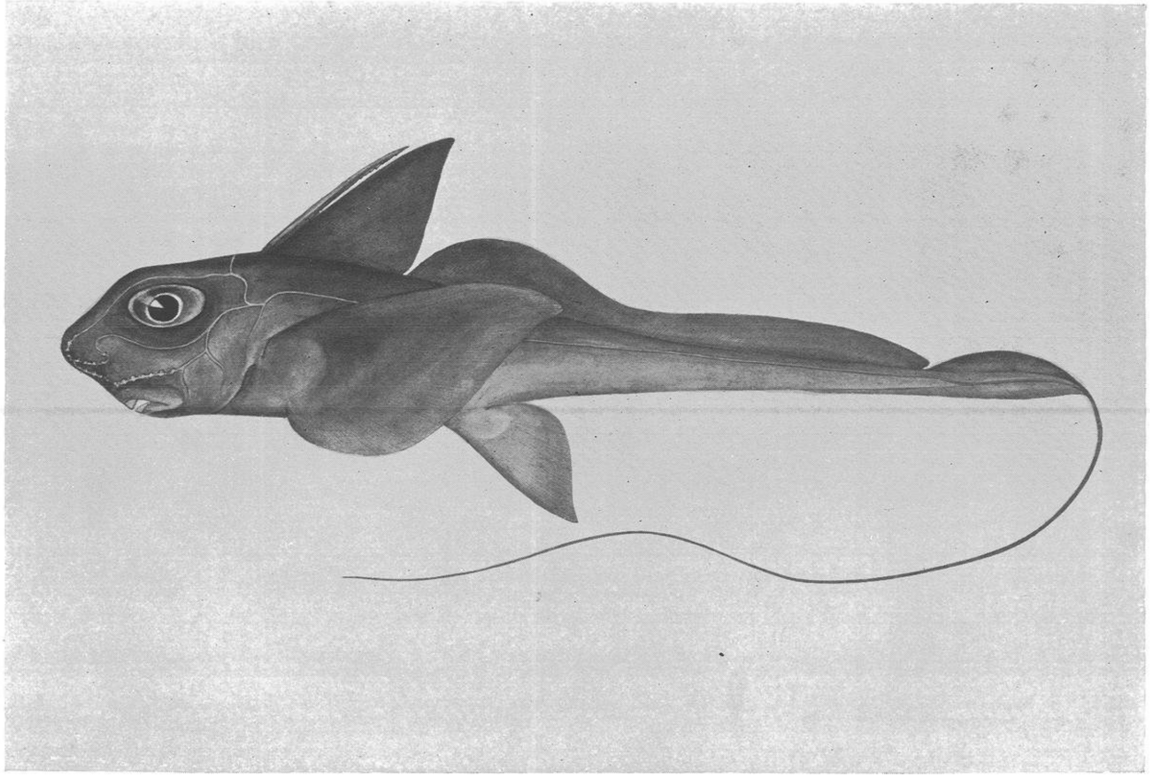
The fringe-fins generally are regarded as the most primitive of the "true mouths." This group once included a large number of important fishes. Representatives first appear in the Devonian formation and continue through the Carboniferous. Only two genera, including about ten known species, all inhabiting African rivers (the Congo, the Niger, and the Nile), occur among living fishes. Of these none have been found fossil, yet they appear to have diverged little in general structure from their Devonian

PLATE 2



Ostracoderms from the Lower Devonian, restored. Small armored fishes forming a connecting link with crustaceans. After Koken

PLATE 3



Chimaeroid (*Chimaera deani*) from the Philippines, about fifteen inches long kindred. The fringe-fins, living and fossil, resemble the common American gar pike in shape and form and in the body covering which in both groups consists of small, hard, imbricated, rhomboid bony plates. The gar pike, however, has a more elongate snout.

But what particularly distinguishes the fringe-fins and stirs our interest in them is the fact that the pectoral fins or fore limbs are jointed. Is this the first step up in the development of the jointed limbs of the higher vertebrates?

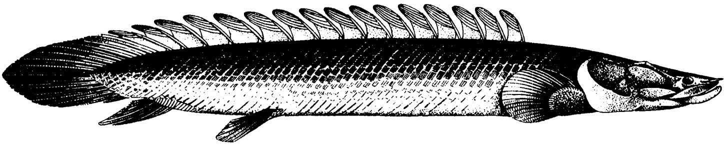


FIG. 8. A fringe-fin, *Polypterus bichir*, of the Nile, most primitive of the true-mouths. After Boulenger

Some paleontologists believe so and regard these fishes as the almost immediate ancestors of the amphibians, that is, the salamanders, frogs, and related forms. Furthermore, the cranium of the fringe-fins resembles that of amphibians, and the jaws and teeth are similar to those of the higher vertebrates and quite different from ordinary bony fishes. The young of the living forms have external gills which disappear in the adult. These gills, in form and structure, resemble the external gills of amphibians. Finally, the living fringe-fins, at least, possess a somewhat lunglike air bladder. But here the resemblance ends, for the air bladder is not cellular in structure as in the true lungfishes and in the higher, air-breathing vertebrates. Furthermore it lies on the downward or ventral side of the gullet, whereas in other fishes it lies above the gullet, occupying a position similar to the lungs in the higher vertebrates. The position and structure of the air bladder, therefore, do not support the amphibian ancestorship theory. With respect to the development of the air bladder into a lung, it seems more probable that the lungfishes are nearer ancestors of the amphibians than the fringe-fins.

The fringe-fin fishes grow moderately large, the common species from the Nile reaching a length of four feet. The fossil forms apparently were smaller. The recent species are sluggish in habits, occupying mostly quiet waters, living close to the bottom, and occasionally ascending to the surface for a gulp of air. They are used as food and their flesh is said to be of excellent flavor.

The lungfishes, or dipnoans, have long been looked upon as a connecting link between amphibians and fishes. They first appear in the vast darkness of Devonian time and apparently became rather numerous in the Lower Carboniferous. Thereafter they diminished in number until today only three distinct genera are left. One of these, *Neoceratodus*, is found in Australia, another, *Lepidosiren*, in South America, and the third, *Protopterus*, in Africa. All the species inhabit fresh water, generally sluggish, stagnant, or even muddy pools or streams.

Lungfishes, recent and fossil, have the two sets of paired fins corresponding to limbs, either with or without rays. The brain case is cartilaginous but is roofed by dermal bones, somewhat similar to that of the bony fishes. The lower jaw, as in the chimaeroids, is articulated directly with the skull. Two pairs of nostrils are present, the anterior pair opening under the upper lip and the posterior pair within the mouth. All the species have a row of small gill arches, whose single external opening is protected by a membrane bone, the operculum.

The living species of South America and Africa, especially, resemble the salamanders, one of the more primitive orders of amphibians (Fig. 9). The body is thick and spindle shaped, but unlike the salamander's in that the skin, exclusive of the head, is covered with round, bony scales. The head bears a distinct resemblance to that of the salamander in shape and is covered with a slimy skin precisely as is the salamander's. The slender paired fins suggest the legs of the salamanders, although less leglike in structure than the paired fins of the fringe-fins.

Young lungfishes, like embryo sharks and salamanders, possess external gills. These almost wholly disappear with age, and the small covered gills that remain are unable to supply the respiratory needs, so that the animal must rise to the surface at intervals for air, like a frog. The cellular air bladder serves as a lung. The South American species at least, is reported to breathe as continuously and as rythmically as a mammal. During the rainy season the South American lungfish lives in swamps a few feet deep. When the dry season comes it burrows in the mud, closing its burrow at the top with a lid of

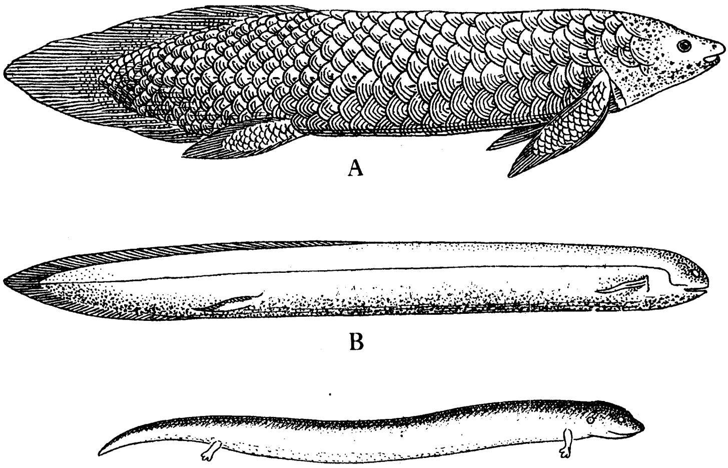


Fig. 9. Two lungfishes, A, *Neoceratodus* of Australia, and B, *Lepidosiren* of South America. C, a salamander, *Amphiuma*, showing close external resemblance, in limbs, etc., to lungfish

mud. The fish surrounds itself with a mucous secretion and during its aestivation closes its gill openings and breathes through the mouth, the air reaching it through the perforated clay lid of its burrow. When the rainy season returns the lid is pushed off the burrow and the animal comes out as soon as the water is deep enough.

The African genus from the White Nile and the Congo which has long been handled by dealers has very similar habits. It encases itself in a cocoon of mud in which it may be transported long distances. When the cocoon is placed in tepid water the mud is dissolved and the fish soon revives.

The Australian genus has better developed gills than the South American and African genera and, so far as known, it always lives in water, although doubtless coming to the surface at intervals for air.

No fossil remains of the South American or of the African genera have been found. However, fossilized parts, especially teeth, of near relatives of the Australian form, known in Queensland as *Barramunda*, have come to light in abundance. The characteristic triangular, platelike teeth of these fishes occur in fossil form in England, Germany, India, South Africa, and also in the United States (in Colorado and Wyoming), indicating a widespread distribution in contrast with the very limited range of the single living species.

The barramunda is a food fish of importance in Queensland, having been compared in size and taste with a salmon. Also, its meat is red. In form it is a heavier-bodied fish than its living relatives, though resembling them in the rather sharp head and pointed tail. It reaches a length of from five to six feet.

We can not know, of course, how far back in geological times the ancestors of the lungfishes developed lungs and began to breathe air, as the air bladders obviously are not preserved in the rocks.

Doubtless this took place a very long time ago. We may suppose, to quote J. T. Cunningham, that

> . . . the original fishes, more or less similar to sharks and dog-fishes, were inhabitants of the sea, where the water being saturated with oxygen there was no need of any atmospheric respiration to supplement

the action of the gills. Some of these original fishes ascended the rivers and became inhabitants of fresh water, as some selachians and rays ascend the Amazon at the present day. Some of these forms made their way into streams or lakes where, from the hot climate and the decomposition of vegetable matter, oxygen was deficient and they began to swallow air at the surface to compensate for the failure of aquatic respiration. This appears from the evidence to have been the origin of the air bladder, and at the same time, of the teleostome type. From these air-breathing teleostomes at a very early stage arose the earliest Amphibia, and on the other hand they multiplied in all the fresh waters, until some of them again reached the sea, where the air bladder lost entirely its respiratory function and became a swim bladder.

The fishes we know best are ray-fins, which include all fishes not grouped under the sharks and rays, chimaeroids, fringe-fins, and lungfishes. This subclass of the Teleostomi generally is subdivided into two time-honored groups, the ganoids and teleosts, but they have representatives which are extremely closely related and can scarcely be separated. In general the ganoids include the "old-fashioned" fishes, possessing rhombic bony plates and a cartilaginous skeleton, while the teleosts constitute the "modern" bony fishes, covered with round scales and having a well calcified skeleton. To these definitions there are several exceptions, as the one group merges almost imperceptibly into the other.

The gar pike probably is the most typical living representative of the one-time numerous group of ganoids. Every midwestern boy knows this very elongate fish, with its long jaws well provided with teeth, two pairs of limbs, and complete body covering of a series of hard, enameled, rhombic plates. The skeleton is cartilaginous, the heart (arterial cone) contains several valves, and the air bladder is somewhat cellular, as in the lungfishes, and has a respiratory function. The alimentary canal is short and possesses a spiral valve, as in the sharks and the chimaeroids.

The gar pike occurs commonly in the fresh waters of North America and is especially abundant in the Mississippi, Great Lakes, and the rivers of the Southern States. It is represented by three species, the largest of which, the alligator gar (*Lepisosteus tristoechus*), is reported to reach a length of twenty feet. The gar pike prefers quiet water and is rather sluggish in its habits, yet at times aggressive. The complete armor of dermal plates saves it from easy destruction by fish or other predatory animals, and the enamel scales of the alligator gar may even resist shot. When taken from the water it exhibits a remarkable tenacity to life, often living for hours. Fishermen consider the fish a general nuisance, for it "steals" bait, tears nets, and its flesh is almost worthless.

Of all living ganoids the gar pike resembles most perfectly the structural characters of the abundant Paleozoic and Mesozoic forms, although its genus occurs first in the

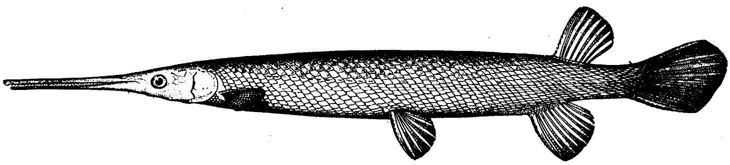


FIG. 10. The long-nosed gar pike, *Lepisosteus osseus*, of the Great Lakes and Mississippi Valley. A typical ganoid with rhomboid plates instead of true scales

Eocene. Many of the fossil ganoids are not elongate in body, nor do they possess long jaws, yet they resemble the gar pike in the structure of the rhombic bony plates covering the body, in the fins, the teeth, and in the partially calcified skeleton.

The sturgeons, of which about thirty species are known, and the paddlefishes also belong to the ganoid group. The dermal plates, completely covering the body in the gar pike, have been reduced in the sturgeons to five longitudinal rows of large shields, leaving most of the body naked, while in the paddlefishes dermal plates are entirely wanting. Very young sturgeons have conical teeth which they lose early in life, leaving the mouth toothless. The tail of this fish resembles closely that of the shark, the upper lobe being much the larger and supported in part by the upward curved spinal column, a character indicating a relationship to the sharks. The sturgeon also has a long projecting snout, underneath which is placed the comparatively small, protractile mouth and one or more pairs of barbels or feelers. They are large animals, varying in length from three to thirty feet when adult, and inhabit streams, lakes, and the coasts of the Northern Hemisphere. They are used everywhere as food, and the roe, known as "caviar" after it is salted and dried, brings more than the fish on the market.

The sturgeons apparently are the most recent of the ganoids. Although fossils of an extinct sturgeonlike fish belonging to an early period have been found, a modern genus does not appear until the Lower Eocene.

The paddlefishes, close relatives of the sturgeon, include only two living species, one, *Polyodon spathula*, inhabiting the Mississippi Valley, and the other *Psephurus gladius*, the great rivers of China. The American species reaches a length of about four feet, and is very sharklike in appearance. Instead of the complete plating of the gar pike, or the five rows of dermal plates possessed by the sturgeons, the paddlefishes have the skin quite naked. A long snout projects far beyond the mouth and accounts for the several names—paddlefish, spoon-billed cat, duck-billed cat, and shovelfish—bestowed on the American species.

No representatives of the living genera appear to have been found fossilized, although a relative and probably an ancestor of the living species has come to light in Eocene shales. This primitive paddlefish had a shorter snout, and small, thin, quadrate scales covered the body, a fact which appears to indicate that the paddlefishes may have sprung from a primitive type of fish having rhombic plates, like the gar pike.

The bowfin (*Amia calva*), also known as dogfish, mud-fish, lawyer, and John A. Grindle, completes the ganoids. The single species of this order abounds in lakes and swamps of the Mississippi Valley, the Great Lakes region, and southward to Georgia. It has a calcified skeleton and is covered with round scales like most modern fishes. The tail is round and the backbone does not enter into it

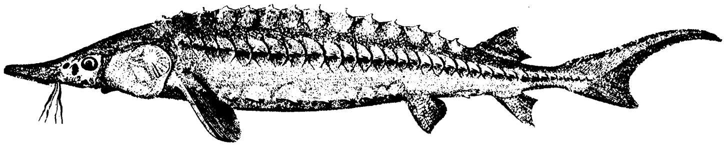


FIG. 11. Lake sturgeon, *Acipenser rubicundus*, from the Great Lakes. Compare dermal plates with those of gar pike. Courtesy Bureau of Fisheries

prominently. For these reasons it very closely resembles the true bony fishes or teleosts and forms a sort of connecting link between them and the ganoids. It retains a cellular air bladder which is of respiratory value, as in the gar pike. The bowfin probably is the most tenacious of life after removal from water, of any American species of fish, as it is able to breath air by means of its lunglike air bladder.

Bowfins reach a length of about two and a half feet. The bad flavor of the flesh limits their use for food, though in recent years it has been found that smoking much improves the taste, so that in certain localities the species is being eaten somewhat more extensively than formerly.

Several fossil forms from the Miocene and Eocene, although differing from the only living one as to species, have been referred to the modern genus. Evidently this group attained much greater numbers in prehistoric times and also enjoyed much wider distribution, for related fossil forms have been found in Europe as well as in America.

We have in the ganoids as a whole, a case of decline so far inexplicable. Beyond a doubt they were once much more numerous than at present. Yet they appear ex-

PLATE 4

The naked-skinned paddlefish, *Polyodon spathula*, from the Mississippi.
Courtesy of the Bureau of Fisheries

tremely well adapted for carrying on the processes of life, at least with conditions such as we now know them. Why, then, should they have diminished so greatly in numbers?

While the ganoids proper were on the decline a side branch appears to have been developing which grew out of all proportion to the size of the original trunk. This branch constitutes the now overwhelmingly predominating subclass of fishes, namely the teleosts or bony fishes, which naturalists generally agree are descendants, many times removed, from the ancient ganoid stock.

As fossils the teleosts, or "true bones," first appear in the Jurassic, whereas the first fossil ganoids date back to the ancient Devonian period. These earlier fishes made their appearance contemporaneously with air-breathing, land-living vertebrates, which were well established long before the first teleost came on the scene. The other fishes—sharks, chimaeroids, fringe-fins, and lungfishes—equal or exceed the ganoids in antiquity, so that the teleosts are by far the youngest of the great class of fishes. Some of the species have diverged far from their ancestral group, but others have retained many of the characters possessed by the recent ganoids, leaving certain species that merge almost imperceptibly from one genus into the other. And even those species that have got farthest away from the ancestral stock still often display ganoid characters in the embryonic and larval stages.

In general, teleosts have a thoroughly calcified skeleton; the backbone seldom enters the upper lobe of the tail fin; the air bladder no longer is lunglike and does not assist in respiration; and the spiral valve of the intestine disappears. They differ from ganoids also in having fewer valves in the heart (or arterial bulb), and in the arrangement of the optic nerves, which are not interfused but remain separate, one running to each eye without crossing. The dermal bones of the head, which in the ancestral ganoids are at the surface and enamel-coated, are here deep-seated in the head and not infrequently covered with skin and scales.

Scales disclose great variety and sometimes are missing altogether, but when present they generally are round, with free posterior margins which overlap succeeding rows of scales.

Teleosts vary widely in the detail of almost every structural character. Great differences occur among the species with respect to the gills, teeth, scales, the digestive tract, circulatory system, nervous system, and sensory structures. These wide variations are interpreted as indicating that the species are competing keenly in their struggle for existence, undergoing whatever modifications are necessary to meet the conditions confronting them.

But we can not deal with large numbers of anything without classification, and the true bony fishes have to be classified in spite of their wide divergencies in detail. The basis of grouping is inevitably technical, but we shall try to avoid technicality here as much as possible by discussing only the major divisions. Two general superorders of teleosts, based on the position of the ventral fins, are recognized. To each of those, however, several exceptions exist. The first large division consists of those fishes that have the ventral fins (hind limbs) attached to the abdomen, that is, inserted back of the pectoral fins (fore limbs) and with the supporting arches of bones (clavicle and pelvis) separate and attached to different parts of the skeleton. These fishes sometimes are referred to as abdominal fishes. Most of the Abdominales have only soft rays in the fin on the median line of the back (dorsal fin) and in the one on the median ventral line (anal fin), or at least these fins do not possess a series of spines.

The other superorder includes those species that generally have the ventral fins (hind limbs) attached forward and the supporting bones united with the shoulder girdle. These fishes usually have several spines in the dorsal and anal fins and, as a rule, the ventral fins are composed of one spine and five soft rays. The animals thus defined are referred to as spiny-rayed fishes.

The common herring of the North Atlantic and a near relative in the North Pacific are probably the most typical of all abdominal or soft-rayed fishes (Fig. 12). In shape they are elongate, tapering both toward the head

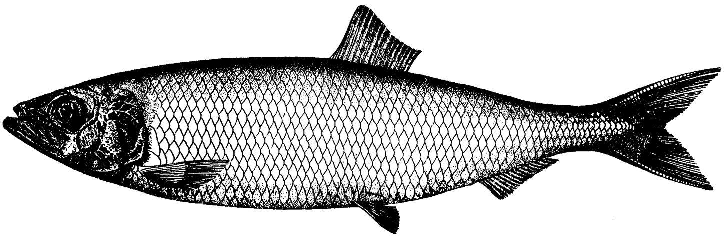


Fig. 12. The common herring of the North Atlantic, *Clupea harengus*, the typical abdominal fish. Courtesy Bureau of Fisheries

and the tail, and are rather compressed. They have a single fin on the back and one of like size below the body, each composed of soft rays only. The tail fin is forked and the paired fins, representing the limbs, are far apart. The ventral fins (hind limbs) occur far back and are attached to the abdomen, while the pectoral fins are inserted low under the margin of the gill covers. Moderately large, smooth scales cover the body.

Many species are allied to the herrings and more than a few have been found fossilized. Their relationship with the ganoids on the one hand is very close, and they merge by various stages through several families almost imperceptibly into the spiny-rayed group, on the other. In fact, there are those who believe that a primitive herring is the ancestor of all modern bony fishes.

The Abdominales include, besides the commercially important herrings, the salmons, trouts, smelts, and catfishes. They include also numerous minnows and a considerable number of deep-sea species.

The yellow perch of the fresh waters of North America, which has a near relative in European waters, is often referred to as the most perfect example of a fish, and it serves well as a typical example of a spiny-rayed fish (Fig. 13). The yellow perch is rather round or spindle-shaped, yet somewhat deeper than broad. It has a pointed head and a somewhat raised back, upon which are

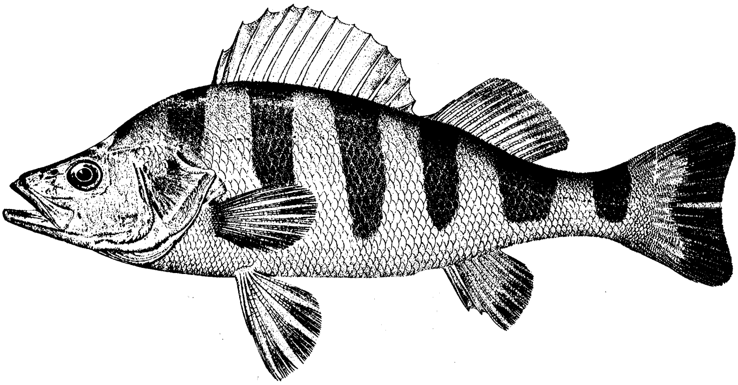


Fig. 13. Yellow perch of North America, *Perca flavescens.* Most perfect example of a fish and typical spiny-rayed fish. Courtesy Bureau of Fisheries

inserted two separate fins, the first one consisting of a series of spines and the second one of two spines and several soft rays. The tail fin possesses a straight to slightly concave margin; the fin below the body, known as the anal fin, situated just behind the vent, has two spines and several soft rays. The paired fins are close together, the ventral fins, representing the hind limbs, being inserted on the chest, only slightly behind the pectorals, or front limbs. The latter, instead of being attached low under the margin of the gill covers, as in the Abdominales, are inserted higher on the body and only a little below the median line of the side. The body is covered with moderately small, firm, rough scales.

The reader must understand that even though the perch may be a typical spiny-rayed fish, the variation in shape and form and with respect to nearly every detail of structure is exceedingly great within the group. In fact, no other group shows a wider divergence of its members from the typical form.

The spiny-rayed fishes are very numerous and include the majority of common food fishes, among which, in addition to the typical perches, may be mentioned the mackerels, pompanos, sunfishes, sea basses, butterfishes, the bluefish, and a host of others.

We begin now, perhaps, to have some idea of the antiquity of fishes, their geological history and relationships, and their many kinds. Great as are the numbers of species now living, we know whole groups of fossilized fishes which have no living representatives. We can only assume that changes in the environment to which they were unable to adapt themselves led to their extinction. The infinite variety of shape, structure, and habits of the living species will engage the attention of the remainder of this book.

CHAPTER III

THE STRUCTURE OF A FISH

THE shape of the fish is generally a key to its habits, past or present. It would be unreasonable to suppose otherwise. The aquatic mammals illustrate the manner in which life suits its form to the mechanical needs of its environment, for so completely have the seals, whales, dolphins and other mammals adapted themselves to water-living that early naturalists were deceived into including them among the fishes.

The typical fish shape may be likened to a boat or, still more appropriately, to a cigar. The fresh-water perch and salt-water mackerel are common examples. It is a shape which offers little resistance in the water, and those fishes possessing it generally are capable of swimming at great speed. As such species habitually live by preying on other fishes and animals, and have often to swim long distances in search of food, speed is essential to them. It is said that a mackerel, shark, or pike can swim twenty or twenty-five miles per hour, including stoppages, for weeks at a time.

As examples of extreme variation from this cigar-shaped norm, I have already mentioned the wormlike lampreys, the narrow and deep spadefishes, and the horizontally flat skates and rays. Another oddity is the globular type, well represented by the common porcupine fish, which is short and plump and can inflate its body either with air or water, making itself nearly as round as a ball.

Many intermediate forms exist, of course, too numerous for description here, but we ought to call attention to two, so odd in outline that they have attracted special notice ever since their discovery hundreds of years ago. I refer to the ocean sunfish and the sea horse.

The ocean sunfish, known also as headfish, found occasionally in all tropical and temperate seas, may certainly claim the distinction of being one of the most unnatural looking creatures in all nature. It is an enormous head, moving bodiless and tailless through the water, about as extraordinary as the disembodied grin of the Cheshire cat which Alice saw in Wonderland. No suggestion of a tail or even a tail fin relieves its seeming incompleteness, and great size exaggerates the freak—a specimen more than eight feet long, or better, across, and weighing 1,200 pounds having been reported. Early naturalists saw in it a resemblance to an immense mill wheel, wherefore they named it *Mola mola.* It has no scales, but a tough leathery skin. One wonders how this odd fish, without a tail and much too heavy forward of the rather high fins (one on the back and the other on the ventral edge near the posterior end of the body) is able to orient itself in its watery home. However, not only does it hold itself erect, but swims lazily and with apparent ease near the surface, with its high dorsal fin often projecting above water.

The sea horse, *Hippocampus,* is complete enough, but it looks nothing like a fish. The head, horselike in appearance, is attached at right angles to the body and can not be straightened without injury to the "neck." A long, coiled tail serves the fish as a prehensile appendage by which it clings to plants, some species attaching themselves to floating seaweeds which carry them great distances; others, to rooted plants which hold them close to the shore. In contrast to the naked skin of the headfish, the sea horse's body is encased in bony rings, which frequently bear spines to which fleshy flaps are attached. These curious fishes, represented by numerous species, inhabit nearly all warm seas, and vary in length from five to ten inches.

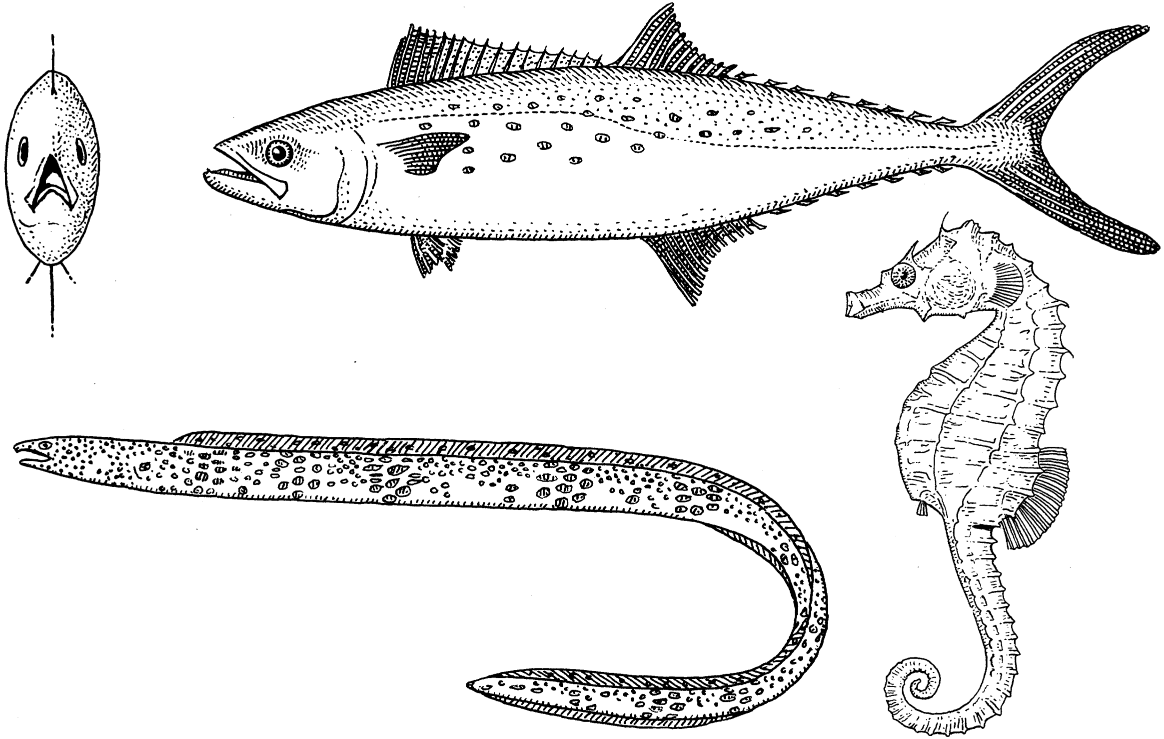
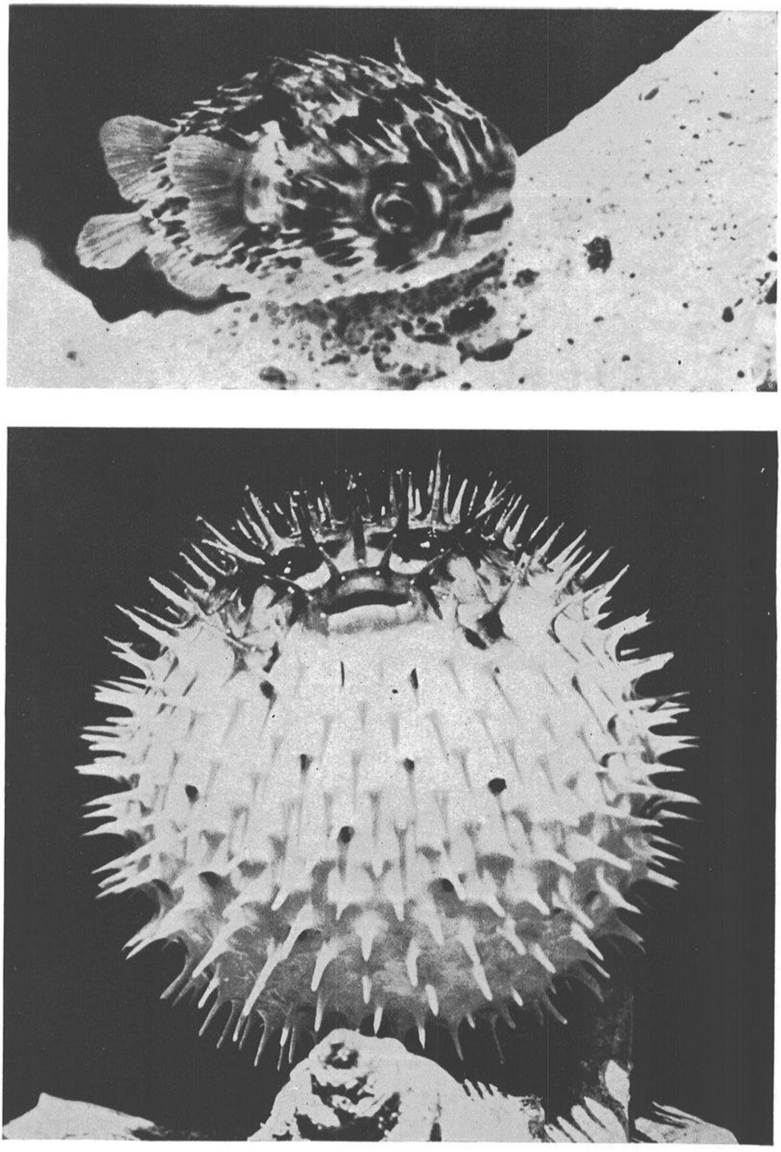


Fig. 14. Examples of fish shapes. Upper, end and side view of swift-swimming mackerel; right, the strange sea horse; lower, the eel-like type. Drawings are not in proportion to sizes of fishes

PLATE 5



Porcupine fish, *Diodon hystrix*, and the same fish inflated with water or air for self-protection. Courtesy of Dr. Myron Gordon

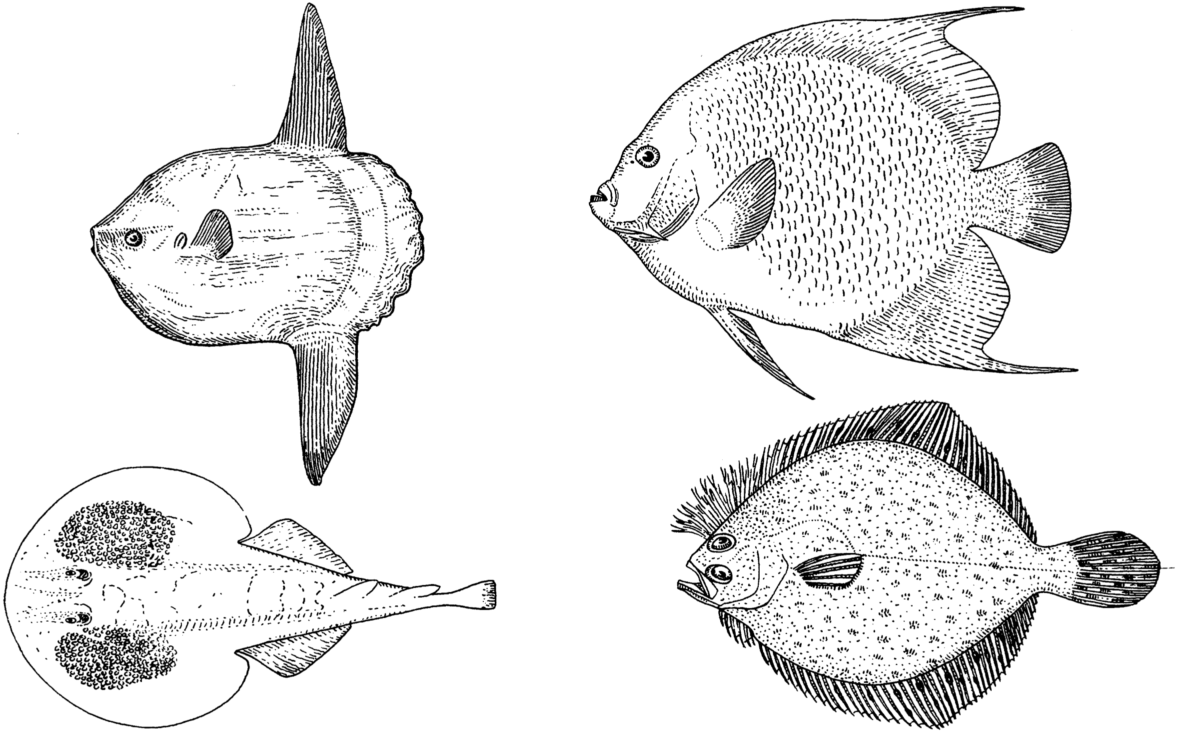


FIG. 15. Further examples of fish shapes. Upper: left, tailless ocean headfish; right, compressed black angel fish; lower: left, depressed electric ray; right, flounder. Drawings are not in proportion to sizes of fishes

In recognition of their oddity, people often dry them for preservation as curios.

Skin and Scales

Not all fishes have scales, in spite of the vague popular belief to that effect. In general scales seem to be a perquisite of the higher or bony fishes, though by no means of all of these. Their chief purpose, no doubt, is protective; and they are only one of several means which nature, with her unlimited capacity for invention, has found for achieving that purpose for different fishes. Bony plates, spines, prickles, and shagreen are all made use of, and when all these are wanting the usually tender skin becomes hard and leathery in compensation. The evidence leads us to believe that all true fishes have had an outer covering of some sort and that those which appear naked have lost it.

Whichever one of these extra protective devices nature employs, they all grow out of the skin itself. As in other vertebrates, the skin of the fish consists of two layers. On the outside is the epidermis, made up of several layers of cells without blood vessels, and on the inside the thicker dermis, composed of fibers and supplied with blood vessels and nerves. The epidermis is almost transparent and so soft that friction will easily remove it. In the dermis, incidentally, we find the explanation of the distinctive beauty of fishes—their silvery iridescence. This results from the presence of elements with a remarkable power of reflecting light, called iridocytes. When they occur in a thick and dense layer called the argenteum, on the inner surface of the skin, they give to the fish its silvery appearance. When they are scattered singly they cause an iridescence, or play of colors. Besides the iridocytes, the dermis contains the fish's pigment cells, some of which are black and others colored.

Scales grow out of the dermis beneath the epidermis, but the posterior edge may project to some extent through the latter. They are thin calcified plates, being more hornlike in composition than bones and comparable to human finger nails. True scales in an adult fish usually overlap one another like shingles on a roof, the outer edges always directed toward the tail of the fish, and the scale in front covering about three-fourths of the one behind it.

Once a race of fishes have developed a complete body covering of scales, they may for some reason lose it wholly or in part; or they may retain it only in a degenerate form as oblong plates partly embedded in the skin, or as small spines or prickles. The carp (*Cyprinus carpio*), offers an example of a single species some members of which may be completely scaled, others, such as the mirror carp, only partly scaled, and still others, such as the leather carp, wholly naked. The fresh-water eels have degenerated scales consisting of oblong plates arranged in groups set at right angles to each other and partly buried in the skin. Only very close examination will disclose these structures in the eel. The filefishes, some of the puffers, and certain sculpins all show degenerate or modified scales in the form of small spines or prickles (see Plate 5).

To return now to the protective body coverings other than scales, we call attention again to the bony rings which inclose the sea horses. They form a sort of exterior or *exo*skeleton and an effective armor; yet they do not make the body rigid, as each ring is at least partly free from its neighbor, thereby permitting movement and considerable flexibility. The trunkfishes, on the other hand, are completely inclosed, exclusive of the tail, in a rigid bony case composed of thoroughly united plates, forming a continuous armor and leaving flexibility to the tail only. This bony case generally is provided with several strong spines. One of the species, *Lactophrys tricornis*, for example, has a spine above and in front of each eye, which is directed forward and resembles a horn, earning the creature the popular name "cowfish."

The word *ganoid*, used to describe one of the two time-honored groups of the subclass ray-fins, refers to the substance which covers the outer surface of the bony plates protecting members of this great group of fishes. This substance resembles dentine and is called *ganoin*. The ganoid plates on the American gar pike (Fig. 16), which may be taken as the most typical example of this kind of covering, are large, bony, and rectangular, arranged in rows and placed edge to edge, in contrast to the overlapping scales already described. These plates are very hard and form an excellent armor. Although interlocked for additional strength, they do not make the body rigid, as they may separate or partly slide over each other when the fish moves its body from side to side. The free edges of the plates are so sharp that a large live fish, when held in the hands, can cut deep wounds by throwing its body from side to side in its effort to escape, thereby pinching the hands and fingers between the margins of the plates.

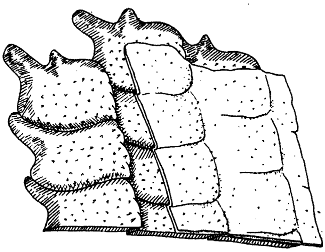


Fig. 16. Ganoid plates of the American gar pike, *Lepisosteus osseus*. After Lankester

In the sturgeons—among the largest fishes of our seashores, rivers, and lakes—the ganoid plates only partly cover the body (see Fig. 11). Generally two rows of plates lie on the back, one along the side, and another along the edge of the abdomen. Those sections unprotected by bony shields are covered with rough, leathery skin. Finally, in the paddlefishes the ganoid plates have disappeared entirely, leaving the skin almost smooth (see Plate 4).

The porcupine fishes, already referred to because of their spherical or globular body, derive their name from the sharp spines with which they are covered. The spines often are so broad at the base that, together with the roots they bear, a continuous coat of mail is formed.

PLATE 6

A conventionalized painting of the trunkfish or boxfish, *Lactophrys bicaudalis*, from the Atlantic. By Stephen Haweis. Courtesy of Dr. William Mann

In some species the spines bear two roots, and are then generally movable, while in others they bear three roots and are stationary.

But the strangest of body coverings is reserved for the sharks, the most primitive of existing true fishes. They alone, not only of all fishes but of all vertebrate animals, grow teeth all over the body (Fig. 17). Naturalists call them *dermal denticles*, that is, "skin teeth," and their

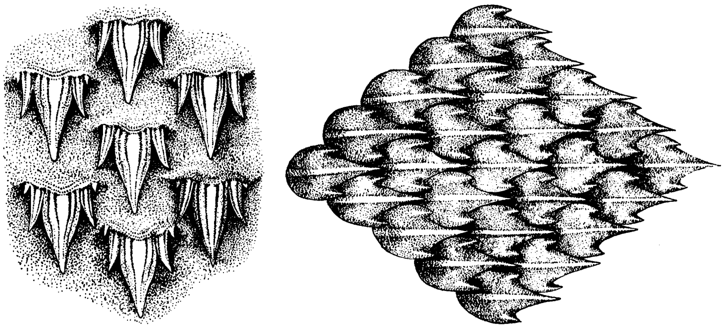


FIG. 17. Left, teeth of upper jaw of a Philippine shark, *Pentanchus profundicolus*, compared with (right) teeth, or dermal denticles, that cover the skin of the same shark

structure closely resembles that of the teeth in the mouths of bony fishes, amphibians, reptiles and mammals. They are situated in the dermis; each consists of a flat base having the structure of bone and a pointed spine projecting outwards and backwards. The spine is covered with a layer of enamel; below that comes a coat of dentine or ivory, the characteristic substance of teeth; and within this occurs the "pulp," containing blood vessels, nerves, and connective tissue. The denticles are close-set and form a fine shagreen.

We have dealt with this subject of body covering in fishes in the reverse order from that which the student of evolution would follow, for it appears that the bony coverings of the ganoids and the true scales of the teleosts represent progressive modifications of the dermal denticles of sharks. In the ganoids the bony base, covered with a substance resembling dentine, remains, while in the teleosts the body scales become a horny substance and the enamel covering is completely lost. One point of special interest is the relation of the body covering in fishes, which is really an external skeleton, to the internal skeleton. On this point J. T. Cunningham makes the following commentary:

> In the bony fish the skeleton consists of the ossified internal skeleton united in the head and pectoral girdle with bones derived from the external skeleton of the skin; these bones are known as dermal bones or membrane bones, and many of them persist in the skull and pectoral girdle of the higher terrestrial vertebrates. Thus we have the remarkable fact that the frontal and parietal bones of the human skull are originally derived from the bony scales on the head of fishes, and at a still earlier stage of evolution from the dermal denticles on the skin of the head of the sharklike ancestor, so that the frontal bone and the teeth were originally of the same nature.

Scales, shagreen, bony plates, and spines, as body coverings, have been compared with fur, hair, and feathers in higher vertebrates. In so far as these structures provide protection for the tender parts underneath, the analogy is correct, but fur, hair, and feathers often serve the additional purpose of retaining heat within the body. Such a function could scarcely be ascribed to body coverings in fish, the chief function of which, no doubt, is protection.

Fins and Fin Uses

Fins are hands and feet to fishes; they are rudders and balancers, feelers, weapons, sucking disks, and even bait to attract prey. Whatever service a fish species has demanded of them they seem to have adapted themselves to fill. In consequence, of course, they have taken on a multitude of sizes and shapes; they display a variety of structures; and they occur in widely different places on the body in different species of fish. These variations are all the more interesting when viewed in the light of the probable common origin of all fins. In the primeval fish they were, so naturalists believe, mere folds of skin, as they remain to this day in some very low forms. That is the way they begin also in the embryos of the higher fishes. Later soft, threadlike gristles appear running through the skin fold. At this stage the fin forms a single unit running from the head down the length of the back, around the tail, and forward again underneath, where it forks up to the gill slit on both sides. Still later the soft rays harden into spines (in those fishes which have spines) and the continuous single fin breaks up into several fins —whatever number is peculiar to the species of fish in question—each of which assumes the position occupied by the corresponding fin in the adult.

Fins divide themselves naturally into two main groups—the paired fins, which are, of course, self-explanatory, and the vertical fins, so named because they are always perpendicular to the backbone of the body (Fig. 19). The paired fins correspond to the four limbs of the higher vertebrates. One set, known as pectoral fins and representing the fore limbs, is attached to the shoulders, while the hind limbs, or ventral fins, may be attached to the abdomen, to the chest, or even under the throat. Either or both pairs may be absent, but the ventrals are missing much more frequently than the pectorals.

In contrast to the paired fins the vertical fins always occur on the median line of the body, though they may move forward or to the rear in different species. Most frequently they are three in number, the *dorsal*, on the back, the *caudal*, or tail fin, and the *anal*, on the lower median line.

We have seen that fins consist of bony or cartilaginous rods known as rays, which are connected by membranes. These rays may be simple or branched. In the latter case they are always, and in the former they are sometimes

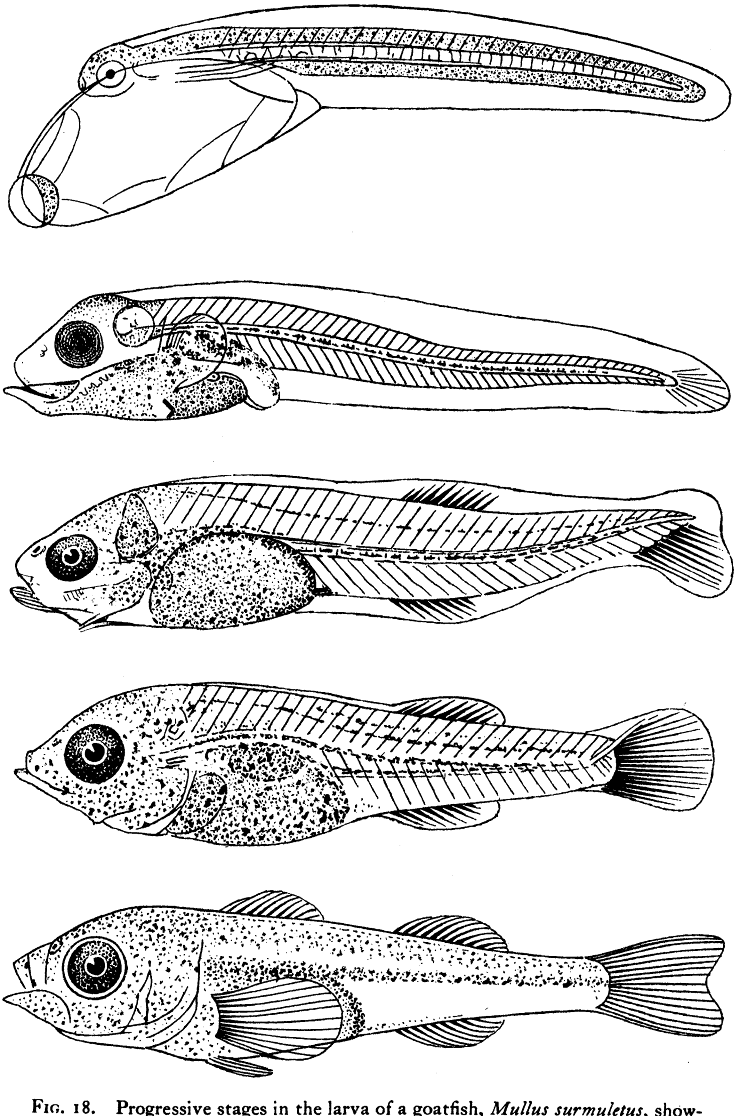
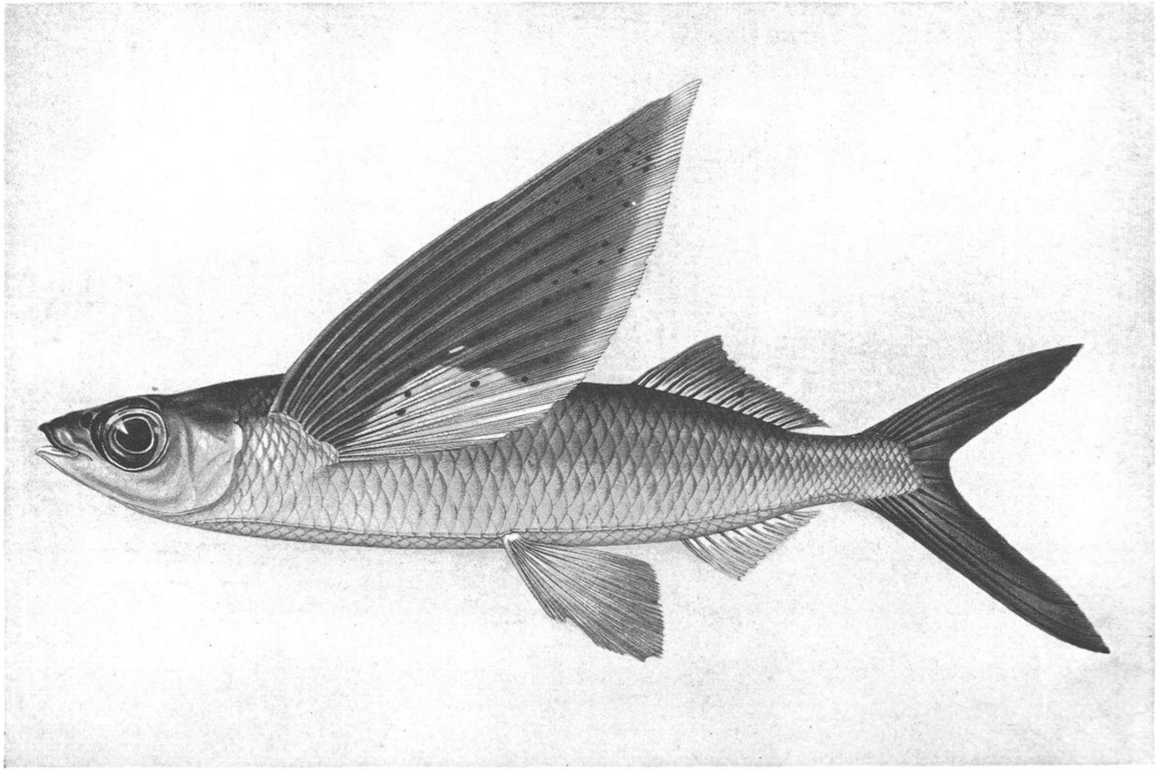


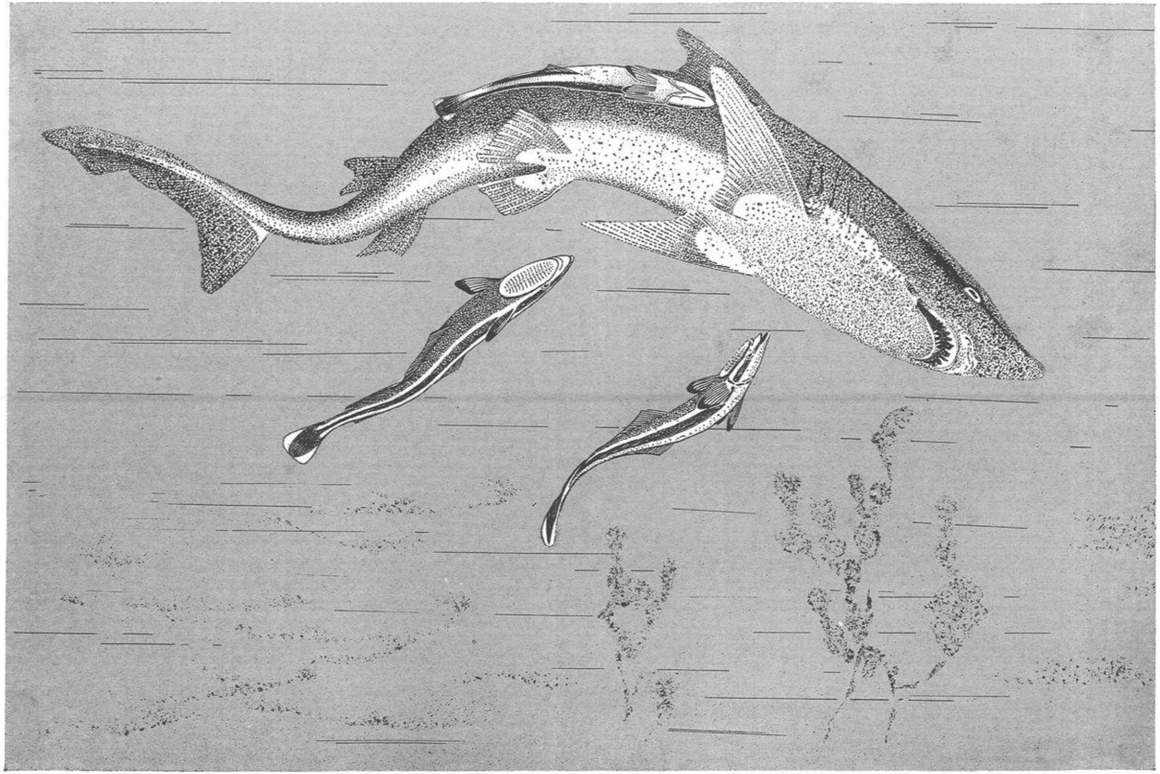
FIG. 18. Progressive stages in the larva of a goatfish, *Mullus surmuletus*, showing the development of the fins from an unbroken fold of skin. Drawings not in proportion to sizes of larvae. After Ehrenbaum

PLATE 7



Two-winged flying fish, *Cypsilurus*, from the western Pacific, showing the great development of the pectorals

PLATE 8



Shark suckers, or remoras, which attach themselves to sharks, barracudas, and other large fish by a sucking disk formed of the first dorsal fin articulated, that is, crossed by many fine joints which make them flexible. This gives the key to the distinction between *soft rays*, jointed and flexible, and *spines*, neither jointed nor branched. Spines need not be stiff, however,

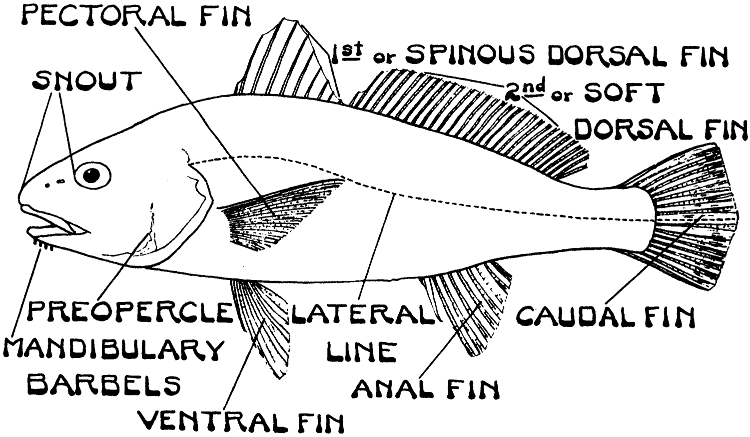


FIG. 19. Diagram of a typical fish, sciaenid or croaker, showing the vertical fins and the paired fins of the left side. Courtesy Bureau of Fisheries

for in some species they are long and flexible and only distinguished from soft rays by the absence of joints.

The shad (*Alosa sapidissima*) illustrates a common arrangement of fins, with a single dorsal and a single anal fin, both consisting of soft rays only, and a forked caudal fin. As for the paired fins, the ventrals are attached to the abdomen and the pectorals occur low on the shoulder girdle.

Rather rarely fishes have more than two dorsal fins and more than a single anal; as, for example, the codfishes, with three dorsals and two anals, all composed of soft rays. In the mackerels and mackerel-like fishes the normally placed and normally formed dorsal and anal fins are followed by a whole series of small detached finlets, each consisting of a single ray. Sometimes the dorsal is followed by a small fin, which has no rays or spines and for that reason is called a flesh fin, or perhaps more frequently, an adipose fin, as seen in catfishes, salmons, trouts, and many other fishes.

So far we have considered only fishes possessed of complete sets of fins, but many species exist in which one or more of the paired or vertical fins are missing. Eels, for example, have no ventral fins, a fact which gives them their scientific name of *apodal* fishes, that is, "without feet." Skates and rays have no anal fin, probably because they have no use for one, the body being so broad that the fish can not easily lose its balance. Furthermore, these fishes live so close to the bottom that such a fin actually would be in the way or subject to constant injury dragging over the bottom during the animal's movements. These same fishes sometimes lack the dorsal fin, too, or have it only in an abbreviated form.

The common eel illustrates a condition in which the continuity of the vertical fins is unbroken, as it was in the primitive fishes. The dorsal and anal fins continue without interruption around the tail, and one can not tell where either of these fins properly ends and the tail begins.

The paired pectorals illustrate the remarkable variations both in size and in shape to which fins are subject. They aid in balancing the body and generally do not serve as organs of locomotion, notwithstanding that they are analogous to the fore limbs in the higher vertebrates. But there are outstanding exceptions, for in the skates and rays locomotion is their chief use. So spread out are they that they account for the unusual breadth of these fishes as seen from above (see Plate 11). A somewhat similar function, though exercised in the air, may be ascribed to the greatly enlarged pectorals of the flying fishes (*Exocoetidae*). These creatures actually rise above the surface of the water and soar considerable distances through the air. As no great movement of the pectorals takes place during flight, it is generally believed that the fish gains no momentum while in the air and that the flight is only a powerful leap from the water; but the wide spread of the pectorals makes this soar possible just as his motionless wings make it possible for the turkey buzzard to glide.

In still another exception the pectorals actually serve as legs for clumsy walking and even climbing out of the water. In the mudskippers this pair of fins are stiff and spiny and project downward, so that the fish may walk, leap, and climb by their aid (see Plate 17). The beautiful sea robin, *Prionotus*, has developed an even more astounding variant from the norm by converting three of the front rays of its pectorals into separate feelers which it uses to feel the bottom (Fig. 20).

Great development of the pectorals does not seem consistent with speed, since in the swiftest swimmers, such

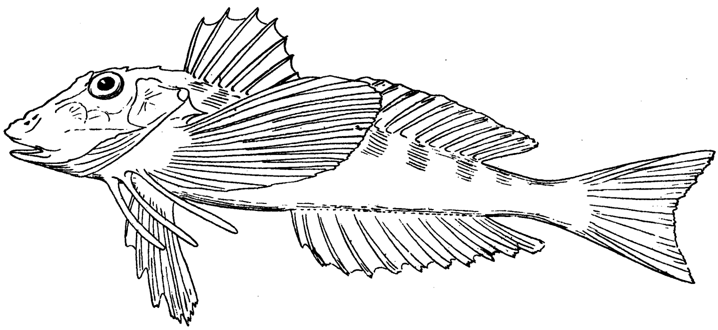


Fig. 20. The sea robin, *Prionotus*, which uses three front rays of its pectoral fins as feelers

as mackerel and salmon, they are small and folded back against the body when the fish is going fast.

The ventral fins (corresponding to the hind limbs in the higher vertebrates), like the pectorals, seldom have a great part in locomotion, but are balancing organs. We have said that these fins are attached to the lower side of the fish at various points, from the head backward to the rear part of the abdomen. In shape and size and use, the variation is equally as remarkable as in the pectoral fins.

The blennies and blennylike fishes furnish cases in which the ventrals sometimes are completely wanting or greatly reduced in size. The common cuskeel (*Rissola marginata*), of the South Atlantic coast of the United States, whose ventrals are reduced to long, forked organs attached at the throat, seems to use them as the sea robin uses its pectorals, namely as feelers (see Fig. 34). The fact that the cuskeel is a night prowler lends support to this view. It lies buried all day in the sand, into which it descends vertically, tail down, leaving its head just near enough to the surface to admit a current of water to flow over the gills. When night comes it leaves the sand in search of a livelihood. Some observers have reported that the cuskeel possesses luminescent spots by means of which it makes light, and it is true that the fish has a row of pale spots along the side which are suggestive of luminescent spots. Furthermore, ample evidence has been produced to show that similar spots in a related Pacific coast form are luminescent. Nevertheless, I have made many observations on the Atlantic cusk-eel without seeing the slightest indication of luminescence, and I am of the opinion, therefore, that the feelerlike ventral fins are the chief organs by means of which the animal feels its way over the bottom to seek the small crustaceans, fish, and other animals of suitable size upon which it feeds. The cuskeel apparently becomes aware of the presence of the animals constituting its food through the sense of touch, from a stimulation in the sensitive ventral fins. Then, under the cover of darkness, it seizes its unwary and probably sleeping prey and devours it.

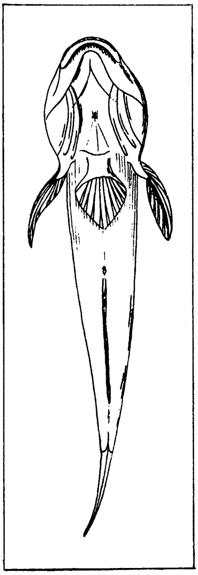


FIG. 21. Ventral view of goby, *Gobiosoma bosci*, to show clinging disk formed by union of the two ventral fins

Some of the flying fishes whose pectorals serve them as gliding wings have the ventrals enlarged also, though to a less exaggerated degree. It is quite probable that the ventral fins in these four-winged flying fishes aid flight in the same way as the pectorals.

In the sharks and rays the ventral fins are prominently associated with sex; for in the males, claspers, which serve as a conduit for sperm cells, are attached to these fins, causing a great modification in the appearance thereof (see Plate 11). In certain other fishes, for example in some of the top minnows, the ventrals are enlarged in the male, but so far as known, for no definite purpose.

The clingfishes (*Gobiesocidae*) and some of the gobies make, perhaps, the most original use of the ventral fins in modifying them to form a sucking disk (Figs. 21 and 22). The fins themselves may form a part of the disk, or the latter may only be attached to them. The disk is median in position and, if it does not involve the ventrals wholly or in part, lies between them. By means of this aid the fish clings to objects in the water, most frequently rocks or corals.

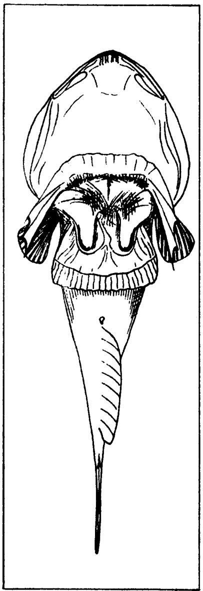


Fig. 22. Ventral view of clingfish, *Gobiesox strumosus*, with sucking disk formed of skin, muscle, ventral and possibly pectoral fins

The disadvantage of water as a medium in which to exist is that it does not afford the complete support against the action of gravity which solid earth offers. Thus a deep-bodied fish tends to turn over on its side and has to have paired fins to prevent this, and when the tail is undulating to provide locomotion the body tends to wigwag. The dorsal and presumably the anal fins help to resist this tendency.

The dorsal fin, therefore, resembles the paired fins in serving primarily as a stabilizer. Very few exceptions to this rule exist.

In rare cases, as in some of the rays, the dorsal fin is absent or abbreviated. In the flatfishes, on the other hand, it usually begins at the head and extends all the way to the tail without an interruption. While the rays of the dorsal fin may be short, as in the common eel, in the sailfish this long fin stands up like a sail, as the name implies.

In the marine gaff-topsail catfish (*Felichthys felis*) the dorsal fin forward bears a long ribbon-shaped filament, extending high overhead (see Plate 21). This fish, which inhabits the coastal waters of North America from Cape Cod to Panama, often is seen swimming to and fro with the long dorsal filament (from which the fish receives its name) projecting well above the surface of the water. It is difficult to ascribe any function to this peculiar structure, or to explain why the fish so often reveals its presence and its movements by displaying its "gaff."

The modification of the ventral fins of some gobies to serve as a sucking disk has a counterpart in the use to which the remoras or shark suckers (*Echeneididae*) have converted their dorsal fin (Plate 8). They have a large sucking disk on the head, composed of crosswise partitions and a single median partition running lengthwise. Anatomists tell us that this disk, by which remoras attach themselves to sharks, other large fish, and turtles, is only a modified dorsal fin. Certainly a strange modification. The shark sucker, incidentally, is not a parasite, merely a hobo out for a free ride. It does no harm to the animals to which it attaches itself. But why does it want free rides? If a certain German author reports correctly, the fish gains more than transportation from its association with sharks, for he claims that when the shark catches its prey the remora swims forward to partake of any fragments which the shark may drop as it destroys the captured animal. The same author states that the remora is found attached only to solitary sharks and is not present when two or more sharks swim together. The inference is that under such conditions the remora could not in safety ply his trade of feeding on the fragments dropped by the shark but would probably be destroyed by the second shark should he advance to receive the crumbs from his host's meal.

A structure and function of the dorsal fin no less odd is found in the anglers and frog fishes, in which the first dorsal spine, which is very slender and flexible, is inserted

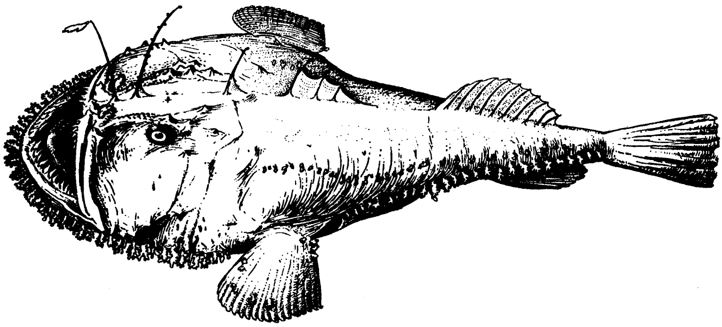


FIG. 23. The fishing frog of the Atlantic, *Lophius piscatorius*, whose first dorsal spine serves as a bait to attract prey to its mouth

over the head, and bears at its end a fleshy enlargement which constitutes a bait (Fig. 23). When in search of food, the fish partly conceals itself and bends the slender spine with the bait at the end forward so that it hangs in front of his mouth. Then, much like the human angler, he waits for an unsuspecting hungry fish. But the fish angler does not wait for a strike. If he did he might lose his bait. For him the approach of his victim suffices and then he opens his very large mouth and, with almost no movement of the body, engulfs the small fish.

In the caudal fin we come to one whose primary purpose, as a rule, is to provide locomotion and so differs from that of all the others. It is the fish's propeller. Most species

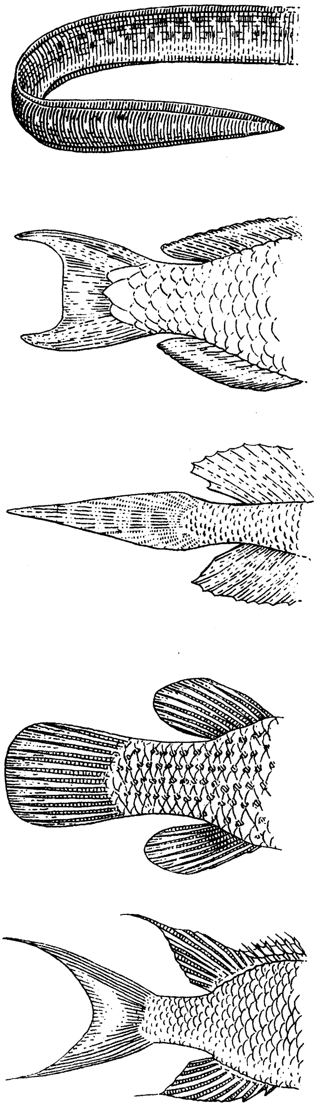
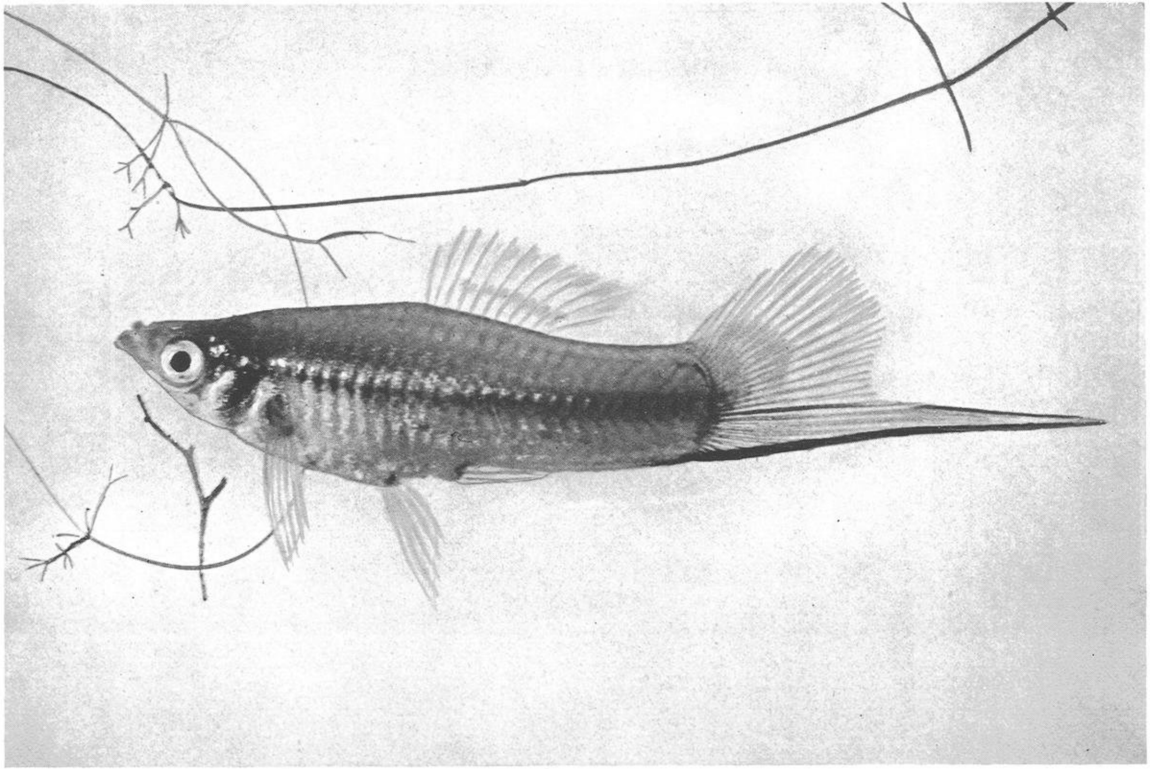


FIG. 24. Various shapes of the tail fin in fishes

have powerful muscles in the tail by which they are able to swing the caudal fin right and left with great force, sculling the body through the water. Anyone who has been slapped in the face by the tail of a large fish knows there is power behind the blow and would scarcely be willing to turn the other cheek.

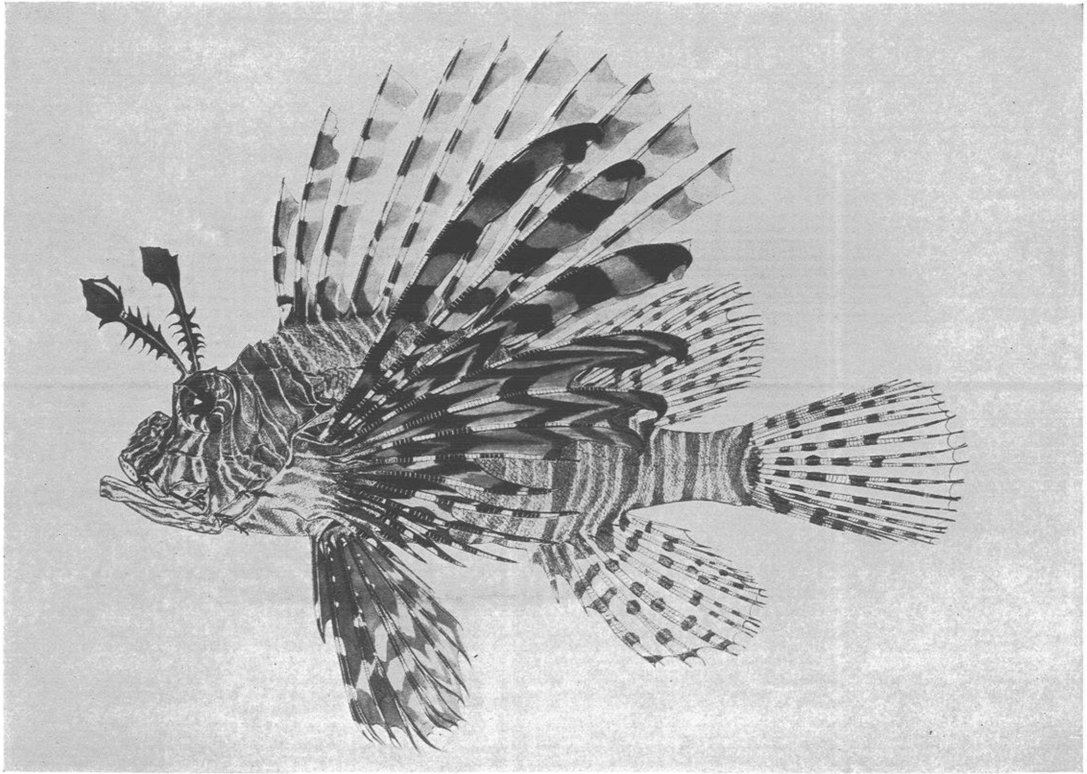
But of course there exist exceptions to this use of the tail fin as there do to the primary uses of all the others. Thus the headfish is practically tailless, and the skates and rays employ their pectoral fins as their chief swimming organs, while their tails are almost ratlike in shape and bareness. The stingarees, with their long, whiplike, pointed tails equipped with dangerous spines, or stings, at about the midway point, are among the comparatively few fishes that have no tail fin. The caudal fin is the only one which never contains true spines, although rudimentary rays resembling spines sometimes are present on the base of the upper and lower margins of the fin, as for example, in the common gar pike.

Most fishes have the posterior margin of the caudal fin



Male Mexican swordtail minnow, *Xiphophorus helleri*, with the lower rays of the caudal fin produced. Much enlarged

PLATE 10



Scorpion fish from the western Pacific with a venom gland at the base of each dorsal spine either forked or round, with many intermediate shapes from deeply forked to square, pointed, and even diamond shaped (Fig. 24). The thresher shark, in which the upper lobe of the caudal fin equals in length the rest of the fish, constitutes the outstanding variation from the usual equality of lobes. This shark, although it reaches a length of some twenty-five feet, feeds almost wholly on small fish and it is said to use the long tail in rounding up and killing the fish which constitute its food.

In one of the Mexican top minnows (*Xiphophorus helleri*), known as the swordtail, which makes a rather interesting and pretty aquarium fish, the lower rays are greatly produced in the male fish, forming a "sword" (Plate 9). This is one of the very few instances in which the caudal fin differs in shape in the sexes.

In most fishes the backbone ends at the base of the caudal fin, or it is bent upward and extends more or less into the upper lobe; but in the cornet fishes, the backbone extends through the forked caudal and the tail bears a long filament.

The anal fin frequently is placed opposite the dorsal and the two fins often resemble each other in shape and size. The function of both appears to be identical, each serving principally as a balancing organ. The anal is nearly always single, though rarely, as in the codfishes, it may be double, and sometimes it is missing, as in the greatly depressed skates and rays, which move about and feed very close to the bottom.

The flatfishes, which, in contrast to the depressed skates and rays, lie upon their sides, have long and moderately high anal fins similar to their dorsals.

In the eels the dorsal and anal fins are equally long and low, but the sailfish has quite a small anal fin in contrast to the extremely large dorsal.

The anal fin has a direct connection with sex in those top minnows which give birth to live young, like

Gambusia,[1] the famous mosquito-eating fishes. In these species (there are several in the genus) the fin is peculiarly modified, for in the male the anterior rays are united and produced in such a way that a prong-shaped organ is formed. This modified part of the fin is used in conveying the sperm to the female.

When a higher vertebrate, such as a dog or horse, loses a limb, it never grows back. But a fish is more fortunate, for if he has a fin bitten off, in a short time he grows a new one to replace it. This is what the naturalist calls "regeneration." The regenerated fin does not always look exactly like the original, being frequently somewhat rougher and often more or less irregular, so that it is readily recognized as a regrown fin. I once observed a very remarkable case of regeneration in a tropical pipefish, which had evidently lost not only its caudal fin but a part of the tail itself. At least the tail was shorter and had fewer bony rings than that of a normal fish. Nevertheless, a small though somewhat distorted fin had developed on the stump of the tail.

Many a boy knows from painful experience that it is safest to handle the small catfishes of our fresh-water streams, known as "mad-toms," with care, for a slight prick from the spine attached to the pectoral fin is very painful. The prick may be scarcely visible, yet it hurts badly, almost as much as a bee sting. The intense pain results from a venom which the fish transmits with the prick, for a groove in the spine carries the poison from a gland at the base to the tip, to be introduced into the wound.

Other fishes have this same offensive and defensive equipment. In the rivers of Panama, for example, lives a catfish, somewhat similar to the mad-toms and generally

[1] Numerous species of minnows commonly are designated as top minnows. As many of them lay eggs and do not give birth to live young, it is necessary to use the scientific name *Gambusia* here in order to designate which species are meant. *Gambusia* is of Spanish origin, meaning "nothing." That is to say, the fishes are so small that when one catches a *Gambusia*, he has caught nothing. However, the fishes of this genus, as shown elsewhere, are proving their worth.

less than five inches long. It is more slender of body, however, and it has two black bands on the back and another along the middle of the side. The natives call this fish *bagre,* which seems to be a general name for all catfishes in the Central American countries. I have seen natives roll on the ground and groan with pain after being "finned" by this ferocious little animal, whose sting is much worse than that of the mad-toms. I, too, was stung on more than one occasion. The severe pain lasts for half an hour or so and then gradually disappears. Little or no swelling was caused in the cases observed and within a day's time the wound was so nearly well that one no longer paid any attention to it.

The scorpion fishes (*Scorpaenidae*), as one might infer from the name, have a venom gland at the base of each of about twelve dorsal spines (Plate 10). They inhabit warm and tropical seas and, although good food fishes, they are much disliked by fishermen, because of the precaution that must be taken in handling them. Their sting surpasses in severity that of the catfishes previously mentioned, a fact to which I can likewise bear personal witness. The poison injected was of a rather violent nature, for it caused swelling of the entire hand and forearm, accompanied by severe pains, although only a barely visible prick in the thumb had been inflicted. The pain lasted only a few hours, however, and within a day the swelling had disappeared and, except for a bit of soreness in the wounded thumb, no further ill effects were apparent.

But the poison apparatus of the species mentioned is elemental compared with the highly specialized mechanism for conveying venom possessed by the poisonous toadfishes. Where the catfishes and scorpion fishes have mere grooves on the exterior of the spine along which the venom runs after an incision has been made, the toadfish's spine, with its hollow interior, corresponds to a hypodermic needle. As the spine enters the skin, the venom gland situated at its base shoots the poison into the wound. The fish apparently exudes the poison at will. Its hollow spines, which occur in the dorsal fin and on the gill covers as well, closely resemble in structure and use the fangs of venomous snakes.

Happily I have had no first-hand experience as to the virulence of the venom of the poisonous toadfishes, for I have carefully avoided acquiring any by taking advantage of their fighting habits. When caught in a net and hauled on land they become "fighting mad" and will seize with the mouth the nearest object, whatever that may be; so that, as I was aware of the malignancy of their venom, I was quite content to present a small stick, which my specimens grasped so tightly that I could easily transfer them to the collecting can. It is said, however, that the venom of the poisonous toadfishes causes considerable swelling, accompanied by severe pains and fever. No fatal results are of record and generally the effects are no more serious than those of a scorpion sting, to which the toadfish's sting has been compared. If the comparison is sound I can vouch both for its painfulness and for its harmlessness.

In discussing the relationship of fin rays to poison glands, the sting of the stingrays, or stingarees (*Dasyatidae*), perhaps should be included, for it is generally believed that these animals, too, introduce a venom when they make a wound with the large barbed spine which occurs on the upper side of the long whiplike tail (Plate 11). Naturalists have found no evidence of poison glands, however, and it is thought that the pain results from the rough, tearing character of the wound made by the spine. Furthermore, infection apparently often sets in because of bacteria that are introduced. It is a well-known fact that wounds from fish spines in general are painful and often become infected. This has led to the plausible belief that harmful bacteria may find an abode in the slime with which fish always are covered.

THE STRUCTURE OF A FISH

The Mouth

Like everything else about them, fishes' mouths are adapted to their special habits, so that these exhibit a great range of size and form, from a pinhole tube to a generous gash across the head running almost from gill to gill. This gash may form a straight line across the head or curve upward or downward; it may occur at the end of the body or well back of that point on the upper or lower side. Whatever the size, shape, or position of the mouth, these are determined by the present or recent feeding habits of the fish.

This adaptation is all the more inevitable and specialized because the mouth serves the fish in more capacities than as the mere eating mechanism of most of the higher vertebrates. It takes the place of hands or feet in catching food, and although fish seldom chew their food the mouth has to hold and manipulate it for swallowing.

The usual form of mouth among the common food fishes is one of moderate size, terminal or nearly so in position, and generally with a slightly oblique gape. The fresh-water sunfishes, the sea basses, the mullets, the grunts, the snappers, and many other species all have such a mouth.

The very large beaklike mouths with the jaws greatly produced and bearing large, sharply pointed teeth, found in the barracudas and in the salt- and fresh-water gars, readily reveal their feeding habits. These fishes are all highly predatory, and the long, forceps-like jaws form an excellent organ for grasping the prey, whose chances of escape are very slight indeed.

The pipefishes, cornet fishes, and trumpet fishes resemble the gars and barracudas in the great length of the snout, but the totally different feeding habits are indicated by the small mouth situated at the anterior extremity of the tubelike snout (Fig. 25). Animals with such small mouths, provided with small teeth only, obviously can not catch and devour large prey. A study of their food shows that they eat such small animal life as sand fleas and various other small crustaceans, which they generally find among plants.

Most of the flying fishes, as well as the frog- and goosefishes, the toadfishes, and many others, have a superior

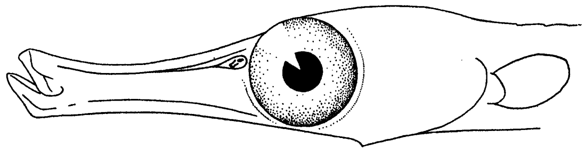


Fig. 25. Head of pipefish, *Syngnathus louisianae*, showing the long tubelike snout terminated by the small mouth

mouth, that is, opening upward, with the lower jaw projecting beyond the upper one. An extreme case of this occurs in the halfbeaks, in which the lower jaw is frequently longer than the rest of the head. In these fishes only half the beak is developed, a characteristic which earns them their name. They strongly resemble the salt-water gars, which have very long beaks.

The inferior mouth, that is, one opening downward below a projecting upper jaw, occurs more frequently than the other type and generally suggests bottom feeding. The sharks, skates, sturgeons, sailfishes, spearfishes, swordfishes, most catfishes, suckers, and buffalo fishes all have it. But sharks usually are not bottom feeders. No, but they were once, in ancient geological times, as their fossil teeth show. Instead of the lancelike teeth of the present dangerous sharks, these very old ancestors had only crushing teeth, showing that they fed on bottom-living mollusks. Some living sharks still have blunt teeth.

The sawfishes (*Pristididae*) have the upper jaw greatly produced, so much so, in fact, that it is longer than the rest of the head (Fig. 26). On each side a row of large teeth arm this projection, giving it the appearance of a double-edged saw. It is generally supposed that the saw is a dangerous weapon, but I have netted many sawfishes while collecting specimens in tropical American waters, and it was my observation that the saw is manipulated rather clumsily, the animal being capable of swinging it only from side to side. The side strokes, although rather slow, are quite powerful and they might be effective against an enemy. It seems unlikely, however, that this organ could be manipulated rapidly enough to aid the fish greatly in the capture of its prey, and the probability is, therefore, that the saw serves as an organ of defense rather than of offense.

Net fishermen greatly dislike the sawfish and avoid it as far as possible, because it generally becomes badly entangled in the meshes of the net by means of the teeth on the saw and is difficult to remove, besides frequently doing great damage to the net. Sawfishes reach a length of from ten to twenty feet and are found chiefly in the mouths of rivers of tropical America and West Africa.

The swordfishes, spearfishes, and sailfishes, too, have a greatly prolonged upper jaw, composed of consolidated bones and resembling that of the sawfishes in shape but differing in being entirely unarmed. The names "sword" and "spear"

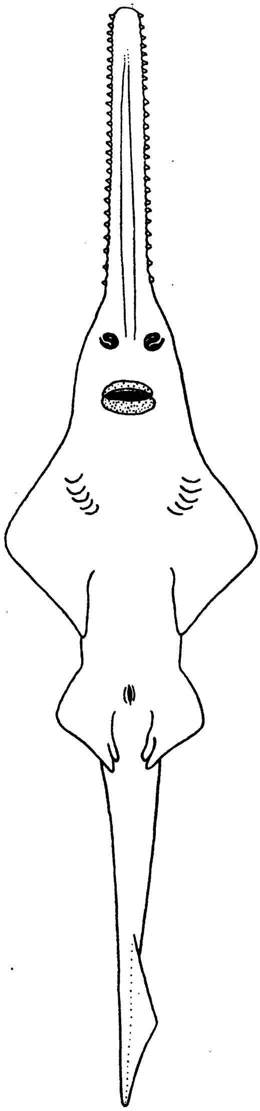


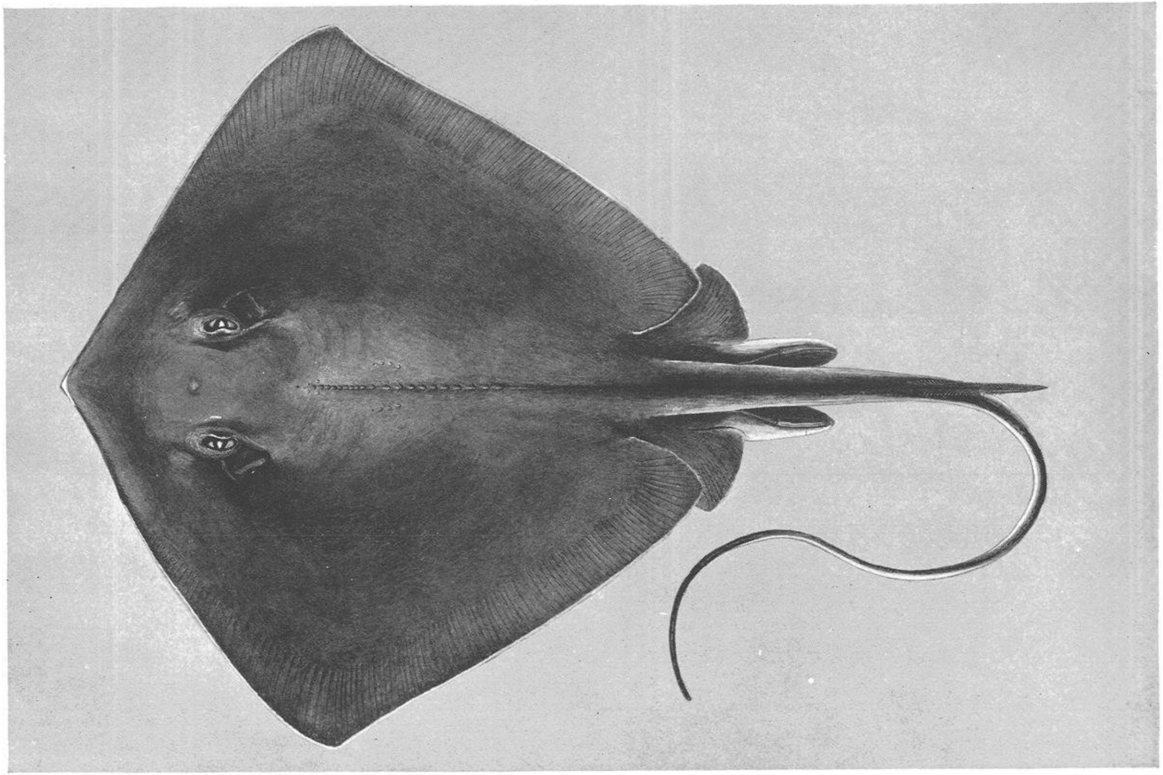
Fig. 26. Sawfish, *Pristis*, ventral view. After Dean

suggest the appearance of the jaw. These fishes inhabit the warm and temperate seas, growing to large size and great power. Many stories are told of ferocious attacks made and damage done to men and boats by infuriated swordfishes using the sword as a weapon of attack. It is not strange that a harpooned fish should retaliate by striking at its assailant. However, fishermen tell of apparently unprovoked attacks upon their boats by swordfish, which sometimes strike again and again with great force.

We have already referred to the very long, thin, flat projecting upper jaw, resembling a spoon, of the spoonbill catfish. This prolongation, though unarmed, is provided with numerous sense organs. It serves neither for offense nor defense, but stirs up the mud from which the fish obtains the minute plants and animals upon which it feeds. Although this fish attains the considerable weight of 150 pounds or more, its food throughout life consists of microscopic, or almost microscopic, plants and animals which it is able to strain from the muddy waters it inhabits by means of an effective sieve situated in the back of its mouth. This apparatus is composed of many fine hairlike strands attached to the gills, which catch the small particles used as food while the water passes on through the gill openings.

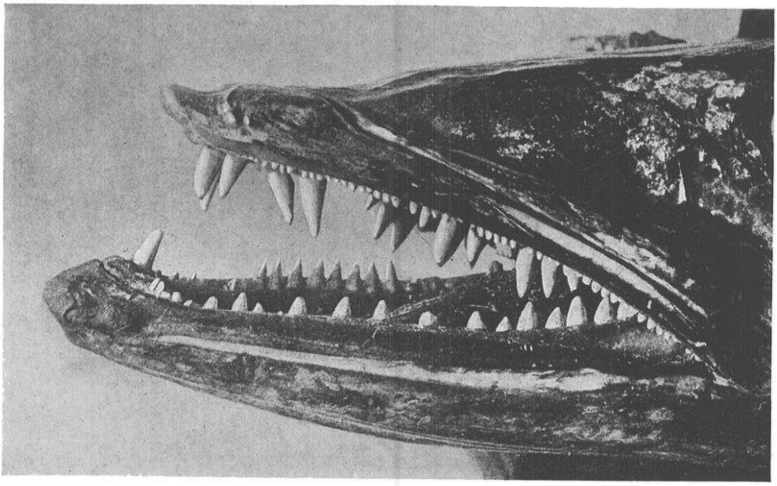
The sturgeons, too, have a "nose" which projects beyond the small, inferior mouth, though not to the same extent as in the spoonbill cat. It more nearly resembles a shovel in shape. Apparently it has a function very similar to the other's spoon, and is used in stirring up from the bottom the small plants and animals upon which sturgeons feed.

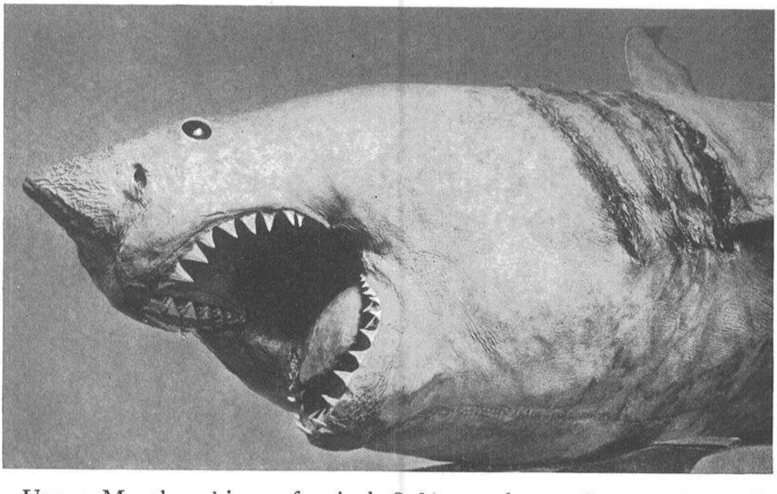
Sturgeons have a small mouth like a sucker situated under this upper jaw. Suckers and buffalo fishes have somewhat similar mouths, surmounted by a hoglike nose, which sometimes serves to roll over stones and other objects in the water while the mouth sucks in the small



Male sting ray, *Dasyatus hastatus*, with saw-toothed spine projecting from tail. Note development of claspers on ventral fins and great development of pectorals

PLATE 12





Upper: Mouth and jaws of 55-inch *Sphyraena barracuda*, more dreaded than the shark

Lower: Head of man-eating shark, *Carcharodon carcharias*. Note reserve rows of teeth folded back in jaw plants and animals from which these fishes gain their sustenance.

Teeth

The possession by the sharks of dermal denticles over all the body has already taught us to expect the unusual in the teeth of fishes. To the physiologist, however, there is nothing particularly startling in this characteristic of sharks, for teeth are outgrowths of the skin and if they

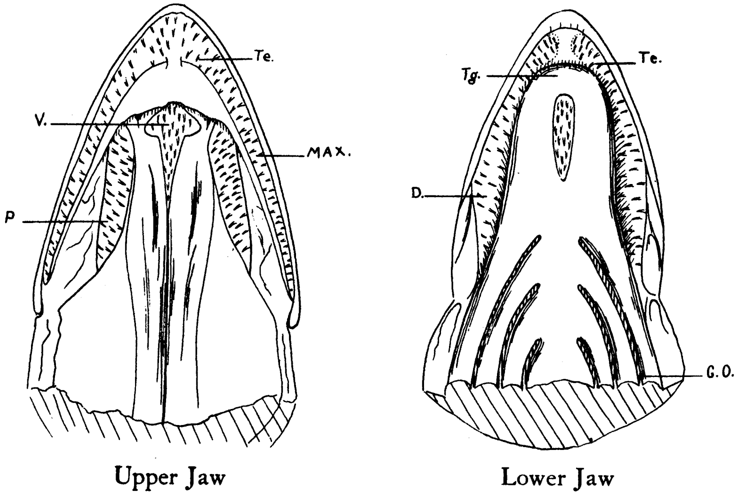


Fig. 27. Mouth of amber fish, *Seriola*, showing various positions of teeth. Tg, tongue; Te, teeth; D, dentary bone; V, vomer; Max, maxillary; P, palatine bone; G. O., gill opening

are confined to the mouth in most animals, the reason is probably that no need exists for them elsewhere on the body.

With the exception of the sharks, fishes have teeth in the mouth only; but the teeth are not restricted to the jaws, for they may occur on the tongue, on the bones forming the roof of the mouth, on the pharyngeal bones situated far back, or almost in the throat (Fig. 27). They vary widely in shape, structure, and function, and in methods of shedding and growth. Finally, they are, in the adults of several species, entirely wanting.

Among the tigers of the sea, such as the barracuda, the teeth are set solidly in bone for strength, but fish of less destructively predatory habits frequently have them fastened merely to the skin or flesh. The angler and some other species have a peculiar arrangement of gristly fibers attaching the teeth to the bone in such a manner that they may be bent down the throat as the prey is swallowed, but not bent outward—apparently an extra insurance against the loss of a victim.

Each species of fish possesses the type of teeth (or no teeth) adapted to grasping and otherwise manipulating the particular kind, or kinds, of food utilized. Usually the size and the sharpness of the teeth are in proportion to the voracity of the fish. The teeth usually found in fishes occur in villiform bands—they are short, slender, even, and set close together, forming a coarse velvety surface, as in the common top minnows, catfishes, pompanos, and rudder fishes. In addition to these villiform bands many species have from a few to many enlarged, pointed teeth, known as canines.

Some fishes have cutting teeth, resembling the incisors of the higher vertebrates and frequently notched along the cutting edge. Such teeth in the trigger fishes grow out of proportion to the size of the fish, and in a specimen two feet long may be as large as those of a man. I know from painful experience that they are highly efficient cutters.

The barracudas, bluefishes, cutlass fishes, and others possess cutting teeth of a different type. Though compressed, they are pointed and sometimes more or less spear-shaped, with a cutting edge on each side. These large, formidable teeth are set in the bones of the jaws and solidly fixed in the big mouths of the species mentioned, all of which belong in the category of the most predatory fishes and so have need of such wicked weapons.

In the tropics the barracudas (*Sphyraenidae*) are more dangerous to man than any shark. Reaching possibly eight feet in length, they are as fearless as they are ferocious (Plate 12).

At the other extreme, minute teeth, loosely set in the gums and easily depressible, are not uncommon. They occur in the mullets, fishes which feed mainly on plants of microscopic size, and so have little need for teeth. Among the species having no teeth when adult we may mention the common shad, taken in large numbers in the streams of the Atlantic sea border of the United States during the spring of the year, when it ascends rivers to spawn. This fish has feeding habits somewhat similar to the mullets and the spadefishes, but it has no teeth at all when adult, though minute ones are present in the young.

Occasionally the teeth in the jaws become fused and form a continuous cutting edge, as in the puffers and parrot fishes (Plate 13). The fusion in the puffers is so complete that the teeth have the appearance of being a continuous piece of bone. However, in the parrot fishes the process has not progressed quite so far, and generally the outlines of individual teeth are still visible.

It is not surprising that the shark's mouth should be well equipped with teeth (Plate 12). It has several rows (five or more) in each jaw. The teeth are compressed and usually have a very broad base surmounted by a large cusp, sometimes with a smaller cusp on each side of the large central one. The cusps bear sharp cutting edges which may be either smooth or notched. Generally only the outer row of teeth functions, but when this row wears out it is replaced by the succeeding row, so that the shark always has several sets of teeth in reserve.

We may well believe that sharks, as a rule, constitute a terror among fishes. If the animal attacked is too large to manage as a whole, the shark may take only a bite. An instance of this was once observed by the crew of the United States Fisheries Steamer "Fish Hawk" on meeting a school of tiger sharks off Beaufort, North

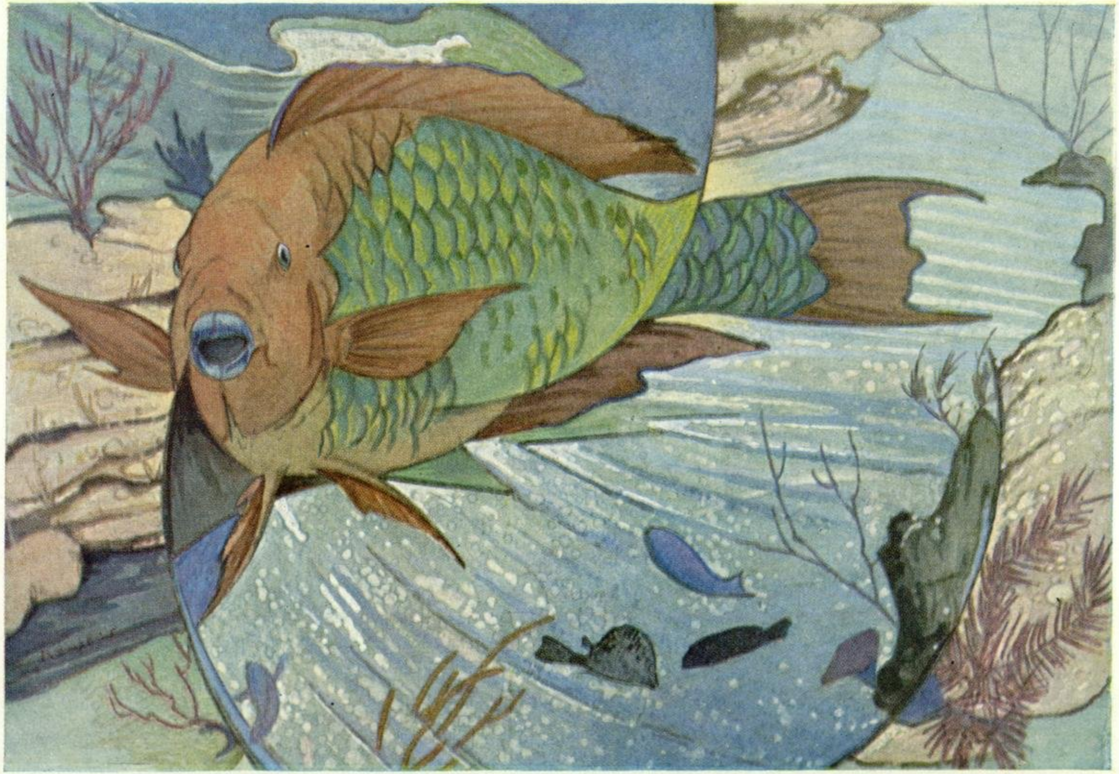
Carolina. They had hooked one specimen, and while he struggled in the water a larger one came by and took a bite from his abdomen. The cut made was as smooth as though a knife had been used. Later the crew caught another shark which proved, on examination of the stomach contents, to be the one that had mutilated the first. It was estimated that the abdominal walls, the liver and other internal organs, all included in the single bite, weighed about forty pounds. The two sharks measured, respectively, ten and a half and twelve feet in length.

Broad, blunt teeth, often arranged like bricks or cobblestones in a pavement, occur frequently in the skates and rays, and constitute an adaptation for crushing hard objects. One is not surprised, therefore, to learn that these fishes feed largely upon clams, oysters, and other mollusks, apparently rejecting the shell after crushing and swallowing the soft parts. The amber fish, or amber jack, also known as the rudder fish, and the shark pilot, reaching a maximum weight of about 100 pounds, have broad bands of villiform teeth not only on the jaws but also on the tongue, the vomer, and the palatines (bones forming the roof of the mouth).

The teeth occurring on the bones within the mouth also vary. In some of the Central American marine catfishes, for instance, the vomerine and palatine teeth are blunt. The black drum (Fig. 28), the tautog, and others have paved teeth on the pharyngeal bones which they use in crushing and grinding mollusks and crustaceans. The oddest place for teeth is found in the butterfishes, which have sacs formed in the sides of the gullet containing hooked teeth. Just how these teeth function appears to be unknown.

The Skeleton

His bones tell more about his family and relations than do any other parts of a fish. To the student of classification bones are therefore of the utmost importance.



A conventionalized painting of a parrot fish (Scaridae) of the South Atlantic, showing the almost complete fusion of the teeth into a continuous cutting edge. By Stephen Haweis. Courtesy of Dr. William Mann

As we have found in other features, a long evolutionary development of the skeleton is illustrated in fish forms now living. In the lancelets, which constitute the lowest type of fishes, the skeleton consists merely of a cartilaginous rod, or notochord, occupying the usual position of

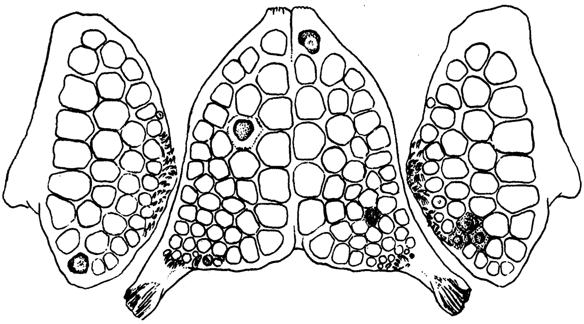


FIG. 28. Crushing teeth of the black drum, *Pogonias cromis*, forming two pavements on the roof and floor of the mouth

the backbone. Advancing to the most primitive of the fishes possessing a true spinal column, namely the sharks, we find the skeleton still cartilaginous, though, of course, much more developed than in the lancelets. The same is true of the skates, lampreys, sturgeons, and a few other groups, and on this account they are, with the sharks, often referred to as cartilaginous fishes. Finally we come to the highest group possessing an ossified skeleton, known as bony fishes, or teleosts (Fig. 29). To this group all American common food fishes except the sturgeons belong.

In a general way the fish skeleton corresponds to that of man and the other vertebrates, though details of structure are vastly different. The backbone is present, of course, and all except the lowest forms have a cranium. The higher fishes also possess some sort of shoulder girdle, to which the pectoral fins, corresponding to the arms in man, are attached. We see, furthermore, a gradual development of ribs from mere gristly hints in the lowest forms, through short stumps of cartilage in the sharks and sturgeons, to real ribs of various shapes and in various positions in the bony fishes. In some species the ribs may even reach the breastbone, which in itself, when present, is a small and unimportant bone.

A fish's ribs, unlike man's, afford no help to it in breathing, but they seem to be of great use, for instance, in framing the body for greater speed.

Whereas in man the vertebrae which make up the backbone, or vertebral column, number thirty-three or

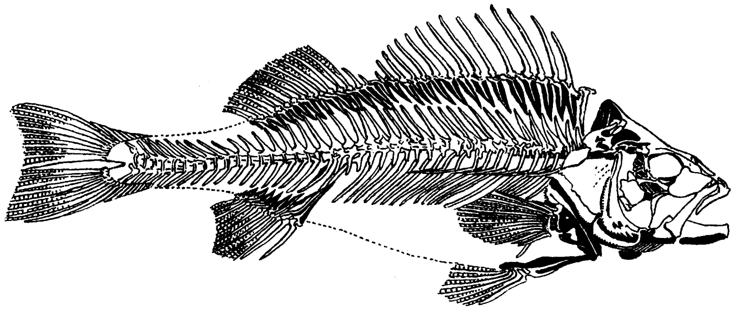


FIG. 29. Skeleton of the perch, *Perca*, a typical bony fish. After Günther

thirty-four, in fishes the number may vary from sixteen to four hundred or more. Numbers respond to the need, naturally, so that the short-bodied forms such as the ocean sunfish have few vertebrae, while the long snake-like eels have hundreds.

Each vertebra has a central portion called the *centrum*, from which a spine always projects upward, called the *neural spine*. Those behind the abdominal cavity have in addition spines projecting downward, called *haemals*. Those with both types of spines constitute the caudal vertebrae, while those above the abdominal cavity, with only one spine, are the abdominal vertebrae. It is to these latter that the ribs are loosely attached.

As a moment's reflection would lead us to expect, the dorsal and anal fins are supported below their bases by a series of spinelike bones which lie within the flesh and are unattached to other bones, though they reach down toward the neural spines of the backbone. These spines form the attachment and support of the fin rays.

The manner in which the backbone terminates at the tail fin generally tells a good deal about the position of the fish in the evolutionary scale. In all the more primitive

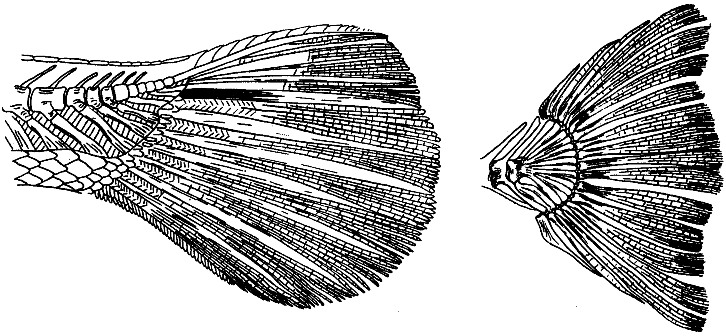


FIG. 30. Left, tail of gar pike in which backbone extends into upper lobe; right, tail of flounder, with backbone ending abruptly in center of fin. After Jordan

forms—sharks, gar pikes, sturgeons, and so on—the tip of the spinal column bends upward and runs into the upper lobe of the tail fin which is generally longer than the lower lobe (Fig. 30). This is the case to an exaggerated degree in the thresher shark. In most of the bony fishes, however, the spinal column ends rather abruptly in a modified vertebra at the base of the caudal fin. It seems probable that the bent-up tail bone was the earliest form, not only because we still see it in the most primitive fishes, but also because in the embryo and young of the straight tail-boned bony fishes the bend is very evident.

The paired fins, pectorals and ventrals, as we have seen, correspond to the four limbs of the higher vertebrates, but they will not stand detailed comparison with them. For instance, fish pectorals reveal no trace of the long bone of the upper arm, anything comparable to the two bones in the forearm is very hard to recognize, and the rays of the fin are in no sense fingers. The pectoral fins are attached to a shoulder girdle, vaguely similar to the shoulder joint in man; but in most fishes this girdle is jointed to the cranium, as in the striped bass. In the trigger fishes it is grown solidly to the skull, and in the eels, in which the girdle apparently has degenerated, the bones lie loose in the flesh behind the cranium.

The ventral fins—roughly, the hind limbs of fishes—have in many species moved forward so far that they are actually situated under the head or the shoulder girdle from which hang the fore limbs; but they are generally unattached to a definite girdle so that the pelvic arch may be said to be missing in fishes.

We have already called attention to the interesting fact that in the group of relatively primitive fishes called the fringe-fins, the pectoral fins are jointed and suggestive of adaptation for land dwelling. It may be that the fringe-fins mark a stage in evolution in which these fishes started toward adaptation to land conditions only to return and readjust themselves perfectly to aquatic conditions.

From the complete absence of a skull in the lowly lancelets we come to a sort of skinny capsule in the lamprey forms, to a continuous box without sutures in the sharks, and finally to the complex cranium of the bony fishes, in which most of the bones are comparable to those in the higher vertebrates and bear the same names—frontal, parietal, ethmoid, sphenoid, and occipital. Besides these, several bones with less familiar names are present. Though the fish brain is comparatively small, its case is rather intricately constructed.

All fishes, exclusive of the lancelets and lampreys, have an upper and lower jaw. The jaw bones are sutured with the cranium in only a few primitive fishes; in all others they are attached by membranes only. The upper jaw is composed of several bones, of which the two premaxillaries form the rim of the mouth, and behind them on each side is the maxillary. Frequently both pairs of bones bear teeth, and these are the so-called jaw teeth. Sometimes teeth are missing on one or the other pair, and rarely they are wanting on both.

The lower jaw differs from that of man and all other mammals in that it is not joined directly to the skull but is attached by a chain of bones which vary greatly in different groups of fishes. It is the lower jaw, of course, which gives motion to the mouth. Several bones combine to form the lower jaw, the anterior pair of which join in front by a suture and carry the teeth.

The bony fishes have membrane bones in the "face" which are missing in the lower forms, such as the sharks, skates, lampreys and others; and, of course, the higher vertebrates have no bones that are comparable. These "face" bones lie on the surface of the head and are covered with thin skin. They include the preorbital, which lies in front of and below the eye; the suborbitals, behind and below the eye; and behind these, the bones which form the gill covers.

The special breathing apparatus common to fishes, the gills, requires a special chamber composed of numerous bones. Usually five pairs of bones form the gill arches. The first four pairs bear the gill fringes, but the fifth pair have undergone great modification to adapt themselves to a use quite distinct from respiration, that is, mastication. For this purpose they usually bear teeth and are known as the *lower pharyngeals*; opposite them, to complete the grinding apparatus which is sometimes strongly developed occur the *upper pharyngeals*.

In some species the first pair of gill arches likewise fulfill a function connected with the nourishment of the fish. In such species the arches support numerous long, slender, hairlike appendages called gill rakers, which form a straining apparatus for screening from the water the small organisms upon which the fish feed (see Plate 27). The spoonbill cat is so equipped. But many other species have gill rakers widely different in size, structure, and number, which have only a limited use or perhaps none at all. Where they have no use, they are short and few in number.

In general, fishes, of the entire group of vertebrates, have the most complex skeletons; and to fully understand the functions of all the bones possessed by some fishes, if indeed they serve any useful purpose, requires much more study than science has yet given them.

The Sense Organs

Eyes in fishes differ chiefly from those of the higher backboned animals in having a more convex (ellipsoid) lens, required presumably because the lens is not much denser than the water in which it is used. This characteristic, in the opinion of students, causes nearsightedness in nearly all fishes, a belief in support of which considerable experimental evidence has been accumulated. However, all fishes are certainly not equally nearsighted.

Like the snakes, frogs, and other cold-blooded vertebrates, fishes lack true eyelids. The skin of the head passes over the eyes, becoming transparent as it crosses the orbits. The nearest approach to an eyelid is found in those sharks which possess a nictitating membrane, a sort of lower eyelid which the animal can draw up and thereby partly, or wholly, shut the eye, just as chickens can with a similar equipment. The blue sharks (*Prionace glauca*), which are among the comparatively few fishes that can close their eyes, have this membrane most highly developed. We do not know its exact function or functions, but presumably it is used to shut out a part, or all, the light rays when they are too strong from the eye. Again, the eye may be closed for protection from an enemy or when coming in contact with injurious objects. Whether sharks close their eyes when asleep does not seem to be known.

With the eye constantly in the water, a fish has little need for lids to moisten the eye ball from time to time. But when a species gets the habit of leaving the water for the land occasionally, it seems to require some substitute for the water to fulfill this function. Thus the mud-skipper pulls its eye down into the socket and turns it round so that it looks back into the head instead of forward. This amounts to sweeping the ball under the lid instead of the lid over the ball.

In the mullets, mackerels, and some other fishes, the skin above the eyes is thickened, although still transparent. This structure is called an adipose eyelid, and seems to have some correlation with the spawning period, for it is said, in some species at least, to become at that season greatly thickened and loaded with fat, so as to nearly cover the whole eye. Sometimes this membrane covers a part of the head also, extending backward to the shoulders.

As for the parts of the eye proper, there is present an iris which surrounds a round pupil but which has little power of contraction. It is frequently brightly colored with red, yellow, green, blue, or even black pigment. In some of the bottom-dwelling fishes, such as the skates and flounders, that part of the iris above the pupil is black, presumably to form a sort of curtain for shutting out light rays.

We find in the position, direction, and size of the eyes in fishes great variety. In general it may be said that they are so directed that light may enter them. At least, they are never turned entirely away from the light. The majority of fishes have an eye on each side of the more or less compressed head, thus giving the vision a general lateral direction. This arrangement forces us to the interesting conclusion that the fishes having it possess monocular vision, for certainly both eyes can scarcely be focused on the same object at the same time, and the action of one eye must be quite independent of the other.

The species with broad, depressed heads frequently have the eyes inserted in the upper surface, causing them to be directed more or less upward or skyward, as in the skates, the toadfishes, the stargazers, the angler fishes, and others. In some of these, especially in the stargazers, the eyes come so close together that conceivably they have binocular vision, with both eyes focused on one object at the same time.

A most amazing adaptation to changed living conditions appears in the eyes of the flatfishes (Heterosomata). When adult they have both eyes on one side of the head and asymmetrical, that is, one generally is higher and farther forward than the other. The history of this remarkable adaptation we can see retold in every specimen for when young the eyes of the flatfish are on opposite sides of the head (Fig. 31). Very soon after hatching it begins life on the bottom, lying and swimming on one side. Some species turn the left, others the right side, toward the heavens. Thereupon, the eye on the downward side begins a "migration" toward the light, that is, toward the upper side. In the course of this movement, which in one flounder (*Pseudopleuronectes americanus*) is reported to take only three days, such a drastic process as the twisting of the skull is involved. Although it has been asserted that in some species the eye in its migration passes through the substance of the head, in all species observed by myself it gradually moves upward and finally crosses over the ridge or dorsal margin of the head and becomes permanently fixed with its fellow on what, thereafter, is the eyed side. The eyes, as already stated, are never on the same level nor equally distant from the tip of the snout.

In certain marine species, as in the big-eyes, or catalufas (Priacanthidae), the organs of sight are very large. At one time students thought that such species descend to great depths where almost total darkness prevails and where the large eyes would admit the dim rays present. Again, it was thought that fishes with large eyes prob-

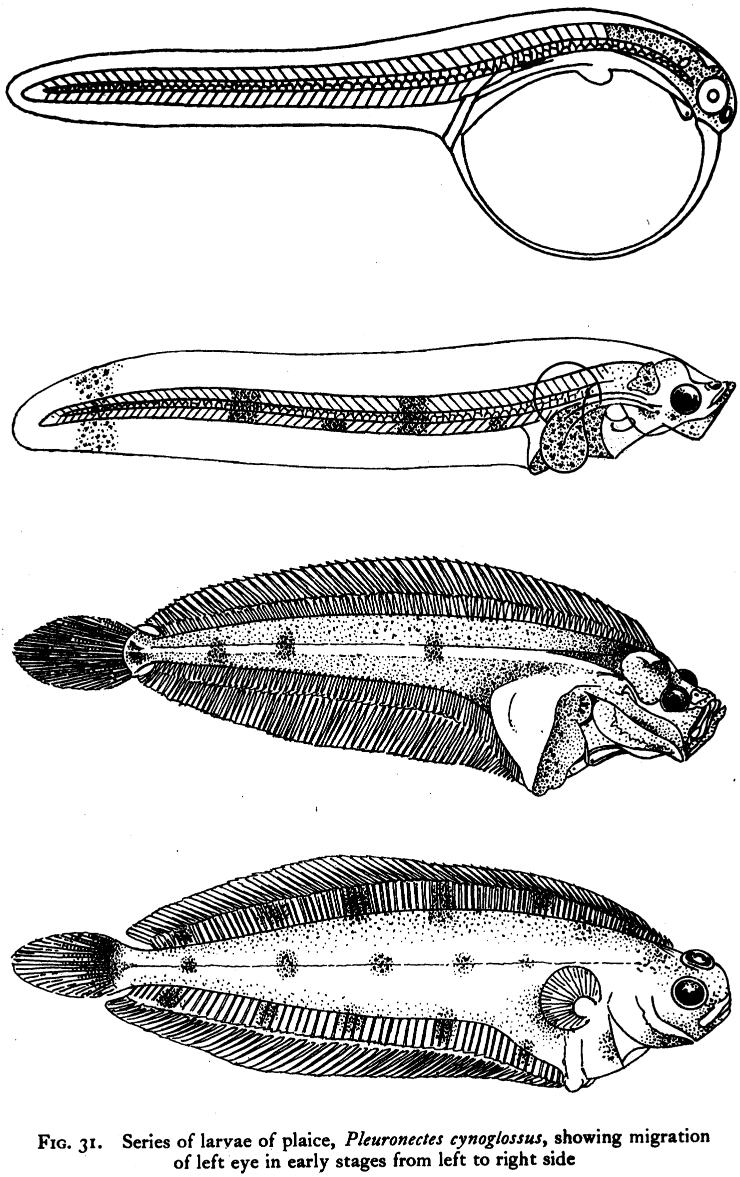


FIG. 31. Series of larvae of plaice, *Pleuronectes cynoglossus*, showing migration of left eye in early stages from left to right side

ably were nocturnal in their habits. It does not seem certain, however, that the greater size would help in the use of the failing light. Furthermore, it is well known that some fishes with undoubted nocturnal habits do not have large eyes and many deep-sea forms have very small to rudimentary ones. The utility of a very large eye, therefore, seems still an open question.

How much we don't know about sight in fishes is further illustrated by our inability to account for those that have eyes raised on a stalk and which the fish can move at will. Possibly this rather unusual telescopic structure serves for binocular vision and permits both eyes to be focused on the same definite object. However, the species with stalked eyes generally live in the deep sea where there is little or no light, so the utility of the stalked eye remains surrounded by mystery. Why the hammerhead shark has its eyes on large fleshy stems sticking out from the sides of the head is likewise an unsolved problem.

Efficiency in vision reaches its highest point in a few species possessed of bifocal lenses; for example, the Central American fresh-water fish called *quatro-ojos*, or "four-eyes" *Anableps* (Fig. 32). In these strange fishes the pupil is crossed by a dark, horizontal line composed of narrow anterior and posterior projections of the iris. This line is exactly at the level of the water when the fish swims at the surface in quest of food. The upper half of the pupil, therefore, being exposed to the air at such times, is used for vision in that medium, while the lower half remains below the water level and is used for vision in water. The degree of vision in the air certainly is much keener in this species than in fishes with eyes of a more usual structure, as I have had ample occasion to discover when collecting specimens.

The four-eyes generally run in schools. It seems probable that they can see a man approaching from a distance of twenty yards or more, as an offshore movement generally takes place long before one can reach the bank. In my attempts to catch some of these fish with a collecting seine, the schools generally kept well ahead of the men handling the seine. When the men would quicken their speed, the fish would do likewise. We caught none until one day several men entered the water

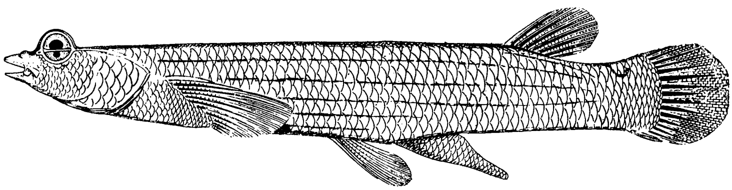


FIG. 32. Four-eyed fish, *Anableps tetrophthalmus*, with pupils adapted for vision in air and in water

and so succeeded in driving the four-eyes, like so many sheep, into a cove where they could be surrounded by a net.

In some of the deep-sea fishes, which live at such great depths that no light can penetrate, the eyes have degenerated so that they are very small and overgrown with skin. Other deep-sea species, however, retain eyes, and several kinds are provided with luminescent spots by means of which they are able to make light.

Fresh-water fishes living in continual darkness in caves have, like the deep-sea dwellers mentioned, lost the use of their eyes. A special study of these organs has shown every indication of degeneration. In other words, the structures reveal that the eyes once functioned but, because of existence in continued darkness in which they were useless, they gradually degenerated and eventually became very small, overgrown with skin, and incapable of functioning even in the presence of light.

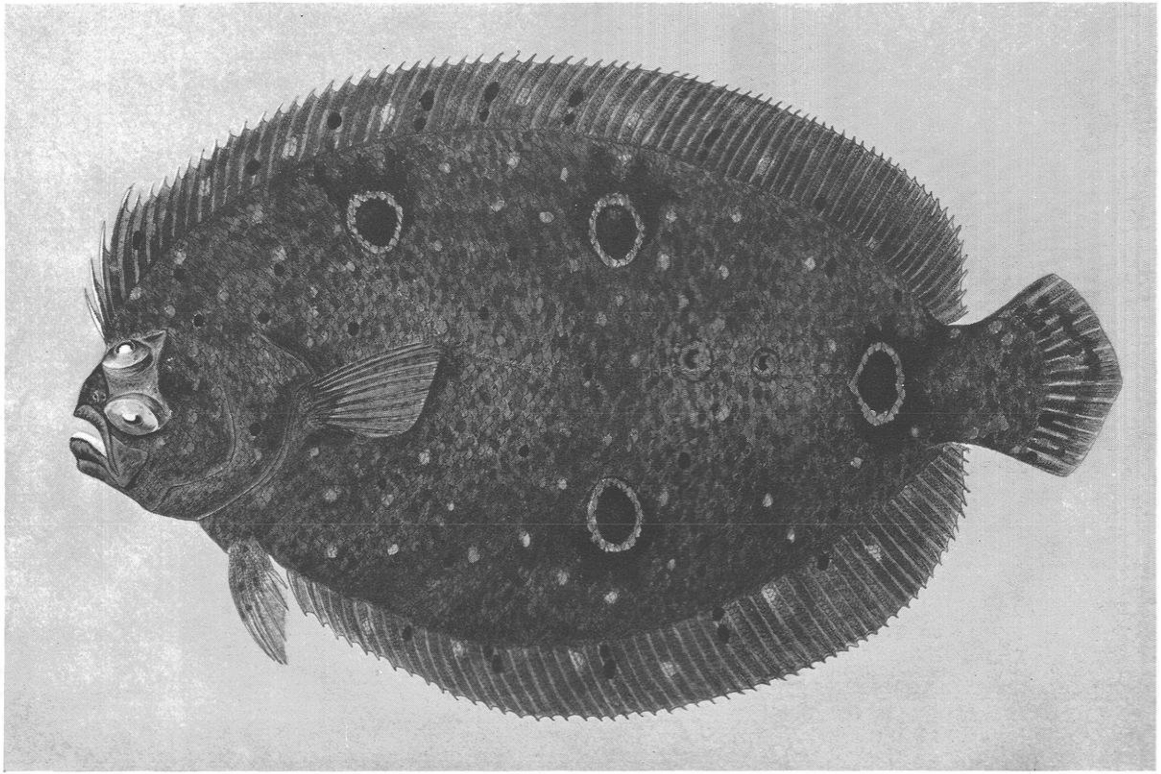
A quite different condition is found in the lowest fish forms, the lancelets, whose sight is no better than that of these cave dwellers. In them, instead of degeneracy we find only the beginnings of organs of sight, consisting simply of a small pigment spot situated at the anterior end of the central nervous system. This is interesting in view of the belief held by some students that the eye began as a cluster of colored grains which could feel light somewhat as the skin feels heat or cold. Our own eyes have color-stained cells like these clustered together back in the ball, a fact which may point to the correctness of this belief. In the groups next above the lancelets, the hagfishes and lampreys, the eyes are still very small and almost hidden by the skin that passes over them.

But how well can fishes with fully developed eyes see? The extremely close relationship between vision and the sense of smell, for it is hard to tell whether a fish is warned by his nose or his eyes, increases the difficulties of answering this question. We have already pointed out the probability of nearsightedness in fishes suggested by the great convexity of the lens. It seems probable that in most species vision consists of little more than a discrimination of light, shade, movements, and a varying degree of perception of color, sometimes very considerable. I shall come back to this later.

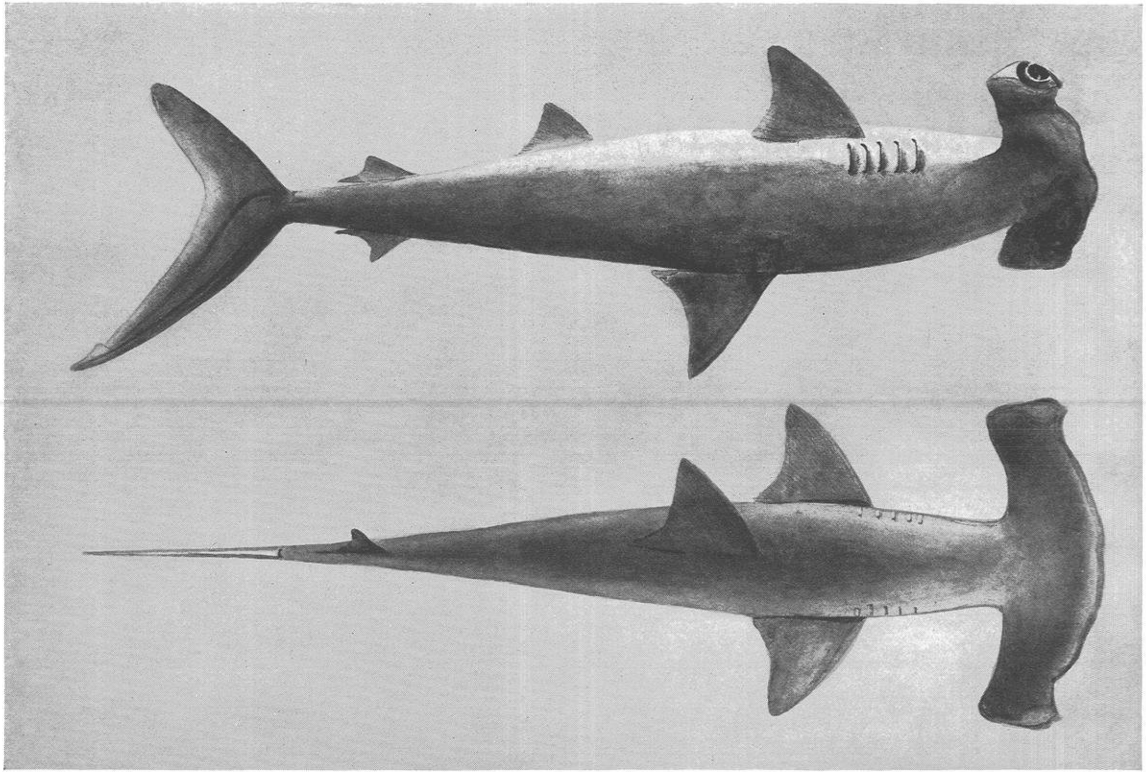
One exception to this rule of poor vision we have already discerned in the four-eyed fish, which appears to see clearly in the air. Another exception occurs in the pond-skipper of Japan and India, for we are told that this fish is quite equal to a frog when hunting insects on the mud flats which it inhabits.

The mosquito fish, *Gambusia*, of whose habits I made a special study for several years, is quite nearsighted and its vision, even at close range, is far less distinct than that of man. It can not see mosquito larvae, one of its chief foods, at a distance exceeding three inches and it is unable at any and all distances to distinguish between the larvae and bits of stick. The fish appears to be quick in discerning movements in the water within a three-inch radius, and a wiggle by a mosquito larva within that range spells almost certain death. It seems quite certain, therefore, that this fish and, no doubt, many others that

PLATE 14



Adult four-spot flounder, *Ancyclopsetta quadrocellata*, in which right eye has migrated to left side



Hammerhead shark, *Sphyrna zygaena*. Why the eyes are on fleshy stalks remains a mystery. Courtesy of the Bureau of Fisheries prey on live animals are guided in their search for food largely by the perception of movements.

No fish breathes through his nose. In fact, his nostrils are scarcely more than pits in the snout, having, except in a few of the lowest forms, namely the hagfishes, no communication with the mouth or throat. In nearly all of our common fishes these pits consist of a single cavity on each side of the snout. Generally they are provided with two external openings, but the sharks and rays differ from the majority in having only a single opening for each nostril. However, in them the nostrils are large and the openings have valvular flaps by means of which the animal can partly close them at will.

Going still farther back to some of the lowest forms, as the lancelets, hagfishes, and lampreys, the nostril is single and median in position. In the hagfishes it pierces the roof of the mouth, a very unusual condition in fishes.

The interior of the nasal pit is lined with a delicate or fringed membrane, well supplied with blood vessels and with nerves which communicate with the olfactory lobes and so convey their sensations to the brain. Presumably, therefore, a fish's nose differs from that of the higher vertebrates in serving solely as an organ for smelling. The general assumption is that it fulfills this function very well and that the sense of smell is rather acute in fishes. It is a well-known fact that some species readily detect the presence of blood or meat in the water. Sharks are believed to be attracted especially by the presence of a decaying carcass. Nevertheless, the extent to which the nostrils function independently of the sense of taste largely remains to be determined by future investigations.

The ear in fishes is not visible without dissection, for no external ear is present. In fact, the organ of hearing seldom has an external or internal opening, and in a restricted sense of the word it is perhaps not an ear at all. Within the skull, however, lies a labyrinth, including a vestibule and two or three semicircular canals (Fig. 33). The latter dilate into sacs which contain one or more loose bones, the ear "stones," or *otoliths*.

The internal ear lies close to the brain, being separated only by a thin wall of membrane or cartilage. Although there appears to be no direct or special auditory nerve connection between the ear and the brain, their close proximity must insure the conveyance of sound waves with distinctness. In some species, as in the carp and its allies and in the catfishes, a series of bones, or in some cases canals, brings the ear into very close connection with the air bladder, which it is thought may act as a supplemental organ of hearing.

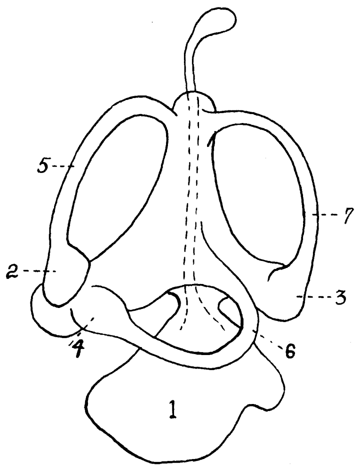


FIG. 33. Hearing organ of a fish. 1, sack containing "ear stones"; 2-4, ampulla containing sense organs; 5-7, semicircular canals. After Wiedersheim

The otoliths commonly number two in each labyrinth and are composed in the bony fishes of firm, calcareous material with a hard enameled surface, variously grooved and marked. The bones form in layers so that sometimes one can determine thereby the age of the fish. In the sharks and rays, on the other hand, the otoliths are soft and chalklike and crumble easily. Lancelets have no ear whatever, and lampreys have only a sac containing the simplest parts of an ear.

The sense of hearing in fishes, in view of the primitive ear possessed, can not be very acute. In fact, it seems doubtful whether fishes hear at all in the sense that man does, and the most they can do probably is to perceive disturbances in the water. Experiment has shown that killifishes, for example, will respond to sound, but it is thought that in this case the sense organs of the lateral line aid the ear.

The majority of fishes swallow their food whole, without mastication. The few exceptions only cut it or crush it somewhat, for there is no true mastication in fishes, wherefore we may conclude that their sense of taste is not keen. In fact, students question whether they actually possess such a sense, and certainly no definite organs for that purpose are developed. The tongue often is entirely absent and when present is imperfectly evolved and never furnished with muscles capable of extending or retracting it as in the higher vertebrates. Moreover, all evidence of taste buds is lacking. Some fresh-water species, as the carp and its relatives, have in the roof of the mouth a soft cushion richly furnished with nerves, which probably serve one of the senses, but no evidence exists to show that this is taste.

Gambusia, the mosquito-eating fish, when confined in an aquarium will accept almost any object, such as a bit of stick that resembles in size and shape a mosquito larva, but it quickly rejects such objects on taking them into the mouth. We do not know, however, whether the fish distinguishes between a mosquito larva and the inanimate object through the sense of touch or taste. I have had occasion to determine that this fish can distinguish between a live and a dead mosquito larva. It will eat dead wiggletails when hungry and when live ones can not be had. However, when both dead and live ones are available and the fish is not too hungry, it carefully expels from the mouth the dead larvae but swallows the live ones. It seems possible that this discrimination may be made, in part, through the sense of taste.

Many fishes depend on the sense of touch for food and apparently for protection, so that we need not be surprised to find numerous and varied organs for that purpose. In general the entire surface of the skin is sensitive to touch,

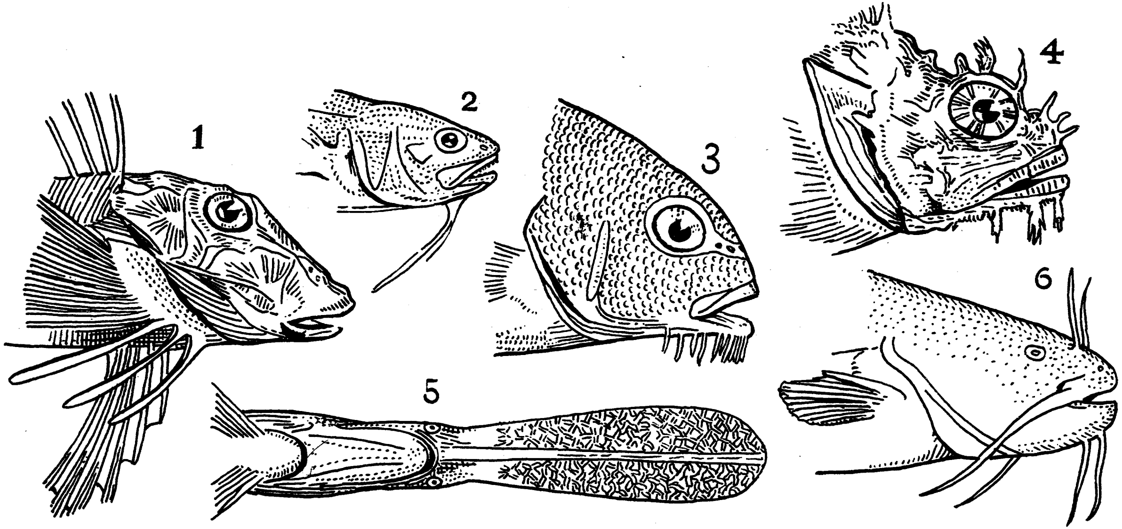


FIG. 34. Barbels and other tactile sense organs. 1, sea robin; 2, cuskeel; 3, drumfish; 4, sea raven; 5, paddlefish; 6, catfish. After Dean

due to the presence everywhere of "end buds," simplest form of sense organs. However, just as the tips of man's fingers have a more acute capacity for feeling than other parts of his body, so fish have structures developed exclusively for feeling.

Such are the barbels seen in the catfishes, goatfishes, whitings, codfishes, drumfishes, and many others—fleshy filaments like a cat's whiskers attached somewhere to the head (Fig. 34). They exhibit much variety of form and position, but wherever and however developed they constitute organs of touch.

We have already had occasion to discuss the small feeler-like ventral fins in the cuskeel, and the detached rays on the pectoral fins typical of the threadfins and the sea robins. Such structures also are used as organs of touch; that is, for exploring the bottom and searching for food, so that they really serve as barbels.

It will be a consolation to many anglers to know that the sense of pain in fishes appears to be very feeble. It is reported that the Greenland shark when feeding on the carcass of a whale will allow itself to be stabbed in the head repeatedly without abandoning its prey. Many incidents are related of fishes with torn and bleeding mouths which still will yield to the temptation of another bait. When fishing off Taboga Island in Panama Bay, I once hooked a large moray (eel) three times before I succeeded in landing it. When it finally was brought aboard the boat it had three hooks deeply implanted in its oesophagus. Certainly had the pain been acute it would have overcome the pangs of hunger, at least temporarily.

The Lateral Line

Most fishes possess a structure which seems capable of aiding the three senses of sight, smell, and hearing. This is the "lateral line," which when present generally extends the length of the body. In spiny-rayed fishes, as a rule, it runs parallel with the outline of the back, whereas in soft-rayed fishes it usually follows that of the belly. It may be branched, it may be double or triple, and occasionally the whole fish may be covered with such lines. It is so universally present in fishes that its absence in the herrings, herringlike species, and in the mullets is worthy of note.

Examination reveals this structure as a series of well-developed organs sunk in the skin below the scales. Each organ possesses a mucus tube which pierces the skin or scale and so provides an external opening. Sometimes around these pores the scales rise up into high, horny ridges which throw the line into sharp relief. At the base of each tube or behind it occur numerous nerves.

The uses of the lateral line appear to be quite complex. Certainly the presence of the mucus tubes proves that one purpose is to aid in the secretion of this substance, so valuable to fishes in decreasing friction as they speed through the water, and in preserving them from their enemies—both by making them difficult to hold and by being sometimes disagreeable, if not poisonous. Though it is a little irrelevant at this point, the curious capacity of the hagfishes (Hyperotreta) to throw out a mucus screen to confound their enemies deserves mention. They can, through certain holes in the skin, pour out a fluid almost as thick as jelly so rapidly as to completely hide themselves from view.

But to return to the lateral line, some investigators believe that its specialized organs assist the sense of smell. Their main function, however, appears to be that of aiding the imperfectly developed ear and eye. Experiment has proved that neither light, heat, salinity of the water, food, oxygen, water pressure, nor sound stimulate them. The only thing they do respond to, apparently, is gentle vibrations of low frequency in the water. It is thought that the reflex waves set up by the fish itself when swimming may inform the animal how close it is to an object in the water. This appears to explain how the blind cave fishes avoid obstacles. When the water is violently agitated the lateral-line organs do not respond and the fish, if held in the aquarium, for example, will dash itself against the sides. These organs seem, also, to be of some use in orientation and in balancing. One investigator found that the toadfish could maintain its equilibrium after its ventral and pectoral fins had been removed, as long as the lateral line was left intact.

The evidence of embryology indicates that the sense organs of this line were confined in ancestral fishes to the branchial clefts and that the organ that passes for the ear in fishes is one of these line organs greatly modified. This fact would help to explain and confirm their sensitivity to vibrations, though of lesser frequency than the delicate vibrations of sound to which the auditory organ is attuned.

Finally in certain deep-sea fishes to which the lantern fishes (Suborder Iniomi) belong, the lateral-line organs seem to have been enlarged and developed so as to produce light, though some authorities doubt their performance of this function. In any case, the belief leads us to the interesting subject of light production in fishes.

Luminous Organs or Photophores

Some species of fish carry their own light just as do fireflies. Their equipment for this purpose—apparently not the same in different species—is variously known as luminous organs, phosphorescent organs, and photophores. These organs appear, inexplicably enough, in entirely unrelated groups of fishes, including certain sharks, a toadfish, and lantern fishes, being most highly developed in the latter and their many relatives which live in the deep sea.

The luminescent organs may occur on any part of the fish, on the head, along the lateral line, on the sides of the belly, in transverse rows between muscle segments, or on barbels. They may be large or small, and they may vary in size and structure even on the same fish. Large luminescent areas generally do not show the specialized structure of the smaller phosphorescent spots.

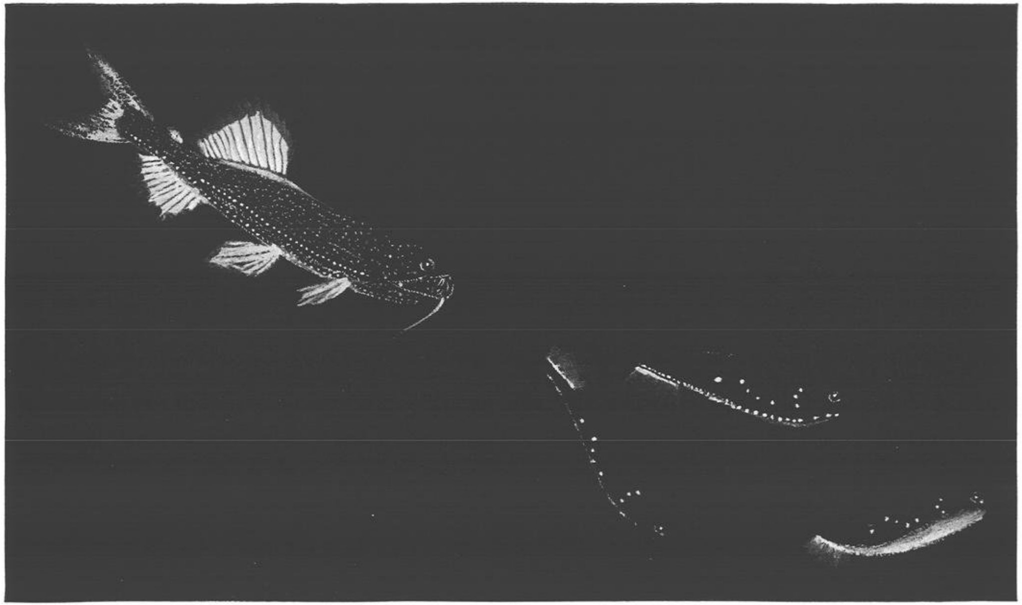
One of the lantern fishes (*Diaphus lucidus*) has the entire forehead, or snout, covered with a light organ, suggestive of the headlight of a locomotive, which has earned him the name of "headlight fish." In addition, *lucidus* has small photophores along each side of the belly, which are said to shine like stars in the darkness.

The toadfish *Porichthys*, which occurs along the Pacific coast from Alaska to Panama, bears numerous series of small light-spots on the skin, averaging about 350 spots on a side. Several abyssal forms of the angler family, to whose ability to extend the dorsal spine into a filament hanging in front of the mouth as a bait for unsuspecting prey we have already referred, possess light-emitting organs at the end of this filament. In these forms the light appears to be the lure which attracts other fish within range of the angler's jaws.

J. T. Cunningham gives an account of the remarkable luminous organs of two small species occurring in the East Indies, *Anomalops graeffi* and *Photoblepharon palpebratus:*

> The luminous organ in these fishes is a movable disc below the eye which can be withdrawn into the orbit and is then covered by a flap of skin like an eyelid, situated above the organ; when the organ is exposed, the edge of the disc extends to the edge of the pupil so that the vision of the fish is not obscured and the light is prevented from passing through the coats of the eye by the dense pigment with which the inner surface of the organ is covered. The luminous organ is thus like a dark lantern placed immediately beneath the eye and the light can be exposed or covered at the will of the fish. When the disc is cut out from the head of the fish it retains its luminous power for several hours, and it is put on a hook and used as a luminous bait by the native fishermen, who are extremely ingenious and energetic. It has been supposed that these fishes were abyssal but this is not the case; *Anomalops*, called by the natives *ikan leweri laut*, swims in shoals at the surface of the sea; *Photoblepharon*, distinguished as *ikan leweri batu*, lives singly among the rocks. Obviously the luminous organ can only be of advantage as a bait in the dark, and in the living fish likewise the habits must be nocturnal.

It was formerly believed that luminosity occurred only among the fishes living in the depths of the oceans, and this



Luminous fishes by night. At right, three minnow-sized Myctophidae pursued by larger *Astronesthes*. Painting by Helen Tee-Van. Courtesy of Dr. William Beebe

faculty of producing light was thought to be useful to them in finding their way, in searching for food, and in repelling or avoiding enemies. But all deep-sea fishes do not possess light organs, and many of those that have them do not live at any great depth. Furthermore, some sharks that are not deep-sea forms are luminescent; the California toadfish, known as "midshipman," is a shore fish; and we are informed that a fish living in the rivers and estuaries of India becomes brilliantly luminescent all over the body when caught. Evidently luminescence is not peculiar to the fishes inhabiting the deepest and darkest waters.

Recent investigations have not thrown much light on the nature of the functions fulfilled by luminescent organs in fishes. Their discovery in shallow-water fishes, however, has discredited the belief that the sole purpose of phosphorescent organs is that of furnishing light for the guidance of the fish. One of the recent theories, for which there is some scientific evidence, is that luminescence occurs only in the presence of bacteria and that their entrance may actually cause the development of the peculiar structures known as light organs. If that be the case, luminescent organs may serve no useful purpose to the animals possessing them.

The question as to how the luminescence is produced lies in an obscurity almost as deep as why it is produced. Again quoting Cunningham:

> Of the various theories which have been suggested concerning the process by which light is produced in the luminous organs of fishes and other animals, the most definite and probable is that the essential part of each organ consists of glandular cells, which secrete a substance containing phosphorus, that this substance is oxidized by oxygen supplied by the blood, and that the light is due to this oxidation.

But even that theory runs up against a snag when the circumstances in some cases are examined. We shall have to leave the decision to the students of the future.

Electric Batteries

Other animals, such as the fireflies mentioned and certain crustaceans, produce light, but so far as we have any record fishes are alone in producing electricity. No such energy is developed in the higher vertebrates, not even in man. But among these lowest of backboned creatures we find the power to produce electricity possessed by more than one family.

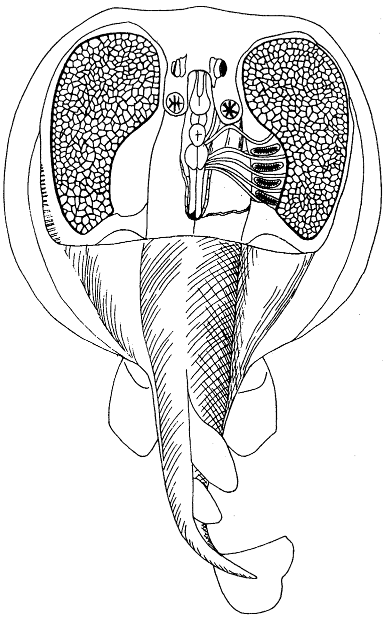


Fig. 35. Electric ray, *Torpedo marmorata*, with the skin removed from the head showing the electric organs as honeycomb sections. After Fritsch

In general, fishes possessing electric organs have certain characteristics in common. They are in most cases, naked-skinned, at least in the region of the electric organs, perhaps so that good contact may be made. Again, with the possible exception of the Mormyridae, a family of soft-finned fishes occupying the rivers of Africa, all are of a sluggish nature, the marine species, such as the torpedo rays, living on the bottom in the shallow waters they prefer, while the fresh-water species usually frequent shallow and stagnant waters.

In the torpedo rays (Torpedinidae), which occur in both the Atlantic and Pacific oceans and in the Mediterranean and other seas, the electric organs are situated on each side just behind the head (Fig. 35). The organs consist of more than 400 large honeycomblike structures in the form of vertical hexagonal prisms, each filled with a clear, trembling, jellylike mass. Each compartment contains an electric plate composed of a muscular fiber which has undergone a transformation into a special granular substance containing numerous nuclei. Four large nerves connect the organs with a special outgrowth of the brain called the electric lobe. If these nerves be cut no shock can be given, so that the current apparently is under the control of the fish. One writer states that each cell possesses an electromotive force of 0.02 to 0.05 volt and a shock from a torpedo ray may represent as much as 35 volts. On the other hand, it has been repeatedly stated in literature that a large ray, presumably one weighing a hundred pounds or more, is capable of giving a shock sufficiently strong to "knock a man down." The amount of electric energy possessed, however, seems to vary greatly. At least, it is quickly expended, for the fish is capable of giving only a limited number of shocks at one time, each weaker than the previous one. Thereafter, the animal requires rest and food to build up new energy.

The electric eel (*Electrophorus electricus*), inhabiting rivers in Brazil and in other warm South American countries, possesses the most powerful electric organs of all fishes. This fish, which is an eel in shape only, has very large cells, extending in two rows the whole length of the body, which by some authorities is said to be as great as six feet. It is reported capable of giving a shock representing over 300 volts and as many as several hundred in a second.

The electric catfish (*Torpedo electricus*) of the Nile, which reaches a length of three feet, is the only member of its family with power to produce electricity. The organ, which in this fish extends all round the body, differs in structure from those of all other electric fishes and seems to have evolved from the skin rather than from muscular tissue. It consists of an almost uniform layer of gelatinous tissue, not divided into columns of plates as in the other cases, though plates are present, each with its nerve-fiber connection.

In the sluggish American star-gazers, *Astroscopus*, the electric organs are located underneath the naked skin on top of the head.

The shocks that fishes endowed with such organs can give are very sudden and disagreeable, and appear to serve the useful purpose of stunning prey and warding off enemies. But we do not know how the organs work, and though we can follow in the embryo of the torpedo ray the development of the electric plates from muscles of the outer parts of the branchial arches, we can not explain their evolution.

Organs of Respiration

The breathing mechanism of a fish is so distinctive as to serve as one element in helping to differentiate it from all other animals. Thus in our definition of the fish we stated that it breathes by means of gills. Though so different in structure, these organs function much as lungs do in air-breathing vertebrates. In fact, any respiratory organ consists essentially of a thin membrane which separates the blood on the one side from the medium containing oxygen on the other, and permits the passage of oxygen into, and of the waste product, carbon dioxide, out of the blood. Such a membrane is found in the lungs of air-breathing vertebrates and likewise in the gills of fishes. In addition, invertebrate creatures have found other distinctive structures which serve the same purpose. Before the development of gills as we now know them, the predecessors of the fishes appear to have had little tufts, threads, or cells serving as breathing mechanisms and placed anywhere about the body. A favorite position was in the digestive tract below the stomach, probably because the animal swallowed air as it ate.

Gills vary considerably in structure but their position is quite constant, and that is, in adult fishes, behind the mouth cavity, although in embryo sharks and a few other forms external gills (the gill tufts just mentioned), resembling those of the fresh-water newt, are present (Fig. 36). Structurally three main types occur among fishes. The lampreys, for example, have purse-shaped gills situated in

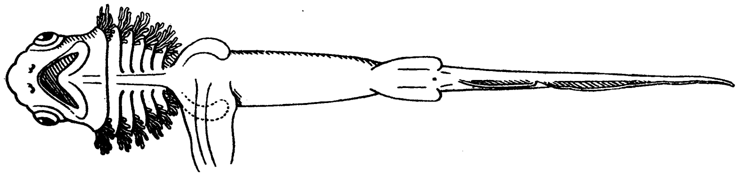


Fig. 36. Ventral view of larval frill shark, *Chlamydoselachus anguineus*, showing external gill tufts. After Garman

several depressions on each side of the anterior part of the body. Each sac is lined with fringes well supplied with blood capillaries, and the whole series of sacs is supported by a so-called branchial basket, formed of cartilage.

Sharks and rays, as well as a few other forms, have another type known as plate gills. These structures are membranous laminae, or thin plates, attached to cartilaginous arches, called gill arches. The laminae in this type of gill, like the fringes in the lampreys, are richly supplied with small blood vessels. In the sharks and rays each gill has a separate opening, known as a gill slit, of which usually five are present on each side (see Plate 15).

Finally, the ordinary fishes, including the bony fishes, have fringe gills (Fig. 37). That is to say, gill filaments, or fringes, are attached to the outer edge of the supporting bony gill arches, the fringes usually occurring in two rows. The length and the number of fringes present vary greatly among species, probably in proportion to the amount of oxygen needed by different fishes. Fishes which have this type of gill have all the gill arches, which generally consist of four pairs, in a single cavity, the branchial chamber, which is well protected by bony gill covers and usually has a single opening on each side. This further differentiates them from the shark forms, which have a separate opening for each gill.

But whatever the form, as we have said, gills are all adapted to bringing the blood in the gill fringes or in the laminae very close to the water, and their peculiar structure exposes a proportionately large amount of surface of comparatively thin membrane to the water on the outside and to the blood on the inside of the capillaries situated within the structure. It is through the walls of these capillaries, of course, that the interchange between the water and the blood takes place, that is, oxygen is taken up and carbon dioxide, principally, is given out through the thin capillary walls.

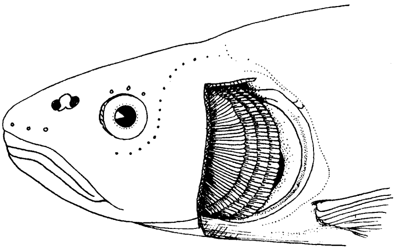


FIG. 37. Left branchial cavity of fresh-water dace, *Semotilus atromaculatus*, with opercle removed to show left pharyngeal arch and gill filaments. After Forbes and Richardson

In breathing, the fish is able to take from the water only the free oxygen that has been absorbed from the air, for it has no way of breaking up the chemical composition of water. This is the reason that fish often suffocate in warm water which holds less oxygen than cold or cool water. Likewise a depleted supply of oxygen explains why fish suffocate when overcrowded in a tank, or when confined in polluted water.

The mechanism of breathing is interesting. What the fish does is to swallow great quantities of water. But he does not take it into the gullet. He closes his mouth and forces it out at the gill openings. The process in some of the sharks and rays differs in that the water, instead of entering the mouth, is drawn in through a hole in the head known as a spiracle, situated just behind each eye, and is then expelled through the gill openings. Animals with spiracles are or have been bottom-dwelling forms, and it is believed that the openings in the head permit these species to lie on the bottom without danger of inhaling sand. The lampreys and hagfishes have several sacs along the sides into which the water flows from the mouth. In a few species tubes connect these sacs with the gullet so that water may be swallowed into them. In some there is an outer opening for each sac, in others only one for all the sacs.

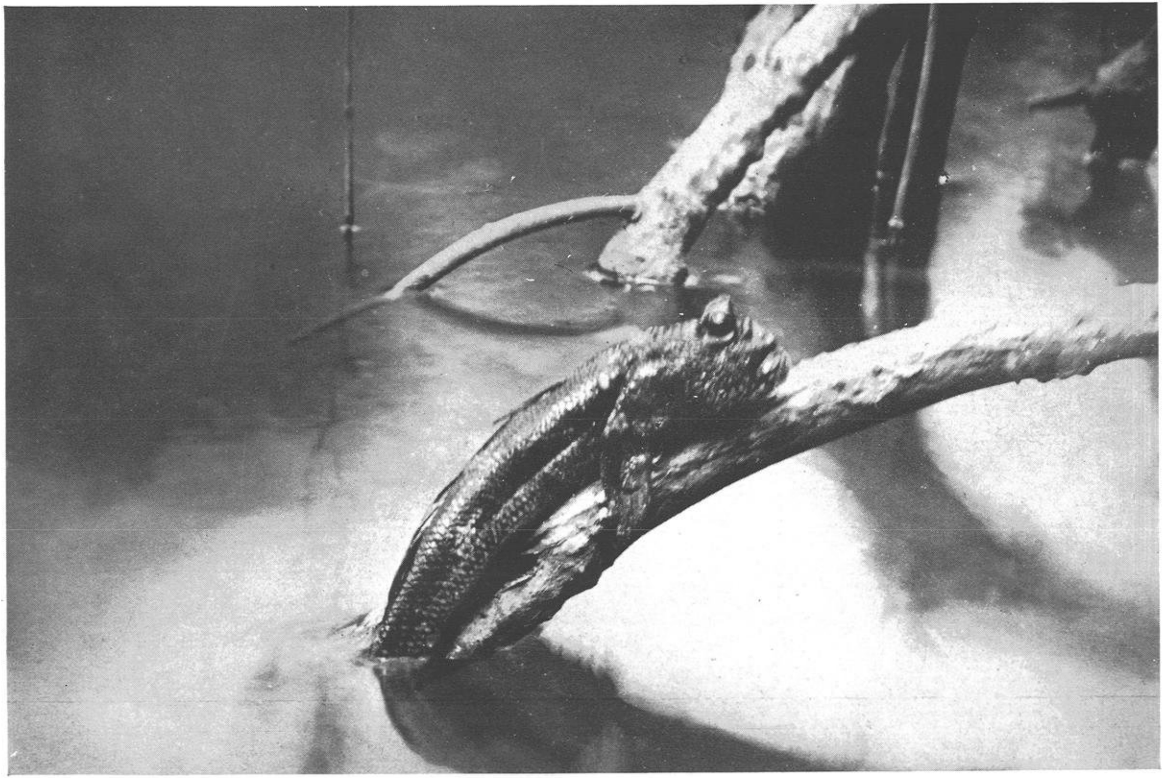
The lowest fishlike animal to which we have so frequently referred, the lancelet, has no true mouth equipped with jaws, teeth, etc., so that a number of flesh strings are necessary to fan the water into the body cavity. It first passes through a great number of slits near the breathing surfaces, and then drops back to the body cavity to be ejected at a special single vent.

But regardless of how the water is drawn in or ejected, the result is the same, that is, the water flows in a more or less continuous current over the gills. Thus an ideal condition for the interchange of oxygen and body wastes through the capillary walls is provided, and one not very different from that found in air-breathing vertebrates. In the one group of animals a new supply of water containing oxygen is provided continuously, while in the other a new supply of air is constantly furnished. The final results clearly are identical.

The gill arches in many species have teeth or bristles on the anterior edge, extending in the opposite direction from the gill filaments. These structures are called gill rakers and are only indirectly connected with respiration. While not actually raking the gills, as the name implies, they do at times serve the purpose of keeping foreign particles from reaching the gill filaments and interfering with the proper functioning of the latter. In certain species, as for example in the spoonbill cat, in which they are long, numerous, very close-set, and bristlelike, the gill rakers form a sieve for screening from the water the small plants and animals upon which the fish feeds (see Plate 27). In some species the gill rakers, however, are so short that they can serve no useful purpose, and sometimes they are even missing.

But not all fishes breathe by means of gills only, though gills, of course, constitute their principal organs of respiration. The skin, as in the amphibians and reptiles, serves fishes as an important auxiliary respiratory mechanism and it is said that a few fishes, if left in well aerated water, will live a long time even after their gills have been taken out. Some species have special subsidiary and accessory structures for breathing. The codfish has two flaps or folds of skin just inside the mouth, called breathing valves, which are believed to aid the fish in swallowing the water in the process of respiration. The climbing perch of India has a contrivance for holding moisture above the gills, from which it obtains its oxygen when out of the water. The walking goby or mud skipper breathes by means of a special structure in his tail. This enables him to sit, as he often does, with his head exposed, leaving only the tail in the water (Plate 17). All breathing membranes, whether gills or lungs, must be kept moist. Generally those fishes—other than the species provided with lungs—which are able to retain enough water to keep the gills moist, live longest out of water, whereas those that throw the mouth and gill covers open die very quickly.

Some species come to the surface not only to catch insects but because the water there contains more oxygen than it does elsewhere. The mosquito-eating fish, *Gambusia*, for example, which generally occupies stagnant water suitable for mosquito breeding, stays at the surface almost constantly during hot weather and more particularly so during the heat of the day. On the other hand, in cool weather and on cloudy days it is much less in evidence, for then it lives at some distance below the surface. It seems justifiable to conclude that this change in habit is determined largely by the supply of oxygen, which



Goggle-eyed mudskipper, *Periophthalmus argentilineatus*, of Australia, breathing through its tail in the water. From photograph by A. R. McCulloch in the *Australian Museum Magazine*

changes with the temperature. We learned, furthermore, in transporting this fish, that a comparatively small amount of water, not exceeding a depth of five inches, in a container having a diameter of about sixteen inches, was more advantageous than a larger amount. When the depth of water is not great a large amount of oxygen in proportion to the quantity of water is taken up, and the fish is obliged to stay near the surface, where the oxygen is being absorbed from the air, and so suffocates less readily than in deeper water.

Other fishes come to the surface regularly to take gulps of air and from this habit several interesting organs have been developed. In some of the catfishes, for example, a bony support projecting from one or more gill rakers is lined with a vascular membrane which, it is believed, enables the fish to breathe air in part. In still other fishes the air passes into lunglike pockets or sacs.

This leads us to the few primitive fishes, such as the lungfishes, the fresh-water gar pikes, and the bowfin, in which the air bladder is vascular and forms a primitive lung, enabling these fishes to breathe air. Because of it, as we have seen, they can remain alive out of water for comparatively long periods of time.

The Air Bladder

The air bladder is somewhat of a mystery to icthyologists, who can not say for certain how it developed. Though the majority of fishes possess it, some have lost it and others never have had it. Furthermore, it does not serve the same purpose in all the species in which it is present, but on the contrary, its uses are quite varied and unrelated. A fact that further complicates the subject is the presence of the air bladder in one species with certain habits and its absence in another species with comparable habits. In structure, likewise, the organ presents a wide range.

No fishes lower in the evolutionary scale than the sturgeon forms, show any traces of an air bladder. At the other end of the scale, that is, among the highest of the bony fishes, the organ is also apt to be missing; but here the case differs from that of the sharks, for whereas the latter have never had one, the bony fishes without it generally appear to have lost it. Many bottom-dwelling species, such as the flatfishes and the rays, do not have the organ, and it is missing, also, in the sluggish pipefishes which generally live in vegetation in shallow water or drift with floating plants. But the air bladder is wanting also in such an active pelagic swimmer as the adult common mackerel (although present in the young), while the closely related chub mackerel has one. Furthermore, among the rockfishes of the Pacific coast of America, species with and without this organ sometimes are scarcely distinguishable externally. What law governs all these divergencies?

As to its structural variations, we find the air bladder ranging from a small and simple sac, in some species, to a large organ, with or without appendages, in others. Again, it may be paired or unpaired, divided by a lengthwise partition or by cross partitions and structures, or it may be cellular in structure, similar to a lung. Sometimes it lies almost free in the abdominal cavity, again it closely adheres to the back, and occasionally it is inclosed, at least partly, in a bony capsule formed by the backbone. Finally, the organ may connect with the gullet by a tube, it may contact with the ear, or it may be closed entirely, in which case it is generally compressible and expansible.

The wall of the air bladder is composed usually of two layers of membrane, of which the outer one is shining silvery in color and is supplied with muscular fibers. Incidentally this is the material from which isinglass, a very pure gelatin, is manufactured. The inner layer of membrane contains many blood vessels. The organ is filled with gas which consists principally of nitrogen in freshwater fishes and of oxygen in salt-water forms. It has been determined that these gases, where the air bladder is completely closed, are, in part at least, secreted from the blood.

Writers commonly have compared the air bladder with the lungs of the air-breathing vertebrates; and, as already shown, in some of the primitive fishes like the lungfishes, the fresh-water gar pikes, and the bowfin, the organ is modified into a cellular structure, resembling lungs, and serves undoubtedly as an aid to respiration. However, in most fishes it appears to have nothing to do with

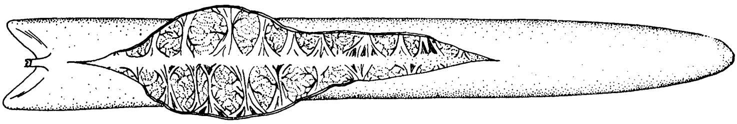


FIG. 38. Air bladder of fresh-water gar pike, cut open to show lunglike interior structure

breathing but to serve either as an organ of hearing, or an organ of equilibrium, or occasionally even an organ of "voice." Certainly air bladders resemble lungs in so many important characters that it is difficult to regard these organs as entirely distinct in their origin. Moreover, the air bladder occupies a place in the abdominal cavity generally occupied by the lungs in the higher vertebrates, and no other structure in fishes is at all analogous to lungs. Some authors hold that the air bladder represents a degenerated lung; that is, they maintain that at a certain period in their evolutionary history which corresponds to the first appearance of the lungfishes, some of the sea dwellers left the sea for inland waters, which dried up seasonally and forced them to adapt themselves to air breathing or perish. Thus they developed an air bladder. But subsequently some of them—the ancestors of our bony fishes—returned to an exclusively marine existence, and the air bladder as a respiratory organ lost its usefulness and either became adapted to other functions or disappeared. Other writers have held that an air bladder is an undeveloped lung, or stated conversely, that a lung is a developed air bladder. This theory, of course, is based on the assumption that the air-breathing vertebrates have been evolved from water-breathing animals. Still other investigators have taken more of a middle ground by arguing that both lungs and air bladders have been developed, presumably more or less simultaneously, from primitive breathing sacs which originally were only diversions from the oesophagus or gullet.

But the use of this interesting organ is no longer, if it ever was, primarily to aid in breathing. In the large majority of cases it now serves as a hydrostatic organ of equilibrium, aiding the fish to rise and descend in the water. In fact, the popular name for the structure is swim bladder. Deep-sea fishes which make this use of the organ pay dearly for the aid it gives them, as it limits them strictly to certain levels of pressure. Concerning the physical principles involved in this interesting adjustment, Cunningham has the following to say:

> Everyone knows that when fishes are caught and brought to the surface, even from depths of only a few fathoms, the air in the bladder expands to such a degree that the stomach of the fish is often pushed out through the mouth. When the pressure on a gas is diminished by a half, the gas expands till its volume is doubled: at a depth of only five fathoms in the sea, the pressure on a fish is double the atmospheric pressure on the surface, and increases by one atmosphere for every five fathoms of depth. It is easy, therefore, to understand that great force of expansion exerted by the gas enclosed in the air bladder when a fish is suddenly brought to the surface. The effect of the air bladder at any depth when the fish is alive and in normal condition is to render the weight of the fish equal to that of the water which it displaces: in these circumstances the fish has no tendency either to rise or sink, and can therefore keep at the same level in the water without any muscular exertion. A shark or dogfish, on the other hand, having no bladder, is heavier than the water and always has a tendency to sink; it can only keep up by the action of its tail and fins. If, however, the fish with an air bladder swims to a higher level, the gas in the bladder expands, the fish as a whole becomes larger and therefore lighter than the water it displaces, and has a tendency to rise more and more rapidly

till it reaches the surface. Conversely, if a fish with an air bladder swims to a slightly greater depth the bladder is compressed, the fish as a whole becomes smaller and heavier than the water displaced, and tends to sink with increasing velocity to the bottom. Such a fish in fact is in the condition of the scientific toy known as the Cartesian diver. This consists of a hollow figure containing a bubble of air which cannot escape because the aperture is at the lower end. The figure is placed in a tall jar of water over the mouth of which is fastened an air-tight cover of India rubber or other flexible membrane. If the figure is so adjusted that it floats just at the surface of the jar, very slight pressure on the cover causes it to sink to the bottom and when the pressure is removed the diver rises again. It is easy by adjusting the pressure of the finger on the membrane to keep the figure in the middle of the depth of water. The pressure is transmitted to the air within the figure and compresses it so that it displaces less water and therefore the figure and the air together become heavier than the water. It is evident, then, that the air bladder confines the fish to a very restricted range of depth, and it would be liable to float to the surface or to sink to the bottom at the slightest movement if it were not able to counteract the effect of changes of pressure by muscular compression or relaxation of the bladder or by increasing or diminishing the amount of gas in the bladder. This power, however, it can only exercise within narrow limits, and if suddenly brought to the surface it is quite unable to descend again. Fish caught to be kept alive in an aquarium are often, though otherwise uninjured, in this condition and float helpless at the surface. By pricking the air bladder with a needle through the side of the body some of the air is allowed to escape and then the fish recovers and may live for an indefinite time, whereas if left to itself it would very soon die.

It is evident from the above that an air bladder would be unnecessary to a fish which lived on the ground, and a positive disadvantage to fishes which require to change rapidly from one depth to another. Accordingly we find that in ground-fishes the air bladder is wanting, having disappeared in the course of evolution. It is entirely absent in the Pleuronectidae or flatfishes, in the Cyclopteridae which cling to rocks by means of their suckers in shallow water, and in many of the littoral Blenniidae. Its absence in many of the Scopelidae seems to be related to the habit of these phosphorescent fishes of coming to the surface at night and sinking to considerable depths during the day. In the mackerel some species like the common British species have no air bladder, and others possess one, although it is never very large; these are active predacious fishes which change their depth very rapidly.

In the carp and its allies and in the catfishes the air bladder has remarkable special connections with the ear through a chain of modified vertebrae. It appears, therefore, that in them the organ aids in hearing, though it is difficult to prove this fact experimentally. In many other fishes, including the cod and sea-bream families, the air bladder also connects with the organs of hearing, though the mechanism of connection is different.

This same curious organ appears also to help in the production of sound, for in some species it is associated with drumming or croaking which is the nearest approach to a voice in our common food fishes. The croaker and the squeteague have developed this capacity more fully than any other fishes. In the former both sexes are able to croak, and the sound can be heard at a considerable distance below the surface of the water. Furthermore, it continues after the fish is landed. In the squeteagues, or weakfishes, the male only has a "voice." The croaking or drumming structure consists simply of the air bladder and of a pair of muscles, one lying in the side of the abdominal walls on either side of the median line of the belly. These muscles are in close contact with the large gas-inflated air bladder and by rapid contractions they beat on it so that it acts as a resonator, producing the peculiar croaking or drumming noise familiar to those who have fished on the seashore.

All in all, we may say that no organ performing an important function presents such an extraordinary degree of variation in related species. Such great variations generally are interpreted to indicate that the organ has no important function or that it does not retain its original function. If that be the case, then what was the original function of the air bladder? The resemblance between the structure and a lung and their probable common origin already has been pointed out, and the most generally accepted and apparently the most plausible view is that air bladders, even though now ductless in many species, all originally were connected with the gullet and were organs of respiration. This does not mean, as I see it, that air bladders once resembled lungs, or that they were highly developed structures, for they may have been simple air sacs, consisting of diversions from the gullet. Regardless of structure and development, their function, however, was that of respiration.

The Digestive Tract

The alimentary canal, or the intestinal tract, in fishes may be long and greatly twisted and coiled, or it may be a short and nearly straight tube. In some species its total length scarcely equals that of the body, while in others it is several times as long as the fish and so more closely resembles that of the mammals. In general, a short and simple alimentary canal is associated with those species that feed on an animal diet, and a long and complex tract with those feeding on plants.

The intestinal tract, as a rule, is divided into four parts, namely, the oesophagus or gullet, the stomach, and the large and small intestine. However, in the lancelets, for example, the alimentary canal is a simple, straight tube without evident subdivisions, while in the lampreys the oesophagus is distinguishable from the stomach.

In the bony fishes the stomach is differentiated as an enlarged pouch with an opening at each end or as a blind sac with both the entrance, or cardiac opening, and the outlet, or pyloric opening, close together. Very often blind appendages, known in textbooks as pyloric caeca, which vary from a few to many in number, are attached near the pyloric opening and secrete a pale digestive fluid into the stomach.

In the various species of mullets and in the gizzard shad, which feed on minute plants and animals mixed with mud, the walls of the stomach are greatly thickened, becoming as muscular as the gizzard in a chicken. On those seashores where mullets are taken in large quantities and are opened for salting, the boys of the poorer families often get permission to remove the gizzards from the entrails before they are thrown overboard. When the fish are perfectly fresh, the muscular stomachs have a fine flavor quite unlike other fish meat; but if the animals are not eviscerated very soon after they are caught, the gizzards become bitter and of unpleasant taste.

In accordance with the rule that fishes feeding on plants have long digestive tracts, we find an excessively long canal in the stoneroller, a fresh-water minnow of the Mississippi Valley. Incidentally, in this fish the mysterious air bladder fills a new role, though apparently a passive one, for the very long intestine filled with vegetable matter is wound around the air bladder somewhat after the fashion of thread on a spool. In all other fishes possessing an air bladder except the fringe-fin, this organ lies on the dorsal side of the intestinal tract.

In the sharks and skates, and to a smaller degree in the fresh-water gar pikes and the bowfin, the large intestine is provided with a peculiar structure known as a spiral valve, which may have as many as forty gyrations. This valve greatly increases the digestive surface of the intestine and eliminates the necessity for a long tract (Fig. 39).

Situated within the abdominal cavity and connected with the alimentary canal are several small organs of more or less importance as organs of nutrition. Behind the stomach in the sharks and many other fishes occurs a glandular mass, the pancreas, which throws its secretions into the small intestine through a separate duct or through one that is coalesced with the bile duct. In the true fishes the liver is a large brownish gland, irregular in shape, and fills a considerable part of the abdominal cavity. Usually, though not always, this organ is provided with a gall bladder and a bile duct as in the higher vertebrates. The spleen, a dark-red gland, is present in all fishes except the lancelets, but its function, as in the higher vertebrates, is obscure.

The opening of the intestine, the vent, generally occurs a short distance in front of the anal fin. In a few species, however, as in the fresh-water pirate perch, it lies almost at the throat in the adult, although normally placed in the young. Behind the vent and generally at the beginning of the anal fin, is a second opening, known as the urogenital, which provides a passageway for the eggs and semen.

It is evident, therefore, that the alimentary canal and the accessory organs in fishes do not differ greatly from those of the higher vertebrates, which, however, have no spiral valve or pyloric caeca, unless the latter correspond to the troublesome appendix in man.

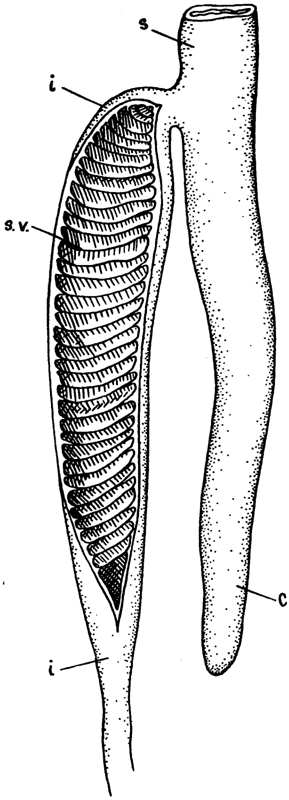


Fig. 39. Stomach and intestine of *Chirocentrus dorab*, cut longitudinally. s, stomach; i, intestine; s. v., spiral valve; c, caecum. After Lankester

Circulation of the Blood

Respiration by gills or lungs implies, of course, circulation of the blood, for if its contact with the oxygen supply were not constantly renewed the animal would asphyxiate. So fishes, in common with the higher vertebrates, have a circulation of blood to the organs of respiration for purification and replenishment of oxygen, and another which carries food and oxygen to the tissues of the body.

The lowest fishes have this difference in circulation from the highest vertebrates, however, namely, that in them only a part of the blood really goes to the gills as it makes its round trip; some of it passes on by other branches and goes around again in the circuit. Such fishes are said, therefore, to have a mixed circulation, one in which the aerated and used blood are mixed.

The motor which provides the power to keep the blood in circulation is, as in other vertebrates, the heart; but this organ in fishes is a simple structure, comparatively

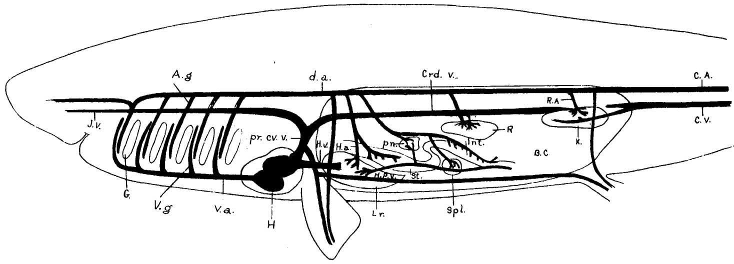


Fig. 40. Semidiagrammatic side view of the blood-circulation system of dogfish shark. H, heart; R, reproductive organ; d. a., dorsal artery; Spl, spleen; Lr, liver; K, kidney; R. A., renal artery; pr. cv. v., precaval vein; pn, pancreas; V. a., ventral artery; G, gill opening; J. v., jugular vein; V. g., vein to gill; A. g., artery to gill; C. A., caudal artery; C. V., caudal vein; St, stomach; Int, intestine; H. p. v., hepatic portal vein; H. a., hepatic artery; H. v., hepatic vein; Crd. v., posterior cardinal vein; B. C., body cavity. After Hegner

small, and situated between the chamber containing the gills and the abdominal cavity. It is not the paired organ found in mammals, for it has a single auricle and a single ventricle. In addition, it has an enlargement where the veins enter and a bulb at the base of the large artery which carries the blood to the gills.

The blood in fishes generally is thin and pale red. The corpuscles are elliptical in shape (except in the lancelets, in which they are round). Circulation is rather slow and, since fishes are cold-blooded creatures, the temperature of the blood seldom rises much above that of the water in which the animals live.

Nerves and a Brain

For the direction of all this complicated mechanism, the broad outlines of which we have spent so much time in sketching, fishes possess, as do the higher vertebrates, a nervous system consisting of a brain and a spinal cord with sensory and motor nerves, but the whole system is relatively small and less developed than in the higher forms. Particularly is this true of the brain, which, incidentally, is proportionately smaller in adults than in the young, indicating that its growth does not keep up with that of the rest of the body.

Aside from its small size, the brain is chiefly distinguished by the great development of the cerebellum and the insignificance of the cerebral hemispheres in most fishes. A good deal of the brain case is taken up by a fatty substance, while the gray matter, or nerve cells, occupies the small remainder. It is of interest to note that the brain increases in size the higher up we go in the evolutionary scale in fishes. Thus the common perch and other bony fishes have relatively much more gray matter than the large sharks.

With such a poorly developed nervous system, it is not surprising that a fish lives to eat and that nearly all its efforts appear to be devoted to that purpose. The low state of development of the nervous system apparently explains, also, why a fish is so insensible to pain that it will continue to feed with a torn and lacerated mouth, or even with a couple of fishhooks in its gullet, as shown elsewhere.

CHAPTER IV

SEX AND REPRODUCTION

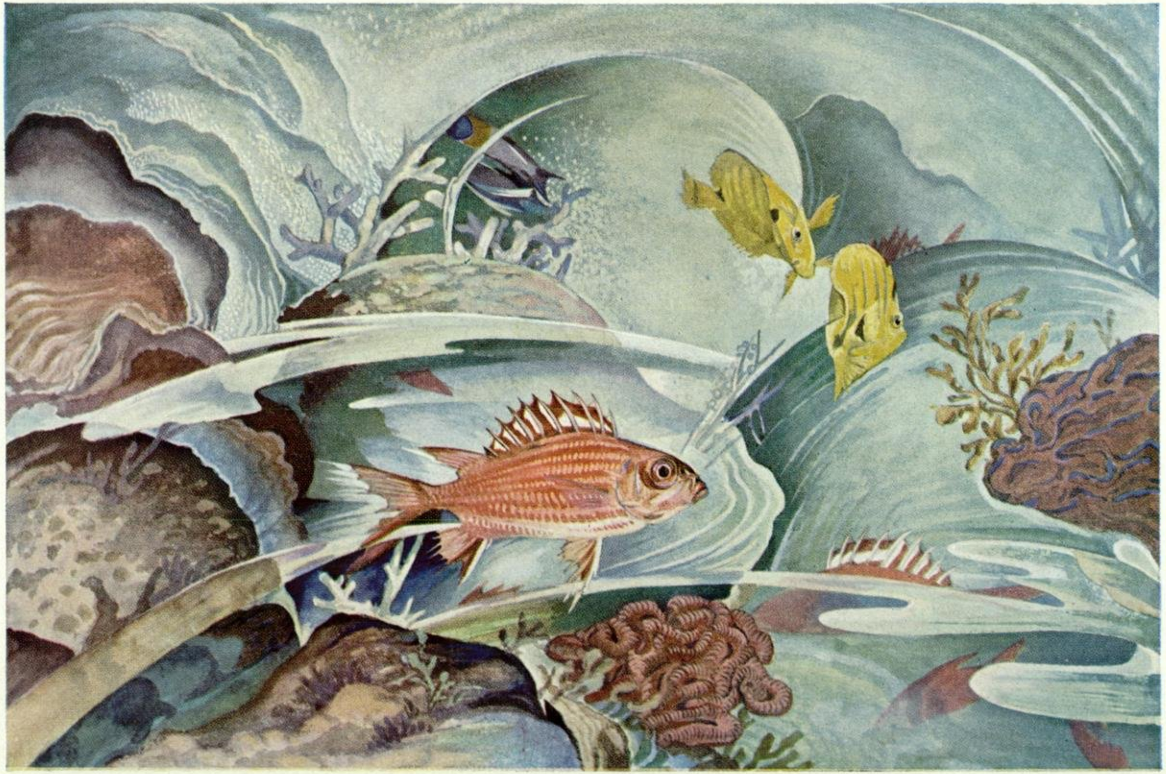
ALL fishes normally are of distinct sex, as in the higher vertebrates. Hermaphroditism, where both sexes exist in one individual, occurs among fishes but rarely and usually is an abnormal condition. In some of the European sea perches, however, it is encountered so constantly as to render its abnormality doubtful, although some individuals of this species are distinctly male and others are distinctly female.

In many fishes the two sexes, unlike most mammals and birds, so closely resemble one another that they can not be distinguished externally. But any one of a number of special characteristics, such as externally developed sex organs, modified fins, or more numerous, stronger or higher spines may identify the male in a number of species; in other species such distinguishing characters as horny processes on the head or different coloration may be developed, especially during the breeding season.

Sharks and skates, as we saw in dealing with fins, have peculiar structures attached to the ventral fins known as claspers, an incorrect term, as they are not structures for holding the female but sex organs for conveying the sperm to the female. Naturally, the presence of such organs means that in the species having them fertilization is internal. The male chimaeroid, however, though he possesses an intromittent organ, also has claspers which really serve the purpose of holding the female.

Internal fertilization takes place in several widely separated groups, so that we must conclude it to be a

PLATE 18



Squirrel fish, *Holocentrus*, of Honolulu, with butterfly fishes in background. By Stephen Haweis

process independently developed in many cases, and we need not be surprised to discover several quite dissimilar adaptations for making it possible. Thus, while the sharks have modified the ventral fins, several of the top minnows, including *Gambusia*, the mosquito fish, have united and lengthened more or less the anterior rays of the anal fin for the same purpose. In this process the whole fin, normally placed in the young, is moved forward in the adult.

Fishes compare favorably with birds in the wealth and brilliance of coloring exhibited among them. Some, at least, of this coloration has a definite connection with sex and enables us to distinguish the male from the female. Thus the male of the striped killifish (*Fundulus majalis*) has black crossbars, whereas the adult female has one or two black longitudinal stripes along the sides with a few vertical bars on the tail. The mature female of the common killifish, or mummichog (*Fundulus heteroclitus*), is a uniform somber gray above with a white belly, but her mate, especially during the breeding season, wears a much brighter coat, dark green to olive on the back, blending into silver on the sides and with the belly yellowish to orange. The sides, furthermore, are decorated with several narrow pale silvery bars and many irregular pearly and yellowish spots.

The male of the red-bellied dace (*Chrosomus erythrogaster*), an inhabitant of small, clear brooks of most of the United States east of the Rocky Mountains, becomes bright scarlet on the chin, chest, and belly, whereas these parts are white and overlaid with silver in the female.

A sex-recognition mark of quite another sort occurs in the weakfish, a species in which the male may be distinguished from the female by a thickening of the abdominal wall on each side of the median line of the belly. This thickening is due to the presence of the croaking muscle, already described, which is possessed by the male only.

In the salmon, especially the Pacific coast species, the adult male is recognized at the spawning season by a greatly distorted mouth, the jaws and teeth being produced and twisted to such an extent as to prevent the closing of the mouth, and by the development of a distinct hump at the shoulders. Male trout show similar modifications but not to the same exaggerated degree.

The various nuptial adornments of the males may not be of any special value to the fish. Certainly no direct evidence that the brilliantly adorned males are preferred, nor in fact that a special selection of males takes place among fishes, is available. Nevertheless, such males generally are the most mature and vigorous and that in itself gives them a certain advantage over other males. Attention may be called to the fact that among fishes the male wears the brighter colors, a contrast to the custom in the human race of the present day.

The internal sex organs of fishes consist of paired ovaries and testes. However, in some of the very elongate species, as in the salt-water gar pikes, or houndfishes, only one of the organs is developed. In the top minnows, as for example in *Gambusia*, the organs are coalesced. The ovaries, in general, have proceeded further in this direction than the testes. In both sexes the reproductive organs generally are arranged symmetrically, one on each side of the posterior part of the abdominal cavity and above, or dorsally of, the intestines. During the breeding season these organs, particularly the ovaries, become greatly swollen with the sex products, frequently so much so as to distend the abdominal walls and to make the fish pot-bellied. Ripe females frequently may be recognized by this distortion. During the remainder of the year the sex organs are small and collapsed, and often the ovaries can not be distinguished from the testes, except by microscopic examination of the contents. When the organs are active the ovaries with their contents are reddish to yellowish in color, whereas the testes are whitish to pinkish and their secretion is milk-white.

While a large majority of fishes lay eggs and are called oviparous, several species, as already indicated, produce live young and are said to be viviparous. What determines this difference in the mode of reproduction we do not know for certain, as the viviparous habit is widely scattered among families, and yet it may be present in one species and absent in another closely related. It would appear, therefore, to be not necessarily the result of conditions but largely accidental. In most cases, of course, it follows from development of internal fertilization of the ovum. The egg-laying forms usually produce a much larger number of ova than those that give birth to young, but we find a very great range in the number of eggs laid among different species, as well as within a species. In general, fishes that produce large eggs lay a smaller number than those that have small eggs, and a large fish will produce many more eggs than a small individual of the same species.

According to one author, 25,000 eggs have been counted in a herring, 155,000 in a lumpfish (another author claims that one lumpfish may have considerably more than 1,000,000 eggs), 3,500,000 in a halibut, 635,500 in a sturgeon, and 9,344,000 in a cod. It has also been reported that the red salmon and king salmon, which have comparatively large eggs, produce, respectively, about 3,500 and 5,200 eggs. The gaff-topsail catfish, a marine species which has eggs about an inch in diameter, usually lays only some two dozen at a time, with a known maximum of fifty-five. The size of the egg in all cases is determined, of course, by the amount of yolk on which the embryo is nourished during gestation.

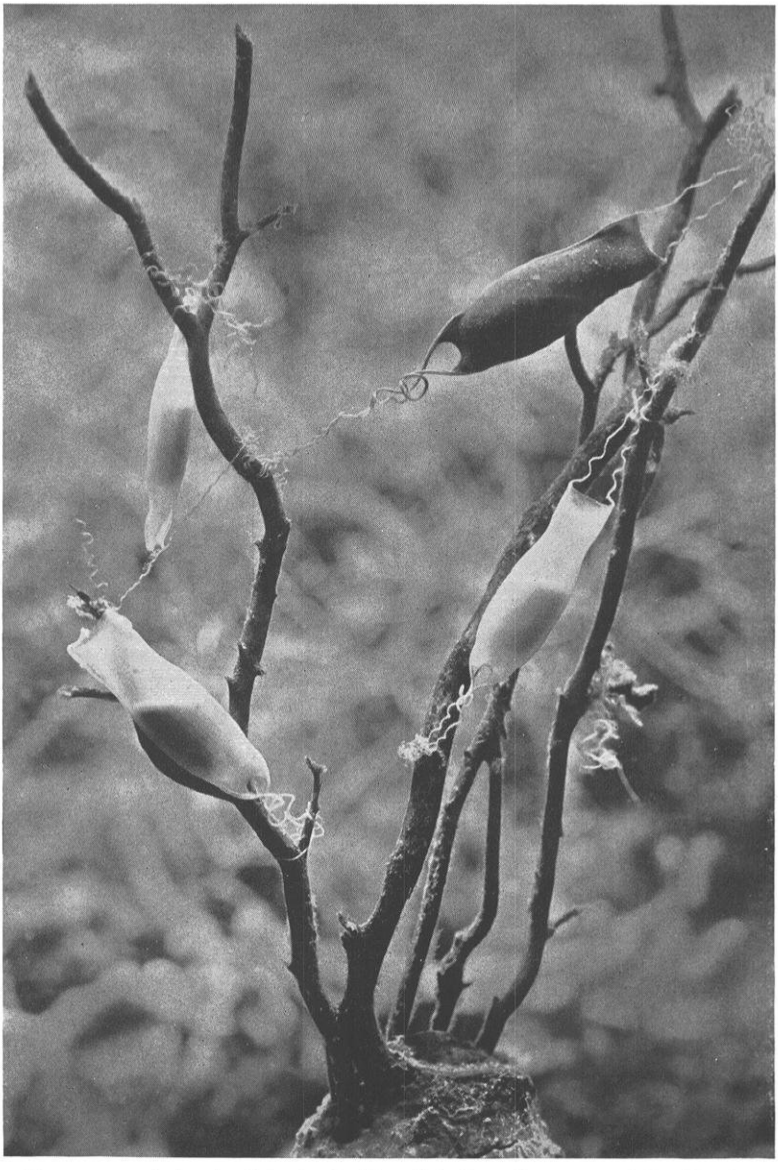
As an example of the small number of ova produced by viviparous forms, some of the skates are reported to give birth to only two young at a time, while none produce very many. The maximum number known for sharks is not more than a dozen.

In contrast to the large sharks with their small broods, the tiny viviparous top minnows generally give birth to big families, though these offspring are far fewer than the usual number of eggs laid by the oviparous species. *Gambusia*, for example, the female of which measures about 1¾ inches, is known rarely to produce upward of 200 young at a time. A litter of 100, however, is a large one and the average number for a female probably does not exceed twenty-five. But each of these may measure half an inch in length, which is astonishing, considering the size of the mother.

No viviparous fishes, exclusive of a few sharks, have any semblance of a placenta and the embryo receives no nourishment from the blood of the mother, though, of course, it obtains oxygen from the maternal supplies. In general, the principal differences in the process of reproduction between oviparous and viviparous fishes lie in the methods of fertilization and incubation of the eggs. The eggs that are laid, usually but not always, are fertilized externally and incubated in the water. In all fishes that give birth to live young the eggs are fertilized and incubated internally. Several species of sharks and skates constitute exceptions to the general rule of external fertilization of eggs that are laid. With them, after internal fecundation, gestation takes place externally, the ova being inclosed in horny cases much like the hen's eggs, but of various sizes and shapes. The egg cases of the bullhead sharks are spirally twisted; those of the cat sharks are quadrate with long filaments at the angles. Nearly every visitor to the seashore has seen the egg cases of the rays, sometimes called "mermaid's purses." They are almost square in shape and each corner is provided with a hornlike projection, stiff rods, or tendrils. One such case may contain several eggs and hatch out several young.

The history of fish eggs from the moment of extrusion contains much of interest and varies greatly with different species. The higher fishes may cast their eggs loose in the water, or lay them in nests. In either case, they are

PLATE 19



Egg cases of the dogfish shark (Squalidae). Courtesy of the Naples Aquarium

fertilized immediately upon being laid, the male fish generally remaining near the female during deposition, and exuding in extravagant quantities his secretion, the milt, into the water. Only very little of the milt containing the spermatozoa needs to come in contact with the eggs to accomplish fecundation, for only one spermatozoon can enter each egg.

In shape the ova are usually spherical, though a few, as for example those of the anchovy, are elongate. The very great variation in size has been referred to already. Many common marine fishes have pelagic eggs (eggs that float at or near the surface) only about one millimeter (one twenty-fifth of an inch) in diameter, while those of the salmon and trout range from three to five millimeters. Small eggs, as a rule, hatch much more quickly than large ones: those of the small goby known as the scallop fish, for example, which are considerably less than a millimeter in diameter, have been hatched in eighteen hours, whereas the average incubation period for salmon eggs is about one month. The length of time required for hatching is, of course, greatly affected by the temperature, and roughly five days' difference must be allowed for every degree of change in the water temperature. Most of the floating eggs of the marine fishes of the Middle Atlantic States of America laid during the summer, such as the eggs of the pigfish, or hogfish (*Orthopristis chrysopterus*), require an incubation period of only about forty-eight hours.

Young fishes born alive generally are larger and better developed than are those hatched from eggs. They usually resemble the adult in nearly all characters and, in contrast to the absolute helplessness of those hatched from small eggs, are fully able to take care of themselves at birth. The chance of survival among such young appears to be excellent, and it may be for this reason that nature again has provided for a small number of offspring in comparison with those of most egg-laying species.

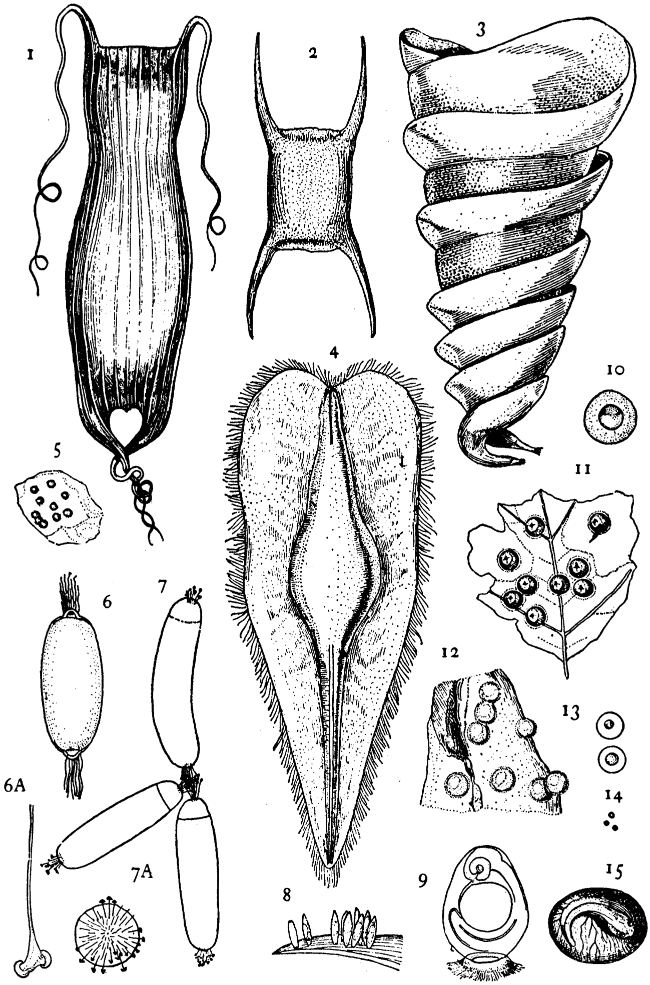


FIG. 41. Eggs and egg cases of various fishes: Egg cases 1, of cat shark; 2, of skate; 3, of Port Jackson shark; 4, of chimaeroid; 5, lamprey eggs; 6, 6a, hagfish, *Myxine*, eggs and terminal process thereof; 7, 7a, hagfish, *Eptatretus*, eggs in cluster, and terminal hook processes; 8, blenny egg capsules attached to seaweed; 9, enlarged blenny egg showing mode of attachment of capsule; 10, lungfish egg; 11, sturgeon eggs attached; 12, gar-pike eggs attached; 13, sea-bass eggs; 14, shad eggs; 15, catfish egg, showing larva. Courtesy Bureau of Fisheries

Where the egg is tiny the young are very small and helpless, some of them being less than two millimeters long. Generally, they float on the back, drifting with the winds, waves, and tides until the yolk is all absorbed. Then they orient themselves, though still scarcely three millimeters in length. The critical time has now come, for the little fishes must have food or they will die very soon. All depends on whether they are fortunate enough to have drifted to a spot where the microscopic organisms upon which they feed are available. Often the chances are against them, and the mortality must be exceedingly great at this critical stage of their lives.

The young hatched from such large eggs as the salmons lay have attained an inch or more in length by the time the yolk is all used up, while the extraordinarily large eggs of the gaff-topsail catfish hatch young measuring two inches or more. Such fry certainly have a much better chance to survive than the helpless little creatures mentioned in the preceding paragraph. Nature apparently provided for a heavy loss among fishes that lay small eggs, like the codfish and pigfish, through the extraordinarily large number of ova produced. If a fish were matured from each egg laid by such species, it is apparent that the sea would soon become crowded.

The most interesting and important habits of fishes, as of other animals, have to do with reproduction. On them the continuance of the race depends; they involve the most complex activities. The attention which different species give to their eggs and young ranges from almost complete indifference to nest building and postnatal solicitude. Even the many species, both from salt and fresh water, that build no nests and cast their eggs loose, have more or less definite spawning grounds, certain supposedly favorable areas to which they go annually to reproduce their kind.

The eggs of many marine species are pelagic. Parental care in such species ends with the laying of the eggs in some locality where the conditions for hatching normally are favorable and where food is available for the newly hatched young. It is readily understandable, however, that adverse weather conditions, such as storms causing the eggs to be carried far away from the spawning grounds, or an excessively high temperature, might result in a heavy mortality among the eggs or the newly hatched young, or both. Many investigators believe that the great fluctuations in numbers which take place from time to time among marine fishes are due, at least in a very large measure, to weather conditions during the spawning period. A poor hatch, regardless of the cause, is almost certain to be reflected when, after the young of that year mature, only a few fish return to the spawning grounds; moreover, a single year will not suffice to restore the depleted numbers to normal.

Some marine species and nearly all fresh-water species have eggs that are heavier than water, generally referred to as demersal eggs. A number of these species simply cast their eggs in the water to sink to the bottom and be left to chance. If, by good fortune, they fall on favorable ground, they will hatch; if they fall on muddy or otherwise unsuitable bottom, they probably will perish.

A considerable number of fresh-water species show more concern for the fate of their progeny and build some sort of nest. Often, as in the case of nearly all the fresh-water sunfish family (Centrarchidae), the nest consists only of a spot on solid bottom (clay, sand, gravel and the like), swept clean and bare probably by the fanning with the lower fins of one of the parent fish, a duty which almost always falls to the male. Laymen refer to this nest building as bedding. When the eggs have been deposited in the nest, the male fish stands guard, fanning the eggs with his fins, probably partly for the purpose of keeping them free of sediment and partly for proper aeration. In case an intruder approaches, the sentinel will wage a game fight in an effort to drive the enemy away.

The nest building of the American bowfin (*Amia calva*), reveals extensive care on the part of the male parent, which Jacob Reighard describes as follows:

In water of 30 to 60 centimetres depth with abundant growing plants, males select small areas on the bottom which are relatively free of growing plants and are often concealed, and from these, by movements

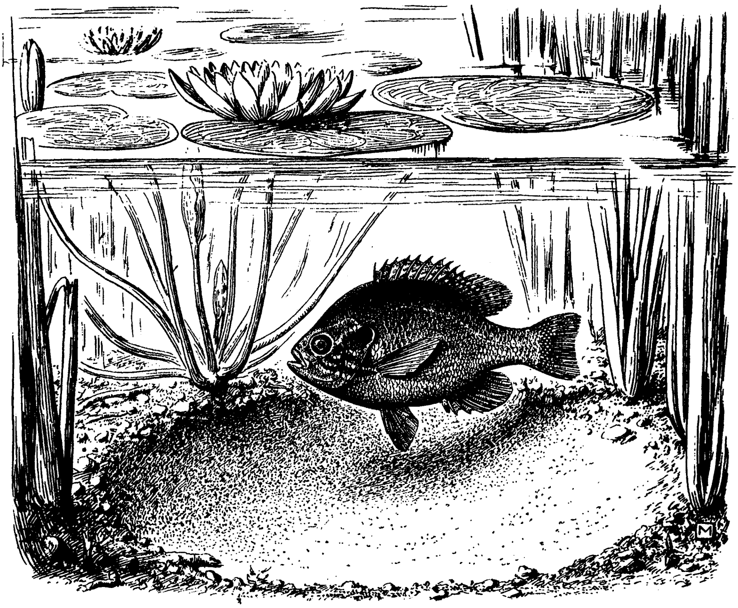


FIG. 42. Common sunfish, *Eupomotis gibbosus*, on nest

of the body and fins and perhaps by biting, they remove the few plants and the bottom ooze so as to leave exposed the fibrous roots of the plants or the sand, gravel, or other subjacent material. The nests are thus excavated in the absence of the females and chiefly at night. Their proximity to one another varies with the number of males as related to the area of available spawning ground and with the character of the ground. These nests, while still empty, are guarded by the males for usually twenty-four to thirty-six hours, but often for a much longer time. They are then usually approached by the females and spawning takes place. If the female does not appear, the nest is abandoned. The spawning is intermittent, and the characteristic spawning movements last from one to three hours, during which the fish are very active. During the spawning movements there is no evidence that the male displays his colors before the female. . . . In some cases a single female probably spawns in more than one nest. A single male may, after an interval of some days, receive a second female into his nest, and her eggs may be laid along with those previously in the nest or may supplant them. The number of eggs laid in a nest varies greatly. I have seen as few as 25 freshly laid. Their maximum number is probably many thousand, but I have never counted them. They may be over the whole inner surface of the nest, on the bottom only, or on one side only. If fibrous roots are present they are invariably on these.

For size of nest, probably few equal that built by *Heterotis*, the African genus of the Osteoglossidae, which measures up to four feet in diameter. Its walls are eight inches thick and are made of grasses cut from the interior, which is left smooth and bare. The nest is said to have the appearance of a miniature lagoon among the dense aquatic vegetation.

The small sticklebacks (Gasterosteidae), which seldom exceed a length of three inches, have carried nest building to its highest development among fishes. The male constructs quite an elaborate nest by binding together grass or weeds by means of mucous threads which he secretes from the kidneys, thus affording, incidentally, the only verified instance of spinning among vertebrate animals. He builds the nest first and then looks about for a mate whom he seeks to entice inside. If gentle solicitations do not have the desired effect, we are told that the male drives one or more females into the nest until the quota of eggs satisfies him, whereupon he jealously guards his possession for the many days of incubation.

It is quite the usual custom for male fishes to take care of the eggs (if they are taken care of at all), and sometimes they watch over the young. The females have very little reputation as mothers to boast of, with two or three rare exceptions, one of which occurs among some catfishes, the aspredinids. In these cases, the female apparently hovers over the eggs after they are laid so that they may adhere to a peculiar soft, spongy skin structure on the lower side of the body. She then carries them until they hatch. One of the pipefishes offers another exception to the rule of female indifference to eggs and young. She has a pouch on the belly for retaining and incubating the eggs.

Pouches are also found in the common pipefishes (Syngnathidae) and in the sea horses, *Hippocampus*, but only in the males which, in accordance with the general rule, take care of the eggs. Two membranes with a slit on the median line compose the pouch, which is found either underneath the belly or underneath the tail, according to the species. Fortunately, spawning has been observed in one of the common pipefishes of the Atlantic coast of the United States, so that we know how the eggs are transferred from the female to the male receptacle. In the process the two sexes intertwine their bodies like two letter S's, the one being reversed upon the other. This brings the pouch close to the genital opening of the female for the reception of the eggs. Presumably, the eggs are fertilized at the moment they are transferred from the female to the male.

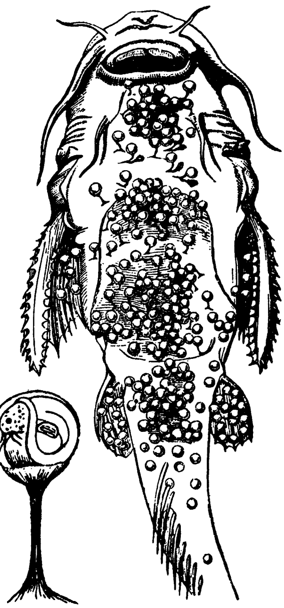


FIG. 43. Female catfish, *Aspredo laevis*, with eggs attached to under side including fins. Left, pedicel on stalk with egg attached, much enlarged

Afterwards the ova are neatly arranged in regular and even rows within the pouch where they remain for a period of ten days or so before hatching. When the young are ready to begin an independent existence, the parent permits their escape from the pouch, a structure which has been compared with the marsupium of the pouched mammals, such as the opossum. However, the two structures, although serving a somewhat similar function, are not directly comparable. In the case of the opossum the young are born when very immature and are then retained in the marsupium until they have gained considerable growth, in the meantime receiving nourishment from the mother. The pouch in the pipefishes serves only as an incubator for the eggs, the young being released soon after hatching.

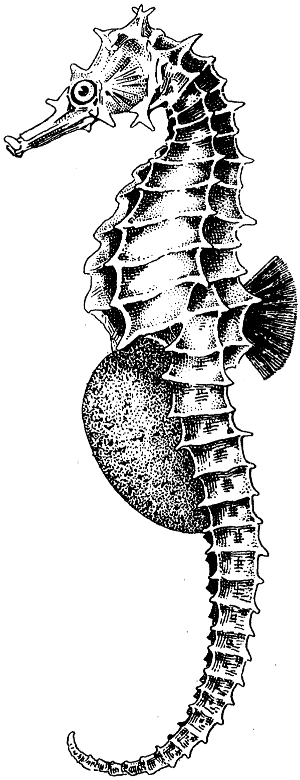
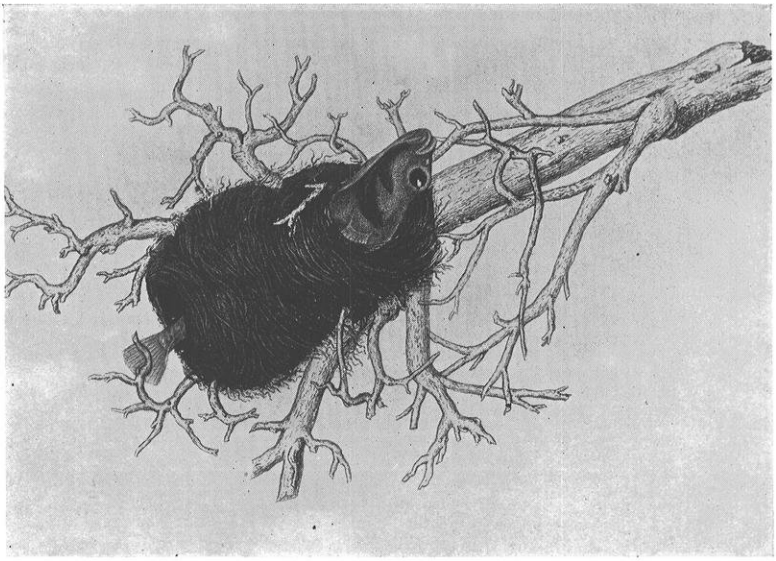
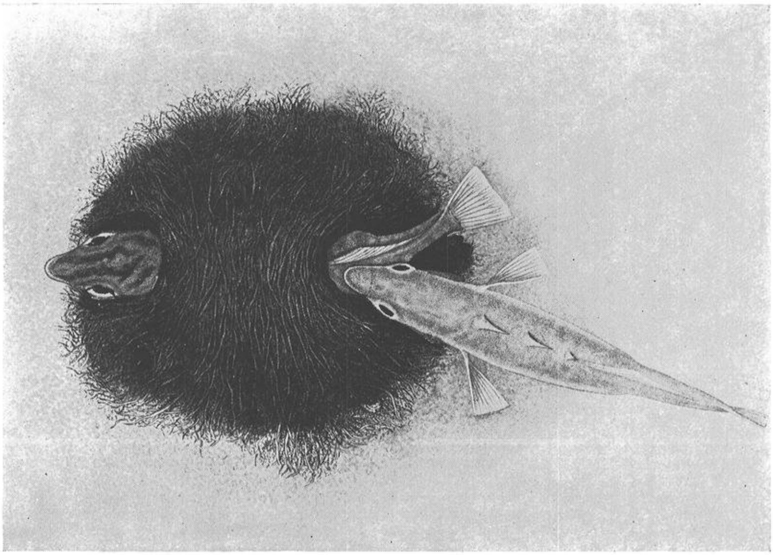


FIG. 44 Male sea horse, *Hippocampus*, with pouch for incubating eggs

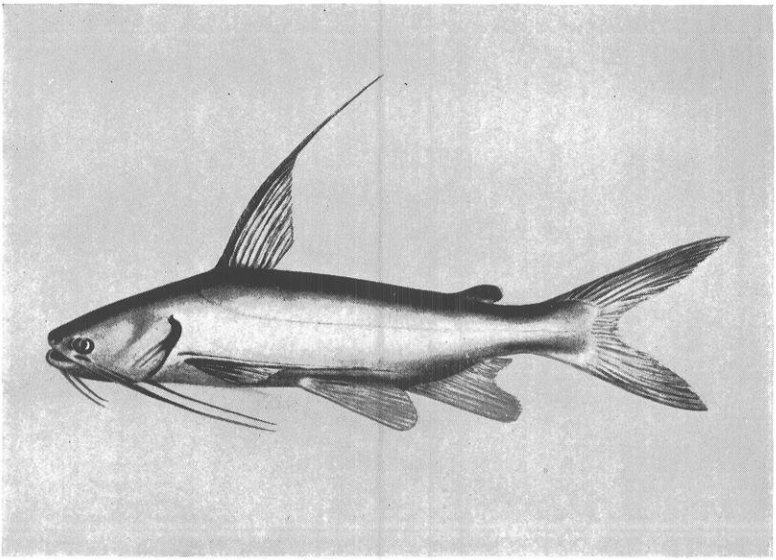
The common toadfish of the American side of the North Atlantic lays its comparatively large eggs in mollusk shells, in old shoes, in iron pipes or tubes, or any similar container available. The eggs adhere tightly to the surface upon which they are laid and are guarded by the parent fish. Some of the gobies and blennies similarly convert mollusk shells into nests to which the eggs adhere and where the male parent guards them.

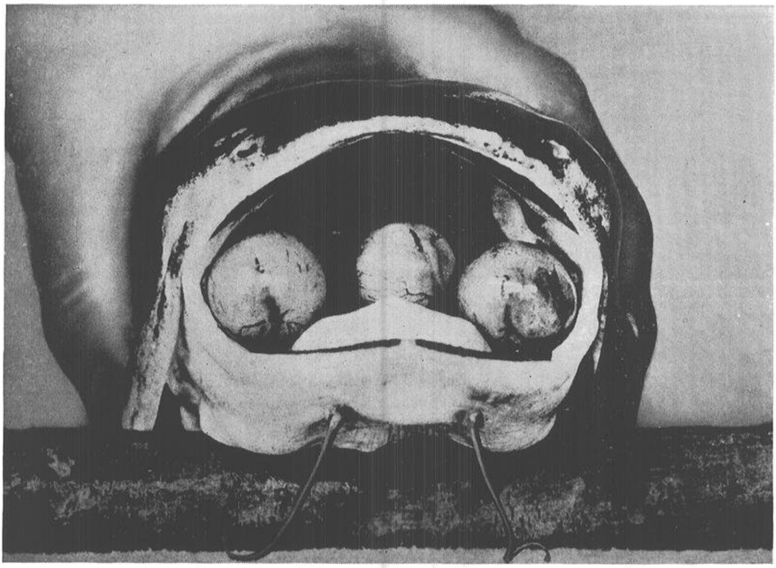
More than one species of fish makes a nest of air bubbles for its offspring. The bubbles are blown from the mouth and inclosed and held together with some secretion accompanying them. In the case of an African species of the Characinidae, which builds such a nest of floating foam, the larvae after hatching are said to hang for some time from the surface





Upper: Male ten-spined stickleback, *Pungitius*, rotating in his nest to make it tubular
Lower: Three-spined stickleback, *Gasterosteus;* male assisting female in spawning. After Coste





Upper: Female gaff-topsail catfish, *Felichthys felis*, 19.25 inches long
Lower: Front view of mouth of male gaff-topsail, incubating eggs.
After Gudger

of the water by means of a large suckerlike organ on the front of the head.

But the oddest form of parental care is exhibited by the marine catfishes, in some species, at least, of which the eggs are incubated in the mouth of the male parent (Plate 21). And not only incubated, but occasionally carried in this curious nest for some time after hatching. The eggs of the gaff-topsail catfish (*Felichthys felis*), are nearly an inch in diameter, yet as many as fifty-five have been counted in the mouth of one male parent.

How does the fish eat with the mouth cavity filled as far back as the gills, so that the throat bulges? Probably it does not eat at all while the eggs are incubating. Investigators have never found any food in the stomach or intestines of fishes carrying eggs in this way. Since the eggs are large, requiring lengthy incubation, this fasting period is probably extended and is increased by the habit of retaining the young for some time after hatching. One investigator who has made a special study of the gaff-topsail catfish states that young fish are about four inches long before they are freed from the shelter of the parental mouth. In fact, it seems certain that the parent fish has to do without food for a month or more. This would be a great hardship to the higher vertebrates, but the cold-blooded vertebrates are able to fast for long periods of time without, so far as one can tell, suffering great discomfort and certainly without any permanent injury. Many of these animals, of course, feed quite irregularly at all times, swallowing great morsels when obtainable, and then lying more or less dormant until hunger prompts another search for food.

The Central American fresh-water mojarras (Cichlidae), apparently guard their young long after the yolk is absorbed and the fry have gained considerable growth. They are more timid, however, than our sunfishes and sticklebacks and will more quickly desert their charges, but they return the instant danger has passed and their solicitude continues for a longer time. Whether the parents aid the fry in finding food or merely protect them from danger is not known.

But fishes are not consistent in their parental solicitude. We are told that even those species which make comparatively great sacrifices in guarding the eggs and fry, later when the period of parental care has ended, will not hesitate to eat their own young. Many years ago there appeared an account of how two bullheads, or yellow catfishes, which spawned in a tank at the United States Bureau of Fisheries, zealously guarded the progeny before and some considerable time after hatching. Eventually, however, the offspring began to dwindle day by day and within six weeks 500 fry had disappeared, although a liberal supply of other food was provided.

The viviparous top minnow, *Gambusia*, to which we have so frequently referred, appears to be entirely devoid of parental instincts, for in the aquarium where the animal can be observed, it usually eats all of its own young as soon as they are born. This fish is especially attracted by movements in the water, such as the wiggling of an insect larva, and it may be that the urge to seize and to devour all small wiggling animals is so great that the mother *Gambusia* cannot withstand the swimming movements of her own young. In nature, of course, the offspring have a better opportunity to escape by hiding from the mother, yet adult *Gambusia* that have fed on young of their own kind are rather frequently taken in their natural habitat. In spite of this situation it is doubtful if any other fish multiplies more rapidly than *Gambusia* when conditions are favorable.

A similar cannibalistic habit in the hagfishes works to the advantage of other fishes. These low fish forms, which alone among fishes are truly parasitic, fasten themselves at the throats of large fishes and devour all the muscles of the victim without further breaking the skin or disturbing the viscera. According to Doctor Jordan large numbers of hagfish eggs are taken from the stomach of the male hagfish, which seems to be almost the only enemy of his own species, keeping its numbers in check.

Nature has provided other security than parental care for the eggs of several species of fish in the shape of special structures offering a degree of protection and making hatching more certain. The goosefish (*Lophius piscatorius*), also known as "all-mouth" because of the size of that organ, lays its many eggs inclosed in a jellylike substance which forms a sheet or veil, reported sometimes to reach the enormous length of thirty to forty feet and a width of two or three feet. It is believed that each sheet is the product of a single female. It floats at the surface and no doubt offers some protection to the eggs by keeping them afloat as well as preventing, in a measure, fishes and other predatory animals from eating them. The yellow perch of our fresh waters protects its eggs somewhat similarly, laying them in gelatinous strings which generally are attached to submerged plants.

The eggs of the silversides (Atherinidae) bear gelatinous threads which fix them to the eelgrass or other plants among which the fish spawns. A school of silversides sometimes collect in shallow grassy areas for the purpose of depositing their eggs. A great churning of the water takes place and the millions of eggs laid quickly become attached to the plants by threads which branch from the ova at one point only. The value of this arrangement lies in the fact that it prevents the eggs from falling into the mud where they would probably be choked for want of oxygen. The habit of certain fishes of blowing air bubbles to keep their progeny afloat has already been referred to.

On the coast of California occurs a small food fish of some importance known as grunion (*Leuresthes tenuis*), which has one of the most unusual methods of spawning known. This little animal remains on shore when the breakers recede, and with its tail down, partly disappears in the sand where it deposits its eggs and leaves them to be hatched. After that event the young work their own way out of the sand and enter the water where they take care of themselves.

All seasons of the year will find some species of fish spawning, spring, summer, autumn, and even winter having each their quota of breeding fish. The majority of fresh-water fishes of the United States prefer the spring or early summer, but in the salt waters of the southern shores of this country there apparently is no time during the course of the year when fish are not spawning.

More remarkable still, a single species, the European herring, *Clupea*, is reported to carry on its breeding activities at all seasons of the year. However, spawning does not take place in one locality at all seasons, for winter young are reported from one region, spring young from another, and summer and fall young from still others. The same species of herring on the American side of the Atlantic has a breeding season similarly unlimited except that winter spawning seems not to have been observed. The American menhaden (*Brevoortia tyrannus*), another member of the herring family, is likewise known to spawn in summer off the New England coast and in late fall and winter off the South Atlantic States. This is a rather curious thing, but it is not to be assumed that the same individuals spawn more than once a year. It seems probable that different races of the same species inhabiting different localities breed at different seasons of the year, and not that the same individuals migrate from one locality to another, there to repeat the reproductive process.

As for the duration of the breeding season, that varies considerably among species. Those that have a short spawning period, which include the majority of the food fishes, generally cast all of their eggs at one time. Long reproductive periods occur among the fishes of the top-minnow families, both among the egg-laying and among the viviparous species, and several batches of eggs are

Colorful fishes of the Hawaiian shore. Wrasse, surgeon, and butterfly fishes. By Stephen Haweis

laid, or several litters of young are born throughout the spring and summer. Among the oviparous species that lay several times during one season are the killifishes, the sheepshead, or variegated minnows, and the rainwater fish, of the fresh and brackish waters of the Eastern States. *Gambusia* is known to give birth sometimes to as many as six litters during one spring and summer, that is, from May to September.

Of the breeding habits of all manner of fishes, surely none contain more romance than the extraordinary migrations undertaken by such species as the salmon and the eel in response to the reproductive instinct. But these more properly come under the head of migrations, at which we have now arrived.

CHAPTER V

MIGRATIONS

THE annual flight of migratory birds from the shadow of the North to the shadow of the South Pole merits no more, if as much, wonder as the long journeys undertaken periodically by certain species of fish. Birds at least remain in the same medium and the dangers they face, apart from their ever present enemies, are inclement weather or failure of food supply. But migratory fishes like the salmon or eel change from salt to fresh water or the reverse, a transfer which means death to most species; and the Pacific salmon, at least, goes through one Odyssey of battles with an opposing river current armed with cataracts and rapids, and another Odyssey of battles with his own kind. And all this under the lash of famine, with inevitable death at the end, for he takes no food from the time he leaves the sea for a two-thousand-mile journey, and when his mission is fulfilled, exhausted he dies.

Birds follow their food, but the salmon and the eel move at the behest of the reproductive instinct. Most of the long voyages made by fishes undoubtedly are undertaken for the purpose of carrying the spawn to certain definite localities called spawning grounds. It is true that some species migrate for other reasons, in order, for instance, to find or to stay in a comfortable temperature to seek an adequate food supply, or to escape an uncomfortable state of salinity, disagreeable light, pollutions, strong currents, or other inimical conditions.

Several species that spend most of their lives in the sea, including some of the important food fishes—the salmons, shads, river herring, striped bass, and sturgeons—make long voyages to fresh-water streams to cast their spawn. Those that make this transfer from salt to fresh water are called anadromous species.

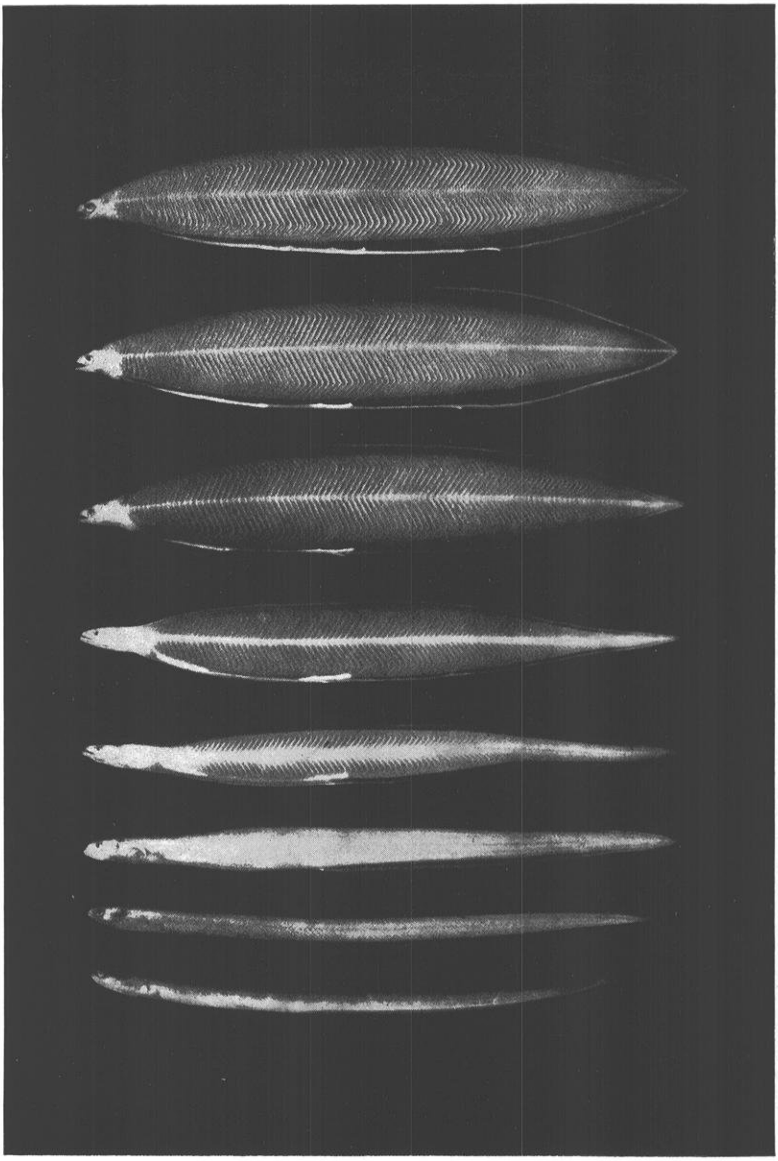
Only one American fish is known to reverse the spawning migration of the anadromous fishes, going from fresh to salt water, and that is the common fresh-water eel (*Anguilla rostrata*), which because of this habit is said to be catadromous. The European eel (*A. vulgaris*), a closely related species, follows the same curious practice. Ichthyology contains few phenomena of greater interest than the life history of these fishes, which is the more remarkable in that it has remained a mystery throughout the centuries until very recent years. Until 1864 no one recognized the relationship between the adult eel and its larva; until the recent work of Dr. Johannes Schmidt, a Danish investigator, no one knew where the eel spawned, though many made false guesses.

The female eel, at least, spends most of her life, a period extending probably from eight to twelve years, in fresh water. At the end of that time the sex products reach a state of great development and the eel responds to an instinctive urge to return to the spawning grounds far out to sea, where she herself was born, to cast her eggs. The male, though probably several years younger, makes a similar response to a similar urge and migrates to fertilize the ova at the breeding grounds. Doctor Schmidt believes now that he has discovered the chief spawning area of the eels in a region of deep water somewhat to the southwest of Bermuda.

The strangest aspect of this singular phenomenon is that both the American and European species come to the same general locality to carry out the process of reproduction. And their respective progeny, very soon after they are hatched, begin to retrace the path followed by their parents, the American species finding its way to the fresh waters of this continent, and the European species to the rivers of Great Britain and the continent, including those emptying into the Mediterranean and the Baltic. It is believed that the fresh-water eels spawn only once in a lifetime and that they probably die in the vicinity of the spawning grounds shortly after the eggs have been cast and fertilized. Thus the new-born eels have no parental aid to guide them to their separate destinations, as much in some cases as 5,000 miles away. It takes the American species a year to reach the coast and fresh water, and the European eel spends three years on the journey across the Atlantic.

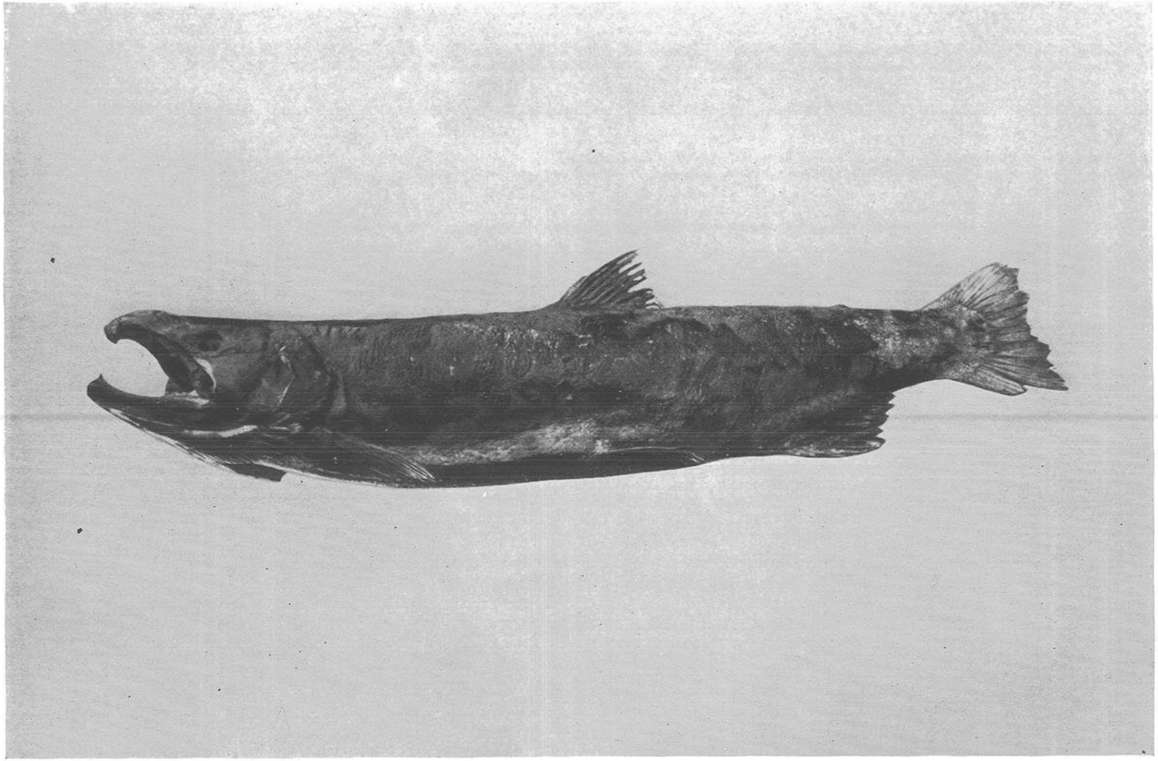
The young or larval eel, known as a *leptocephalus*, is thin, flat, ribbon-shaped, and nearly transparent, and so different from the adult that for a century after it was first described it was thought to be an independent species. The leptocephalus continues to grow during the migration to fresh waters, but retains its flat, ribbon shape until it reaches the shore (Plate 23). Some specimens at this time measure from four to six inches. Then a metamorphosis takes place, the body gradually becoming round like that of the adult. In this process the length is reduced by nearly a third, probably because the larva seems to take no food during the transformation. Once it has acquired the snakelike form of the adult—which involves loss of the long larval teeth, movement forward of the beginnings of the dorsal and anal fins and of the anus, great reduction in depth, and the acquisition of an air bladder—the elver enters fresh water. However, it is still unpigmented, and its pale, almost transparent appearance causes it to be known in this stage as a "glass eel." Very slowly it acquires the color of the adult.

How long an eel requires to reach maturity is not definitely known, though the time probably varies from eight to twelve years for the female and less for the male. It is possible to determine the age of an eel by the concentric rings of small calcareous plates formed on the outer side of the rudimentary scales and by the annual growth rings



Metamorphosis of the larva of the eel, from a full-grown larva (a) in the leaflike form, to the glass-eel or elver (g), the youngest stage at which they are found in the North Sea. From Johs. Schmidt

PLATE 24



Pacific salmon, *Oncorhynchus* sp., taken from the water just after spawning, showing the emaciated and scarred condition of the flesh and fins and the hooked jaw. Courtesy of the Bureau of Fisheries found in a cross section of the ear stones. The arrival of maturity is indicated by the great development of the reproductive organs, which in the early years are so inconspicuous as to be sexually indistinguishable without the aid of a microscope. Eels kept in aquaria have been reported to stop feeding with the maturation of the generative organs, and to continue for six months or so in a fasting condition, whereupon they die, with all the other organs except the ovaries much reduced. It is this fact which lends support to the belief that eels spawn but once and then die. Eels whose sex organs seem never to have come to maturity have been reported as living for as many as twenty-two years in aquaria.

Scarcely less remarkable than the life history of the eel are the long and perilous migrations made by some of the Pacific Coast salmon. It is definitely known that at least some of these return, to cast their sexual products, to the river and even to the very tributary where they themselves were hatched. Some ichthyologists believe this to be an established habit among all anadromous species, a belief called the parent-stream theory. No one has yet been able to account satisfactorily for this phenomenon. How does the fish know, when it reaches the mouths of many tributaries, which ones to pass by and which one to enter? The most plausible explanation yet advanced, though it is far from proved, is that the highly developed sense of smell possessed by fishes enables them to retain a perception of the odor of their parent stream through the years between their birth and their return to spawn.

Those individuals of the king salmon (*Oncorhynchus tschawytscha*) which mount to the headwaters of streams, begin the ascent of the Columbia River, for example, with the spring freshets in March and April. They spend the whole summer in working up the river and its tributaries against a swift current, jumping through rapids and falls. By autumn they have reached the mountain streams, having traveled in the Columbia perhaps a

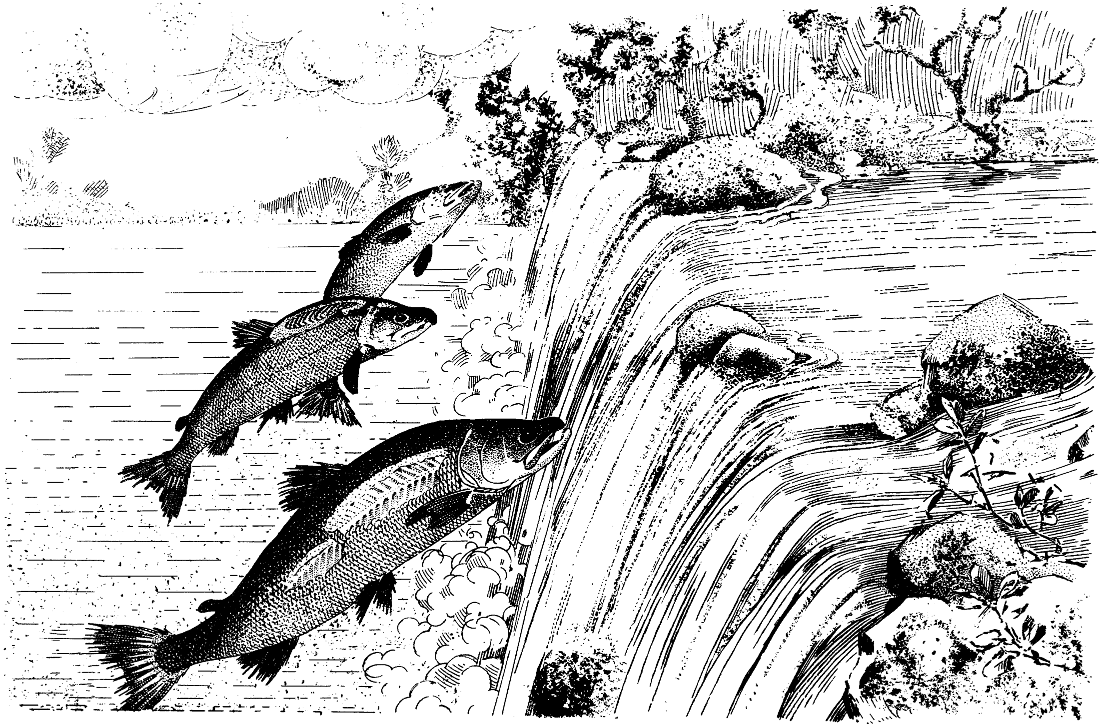


FIG. 45. Pacific salmon jumping falls on their spawning migration upstream

thousand miles from the sea, whereas those that ascend the Yukon may have journeyed twice that far. Other individuals which enter fresh water later in the spring and summer do not migrate as far as the early ones, but spawn in the lower tributaries. As already stated, the entire voyage to the spawning grounds, with its hardships of several months' duration, is made without taking food, for the adult salmon does not feed in fresh water.

The salmon do not endure so much without paying a heavy toll in vigor and appearance. Instead of the bright silvery color in which they left the ocean, they are now a dark and dirty brown, the fins are frayed, often patches of scales have been lost, and the naked areas are attacked by fungus; sometimes even the eyes are injured or destroyed (Plate 24). The body becomes emaciated, the flesh pale, and the stomach shrinks to a very small size. The male develops a conspicuous hump on his back and his jaws transform into such a hook that the mouth can not be closed. His teeth become greatly enlarged and doglike and are used in fighting for the females.

When the spawning grounds are reached, the sexes pair off. The parents excavate a shallow nest in the gravel of a small creek, in which the female deposits her eggs to be fertilized and covered with gravel. The great task accomplished, both parents float downstream, tail foremost, and soon die. So far as known, no king salmon ever survives the act of spawning.

In the light of our incomplete knowledge, we are not justified in assuming that long spawning journeys and other sacrifices in the process of reproduction, made by the king salmon and other fishes, are endured for any care of the offspring. What happens probably is that the body becomes charged with the sexual products at certain definite seasons, and this urges or impels both sexes to get rid of them under certain definite conditions with respect to ground, depth of water, temperature, and so on.

Five other species of Pacific salmon have similar spawning habits, although they generally do not travel as far as the king salmon.

The eggs of the king salmon hatch in about sixty days at ordinary water temperatures, and the young generally spend the winter in their parent stream, undertaking the journey to the sea during high water in the following spring when the snow in the mountains melts. They grow rapidly in salt water and sometime between their second and seventh years, when they are said to have an average weight of twenty-two pounds, they reenter the river which they descended, to repeat the perilous journey of their ancestors, probably returning to the very same brook in which they were hatched.

The Atlantic salmons, too, migrate from the sea to fresh-water streams to breed. But while it is of record that some of them die after spawning, the majority undoubtedly survive and return to the sea, possibly to repeat the voyage the next year and reproduce again.

The shad, the alewife or river herring, the smelt, and the striped bass are other American fishes that migrate yearly from salt to fresh water to spawn. These fishes are all native to the Atlantic; but the shad and the striped bass have been introduced into the Pacific where they are thriving and making annual spawning runs up the coastal streams. All of these fishes spawn in the spring, and their migrations generally take much less time and cover a much shorter distance than do those of most of the salmons. The entire expedition of the shad and alewife extends over a period of only a few months, and that of the striped bass probably is even shorter. The spawning individuals of this group generally survive the reproductive process and live to return to the sea, though the shad and the alewife, like the salmon, apparently do not take food while in fresh water and are thin and emaciated on the voyage back to sea.

The young shads and alewives remain in fresh water during their first summer, but when the temperature of the water begins to fall in October and November they descend to the sea. A few may stop in the larger bays, as in the Chesapeake, but the great majority go out to sea to parts as yet unknown to naturalists and generally are seen no more until they return as mature fish to repeat the voyage and the spawning process of their ancestors.

Many other fishes migrate greater or lesser distances to cast their spawn in certain definite localities where presumably optimum conditions for the incubation of the eggs prevail and where the young can find suitable food when they are ready to feed. The lake trout and the whitefish and cisco of the Great Lakes, which spend the greater part of the year in deep water, approach the shores and shallow waters in autumn, when their spawning time comes, for the purpose of depositing their eggs.

When the urge to spawn overtakes several species of our fresh-water suckers in the spring, they leave the deeper and larger waters they usually inhabit and ascend small brooks, there to cast their spawn on the gravel in the swiftly flowing water of the ripples.

Several marine fishes which live in moderately deep water most of the year make rather definite inshore migrations during the spawning season. Among these the important food fishes, the mackerel, cod, haddock, and pollack, may be mentioned. It is supposed that the inshore waters probably offer better and safer conditions for the newly hatched young than the deeper offshore waters, although it would seem that the floating eggs cast by these fishes ought to be in more danger of becoming stranded by winds and tides in the inshore waters than they would be farther out.

A migration in the reverse direction seems to characterize certain other marine fishes, as for example the gray sea trout and the spot, which appear to leave the smaller bays and estuaries and journey to the larger bays or to the open sea to cast their spawn.

Most of the great fisheries of the world depend on the spawning migrations of fishes, and we observe fishermen moving back and forth from place to place, year after year, in order to take advantage of the runs of fish that occur in different localities and at different seasons of the year. On the Atlantic coast of the United States occur the runs or spawning migrations of the shad, alewife, striped bass, and smelt, all of which support important fisheries. Formerly the Atlantic salmon contributed effectively to the catch along the coast of New England, but due to industrial development and to the lack of proper conservation, this fish is now of comparatively little importance in eastern United States waters. In the waters of Canada the same species has suffered less and enjoyed better protection, so that it still constitutes a source of considerable revenue to that country.

The spawning migrations of the salmon on the Pacific coast of the United States, Canada, and Alaska support the greatest fishery in the world. However, this invaluable food fish, in the most highly industrialized section of its range, is also feeling the press of civilization and the catches are dwindling. Only the strictest measures of conservation will be successful in preserving the fishery. The largest catches are now confined to Alaska; and the pink and red meat, which graces the table at one time or another of nearly every man, woman, and child in the United States and in many other lands, comes principally from these far northern waters. Conservationists are already much concerned as to whether or not these waters will be able to stand the drain indefinitely.

Those migrations of fishes undertaken for other purposes than to carry out the processes of reproduction, as a rule, are less pronounced, though definite runs of mullets, for example, take place toward autumn and are especially important in the coastal waters of the South Atlantic States. In the light of our present knowledge we can not correlate these runs with spawning, but neither can we ascribe any other purpose to them. It is true that some of the migrating fish are mature and contain well-developed roe, but many of the schools included in the runs consist of immature individuals. The mullet has guarded its secrets so efficiently, however, that much of its life history still remains unknown.

The menhaden, at least on the coasts of the South Atlantic States, equals the mullet in the extent of its fall migration, but it undertakes also a more or less definite spring run. The species also schools, usually in much larger numbers than the mullet, though the two fishes agree in that the individuals of any one school are all of nearly one size and presumably of one age. The spring and summer runs of menhaden consist of apparently immature individuals: at least the sexual organs at that time are not enlarged with spawn, as they are in the individuals of many schools included in the autumn migrations. But we can no more ascribe this fall run of the menhaden to spawning than we can that of the mullet, and for the same negative reason, namely, that the small and immature fish migrate too.

It was thought at one time that the major movements of the mullet and the menhaden consisted of northward and southward migrations, and that they were made for the purpose of finding, or remaining, in water having an agreeable temperature. Now, however, that these migrations are northward and southward is doubted and it is believed that they may consist rather of inshore and offshore movements. It is a well-known fact, at least, that no adult mullet or menhaden remains in shallow water during the winter at any point north of Florida; and the journeys of these fishes are certainly influenced in a measure by temperature and very probably by food.

Definite offshore migrations are made each autumn by the majority of fishes which inhabit the bays and estuaries during the summer, followed, of course, by a return migration the next spring. Only a few species remain over the winter even in as large a body of water as Chesapeake Bay. In fact, this fishing ground, so exceedingly rich during the summer, is so barren of fish life in winter that almost all exploitation is abandoned. Virtually identical conditions prevail in the sounds on the coast of North Carolina.

It is generally believed that fishes abandon the shallower inshore waters in the autumn in order to escape a disagreeable temperature, though the scarcity of food may also be a factor. Temperature is important, however, for the writer knows from personal observation that several of the common inhabitants of bays, if they fail to leave the shallow waters in time, or if prevented from leaving by artificial means, are numbed and even killed by the cold. For example, spots and pinfishes retained in a shallow inclosure became numb and died when the air temperature dropped to 12° and the water to 39° Fahrenheit. Mullets held in the same inclosure, however, survived, for these fishes are able to endure great variations in temperature as well as in salinity.

Cold drives the fishes offshore in the fall, but it is the prospect of food which brings them back in the spring. It is true that some species spawn in the bays and sounds, so that the urge to reproduce may influence the inshore migrations; but a number of them are fall and winter spawners and do not cast their eggs in the inshore waters. The evidence appears to show rather conclusively that the migration back to the bays and sounds is made because such waters offer a rich pasture during the summer.

Rather definite migrations of young spots and mullets to fresh- and brackish-water creeks and ditches have been noticed on the coast of North Carolina, but the entire fry membership of these fishes does not join in the movements. The young fish that do enter fresh water soon attain a much larger size than those of the same age which remain in salt water. The probabilities are that this faster rate of growth is due to a more plentiful food supply and that the migrations are made in order to obtain this food, although other factors, not well understood, may have an influence also.

Bluefishes migrate in pursuit of smaller migrating fishes such as the menhaden and herring, and their movements depend on the movements of their prey. As wolves travel

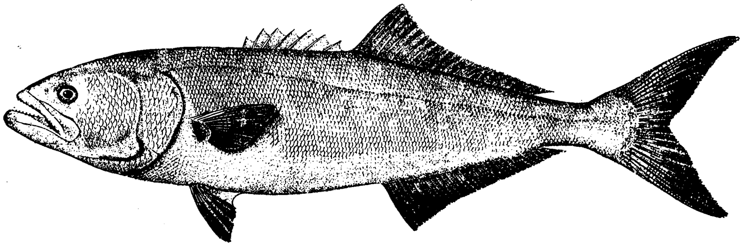


FIG. 46. Bluefish, *Pomatomus saltatrix*, a wanton destroyer of other fish. Courtesy Bureau of Fisheries

in packs when hungry, these predatory fishes travel in schools and display a lust to kill which has no equal in the fish kingdom. It is reported that they spare nothing, but will go on killing for killing's sake long after they have eaten all they can hold. Fishermen take advantage of this persistence in destruction and when they encounter schools of menhaden and herring they make preparations for catching the bluefishes which are almost sure to be in pursuit.

The Spanish mackerel's movements are likewise determined by those of its prey. However, as far as my observations permit me to judge, the schools of Spanish mackerel follow great shoals of crustaceans, principally small shrimps, rather than schools of fish.

Even such solitary fishes as the sharks and skates appear to make rather definite migrations, for reasons not well understood, but probably in search of rich feeding grounds. An investigator stationed at Cape Lookout for several years was able to predict very precisely, that is, within a margin of a week or so, when the eagle ray and the devilfish would arrive there. He also came to know, after years of observation, how long they remained in the neighborhood of the cape. Nearly all fishermen along the Atlantic coast are familiar with the seasonal runs of the small sharks known as dogfish, which are so destructive of nets. The dogfish are voracious feeders and their appearance in the shallower inshore waters in the spring with the return of the numerous summer inhabitants of the bays, sounds, and estuaries, may be interpreted as a migration in pursuit of food.

On those sections of the seashore where the tides are heavy, the fish make daily excursions in the wake of the water. On the Pacific coast of Panama, for example, the water level varies on an average, between high and low tides, nearly fourteen feet, flooding large areas at high water and exposing them at low water. Also many tidal streams, some of them of considerable size, which at low tide contain little or no water, are formed during the flood stage. Numerous marine fishes follow the tide waters inland. The small fish generally are the first ones to arrive, swimming gleefully at the head of the tide, and the last ones to return to the sea as the waters recede. Many large fishes, including snappers, groupers, catfishes, toadfishes, eels, and numerous other species, follow in the somewhat deeper water and run many miles up the tidal streams.

A fish may swim as much as thirty to forty miles on such an excursion, presumably in search of food. At first thought one might question whether sufficient sustenance could be secured by the fish to provide the energy required to swim such a long distance within a period that at most does not exceed twelve hours. It may be assumed, however, that the fish swims, or perhaps drifts, almost continuously with the current and that, as the flow of water is very rapid, little energy is required.

Incidentally, such is the swiftness of the rise and flow of water in the tidal streams on the Pacific coast of

Panama that one can hear the roar at a considerable distance. On one occasion I was at most 500 yards upstream from my boat which lay upon the bed of a waterless creek. Suddenly the tide came; before I could reach the boat the water had risen more than waist deep and my boatman had to come to my rescue. In this region a slight miscalculation in time or in speed may land one's boat high and dry miles from the water, with no hope of relief until the next tide.

It is highly improbable, of course, that any fish exists which is not obliged to work for its food by going on more or less definite migrations, or, better perhaps, excursions. Even pond fishes, which generally occupy a definite area when at rest, often in a deep section of the pond, are obliged, when hunger overtakes them, to go afield in search of food, not infrequently to shallow water where they are not seen at any other time. One investigator states that a pike, for example, will select a definite spot in a pond and make all of its excursions from this point, returning to it when the search for food has ended.

Flood conditions in rivers and streams often bring about a migration of fishes, causing them to scatter over flooded land in search of food. Droughts, on the other hand, often have the effect of driving the fish from the smaller tributaries into larger ones or into the main streams. It is a well-known fact that millions of fish become stranded in flooded areas when the waters recede. The loss from this source has been so great in the Mississippi Valley that the United States Bureau of Fisheries has had to take heed of it and now each year this bureau sends out rescue crews to catch the fish left in the shallow ponds after floods and return them to the rivers and creeks.

Oddly enough, it is the young fish that get stranded after floods. The adults freely enter the flooded area, but they leave before it is too late. Some investigators believe that the adult fish has developed something in the nature of a sense by means of which it knows when the waters are receding. In this sense the lateral line organs, touch organs in the skin, and the ear may all play a part.

A sense of direction has been noticed in the common killifish of the Atlantic coast. Although the adult killifish seldom, if ever, remains in a tide pool until it is entirely disconnected, it appears to know the way back to the sea when cut off by an artificial dam. The fish will swim around the pool several times and when convinced that the last passageway has been cut off it will deliberately jump out of the pool on the side nearest to the main body of water, seldom making the mistake of leaving the pool on the opposite side. Once on land, a series of jumps unerringly carries it to the water.

The majority of still-water fishes, including the killifishes, the rainwater fishes, *Gambusia*, and several others, avoid currents, for they are such poor swimmers that they are quite helpless in swift-flowing water. On the other hand, not a few forms, both fresh-water and marine, enter currents to watch for food.

CHAPTER VI

GROWTH AND FOOD

So unlike their parents are most newly hatched fishes that the young of many of our common species still remain unknown. This dissimilarity is true especially of the species having small eggs, such as the white perch. The young of the catfishes, the sharks, and the skates, on the other hand, all of which have large eggs providing sufficient yolk to nourish the embryo to an advanced stage of development, plainly resemble the adults before they hatch or certainly by the time the yolk is absorbed. Likewise, those sharks and rays giving birth to live young, as well as the viviparous teleosts, all have progeny well-developed at birth, and readily identifiable with the adults. But considering fishes as a whole, these are the exceptions. The great majority go through a gradual metamorphosis more or less pronounced, though rarely so complete as that of the eel discussed in the last chapter.

If fishes could be grown in an aquarium, it would not be difficult to obtain complete series showing all the various stages in their development and so remove our present ignorance of the young of many species. Although it usually is not difficult to hatch the eggs in the laboratory, rearing the young, especially those of the marine species, generally has not been successful, so that one has to rely upon net catches for the specimens desired. The difficulty often experienced in obtaining the sizes needed scarcely can be appreciated by the layman. It took us three seasons of rather intensive collecting to obtain specimens of the pigfish (*Orthopristis chrysopterus*), a very common commercial species on the coast of North Carolina, where the collections were made. With the less common species the difficulties frequently are even greater.

The young of many of the teleosts are less than two millimeters long, and are so soft and delicate that the mere contact with a rough surface will cause an injury which generally results in death. At the time of hatching, the young fish still has a comparatively large yolk sac attached to the ventral side of the forward part of the body, often provided with one or more oil globules. In this condition the miniature creature floats on its back, helpless and at the mercy of wind, wave, and tide, for a period of two or three days. At the end of that time it begins to orient itself, greatly improving its swimming movements.

The most striking feature of the newly hatched fish is the eyes, which are especially big and well developed, and in addition are emphasized by the colorlessness of the rest of the body. In fact, in many species, the larvae (a term used to describe the young of any animal which is distinctly different from the adult) are so transparent and colorless that they would be difficult to find were it not for the big shining eyes which generally contain some pigment. The body is usually narrow, slender, and somewhat curved, or at least the anterior part is deflected, perhaps because of the circular position into which the embryo is forced in the egg. At first no definite fins appear, but in their place a membrane occupies the median line of the body, generally beginning behind the head, continuing around the tail and extending forward on the ventral side to the vent, a characteristic which we have already considered because of the evidence it gives of the evolution of fins. This membrane is known as the fin fold, for within it the fins develop, after which it disappears.

The newly hatched fish is not only finless but scaleless, though in many species the larvae are provided with spines on the head and body which the adults do not possess.

Thus the young spot has spines on the gill covers which are absent in the adult, and the young sailfish has equally transient spines on the head, while spines occur all over the body of the young headfish or ocean sunfish only to disappear as it grows up. But nature never adopts a pat-

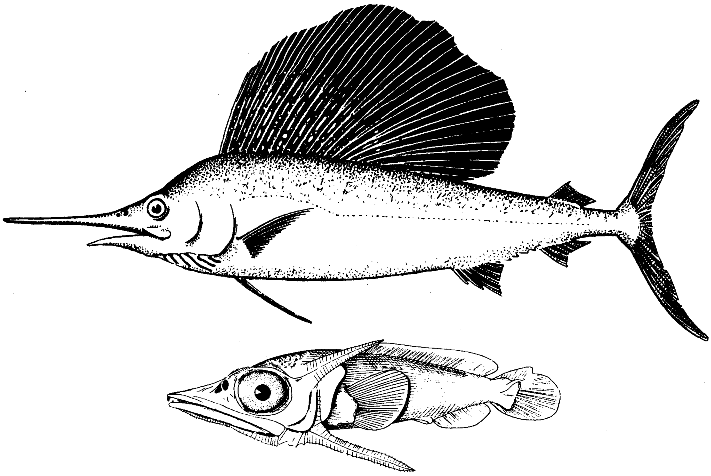


FIG. 47. Sailfish, *Istiophorus*, about six feet long, compared with young of same genus, about half inch long, to show change in snout, dorsal fin, gill spines, etc., during growth

tern to stick to it, for in the trunkfishes it is the adult which has two or more stout spines on the bony box in which it is inclosed, while the young has none.

The mouth, also, in newly hatched fishes, generally differs in shape, sometimes being nearly vertical as distinct from the horizontal mouth of the adult. Usually no teeth are present in the larva, though the sturgeon and the shad are exceptions to this rule. The young of these fishes are provided with teeth and the adults are toothless, indicating, no doubt, a degeneration of structure due to a change in feeding habits.

The transformation that takes place in the eel has already been noticed, as has the extraordinary metamorphosis in the eye of larval flatfishes, in which one eye migrates from its normal place, on the side of the head opposite that of its fellow, to the same side. But many other species have oddly formed young which differ

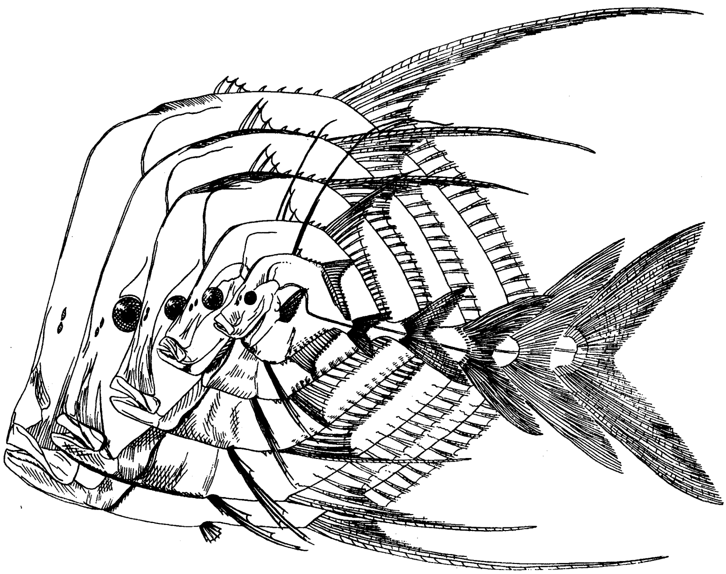


FIG. 48. Moonfish, *Selene vomer*, showing changes in profile, and in the dorsal and ventral fins during growth. After Lütken

markedly from the adult even after a considerable size has been attained. The larva of the lamprey is very worm-like in appearance, nearly blind and toothless, and it was long supposed to belong to a different genus from the adult. In some of the young flying fishes the lower jaw projects far beyond the upper one, as in the halfbeaks, whereas in the adult it is but little longer than the upper. The swordfish reverses this order, both jaws being greatly prolonged in the young, whereas in the adult the upper jaw projects far beyond the lower.

Generally the fin rays are the first characters to appear

PLATE 25

Moonfishes, *Selene vomer*, off the Atlantic coast, and a cow- or trunkfish, with horns, *Lactophrys tricornis*. By Stephen Haweis

that are stationary and aid in identifying the larva with the adult. The soft rays appear in the spiny-rayed fishes before the spines are developed, and those of any one fin apparently develop simultaneously, whereas the spines may come one or a few at a time. Nor do all the fins appear at once. The rays of the caudal fin generally appear first. Next the soft rays in the dorsal and anal fins are developed simultaneously, followed by the development of the spines in spiny-rayed fishes. Lastly the pectoral and ventral fins make their appearance. The fins undergo many and comparatively great changes during the growth of the fish, but the number of rays remains quite stationary.

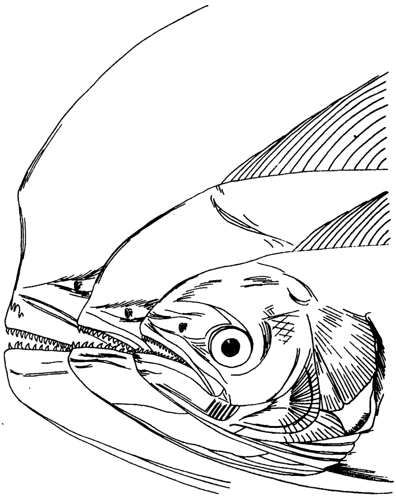


FIG. 49. Male dolphin fishes, *Coryphaena hippurus*, showing changes in the shape of the head during growth. After Lütken

Very pronounced changes in the shape of the fins occur in the cavalla, pompano, and related species. The moonfish, which is related to the pompano, has very long ventral fins when young, their length reaching nearly two thirds of the total length of the fish. As the fish grows these fins not only decrease in length in proportion to the size of the body of the fish, but they actually become shorter, so that in an adult five or six inches long the ventral fins are only about one fourth as long by actual measurement as they are in a fish measuring one and one half inches (Fig. 48).

The dolphin fish (*Coryphaena hippurus*)—which in no way resembles the mammal of the same name—undergoes such pronounced changes in the form of the body and in color that its young at several stages are reported to have been erroneously described as separate and distinct species. Young individuals of the common dolphin fish, only a few inches in length, are very elongate and slender, the mouth being oblique and the color nearly uniform dark-brown, or at most interrupted by a few lighter bars or dots. In the adult the body is much more compressed; the head is strongly elevated; the mouth is horizontal; and the color is very brilliantly golden-blue, interrupted by deep-blue spots (Fig. 49).

This last-mentioned characteristic—color—probably changes more during development than any other. Many species begin life out of the egg without any color or at best with only a few pigment spots. This rule, of course, does not apply to viviparous fishes or to fishes hatched from large eggs, but most of those hatched from small eggs do not acquire even the general color pattern of the adult for a long time after hatching and not until a considerable size has been attained.

Food and Feeding Habits

Fishes are greedy feeders and more than any other class of vertebrate animals do they eat one another. So catholic are their appetites that it is easier to list what they pass by than what they eat. In general they do not eat most jellyfishes, the sponges, or the majority of starfishes. Practically every other organic substance that occurs in, or finds its way to the sea, from a minute organism no bigger than a pinpoint to a whale, is grist for the mill of one species or another.

But all flesh is grass, and at the base of the dietary pyramid of fishes we find single-celled plants, the microscopic but innumerable diatoms. These, like all plants, have the capacity of employing the sun's rays to convert inorganic substances into organic. They are the most ubiquitous of sea plants, occurring everywhere around the coasts and forming a sediment on the surface of mud deposits. In the open ocean they constitute practically the only form of plant life and abound from the surface to a depth of some 600 feet, which is the limit to which sunlight penetrates. These plants, then, supplemented by other algae or seaweeds which grow on rocks in the shore regions, form the basic food of the sea. On them feed directly many of the invertebrate animals of the sea—bivalve mollusks, like the oyster, mussel, and clam; copepods, or small crustaceans, which abound in the open sea; and annelids and sea-cucumbers which live in the bottom muds.

These invertebrates, which range in size from the microscopic to the huge, in their turn nourish many species of fish, which likewise prey almost universally upon one another as their size and ferocity permit. But in spite of their carnivorous habits few fishes are wholly animal feeders and still fewer eat only plants. The German carp, for example, is classed as herbivorous, yet it feeds willingly on animals of suitable size.

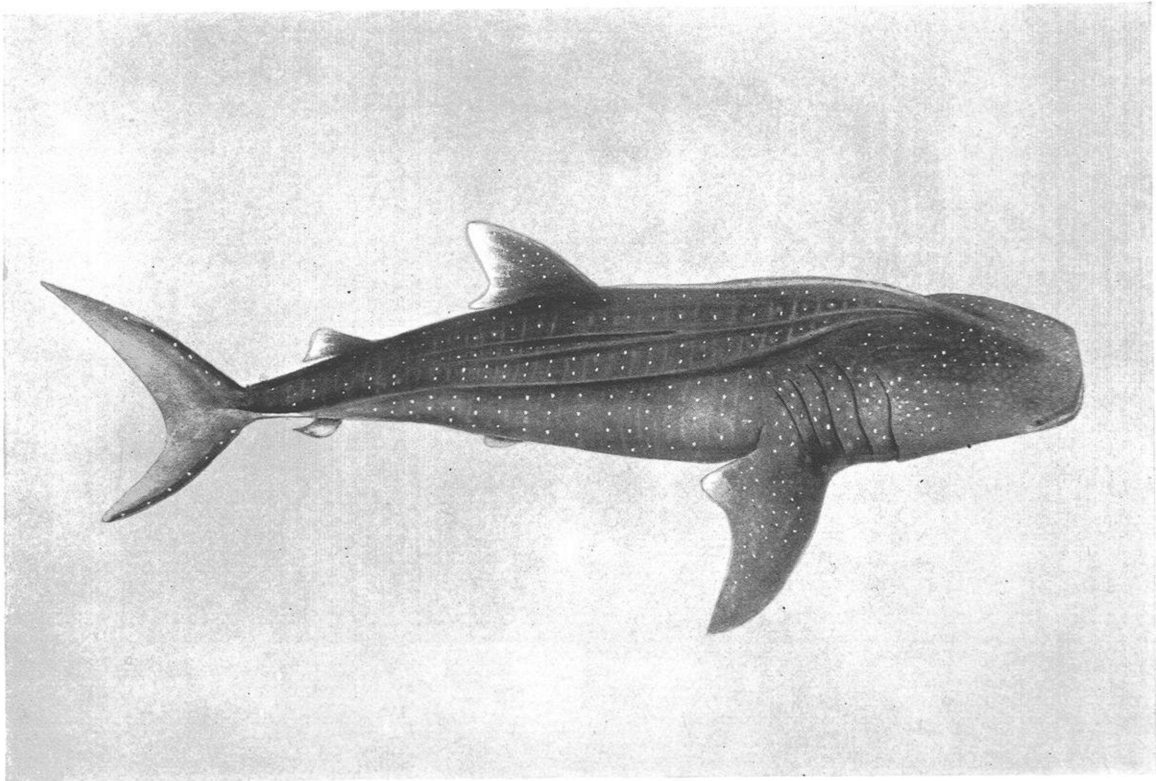
The porgy, or spadefish, feeds mostly on plants growing on rocks and piling, and it is properly classed as herbivorous. However, while ingesting the plants, it incidentally takes also quite a few small crustaceans and worms. The feeding habits of the rudder fish are very similar. This fish receives its name, however, from its habit of following ships and floating objects, like boxes and logs.

The codfishes (Gadidae), on the other hand, are classed as a carnivorous bottom-feeding family, and in general this is true, but occasionally they are said to feed on algae also. Furthermore, they sometimes leave the bottom and feed at the surface or in between. Omnivorous would probably be the best description of the family, for they include in their diet many species of fish, mollusks, crustaceans, worms, and even an occasional starfish and hydroid, in addition to algae. The greediness of a cod will sometimes trick it into swallowing, as its stomach contents have revealed, pieces of metal, gravel, wood, rope, rubber, clothing, and even cigarette boxes.

As they grow, the majority of fishes eat larger and larger organisms, but not all. Several species continue to feed on minute forms throughout life, so that the size of the fish is no criterion of the sort of food it eats. Thus the basking shark (*Cetorhinus maximus*) and the whale shark (*Rhineodon typicus*), largest of its race, feed solely on plankton, which is the general term to describe the teeming small life of the sea, including the microscopic diatoms and the small copepods. For this purpose they have long, slender, close-set rakers on the gills which strain all solid particles out of the water passing over the gills.

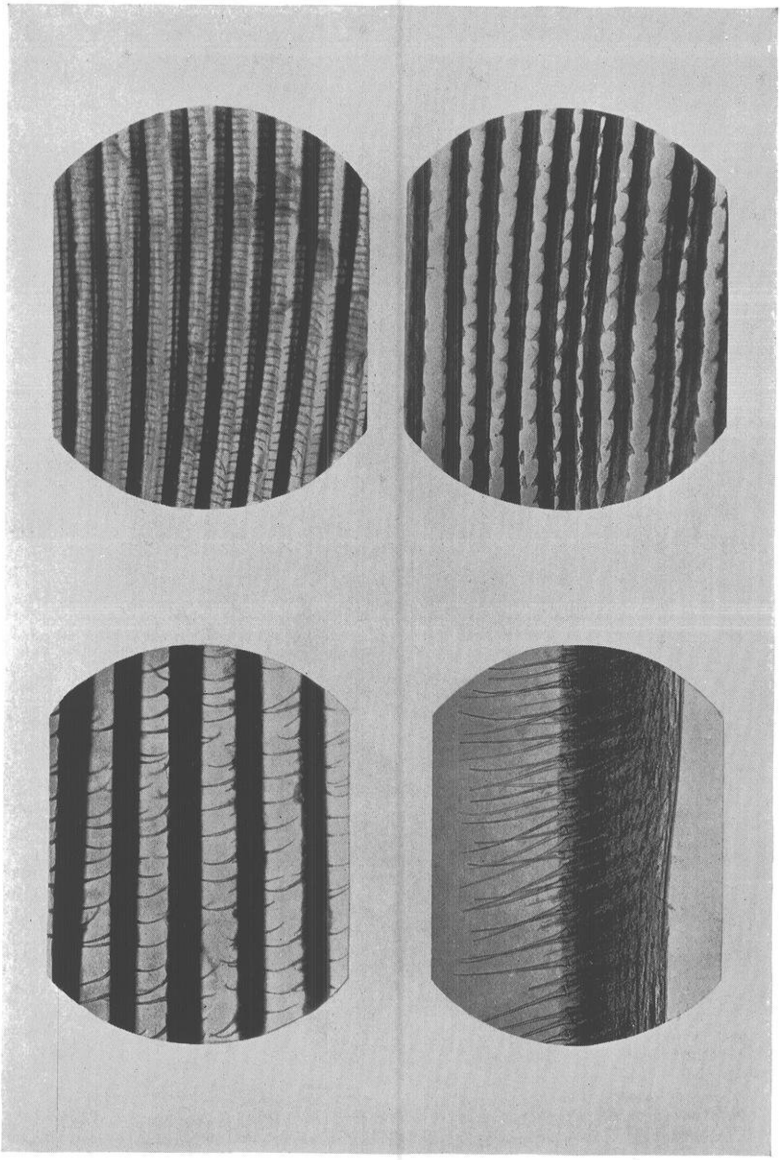
Among the common commercial species with a similar straining apparatus that feed almost exclusively on microscopic organisms are the menhaden, the shad, and the spoonbill cat. The first two feed on free-swimming forms acquired by straining large quantities of water, principally at or near the surface. The spoonbill cat, however, first stirs up the mud on the bottom with its long spoon-shaped snout and then strains its food from the muddy water. The mullets likewise depend on the mud for their sustenance, but they have no straining apparatus. They swallow the mud and digest the small organisms or their remains contained in it by means of a very muscular, gizzardlike stomach. The gizzard or hickory shad of the Mississippi and other rivers of the Central States has a like stomach about the size and shape of a hickory nut, and a small, contracted, toothless mouth. In general, as has been stated, carnivorous fishes have a short intestine, while herbivorous forms have long, convoluted intestines and muscular stomachs.

Most sharks are highly predatory, feeding mostly on fish, although they do not refuse slaughterhouse waste, garbage, and carcasses of various animals, even though they are in a state of putrefaction. Many tales of attacks by sharks on human beings are told, some of which



Whale shark, *Rhineodon typicus*, largest of fishes, attaining seventy feet, which feeds almost wholly on microscopic plants and animals. Courtesy of the Bureau of Fisheries

PLATE 27



Segments of the branchial sieves of three common fishes that feed wholly or in part on plankton—a, menhaden; b, herring; c, mackerel; d, side view of mackerel gill raker with gill fringes. Much enlarged.
Courtesy of the Bureau of Fisheries

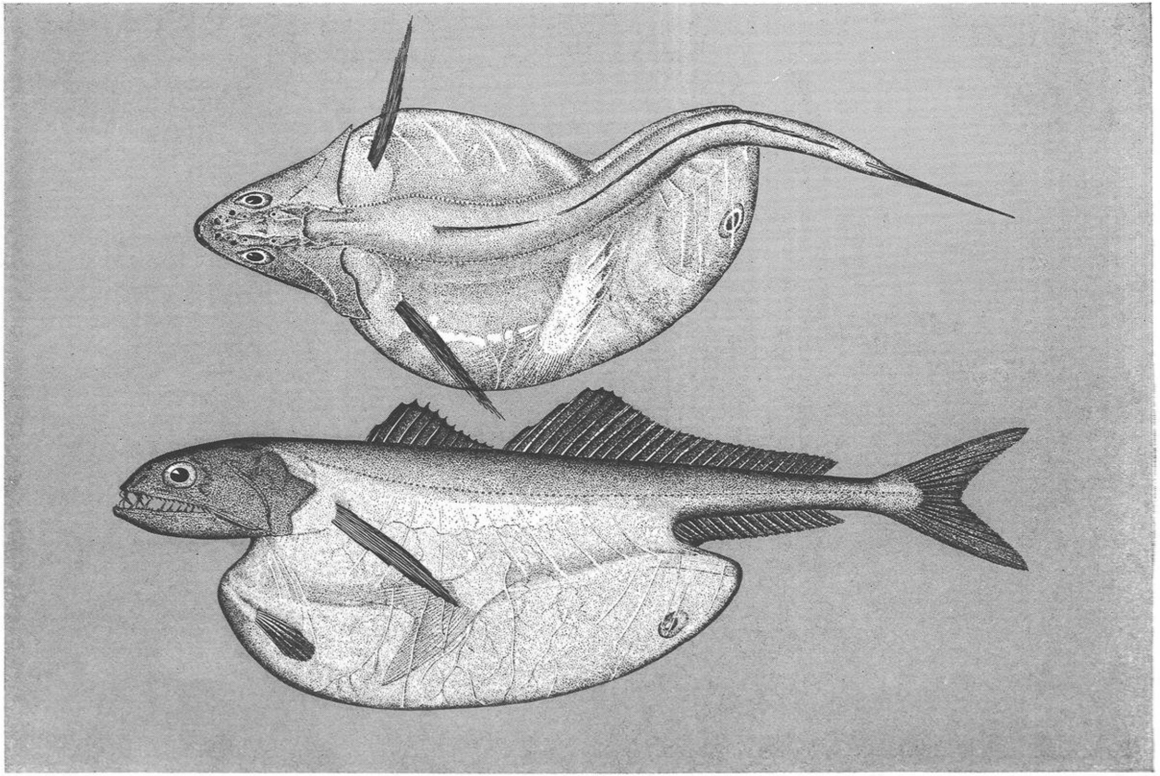
are authentic, though the majority appear to be without foundation. However, a large, hungry shark is a ferocious animal and may well be feared by man and beast. I once saw a catfish pursued by a shark. The catfish made a last desperate effort to escape from the shark's jaws by jumping on the beach, several feet beyond the water line. The shark was not to be outdone, however, but likewise came ashore, seized its prey, and returned to the water.

Certain birds, of course, are inveterate enemies of fishes, but it is a rarer thing for a fish to attack a bird. In May, 1929, two observers came upon a skate, washed ashore on Long Island, from the mouth of which protruded the tail feathers of a gull. Both fish and bird were apparently newly dead. The bird was jammed in the capacious maw with its head twisted back at the gullet. Perhaps the skate had been unable to get so large a morsel down its gullet or to eject the bird past its barbed teeth and so, unable to close its mouth, had died. It may be that the gull had been caught while diving after other prey.

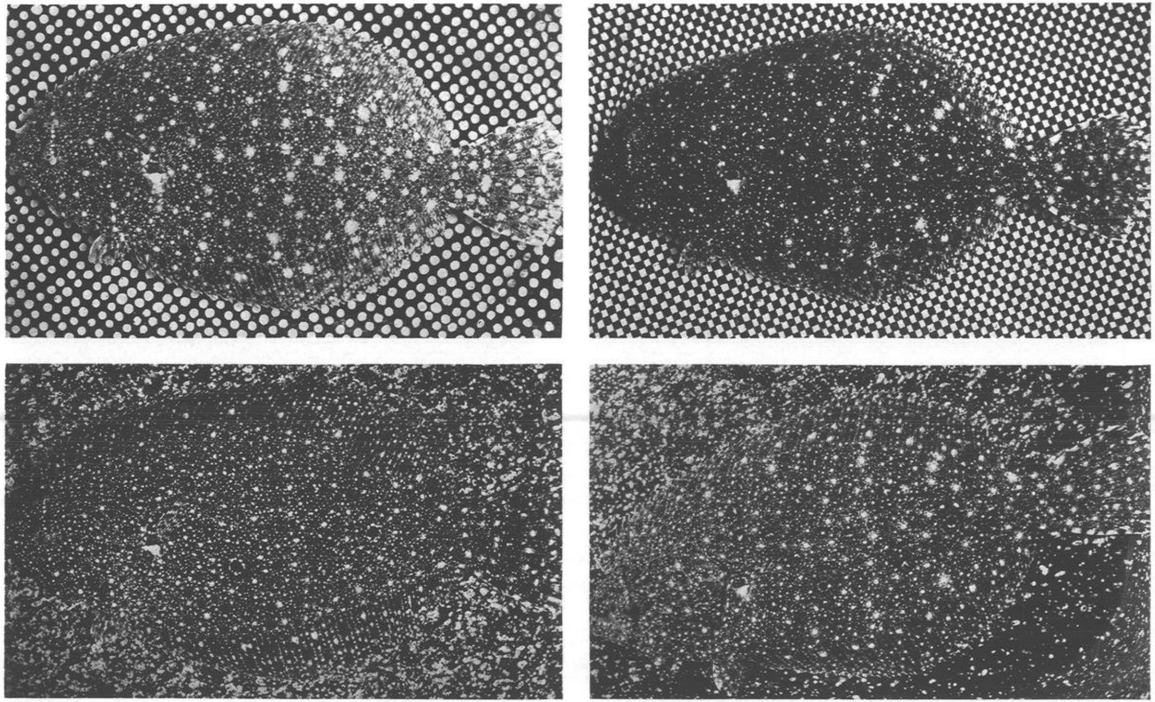
The goosefish, or all-mouth as it is sometimes called, receives its name from the fact that it is supposed to feed on wild geese. While it is doubted by some naturalists whether the fish could swallow such a large bird, others are equally certain that it does occasionally devour a goose. In any case this fish may be classed as an enemy of birds, for if it can not swallow a goose, it certainly can manage smaller aquatic birds.

The greediness of the skate in trying to swallow an object almost as big as itself constitutes nothing new in fish history. It is of record that fishes have swallowed other fishes exceeding their own length. In that event the fish swallowed, of course, must be slender enough to admit of more or less coiling. The writer once took a tropical brackish-water goby 14½ inches long which had attempted to swallow a goby of another species 8½ inches in length. The head of this morsel was near the vent and partly digested, while the tail was still visible in the mouth. The fish that had been captured in this instance was too stocky to coil, and therefore its head had to be digested before its tail could really be swallowed. The Smithsonian Institution has on exhibit a twelve-foot fossil skeleton of an extinct fish, *Portheus*, which died millions of years ago, inside of which is the fossil skeleton of a six-foot specimen of the same species. The big fish probably died for his gluttonous cannibalism.

Insects, of course, form an important item in the diet of many species of fish. *Gambusia*, the mosquito-eating fish, shows such a marked preference for wiggle-tails that it constitutes the worst natural enemy the mosquito has, and for that reason this little minnow has been distributed far and wide within the warm zones of the world, that it may aid man in his combat against the disease-carrying species of this insect. *Gambusia* does not limit itself to mosquito larvae for food, however, as it also feeds on other animals of suitable size; and when these more usual foods are scarce it partakes very freely of algae and tender shoots of higher plants.



Black swallower, *Chiasmodon niger*, seen from above and side, containing a fish larger than itself



Photographs of summer flounders, *Paralichthys albiguttus*, showing variations in skin patterns to suit different backgrounds. Two photographs on left are of one specimen, those on right of another. After Mast. Courtesy of the Bureau of Fisheries

CHAPTER VII

SOME ADAPTATIONS

If we can conceive of a generalized fish form, a normal fish, then any measurable departure therefrom to meet particular conditions of life will be an adaptation. Many of the subjects discussed in the preceding pages would come within this definition: Electric or light-producing organs, for example; the loss of teeth in many mud-feeding species such as the adult sturgeon; the loss of sight in fishes that dwell in the perpetual darkness of caves; and the modification of the pectoral fins into organs of flight in the flying fishes or of the dorsal fins into sucking disks in the remoras.

A consideration of this list will reveal that an adaptation may consist equally in the loss of an organ or structure or in the acquisition or modification of one. Thus it may be assumed that the ocean headfish once possessed a tail somewhat similar to those of nearly all other fishes. Possibly because this species made little use of the tail in its sluggish life habits, this appendage, very important to most fishes because it generally is the chief organ of locomotion, was lost. The high dorsal and anal fins became the organs of propulsion, so that the fish swims in spite of the loss of its tail. And on the other hand we know that the electric organs of certain fishes represent the acquisition of a new organ, because in the embryo we can follow its development from muscular tissue.

There are, of course, a great many interesting adaptations which have not come up under the subjects treated, but which ought not to be omitted from a general discussion of fishes. In connection with the extraordinary migration of the eye in the flatfishes there are several other departures from the normal. The lower side of the fish loses its pigment and turns white; the dorsal fin extends along the line outside the dorsal eye, instead of between the eyes, as in other fishes; usually the jaws and teeth are much more strongly developed on the lower side where they are most used for seizing food; but both the scales and the pectoral fin are usually less developed on the lower side.

The sluggish globefishes, including the porcupine- and swell-fishes, unable to flee from enemies through rapid swimming, have developed several substitute adaptations for protection. They inflate the body, either with water or air, until it is almost spherical, increasing their size tremendously thereby. Many of the species of this group bear spines on the skin all over the body and when inflated each spine stands erect, rendering them at once formidable and difficult to swallow. Furthermore, the flesh of at least some members of the group is said to be poisonous. It is reported, also, that the porcupine fishes sometimes gnaw their way out of the stomachs and through the abdominal walls of sharks, escaping alive, while the sharks are killed. The group are amply provided with cutting teeth and no doubt are able to do effective gnawing and biting. At least some of these fishes throw out a secretion from the skin of the belly when inflated and it has been suggested that such a secretion may counteract the acid juices in the stomach for a sufficiently long time to enable the fish to bore its way out of the shark, though how it avoids destruction by the bite of the shark's extremely well-developed teeth remains an unexplained mystery Certainly a fish that can pass unharmed through the mouth of a shark and then bore its way out of the stomach of the monster deserves to live.

In the pipefishes and sea horses the snout is very long and tubelike with only a small mouth at its extremity. It is extremely difficult to explain how this odd development came about or its exact utility, though these fishes manage to suck in the small organisms upon which they feed and occasionally they catch an animal of fair size. However, this family offers some striking examples of protective resemblance, the usefulness of which is manifest. The pipefishes all live among seaweeds and their slender, stiff bodies resemble more or less in color and shape the blades of grass. The sea horse also swims vertically, and when he curls his prehensile tail around the stem of a seaweed he is very difficult indeed to distinguish.

The subject of coloration in fishes has been discussed in literature to a greater extent than any other character coming within the scope of adaptations. It is a well-known fact that the tint in many species harmonizes remarkably well with the surroundings. Divers who have studied the brilliantly marked tropical fishes report that even those gorgeous colors, when seen in the water among the sea fans, corals, and tropical plants, harmonize quite nicely with their surroundings.

It is well known, furthermore, that most species of fishes have some control over their color and are able to change it, to a certain extent at least, to resemble the surroundings. For example, a fish taken on a white sandy bottom almost invariably presents a lighter shade than another one of the same species taken on a dark, muddy bottom, while a third specimen taken from among green plants is quite apt to be more or less greenish.

Color adaptation apparently is more highly developed in the flounders than in any other group of fishes. In fact, a chameleon is no more, and probably less, proficient in changing its hue than some species of this group, for example, the summer flounder (*Paralichthys dentatus*), of our South Atlantic coast, which is able to dress itself in almost any color of the rainbow. When kept in the aquarium until acclimated it responds very readily to backgrounds of different shades, so that on a white bottom the fish becomes very pale, on black it becomes quite dark, on blue it acquires a shade of blue, on red it becomes reddish. But this is not the whole of the phenomenon. If placed on a background of fine sand the flounder not only changes its ground color to fit, but it acquires a finely specked pattern resembling sand, and if the bottom be pebbles or coarsely broken shells, it acquires a color pattern containing larger and coarser markings (Plate 29).

We find fish pigmentation to be of two types: Ground color, which is more subject to local variation, and ornamentation, which responds less to the background but more to age and sex. Thus, with all the wide gamut of coloration of which the summer flounder is master, it always retains certain dark markings which vary in intensity but never entirely disappear.

It has long been thought that this fish changes its color to conform with its surroundings for the purpose of protection, to render it invisible to its enemies. A few recent authors have argued, however, that color is a product of the metabolism of the fish on the one hand and the rays of light on the other. They point out that in the tropics where both these factors are intense the colors are vivid, and where both are feeble, as in caves, the colors may be entirely wanting. They conclude, therefore, that the protection, if any, afforded by color consists in the absorption of dangerous rays of light by the pigment and has absolutely nothing to do with protection from predatory animals. In considering this view, it may be pointed out that by no means are all tropical fishes brightly colored. In fact, the fishes of the fresh waters of tropical America as a rule are less brilliantly colored than those of temperate America. The statement that the combined intensity of metabolism and the rays of light produce bright colors, therefore, appears to have need of some modification, as it does not apply uniformly.

On the other hand, any one who has lived on the seashore and who has had the opportunity to study the habits of flounders both in nature and in the aquarium, can scarcely come to any other conclusion than that the power of changing color in these fishes is a protection against enemies. Indeed, it seems probable that this color assimilation may serve a double purpose, as it not only conceals the flounder from its enemies but also from its prey. If color assimilation protects the flounders, as it most surely does, it may be assumed that certain other fishes which likewise take on the color of their surroundings, although generally less perfectly, do so as a defense mechanism.

An excellent illustration of modifications in structure brought about in comparatively recent times through the environment is found on the Isthmus of Panama. All geological and biological evidence overwhelmingly points to the existence of a natural interocean waterway across the Isthmus in rather recent times, through which fish could pass from ocean to ocean. This passageway in time was closed. At an even later date the first barrier between the fresh-water forms of the opposite slopes appeared. Since these separations took place many species have undergone changes, which, though generally not pronounced, are constant and by no means trivial. This makes it possible to separate into distinct species the majority of the marine forms from the opposite coasts, as well as the fresh-water fishes of the opposite slopes. The modifications have affected various body structures. Sometimes a slight difference in the number and length of gill rakers is found; again a slight difference in the scales exists, or in the size and number of spines on the opercle and preopercle, or a small difference in the depth of the body, the length of the fins, the size of the eye. All species did not yield equally to the change in the environment after their members became separated and even today several forms remain common to both coasts and to both slopes. Those species that failed to respond are probably the older forms whose characters are more firmly established.

Before we leave the subject of adaptations, let us consider changes from the norm of another sort—monstrosities. They are extremely rare among fishes under natural conditions. In hatcheries, however, two-headed fish, or united fish—that is, "Siamese twins"—are not uncommon, though such young seldom live long. Sometimes, as in the goldfish, the oddly shaped forms have been perpetuated to become distinct breeds or races, so that we have goldfish with telescopic eyes and fan-shaped tails, and with the color changed from its natural green to orange.

CHAPTER VIII

GEOGRAPHICAL AND VERTICAL DISTRIBUTION

It is much more difficult to follow the movements of fishes than those of land animals, whose courses or trails can be seen and whose medium is our own, and consequently we have to deduce the distribution of fishes generally from the localities and depths at which representatives are taken, an obviously imperfect method. With respect to the fresh-water fishes, Dr. David Starr Jordan has said, "You cannot often say that a species does not live in a certain stream. You can only affirm that you have not yet found it there, and you can rarely fish in any stream so long that you can find nothing that you have not taken before." To determine the habitat and range of distribution of a fish living in the ocean, obviously, is even more difficult, and our knowledge, consequently, is far from complete.

Superficially it looks easy for a fish to swim on and on in the broad seas without hindrance, but if that actually took place, we should have many cosmopolitan species. As a matter of fact, comparatively few fishes are of such general distribution that they can be considered cosmopolitan.

The geographical range of fishes in general appears to be limited by three factors: Physical barriers, unsuitability of environment, and adaptation of the fish to a new environment to such a degree that it loses its original identity. The most common barriers are land, water temperatures, and water depths. (Shallow water would probably hinder a deep-water species, whereas shore forms would find deep water an obstacle.) As to the second factor: A species may succeed in reaching a certain locality but may not be able to adapt itself because of the chemical and physical conditions, or of competition with other fishes or other animals, or its young may not be able to mature. The third factor is of another sort: A species may be able to maintain itself and to multiply, but in the course of time it may undergo such pronounced changes in the process of adaptation to the new environment that it becomes a species distinct from the original type.

Comparatively few fresh-water species of fishes are limited in their distribution to a single river system, yet not many are found on both sides of a high mountain ridge, such as the Rocky Mountains in North America and the Andes in South America. That is to say, the fishes of the Mississippi Valley are generally different and distinct from those of the Pacific slope of North America.

While it is a well-known fact that the fish life in no two river systems, even though they empty into the sea on the same side of a divide, is exactly identical, such streams do have many species in common. The principal rivers of the Atlantic slope of the United States, for example, contain several species common to all of them, including the common bullhead catfish, the bluegill sunfish, the pumpkin seed, and the large-mouthed bass. None of these species can endure salt water, so that they can not now migrate from one river system to another. On the other hand, the more northern streams contain species not found in the southern ones, and *vice versa*. The common pike, for example, is found in the Atlantic slope streams from Maryland northward, and the brook trout and yellow perch occur only in North Carolina and northward, while the fork-tailed catfish is found only from Virginia southward, and a few less well known catfishes and sunfishes and several minnows occur only in the streams from North Carolina southward.

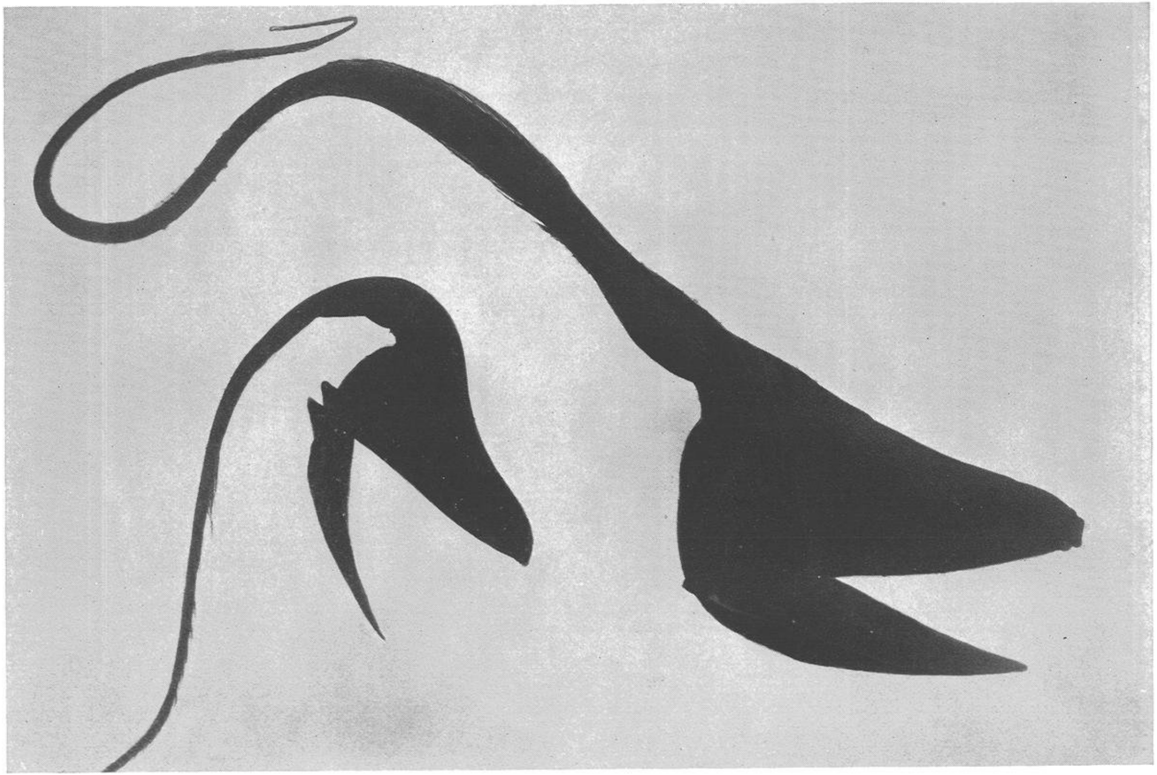
How the present distribution came about must remain a matter of conjecture. It is quite probable that some of the streams, including those on opposite sides of a divide, may have been connected at one time. Again, streams may be entirely separate during normal weather, but an exceptionally heavy rainfall or the sudden melting of the snow in the uplands sometimes causes floods which may form a temporary connection between them, providing a passageway for fishes from one to the other. It is possible, also, that water birds may accidentally carry fish or spawn from one stream to another, or that man may be instrumental in such a transfer.

It is of record that in Two Ocean Pass, situated just south of the Yellowstone National Park, the Yellowstone and the Snake Rivers are still connected by two streams crossing the main divide of the Rocky Mountains, and the same species of trout is taken on each side of the divide. The fish fauna of the fresh waters of the Isthmus of Panama is typically South American and, furthermore, is of the Atlantic rather than of the Pacific drainage of that continent. A study of the fishes of the Rio Tuyra, situated near the Colombian border on the Pacific slope of Panama, and those of the Rio Atrato, on the Atlantic slope of Colombia, has revealed the fact that the fauna of these two streams are very closely related, several of the species being identical. The headwaters of the two river systems come so close together that the Indians today drag their wooden dugouts across the divide from one stream into the other. This appears to have been the last gateway through which fishes could pass from one slope to the other, and it apparently also was the chief passageway through which South American fishes reached the Isthmus of Panama. This explains how species sometimes cross a divide and how it happens that even as high a divide as the Rocky Mountains fails to form a complete barrier.

Evidently, then, fresh-water fishes may become distributed far beyond the confines of the stream of their origin. The chief factor in limiting the still wider distribution of fresh-water (as well as marine) species is temperature. This forms such an efficient barrier that comparatively few species of fresh-water fishes of the United States extend their range into Mexico. In Panama only one fish common to the fresh waters of the States has been taken, and that is the eel, which, after all, is not strictly a fresh-water form, as it enters salt water to spawn and is taken in fairly salty water at other times.

Marine fishes are probably limited to an even greater extent in distribution by temperature than are the fresh-water forms. Of course, other limiting factors, including shallow water for some species and deep water for others, salinity, and land barriers, must all be considered. The great influence of temperature on distribution is shown by ocean currents. In the Gulf Stream many species of tropical fishes either swim or are carried northward in the warm water far beyond their usual habitat and they come ashore as far north as Rhode Island and Massachusetts, where many of them probably perish. It is thought by some writers that these fishes are involuntarily carried northward by the current, but while many of the specimens of tropical fishes taken on the coast of New England are immature, they generally are large and strong enough to swim vigorously and for that reason I doubt whether they reach these northern realms wholly involuntarily. They probably find conditions quite agreeable in the Gulf Stream and, being assisted by the current, they swim on and on. Whether any of the northern stragglers ever return to tropical waters is not known.

Marine fishes are so greatly influenced by temperature that some authors divide them into general groups on that basis. Thus we speak of arctic, north temperate, tropical, south temperate, and antarctic types. It is of interest to note that the forms of the two frigid zones, even



Deep-sea fishes, *Gastrostomus bairdii*, taken at 700 fathoms' depth, off Nonsuch Island, by the Bermuda Oceanographic Expedition. Courtesy of Dr. William Beebe

though widely separated, are similar. That is to say, arctic and antarctic fish forms generally closely resemble one another, certainly much more so than either group resembles the tropical forms.

The distribution of fresh-water fishes at various depths —vertical distribution—is more limited than that of marine fishes, as the range in depth of fresh-water is usually less than that of salt-water bodies. The Great Lakes, however, are deep enough to harbor cold-water forms, such as the whitefishes, the lake herring or cisco, and the lake trout. Like the cod, mackerel, and several other marine fishes, these deep-water lake forms come inshore to spawn.

Certain fresh-water forms live more or less habitually on the bottom, whereas others stay at or near the surface. The catfishes, the bowfin, and the mud minnows are notable examples of bottom-dwelling species, while the top minnows and especially the four-eyes of Central America are examples of surface-dwelling fishes. The large majority of fresh-water fishes, however, can not be classed as either surface- or bottom-dwelling species, as they occur at all depths. This characteristic is, of course, correlated with feeding.

Most of our common marine food fishes live near the shores, or they at least come near them at certain seasons of the year, as we saw in the chapter on migration, but there is one exception, the tilefish (*Lopholatilus chamaeleonticeps*), which apparently never enters shallow water. This species generally stays on the outer edge of the continental shelf from New England to Virginia in water varying from fifty to two hundred fathoms in depth.

Among the marine species is a group (including especially the allies of the mackerel family) known as pelagic fishes, that is, fishes that inhabit the open seas, most frequently swimming at the surface and ranging widely within certain limits of temperature. Some of the pelagic fishes are almost cosmopolitan in their distribution, several species being known to inhabit all the warm seas. The pelagic species shade into the shore fishes on the one hand and into the deep-sea fishes on the other.

The deep-sea fishes include those forms which live below the line of adequate light. Some of them, however, dwell at much greater depths than others. These species, too, are somewhat localized in their distribution, yet as they dwell at great depths they are little influenced by the sun's rays and surface temperatures, so that the same forms found at the equator may occur also in the arctic regions. The deep-sea fishes shade off by degrees into pelagic and shore types.

The fishes coming from great depths generally are very soft, apparently due to a degeneration of the bones and the muscles. They often reveal fantastic shapes; sometimes they are all black in color; some of them are blind; others have very large eyes, exceedingly large mouths, or long tails; and many of them are provided with luminous spots or areas, which are thought by some authors to serve them in furnishing light in the great depths to which the sun's rays do not penetrate.

The shore fishes, or littoral fishes, as a rule, are of a narrower distribution than other marine fishes, and they can be assigned more definitely to geographical areas. Of the 202 species recorded from Chesapeake Bay, for example, 27 find this body of water the northern point of their range, and for 12 species it is the southern limit of their distribution, whereas 106 are known from localities both north and south of this bay. Temperature undoubtedly is the chief controlling factor in this distribution. Among the shore fishes there is a vertical distribution somewhat similar to that already described for fresh-water species. The menhaden, which is allied in a measure to the pelagic species, swims and feeds at the surface; the flatfishes dwell at the bottom; whereas the weakfishes are one of the many genera which live at various depths within the waters they occupy.

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PART II

AMPHIBIANS

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PREFACE TO PARTS II AND III

Because the study of fossil amphibians (or batrachians) and reptiles constitutes a specialty distinct from the study of living amphibians and reptiles, we have followed this arbitrary division in the presentation of the subjects in this book. Thus in Part II, on amphibians, Chapter I is devoted to fossil forms and is wholly the work of Mr. Gilmore, while Chapters II–IV discuss living forms and are by Miss Cochran. Again in Part III, which treats of reptiles, Mr. Gilmore is responsible for Chapters I–VI—on fossil forms, while Miss Cochran has compiled Chapters VII–XII—on living forms. Each author, therefore, stands accountable for the material in his or her own chapter.

CHAPTER I

FOSSIL AMPHIBIANS

COLD-BLOODEDNESS is a characteristic shared by fishes with two other classes of backboned animals—amphibians and reptiles. It forms one of the symbols of the close relationship existing between the three. There are many others. The term *amphibious* in the Greek means literally "leading a double life." This is an apt word to designate the water- and land-living habits of the frog, toad, newt, and salamander, which comprise the commonest examples of the class Amphibia. In the first part of their existence they live in water and breathe by means of gills, as fishes do. Afterwards they discard the gills, develop lungs to enable them to breathe air, and behave very much like reptiles. Thus in habits and appearance they are half fish and half reptile.

How a water-breathing vertebrate first came to exchange its gills for lungs, and so take the great step toward becoming an amphibian, has received attention in the preceding section of this volume, where the lungfishes were referred to as showing characteristics common to both amphibians and fishes. In them the gills almost wholly disappear with age, and the remnant can not supply their respiratory needs. Like a frog, these fishes must rise periodically to the surface for air, which they breathe by means of lungs developed from the air bladder.

This change of structure and habit in the lungfish seems to foreshadow the process of metamorphosis of the tadpole into the frog, a phenomenon familiar to almost every one and, in a way, an object lesson on the part of nature to illustrate to us in a short space of time how the transformation from fishlike to reptilelike forms came about. We have proof, in the fossils of small amphibians from the Gaskohle formation of Bohemia, that some of the very early members of this class underwent a series of

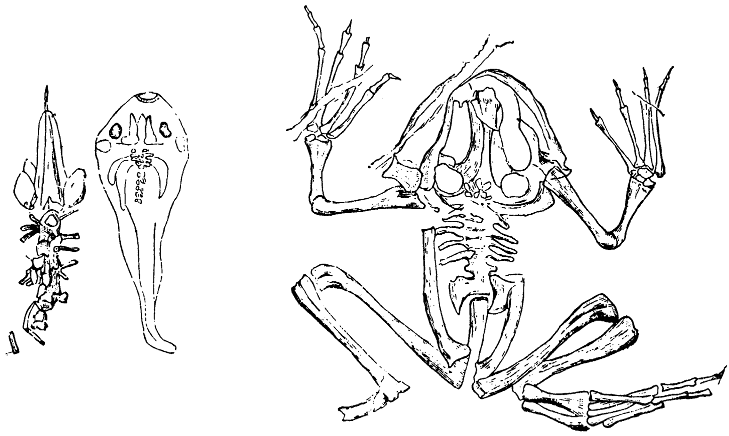


FIG. 50. Fossil larvae and fossil frog, *Paleobatrachus*, from the Miocene of Bohemia. After Wolterstorff and Meyer

changes similar to the metamorphosis of the common frog (Fig. 50). In studying the fossil specimens Doctor Fritsch found some so well preserved as to enable him to recognize the presence of the gills by means of which in their early life they breathed in water like fishes.

Once this major step toward land living had been taken, amphibians developed into many forms and great numbers. They were pioneer vertebrates on a virgin earth. They had no serious competition from outsiders, no enemies to prey upon them. In consequence they became for a long period masters of the land. The amphibians living today constitute but a meager remnant of the great race they once were.

All this took place in and before the Carboniferous period in which the earliest known amphibian skeletons occur. How much before we don't know, but it must have been millions of years to permit of the evolution of the forms we find in the Carboniferous, when the Amphibia were the dominant type of animal life. The world they knew differed widely from ours, not only in its animals but in its plants and in the outlines of its continents. Vast areas were covered with coal forests, chiefly ferns and fernlike plants, giant equisetums and club mosses. These formed the great coal beds on which we now chiefly depend to supply heat and power for our homes and industries. The insects were represented by only the lower orders, but some of them attained a wing spread of twenty-nine inches.

In such an environment our amphibians developed in great diversity, as proved by the fossils which have come to light. They ranged from an inch or two in length to perhaps eight feet, which is far larger than any known today. Toward the end of this golden age of amphibians, the reptiles, so the rocks tell us, began to evolve from them. The wide gap that now exists between these two great classes was then so slight as to make it difficult to tell where the one left off and the other began. In any event, the reptiles were sufficiently different to be better adapted—so we are to presume—to the conditions of life then existing, and they eventually relegated the amphibians to second place. The Amphibia as a class dwindled away and many of the small forms disappeared altogether.

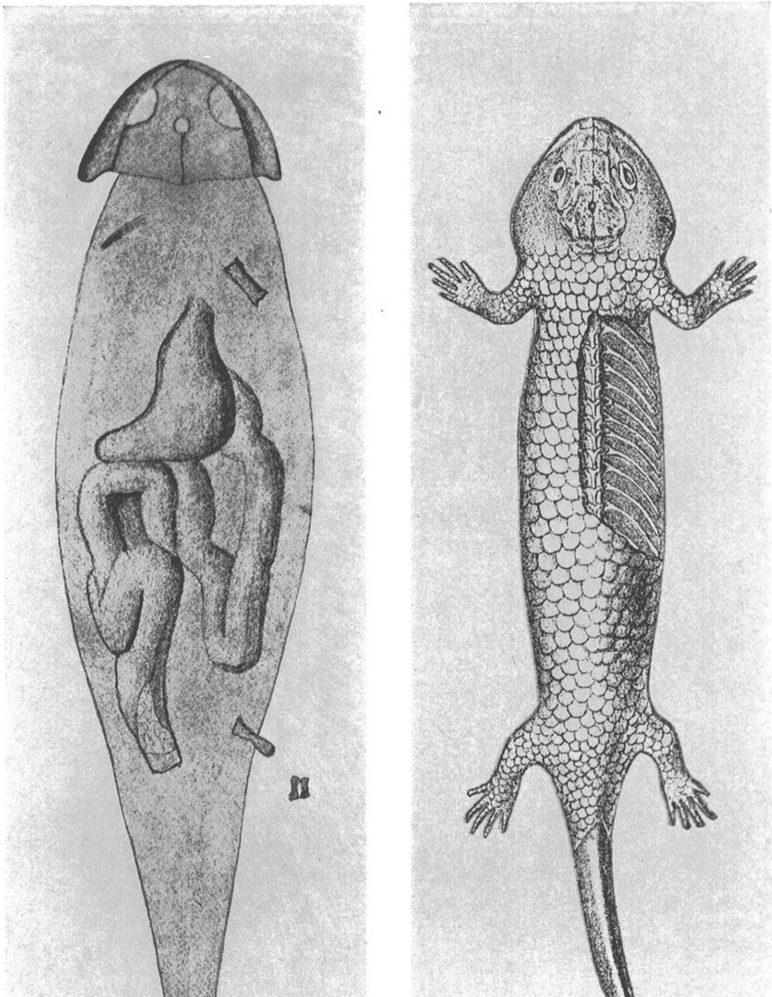
The race as a whole has never recovered from this first eclipse but has occupied a subordinate position in world affairs ever since. The fossil evidence of its subsequent history is meager. Such as it is, it enables us to trace broadly the evolution of the ancient forms into those of our day.

In connection with this great rarity of fossil amphibians, Moodie has computed their comparative occurrence in the Mazon Creek fossil-bearing locality of Grundy County, Ill. His figures, while, of course, not true for the whole world, give an impression of general scarcity which is correct. The Mazon Creek fossils occur in small stony nodules found in a shale bed. Of 100,000 nodules Moodie found that 20,000 were barren or contained only indeterminate fragments; 68,500 contained plant remains; 7,500, insects; 3,900, fishes or fragments of fishes; 4, mollusks; while only 1 contained a single amphibian.

However, paleontologists have enough information to tell what a good many of the extinct amphibians looked like. Some suggested a likeness to the snakes, others to the lizards, while still others that retained gills throughout life resembled finless fishes like the lampreys. Thus they struck out in about as many directions as their relatives the reptiles did later, ranging from the serpentlike form to the short-bodied, four-legged, turtle- and alligatorlike types. The body covering in some species was a coat of small bony scales, while in others it was smooth and probably slimy, as in living members of the class.

Impressions of the soft parts of the anatomy of extinct animals come to light in the rocks only very rarely, but occasionally such specimens are found; and as time goes on and the search is continued, our confidence in the preserving power of the rocks grows and leads to the hope that characteristics of other animals now unknown or obscure will eventually be revealed. The body outlines of the fishes and of the reptilian ichthyosaurs and mosasaurs have long been known, but it remained for a contemporary paleontologist, Dr. Roy L. Moodie, to study and describe an extinct amphibian, showing not only the body contours but the impression of the entire alimentary canal as well. So distinct is the preservation of this organ that Moodie was able to describe all of its various divisions in considerable detail. In addition, the rocks preserved the pigment of the skin and the color pattern it assumed; the black pigment of the eye; the minute scales which covered the body; and the scutes that covered the belly. Taken all in all, its remarkable conservation leaves but

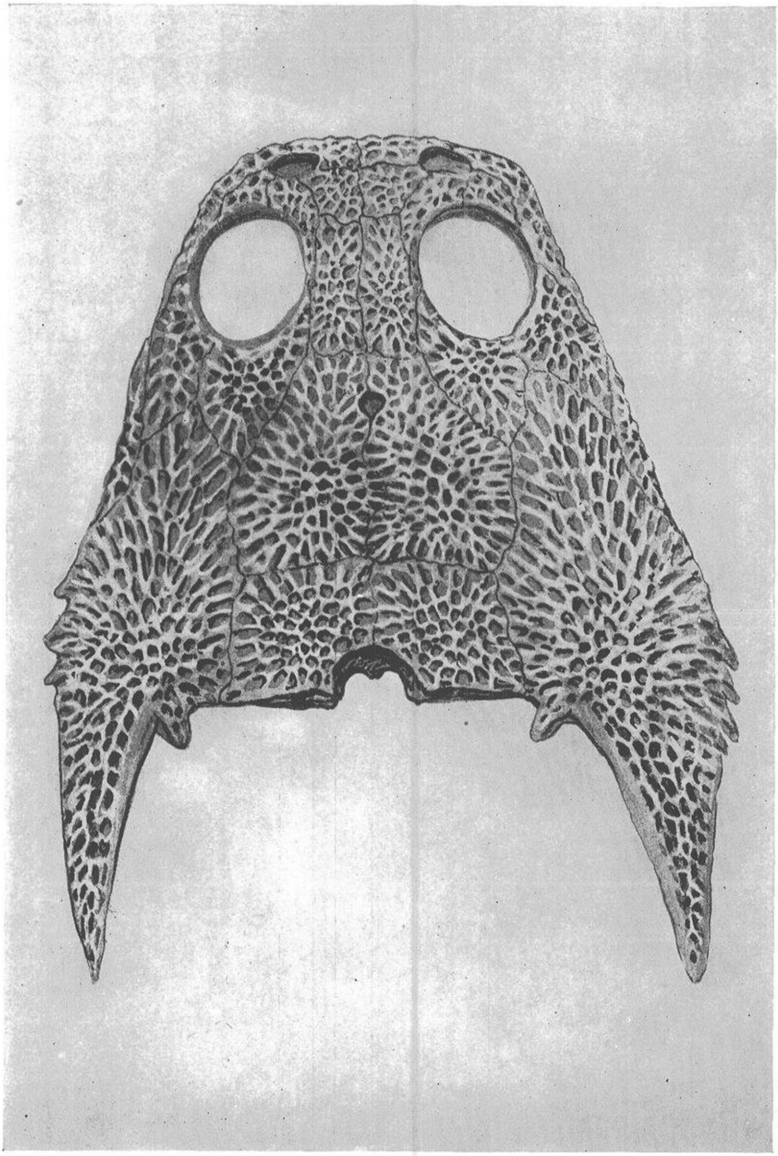
PLATE 31



Left: The most perfectly preserved amphibian, *Eumicrerpeton*, from Illinois. After Moodie

Right: *Ricnodon*, from the Permian strata of Bohemia. After Fritsch

PLATE 32



Skull of *Diceratosaurus* showing opening for third eye. Note solid and ornamented character of skull back of orbits. After Jaekel little to conjecture regarding either the internal or external anatomy of this long extinct animal (Plate 31).

The name *Eumicrerpeton parvum* is longer than the specimen itself, for the stony nodule which contains this salamander measures only two and a quarter inches in length and the fossil occurs nearly in the center of the nodule. It came from the Mazon Creek locality in Grundy County, Ill., concerning which Moodie made the estimates quoted above.

But the earliest amphibian—and therefore the earliest land vertebrate—to which we have a clue lived long before the Carboniferous, for in 1849 Isaac Lea discovered fossil footprints in rocks of Devonian age, which had never before yielded traces of animals higher in the scale than the fishes. For two good reasons these footprints were attributed to an amphibian: First, they resemble some found associated with amphibian skeletons in later formations; and second, they must have been made by animals of the next higher class than the fishes (the Amphibia) and the first to have feet, for it is their possession of feet that chiefly distinguishes the Amphibia from the fishes.

Our knowledge of the extinct Amphibia is said to have had its beginning with Professor Scheuchzer's description in 1725 of the fossil skeleton of a large salamander, which he called *Homo diluvii testis*, or "the man that witnessed the Deluge." His engraving of this witness of the Flood was printed in the famous "Copper Bible" as positive proof of the literal accuracy of the Biblical record. In this specimen, which is still preserved in the Museum at Haarlem, under the name *Andrias scheuchzeri*, Scheuchzer thought that he detected not only the skeleton of a man but even the brain, liver, and muscles, the "sorrowful skeleton of an old sinner drowned in the Flood."

Since Scheuchzer's time fossil amphibians have been turning up sporadically over the whole world. The Mazon Creek area has proved a fruitful source of material. Another locality in the valley of Yellow Creek in eastern

Ohio, which was once a coal-mining center, has yielded some of the finest examples of the Amphibia found on this continent, as well as the earliest known reptile. The fossils occur in blocks of coal shale, and although always crushed flat, some specimens preserve the minutest details of their bodily structure.

The amphibians of this epoch (Pennsylvanian) were for the most part salamanderlike creatures, nearly all belonging to a group known as the Stegocephalia (meaning roof-skulled), except that near the close of the epoch there appeared small slender-legged aquatic forms which are considered the ancient representatives of the real salamanders of modern times.

The erect fossil tree trunks (genus *Sigillaria*) found at South Joggins, Nova Scotia, present perhaps the most remarkable repositories for amphibian remains ever discovered. The skeletons occur in the decayed cavities of these ancient tree trunks, where the animals had evidently gone in search of prey. Sir John Dawson found in one stump the fossil skeletons of no less than nine specimens, representing four species.

In the year 1824 Professor Jaeger discovered in Württemberg, Germany, the fossil remains of an amphibian so large that he applied to it the name *Mastodonsaurus*, not because it had any relationship to the elephantlike mastodon—which is, of course, a mammal—but in reference to its very great size. It is the largest of all known extinct Amphibia. The skull alone attains enormous proportions for an amphibian, often reaching a length of four feet and a breadth of two and one-half feet.

Mastodonsaurus belongs to a group known as the labyrinthodonts. Examining the teeth of this animal under the microscope Sir Richard Owen found a distinctive and remarkable structure, with the whole of the internal portion made up of a complex series of foldings, resembling the windings of a labyrinth; and this feature suggested to him the name "labyrinth-toothed."

The minute internal structure of a tooth may seem to be of little importance, but all anatomists recognize that the teeth of animals aid greatly in indicating their proper place in the classificatory scheme of the animal kingdom. In the present instance, the labyrinthian structure indicates in one direction affinity of the specimen with certain ganoid fishes that possess teeth similarly infolded, and in the other affinity with certain of the reptiles known as the Ichthyosauria, whose teeth show an approach to the same peculiar structure.

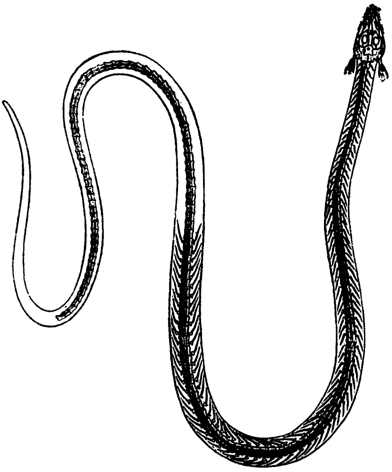


FIG. 51. A snakelike labyrinthodont, *Dolichosoma*, from Carboniferous strata, Bohemia. After Fritsch

Among other general structural peculiarities which distinguish the amphibians, we find in the skull one feature peculiar to the group that is rarely found in reptiles living or extinct; that is, the complete, highly ornamented, bony roof that covers the whole upper surface of the skull behind the orbits. Some of the lower fishes have skulls similarly roofed over; but in the reptiles, except in the oldest forms, this part of the skull is usually perforated by two openings, called fenestra, one on either side of the midline; still others occur lower down on the sides.

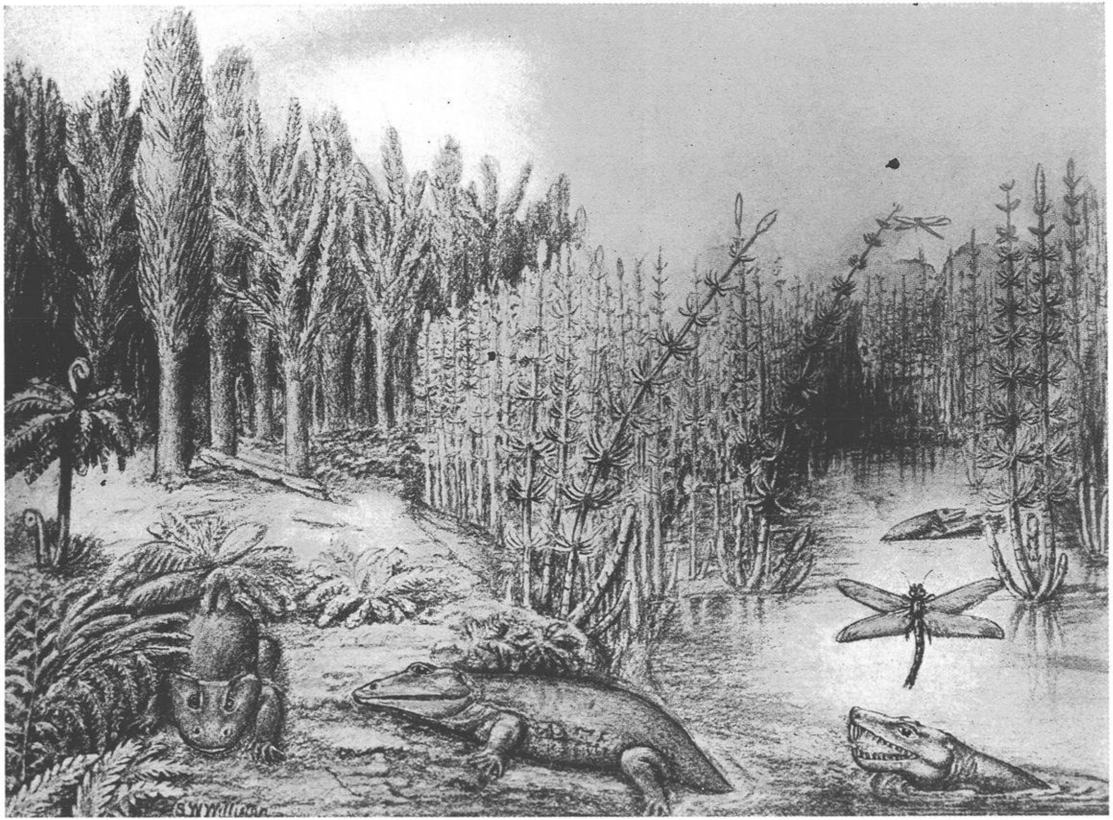
More striking perhaps, to the nonspecialist, is the pineal or third eye. On the skull of *Diceratosaurus* (Plate 32) there can be seen on the middle line back of the orbits a small rounded opening which lies over the brain cavity. This marks the position of the curious organ, but whether the little eye was of any use to the animal or not is somewhat a matter of doubt. A similar aperture overlying a now quite useless rudiment of an eye down in the brain is present in the lizardlike reptile known as *Sphenodon* living in New Zealand today. The third eye must have served a purpose at some time, however, and the probabilities are that in the early amphibians it was functional. In *Sphenodon* we appear to have a relic of a one-time useful organ comparable to the gill slits in the human embryo.

In all of the fishes the segments of the backbone, known as vertebrae, have their articular ends hollowed out, and it should now occasion no surprise to learn that the Amphibia have similar biconcave or cup-shaped vertebrae. In some of the more primitive and ancient forms the centrum of the vertebra is made up of three separate pieces, an arrangement also found in certain primitive fishes.

The skeletal features briefly mentioned above constitute only a few of the many characteristics that, taken together, distinguish the Amphibia from other classes of vertebrate animals. Let us look for a moment at some of the more striking of the individual fossil species discovered.

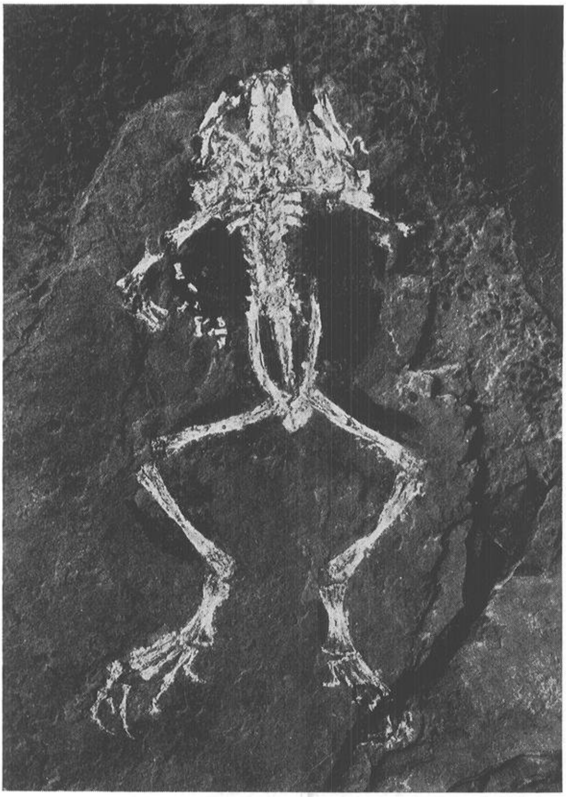
In *Eryops* we have the largest as well as the best known of the ancient North American amphibians. This animal was not unlike an overgrown salamander, sometimes reaching a length of eight feet, two of which were head. A wide, flat skull, with the lower jaws hinged at the back so that the animal had a tremendous gape; no neck; a thick, heavy body that the short sprawling legs could not raise from the ground except through great effort; and a heavy, flattened tail—all combined to make *Eryops* a clumsy looking creature. That this beast, slow and small-brained, should have been one of the highest types of living things in the ancient world may help us to realize how remote and far away was the period in which he flourished.

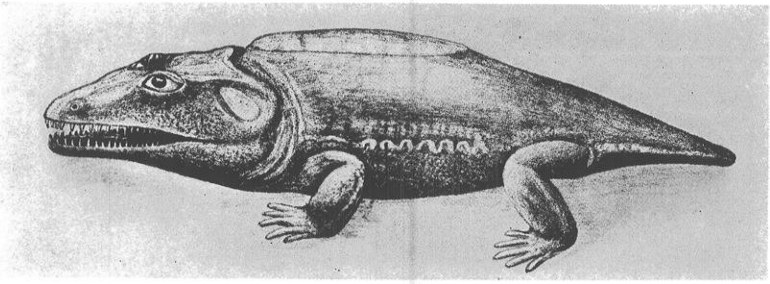
The jaws were armed with sharp conical teeth which at



Restoration of a Permocarboniferous landscape, with two specimens of *Eryops* upon the bank, each about seven feet long, and *Limnoscelis*, a reptile, in the water. After Williston

PLATE 34





Upper: Most perfect skeleton of a fossil frog yet found in America. From the Eocene of Wyoming

Lower: Restoration of *Cacops*, a stegocephalian amphibian from the Permian of Texas. After Williston the front formed powerful tusks. From the weak character of the limbs it would seem that *Eryops* was probably more at home in the water, living in the pools and sluggish streams that traversed the coastal marshes of the great interior sea of Permo-Carboniferous times. In such an environment this animal may have played a rôle

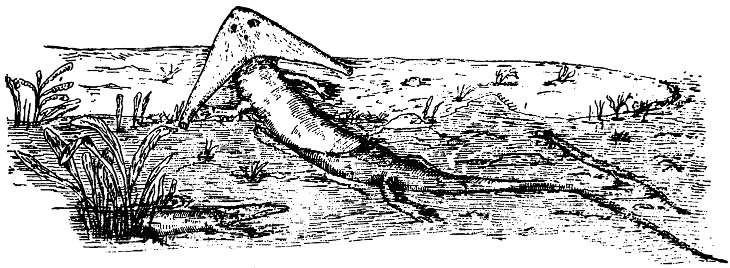


FIG. 52. Restoration of *Diplocaulus*, the exclusively aquatic amphibian, and of *Lysorophus*. After Case

somewhat similar to that of the modern alligator; so that we may picture him as lying nearly covered in the water, with eyes and nostrils exposed, till prey appeared, then gliding slowly until within a short distance, when a sudden fierce rush ended with the passage of the victim down the capacious maw.

One of the oddities of all paleontology appears in *Cacops*, described by Professor Williston from the Permian strata of Texas. He is a most absurd-looking creature, almost froglike in general appearance, with a huge head, no neck, and short tail. He reaches a length of twenty-nine inches, and his outstanding feature is a carapace of bony plates forming a row along the middle of the back. The restoration shown in Plate 34 is based upon a skeleton found associated with a dozen or more specimens in a space about six by eight feet square.

At least one amphibian of Permian times, like the whales and other mammals of our day, refused to avail himself of the capacity his immediate ancestors had acquired of living on the land, and followed his distant fish forefathers back to an exclusively marine existence. Professor Cope, who described him, called him the *Diplocaulus* (Fig. 52). He grew to a length of three feet. The arrow-shaped form of the head and the long, slender body with tiny legs of no terrestrial and little aquatic use, mark him as one of the strikingly odd forms of this group.

The location of the eyes and nostrils entirely on the upper surface of the skull has suggested the idea that *Diplocaulus* habitually lay upon the bottom of pools. Moving sluggishly over the slime of the bottom, he would devour such small animal life as he might discover. The suggestion has been made that the large projecting horns of the skull may have sheltered external gills but of this we have no knowledge.

The Salientia, the group comprising frogs and toads, are known as far back in geological time as the Jurassic, but their remains are very rare in the fossil state. In fact, in all the world not more than two score fossil species have been described, whereas there are said to be 1,500 living species. These early frogs, however, are as typically jumping frogs as any living today, so we must deduce that their ancestors existed long before the Jurassic. On Plate 34, the lower figure, reproduced from a specimen in the National Museum, shows an extinct frog found in the Eocene deposits of Wyoming, the most perfect specimen yet found in America. Fossil larvae on which this animal may have fed may be observed on the surface of the surrounding rock. The skeleton is crushed flat, but being a lighter color than the shale in which it is embedded, the outlines of the bones stand out in strong relief.

In the phosphorite deposits of Quercy, France, mummies of both toads and frogs have been found, and, in the Braunkohle formation of Germany, fossil larvae and skeletons of *Paleobatrachus*, an extinct frog. (See Fig. 50.)

Lysorophus (Fig. 52), first described by Professor Cope, has been the subject of more discussion than its small size would seem to warrant. For a number of years considerable controversy raged between certain paleontologists as to whether this animal was an amphibian or a reptile, but more recent researches have definitely disclosed its amphibian characteristics. That it was snakelike in life is proved by the long, connected series of vertebrae of nearly uniform size; that it had but feeble sight is proved by the very small size of the eyes. Doubtless also, its skin was bare and it was more or less given to burrowing in the mud. In certain limited localities skeletons of the species are found in great numbers, suggesting that they were thus gathered together in slowly drying pools. The backbone, which is relatively long, is always found more or less perfectly coiled.

Last to be mentioned is the little *Branchiosaurus*, of which great numbers in all stages of growth have been found in the lower Permian strata of Saxony, Bohemia, and France. The preservation of many of these specimens is so perfect that not only are the minutest details of their skeletal structure revealed but even impressions of the soft tissues remain, so that we know the outlines of the body, legs, and tail of this long extinct amphibian. The tail, most of the vertebrae of which remained unossified and were not fossilized, is shown by these impressions to have been as long as the trunk and head combined.

The head was short and broad, with large orbits for the eyes. In the shape of the head as well as in bodily contour the members of the suborder Branchiosauria closely resembled the smaller salamanders of the present day. In fact, several authorities have suggested that among the Branchiosauria were the direct ancestral forms from which the tailed order (Caudata) of the class Amphibia originated.

The largest of the branchiosaurs were less than five inches in length. The French specimens are usually referred to under the generic name *Protriton*.

This brief review of a few of the outstanding members of the fossil Amphibia will perhaps indicate the similarities and the differences between them and the living forms. In all there are only four orders of known Amphibia, both fossil and recent—Stegocephalia, Apoda, Caudata, and Salientia. Contrast this scarcity with the twelve or fourteen orders of known reptiles. In all America only 156 species of extinct amphibians are known today. Evidently we have record of but a fraction of the great host that once occupied the earth.

CHAPTER II

SOME EVOLUTIONARY ASPECTS OF AMPHIBIANS

As already suggested in earlier sections of this volume, certain characteristics of living amphibians indicate that these first land-dwelling vertebrates may have owed their origin to an ability, similar to that of the lungfishes, to survive long periods of drought by burying themselves in the mud. This very habit is exhibited by some of the salamanders and by the Apoda, or limbless amphibians, which latter group comprises certain tropical wormlike forms known as caecilians. The Apoda, after passing through a fishlike larval stage, lose the gills and the greater part of the tail, develop lungs, and proceed to bury themselves even more permanently than did their predecessors. For most adult caecilians spend their whole life, instead of only a season, underground. One South American genus, *Typhlonectes*, looks very much like an eel, however, and is found in some of the rivers of Colombia and Venezuela.

Again, it seems reasonable to suppose that the Amphibia came from fresh-water forms, for salt, even in a solution of only one per cent, is usually fatal to them in whatever stage—egg, larva, or adult. The most completely aquatic forms of amphibians are found among the lizardlike salamanders and newts, comprising the order Caudata, or Urodela, the tailed amphibians. Many of these live only in clear, cold, running streams. Some retain gills throughout life, and although never entirely limbless like the Apoda, sometimes they have lost the hind legs; even when they possess all four limbs, these are always relatively small and feeble.

Much more numerous than both the other orders combined are the Salientia, sometimes called the Ecaudata, or Anura, the tailless amphibians, including among other forms our familiar frogs and toads. These latter in the adult stage seem perfectly adapted to a terrestrial life. They have not only lungs with which to breathe but also four very efficient limbs—legs for hopping and arms for clasping—terminating in hands and feet, the former furnished with four fingers and the latter with five supple toes.

For the purpose of propagating the next generation, however, the frogs and toads usually resort to their ancestral element. Because their eggs are not incased in a firm, impervious shell, as in many reptiles, they are forced to deposit them in water to prevent them from drying up before the young have hatched. These, like the young of most other amphibians, make their appearance with gills and a fishlike tail, and must undergo a period of development as swimming tadpoles before they acquire their complete equipment for breathing air and for hopping on dry land.

The Amphibia, as a class, may then be regarded as animals which in the course of their life history pass from fishlike to reptilelike forms. This is true, however, only in general, for some Amphibia never exhibit fishlike characters except in their very early stages.

Among other fishlike characters, amphibians in the larval stage carry sense organs in the skin of the head and sides, forming not one lateral line merely, but two or more. These organs tend to disappear, with the gills, on the completion of metamorphosis. In the Caudata, however, when the newts take to the water during the breeding season, these organs again become conspicuous on the surface of the skin.

In other respects, the skin of amphibians, as has been already noted, forms one of their distinguishing characteristics, being usually smooth and devoid of the scaly armor of most fishes and reptiles. Instead, the amphibian skin is supplied with slime glands and in some species with still other glands that emit a more or less poisonous secretion—the sole weapon of these otherwise defenseless creatures. Periodically the upper cell layer of the skin becomes horny and loosened from the inner layer. This thin outer portion of the epidermis is then shed, often in one piece, to permit the growth of the animal. Each molt reveals a moist, shiny surface which soon dries and hardens.

Being moist and richly supplied with blood, the skin frequently serves as an aid in breathing, particularly during hibernation or aestivation, when the ordinary functions are suspended. In some cases, indeed, both lungs and gills have been eliminated and the skin is the only organ of respiration. This condition, however, is exceptional, and the majority of amphibians, once they have reached the adult state, breathe by means of lungs.

Besides well-developed lungs, hands, and feet, the Amphibia, except for one suborder of the Salientia, possess a fully developed tongue. The tongues of amphibians display various shapes and sizes and function in various ways, but they all play an important part in the life history of these animals. In most amphibians this organ, being long and flexible, serves as an admirable instrument for the capture of prey, as anyone will appreciate who has observed an otherwise motionless toad snap up a fly. For all full-grown amphibians are carnivorous, living chiefly on small creeping or flying things, which they seem to perceive only by their movements. To induce a frog in captivity to eat a morsel of raw meat, one must dangle it before him in order to attract his attention. Tadpoles, on the other hand, are largely herbivorous, although they feed also on carrion or on bits of fresh meat. This they nibble; for, although tongueless, like many fishes, they are equipped with toothlike structures.

The change in the feeding habits of the young amphibian as it develops into the adult is reflected in the change in structure of its alimentary canal. Tadpoles, in common with most vegetable feeders, whose food is relatively tough and fibrous, require a long, involved digestive tract for its assimilation. In full-grown amphibians, on the contrary, the digestive tract is more simple than that of some fishes, being in many cases an almost straight tube in which the stomach is represented by only a slight swelling. Salivary glands are entirely lacking, and the other organs, such as the liver, kidneys, etc., are much more simple than in the higher vertebrates.

Structurally neither the eye nor the ear of amphibians seems to show much improvement over those of fishes. In some species, indeed, a subterranean existence has led to the almost total degeneration of the eye. The ears of amphibians in the tadpole stage, as well as in the adults of the lowest forms, consist of mere sacs containing chalky bodies in a cavity of bone, simply covered with skin. No amphibian has an outside opening to the ear, but in the higher frogs and toads the cavity is covered by a tough drum membrane flush with the surface, sometimes showing conspicuously as a sort of ring or plate.

We are indebted to the Amphibia, however, for the first voice ever to be lifted on the earth, if we except the "grunting" of certain fishes like the croaker and the squeteague. Most of us are familiar with the vocal powers of the frog, but few, perhaps, realize that he keeps both mouth and nostrils firmly closed while croaking. He possesses, moreover, an effective sound amplifier—a pair of *vocal sacs*, which act as resonators, thus aiding him to broadcast his song.

Equipped with hands, feet, and lungs, and, for the most part, equally at home on land or in fresh water, the amphibians have succeeded in spreading over the face of the earth and in maintaining themselves even against their more highly organized competitors, the reptiles.

CHAPTER III

CAECILIANS AND SALAMANDERS

The Caecilians

About fifty species are included in the primitive order of the Apoda, which comprises only one family, the Caeciliidae, or caecilians, so named from the fact that because of their burrowing habits they have become blind or nearly so (Latin, *caecus*). All the species inhabit the tropical regions of South America, Africa, or Asia. They do not vary much in size from a minimum of ten inches when full grown. One giant species of the genus *Caecilia*, found in Ecuador, however, measures over three feet in length.

In these modern descendants of the extinct Paleozoic stegocephalians, the armored plates of that once mighty order are represented only by small calcified scales buried in the skin. Externally the skin of a caecilian is smooth and slimy, with numerous transverse folds that give the creature the appearance of a large segmented earthworm. Besides the scales and the ordinary slime glands, the caecilians possess squirt glands, through which they eject a somewhat poisonous fluid that causes those that come in contact with it to sneeze. The most characteristic and striking features of the caecilian physiognomy are the two so-called facial tentacles, little conical or globular-shaped feelers, the function of which is probably to help the animal direct its course underground.

Of the habits of caecilians little is known, as only one of the species, *Ichthyophis glutinosus*, of southern Asia, has been subjected to extensive study.

Ichthyophis glutinosus is rather broad, for a caecilian, in proportion to its length, being one-half inch in diameter and about twelve inches long. Its dull-colored body—dark brown or bluish-black—is enlivened by a yellow band along each side, and its narrow transverse folds, except

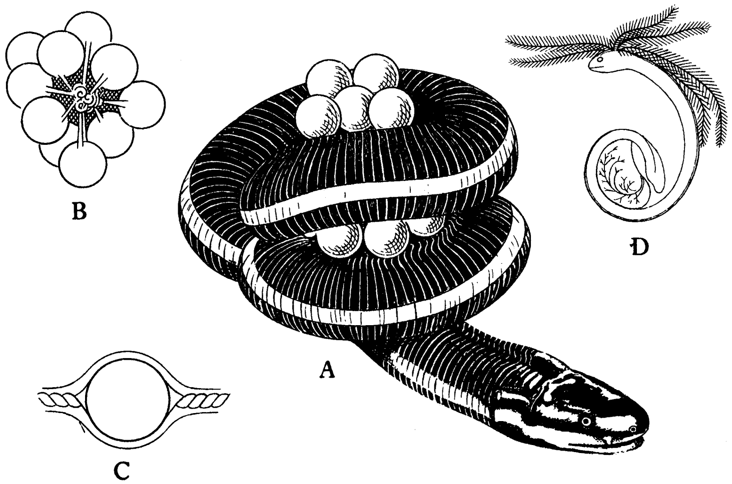


FIG. 53. The development of a caecilian, *Ichthyophis glutinosus*, a burrowing, limbless, and nearly blind amphibian of southern Asia. A, female coiled about her egg cluster; B, bunch of newly-laid eggs; C, single egg; D, a nearly ripe embryo. After P. and F. Sarasin

when the skin is distended, resemble a series of very fine tucks. It breeds, in the neighborhood of Ceylon, after the spring monsoon.

The incubation of the eggs is undertaken by the female who digs a hole for this purpose close to the surface in moist ground near running water. Here she deposits about two dozen yellow eggs, measuring from eight to ten millimeters in diameter, around which she coils herself (Fig. 53). The eggs are connected by a sort of twisted membranous cord and increase to twice their size during incubation, the mature embryo weighing four times as much as the newly laid egg.

The embryo at first develops three pairs of long, delicately fringed gills by which it breathes. Before hatching these gills shrivel up, and only a hole, known as the gill-cleft, remains in their place. Despite its gill-less state the young larva takes to the water, where it lives a long time, swimming about by means of two finlike crests on the tail and coming up to the surface to breathe. At this stage the eyes, though small, are well developed, and about fifty epidermal sense organs appear from the gill opening to the tip of the tail, showing as white spots on the gray skin.

As growth continues, the tail shortens and loses its crests, a film of skin covers the eyes, the facial tentacles make their appearance, and the skin undergoes complete transformation. Finally the fishlike larva turns into a burrowing earth creature which spends the rest of its life underground.

The Salamanders

The salamanders, whose three suborders constitute the order Caudata (known also as the Urodela), or tailed amphibians, are confined to the north temperate zone, except for a few species found in the tropics—in similar habitats in Central and South America and Africa north of the Sahara. Though much more varied and widely distributed than the primitive caecilians, because of their aversion to the sun and its heat they are rarely seen and consequently are little known. Even when an occasional specimen is brought up from the depths of a well, it goes by the name of "spring lizard" and is seldom recognized as a salamander.

Most of us, indeed, are better acquainted with mythical salamanders than with real ones. Strangely enough, the salamanders described by Paracelsus as inhabiting the "element" fire, were in their fondness for high temperatures the exact opposites of their present-day namesakes. For of all the amphibians, these are the most tolerant of cold. Some live in mountain brooks fed by melting ice caps from surrounding peaks; some dwell deep in subterranean caves in the chill of perpetual darkness; while others begin to breed and to deposit their eggs during the dead of winter in ponds filmed over by sheets of ice. Cold is not their enemy: desiccation is the fate they must avoid.

The strong rays of the sun soon dry out the porous glandular skin of most salamanders. Hence they have become crepuscular or nocturnal, while during the day they hide away under logs or stones, in boggy places or in cool dark holes under overhanging banks of streams. Such species as live in warm climates have learned to aestivate through the rainless periods. Lieut. George C. Lewis, of the U. S. Signal Corps, reported an instance of such aestivation from Jackson County, Texas, in 1909. Large numbers of sirens had been found in a field which was being plowed in April, no rain having fallen for five months:

> There must have been several hundred visible during the morning. The largest seen was 26½ inches long—the average length about twelve to fifteen inches, while several dozen were four or five inches long. The only difference . . . between the larger and smaller forms was that the smaller ones had more branchiate gills, while the big fellow mentioned above had merely buttonlike knobs. When first discovered they were inert and made but little effort to get out of the hand. They were covered with a crust or sheath of dried black slime which peels off as soon as they are put in water. In five minutes after being put in a tub they are so alert that it is difficult to catch them with the hand. I dug several out carefully and found no trace of an entrance to a burrow and no cell or regular position of the body. They were simply in a soft sand, like so many sticks, at an average depth of ten inches and must have taken this position while the sand was soft and wet. When dug up the sand was only slightly moist, and would sift into your shoes and blow from the plough point in a strong wind.

This field was poorly drained, and it is likely that the sirens had gone there from drier locations to escape complete desiccation.

Aside from their nocturnal habits, most salamanders manage to elude observation by their small size also (some being less than two inches in length) and the indeterminate color of their almost translucent bodies. The larger forms are aquatic during their whole existence, and their dull gum color, irregular folds of skin, and gill fringes, which help to break up the outline of the body, make them well-nigh invisible against the river bottom. None are aggressive—yet one of the California species will bite when picked up. While the glandular secretions of the skin may serve as a protection to salamanders, their safety lies almost entirely in concealment. These creatures, many of which look like phantom lizards, live wholly on animal food such as insects, spiders, worms, small crustaceans, and the eggs and larvae of fish.

Some species of salamander can project the tongue a distance equal to half the length of the body, while in others this organ is free all around the edge and tied in the center. Sometimes it consists only of the central stem, or pedicel, topped by a mushroomlike cap. When this is so the tongue's chief function is supposed to be that of crushing food against the teeth, which these species carry in the roof of the mouth. In a few cases, however, the pedicel may be stretched and the cap thrust out of the mouth. In the giant salamanders the tongue is a mere wrinkly membrane in the floor of the mouth.

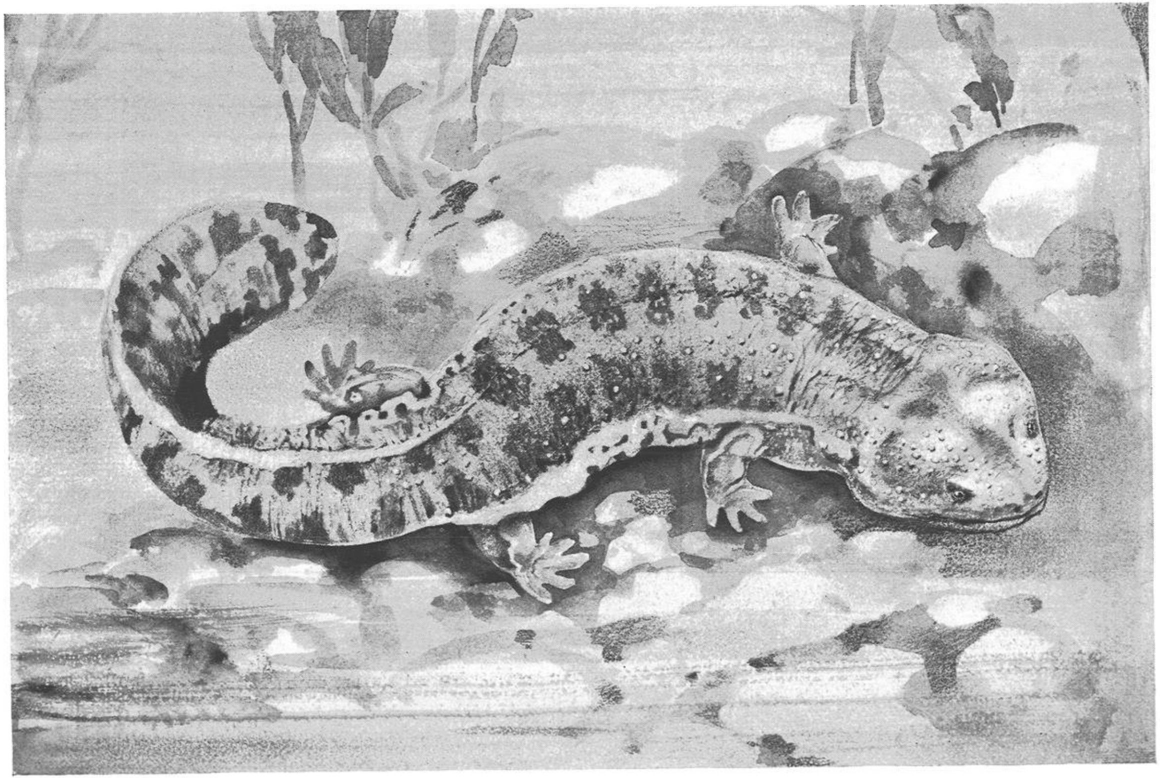
The three suborders of tailed amphibians are: First, the Meantes, with a single family, the Sirenidae, or sirens; second, the Mutabilia, including the giant salamander of Japan (largest of the Caudata), the American hellbender, and the true salamanders and newts, as well as most of the lungless species; third, the Proteida, comprising the so-called perennibranchiate forms, or permanent larvae, which retain their gills through life and are represented by the mudpuppy and the blind *Typhlomolge* in North America and by *Proteus* in Europe.

The best-known representative of the Mutabilia in America is the hellbender (*Cryptobranchus alleghaniensis*). This large aquatic salamander, which haunts the mountain streams of the Eastern States, is celebrated chiefly for its bad reputation among fishermen. Being very voracious and living on worms and fish, it not only steals the angler's bait, but worse still, destroys great quantities of valuable food fish. The adult hellbender reaches a length of about eighteen inches and is of a dull brown or gray color, sometimes with darker patches and lighter under surface.

Related to our hellbender is the largest of all salamanders, the giant *Megalobatrachus* of Japan, which attains the surprising length of four feet. It lives in high mountain valleys, frequenting the small and shallow but swiftly flowing brooks running from the icy springs. It hides in dark holes under the banks or beneath rocks, its purplish-brown hue blending with its surroundings. A rock cave inhabited by one of these salamanders may be recognized by the fact that the floor at the entrance is kept clean by the brushing of the animal's body in passing in and out. It feeds on frogs and fish and is easily caught on a baited fishhook. The Japanese eat its flesh, which is said to be delicious. It lives very well in captivity and has even been known to breed in a large aquarium tank, so that the development of its larvae is quite well known. A closely allied form lives in the mountains of western China.

Of the Mutabilia none have given occasion for more discussion among scientists than the species which have learned to do not only without gills but without lungs as well. How this condition came about and by what means these animals manage still to breathe have been fruitful subjects for investigation, experiment, and conjecture. It has been suggested that the lungless salamanders evolved in mountain brooks where, from a hydrostatic standpoint, lungs were disadvantageous and hence were lost through lack of use. In such forms the skin is probably the principal respiratory organ.

Whatever the origin of these species, some of them have adopted a thoroughly terrestrial mode of life. The lungless salamander of California (*Aneides lugubris*) actually becomes arboreal at times. It is common in the central and southern parts of the State, living both on the ground



Giant salamander of Japan, *Megalobatrachus*, four feet long. The Japanese consider its flesh delicious

and in the trees. Workmen engaged in cleaning out cavities in live-oak trees on the University of California campus found more than a hundred adults and at least twelve bunches of eggs. A number of adaptations for arboreal life are evident in examining this animal. The tail is somewhat prehensile and the tips of the digits are slightly dilated and concave beneath, a condition approaching that found in the tree toads. Moreover the salamander has lost its ability to be at home in the water and struggles violently to get out when immersed. On the ground it takes shelter beneath stones or boards, in rotted stumps and logs, and even in nests of wood rats during the day. The teeth are relatively large and the adult females sometimes show fight by biting at a stick or finger thrust near them.

Not only do we find salamanders whose lungs have atrophied for lack of use; some forms that have shunned the light too long have lost the use of their eyes. This is the case with *Typhlotriton spelaeus*, inhabiting the caverns of the Ozark Mountains in Missouri (Fig. 54). The larvae can both see and be seen, as their eyes have not yet ceased to function and they themselves are very dark in color. They are far more abundant in springs outside the caves than within and prefer cold waters with a temperature below 65° F. As they grow and resort to the subterranean waters, the pigmentation is reduced, the eyelids fail to open widely, and the retina undergoes degeneration, although the dark eyeballs still show through the lids.

While a translucent skin and indeterminate coloration are characteristic of most salamanders, certain forms have acquired a more vivid aspect. Perhaps the most strikingly colored salamander in the United States is *Pseudotriton ruber*, whose coral-red ground color is spotted with black on the back, head, and tail. In springs and brooks it frequently occurs in great numbers. According to Dr. Sherman C. Bishop, "it may be found at all seasons of the year, but in winter it is less active and hides beneath stones and rubbish below the surface of the water. If it wanders abroad, the venture is made during the warmer months, and at night, when there is less possibility of the skin becoming dry; for this species belongs to a group whose members are without lungs. The necessary oxygen is obtained through the thin, moist skin of the body and the membrane of the throat. Hence drying means suffocation."

The female *Pseudotriton* lays seventy or more eggs in the fall. They are attached by slender stalks to the under surface of stones in the bed of a spring or stream, where they may be bathed in the coolest waters. To quote Doctor Bishop again:

As the young embryos develop, they gradually take on some semblance of the adult form. The more evident changes are those which involve the molding of tissue to form the head, trunk and tail. Then the development of the gills and fore legs may be observed, and the first blush of color other than that imparted by the yolk. The gills and legs appear first as simple budlike projections; but development is fairly rapid, and the buds elongate to form, in one instance, the delicately fringed gills, and in the other the legs with their slender toes. The hind legs develop more slowly than the fore. In this respect the salamanders differ from our common frogs and toads.

At the time of hatching, the young salamander is scarcely half an inch long. It is endowed with stubby legs and small gills and a belly full of yolk to carry it through the first few months of its existence. The mouth is rudimentary and incapable of functioning, the eyes are indicated by pigmented spots, and the tail is provided with a broad keel. At this stage the tail is the most important appendage, for it serves in the wriggling process which enables the larva to make its way under the stones and rubbish of the spring bottom. Here, through the cold months, it may rest almost inactive, developing its eyes and legs and mouth at the expense of the yolk and acquiring the color and other characteristics of its kind. The yolk is lighter than the other body tissues and its buoyancy often as not turns the larva upside down. . . .

The adult salamanders are not usually social in their habits, but occasionally several will share the same small spring, and two may sometimes occupy a hollowed-out retreat beneath some log or stone. Worms, insects and other salamanders are the chief items in the diet of the adult. They feed readily in captivity and thrive on earthworms and bits of fresh meat.

The purple salamander, *Gyrinophilus porphyriticus,* and the red salamander, *Pseudotriton ruber*, of the eastern United States

The full-grown salamander may measure six inches in length, but many are smaller. In fact, some adult specimens are considerably shorter than the largest larvae.

The spotted salamander (*Ambystoma maculatum*), totally different in color from the red, is found throughout nearly the same range—east of the Mississippi. Its name comes from the large, round, yellow spots which show up conspicuously on its glossy, slate-black skin. In length the species averages about six inches, although sometimes a very large individual measures seven and a half.

During most of the warm weather the spotted salamander is nocturnal and secretive and not easily to be found, as it hides under logs or stones or burrows deeply in leaf mold. Sometimes at this season it gets into people's cellars, seeking darkness and moisture, where it causes much alarm if discovered. But at the breeding season, very early in the spring, certain ponds and streams will be visited by great numbers of salamanders, the females much distended with unlaid eggs, the males handsome with the brilliant accentuation of the orange-yellow spots, which are less vivid at other times. The breeding activity lasts for three or four successive nights in late March, if the spring has been a warm one, or a little later if the weather is cool. The eggs, numbering about 200, will be deposited in the water in several large masses, each mass with a thick, inclosing, jellylike membrane, which takes up water immediately after deposition and swells to a considerable thickness. In two weeks or more the pond will be alive with little wriggling dark-colored salamander larvae, fantastic because of the fringes of gills at the sides of their necks by which they may be readily distinguished from frog or toad tadpoles. These larvae "transform" between July and October; that is to say, the gills are absorbed, the legs grow and strengthen, and the little creatures are ready to take up their existence permanently on land. Their yellow spots are acquired soon after this transformation.

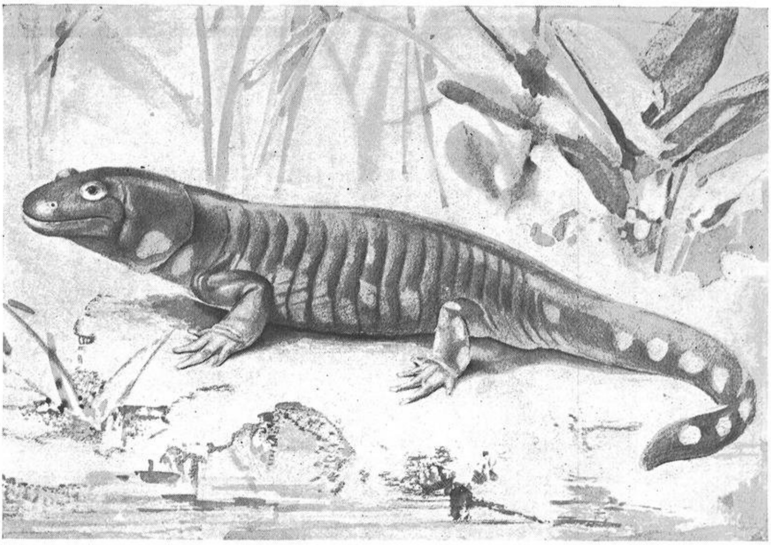
A strange green color sometimes invades the egg clusters before they hatch, while others retain their normal grayish translucence. This greenish color is due to algae which live within the egg-membrane but do not in any way injure the developing egg. This same phenomenon occurs also in the eggs of the closely related marbled salamander (*Dicamptodon ensatus*) of the Pacific Coast, an animal which when fully grown may reach a length of more than eleven inches.

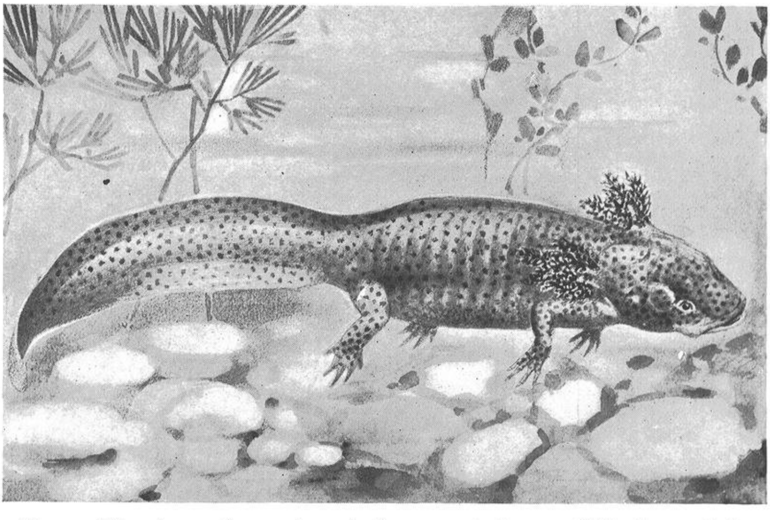
To keep spotted or marbled salamanders successfully in captivity the only requirements are a screened wooden box with a thick layer of wet sand and moss on the bottom, and a very plentiful supply of living angleworms. It is not necessary to tempt the salamander's appetite by offering him the worms at the forceps' end; he prefers to feed unobserved at night, when the angleworms come up to the top of the soil to take their airing also.

Another species, *Ambystoma* (erroneously written *Amblystoma*) *tigrinum*, occurs from Mexico north to California and east to New York (Plate 37). The larva of this species was at one time thought to be the famous axolotl. Its large, plump body measures over eight inches in length. A long, powerful flat tail with a broad ventral and dorsal fin, the latter continuing along the back almost to the neck, provides an effective swimming device. The limbs are small and weak, though fully developed. The outer gills form conspicuous feathery clusters on each side of the neck.

The true "axolotl," a name given by the Mexicans to a close relative of *A. tigrinum*, was found by the Spanish conquerors to occur in great numbers in the lakes near the city of Mexico (Plate 37). The natives eat axolotls either roasted or broiled, with vinegar or cayenne pepper. Some living specimens, said to belong to this species, kept in aquariums in Europe caused a great deal of speculation as to their true life history. Gadow says:

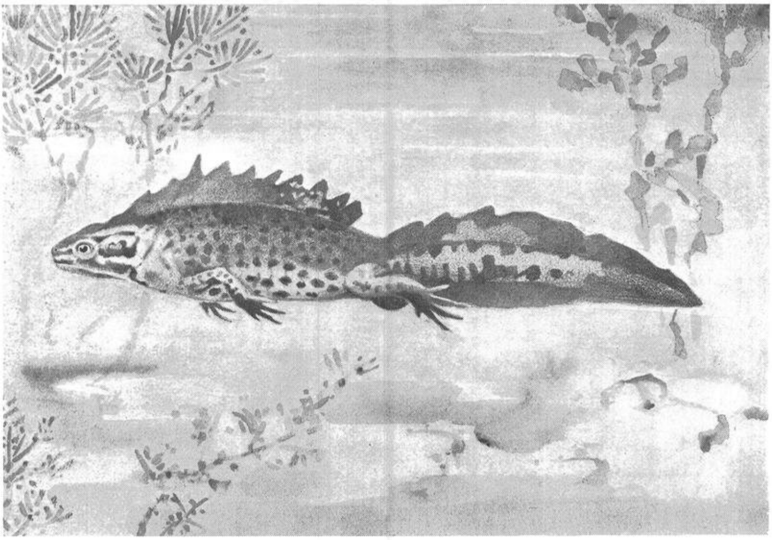
PLATE 37





Upper: The tiger salamander, *Ambystoma tigrinum*, of Mexico and the United States

Lower: The axolotl, *Ambystoma* sp., of Mexico, a larval stage capable of breeding without metamorphosing



Upper: Male crested newt, *Triton cristatus*, of Europe, in his nuptial dress

Lower: The mudpuppy, *Necturus maculosus*, a seventeen-inch salamander of eastern United States streams

For many years these creatures were looked upon as a species of the Perennibranchiata, under the generic names of *Siredon* (*S. axolotl*, *S. pisciformis*, *S. mexicanus*, etc.) . . . The mystery was not cleared up until the year 1865, when some axolotls which had been kept for a year in the Jardin des Plantes at Paris, suddenly began to pair, and laid eggs which within six months developed into full-sized axolotls. . . . Several of these young axolotls gradually lost their gills, the clefts closed up, the fins of the back and tail disappeared, the head became broader, the creatures left the water permanently. . . . [while] other brothers and sisters of the same brood remained aquatic axolotls, which hereby revealed themselves after all as the larval and not as the perfect stages of this remarkable species.

This ability of the larvae to reproduce their kind without first metamorphosing into fully developed animals is possessed by other forms besides the axolotl and is known technically as *neoteny*.

Perhaps the most successful aquarium salamanders are the newts, various kinds being popular in water gardens the world over. The best-known newt occurring in the United States east of the Rocky Mountains is *Triturus viridescens*. The aquatic form, grayish-green or olive in color, with a row of small brilliant crimson spots along each side, grows to be four inches in length including the tail, which is long and blade-shaped. In some parts of its range this newt is completely terrestrial, assuming an orange or brick-red coat which makes it look very different from the aquatic form.

For striking appearance the crested newt, *Triton cristatus*, whose range extends across Europe from England and Scotland to Transcaucasia, stands high among the salamanders (Plate 38). Especially is this true of the male in his nuptial dress, when a high, serrated crest rises along the head and body and the upper surface of the head becomes a black-and-white marble, while the under parts turn orange-yellow spotted with black, and a bluish-white band adorns each side of the tail. The female, always devoid of a crest, generally exhibits a yellow line along the middle of the back. Five to six inches is the newt's average length, with the male smaller than the female.

Quite apart from the rest of the Caudata are the so-called permanent larvae, or perennibranchiates, belonging to the suborder Proteida. Although possessed of four small and feeble limbs, the Proteida retain their babyhood gills throughout their lives, which are spent wholly in the water. They show, however, considerable variation in form, habitat, and habits, and include some of the commonest as well as the strangest examples of the tailed amphibians. The best-known American form belonging to this group is the mudpuppy, sometimes called the "ground puppy," a creature as far removed from any semblance to the dog tribe as can well be imagined.

The mudpuppy (*Necturus maculosus*) occurs in the streams and rivers of the eastern United States and attains a length of seventeen inches (Plate 38). In clear or shallow water it becomes nocturnal in habit, though in muddy places it will snap at fishing lines at all hours of the day. Fishermen generally believe it to be poisonous, but there are no salamanders whose bite is poisonous. As a matter of fact very few will even attempt to bite, so little is pugnacity required in their retiring and unobtrusive lives. The natural food of the mudpuppy, as indeed of other aquatic salamanders, comprises fish, fish eggs, aquatic insects, crawfish, worms, and mollusks. It does considerable harm in eating the eggs of game fish, but as it also eats the eggs of that notorious fish destroyer, the hellbender, it helps to compensate for its own despoiling tendencies. To overcome the perils which beset the small and weak larvae, the female mudpuppy not only constructs a "nest" by making a hollow excavation beneath large flat stones at the bottom of the river, but guards it assiduously after the eggs are laid. The lower surface of the stone serves for the attachment of the eggs, numbering from 90 to 180 to a nest. They are deposited one at a time, being attached by a little stalk which is merely an expansion of the egg envelope. The temperature of the water has much to do with the time of laying the eggs, June being the usual month in the northern United States. The female occupies the nest until the eggs hatch, driving off fish and other salamanders that would like to gobble up the developing young. In about thirty-eight days her vigil is ended for then the inch-long larvae emerge. Sexual maturity is not attained until about the fifth year, when the salamanders measure eight inches in length.

An interesting European species, *Proteus anguinus*, is described and figured by Gadow:

The fore and hind limbs are fully developed and possess only three fingers and two toes. The eyes are completely hidden beneath the opaque skin. This peculiar creature is restricted to the subterranean waters of Carniola, Carinthia, and Dalmatia. The vast caves of Adelsberg not far from Trieste are especially celebrated for the occurrence of the "Olm," the German name of this animal. . . . There, deep down below the surface, in absolute darkness, in an almost constant temperature of about 50° F., is the home of *Proteus*.

Their total length is scarcely one foot. The whole body is white, occasionally suffused with a slight fleshy, rosy tinge, while the three pairs of gill-bunches are carmine red. . . . The contrast between the pure white body and the carmine-red feathery gills is very beautiful.

An American perennibranchiate newt, *Typhlomolge rathbuni*, closely resembling *Proteus*, was discovered in an artesian well at San Marcos, Tex. The first specimens ever taken were described by Stejneger, as follows:

These animals by their want of external eyes and their white color at once proclaimed themselves as cave-dwellers, but their extraordinary proportions, absolutely unique in the order to which they belong, suggest unusual conditions of life, which alone can have produced such profound differences. The most startling external feature is the length and slenderness of the legs, like which there is nothing among the tailed batrachians thus far known. While the normal number of fingers and toes is present (4 and 5), it is worthy of note that not only is there a great variation in the relative length of these members, but even the length of the legs in the same animal may differ as much as two millimeters. Viewed in connection with the well-developed, finned, swimming tail, it can be safely assumed that these extraordinarily slender and elongated legs are not used for locomotion; and the conviction is irresistible that in the inky darkness of the subterranean waters they serve the animals as feelers, their development being thus parallel to the excessive elongation of the antennae of the crustaceans, of which I have been informed by Mr. Benedict [Fig. 54].

The external gills at once suggested that these animals might be only larvae. The fact that one of them contained large eggs and that another expelled three eggs after being caught, was no positive proof to the contrary; but in conjunction with the affinity of the species to other forms known to have persistent gills throughout life, it makes it absolutely certain that we have to do with an adult and final animal.

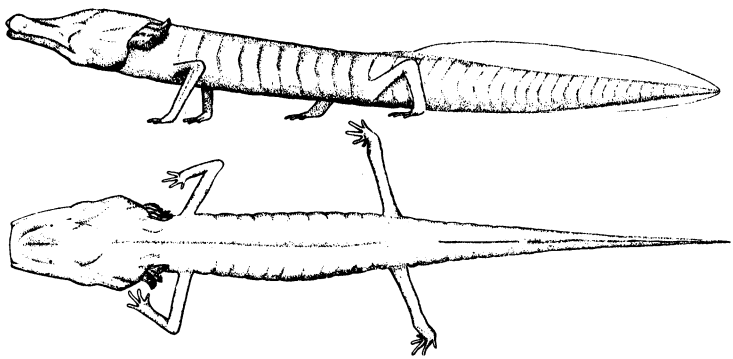


FIG. 54. Blind cave salamander, *Typhlomolge rathbuni*, from an artesian well in Texas, with limbs modified as feelers

Both the European *Proteus* and the American *Typhlomolge* inhabit subterranean caves and it is quite possible that similar conditions of life have produced these closely similar forms absolutely independently of each other. As to the food of these subterranean amphibians, it is suggestive that four kinds of Crustacea, all new to science, came up from the artesian well with the water which contained the *Typhlomolge*. Specimens of *Proteus* have been known to exist for years although they refused to take any of the food supplied to them.

Last in our consideration of the tailed amphibians is the suborder Meantes, or sirens, a small group of only two genera, each represented by but a single species and limited to the southeastern United States. The sirens furnish a very interesting illustration of degeneracy in the absence of many of the skull bones usual in vertebrates. The hind limbs are missing altogether and the fore limbs are short and have only three or four fingers each. But what makes these highly specialized members of the Caudata particularly interesting is the interpretation of their branchial apparatus as the result of a retrograde metamorphosis, suggested by the American naturalist, Cope, who, finding that the gills atrophy in the young and are subsequently redeveloped, concluded that in the sirens branchiae are not a larval character as in other perennibranchiate Amphibia, but a character of maturity. In explanation of this reversal of the usual process, Cope suggests that the present sirens are the descendants of a terrestrial type of amphibians which originally passed through a metamorphosis like other members of their class, but more recently have adopted a permanently aquatic life and have resumed their external gills by reversion. He notes the interesting fact that sirens may be exclusively air breathers as proved by a specimen in an aquarium which for two months had no branchiae at all, due, probably, to the attacks of fishes.

One of the species, *Siren lacertina*, commonly called the "mud eel" from its habit of burrowing in the mud of ponds and ditches, reaches a length of thirty inches, of which one-third is taken up by the tail. The skin is smooth and blackish, sometimes with whitish specks all over the body.

Of the 150 species of tailed amphibians by far the greater number belong to the suborder Mutabilia. One form still carries on the tradition of the mythological fire-haunting salamanders. This is a European species, *Salamandra salamandra*, known as the fire salamander. In dry weather it hides under moss and rotten leaves and in the roots of old trees. Thus it must often have been transported in firewood to men's habitations, and when the encroaching flames of the hearth fire drove it forth from its crevice into the hot ashes, those who saw it wriggling there thought it was born of the fire.

Dr. Stejneger has described the actual occurrence of a tiger salamander (*Ambystoma tigrinum*) in his own camp fire. He says: "While we were sitting around the camp fire in the evening of September 19 [1889], a salamander was suddenly seen writhing in the hot ashes, having probably dropped off one of the burning logs."

Aside from the numbers of young fish and fish eggs which are eaten by the larger aquatic salamanders, the group as a whole is of little economic importance one way or the other. The smaller terrestrial forms feed naturally on spiders and soft-bodied insects, but are not known to devour the really harmful cutworms or wireworms. While it might be possible to utilize some species as food animals, as the Japanese do, it is doubtful if salamander cutlets would ever become a popular dish in North America.

Because of their comparative harmlessness and secretive habits, salamanders are in no danger of extermination as a group. They will doubtless long survive as creations of nature's 'prentice hand before she had evolved the higher group of the tailless amphibians.

CHAPTER IV

FROGS AND TOADS

Our familiar frogs and toads, with their relatives, constitute the order Salientia, or jumping amphibians, known sometimes also as the Ecaudata or Anura, both of which mean tailless. The 1,500 species of the order are distributed among some twelve families of very unequal size. The Salientia are the most widespread of the Amphibia, chiefly, no doubt, because of the extraordinary development of the legs in many of the species, enabling the creatures to move about much more freely than either the caecilians or the salamanders.

The frog's legs are attached close to the end of the spinal column. In order to resist their powerful thrust, the lower part of the backbone, consisting of a single unjointed rod, is reenforced on either side by a projection which carries the bones to which the legs are fastened. The frog is thus provided with three stiff rods in the back, side by side.

The few free vertebrae that the frog possesses are located in the upper part of the spinal column, and only one family has ribs—very short ones at that. On the other hand, the bones of four of the toes show an excessive length. The hind limbs greatly exceed the fore limbs in size, although the fore limbs, too, are well developed, giving to this part of the animal's skeleton an uncannily human aspect. The trunk is relatively short. In the frog also, is a well-indicated breastbone—a member only vaguely hinted at among the fishes, and appearing in the tailed amphibians as mere gristle.

In their power of adapting themselves to almost every sort of habitat the Salientia show great superiority over other amphibians. Although preferring warmth and moisture—tropical swamps and forests being their favorite abodes—they can endure great extremes of temperature

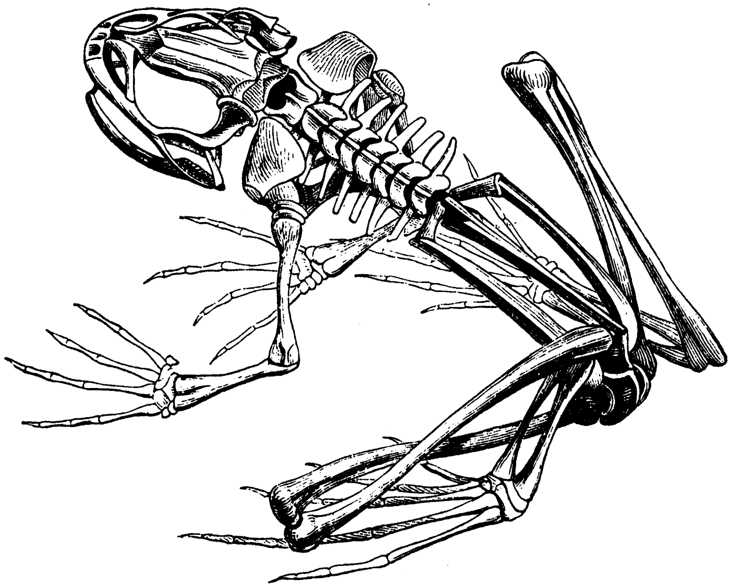


FIG. 55. Frog skeleton. Note the double reenforcement of the lower backbone to resist the thrust of the powerful hind legs

and even a certain degree of drought. Some species, to be sure, are wholly aquatic; but others live almost exclusively on dry land, resorting to the water, if at all, only at the breeding season. Some burrow in the earth; some inhabit the tree tops; and a few have even learned to fly—or at least to glide, after the manner of the flying squirrels.

The ability of the Salientia to withstand extremes of cold and heat depends chiefly on their power to suspend their vital functions during unfavorable seasons. In cold countries they are active only during the warmer parts of the year, hibernating in the winter; species living on the edge of the desert, on the other hand, become dormant during the dry season, when they burrow into the soil and remain there, cool and moist, many feet below the scorching heat.

The philosophers of the Middle Ages resorted to a naïve explanation to account for the activity of frogs in the warm season only and their absence in winter. As late as 1560 Gesner classified the frogs into two large divisions—those which are procreated from seeds and those which originate in some other manner. The latter were again divided into two sections—those which lasted for but a short time in summer and were believed to come from dust moistened by summer showers, and those which fell from the sky with the rains. These theories were based on incomplete observations. People saw the activity of frogs after a summer shower, but failed to realize that during the preceding dry spell they had been aestivating in some cool retreat.

That very young frogs and toads, and even fishes, may seem to fall from the sky has long been known. A storm sweeping over the countryside may actually suck up the entire contents of a small pond and discharge it at a considerable distance.

Salt water forms an effective barrier to the spread of the Salientia. Certain forms have been known to overcome even this limitation by making sea voyages on floating logs. The larvae of some species, moreover, have been found developing in pools of brackish water. Given time, these most plastic and adaptable of amphibians may yet evolve marine forms.

So different in outward appearance are frogs and toads from caecilians and salamanders that they might pass superficially for a separate class of animals, were it not that their relationship to the other amphibians is clearly revealed in the larval or tadpole stage (Fig. 56). On first hatching from the egg the tadpole has an almost globular body entirely continuous with the head, which bears a little slitlike mouth equipped with a tiny black horny beak like that of a parrakeet, used to scrape the growth of green slime containing the minute animalcules and tiny plants on which the tadpole feeds. A pair of

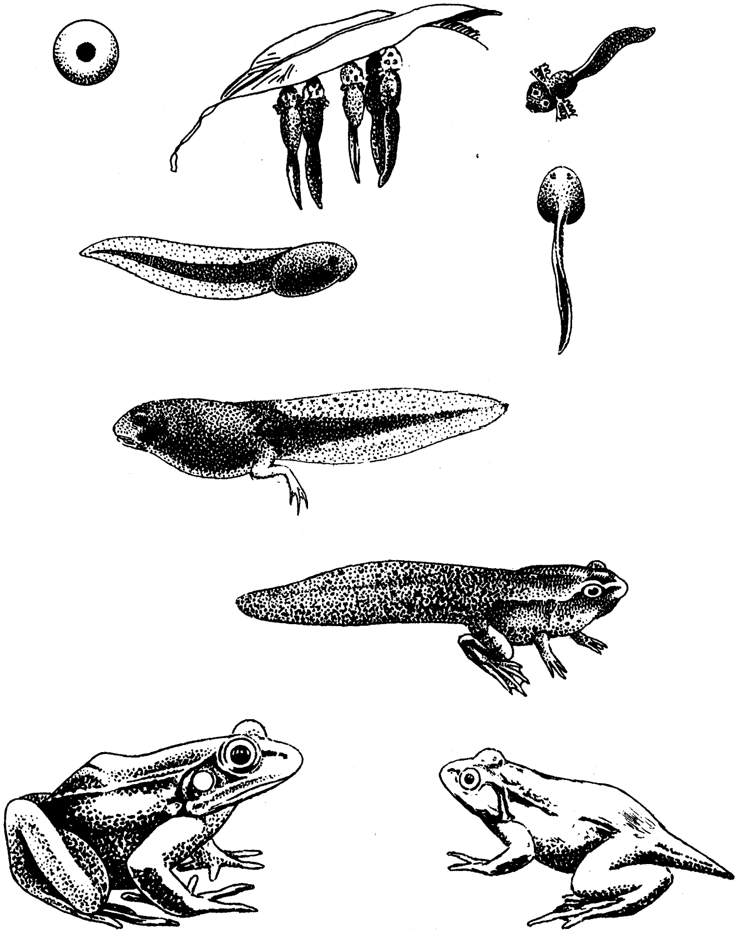


FIG. 56. Metamorphosis of the frog. Note the loss of gills, development of hind and forelegs, and absorption of tail

lidless staring eyes may be seen on the head, but no ears or nostrils are visible. On the left side of the body—in toad tadpoles—there is a little breathing pore, or *spiraculum*, which serves the same function as the gill of a fish, by allowing the water taken in at the mouth to escape after all the oxygen has been utilized. A large rudderlike tail propels the body rapidly through the water, but toward the end of the tadpole stage this conspicuous organ gradually dwindles and shrinks, being absorbed into the increasing body tissues, and not dropping off as folklore might have us believe. As the tail begins to be absorbed, the hind legs make their appearance almost like little flower buds through the skin at its base, and as they grow and elongate the front legs also come into being, the left one piercing its way out through the spiraculum. This occasions much discomfort to the poor tadpole, who needs must dash wildly to the surface at frequent intervals and grab a mouthful of air for which his yet insufficiently formed nostrils are not quite adapted. The transition from a water- to an air-breathing creature is rather rapid, and the whole process of growth from leaving the egg to the absorption of the tail and the development of legs takes only about seven weeks for our common toad (*Bufo americanus*) in water at an ordinary temperature.

As the summer time comes nearer and the pools begin to dry up, the growth of these tadpoles is immensely stimulated by the decreasing depth of water and its corresponding rise in temperature. It is a race against death, because if the pool becomes entirely dry before the tadpoles have developed their legs and their capacity to breathe air, they will die helplessly as soon as the water in which they swim has evaporated. Most of them, however, metamorphose in time, and the banks of the pond become alive with small jumping black things which behave like leaping grasshoppers, but which are really baby toads.

As each female toad lays between 4,000 and 12,000 eggs each season the numbers of toads would be countless if even a tenth of them survived to reach maturity. But young toads have many enemies, even if they have thus far avoided the dangers which beset tadpoles in the form of hungry fish or waterbeetles. After the toad leaves the water, he must take constant and vigilant care every moment of his after life to avoid being eaten by snakes, crows, ducks, hens, hawks, or owls. Of course, great numbers of them are trodden to death on public roads, and crushed by automobiles. Probably if one toad out of every ten thousand eggs reached maturity, we would have a noticeable increase in the toad population very soon. Toads do not resort to the ponds for breeding until they are three or four years old. During their early years they make their home in field and garden, and have for their main interest in life the capture of their insect food.

The Salientia show an almost endless variety of forms, closely correlated with their different habitats, those species having a similar environment resembling each other in structural adaptations far more than their nearer kinsmen accustomed to different surroundings.

The systematist finds it no easy task to work out the family relationships of the frogs and toads. Even the long-accepted classification which divides the order Salientia into two great suborders—the Aglossa, or tongueless forms, and the Linguata, or tongued forms—is today being supplanted by a much more complicated system which represents the latest conclusions of modern investigators.

The suborder Aglossa is represented by the Surinam toad (*Pipa pipa*) of South America, which incubates its eggs in separate pockets formed on the back of the female, as shown in Plate 39. *Pipa*, like all the Aglossa, has reverted to an exclusively aquatic existence, and some of its most distinguishing characteristics are secondary features resulting from this reversion. Such is the loss of the tongue, for the Aglossa, having become purely aquatic creatures which seize and swallow their prey under water, no longer have need of such an organ. An aquatic character also is the webbing of the feet. Each hand carries four long slender fingers with star-shaped tips.

The accompanying illustration shows the oddly depressed and triangular shape of *Pipa's* head. In color it is dark brown with whitish under parts, sometimes showing a brown stripe down the middle. Small tubercles cover the whole of the skin. Each of these carries a little horny spike, often with a poison gland at the base, and in addition the skin itself is provided with many large poison glands as well as slime glands. The epidermis, which is shed periodically, forms a horny crust over the entire surface.

But what gives this toad its major interest is the placing of the eggs (which have probably been fertilized externally) on the female's back, where they sink into the soft spongy skin, each in its separate pouch, which nature proceeds to cover with a lid. According to Klinckowstroem the lid looks like a sticky layer which has hardened. Although it lies upon the rim of the pouch itself, the lid seems not to be a part of the epidermis, but is perhaps a remnant of the eggshell cast up to the top of the cup after the larva is hatched. The tadpoles remain concealed in their cell-like retreats throughout the whole period of metamorphosis, finally emerging from the mother's back as fully formed young toads.

The African genus *Xenopus*, of the suborder Aglossa, is also entirely aquatic, living in water holes and secreting itself in the mud when disturbed. Floating at the top of the water it looks like a little black balloon, with short arms and legs stiffly projecting, the tip of the nose just above the water, and the enormous webs on the feet stretched to their fullest. The hind toes are equipped with black claws, which have earned for the genus the name of "clawed toad." These little creatures make hardy and amusing pets, for in an aquarium they eat readily bits of raw meat and worms, stuffing the food into their tongueless mouths with a remarkable fanning motion of their fingers. They find their food under water evidently not by sight but by their keen sense of smell. Like the caecilians, they have a pair of facial tentacles emanating from below the eye; but these tentacles are much longer and more prominent in the aquatic, clawed toad than in the burrowing caecilian. I suspect that they have something to do with the perception of motionless food sometimes buried in the silt at the bottom of the water holes, which the active fingers have uncovered. The clawed toad never leaves the water, but lurks under stones or débris when not engaged in looking for food.

The aquarist sometimes finds it pleasing to have an inhabitant different from the ordinary run to watch and study. The European fire toad or bell toad (*Bombina bombina*) is my choice. If you come upon this little creature at rest, idly floating at the top of the aquarium on some tangled water weeds, with hind legs outspread, you see a dusky olive-green frog, with no peculiar or striking features in evidence. But put a finger on the creature's head, or frighten him ever so little, and the legs will become vigorously active; as he dives you will be conscious of a bewildering pattern of brilliant orange and yellow set off with black trimmings. If you examine him more closely, you will see that while his back is a dull, unobtrusive, brownish-green which harmonizes well with the muddy green water weeds in which he usually rests, the whole under surface of his body is brilliantly marked with fire-colored spots, strikingly vivid on a bluish-black ground. Even the palms of the hands and the soles of the feet are marked in this way. When frightened and unable to escape, the fire toad will react by showing his "warning colors"; that is, he stiffens and bends his body backwards and displays the bright surface of his hands and feet, and his enemy, puzzled by the sudden transition of the brownish creature which he was pursuing into this odd and confusing mass of bright spots, is often at a loss to know what to seize hold of, and so leaves the toad in peace.

The fire toad loves to converse, or so it seems. When

PLATE 39

Female Surinam toad, *Pipa pipa*, of South America, which incubates its eggs and carries the tadpoles through the metamorphosis in lidded pockets formed on the back

two persons are talking near the aquarium, pretty soon a small piping voice will join in now and then. The note is faint but quite musical, and two of my fire toads occasionally sang an involuntary duet, their voices making a chord, a perfect major third.

The true toads (genus *Bufo*) occur in all the continents of the globe. One species is found in Alaska, while still others live in the torrid zone, and sixteen occur in the United States. They are among the most completely terrestrial of the amphibians. You may tell them easily from other families of the Linguata by looking at the region just above the tympanum or exposed ear drum. All toads have heavy parotoid glands situated in this region, while most other amphibians lack such specialized glands there. Furthermore, the skin of toads is usually dry to the touch and more or less rough like coarse sandpaper.

For centuries, perhaps, people have believed that handling a toad will produce warts. This belief, of course, is quite unfounded. If a dog bites a toad, however, he will probably not want to repeat the experience, for the toad's skin secretes a whitish substance which will irritate the mucous lining of the dog's mouth. This fluid is not at all injurious to man unless it gets into the mouth or eyes. The toad has been the victim of many unfounded superstitions, such as that which makes him the harbinger of bad luck. When he takes up his abode in our fields and gardens it is because he can get an abundance of caterpillars and grasshoppers and escape some of his natural enemies, such as snakes and skunks. The toad eats almost all kinds of small living things that are afield in the late afternoon and night. He may sit by the hour on a porch to catch the flies and mosquitoes which alight on the base of the screen door in their attempt to get into the house. When a fly comes near his nose, you hear a snap; and if you have watched closely you may have seen his sticky tongue flash out and back again, and the fly disappear.

In southern Europe dwells a toad whose habits in connection with the reproductive process almost rival in interest those of *Pipa pipa.* This is the "midwife toad" (*Alytes obstetricans*) the female of which lays several dozen eggs, fastened together like beads on a string. The male thrusts his hind legs into the mass of eggs, wraps them about his body and hops off to his burrow. There he stays during the daytime, coming out only at night to search for food and to moisten the eggs with dew. In about three weeks, seeming to know instinctively that the larvae are about to emerge, he immerses himself in a pool of water and the larvae break out of the eggs and swim away, thus relieving the parent of his responsibilities.

If we walk along the bank of almost any pond or brook during a hot summer afternoon, we may see a movement in the grass and hear a splash; and if the water is fairly clear we discern a frog swimming quickly to the bottom of the pool, where he will hide in the mud and leaves until the noise of our footsteps has been forgotten. Now, if we keep perfectly still, we may see him coming out of his retreat, swimming slowly upward, poking his nose and queer staring eyes out of the water, and finally hopping out on to the bank again, where he goes about stalking insects until some slight noise or unwonted movement in the grass sends him leaping again to safety.

No slime-covered, stagnant pool mirroring the slowly moving clouds in a June sky would be quite complete without the voice of the bullfrog. He is clearly the patriarch of the pool as he sits on his lily pad with a philosophic detachment, uttering now and then a sonorous "*ker-junk*," until an unwary dragon fly approaches too near, when, literally jumping at his opportunity, he disappears with his prey in a great splash. But soon, having swallowed his catch, he swims leisurely back to his chosen position and scrambles upon the lily leaf with a look of placid self-satisfaction on his broad countenance. This frog, like most of the Linguata, is equipped with a long flexible tongue tied in front and free at the back. He captures his prey by suddenly thrusting forward the rear end of the tongue, curling it about the unhappy victim, and then retracting it within his capacious jaws—all in a flash (Fig. 57).

The bullfrog's metamorphosis resembles in general that of the toad, except that the bullfrog tadpole is relatively large in size, six to eight inches in length, and requires two years to accomplish the transformation to the adult. The frog does not reach his full growth until four or five years after this. Some bullfrogs have lived in captivity a great many years, I believe for upwards of thirty. They make charming pets, and when provided with a tub covered with wire netting and holding some two or three inches of water they will be comfortable, safe, and soon tamed.

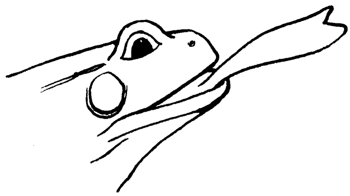


FIG. 57. The frog's tongue is attached to the front of the jaw, the rear end being thrust forward to capture prey

Giants of any sort always interest us. The giant among frogs is *Rana goliath* from the southern Cameroons and the Gabon River region of French Equatorial Africa. Dr. Thomas Barbour says of the species:

> This giant, which is as heavy as a good-sized terrier, is the largest known frog. It lives in deep sluggish forest streams and is only occasionally caught by the Negroes in their fishing operations when the streams are low after long dry spells. The Negroes eat them, as they do most things, and consider their thigh bones priceless for purposes of divination, so that few individuals ever get saved and but few museums have them.

In striking contrast to this monster are the tiny frogs found in the West Indies, some of which are less than an inch in length.

Among the more vividly colored tropical species of the Salientia, the horned toad (*Ceratophrys cornuta*) is perhaps the most beautiful (Plate 40), presenting a gay but harmonious pattern of mingled green, black, and brown, with an orange-yellow stripe over the head and back. This is the true horned toad, not to be confused with the "horned toad" of our Western States, which is really a lizard. *Ceratophrys* takes its name from the peculiar little flexible

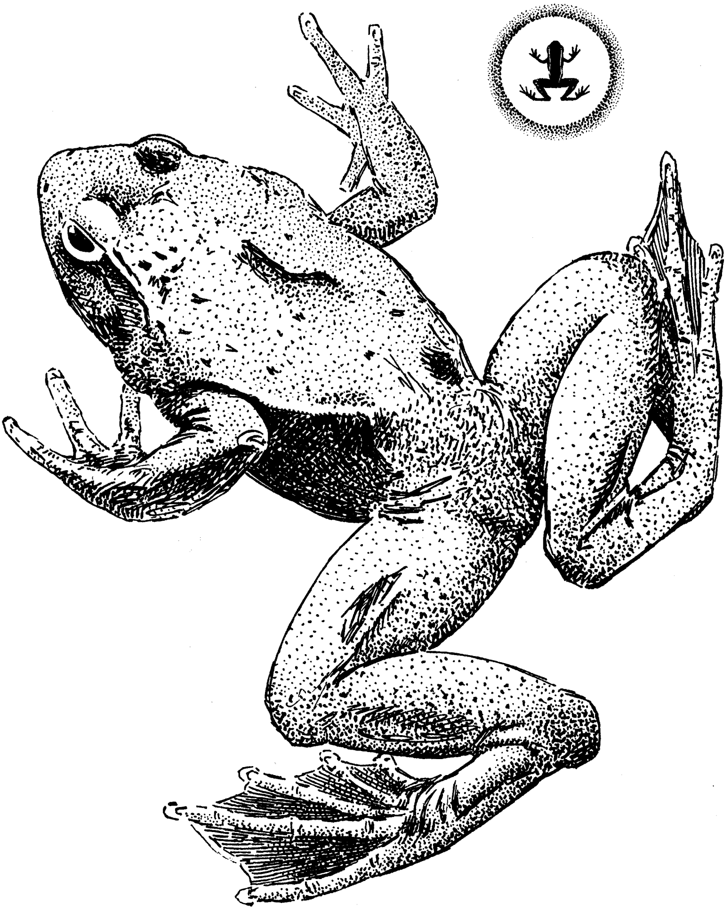


FIG. 58. The giant among frogs, *Rana goliath*, of West Africa, over a foot long, compared with a three-quarter inch frog from the West Indies

PLATE 40

The true horned toad of South America, *Ceratophrys cornuta*, showing beautiful coloration

appendage or "horn," formed by a modification of the eyelid, over each eye.

Arboreal existence has been taken up by several families of the Salientia in various parts of the world, always with a change in the structure of the limbs. Tree toads (or tree frogs as they are frequently called) may be readily told from all other kinds by examining the toes, which possess enlarged adhesive disks at the tips, giving a remarkable clinging power. While we have a dozen kinds of tree toads within the borders of the United States, probably the most familiar species is *Hyla versicolor*, common in orchards from early spring to September, when it retires for its long winter's sleep. *Hyla versicolor* is an artist in color. As his background varies, so does he. In a bright light he is apt to put on yellowish-white with no markings, only to change to deep stone-gray or brown on transferring to a dark moist spot. Among the green leaves of a tree he may bedeck himself in combinations of green and gray. Always he has much bright orange-yellow under his thighs, and generally he is marked by two dark bands on all four limbs and an irregular star on the back.

He does not make these color changes rapidly, it is true, and apparently requires at least an hour to effect any radical change, but give him time and his camouflage is perfect.

This tree frog attaches its eggs singly and in small groups to grasses or plant stems at the surface of the water, according to Miss Mary C. Dickerson, and they are not found except by minute examination. Of the habits of the frog she says:

Hyla versicolor has a relatively keen sense of locality, sometimes remaining in one place for weeks or more at a time. It is said that these tree frogs may stay in one tree for weeks and months. In such a situation they would certainly find themselves surrounded by supplies for their every demand—food, shelter, and moisture. A tree frog is so small that a tree with its many branches and leaves is like a palace for him. There are sunny rooms which flies and beetles visit. There are darker ones where ants and plant-lice, beetles and tree-crickets are to be found. There are rooms on the north side of the tree where the large branches join the trunk. These are cool and moist on the hottest summer day.

The Common Tree Frog is most active at dusk and in the night. It is then that he wanders over his great palace. His bright eyes see every moving caterpillar and beetle, and his sticky tongue snaps them up greedily. He sees moving objects at two or more feet distance, and makes aerial leaps to get them. He is almost sure to catch the insect, and what becomes of himself does not trouble him, since he is certain to touch some leaf or twig with at least one of his four sets of sticky toes. A bit of frantic acrobat-work does the rest, and places him securely on some perch where he can enjoy his meal at leisure.

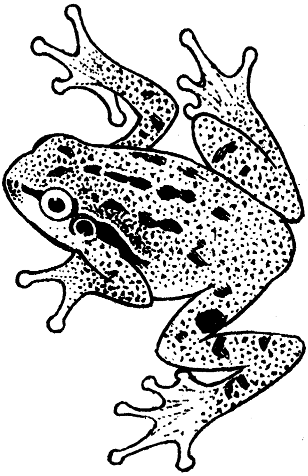
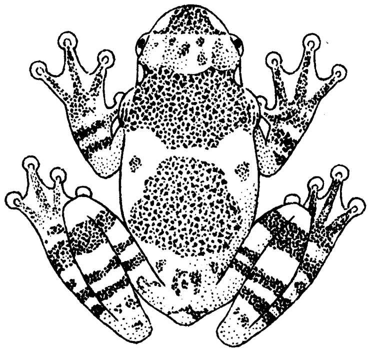


Fig. 59. A typical tree frog, the toes of which end in large adhesive disks

Some of the exotic tree toads have habits which are surprisingly different from those of our more familiar North American forms. Especially is this true of the "nest-building" habit which is found among several distinct groups. The tree toad *Hyla faber*, a native of Brazil, chooses a shallow stream for its operations and there builds a little cuplike crater of mud, the rim of which rises slightly above the surface of the water and prevents diffusion. There the female deposits her eggs, which hatch in a very few days so that the crater is filled with wriggling babies, which during their infancy are thus protected from the voracity of fishes and other enemies. At the next heavy rain, the walls of the crater are destroyed, and the tadpoles are washed into the stream, where they must henceforth fend for themselves. A similar method of caring for the eggs has been developed by a frog (*Leptodactylus ocellatus*) which belongs to a different family.

A complicated nest made by another tree toad is described by Dr. Goeldi:

A peculiar eccentricity is presented by this beautiful Amazonian tree-frog, *Hyla resinifictrix*. Inhabiting the virgin forest, it chooses certain tall trees for its dwelling, where it takes possession of a hollow branch, and constructs there as a nursery a good-sized basin of resinous substances, with a central depression. As is well known, water and other liquids are preserved fresh in vessels varnished with pitch, and in



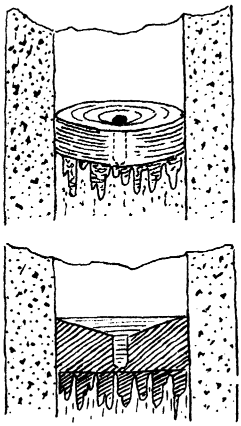


FIG. 60. Amazonian nest builder, *Hyla resinifictrix*, and nest for holding water, made by depositing beeswax in a hollow limb

like manner the rain-water which fills these resinous breeding-bowls presents excellent conditions for hatching and development of the eggs and tadpoles, such as shade and freshness of water without contamination of decayed wood. . . . One very interesting feature is the fact that the Amazonian tree-frog goes in search of the material with which to build the basin.

As was shown subsequently, the material is not pitch, but beeswax which the frog takes from the combs of stingless bees nesting in the hollow trunks. The female of still another tree toad, *Hyla goeldi*, likewise from Brazil, carries her eggs in a saucerlike depression on her back, where they develop through the tadpole stage. The whole surface of her back is covered by a layer of about two dozen large pale-yellow eggs, in which the embryos can easily be seen. The skin of the back expands into a fold which supports the egg mass. The tadpole has fully developed limbs when it leaves the mother.

The coloration of some of the tropical species is most amazing. Some are exquisite jade-green; others have a purple iridescence. Some are handsomely spotted with black, crimson, and gold; others are dove-gray with golden lines. There is no end to the beautiful combinations which appear on the moist, velvety skin of these creatures. The eyes have a jewel-like brilliance; some are like amber, or yellow topaz, or opal—or like nothing but frogs' eyes, beautiful beyond description.

The so-called flying frogs, belonging to the genus *Polypedates*, of tropical Asia, resemble the tree frogs in general appearance, having the same modifications in the structure of the feet.

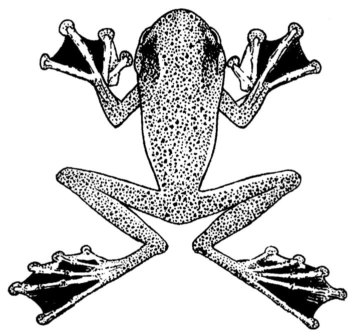


FIG. 61. The so-called flying frog of tropical Asia, which glides by the aid of its webbed feet

Aside from their interest to the nature lover and zoologist, frogs and toads are of positive benefit to mankind economically, because of the numbers of harmful insects they devour. Especially is this true in regard to the toad as the guardian of greenhouse, garden, and farm. The economic value of toads is limited, however, by their comparative scarcity, and by their inability to traverse wide stretches of land in order to combat local abnormal increases of certain insects.

NOTE.—The combined bibliography to Parts II and III will be found at the end of Part III, page 356.

PART III

REPTILES

By

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CHAPTER I

INTRODUCTION

IF a parade of reptiles could be staged today, made up of individuals of each existing kind, an army of more than five thousand would pass in review. This army would be made up of four main divisions or groups: Serpents and lizards, crocodiles, turtles, and the tuatara. Immense and varied as it would appear, it would represent but a small fragment of the host that the reptiles of the earth could once have marshaled; for no doubt now exists that the reptiles of past geologic ages far exceeded those of today both in kind and number. We can never hope to know more than a small part of this vanished host, however, because of the fortuities of fossilization. The remains of animals that lived in or around water have been better preserved and in greater number than those of strictly land animals, since fossilization is accomplished largely by the preserving action of water. Of the land-living reptile life of long periods in the earth's history—millions of years at a stretch—the rocks have yielded no trace, although reptiles must have existed in abundance during those periods.

Although all living reptiles fall into four great groups or orders, for each of which fossil representatives have been found, there are recognized today no less than eleven orders of forms now extinct—with no living representatives—and known therefore only from their skeletal remains. These show a great diversity of forms, but whether land-living, swimming, or flying, they possess in common certain structural characters which mark them as reptiles. It is true that some of them approach so closely amphibians on the one hand and mammals on the other that nearly complete skeletons are required in order to recognize their distinguishing characteristics.

The late Dr. S. W. Williston, one of America's foremost authorities on extinct Reptilia, defined a reptile as a "cold-blooded, backboned animal which breathes air throughout life," thus distinguishing the class both from the amphibians, which, in the early part of their life cycle are water breathers, and from the air-breathing, but warm-blooded mammals.

So far as known at the present time, the earliest reptiles appeared in the Upper Carboniferous and early Permian epochs. They became the dominant animal form in the Mesozoic era, popularly referred to as the Age of Reptiles, which includes the three main geologic periods known as the Triassic, Jurassic, and Cretaceous. It was during the Mesozoic era that the dinosaurs reigned supreme, an era lasting some 135,000,000 years as measured by the latest methods employed in the calculation of geologic time. Estimating by the same methods we find that the reptiles of the Triassic existed about 190,000,000 years ago, those of the Jurassic 155,000,000 years ago, and those of the Cretaceous 95,000,000 years ago.

CHAPTER II

THE DINOSAURS

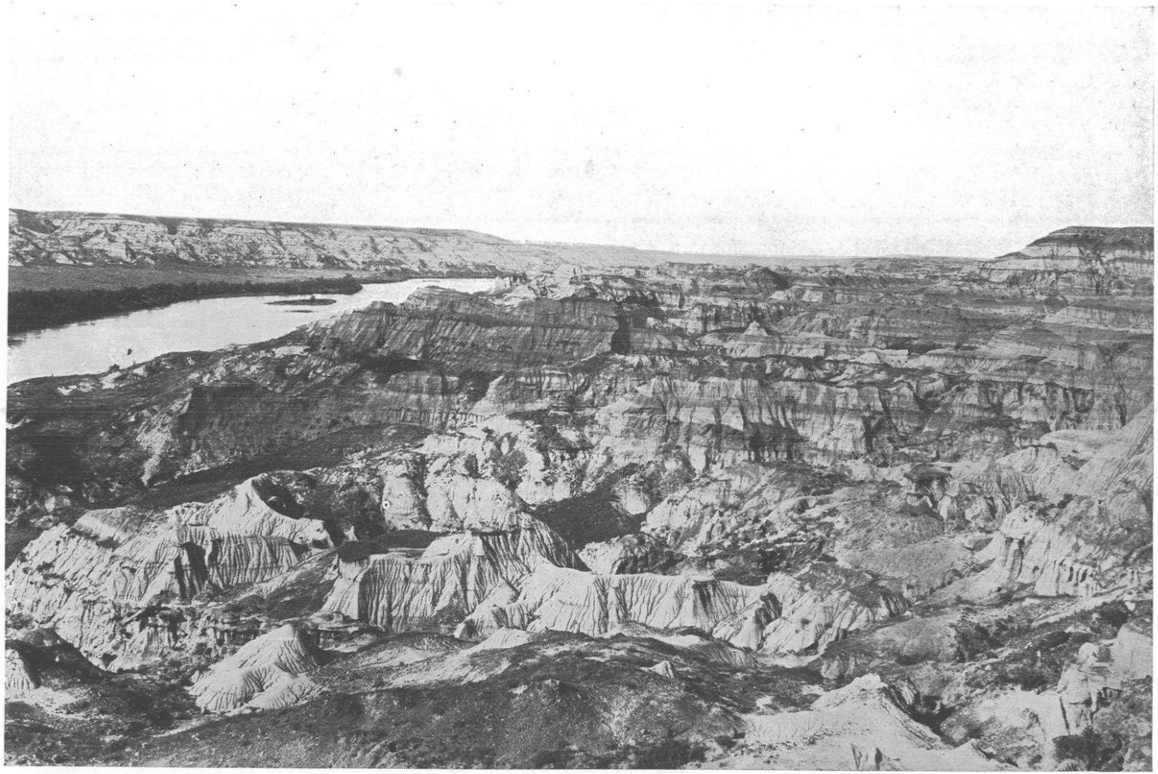
FROM time to time we hear rumors of the sighting of huge strange animals—usually called dinosaurs—in Africa, in Patagonia, in New Guinea, or in Alaska. As a matter of fact, however, no dinosaur exists today. The animals which give rise to the perturbing reports are in all probability elephants, bears, or other creatures of our own time, magnified in size and endowed by vivid imaginations with the features of the giant reptiles of long ago, which disappeared from the face of the earth millions of years before man came to live upon it. It is one of the achievements of science that we have learned so much of these long-extinct animals merely from a study of their fossil remains; that we know how they looked when alive, what they ate, where they made their homes, and, sometimes, even how they died.

The word "dinosaur" usually conjures up in our minds an animal of great bulk, with a long tail and a long neck—a conception that is somewhat misleading; for, while certain of the dinosaurs were the largest land animals the world has ever known, others living at the same time were very small. In shape, structure, and habit, the dinosaur tribe offered great diversity: some walked on four feet; others, because of their weakly developed fore limbs, walked upon strong hind limbs, like the ostrich or kangaroo. There were dinosaurs with large heads and dinosaurs with small heads; big and cumbersome dinosaurs, and graceful little ones which, in their skeletal remains, so closely resemble birds that only a skilled anatomist can tell the difference. These extinct reptiles included some which ate flesh and others which fed only upon plants and shrubs. And all these diverse kinds made up the dominant life of the great geologic era called the Mesozoic, or "Age of Reptiles." During this era the dinosaurs must have inhabited most of the globe, for their fossil remains are strewn through North and South America, Europe (including Great Britain), Asia, Africa, and Australia, where they have been unearthed and puzzled over only in recent times.

The earth as the dinosaurs knew it would be as unfamiliar to us as America was to Columbus. We know that they enjoyed a climate warmer than do we today, because of the palms, cycads, figs, ginkgoes, sycamores, and other subtropical plants found preserved as fossils in the same rocks with the reptile remains. It is not improbable that when the dinosaurs lived and flourished physical conditions prevailed over much of the earth somewhat similar to those which exist today in tropical America. A typical region is the coastal plain of the lower Amazon, with its numerous bayous and islands, or the more elevated lands of the interior, with their many lakes and wide meandering rivers whose broad level valleys covered with luxuriant vegetation are subject to periodic inundation. Only in the midst of such conditions can we suppose it possible for these animals to have existed. Reptiles as we know them today can not survive extremely cold weather unless they burrow in the ground; and if they are large hibernation is out of the question. Unless the dinosaurs were warm-blooded creatures—and it is supposed they were not—many of the regions where their fossil remains are now found must have had a warmer climate than they now have. A dinosaur could not survive a modern winter in Montana, yet we find dinosaur remains there. So we must infer that Montana had a vastly different climate in the period when dinosaurs flourished than it has today. Since these curious creatures could thrive

Restoration of a Mesozoic scene: *Allosaurus* attacking *Stegosaurus*. An exhibit of the Milwaukee Museum

PLATE 42



Upper Cretaceous "bad lands" along the Red Deer River, Alberta, Canada. Ideal collecting ground for dinosaurian specimens. Photograph by the Geological Survey of Canada only under conditions suited to their needs, we must picture for them a moist, semitropical climate and an abundant vegetation.

To the efforts of some of the earlier collectors in the western fields of the United States is due much that we know of this ancient animal. For a good many years Colorado and Wyoming were the hunting ground of searchers for big fossil game, and they unearthed there some famous specimens; but in 1909, in northeastern Utah, Mr. Earl Douglass, of the Carnegie Museum of Pittsburgh, came across what has since proved to be the greatest accumulation of dinosaur skeletons ever discovered. In thirteen consecutive years of work the Pittsburgh institution collected more than 300 tons of specimens from this deposit. So abundant and so well preserved were these fossils that in 1916 the Secretary of the Interior, to insure the proper conservation of those still embedded in the rocks, withdrew a tract of eighty acres from the public domain and designated it the "Dinosaur National Monument."

This one quarry has disclosed a veritable Noah's Ark of the animal life of the Morrison formation which was laid down either in the late Jurassic or early Cretaceous period. Articulated skeletons and disconnected parts of the largest of the dinosaurs; bones of the smaller, but more powerful, carnivorous forms; and those of the sluggish, armored *Stegosaurus* and the smaller and more birdlike *Laosaurus*, and *Camptosaurus*—these are some of the treasures it has yielded. Intermingled with them have been found also turtles and crocodile remains and fragments of fossil tree trunks.

The bones are embedded in a coarse sandstone stratum which has at some time since it was laid down been sharply tilted up to an angle of 60°. From the character of the sediments we can reconstruct a plausible explanation of the presence of the bones in them. Apparently the shallow waters of an old river bar arrested the reptile carcasses, which had collected from many points along the river's course and were drifting downstream. Thus were brought together in this one spot the animals of a whole region—a fact that vastly enhances their interest. Once assembled, the stranded carcasses must have been covered speedily by sand and other river sediments, so that the various bones of the skeletons became fixed before the ligamentary attachments decomposed sufficiently to allow them to shift out of place. Not all the carcasses were so covered, for in some of the larger skeletons, although the bones of the lower side remain undisturbed and in their proper sequence, those of the upper or exposed side are displaced. This scattering was evidently due to the action of the current in the stream, for the parts shifted invariably lie east of the main part. Thus we know that the stream flowed from the west toward the east. The action of the current is further indicated by the strong cross-bedding of the sandstone and the assortment of its constituents into fine and coarse materials.

The Dinosaur National Monument, however, is only one of the many extensive deposits of fossils found in the foothills of the Rocky Mountain region. Como Bluff, Bone Cabin, Sheep Creek, Freeze Out Hills, and Lance Creek, in Wyoming, are all, for the paleontologist, classic localities which have yielded large collections of dinosaur remains. The Denver Basin, Canon City, and the village of Morrison, in Colorado, have likewise contributed their quota of specimens. Another region famous for its fossil reptiles is in southern Alberta, Canada. Here the Red Deer River, in cutting its course through the flat prairie country, has formed a canyon two to five hundred feet in depth but rarely more than a mile in width. In and along this great gorge the surface is eroded into hills and ravines (Plate 42), thus exposing in cross section the fossil-bearing strata of Upper Cretaceous rocks in which are found a wonderful assemblage of dinosaur remains.

While some of the dinosaurs may have exceeded all other animals in length, none of them exceeded the modern whales in bulk. Many of their striking peculiarities are enhanced by their great size; and were some of the living reptiles, especially certain lizards, such as the so-called horned toad (see Plate 72), the chameleon (see Fig. 84), and the Australian moloch, enlarged to like dimensions, they would be equally bizarre in appearance.

Unlike modern lizards and snakes, the dinosaurs had no scales. The epidermal covering of some forms consisted of a checkered skin of mosaic plates, arranged in precise patterns over certain parts of the body and forming small clusters or spots which some authorities believe may have shown a definite color scheme. Such knowledge as we have concerning the character of the skin comes from impressions left in the enveloping rock, for the skin itself does not petrify. It persists as a black carbonized layer which occasionally gives some evidence of the external outlines of the body and neck.

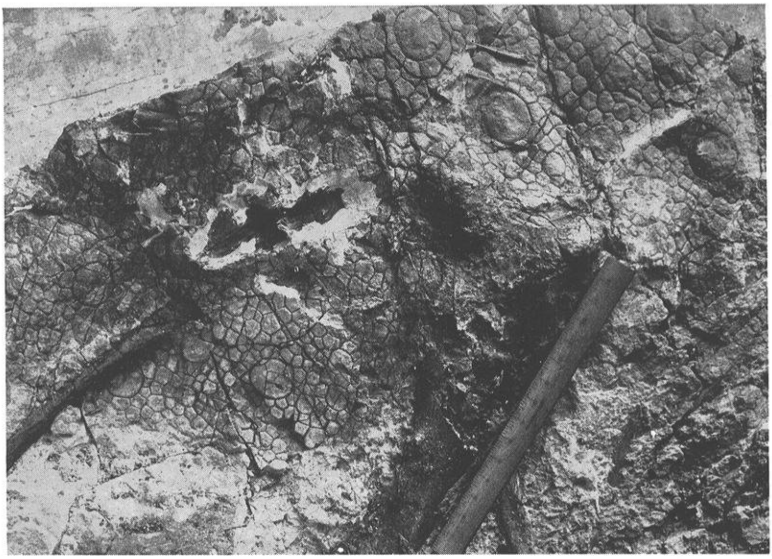
Skin impressions of a considerable number of individuals among the duck-billed and horned dinosaurs have been found and these show patterns as characteristic as are the scale patterns of modern reptiles (Plate 43). In the more recent restorations, attempts have been made to depict a skin made up of plates, whereas in all earlier attempts the skin was represented as being thick and smooth, like that of an elephant. In restorations of the large sauropods the skin is still represented without plates, although impressions of a small patch of skin of one of these animals discovered in England several years ago shows a tessellated pattern, as in the "beaked dinosaur."

The outstanding paleontologic discovery of recent times was the finding in the Gobi desert, in Mongolia, of fossilized eggs attributed to the dinosaur. This discovery by the Asiatic Expedition of the American Museum of Natural History settles a long-debated question as to whether or not dinosaurs brought forth their young alive or through the medium of eggs hatched outside the body of the mother. Several nests containing from five to thirteen eggs each have now been found in a formation of wind-blown sand (Plate 44) in this great desert, some 750 miles west-northwest of Peking. If the nests have not been disturbed the eggs, some of which measure nine inches in length, are found standing nearly on end and arranged in concentric circles. They are cylindrical in form, a shape characteristic of the eggs of many living reptiles, especially the crocodile. This is to be expected, for crocodiles and dinosaurs probably sprang from the same stock. Some turtles lay soft- and some hard-shelled eggs; but dinosaur eggs seem to have been hard-shelled, like crocodile eggs.

Although the eggs of turtles, crocodiles, and birds resemble each other superficially, they differ in form and microstructure. Van Straelen, from a microscopic study of the Gobi eggs, finds them to be distinct from eggs of any of the above-mentioned groups, but to resemble an egg-shell found in the Upper Cretaceous of Rognac, France. He therefore regards it as highly probable that both the Gobi and Rognac egg remains are dinosaurian in origin. Some of the Gobi eggs are said to contain fragments of embryo skeletons, but these fragments have not yet been subjected to scientific study.

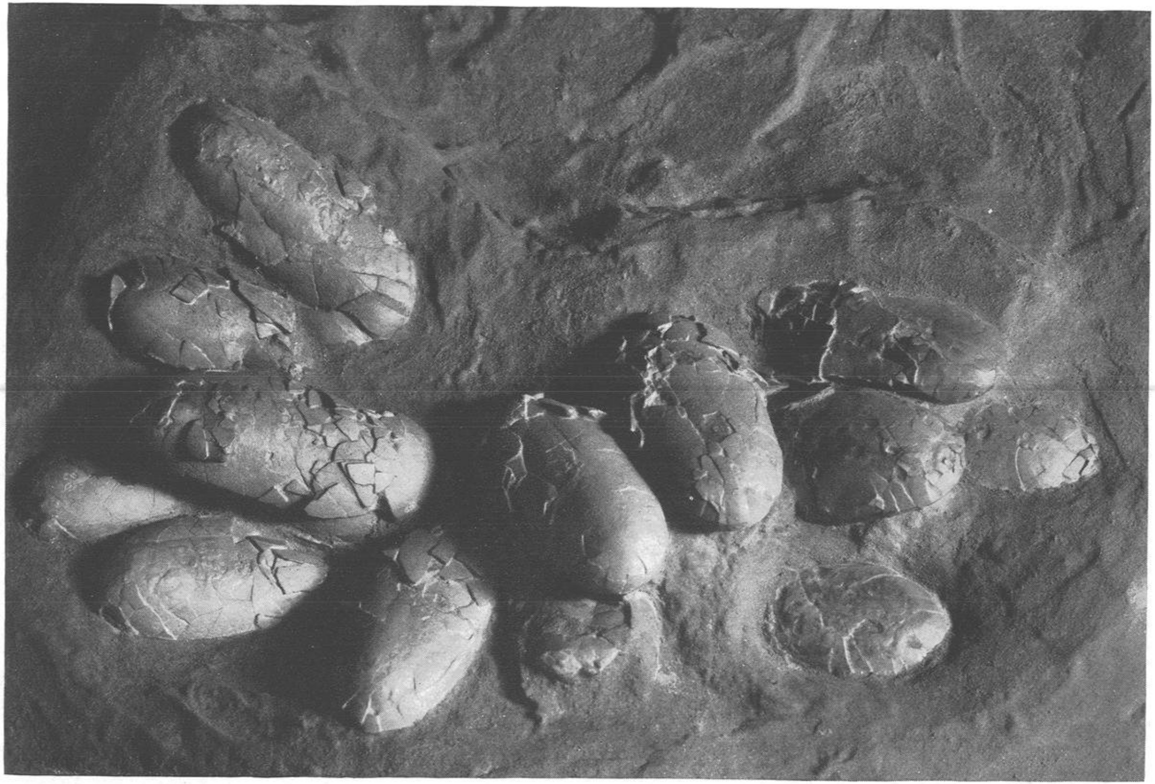
One would naturally expect dinosaur eggs to be large, but the largest of those found is only nine inches in length. Since the reptile which is supposed to have laid them attained a length of about nine feet, the ratio in length of an egg to its parent dinosaur has been established at one to twelve.

Dr. F. A. Bather has called attention to certain large, flattened eggs found in the Oxford clay of England and to a clutch of smaller eggs from the still older oolite, both of which have been in the British Museum since 1864. The eggs from the oolite are fully twice as old geologically as the Gobi eggs. Eggs of animals of any sort are rarely found as fossils, because they make an easily obtained



Upper: Skin impressions overlying the hip bones of the horned dinosaur *Chasmosaurus*. Photograph by the Geological Survey of Canada
Lower: Skin impressions of a duck-billed dinosaur. After Lambe

PLATE 44



A nest of fossil dinosaur eggs, as they were found by the Asiatic Expedition in the Gobi Desert, Mongolia.
Photograph by the American Museum of Natural History

food for animals of other sorts. We may even assume that some of the same lot of Gobi eggs of which the fossilized specimens form part were eaten by a small reptile, whose skeleton was found in a nest with the eggs, where the invader had evidently been overwhelmed by drifting sand.

Many of the Gobi eggs are thought to have been laid by a small horned dinosaur known as *Protoceratops*, a forerunner of the larger *Triceratops*. Others are attributed to some of the iguanodons, whose fossil skeletons have also been found in this region.

The Dinosauria do not form a single homogeneous natural group as paleontologists at first believed, but fall into two suborders, designated Saurischia and Ornithischia. The former includes all the carnivorous as well as the huge herbivorous forms, while the latter includes the popularly styled "beaked dinosaurs," which have a birdlike ischium and a predentary bone. O. C. Marsh, whose work on this group was preeminent, divided the Dinosauria into three suborders known as Theropoda, or beast-footed; Sauropoda, or lizard-footed; and Predentata, or beaked forms. Although this classification has been, in part, discarded, its terms have been widely used in the literature of the subject; and in order to avoid confusion (for after all, the preciseness of such terms concerns only the systematist), I, too, shall use them.

The Theropoda or Flesh Eaters

The Theropoda, or flesh-eating dinosaurs, were active, rapacious forms that walked or ran upon the hind limbs. They ranged in size from a small, slender animal no larger than a turkey up to the gigantic *Tyrannosaurus*, forty-seven feet in length. Sharp, daggerlike teeth and powerful curved claws indicate at once their carnivorous habits. Like the felines of today they relied upon strength and agility for sustenance and defense. We find no indication of aquatic habits among them and therefore must suppose they were dwellers on dry land. The group contains a great list of names, but limitation of space permits mention here of only a few conspicuous forms.

One of the most ancient of all North American theropods is the *Anchisaurus*, whose footprints are found in Triassic strata in the Connecticut Valley. *Anchisaurus* was a carnivorous animal whose fore limbs were larger in propor-

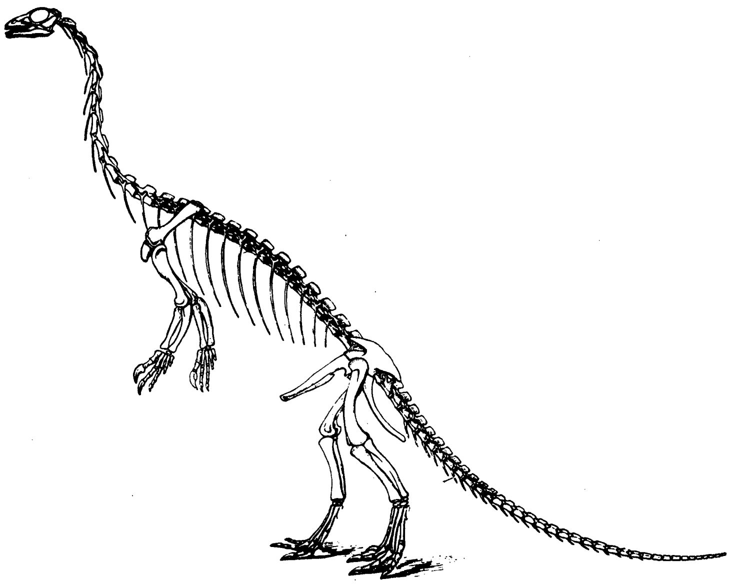


FIG. 62. Skeleton of *Anchisaurus colurus*, a carnivorous dinosaur from the Triassic of the Connecticut Valley. After Marsh

tion to the hind limbs than those of later carnivorous dinosaurs. The skeleton is slender and delicate, only surpassed in this respect by some of the birdlike forms of later periods. *Anchisaurus solus*, whose estimated length was three and one half feet, is the smallest known member of the genus; while *Anchisaurus colurus*, the largest, reached a length of seven feet.

By combining parts of several specimens, Professor Marsh was able to reconstruct the entire skeleton of *Anchi-*

saurus colurus shown in Fig. 62. A glance at this reconstruction at once suggests that the animal did not walk habitually upon the hind legs, as did the later carnivorous dinosaurs, but often on all fours; for it is obvious that the relatively short tail could not properly balance the body. Although geologically one of the earliest dinosaurs, *Anchisaurus* is nevertheless a full-fledged form, which forces us to conclude that the unknown progenitors of the dinosaur tribe must have existed many millions of years before Triassic time. However, we know little of the evolutionary history of the tribe, for no evidence of its existence has been found in strata older than the Triassic. And quite as devoid of information on the subject are the strata laid down during the inconceivably long interval between the Jurassic and Upper Cretaceous periods — those two geologic ages which have furnished the best-known specimens. *Anchisaurus* and its kindred are now held responsible for many of the footprints of the Triassic in the Connecticut Valley, but of all the hundreds of these imprints known, Professor Lull recognizes only one, named *Grallator tenius* (Fig. 63), that fulfills all the requirements of the *Anchisaurus* foot.

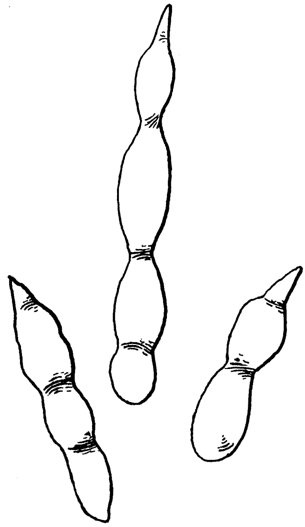


FIG. 63. Track, *Grallator tenuis*, thought to have been made by *Anchisaurus*. After Hitchcock

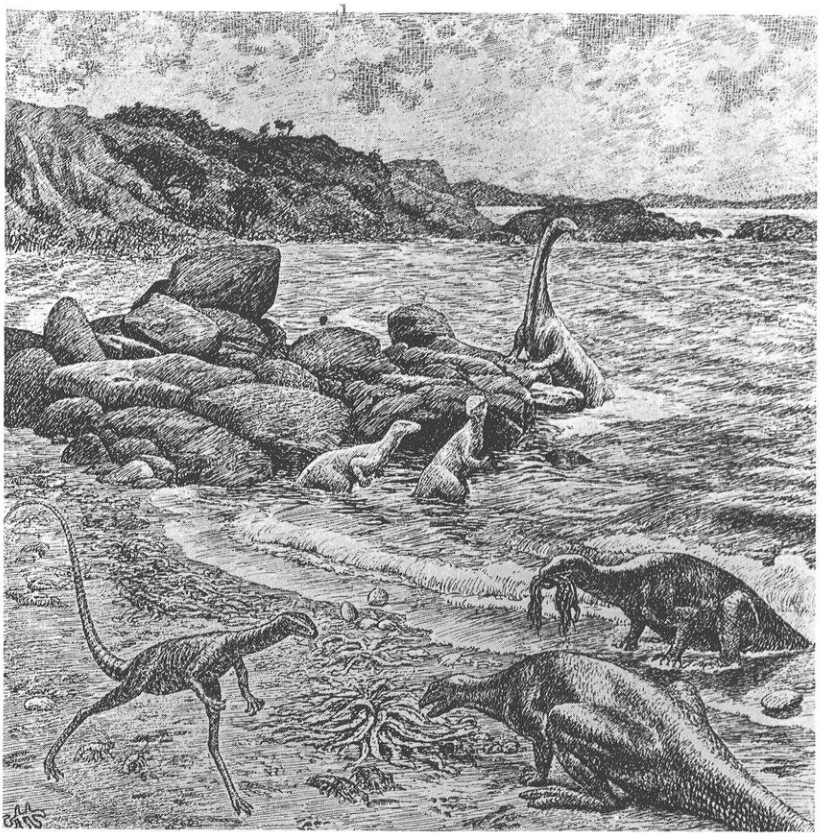
The *Podokesaurus*, described by Doctor Talbot from a specimen found in a glacial bowlder not far from the site of Mount Holyoke College, South Hadley, Mass., was another small carnivorous form of the Triassic. Not more than three feet in length, it must have been extremely agile, for the long, slender legs were surely built for speed.

Its affinities lie in the same family as the famous and oft-described *Compsognathus* of Europe. In the accompanying illustration (Plate 45) *Podokesaurus* is shown running along the beach, with its long, slender tail held high in the air, a pose often assumed by small living lizards when moving at full speed. The original specimen, which furnished all the information we have about this animal, was unfortunately destroyed in a fire, so that all the evidence now remaining of the existence of *Podokesaurus* consists of a few pictures and its scientific description.

These early carnivorous dinosaurs of the Triassic were succeeded in later geologic times by other flesh-eating forms, such as the *Megalosaurus* of England and the *Ceratosaurus* and *Allosaurus* of America. Numerous sharp teeth prove the *Ceratosaurus* to have been well adapted for seizing prey and tearing its flesh. A single, well-developed horn on the nose, which suggested to Professor Marsh the name *Ceratosaurus nasicornis* ("nose-horned saurian"), constitutes a distinctive feature. The exceedingly small fore limbs and feet armed with sharp claws could have been of no use in walking, so that locomotion must have depended entirely upon the strong hind legs. This arrested development of the fore limbs seems a persistent feature in the evolution of the carnivorous Dinosauria; for in the last forms to exist, the number of toes had dwindled from five to two, and the fore limbs were so ridiculously small that they could have served no useful purpose whatever.

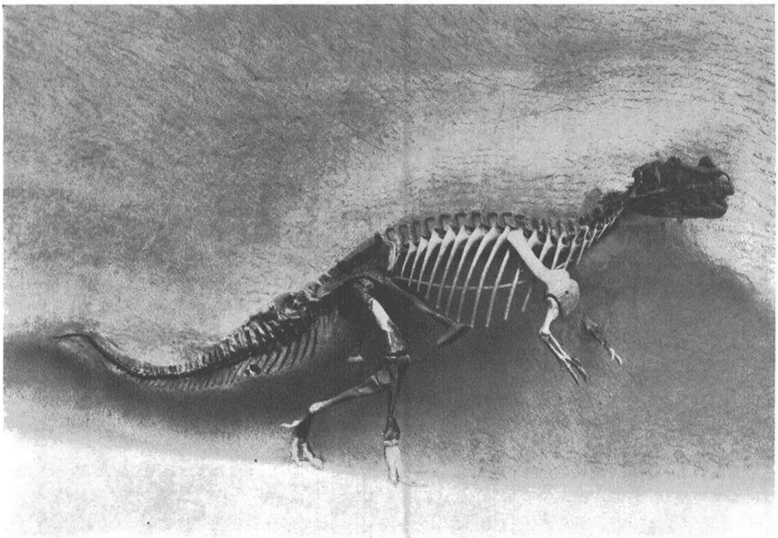
The specimen of *Ceratosaurus* illustrated in Plate 46, the only one of its kind known, was collected near Canon City, Colo., during the years 1883 and 1884. The skeleton was still well articulated when discovered in the rock; but many of the bones, especially those of the skull, were greatly flattened. For this reason the specimen was mounted for exhibition in bas-relief. The backbone stands out boldly from the original sandstone matrix, which forms a small part of the background, whose greater part is made of a composition of sand and cement, chiseled in close imi-

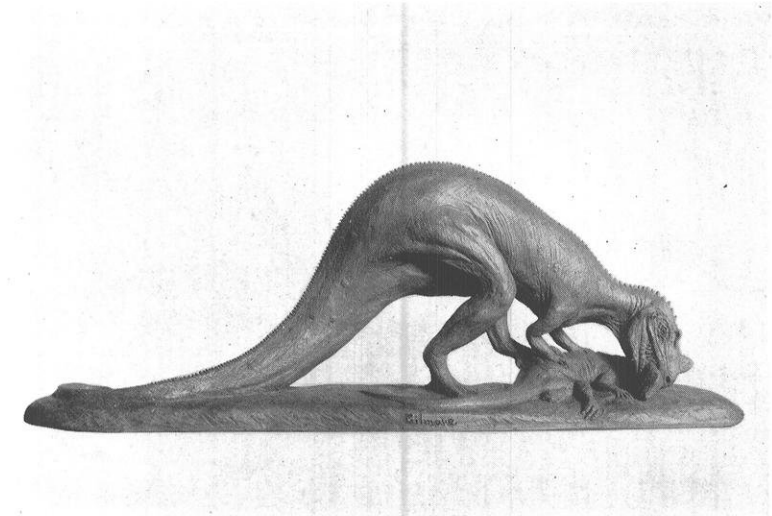
PLATE 45



Triassic life along the shore. The swift-running *Podokosaurus* in left foreground. After Heilman

PLATE 46





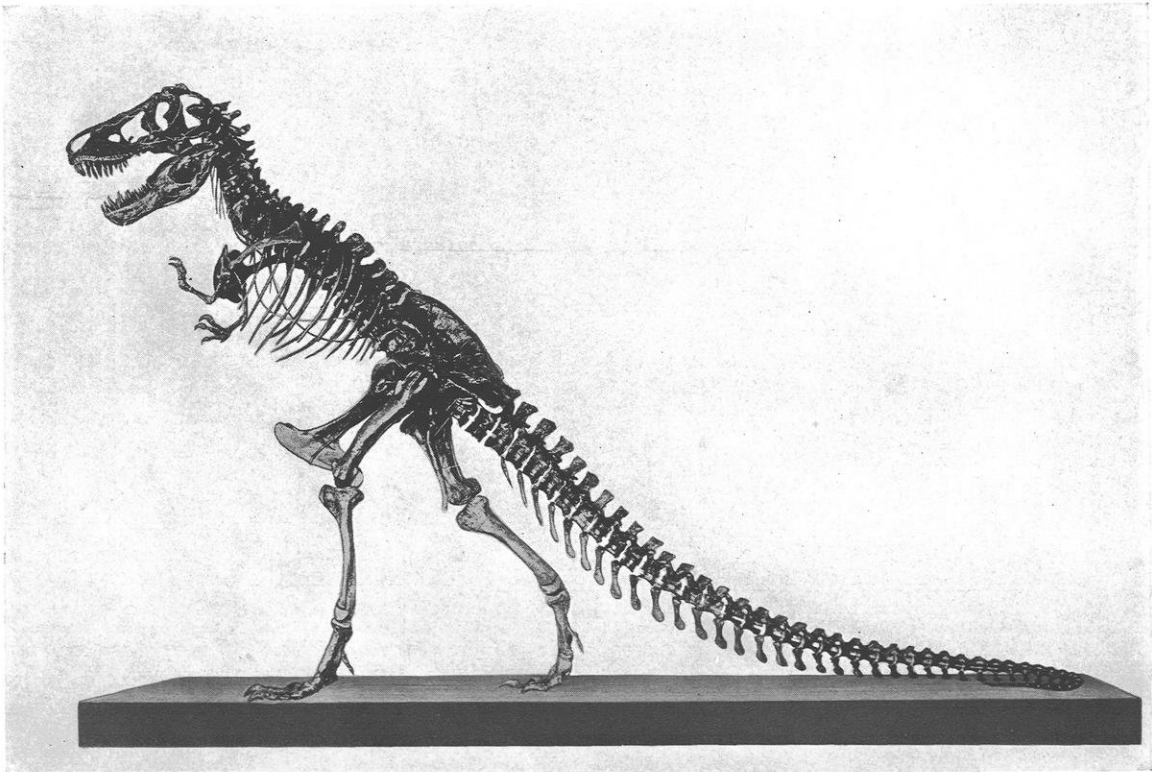
Upper: Mounted skeleton of *Ceratosaurus nasicornis* in the National Museum

Lower: Restoration of *Ceratosaurus* completing the kill of the small plant-eating *Camptosaurus nanus*. Modeled by Charles W. Gilmore tation of the original matrix. The position of the bones when found in the rock was such as to suggest a rapid walking motion and largely determined the pose selected for the skeleton. The long tail is raised clear of the ground to balance the weight and compensate for the swaying of the body and forelegs.

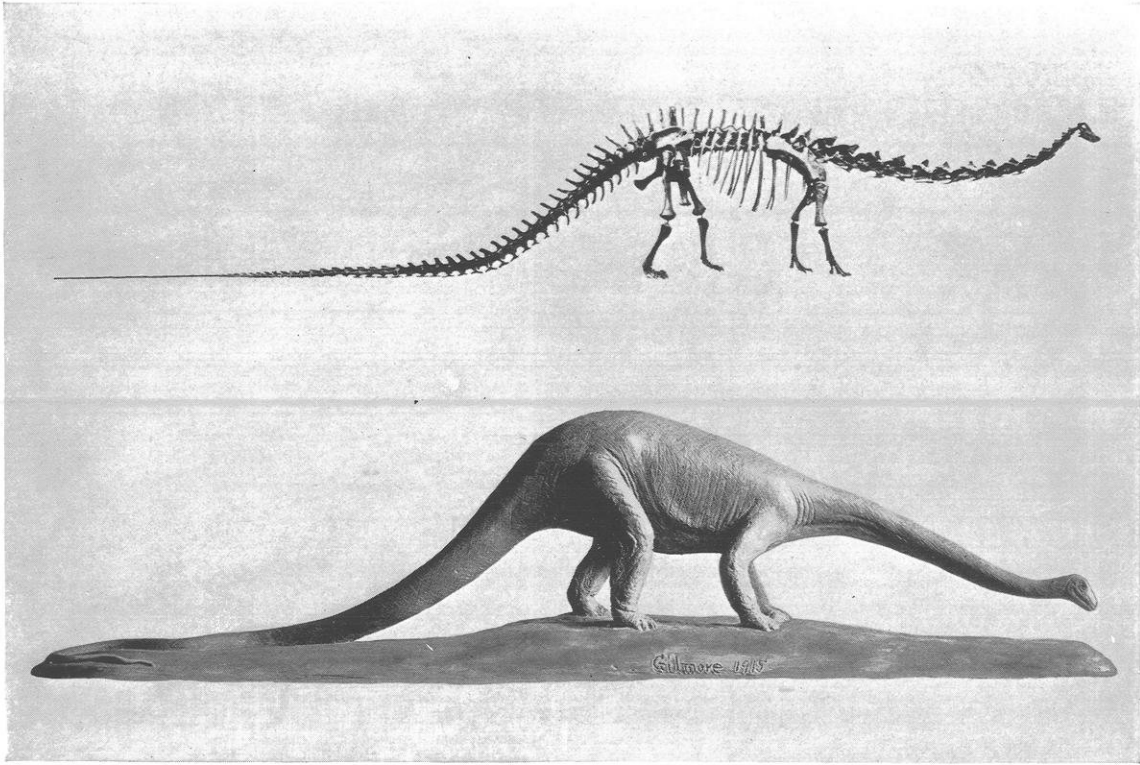
This skeleton measures seventeen feet in length and stands about five feet high at the hips. Several restorations have been made of the animal as it appeared in life, but the latest conception, executed by the writer in 1915, is shown in Plate 46. In order to show graphically that *Ceratosaurus* was a flesh eater, it is depicted in the act of killing a small herbivorous contemporary, *Camptosaurus nanus*, which might well have been the prey of this rapacious brute. Much difference of opinion exists on this point, however, and some authorities are inclined to the opinion that *Ceratosaurus* and some of the other flesh eaters of its order were nothing more than reptilian hyenas, which fed largely upon carrion.

Another carnivorous form of Morrison time is the *Allosaurus*, an animal still larger and more ferocious than *Ceratosaurus*. An adult individual attained a length of thirty feet or more, and when it stood erect on its hind limbs its head was fully fifteen feet above the ground. It lacks the horn of *Ceratosaurus* and has much more powerful fore limbs, with three toes each armed with long, strongly curved, sharply pointed claws. Whether *Allosaurus* actually preyed upon the large sauropods or whether, as has been suggested, it fed only upon their carcasses, we can not determine; but that it did feast upon them is clearly indicated by an incomplete skeleton of *Brontosaurus* (a sauropod) in the American Museum of Natural History. In this specimen several of the bones, especially those of the tail, look as though they had been scored and bitten off. Upon placing a jaw of *Allosaurus* alongside these tail bones it was found that the spaces between the teeth coincided with those between the score marks on the tail. Furthermore, a number of broken *Allosaurus* teeth were found lying beside the *Brontosaurus* bones in the rock; and since no other animal remains occurred with them it seems reasonable to conclude that the teeth were broken off while *Allosaurus* was in the act of devouring the *Brontosaurus* carcass. In order to depict this the restorers posed the *Allosaurus* skeleton standing over and feeding upon the remains of a *Brontosaurus*.

Tyrannosaurus, the "tyrant saurian," as named by Professor Osborn, was the largest and probably the most ferocious flesh-eating animal the world has ever known (Plate 47). It represents the culmination in the evolution of carnivorous dinosaurs, its remains occurring in the Lance formation of the Western States at the close of the Age of Reptiles, in association with *Triceratops*, *Ankylosaurus*, and the duck-billed *Thespesius*. *Tyrannosaurus* reached a length of forty-seven feet and when standing erect on its massive hind legs towered eighteen to twenty feet above the ground. The head alone was four feet three inches long, three feet four inches deep, and two feet nine inches wide, with powerful jaws carrying numerous daggerlike, sharply pointed teeth that ranged from three to six inches in length. The large hind feet had four toes each, one of which projected backward as in some birds. All the toes terminated in sharp claws curved like the talon of a bird of prey. The fore limbs were absurdly small for so large an animal, for the humerus, or upper-arm bone, measures only fourteen inches in length, while the femur or thigh bone, measures four feet eight inches and the knee joint stands six feet above the ground, the height of a tall man. So immense a beast certainly did not leap or spring upon its prey; however, its slow, ponderous stride, gradually quickening into a resistless rush, might well have carried everything before it. We may well imagine *Tyrannosaurus* preying upon the slow-moving *Triceratops* or—what is even more probable—upon the large duck-billed *Thespesius;* for while *Triceratops* had some means of de-



Mounted skeleton, forty-seven feet long, of *Tyrannosaurus rex*, largest carnivorous dinosaur. Photograph by the American Museum of Natural History



Upper: Mounted skeleton of *Diplodocus*, eighty-four feet long, from Wyoming
Lower: Restoration of *Diplodocus*, modeled by Charles W. Gilmore

fense in its armament of horns, *Thespesius* had no way of protecting itself except to escape into the water, and would have fallen an easy prey to such a predacious monster.

We now pass on to the consideration of a dinosaur that combined features of both the birds and reptiles to a greater degree than perhaps any other yet known. *Ornithomimus*, "the bird mimic," was the name given to it by Professor Marsh from bones of a hind foot found in the Upper Cretaceous near Denver, Colo. Had this foot been found before dinosaurs were known it would quite certainly have been described as belonging to an ancient type of bird. Although other fragmentary skeletons of *Ornithomimus* came to light following the original find in 1889, not until Mr. Barnum Brown discovered in 1914 a nearly complete skeleton in the Belly River formation along the Red Deer River in Alberta did its striking characteristics become apparent.

Prior to the discovery of this skeleton paleontologists had confidently predicted that later evidence of these "bird mimics" would prove that they were flesh eaters, with jaws full of sharp cutting teeth; but to the amazement of everyone, the skull which came to light with the skeleton turned out to be toothless and to resemble that of an ostrich. It had long since lost the flesh-eating adaptations which had been observed in the skulls of all other dinosaurs then known, and, according to Professor Osborn, who studied it, had become fitted for the consumption of only soft, tender food. The neck was long and flexible, like that of certain birds. The resemblance of the skull, neck, and hind limbs to those of existing ostriches, rheas, and other struthious birds, caused Professor Osborn to select the name *Struthiomimus*, "the ostrich mimic," for this specimen.

While in the above-mentioned features *Struthiomimus* resembles the birds, the fore limbs and hands are no more like the wings of an ostrich than they are like the fore limbs of the carnivorous dinosaurs. The arm and forearm are long and slender, while the hand consists of three digits of nearly equal length and a thumb, which is set off, as if for grasping. The digits are tipped with long, slightly recurved claws, more useful for digging than for grasping an active prey. The elongated, slender hind legs show the

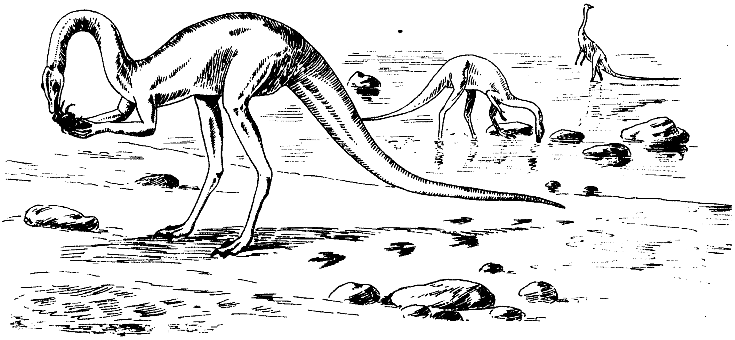


FIG. 64. *Struthiomimus*, the "ostrich mimic," feeding on crustaceans. Restoration in the American Museum of Natural History

animal to have been a runner of no mean attainment, depending upon a balanced mode of progression similar to that seen in the swift movements of certain modern lizards, in which the tail balances the forward part of the body.

The unique structure of *Struthiomimus* has led to a lively discussion as to its habits in life. All authorities have agreed in abandoning the hypothesis that it was carnivorous. One suggests that it was a wader, feeding upon small crustaceans and mollusks (Fig. 64); another believes it was an ant eater, preying on ant hills; and still another considers it herbivorous—a browser whose hands were peculiarly fitted for searching out or grasping some particular kind of shrub or fruit; but none of these explanations are satisfactory.

The Gigantic Sauropoda or Amphibious Dinosaurs

The largest of the dinosaurs—the sauropods—probably never exceeded one hundred feet in length. An actual skeleton of one of these huge reptiles, known as *Diplodocus*, exhibited in the Carnegie Museum in Pittsburgh, measures eighty-four feet from snout to tail tip and stands over twelve feet high at the hips. *Diplodocus* (a typical example of the Sauropoda), may be said to consist principally of tail and neck, which two appendages are connected by a short body supported on four elephantine legs. Its dimensions are as follows: Tail, forty-six feet; body, fifteen feet; neck, twenty-three feet. A small head, about the size of that of a large horse, surmounts the neck, and the tail is prolonged into a whiplash, as in the lizard (Plate 48).

Diplodocus was a plant eater, probably feeding on soft, succulent herbage, such as abounds in the quiet waters of bayous, marshes, and wide meandering streams. The teeth, confined to the forward margins of the jaws, are slender and pencil-like, with slightly spatulate or spoon-shaped ends that must have been used to rake up the plant food. As there are no molars or back teeth we must conclude that *Diplodocus* did not masticate its food but swallowed it whole. Certain smoothly polished stones known as gastroliths, foreign to the rocks in which occur the fossil remains, are occasionally found within the ribs of some sauropod skeletons and suggest the existence of a gizzardlike organ for the reduction of this inert mass of food. As a full-grown *Diplodocus* must have weighed fifteen tons or more, we can but wonder how it managed, with a head no larger than that of a horse, to consume enough food to sustain itself. Surely eating must have occupied the greater part of its waking hours. Or, if this were not so, then these giants of reptiles must have been cold-blooded and sluggish, as are many of their kindred today, not wasting energy in rapid movement and having no need to keep the temperature of their bodies above that of the air, and so requiring less food than warm-blooded animals. It is well known that alligators, snakes, and turtles, especially those living in temperate zones, go for weeks without food, and that during their winter hibernation the digestive and respiratory functions are practically suspended. If the huge reptiles of ages long past were similar in temperament, then they required much less food

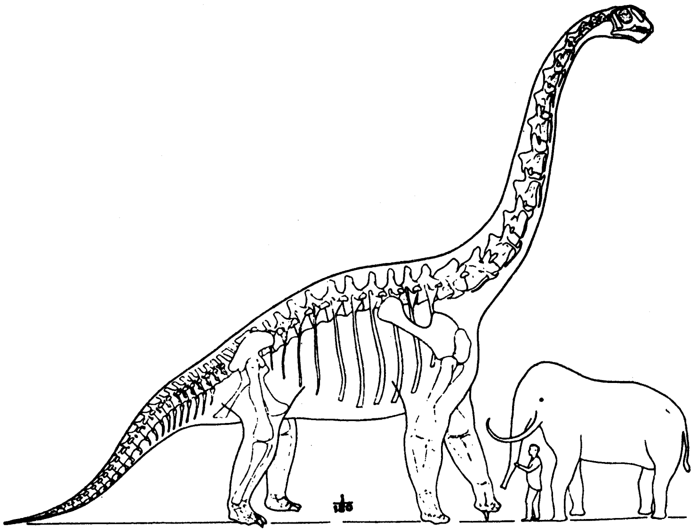


FIG. 65. Sketch restoration of *Brachiosaurus*, largest American dinosaur. After W. D. Matthew

than their colossal size would lead us to think. This assumption, however, is entirely speculative, since we have no means of determining whether the extinct reptiles resembled those of today in their constitution and habits.

As measured by bulk (as distinguished from length), *Diplodocus*, with all its immensity, did not reach the peak of the dinosaur group. Fragmentary skeletons of other forms indicate the existence of sauropods of still greater bulk; though up to the present time no specimen has been examined which, by actual measurement, exceeds *Diplodocus* in length. From time to time accounts appear of the discovery of a dinosaur more than a hundred feet long—a measurement estimated from a fragmentary or partial skeleton; but such estimates have always shrunk perceptibly on further examination of the specimens cited. In our own country the record for size of a single fragment is held by a thigh bone in the Field Museum of Natural History, Chicago, which measures six feet eight inches in length, and weighs, in its fossilized condition, 640 pounds. The gigantic sauropod who possessed this thigh bone—*Brachiosaurus*—differed from others in that its fore limbs were almost as long as its hind ones, so that, at a glance, it must have resembled a giraffe (Fig. 65). It has been suggested that *Brachiosaurus* was a deep-water wader, else it could not have escaped the clutches of the fierce carnivorous monsters who roamed the land during its lifetime.

Giant dinosaur skeletons like *Diplodocus* display an architecture combining marvelous strength with lightness of material. They have been compared to the American truss bridge in attaining the maximum of strength with the minimum of weight. The dinosaurs achieved the ideal in skeletal form by dispensing with every bit of bone which could be spared without rendering their vertebrae too weak to stand the strains and stresses to which they must have been subjected in animals of such colossal size. Each of the various processes of the vertebrae consists of a series of thin plates or laminae, arranged in layers, and set together in such a way as to firmly brace one another against all possible strain, yet leaving large cavities between the laminae. Thus a vertebra when complete is hardly more than a composite of several series of thin plates widely spaced and all joined to the body or centrum of the vertebra. Although these vertebrae appear massive and solid externally, a cross section of their interior proves them to be made up largely of empty chambers and cells—a form of structure devised to lighten the bone and yet maintain the maximum of strength. By comparing one of these chambered dinosaurian vertebra with a somewhat similarly constructed ostrich vertebra, Osborn has estimated that it weighed (before fossilization) only twenty-eight pounds, or half as much as a whale vertebra of the same bulk.

Strata in the Rocky Mountain region of the same geologic period as the strata of the Black Hills have yielded skeletons of still another huge herbivorous dinosaur—*Brontosaurus*—the "thunder saurian" of Marsh. Although this reptile never attained the length of *Diplodocus*, it was far more massive in structure, its neck, chest, hips, and tail being relatively deeper and heavier. The femur, or thigh bone, of one specimen is five feet eight inches in length and is more massive than that of *Diplodocus*. A large skeleton in the American Museum of Natural History measures sixty-eight feet in length (or nearly twenty feet less than the longest known *Diplodocus*), and has a thigh bone about five feet in length. Six more or less complete skeletons of *Brontosaurus* are to be seen in the Yale, American, Carnegie, and Field museums. Estimates of the weight of *Brontosaurus* in life have varied from twenty to thirty-eight tons. The minimum is probably nearest the truth, for it must be remembered that the animal consisted principally of neck and tail, and that the most of its weight was in its body, which is short.

The notion seems to prevail that reptiles, unlike man and other of the higher vertebrates, do not reach their maximum size on the attainment of maturity, but continue to grow throughout life, so that the larger the reptile the older it is. By this reasoning, the dinosaur's span of life must have spread over an incredible number of years as we measure our lives today. Observations among modern animals, however, tend to show the fallacy of such an idea. Jumbo, the one-time famous circus elephant, a giant among his kind, reached his full height of eleven feet and full weight of six and a half tons in twenty-one years. An alligator in the New York Zoological Park grew in a dozen years from seven to twelve feet in length—almost the maximum for an alligator. Tortoises from the

Galápagos Islands have been known to grow in weight from twenty-nine to two hundred and ninety-five pounds in seven years and to reach three hundred and fifty pounds in less than ten years. If modern animals can grow so rapidly, it is reasonable to assume that those of ancient times could also, and that it did not require centuries, as has so often been supposed, for *Diplodocus* and his allies to attain their eighty or more feet of length.

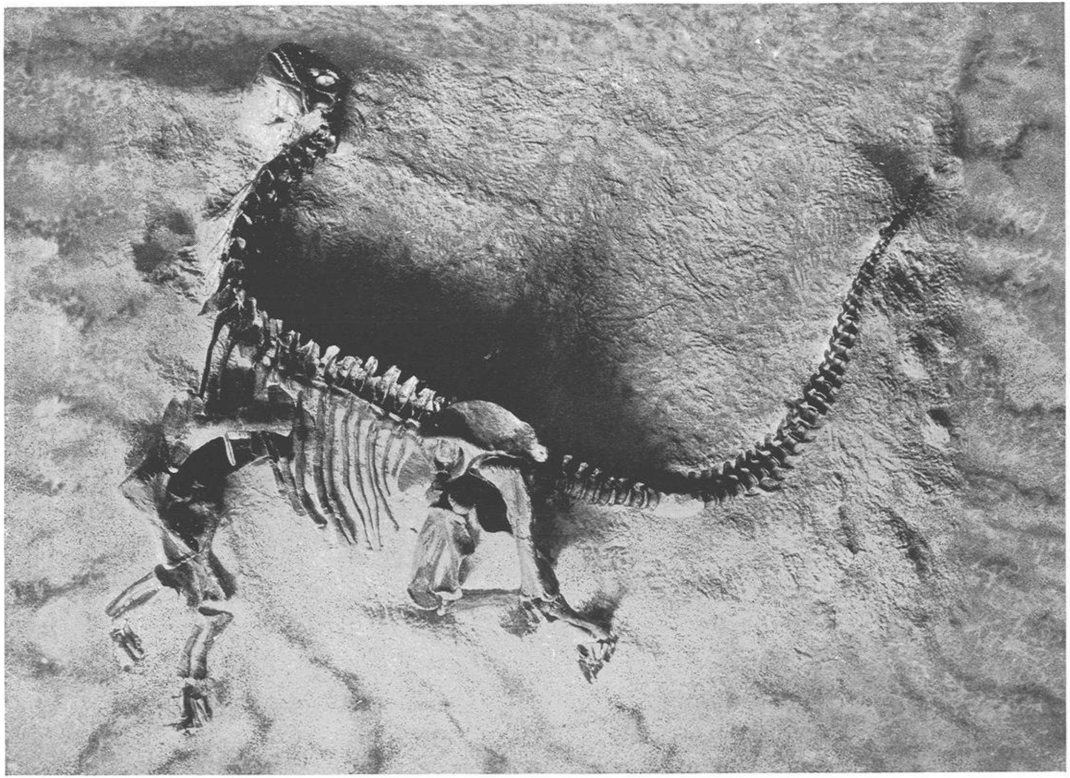
Complete dinosaur skeletons are occasionally found, but rarely are they those of sauropods. The great size of this order of dinosaurs effectively reduced the chances of an entire sauropod skeleton being quickly and entirely covered by sediments after death, and likewise increased the chances of separation and loss of parts of a skeleton after erosion (millions of years later) has again exposed it to view. The discovery, therefore, in Utah's famous Dinosaur National Monument quarry, of so perfect a specimen as the one now in possession of the Carnegie Museum, is of more than passing interest. The skeleton of *Camarasaurus*, as this particular genus is called (Plate 49), appears to be the most perfect specimen of a sauropod dinosaur that has yet been brought to light, and its preservation in so nearly its original form is probably due to its relatively small size. The specimen consists of an articulated skull and backbone, complete from the tip of the nose to the tip of the tail. There are eighty-two vertebrae in the backbone, which has a length of about seventeen feet. The ribs of the lower side remain regularly spaced; the hip bones and those of the limbs and feet are still more or less perfectly articulated; but several bones of the upper side have shifted out of position and a few are entirely missing. The skeleton when found lay on its right side, with both neck and tail bent sharply upward, a posture often assumed in death. The perfect skull differs materially from that of the contemporary *Diplodocus*, for it is short and like that of a bulldog, with large orbits and massive jaws filled with strong, spoon-shaped teeth, indicative of a plant eater.

REPTILES

The Predentata or "Beaked Dinosaurs"

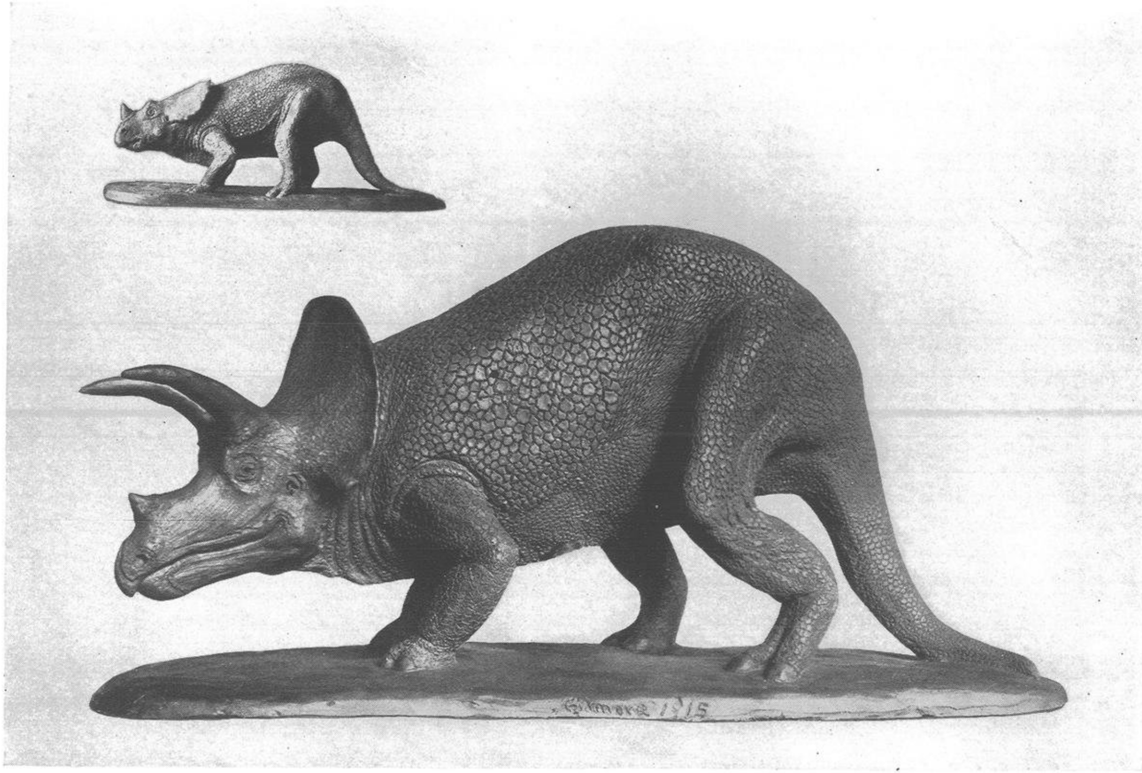
The third suborder of dinosaurs (according to Marsh's classification), called Predentata or Ornithischia, exceeds in the number and diversity of its forms both the Theropoda and Sauropoda. The beak, which gives the group its name, is quite toothless except perhaps in a few primitive forms, and was in life covered with a horny sheath, as in birds and turtles today. Many other birdlike features are found in the skeletal anatomy of the Predentata, such as the joining together of a large number of vertebrae into a solid sacrum, the presence of a prepubis, and the backward direction assumed by the pubic bones, as well as still other less marked similarities observed in the shoulder girdle and feet, all of which strongly suggest that the earliest ancestors of this suborder of dinosaurs were closely related to the ancient birds. But the two groups separated widely in their later development; for the primitive birds gradually became adapted to flight, and the primitive dinosaurs to a terrestrial life. So far as now known, all the Predentata, whether horned, duck-billed, or armored, were herbivorous, subsisting entirely upon plant food.

The Ceratopsia, more popularly called the "horned dinosaurs," were in some ways the most remarkable of the Predentata. They had the largest heads of any land animals ever known, surpassed in this respect only by modern whales. Their popular name refers to the large horns on the head which formed a conspicuous part of the animal's defensive armament. The great size of the skull is accounted for by the enlargement of its base into a bony crest or frill, which extends backward over the neck like an Elizabethan ruff. Average-sized skulls measure six feet in length, but a cranium in the Peabody Museum of Natural History of Yale University, belonging to a species known as *Torosaurus gladius*, has a length over all of eight feet seven inches, the largest horned dinosaur skull yet recorded.



Nearly complete skeleton of *Camarasaurus*, unusually well preserved. In Carnegie Museum, Pittsburgh

PLATE 50



Restorations of *Triceratops*, the giant of the horned dinosaurs, measuring twenty feet, and of *Brachyceratops*, the six-foot pygmy of the group. Modeled by Charles W. Gilmore

When the first specimens of Ceratopsia were found, no one suspected their dinosaurian origin, so unlike were they to any fossil reptile then known. A pair of horn cores, discovered in 1887 in the suburbs of Denver, Colo., were submitted to Professor Marsh, who ascribed them to an extinct buffalo and published a brief account of them under the name *Bison alticornis*. Not until the discovery in Wyoming two years later of complete skulls with similar horns did paleontologists recognize the Denver horn cores as having belonged to a dinosaur. This error on the part of Professor Marsh, however, does not reflect in any way on his sagacity; for until the finding of the Wyoming skulls no one suspected that such extraordinary creatures as the Ceratopsia had ever existed, and it was perfectly natural that he should have been misled by the resemblance of the Denver cores to the horn cores of the buffalo.

It appears that certain teeth and bones found by Dr. F. V. Hayden on one of his expeditions to the Western States as early as 1855, and later like discoveries by Prof. E. D. Cope, in 1873 and 1876, were the remains of horned dinosaurs; but such fragments gave no clue at that time to the identity of the creatures to which they had once belonged. It is now known that a great many different kinds of horned dinosaurs must have existed, from the quantity of fossil remains which have come to light; but as most of them are represented only by skulls and parts of skeletons which can not be accurately classified, we know comparatively little as yet of their early history and evolution. Mention is made here of only a few members of the Ceratopsia, selected for their striking characteristics; but these will serve to show the great diversity of the race.

Triceratops, the largest of the Ceratopsia as well as the last to survive, has a pair of large brow horns and a smaller nasal horn, a peculiar development that suggested to Professor Marsh the name meaning "three-horned face." In *Monoclonius*—a ceratopsian of an earlier period—the arrangement of the horns is reversed, the single horn on the nose being much the largest, while the brow horns are shorter and often vestigial. The frill is also pierced by two large openings, or fenestra, whereas in *Triceratops* it is solid bone (Plate 50).

The examples cited represent, in a way, the two extremes of skull development in the Ceratopsia, between which are various gradations of modification in horn and frill. Some of these differences may be sexual, but at this time we have no way of distinguishing male from female.

The horned dinosaurs were fighters. Broken horns, fractured and healed jaws, and pierced frills give abundant evidence of their combative nature. A pair of *Triceratops* horn cores in the National Museum bears mute witness to an encounter. The stump of one horn (the left) is larger than the other, showing that it still grew after the other had ceased to grow; and its appearance and condition indicate that the animal lived to a good old age and that the horn was broken off after death. The right stump, on the other hand, has healed and rounded over, proving that the horn was broken off comparatively early in life, so that the stump never grew to its full size. Although these appendages may have been useful as offensive and defensive weapons, the horns and skull excrescences of some species must have been largely ornamental, as they are in many of the living lizards. The frills and horn cores of some of the Ceratopsia have ramifying systems of deep channels on their outer surfaces for carrying blood vessels, suggesting that in life a close-fitting, horny skin covered them. This covering was probably much like that of some modern reptiles, such as the horned toad. On the specimen of a young ceratopsian in the Peabody Museum at Yale, Prof. R. S. Lull has observed, surrounding the base of the horn core, a layer of black powdery substance half an inch thick, which is doubtless the carbonized remains of the actual horn.

All of the Ceratopsia were four-footed, with short massive limbs and broad elephantine feet, whose toes were probably tipped with hoofs. Their bodies were short and rounded, but broad-barreled, and they had short necks completely covered by the projecting frills. Their tails were short for dinosaurs, and in life probably dragged upon the ground.

The functional teeth formed a single cutting row in each jaw, the lower row closing inside the upper in the act of eating, so that the wear was on a vertical plane; and in opening and closing the mouth the two rows of teeth acted like the opposing blades of a pair of shears. The tooth

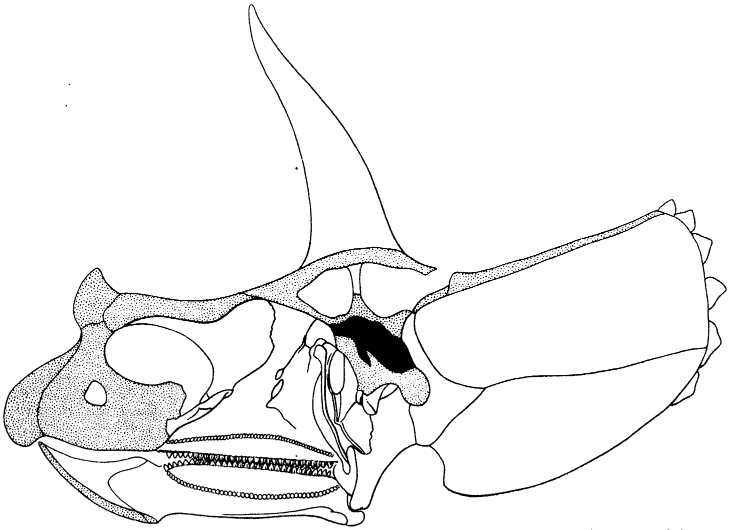
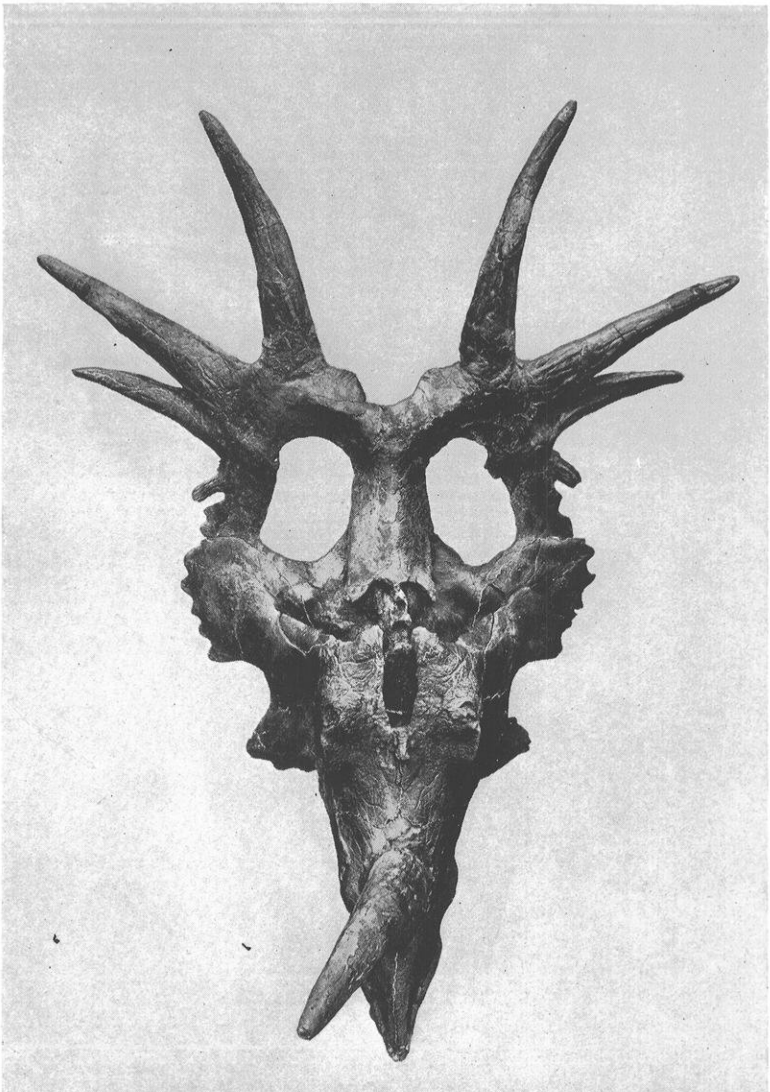


Fig. 66. Longitudinal section of *Triceratops* skull. Black area shows position and extent of brain cavity. After Hatcher

structure and arrangement indicate that the Ceratopsia fed on herbage—probably the stems, small branches, leaves, and twigs of shrubs and trees. This food, gathered by the efficient, turtlelike, cropping beak, was passed back to the teeth, there to be reduced to smaller bits and made suitable for reception into the stomach. The eyes were set in deep, thick-rimmed sockets that afforded ample protection to these highly sensitive organs, and the eyeball was still further protected by a ring of bony sclerotic plates like those of an owl's eye—a development, it has been suggested, for the adjustment of light, probably enabling the animal to see at night as clearly as in the day. The Ceratopsia had an incredibly small brain. In proportion to the size of the skull, the brain is probably smaller than that of any other known vertebrate, as is graphically shown by a longitudinal section through a *Triceratops* skull illustrated in Fig. 66.

Of the many kinds of horned dinosaurs now known, the Canadian specimen of a genus called *Styracosaurus* tops them all in elaborateness of skull decoration. Six feet in length, the skull has a horn on the nose twenty inches high and six inches in diameter, and six horn cores that radiate from the borders of the frill as shown in Plate 51. At its broadest part the skull measures four and one half feet across. The name *Styracosaurus* was chosen because of the bony spikes which made this reptile in life a veritable moving *cheval de frise*. It is of interest to compare this skull with that of the living "horned toad," *Phrynosoma* (see Plate 72), which, by the way, is not a toad at all, but a lizard. The resemblance lies not so much in the shape of the two skulls as in their horny decorations; and if the skull of *Phrynosoma* (which measures only an inch in length) could be enlarged seventy-two times, so as to bring it to the size of that of *Styracosaurus*, it would present fully as bizarre an appearance. The living chameleons also have mimicked certain features of the *Triceratops* skull to a remarkable degree. The male *Chameleon owenii*, from the Cameroons, has a perfect frill as well as three horns—one upon the nose and one above each eye. These horns, however, are epidermal and have no bony cores. Also, in chameleons, only the male develops horns, whereas, so far as we know, both male and female *Triceratops* possessed them.

PLATE 51



Skull of *Styracosaurus*, six feet long, most ornate of horned dinosaur skulls. Photograph by the Geological Survey of Canada

PLATE 52

Restoration of the duck-billed dinosaur *Thespesius.* From the painting by Charles R. Knight in the American Museum of Natural History

Having considered *Triceratops*, the giant of the horned dinosaurs, we may well devote a few moments to *Brachyceratops*, a pygmy of the group (see Plate 50). The skeleton of this ceratopsian has a length over all slightly under six feet and stands two and one-half feet high at the hips. Truly, *Brachyceratops* was a sizable animal, especially when compared with the reptiles of today; but as the whole of its skeleton is shorter than an average skull of its relative, *Triceratops*, the reason for classing it as a pygmy becomes apparent. Comparatively speaking, *Brachyceratops* is a newcomer in scientific circles, as its remains were found for the first time in 1913. A party from the National Museum, exploring the badlands along Milk River, on the Blackfeet Indian Reservation, Montana, came upon the skeletal remains of no less than five individuals, all incomplete, but all of the same size.

The skull of *Brachyceratops* is but twenty-two inches long and is surmounted by three horns; but, unlike *Triceratops*, the horn above each eye is tiny and that on the nose is large. The frill, unlike that of the larger three-horned animal, is perforated on either side. *Brachyceratops* lived earlier in the Upper Cretaceous period than the better-known *Triceratops;* and although it can not be regarded as the direct progenitor of *Triceratops*, it may represent the ancestral group from which this last of the horned dinosaurs was derived.

Brachyceratops represents the smallest horned dinosaur found in North America; but the remains of a still smaller individual, known as *Protoceratops*, have come to light in the Gobi desert in Mongolia. Expeditions from the American Museum of Natural History have collected more than seventy-five skulls of this newly found genus, ranging in development from embryo to fully adult forms. As noted previously in this chapter, the dinosaur eggs of the Gobi desert are supposed to have been laid by *Protoceratops* because of the proximity of skeletons of this genus to the nests containing the eggs.

The hadrosaurs constitute another group of the Predentata. If we may judge by the abundance of their fossilized remains, these duck-billed dinosaurs (Plate 52)—as they are popularly called from the resemblance of the expanded, toothless beak to that of a duck—flourished in considerable numbers in Upper Cretaceous times. Like the horned dinosaurs, their contemporaries, they included a great diversity of forms, but whether large or small, crested or noncrested, all were alike in the possession of long hind limbs, shortened, slender fore limbs, and a long flattened tail. The diminutive fore limbs with long slender toes clearly indicate that the hadrosaurs walked almost entirely on their hind legs, the weight of the forward part of the body being counterbalanced by that of the long, heavy tail. It is probable that the animal dropped on all fours to feed. Full-grown individuals of the largest species known are estimated to have attained a length of forty feet. When walking about on the land (and I use this expression advisedly, because it is believed that the hadrosaur spent much of its time in the water), the top of the head must have been from twelve to fifteen feet above the ground.

The hadrosaurs never had need of false teeth. They possessed a dental battery which in some forms amounted to as many as 500 teeth in each jaw bone, or more than 2,000 in the mouth of a single individual. Each jaw, upper and lower, was provided with forty or more closely set vertical rows, each row having from eight to fourteen teeth, ranged one above another. And the loss of a tooth never inconvenienced its owner, for as in all reptiles, a germ tooth developed at the bottom of each vertical row whenever one was lost from the top.

The most striking peculiarity in the hadrosaurs is displayed in their skulls, on which various kinds of bony crests developed. Plate 53 shows specimens illustrating two of these strange modifications: *Corythosaurus* with a crest which suggests the casque of the living cassowary, and *Parasaurolophus* with a hornlike development of the nasals and premaxillaries, projecting backward and overhanging the neck. The shortness of the skull in *Parasaurolophus*, together with this peculiar curved projection, gives the head a goat- or antelopelike appearance.

The consensus of opinion among paleontologists is that the dinosaurs of this group were amphibious and frequented bayous, lagoons, and other shallow waters, where they fed on the luxuriant plant growth common to marshy places. Most of the specimens of crested hadrosaurs known to science have come to light recently in the Belly River formation (Upper Cretaceous), along the Red Deer River in southern Alberta, Canada. Prior to the finding of the Alberta dinosaurs only one hadrosaur was known—the *Thespesius*—a huge animal with a low-browed skull. Now, however, taken all in all, we probably know more about the duck-billed Predentata than any other group of dinosaurs. Not only have many nearly complete, articulated skeletons been found, but a mummified carcass from Wyoming, now in the American Museum of Natural History, even has impressions of much of the skin preserved—a rare occurrence in specimens of extinct animals. Professor Osborn made the following deductions to account for the preservation of this specimen:

That after a natural death, the body lay exposed to the sun for a long time undisturbed, perhaps upon the sand flat of a stream in the low-water stage; that the muscles and viscera had thus become completely dehydrated or desiccated by the sun, and that the epidermis, hardened and leathery, shrank around the limbs and was tightly drawn down along the bony surfaces. In this way a "dinosaur mummy" may have been formed. On the abdominal surfaces the epidermis was certainly drawn within the body cavity, while it was thrown into creases and folds along the sides of the body and on the arms, apparently owing to the shrinkage of the tissues within.

At the termination of the low-water season during which this process of desiccation took place, the "mummy" may have been caught in a sudden flood, carried down the stream, and rapidly buried in a bed of fine river sand intermingled with sufficient clayey elements to take a perfect cast of all of the epidermal markings before the epidermal tissues became softened under the solvent action of the water.

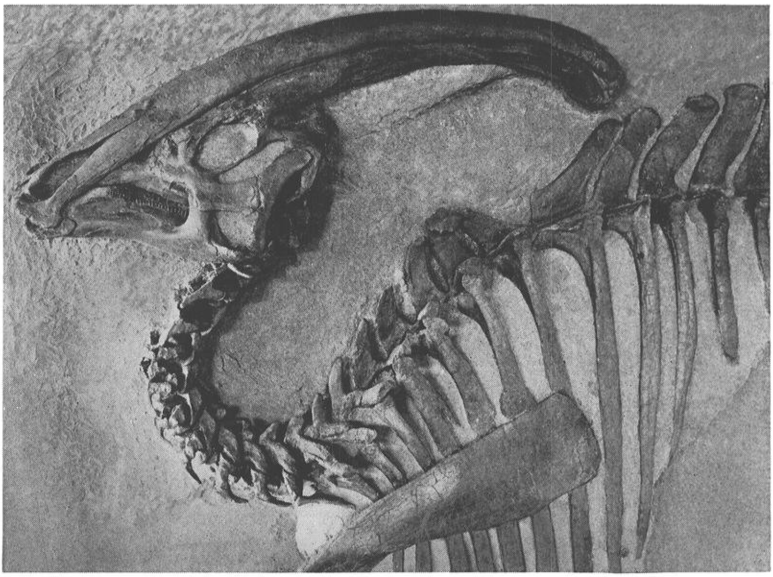
These skin impressions show that the animal was not covered with scales, but with dermal tubercles of small size and varied pattern. It was observed that the larger tubercles concentrated and became most numerous on those portions exposed to the sun, that is, on the outer side of the limbs, sides, and back. On the less exposed areas—the under side of the body and inner side of the legs—the smaller tubercles are more numerous, the larger ones being reduced to small, irregularly arranged patches. From analogy with living lizards and snakes, Osborn was led to believe that in life the animal's skin probably exhibited a distinct color pattern.

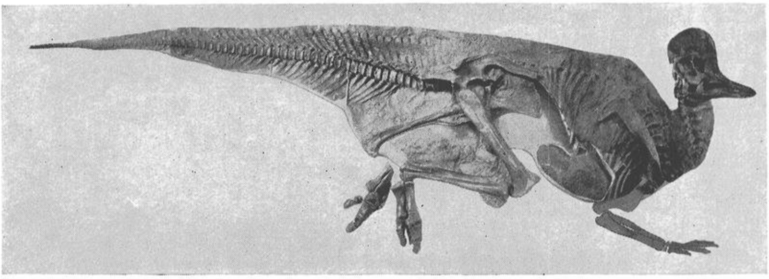
A specimen of the crested *Corythosaurus* from an older formation of the Cretaceous also has much of the skin impression present, showing a different pattern of skin from that of the *Thespesius*, for the tubercles over the sides, back, and tail are larger and without differentiation, and those over the abdomen are arranged in rows and are raised, oval, and limpetlike. More notable still, this specimen has preserved much of the outline of the body, which shows the neck to be slender, as shown in Plate 53. The following features which Mr. Barnum Brown observed in the Cretaceous rocks of the Red Deer River region, where he discovered *Corythosaurus*, led him to believe that the carcass had originally drifted on a beach: The bedding plane under the carcass was unusually irregular; *Unio* shells were everywhere present; and over the carcass three distinct layers of sandstone had been deposited in folds, the cross-bedded planes of which bore traces of water currents from different directions.

The story of the finding of a skeleton of a duck-billed dinosaur, as told by Brown, illustrates how specimens of unusual interest occasionally come to light by accident:

Mr. Oscar Hunter and a companion were riding through the badlands in central Montana when they came upon a partly exposed specimen, with backbone and ribs united in position. The large size of the bones caused some dis-

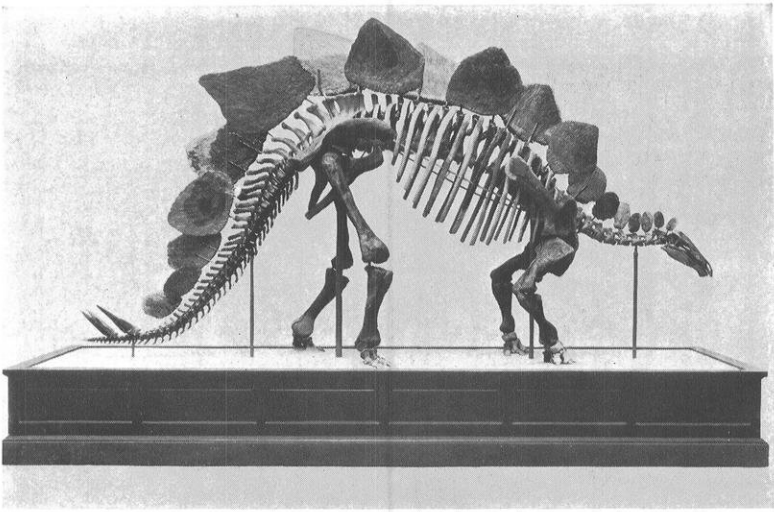
PLATE 53

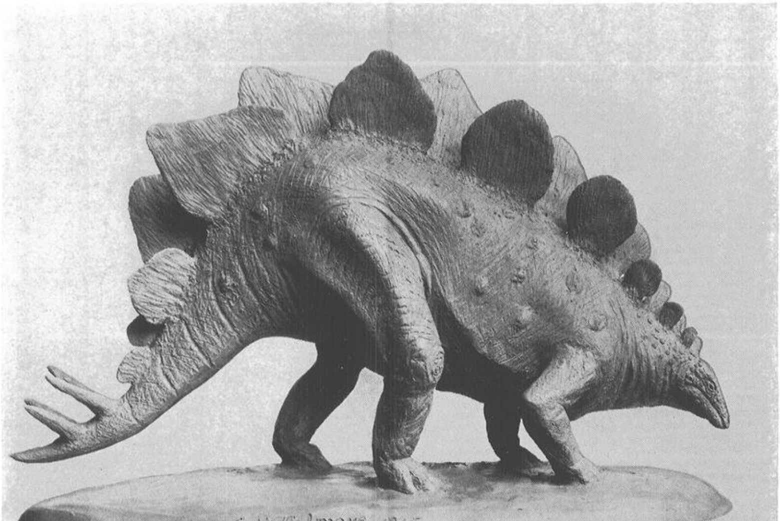




Upper: Skull and forward portion of the skeleton of the duck-billed dinosaur, *Parasaurolophus*. Photograph by W. A. Parks

Lower: Skeleton of the crested dinosaur, *Corythosaurus*, shown much as it lay in the ground. Skin impressions and outline of neck and much of body make this a unique specimen. Photograph by the American Museum of Natural History





Upper: Skeleton of *Stegosaurus stenops* in the National Museum
Lower: Restoration of *Stegosaurus*. Modeled by Charles W. Gilmore.
Note the small head

cussion between the ranchmen, and to settle the question Mr. Hunter dismounted and kicked off all the tops of the vertebrae and rib heads above ground, revealing their brittle nature and thereby proving that they were stone and not buffalo bones, as the other man contended. The proof was conclusive, but it was exasperating to subsequent collectors. Another ranchman heard of the find and knowing it to be valuable traded a six-shooter for an interest in it. Later, the American Museum of Natural History purchased the specimen and today it occupies an important place in the Museum's wonderful collection of extinct animals.

In those early days when the duck-billed dinosaurs flourished, they probably ranged all over North America and the northern portions of the Old World. Fragmentary specimens of their skeletons have been found along the Atlantic seaboard from New Jersey southward. The most perfect specimens, however, have come from the region which extends from the eastern flank of the Rocky Mountains in the northwestern United States, northward to the Red Deer River in Alberta, Canada.

Of all the extinct animals whose remains make up the fauna of the Morrison formation, none was more bizarre than the *Stegosaurus* (plated saurian, Plate 54), a name first given the beast by the late Professor Marsh in allusion to the large bony skin plates which adorn its back. *Triceratops* has the distinction of having the largest head of all the dinosaurs, while *Stegosaurus* has the smallest head in proportion to its whole bulk. As dinosaurs go, *Stegosaurus* was not a big animal, the largest skeleton known, now mounted in the Peabody Museum of Yale University, being a few inches under twenty feet in length. A specimen in the National Museum measures only fourteen feet from the tip of the nose to the tip of the tail. Relatively long hind limbs, a short, high-arched back, and a deep compressed body, all serve to exaggerate the prominence of the dermal plates that ornament the back.

This dermal armor is composed of two parallel rows of alternating erect bony plates that extend along the back from the base of the skull nearly to the end of the tail. The tail itself is armed with two pairs of pointed spikes or spines. The largest of the plates above the hips attained a length of more than two feet and an equal height. Nowhere did the plates exceed an inch in thickness except at their bases, which were widened and roughened (for the better attachment of the skin in which they were embedded) in contrast with their upper borders, which thinned out to a sharp edge. In life a horny skin undoubtedly covered these plates, thus increasing their size. Although the plates appear to have been of bone, in reality they had no contact or articulation with the internal skeleton but were strictly skin structures. In this respect they correspond precisely to the smaller and more or less flattened skin plates found on the backs of the crocodiles and alligators of today. Doubtless the primary purpose of this bony armor was for defense, an end which they served, probably not in any active way, but by giving *Stegosaurus* a forbidding appearance. It has been suggested that *Stegosaurus* when attacked drew its head and limbs under its body, like the armadillo or porcupine, and relied for protection upon its terrifying dorsal armature.

For many years following the discovery of the first *Stegosaurus* remains, scientists differed widely as to whether, in life, the armor plates formed one or two rows, whether they were arranged in pairs or alternated, and whether they stood erect or lay flat. A unique skeleton now in the National Museum finally settled the discussion. When it was found in the rock, most of the dermal plates were still in place—standing erect and alternating in two rows along the backbone, as shown in Plate 54. So important is this specimen as a criterion that it has been prepared for exhibition precisely as it lay in the ground, and it will long serve as a standard for interpreting and coordinating the scattered parts of others of its kind.

The incredibly small size of the brain indicates that *Stegosaurus* had a sluggish, stupid nature. It has been said that the smallest human brain possible to the continuance of life weighs a little over ten ounces; the smallest one capable of functioning as the seat of reason, two pounds. But a cast of the brain cavity of *Stegosaurus* displaces only fifty-six cubic centimeters of water, and a brain which would fill such a cavity to its capacity would weigh but two and a half ounces. The most remarkable feature of this creature's nervous system, however, was the great enlargement of the spinal cord in the sacral region (between the hips), whose mass filled a space twenty times as large as that occupied by the puny brain. It has been suggested that the movement of the hind limbs and tail were directed by nerves from this pelvic center. But at best, the intelligence of *Stegosaurus* was of the lowest order, probably just sufficient to direct the mere mechanical functions of life.

Many years ago when Professor Marsh first called attention to the enlargement of the spinal cord of this reptile in the sacral region, the newspapers of the time seized upon the idea and announced the discovery of an animal having a brain in its pelvis, and in a jesting way made much of it. To an anonymous writer of verse we are indebted for the following amusing explanation of the function of this "pelvic brain":

Behold the mighty Dinosaur,
Famous in prehistoric lore,
Not only for his weight and strength,
But for his intellectual length;
You will observe by these remains
The creature had two sets of brains—
One in his head (the usual place),
The other at his spinal base;
Thus he could reason a priori
As well as a posteriori;

No problems bothered him a bit;
He made both head and tail of it.
So wise he was, so wise and solemn,
Each thought filled just a spinal column.
If one brain found the pressure strong,
It passed a few ideas along;
If something slipped his forward mind
'Twas rescued by the one behind,
And if in error he was caught
He had a saving afterthought.
As he thought twice before he spoke,
He had no judgments to revoke,
For he could think without congestion,
Upon both sides of every question.
O, gaze upon this model beast,
Defunct ten million years at least.

Among the armored dinosaurs we may mention also another family of them known as the Nodosauridae, made up of the following formidable list of genera: *Nodosaurus*, *Palaeoscincus*, *Stegopelta*, *Euoplocephalus*, *Hierosaurus*, *Hoplitosaurus*, *Ankylosaurus*, *Panoplosaurus*, and *Scolosaurus*. Authorities differ as to the propriety of grouping all these genera in one family, but their fossil remains have certain characteristics in common which show them to be of closely related origin. All were protected in life by a coat of bony armor, consisting of plates, spines, and rounded ossicles that together formed a veritable coat of mail. So thoroughly did this armor protect some forms from external attack that Matthew dubbed them the "superdreadnaughts of the animal world." The Nodosauridae were low of stature as dinosaurs go, with wide bodies, heavy tails, stout legs, and low, flat-topped, triangular skulls, strikingly ornamented in some forms with bony, hornlike plates. One form at least has the tip of the tail enlarged into a great rounded mass of bone, known to collectors as the "tail club."

Unfortunately most of the Nodosauridae left a record of their lives only in the form of skulls disconnected from the rest of their skeletons, and scattered plates, spines and bones, so that except in one or two species we know little of the exact arrangement of those elements which go to make up the defensive armor. Paleontologists were therefore greatly interested when the veteran collector, Mr. Charles H. Sternberg, discovered in the famous Belly River beds, in Alberta, the partially articulated skeleton of a *Palaeoscincus*, which was the first specimen unearthed to preserve the original arrangement of the dermal armor on the forward half of the animal. Rows of thick, flat plates arranged in rings at the base of the skull must have protected the broad neck in life; similar plates, less regularly arranged, covered the back; and a row of stout spines, some more than a foot in length, extended along each flank. Between the rings of flat plates the skin was thickly studded with rounded ossicles, which must have made the animal's movements somewhat flexible. *Palaeoscincus* thus resembled the tortoise in its means of protection against carnivorous enemies ready to devour it. Protected from above by its bony plates, too broad and flat to roll over, when *Palaeoscincus* squatted on the ground with its legs drawn under its armor it was about as invulnerable from attack as is the tortoise when drawn into its shell. The extinct reptile was like the modern tortoise in another particular, also: its head had a broad, rounded horny beak with which it bit off the vegetation which formed its food.

In 1856, Dr. F. V. Hayden found in Montana a single small fossil tooth of peculiar pattern, which he sent to Dr. Joseph Leidy of Philadelphia, the foremost paleontologist of that time. Leidy pronounced it the tooth of an extinct lizard, to which he assigned the name *Troodon formosus*. In the years that followed, however, similar teeth came to light and were studied by paleontologists, among whom there arose differences of opinion as to what order of reptile had left them behind. Some contended that the teeth were those of dinosaurs and had no connection with the extinct lizards, while others adhered to Dr. Leidy's theory concerning them. So the matter stood until 1921, when Mr. George F. Sternberg found in Upper

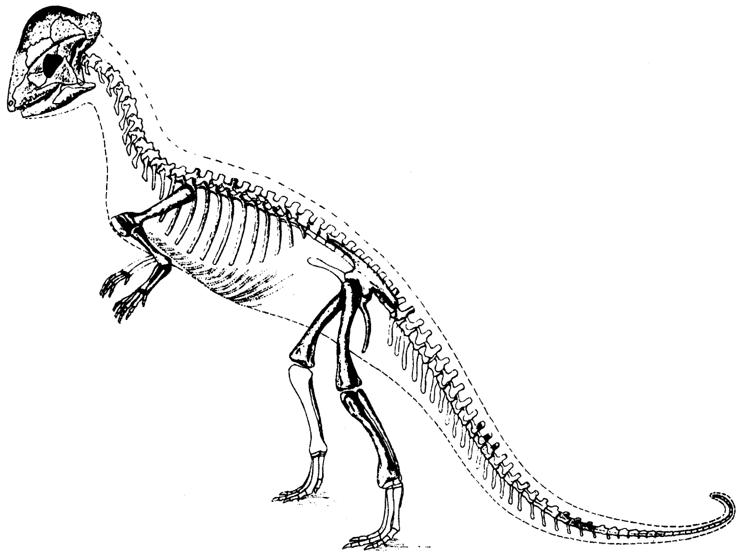


FIG. 67. Sketch restoration of the skeleton of *Troodon validus*

Cretaceous deposits in Alberta the partial skeleton of a reptile, including a complete skull in whose jaws were teeth of the *Troodon* pattern (Fig. 67). This skull, now in the University of Alberta Museum, Edmonton, bears unmistakable evidence that the animal of whom it was once a vital part belonged to that great group of dinosaurs we have just been discussing—the Predentata. This evidence is the predentate bone, joining the two lower jaw bones, a feature peculiar to this group. Thus nearly sixty-five years after the discovery of the first *Troodon* tooth, the true identity of the animal to which it belonged was revealed.

Further study of Sternberg's find shows that *Troodon* possessed distinct peculiarities of skeletal form, the most striking of which were the great bony dome forming the roof of the skull, and the highly ornate sculpturing of the external surface of the head. The dome is composed of solid bone some three inches in thickness, and no known dinosaur possessed its counterpart. The great disparity in size between the fore and hind limbs and the evidence of a tail of considerable length at once indicates that the animal habitually walked upon its hind legs only. *Troodon* was a comparatively small dinosaur, for when walking it could hardly have been more than twenty-two inches high at the hips, with a length over all of possibly six feet. In 1902 the late Dr. L. M. Lambe, of the Canadian Geological Survey, described a thickened dome of a fossil skull whose reptile owner he designated by the name *Stegoceras validus*. When the complete skull of *Troodon* came to light, however, in 1921, *Stegoceras* and *Troodon* were found to be one and the same; and as the name *Troodon* had been in use since 1856 (when it was supposed to apply to an extinct lizard), it took precedence over the other, and *Stegoceras* became a synonym of *Troodon*. But the incidents, as here related, leading up to the final correct identification of the fossil remains of this small armored reptile, serve to show how paleontologists, after years of patient exploration and study, eventually succeed in wresting from the earth a fairly complete knowledge of the animal life which formerly inhabited it.

In 1822, in southeastern England, Mrs. Mantell, wife of the famous English naturalist of that name, found the tooth of a dinosaur of still another species. Her husband did not at first recognize the tooth's affinities; so he sent it to Cuvier, in Paris, who at once pronounced it to be the upper incisor of a rhinoceros. Dissatisfied with Cuvier's diagnosis, Doctor Mantell submitted the tooth to other authorities of his day, who thought it might belong to a big fish or a mammal, although they considered it of too little interest to waste much thought on it. Mantell, however, convinced that the tooth bore evidence of the existence of a fossil reptile then unknown to science, continued his search for further evidence to bear out his theory; and after nearly a quarter of a century the evidence appeared in the form of portions of a jaw with some teeth still attached.

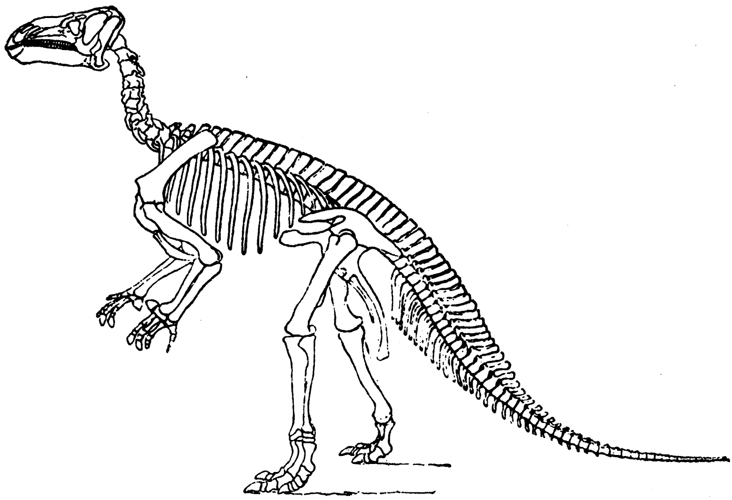


FIG. 68. Skeleton of *Iguanodon bernissartensis.* From the ground to the top of the head as the animal is posed is about fourteen feet. After Abel

This jaw settled the question of the origin of the tooth, and scientists announced the discovery of a new species of herbivorous dinosaur to which they gave the name *Iguanodon* (Fig. 68), from the resemblance of its teeth to those of the living lizard *Iguana.* Through the recovery in subsequent years of other parts of *Iguanodon,* we have learned much about the reptile.

More than fifty years ago, in 1878, an extraordinary find in a coal mine at Bernissart, Belgium, brought to light some twenty-three more or less complete *Iguanodon* skeletons. These were found in an old fissure which had become filled with rocks of Cretaceous age, and which, when open, must have served as a trap into which the animals fell. There the skeletons remained, to be slowly covered by the deposits of long geologic ages, and safely hidden from man until discovered by the coal miners. This find, together with the previous ones in England, made *Iguanodon* the species of dinosaur most familiar to the people of England and western Europe.

Many curious errors have been made by paleontologists in the course of their studies of incomplete and disarticulated skeletons. No fossils have proved more troublesome in this respect than those of the dinosaurs, due to features of their skeletons which have no counterpart or even close resemblance in living animals. The story is told that among the first fragmentary remains of *Iguanodon* to be discovered was a certain pointed bone not unlike a small horn, which seemed to belong on the nose, as it resembled the horn of a rhinoceros. Later, the discovery of other specimens of *Iguanodon* revealed that this bone was the reptile's thumb, which caused Lucas to observe, "To put his thumb to his nose was really an undignified gesture for so ancient an animal."

In making a restoration of this reptile for the exhibit of extinct creatures at the Crystal Palace, London, Waterhouse Hawkins drew on his artistic license rather than on his knowledge, and so provided *Iguanodon* with five toes. When his attention was called to the error by Professor Owen, who pointed out that the animal had only three, Hawkins is said to have replied: "If they were corns I would be glad to remove them, but since they are toes they must remain."

But why did all of this great tribe of animals perish at the close of the Mesozoic? This is a question often asked and one that the paleontologist can not yet positively answer. One student has advanced as a cause internecine warfare among the dinosaurs; another, that the smaller mammals sucked their eggs and thus finally brought about their extermination; and a third, that epidemic diseases transmitted by insect pests swept them away, as it has many of the large game animals in certain sections of Africa today. The most probable solution, however, is that, being highly specialized cold-blooded animals adapted only to certain modes of life and a particular kind of environment, the dinosaurs were unable to adapt themselves to the change which gradually came about in that environment and consequently perished. We now know that toward the close of the Age of Reptiles the region in which the dinosaurs lived underwent a great change in its physical features, which apparently, in its turn, brought about changes in climate. Dr. W. D. Matthew, in *Natural History*, has given the clearest exposition ever presented of the results of these changes:

Its early stages are shown in the slow rising of great parts of the flooded continental interior above sea level, turning them into delta and coastal swamp and then into plains and upland, while great stretches of the ancient land were more violently uplifted into high mountain ranges, whence the rivers brought ever increasing floods of sand and mud to spread over the plains and marshes and built out deltas far into the shallow seas, burying old lagoons and flood plains of the Cretaceous under great thicknesses of sediment, filling up and drying out swamps and changing the environment in which the dinosaurs lived. More important probably was the change of climate which seems to have been going on at the same time that these geological changes were taking place. While on the one hand we find in the Cretaceous formations as far north as Greenland a fossil flora of warm temperate type, on the other we find evidences at the beginning of the Age of Mammals of glaciers existing as far south as southern Colorado. The evidence is very scattered and fragmentary, and scientific opinions vary a good deal as to just how it should be interpreted, but it would seem that a great change in climate must have been in progress at that time, from moist, subtropical, and warm temperate conditions prevailing over all the world, to climatic contrasts much more like those that exist today. Such changes would necessarily sweep away the ancient swamps and forests and alter the entire character of the vegetation almost everywhere. The dinosaurs, highly specialized and adapted to the old conditions, unable to withstand the cold and too bulky to seek refuge in caves or burrows, would disappear and become wholly extinct.

CHAPTER III

RULERS OF THE ANCIENT SEAS

THE dinosaurs in their day dominated the life of the land. At the same time the ancient seas also had their reptilian rulers, many of which, though not equaling the stature of some of their land-living relatives, attained formidable size. A few were of fearsome aspect. I refer especially to the three great reptilian groups known as the ichthyosaurs, or "fish lizards"; mosasaurs, or "sea lizards"; and plesiosaurs, or "long-necked lizards." Strange as it may seem, the fossil evidence goes to show that all of these sea-living reptiles evolved from a land-living ancestry. So far as the ichthyosaurs are concerned, the evidence on this point is especially conclusive.

The era in which the ichthyosaurs gradually abandoned their life on dry land and embarked on their long sea-roving career was an extremely ancient one. In the Triassic period, the earliest known ancestral ichthyosaurs had lost much of their terrestrial form and were fitting themselves for an exclusively aquatic existence. Already the limbs had been modified from the bent form of the land animal into broad, flattened paddles; the distinction between forearms and wrists had passed; and numerous additional joints had been added to the digits. All these features of the limbs became more highly modified in succeeding geologic ages until, near the close of the "Age of Reptiles," the ichthyosaurs had developed the most efficient swimming organs then known in the whole animal kingdom. Varying in length from two to thirty-five feet, with large eyes, a long, tapering snout filled with sharply pointed teeth, a short neck, a complete equipment of paddles and fins, and a body not unlike that of a living porpoise, the ichthyosaur had lost even the most remote resemblance to its land-living forebears (Plate 55).

Our knowledge of *Ichthyosaurus* (a name much jested with) dates back to its discovery by Sir Everard Home in the cliffs of Lyme Regis, England, between 1814 and 1819. Its fossil remains had, however, attracted attention even earlier in the publication by Professor Scheüchzer, of the University of Altorf, Bavaria, of a Latin work entitled *Querulae Piscium*, or *Complaints of the Fishes*, in which a pictured ichthyosaurian vertebra was referred to as "the accursed race destroyed by the flood." Traces of ichthyosaurian skin were found as early as 1836; but it remained for Herr Bernhard Hauff, working in the famous deposits in Holzmaden at the foot of the Swabian Alps, to discover specimens showing the contour of the whole body as well as that of the paddle and fins, thus revealing the actual appearance in life of these reptiles. The cast of the skin made by nature is as thin as tissue paper, but so perfectly are the epidermal cells reproduced that in microscopic preparations they exhibit pigment spots, traces of dermal glands, and underlying muscle striations. Scales appear to be missing. In order to uncover and preserve the delicate skin casts, Herr Hauff has developed a special technique, by which, working under a thin layer of water, he scrapes off the enveloping matrix with a scalpel. Before the finding of these specimens the presence of a fin on the back was unsuspected, but Sir Richard Owen shrewdly conjectured the existence of a tail fin from the downward trend of the distal vertebrae of the tail in many specimens long before the rocks yielded up the proof.

Some of the earlier naturalists held the opinion that the ichthyosaurs laid their eggs on the shore, like sea turtles, but, as they had paddles far more abbreviated than those of the land-going seals or walruses, it would seem that they must have been helpless on shore. Because of this physical handicap it is now thought that they gradually abandoned the habit of returning to the shore to lay their eggs and developed a viviparity that enabled them to live anywhere in the ocean entirely independent of the shore in the production of their young. These deductions are based on the finding of young or embryo skeletons within the body of the mother, one of which has been described by Professor Osborn:

> This one, our "mother ichthyosaur," is believed to be the most perfect of its kind in the world. It belongs to the species named *Ichthyosaurus quadriscissus*, in reference to the four incisions on the back of certain bones of the paddle. It is a form common enough in Germany, but our skeleton is rendered exceptional because of the fact that it contains seven well-preserved young ichthyosaurs partly within and partly floating out of the body cavity. The mother is over nine feet long, the skull measuring eighteen inches. In the young the skulls measure nine and a half inches and are especially well developed, as is usually the case with animals which are precocious at birth. The little strings of vertebrae composing the backbones, as well as parts of the miniature paddles, can readily be seen. The fact that the skeletons are considerably scattered is quite consistent with the supposition that the body wall of the mother was partly ruptured after decomposition and that the small young were more or less scattered by water currents and by the various forms of life which would naturally prey upon them.

While the European deposits of the Jurassic period are most prolific in kinds and numbers of ichthyosaurs, the American deposits can boast of but a single genus, described many years ago by Prof. O. C. Marsh under the name *Baptanodon*, which has since been shown to be the same as the English *Ophthalmosaurus*. This genus was originally thought to be toothless, but later discoveries proved that the long, tapering jaws were filled with numerous sharply pointed teeth. Some of the skulls of reptiles of this genus measure as much as three and one-half feet in length (Fig. 69). So far as known, its general form does not differ greatly from that of its better-known European relatives. The limbs, however, are quite distinctive, the paddles being composed of a great number of flattened, bony disks that do not articulate with one another but are held together by intervening pads of cartilage, whereas in other genera of ichthyosaurs these bones articulate on all sides (Fig. 70). The paddles of the ichthyosaurs have long been a puzzle to naturalists, the difficulty being to

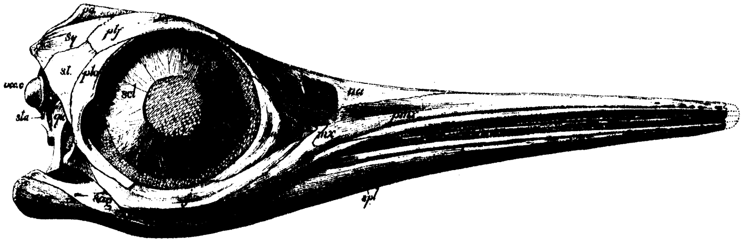


FIG. 69. Skull of fish lizard, *Ophthalmosaurus*, from Wyoming, three and one-half feet long

understand the origin of the increased number of digits as well as the great number of bones in those digits. It is a well-known fact that in no other animals higher in the scale than fishes are there ever more than five toes or fingers, the same number with which air-breathing animals began; but the ichthyosaurs sometimes have as many as ten on each hand and foot, with an increased number of joints in each. This increase in finger and toe bones, or hyperphalangy as it is called, is one of the adaptive changes whereby the walking type of foot and hand becomes a swimming paddle. It is now thought to be a sort of vegetative reproduction whereby the margins and ends of the flippers, hardened by cartilage, become broken by use into nodules, each of which finally becomes ossified.

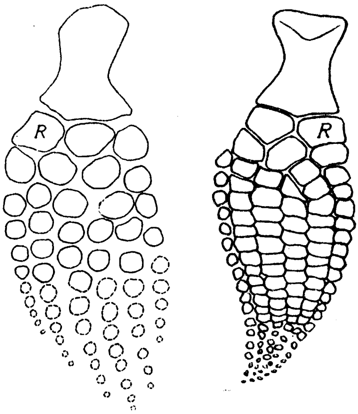


FIG. 70. Paddles of *Ophthalmosaurus* (left) and of *Ichthyosaurus*. Bones of latter articulate on all sides

The American Jurassic ichthyosaurs betray a peculiarity in their occurrence in that their skeletons are always found inclosed in very hard nodular concretions with the tips of the beak, tail, and paddles protruding into the soft shaly strata in which the concretions lie embedded. For this reason the protruding portions are rarely found well preserved. In my experience of several field seasons in the formation in which ichthyosaur remains are most abundant, I have never seen an exception to this concretionary occurrence. It would seem that the skeleton was the nucleus around which the concretion formed, but for some reason the extremities were never included within the rocky mass.

About seventy-five years ago an ichthyosaur christened *Mixosaurus* was discovered in rocks of the Triassic period, a geologic period much earlier than any from which these marine reptiles had previously been unearthed. Baur's study of these reptiles convinced him that the ichthyosaurs had descended from land animals and not from the fishes as had previously been supposed. The lower-limb bones proved to be much longer than those of the later ichthyosaurs, resembling in this the corresponding bones of land animals. More recently many remains of Triassic ichthyosaurs found in California and Nevada have become the object of exhaustive study by Dr. J. C. Merriam, who has demonstrated many of the stages of evolution between the earliest and latest forms in their progressive adaptation to water life and has cleared the subject of all doubt.

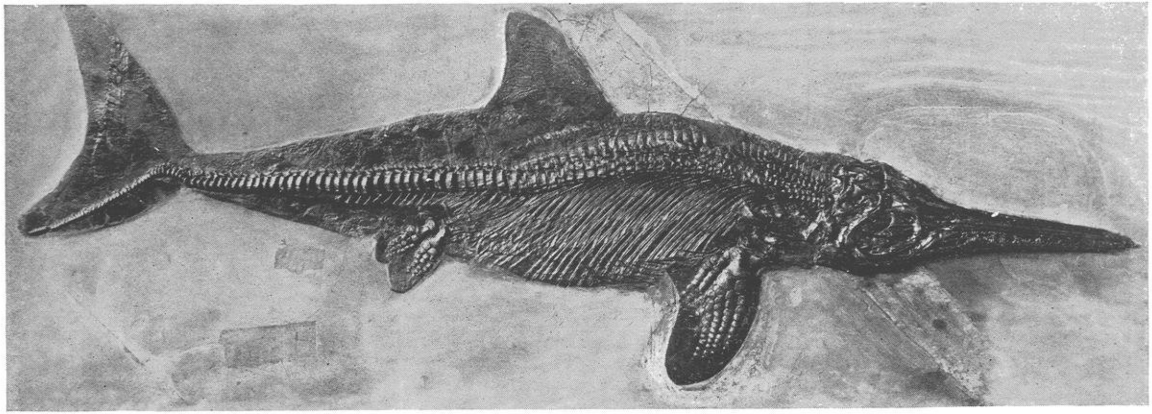
The ichthyosaurs had a wide distribution, spreading to the Arctic, and over Europe, Asia, New Zealand, North America, and South America. Their reign, so far as known from their fossil remains, began in the Triassic and extended through the Jurassic and into the Upper Cretaceous, when they became extinct. If we may judge by the abundance of their skeletons they reached their maximum development in the Jurassic, and from then on declined both in numbers and in kinds.

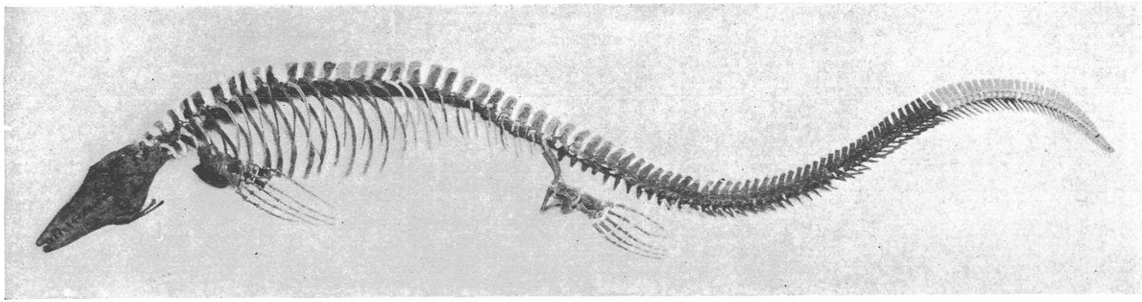
REPTILES

In the western part of Kansas and especially along the Smoky Hill River and its drainage, lie great beds of chalk in which occur the fossil remains of marine reptiles, turtles, and fishes, as well as those of flying reptiles and toothed birds. This region has long been classic ground to paleontologists, especially to those interested in that great group of marine reptiles known as the mosasaurs. Nowhere else in the world, perhaps, do the fossil remains of this group occur in such abundance and excellence of preservation. Here have been found nearly complete skeletons with all the bones preserved in relative sequence; imprints of their bodies, left in the soft ooze before decomposition had set in; impressions of their scaly skin; and even some of the color markings of the living reptile. Literally speaking, hundreds of skeletons have been collected from these deposits, and yet, after more than sixty years of almost constant exploration, they still continue to yield valuable specimens.

The mosasaurs were swimming lizards, overgrown but distant relatives of the *Varanus* or *Monitor*, living today in Asia and Africa. They had slender bodies, with long, flexible tails and with the limbs modified into paddles (Plate 55). The skull was long, with a pointed snout, and the jaws bristled with numerous sharply pointed teeth well adapted to the seizing of an elusive prey, for the mosasaurs doubtless fed upon fish, if not upon the young of their own kind.

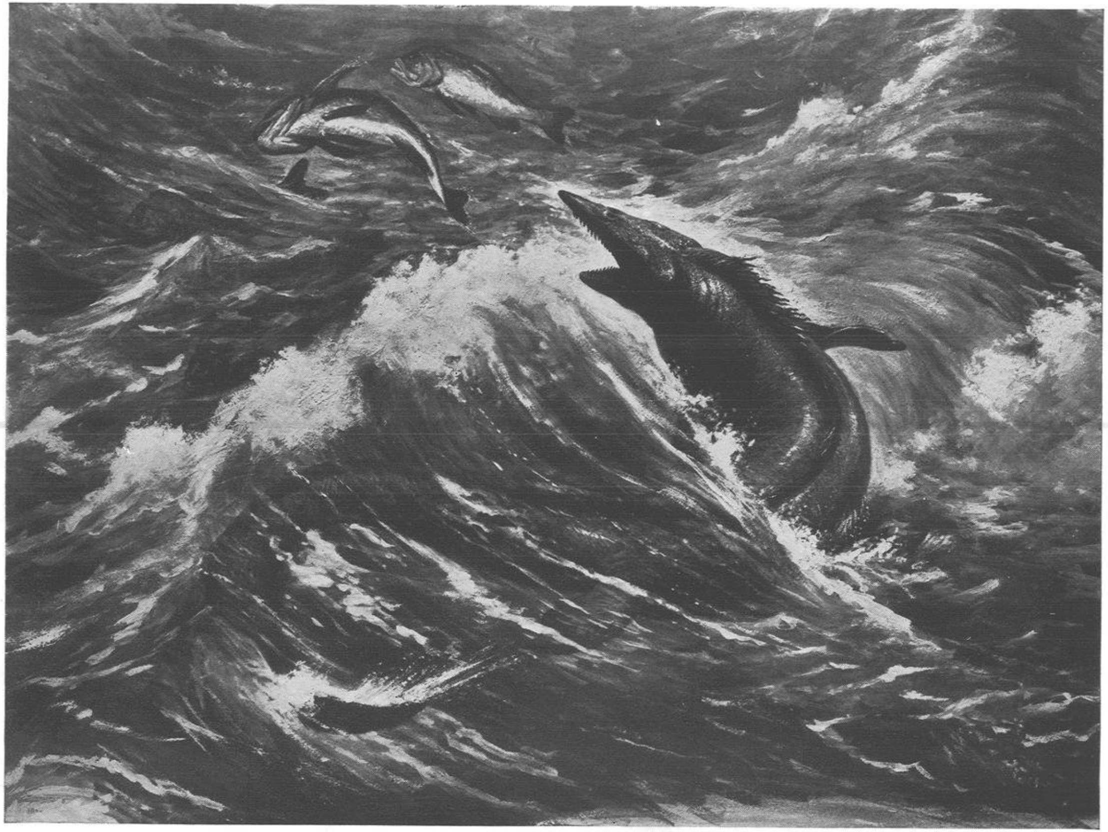
The first mosasaur to bear the name contributed to the history of nations as well as to that of science. The skeleton came to light in 1780 on the banks of the River Meuse, near Maestricht, the Netherlands. In one of the subterranean galleries of the quarries of St. Peter's Mount, some five hundred paces from the entrance and ninety feet below the surface, the quarrymen working under M. Faujas de Font, Commissary for Sciences of the French Army of the North, exposed part of the skull in a block of stone which they were engaged in detaching. They





Upper: A fish lizard, *Ichthyosaurus quadricissus*, showing tail, fin, and body outlines preserved in the rock. Specimen in the Carnegie Museum, Pittsburgh

Lower: Mounted skeleton of a twenty-five-foot sea lizard, *Tylosaurus*, from Kansas. Shown as mounted in the National Museum



Restoration of the giant sea lizard, *Tylosaurus*. From the painting by Charles R. Knight. Photograph by the American Museum of Natural History suspended work at once and notified Doctor Hofmann, surgeon of the forces, who for years had been collecting fossils at this quarry. Arriving on the spot, Doctor Hofmann recognized the signs of a magnificent specimen. He directed the operations of the men so that the block was worked out without injury to the skeleton, and then with his own hands cleaned away the yielding matrix, exposing the jaws and teeth which have been the subject of so many drawings, descriptions, and discussions. This fine specimen, which Hofmann added with so much satisfaction to his collection, became to him, however, a source of chagrin. Doctor Goddin, one of the canons of Maestricht, who owned the land beneath which the quarry was situated, pleaded certain feudal rights in support of his claim to the specimen when its fame reached his ears. Hofmann resisted and the canon went to law. The whole chapter supported their reverend brother; and the decree went against the poor surgeon, who lost not only his specimen, but his money, since he was made to pay the costs of the action. Doctor Goddin, leaving all remorse to the judges who had pronounced the iniquitous sentence, became the happy possessor of this unique object. But justice, though tardy, came at last. When the French bombarded the town they gave directions to spare the suburb where the famous fossil reposed. Shrewdly suspecting the reason for such special favor to his residence, the canon had the specimen removed and hidden in a vault. After the capitulation, the much prized fossil was not to be found, and it is said six hundred bottles of wine were offered for its discovery. So tempting was this offer that in a short time half a dozen grenadiers appeared with the specimen. The French transmitted it at once to the Jardin des Plantes at Paris, where it still forms one of the most interesting objects in that magnificent collection. This specimen furnished the type for the genus *Mosasaurus*, a name supplied by Conybeare in 1828.

The mosasaurian reptiles in North America first received attention about the year 1820, when Major O'Fallon, an Indian agent, found a skeleton near the Great Bend of the Missouri River and took it to his home in St. Louis as a curiosity. It so happened that Prince Maximilian of Wied, on his travels through the Middle West, saw the fossil, secured it, and took it to the Netherlands, where he presented it to the Museum of Haarlem. Here Goldfuss described it under the name *Mosasaurus maximiliani*. For more than thirty years this species remained practically forgotten, but with the revival of interest in these reptiles brought about by the researches of Leidy, Cope, and Marsh, its eventful history was finally revealed.

Some estimates attribute more than fifty species of mosasaurs to North America alone, and double that number to the entire world, for these reptiles were cosmopolitan in their distribution. However, many of the hundred will probably fall before the test of critical examination.

The mosasaurs, also, were fighters, to judge from the many broken and healed bones among the specimens, injuries doubtless received from others of their own kind. Carbonized impressions of their skin show their bodies to have been covered with overlapping scales, resembling those of the living monitors. These scales were very small, however, as Williston points out, a mosasaur twenty feet long having scales of the same size as a monitor six feet long. Fossilized stomach contents containing fishbones and scales furnish further proof, if that be needed, of their fish-eating habits. In this connection attention is called to a remarkable new type of mosasaur from the Cretaceous of Alabama, which I have described but which as yet is known only from very fragmentary remains. The unusual feature of this animal lies in its teeth, which, instead of having the customary elongated form with pointed tips, are nearly spherical, as shown in Figure 71. Their shape suggested the term *Globidens* as a particularly appropriate name for this animal. Teeth of this character could only have been used for crushing and would indicate for this animal habits in life totally different from those hitherto supposed. *Globidens* must have fed upon shellfish, crustaceans or some other hard-shelled sea animal, whose

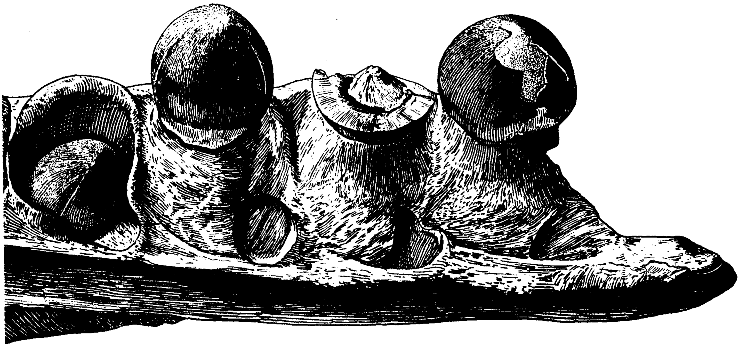


FIG. 71. Teeth of the sea lizard, *Globidens alabamensis*, suggestive of its shellfish diet

tough outer covering had to be crushed before the edible parts within could be got at, and its globular teeth were well adapted to such a purpose. Shortly after the discovery of this American form, Dollo, of Belgium, described a second species, from that country.

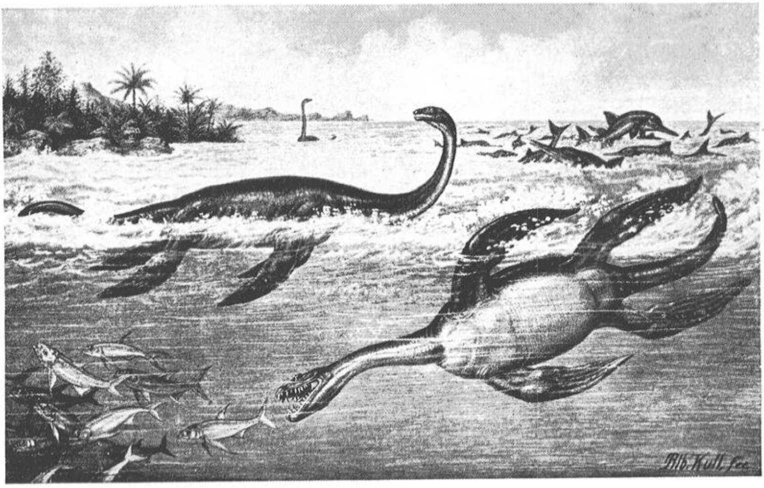
Scientific men have held many and varied opinions as to the relationships of the mosasaurs, but today most authorities agree that their affinities lie with the lizards, an idea first suggested by Peter Camper but which has taken a century to prove.

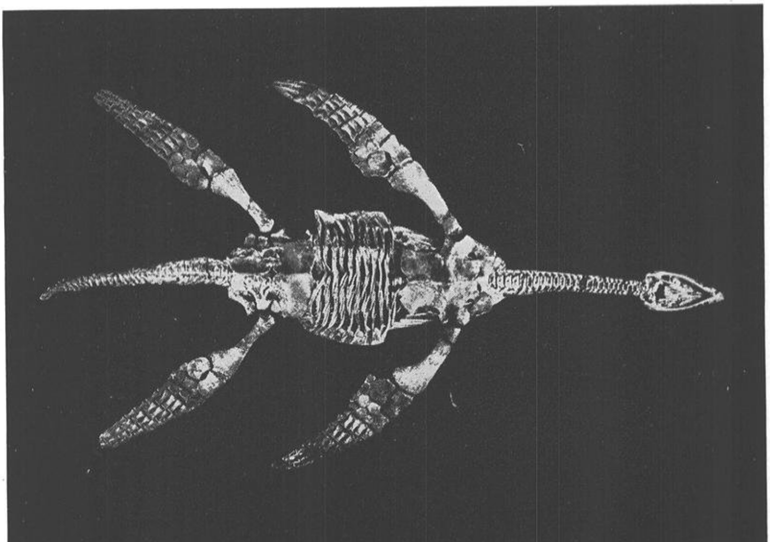
A year or two ago the press of this country carried an item announcing that a great reptile, probably a *Plesiosaurus*, had been seen swimming about in the inland waters of Argentina. Specialists were interviewed, and the organization of an expedition to search for the monster was reported, all of which could but afford amusement to those who knew that the last plesiosaurian reptile passed out of existence millions upon millions of years ago. It would indeed have been a miracle for a lone survivor of this great order of reptiles to have persisted until the present time.

In the popular conception a plesiosaur appears as a huge, short-bodied, swimming reptile possessed of an especially long, snakelike neck and a ferocious-looking head (Plate 57). Some plesiosaurs actually fulfill these requirements, at least sufficiently to justify the oft-quoted simile of an eloquent professor that "the *Plesiosaurus* might be compared to a serpent threaded through the shell of a turtle." Many fabulous tales, both grave and gay, have been told of the plesiosaurs as well as of the ichthyosaurs. The early clergy were wont to use them as evidence of the great world catastrophe of Biblical history and the German student sings of them to the tune of the Lorelei.

Though we find plesiosaur remains distributed most widely, we know much less about them as a group than about either the ichthyosaurs or mosasaurs. The Sauropterygia, as this group is designated, include the largest aquatic reptiles that ever existed, some reaching a length of perhaps fifty feet, of which the neck accounted for twenty-five. As in the ichthyosaurs, the limbs were modified into swimming paddles, the largest reaching a length of six feet. The digits of certain of these paddles have a greater number of segments—sometimes as many as twenty-four—than is known in any other air-breathing vertebrate animal. The forms with the longest necks have up to seventy-six vertebrae in the cervical region. Measurements of one of these animals, known as *Elasmosaurus*, show these proportions: Head, two feet long; neck, twenty-three feet; body, nine feet; and tail, about seven feet. A famous paleontologist once described this as an animal with its head placed upon its tail, a bit of transposition that he was never allowed to forget. A rival made the very pertinent suggestion that it should have been named *Streptosaurus* (reversed reptile), much to the annoyance of the original describer.

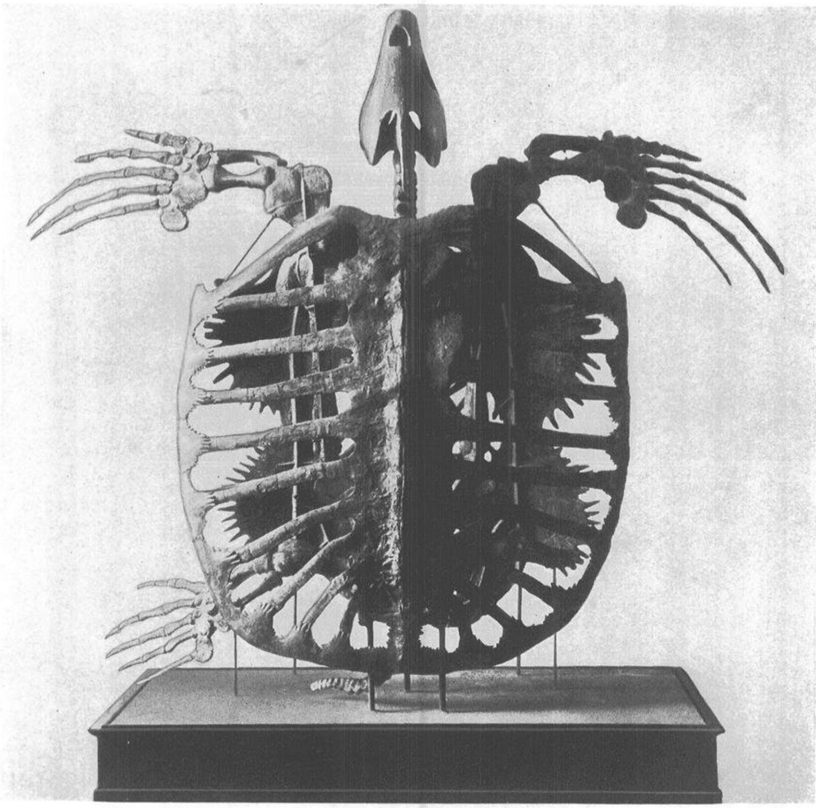
Brachauchenius, on the other hand, a short-necked





Upper: Restoration of a "long-necked lizard," plesiosaurus
Lower: Skeleton of *Plesiosaurus*, seen from under side. After Fraas

PLATE 58



Mounted skeleton of fossil turtle, *Archelon*, in the Peabody Museum of Natural History, Yale University. Specimen is more than twelve feet long, with estimated weight of three tons plesiosaur, has a head two and one-half feet, a neck less than two feet, and a body five feet in length. The tail measurement in this form is as yet unknown. As with the ichthyosaurs, impressions found of the skin show it to have been smooth and bare. A fleshy dilation of the tail described by Dames may represent a steering apparatus, for the swimming was done with the paddles. The sharp-pointed, flaring teeth suggest that these plesiosaurs may have lived upon a quick-moving prey. From the proportions of the body and its analogy with that of turtles, it is supposed they were slow swimmers and usually stayed near the bottom, coming up to their prey stealthily from beneath instead of pursuing it through the water like the swift-swimming ichthyosaur and mosasaur. On the other hand, numerous specimens have been found having a quantity, sometimes as much as a peck, of small pebbles (called gastroliths) within the body cavity, which, as in some of the birds, probably aided in digestion. If so, we must suppose that the diet of the plesiosaurs contained hard parts requiring crushing. This evidence has led to a supposition that they were the scavengers of the ancient seas and fed upon almost anything that came their way—whether living or dead—and that they accepted with equal readiness carrion, squidlike baculites, and belemnites, whose remains abound in these same formations.

Many plesiosaur skeletons, crushed and flattened, but splendidly preserved, have come from the cliffs of Lyme Regis and Whitby, in England, and from the great slate quarries in Holzmaden, Württemberg. The clay pits near Peterborough, England, have likewise yielded a large series. Fragmentary remains have been described from India, South America, Australia, and New Zealand, while the Chalk beds of western Kansas and the Pierre shales of the Rocky Mountain region have also produced their quota of specimens, some of great scientific interest and a few exceptionally well preserved.

The plesiosaurs began their career, so far as we know, near the close of the Triassic period and continued through the Jurassic, becoming extinct at the close of the Cretaceous. We do not know the reason for their extinction.

In the same Cretaceous seas with the mosasaurs and plesiosaurs there lived also some large swimming turtles, one genus of which far surpassed in size any now extant. *Archelon*, as Wieland called this animal, was the giant of all turtles (Plate 58). The skull was a yard long and had a strongly hooked beak resembling that of a bird of prey. The shell measured more than twelve feet. The feet were modified into great swimming flippers. Although we do not actually know the weight of this great swimmer in life, Williston has estimated it at not less than three tons. A mounted skeleton forms one of the outstanding exhibits of the Peabody Museum of Natural History of Yale University. Large and ferocious as its appearance would seem to indicate, *Archelon* did not escape its enemies unscathed; for the Yale specimen lost its right-hand flipper when still a young animal, as evidenced by the fact that what remains of the limb was arrested in growth, probably because of its disuse. Many living sea turtles are found with flippers mutilated by predacious fishes and sharks, so that as the Cretaceous seas nourished a similar population, the loss of the hind flipper of *Archelon* is not a mystery.

CHAPTER IV

ANCIENT FLYING REPTILES

MASTERS of the land and sea, the reptiles had to conquer only the air. And conquer it they did. Millions and millions of years before man even appeared on earth to dream his dreams of imitating the birds with mechanical wings, the reptiles produced giant living airplanes with wings spreading twenty-five feet from tip to tip—the largest flying creatures ever known. The story of these pterodactyls, which nature endowed with the power of flight, can be read only in the ancient rocks, for they flourished in the "Age of Reptiles" and came to an end with it.

The first notice of a pterodactyl appeared in 1784, though the describer, Collini, Director of the Elector-Palatine Museum at Mannheim, had no idea that the skeleton under discussion was that of a flying reptile. He observed that it was neither a bird nor a bat and so came to the conclusion that it was an aquatic animal. In 1801, however, Baron Cuvier of France correctly classified it as a winged reptile, though some of his colleagues still insisted that it was either a bat, a bird, or a flying fish. The key which unlocked for Cuvier the saurian affinities of the pterodactyl seems to have been a certain skull bone, known as the quadrate. In the skulls of birds the quadrate has become firmly fused with the adjacent bones, but in reptiles it is more or less distinct. Cuvier in his famous work, *Ossemens fossiles*, sums up his study of this specimen as follows:

Behold an animal, which in its osteology, from its teeth to the end of its claws, offers all the characters of saurians. . . . But it was, at the same time, an animal provided with the means of flight; one which when stationary could not have made much use of its anterior extremities and may even have kept them folded, as birds keep their wings; which nevertheless might use its small anterior fingers to suspend itself from the branches of trees, but must have rested on its hind feet, like the birds again; and also, like them, must have carried its neck suberect and curved backwards, so that its enormous head should not disturb its equilibrium.

The light-yellow lithographic limestone, which has furnished most of the European specimens of the pterodactyl, contains also a multitude of other fossils—such as king crabs, sea urchins, and marine shells—which indicate that the deposit was laid down in the sea. Remains of flying reptiles in North America were first discovered in the Chalk beds of Kansas in 1870. Since then many specimens have come to light, the Peabody Museum of Yale University alone boasting of some six hundred. Many varieties exist, ranging in size from flyers no larger than a sparrow to veritable giants.

The wings of the pterodactyl were not feathered, like bird wings, but covered with a thin, smooth membrane like those of a bat. They differed from both bird and bat wings in being stretched upon the greatly lengthened fourth finger only, whereas the other digits, also, form part of the wing structure in the flying creatures of our day. In general appearance, however, the pterodactyls resembled the birds to a remarkable degree, their whole organism being adapted to locomotion through the air. Like the birds they presented an infinite variety of types. The length of the head varied from less than an inch, as in the small Solenhofen *Pterodactylus brevirostris*, to nearly four feet, as in the American *Pteranodon ingens*. One type had the head depressed in front, with a flattened beak resembling a duck's, while a second developed a long, slender, daggerlike beak tapering to a point, as in the heron. A third had a square or oblique skull, while in a fourth the skull was rounded at the back, near the brain; and a fifth developed a large crest, which projected backward, overhanging the neck. Most types had round, sharply pointed teeth in their jaws; though a few, like the birds of today, were toothless. The neck varied from slender and cranelike to strong and eaglelike, and the tail from short and inconspicuous to long and slender; but the back was invariably short.

Because of their large orbits, inclosed in a bony ring of sclerotic plates, Cuvier believed that pterodactyls were of nocturnal habits. Powerful flight muscles are suggested by a strong keel on the breast bone, similar to that which serves in birds to attach such muscles. This similarity does not indicate, however, a relationship with birds.

Whether pterodactyls were cold-blooded or warm-blooded has long been debated. Since they had no feathers some scientists have argued that they could not have been warm-blooded; while others have contended that, had they been cold-blooded, they could not have generated the great energy required for flying.

At one time it was believed that pterodactyls differed from birds in the absence of teeth, but this distinction holds good only in comparing them with modern birds. If we go back to Mesozoic time we find birds like *Hesperornis*, the great diver of the Cretaceous, and *Archaeopteryx*, of the still older Jurassic, which had teeth in their jaws.

We first find pterodactyls in Jurassic rocks, where they appear full-fledged, indicating that they must already have had a long evolutionary history of which we know nothing. Between the Jurassic forms and those of the late Cretaceous, in which period they passed out of existence, there is a wide gap, so that we know scarcely more of their later than of their earlier evolutionary development.

The specimens found in the lithographic-stone quarries of Bavaria have supplied most of our information concerning these flying creatures. Here conditions were so favorable to their preservation that skeletons have been found intact, with impressions in the rock of the wing membrane itself. Sometimes this membrane is stretched to its full reach, giving the entire contour of the wings (Plate 59). A specimen of *Rhamphorhynchus* in the National Museum shows the impressions of the partially folded wings, and the extremity of the tail is extended vertically into a leaf-shaped appendage which, like the tail of a boy's kite, may well have acted as a rudder in the flight of the animal.

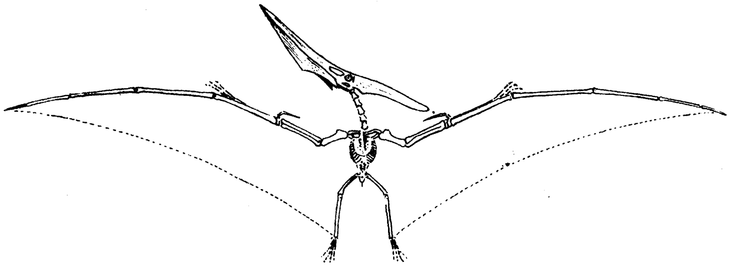


FIG. 72. Restored skeleton of *Pteranodon* measuring twenty-five feet from wing tip to wing tip. After Eaton

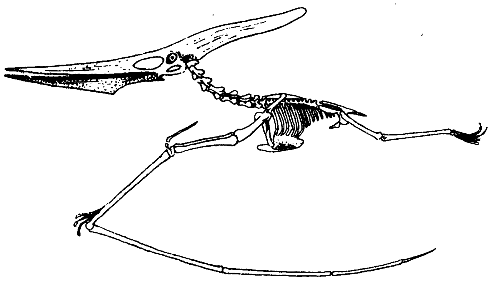
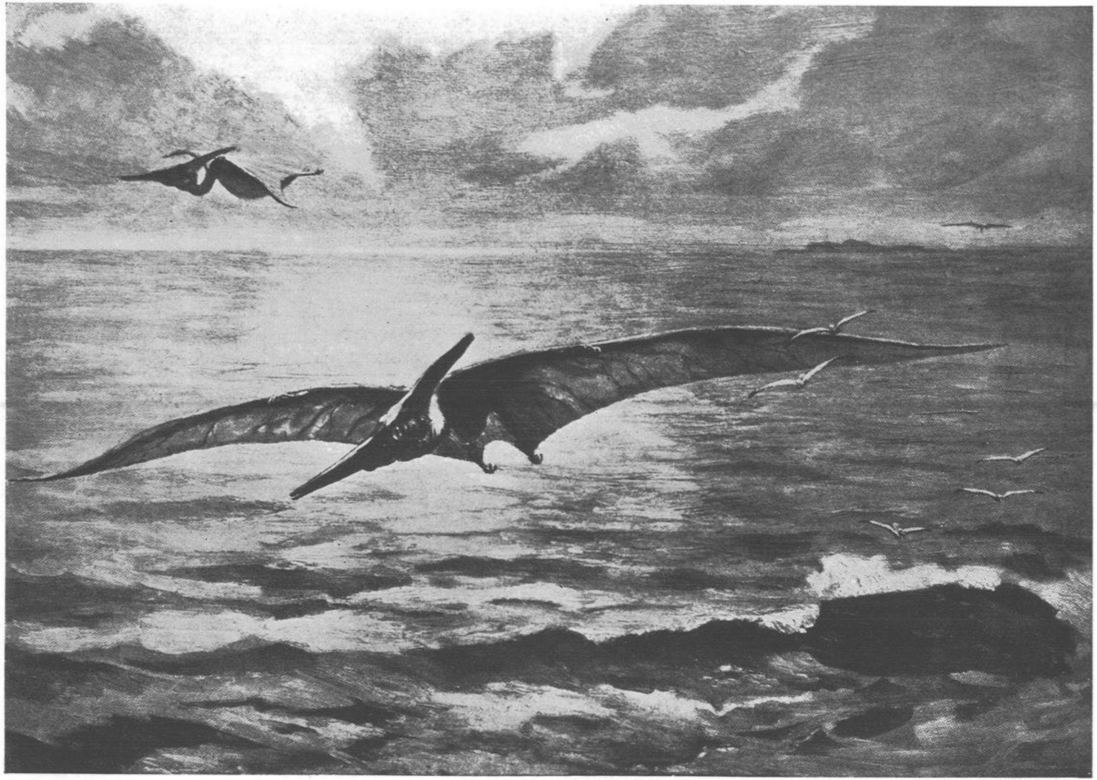


FIG. 73. Side view of *Pteranodon* skeleton. After Eaton

The great animated flying machine known as *Pteranodon* (Figs. 72 and 73), whose fossil remains occur in the Chalk beds of western Kansas, must have abounded on the shores of the great sea which covered that region in Cretaceous times. A single wing of this reptile measures more than ten feet in length. Despite

Skeleton of *Rhamphorhynchus phyllurus*, showing delicate impressions of the wing membranes and the leaflike expansion at the end of the tail. Photograph by the Peabody Museum of Natural History, Yale University



Giant flying reptile, *Pteranodon*. Restoration drawn under the supervision of the late Secretary S. P. Langley, of the Smithsonian Institution. Small white birds supposed to be *Ichthyornis*, a toothed bird of the Cretaceous period this, the *Pteranodon* was by no means a heavy animal, for not only was its body small, but its bones attained the extreme of lightness, being far lighter than those of any bird. The wall of one of the finger bones twenty-six inches long and two inches in diameter is no thicker than that of a cylinder of blotting paper. Because of their fragility the bones are usually found crushed flat. Comparison of the skeletons with those of living birds permits the deduction that an adult *Pteranodon* would not exceed thirty pounds in weight. The hind legs were very small and weak and must have been of little use other than to assist in the spreading of the membrane forming the wings. The small body, as we should expect in a reptile, was either naked or scaled. The skull forms a remarkable feature, being nearly four feet in length, with a long, tapering, sharply pointed, toothless beak in front and an equally long narrow crest projecting behind.

In flight (Plate 60) it seems quite probable that *Pteranodon* glided and sailed through the air after the fashion of some of our large present-day birds. Looking at the skeleton of one of these great flyers it requires little imagination to picture him soaring over the Cretaceous seas, patrolling the broad glistening surface beneath, ever in search of some unwary fish, which with a swoop and a sudden dart of the long beak he snatches from the water before continuing on his way. That it was possible for such an animal to alight on the water and then take off again seems highly improbable. At night he doubtless returned to some favorite roost on shore, hung himself up after the manner of bats, and thus awaited the coming of another day.

If the pterodactyl was a fish eater, as some authorities have thought, it must have had a pouch or throat sac. Recently, Professor Abel, in studying a specimen of *Pterodactylus antiquus* from Bavaria, preserved in the American Museum of Natural History, New York, detected for the first time the outline of such a sac. Although many of these animals had teeth well suited for seizing fish, it seems probable that fowls, small mammals, and even fruits served to vary their diet.

Most of the earlier restorations of the pterodactyls represent them as standing or walking on the ground; but

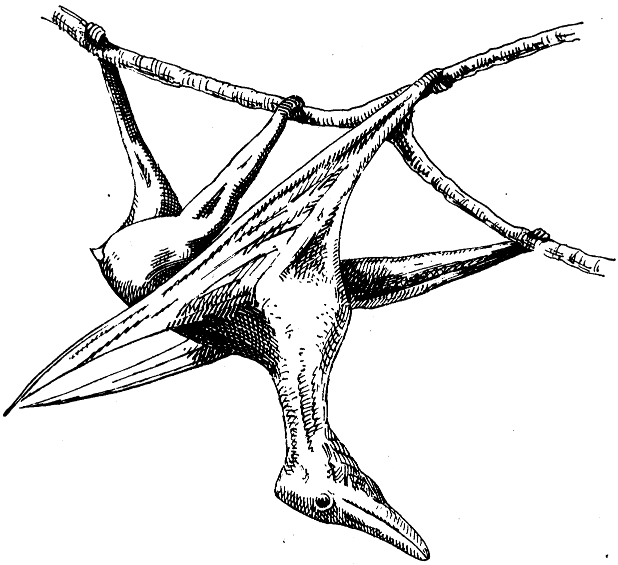


FIG. 74. Sketch restoration of flying reptile, *Pterodactylus suevicus*, hanging from a branch. After Abel

Professor Abel thinks these erroneous, and he proposes the resting attitude depicted in Figure 74, a hanging or clinging posture, suggested to him by the postures assumed by modern fruit bats. The suggestion seems reasonable at least.

Why the pterodactyls should have become extinct in the Upper Cretaceous period is not known, but, as Seeley has suggested, "they endure for geological ages and having fought their battle in life's history, grow old and unable to continue the fight, then disappear from the earth, giving place to more vigorous types adapted to live under new conditions."

CHAPTER V

FOSSIL TRACKS AND TRAILS

A STROLLER along the seashore at low tide, or over sandy or muddy flats whose surface is still plastic enough to retain impressions, must have noticed the numerous tracks and trails made by the animals of the locality. Animals long since extinct have left similar records in the rocks which have endured to our time, often the only evidence of their former existence.

The story is told of an Indian who deduced from a few tracks and signs that at noon a white man had passed, lame in the left foot, blind in the right eye, dressed in gray, carrying a double-barreled gun, and accompanied by a black dog. With no attempt to rival the astuteness of the aborigines, scientists, through a study of ancient tracks and trails, have been able to learn a great deal concerning the animals that made them. These investigations, begun more than half a century ago, led to knowledge which has developed into the dignity of a science known as *ichnology*, which, for convenience in classifying fossil footprints, gives them scientific names, just as the fossil animals themselves are named from their skeletal remains.

The first fossil tracks found in North America were unearthed in the Connecticut Valley, in New England. Here in 1802 Pliny Moody, of South Hadley, Mass., while plowing on his father's farm, turned up a rock on which were small three-toed imprints. Similar discoveries followed, and for nearly a quarter of a century these impressions were observed from time to time by the people of the valley. Owing to their resemblance to bird tracks, with which they were familiar, almost everybody believed that a two-footed animal had made the imprints, and they were frequently referred to as the "tracks of Noah's raven." In 1835 Dr. James Deane, a practicing physician, called the attention of Prof. Edward Hitchcock to certain markings resembling turkey tracks in slabs of flagstone used to pave the streets of the village of Greenfield, Mass. Doctor Deane was the first to suspect that such imprints might have been made by animals other than birds, a suspicion aroused by the occasional occurrence of four- and five-toed impressions with the three-toed ones, and of a few showing the texture of the skin on the sole of the foot, which was unlike that of any known bird. The discovery in later years of dinosaur and other fossil remains in these same rocks confirmed his early suspicion.

Although at first slow to admit the animal origin of these markings, once Professor Hitchcock's interest was aroused, he undertook and for thirty years continued to study them; and in the course of his investigations assembled the remarkable collection of Connecticut Valley footprints which forms such a conspicuous part of the geologic exhibit at Amherst College. More than 150 different kinds of tracks were recognized by Hitchcock, whose studies culminated in his *Ichnology of New England*, published in 1858, probably the most notable exposition of fossil footprints ever written. That his early doubts as to the origin of the footprints were completely dispelled is evidenced by the following from one of his later papers:

Such was the Fauna of sandstone days in the Connecticut Valley. What a wonderful menagerie! Who would believe that such a register lay buried in the strata? To open the leaves, to unroll the papyrus, has been an intensely interesting though difficult work, having all the excitement and marvelous developments of romance. And yet the volume is only partly read. Many a new page I fancy will yet be opened, and many a new key obtained to the hieroglyphic record. I am thankful that I have been allowed to see so much by prying between the folded leaves. At first men supposed that the strange and gigantic races which I had described, were mere creatures of the imagination, like the Gorgons and Chimeras of the ancient poets. But now that hundreds of their footprints, as fresh and distinct as if yesterday impressed upon the mud, arrest the attention of the skeptic on the ample slabs of our cabinets, he might as reasonably doubt his own corporeal existence as that of these enormous and peculiar races.

A study of the region where the tracks are best preserved and most abundant has led geologists to suppose that the Connecticut Valley in Triassic times was a tidal

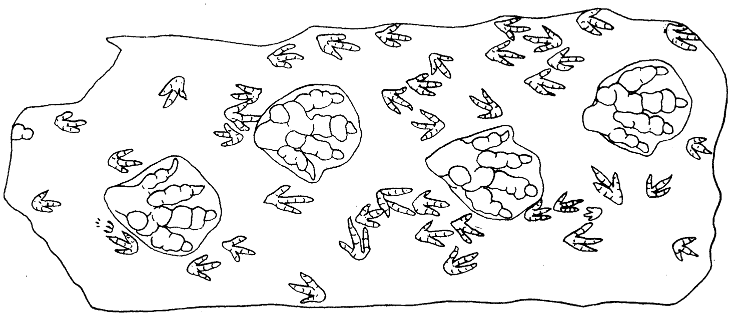


FIG. 75. Slab of Connecticut Valley footprints. After Hitchcock

estuary extending southward from Northfield, Mass., to New Haven, Conn., a distance of 110 miles. Here and there in this estuary were mud flats, left bare by the receding tide, and on these flats and along the shores animals now extinct congregated. Possibly some came for food, others to bask in the sun. The footprints made during their perambulations, slightly hardened by the heat from a tropical sun, endured in spite of the incoming tide, whose burden of sediment gently buried them without injury. Over and over again the waters deposited layer upon layer of sand and mud, which, in the ages that followed, solidified into stone, thus preserving the imprints for future generations to marvel at.

Judging by the abundance of three-toed tracks (Fig. 75), it would seem that those dinosaurs predominated that walked upon the hind legs only. The impressions, while mainly of footprints, give evidence also of claws, of tails that dragged, and of other parts of the body. Attendant phenomena have also left their records, such as raindrops of a summer shower, ripple and other beach marks, and shrinkage cracks like those found in sun-dried mud today, all of which are preserved with wonderful fidelity and minuteness of detail. In the National Museum is a slab of the Connecticut Valley stone, covered with raindrop impressions and crossed by two trails, in the footprints of only one of which appear rain marks. The visitor knows, therefore, that this trail was made before a shower, and that the other, lacking the telltale marks, was not made until after the shower had passed. It would seem unnecessary to explain that such impressions were made in the sediments while they were plastic and not after they had been consolidated into the rocky mass that we see today. Yet the remark of a certain countryman on a visit to the National Museum would indicate that some of us do not grasp this fact. After contemplating a large slab of footprints and hastily reading the accompanying label, he was overheard to say to his companion: "That must have been a derned heavy critter to press his feet into the rock like that."

Although the few fragmentary skeletons found in the Triassic rocks of the valley are those of small carnivorous or flesh-eating dinosaurs, it is apparent from a study of the tracks that some were made by primitive, plant-eating forms, of whose remains not a bone has yet been found. Some of the footprints are immense: one discovered in Massachusetts is twenty inches long, and though only moderately deep, holds four quarts of water. Prof. R. S. Lull describes an extremely interesting slab in the Amherst collection which bears in all about fifty footprints made either by the same animal walking back and forth along the beach or by several animals of the same species and about the same size:

In one of his journeys the creature slows down as shown by the fact that the tail begins to drag, whereas it has been held stiffly out behind to counterbalance the weight of the body. Then the animal stops and comes down on all fours, impressing the little hands and long heels, then, having satisfied his purpose, he again rises to his hind feet, touching one hand and the tail tip once more to the ground in regaining its balance, and then goes on his way. This single slab gives us thus a knowledge of the creature's size, proportions, gait, resting posture, feeding habits, for the little hand with its nail-like claws could never have been used for grasping prey, and, finally, of the texture of the skin on the soles of the feet with creases between the joints, like those of human fingers, and tiny granulations like mustard seed covering the entire surfaces.

This slab gave the first evidence of plant-eating dinosaurs in the Triassic, a record that may eventually be verified by the finding of their bones.

Tracks attributed to dinosaurs have been found in many places in North America besides the Connecticut Valley; but these more or less isolated finds have not attracted sufficient attention from scientists to arouse a general interest in them. That the Nation's Capital and its vicinity were the stamping ground of dinosaurs is shown not only by the finding of their bones within the District of Columbia, but also by a more recent discovery of numerous fossil footprints in the Triassic rocks near Leesburg, Va. In remodeling the President Monroe house in Loudoun County, Mr. F. P. Littleton, the present owner, desired to match the old flagstones in the porch floors, and after some search found the quarry from which the slabs had been obtained. The new flags from this quarry bore footprints which the paleontologists of the National Museum pronounced to be those of dinosaurs and of the same geologic age as the footprints found in the Connecticut Valley. Mr. Littleton made a special search for slabs containing well-preserved series of tracks, with the result that the floors of his enlarged porches are unique in being adorned with fossil footprints, many of them in consecutive series, showing the course and stride of the creatures that made them.

Another such discovery has been called to the attention of the Smithsonian Institution by Mr. George P. Bessent, who found thirteen footprints made by a single animal in the Glen Rose formation near the Texas town of that name. Each track measures fourteen inches in length and thirteen and a half inches in width. The prints of the toes are sunk three inches deep into the rock, indicating the softness of the surface when the animal strode over it. The impressions are approximately forty-eight inches apart, so that in thirteen steps the animal covered a distance of fifty-two feet. Undoubtedly these tracks were made by a large three-toed bipedal dinosaur, but the evidence as to whether it was herbivorous or carnivorous is not altogether clear. As in many other instances, no fossil bones of any animal capable of making such tracks have been found in rocks of the same age in Texas, so that we can expect no help from that source in solving this riddle of the rocks. This series of tracks, however, illustrates how footprints often contribute to a better understanding of the attitude assumed by extinct animals. The deep imprints show that in walking one foot was placed in front of the other, forming a single line of tracks, after the manner of walking birds. The absence of impressions of the fore feet and the lack of a furrow such as would be made by a dragging tail give direct evidence that only the hind legs were used in walking, and that the tail was held free from the ground, its weight counterbalancing that of the body.

Fossil tracks found near Hastings, England, and ascribed to the dinosaur *Iguanodon*, have been traced for seventy-five feet, and show characteristics similar to those of the Glen Rose formation, except that the feet do not point straight forward, but are pigeon-toed (Fig. 76). Dinosaur tracks found in the coal mines of Utah have the same peculiarity. These, by the way, are the largest three-toed tracks yet found in America, some of them measuring thirty inches in length and thirty-one inches in breadth. The stride of the animal which made them was about nine feet. In these tracks the imprints themselves are not preserved, but only their natural casts. It seems that the animal walked over the soft earth which immediately overlay a peat bed, and that this earth was in turn covered by a thick layer of sand, which filled in the deep footprints. In the ages that followed, the sand became

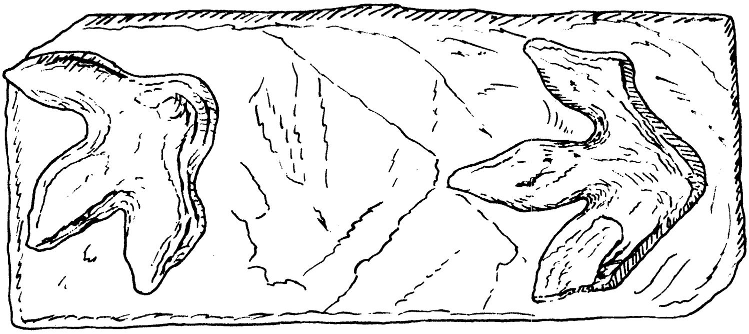
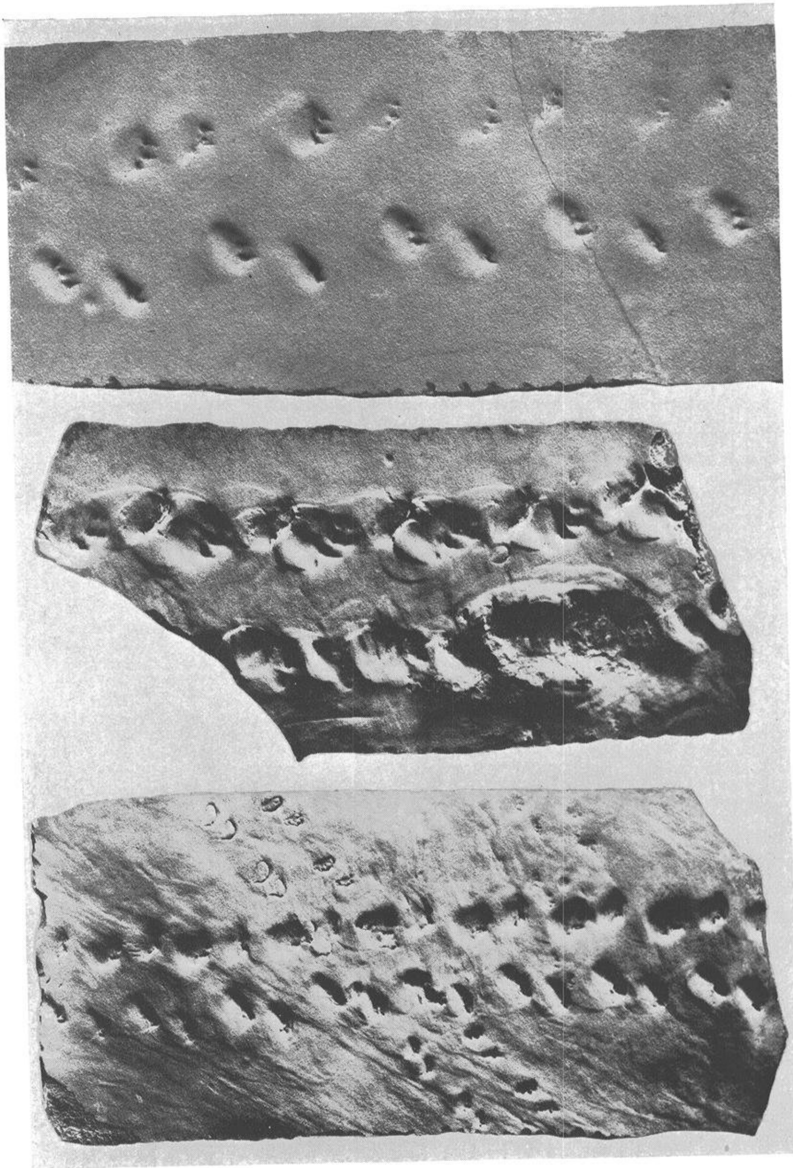


FIG. 76. Tracks of *Iguanodon*, much reduced. From Wealden strata, England. Modified from Hutchinson

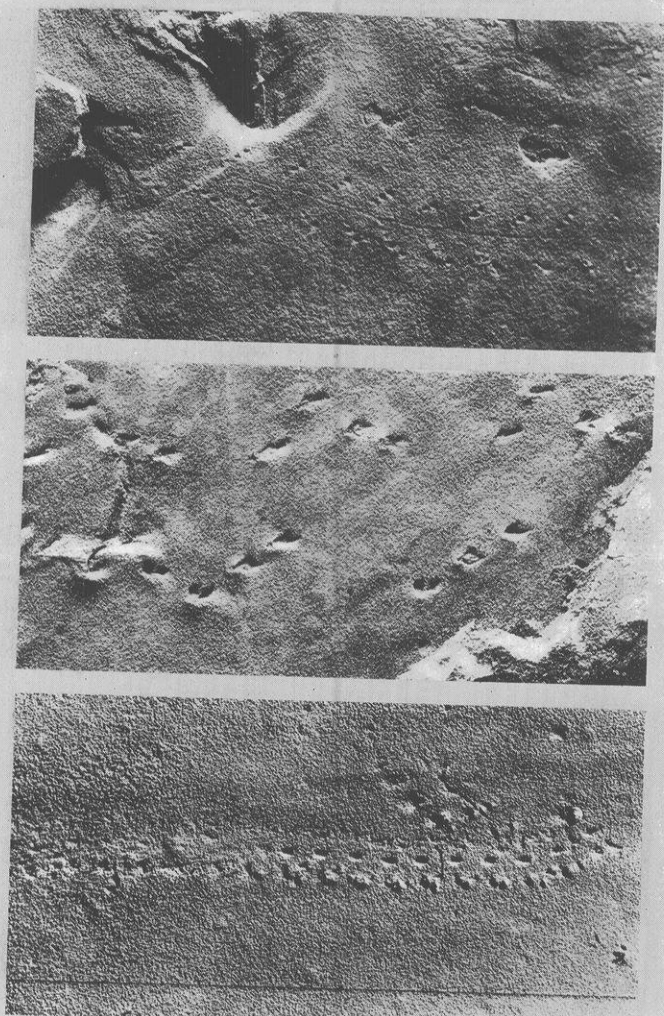
consolidated into the heavy band of sandstone that we see today. When the coal is mined out, the soft, unconsolidated layer containing the tracks cleaves from the underside of the sandstone and leaves the natural casts of the tracks protruding below the general level of the sandstone roof of the mine. It is thus that the trail of the dinosaur has been revealed to us of the present day.

The great antiquity of fossil footprints is nowhere more clearly and convincingly demonstrated than in the Grand Canyon of the Colorado, in Arizona. This area, now set aside as a national park, was in several periods, each separated from the next by millions of years, inhabited by large and varied assemblages of animals, none of which resembled any of the creatures living there today. Fossil tracks and trails preserved at levels hundreds of feet apart in the rock walls of the canyon furnish the evidence for this statement. At the time the tracks were made there was no Grand Canyon and the present rocks were loose sand and mud. In the millions upon millions of years that followed after the earliest animals left their footprints in the soft surface materials, other sediments accumulated above them in successive strata, some of which recorded the footprints of new animals that had arisen to replace the old. Stratum piled upon stratum, until the mass was hundreds of feet thick. Its great weight, aided by the natural cement in the sand and mud, consolidated the underlying layers into sandstones and shales. Thus admirably protected, the petrified tracks remained hidden for untold ages. Then the wind and the rain, the sleet and the snow began their work of wearing away the solid structure, aided by the Colorado River, which cut deep into the rock and transported many of the loosened fragments far away. Thus the elements carved out the Grand Canyon and the ancient tracks came to light.

These footprints have recently been found at many places in the canyon, but those most accessible and extensive in occurrence are crossed by or lie immediately off the famous Hermit and Bright Angel trails. Discovered first by Prof. Charles Schuchert in 1915, and described in part by Professor Lull, the Grand Canyon tracks received little further attention until ten years later, when a large collection of them was made for the National Museum. These tracks, together with collections of subsequent years, have been described by the writer. Today no less than twenty-seven genera and thirty-three species of fossil tracks are known from this one area. They come from three distinct formations of the Permian epoch, which, named in descending order, are known as the Coconino, Hermit, and Supai formations. The tracks are found in three horizons, the first at 900 to 1,080 feet, the second at 1,350 to 1,400 feet, and the third at 1,800 to 1,850 feet below the top of the canyon wall. This is probably the only place in the world where the fossil tracks of three successive groups of animal life,



Tracks from the Coconino sandstone, Grand Canyon, Arizona. Upper, *Laoporus noblei;* middle, *Agostopus*, with part of trail blotted out by a larger track; lower, *Baropezia*, crossed by *Laoporus*. In the National Museum



Trails of invertebrate animals from the Coconino sandstone, Grand Canyon, Arizona. In the National Museum separated by such great geologic intervals, can be found. The Park Service has unearthed at the side of the Hermit Trail, where all who pass may see it, a slab of rock twenty-five feet long and eight feet wide upon whose surface are hundreds of footprints. It is hoped that this interesting out-of-door exhibit will engrave its message upon the minds of the many people who come from all over the world to visit the canyon.

What kind of animals made these tracks? That is a question that can be only partially answered at this time. Study has revealed that quadrupedal animals are responsible for most of them. Some of these animals had only three toes to a foot, others had four, and still others five. Some were provided with long, sharp claws; some were apparently without claws, and some had the toes terminating in blunt, rounded nails. Some were as small as a mouse, while others were very large, with a stride of thirty inches. Some had short limbs and wide, heavy bodies, while others had long, slender limbs and narrow bodies. Certain rocks in Texas and New Mexico of the same geologic age as the track-bearing rocks in the Grand Canyon contain skeletons of many kinds of extinct animals, some of which, it is thought, from measurements of their foot, limb and body bones, might have made footprints resembling those in the Grand Canyon. It therefore seems fair to assume that like animals formerly inhabited the two regions. If these deductions are correct we may know that the Grand Canyon tracks were made by primitive crawling reptiles and amphibians that were unlike any creature living today.

In addition to the footprints just described, the canyon rocks have preserved trails evidently made by crablike animals or large insects (Plate 62), as indicated by the outline of pointed toes in clusters of two and three, with a distinct furrow between, caused by the drag of a tail. They also contain burrows thought to have been made by worms.

More modern animals also have left their tracks. They may be found in rocks of the Pleistocene epoch, which immediately preceded the one in which we now live. Of the footprints of this epoch none have attracted wider attention than those found in 1882 in the prison yard of the State penitentiary at Carson City, Nev. In quarrying for sandstone, tracks attributed to the mammoth, horse, deer, wolf, ground sloth, and birds were uncovered. The startling announcement of the press in the first reports of this discovery attributed the ground-sloth footprints to the sandaled feet of primeval man. This, of course, provoked wide interest, since, if true, it gave evidence of the existence of man on this continent at a period much earlier than scientists were at that time willing to concede. Furthermore the size of the footprints indicated that this supposed man belonged to a race of giants, and, if he, then all his fellows, too—our ancestors. And this is exactly what most people used to believe and hoped that all traces of ancient man would prove. Although naturalists of the time soon pointed out the error of such assumptions, it remained for Prof. Chester Stock to show conclusively that the articulated bones of the ground-sloth's foot (*Mylodon*) were fully capable of making the disputed tracks; and any doubt that may still have existed was dispelled for all time by the discovery of the fragmentary bones of one of these clumsy creatures in the rocks of the prison yard.

In the preceding pages the localities of only a few of the outstanding fossil footprints in North America have been mentioned. These tracks have been noted, however, in many other localities in this country, as well as in foreign lands, particularly in the British Isles and continental Europe, where they have been the object of scientific investigation for many years. Interesting though fossil skeletons may be, they inevitably symbolize creatures in the stillness of death, whereas footprints suggest them in the full vigor of life, and so have a dramatic appeal which only the present tense can give.

CHAPTER VI

THE PRESERVATION AND COLLECTING OF FOSSIL VERTEBRATES

LITERALLY speaking, a fossil is "something dug up," but as Lucas has pointed out, "in actual use the word has a much more restricted meaning. The term is applied only to the remains of plants and animals that have been buried by natural causes and preserved for long periods of time." To be a fossil, a plant or animal remnant need not be petrified. However, in general, the greater the antiquity of a fossil the greater the chemical alteration it has undergone. Exceptions to this rule owe their unaltered state to the unusual climatic conditions prevailing where they occur. Thus specimens of the mammoth and woolly rhinoceros, animals now extinct, have been preserved almost intact through centuries, imprisoned in the ice of Siberia; and the bones of other ancient animals have been found in deposits of asphalt or in caves, somewhat discolored, but otherwise unaltered.

But what is petrifaction? It is the replacement of the original organic matter of the bone by a mineral deposit, either wholly or in part. This replacement is brought about by the infiltration of water carrying minerals in solution, usually lime or silica, which, as the bony matter is dissolved or leached out, is deposited in its place. So gradual and complete is this change that the most delicate internal cellular structure, as well as the general form of the bones, is retained. The petrified bone, to all outward appearances, differs from the original only in its greater weight, increased hardness, and changed coloration; though often the color is only slightly altered, depending upon the character of the mineral replacement. When fully petrified, such bones are as heavy and enduring as stone itself.

Petrifaction can take place only under certain favorable conditions. First of all, the structure must be sufficiently firm or resistant to hold its shape, and thus it is that only the hard parts, such as the bones and teeth of animals, are so preserved. Flesh never petrifies and therefore "petrified bodies" can not be, despite the numerous reports of their discovery.

Nearly every one, at one time or another, has heard of springs or other waters that "turn things into stone." While this does not actually happen, there are waters so thoroughly charged with carbonate of lime that objects immersed in them quickly become incrusted with a stony covering. Those unacquainted with this phenomenon are often deluded into believing that objects thus coated are petrified. Occasionally, also, the outlines of rocks suggest animal forms, faces, and the like, but these are usually the result of weathering. And most deceptive of all as to their origin, are those stony nodules, known as concretions, that often simulate the forms of various familiar objects with which they have no relationship. So close are these general resemblances that it is no wonder the uninitiated are misled into thinking that the concretions are fossil turtles, reptile heads, and what not. Plate 63 illustrates two characteristic examples of these imitative forms reproduced from actual specimens in the National Museum. Both are of inorganic origin and have never had any connection with the animals they seem to represent.

Occasionally impressions showing the clear-cut contour of a body are found, of which the remains of fish from the Green River shales of Wyoming or those of ichthyosaurs (see Plate 49) from the famous Solenhofen quarries of Bavaria are excellent examples. More rarely impressions made by the soft integumentary wing covering of the flying reptiles, or pterodactyls, come to light. So perfect are these last-mentioned impressions that the whole outline of the wing, including even the folds in the overlying membrane when the wings were closed, has been clearly recorded. Of equal rarity are well-preserved impressions, some exhibiting beautiful mosaic patterns, of the scaly skin of certain animals, especially the dinosaur. None of these impressions, however, are petrifactions; for, at the most, all that remains of the organic structure of the animals who made them is a thin layer of black carbonized matter which has lost all semblance of its original character.

Animal remains become entombed in the rocks in various ways; but first of all it should be explained that, however firm and solid or deeply buried they may now be, the rocks in which fossils are found were originally layers of loose surface material, later deposited by wind or water, one layer upon the other, as we find them today. It is thus quite obvious that the succession of stratified rocks must be chronologic in the order of their formation, the oldest being deepest down, since it was necessarily deposited first. It is also obvious that animal remains found in these rock layers must have been deposited there at the same time that the rock-making materials were laid down.

In this connection it is interesting to hark back to some of the earlier theories as to how fossils became embedded in the rock. Once they were regarded as "sports of nature," but at the close of the seventeenth century there arose a theory—which had many adherents among the scholars of the time—that the spawn of fish or the eggs of other creatures were carried up in moist vapor from the sea and land into the clouds, whence they descended in rain, penetrating the earth and giving birth to the fossils; in other words, that all fossils grew in the earth from the germs of living animals. All through the eighteenth and well into the nineteenth century the belief prevailed widely that fossil remains were the relics of animals that perished in the great Biblical flood, and even today this belief has a few adherents.

As an indication of the degree to which the knowledge of the origin of fossils had attained in the early part of the eighteenth century, the account of the work of Professor Beringer, as given by Professor Marsh, is instructive, and especially so since that unhappy man's experience brought about a more careful study of fossilization, which gradually led to the displacement of vague hypotheses:

> Professor Beringer [of the University of Würzburg], in accordance with the views of his time, had taught his pupils that fossil remains, or "figured stones" as they were called, were mere "sports of nature." Some of the fun-loving students reasoned among themselves, "If nature can make figured stones in sport, why can not we?" Accordingly, from the soft limestone in the neighboring hills, they carved out figures of marvelous and fantastic forms, and buried them at the localities where the learned Professor was accustomed to dig for his fossil treasures. His delight at the discovery of these strange forms encouraged further production, and taxed the ingenuity of these youthful imitators of Nature's secret processes. At last Beringer had a large and unique collection of forms, new to him, and to science, which he determined to publish to the world. After long and patient study, his work appeared, in Latin, dedicated to the reigning prince of the country, and illustrated with twenty-one folio plates. Soon after the book was published, the deception practised upon the credulous Professor became known; and, in place of the glory he expected from his great undertaking, he received only ridicule and disgrace. He at once endeavored to repurchase and destroy the volumes already issued, and succeeded so far that few copies of the first edition remain. His small fortune, which had been seriously impaired in bringing out his grand work, was exhausted in the effort to regain what was already issued, as the price rapidly advanced in proportion as fewer copies remained; and, mortified at the failure of his life's work, he died in poverty. It is said that some of his family, dissatisfied with the misfortune brought upon them by this disgrace and the loss of their patrimony, used a remaining copy for the production of a second edition, which met with a large sale, sufficient to repair the previous loss, and restore the family fortune.

If bones are to be preserved they must be protected from the air, and this nature does by covering them with water or at least burying them in moist ground. When the paleontologist finds an articulated skeleton he knows at once that the carcass of which it once formed a part was quickly covered after death; if it had not been, the bones would have fallen apart and intermixed as soon as the soft tissues had decomposed; and flesh-eating animals, similar to those who feed upon carcasses today, would have helped to scatter them. Every one has noted the rapidity with which a carcass on dry ground is scattered and the bones reduced to dust by the elements, which explains the necessity of its being promptly covered if it is to be preserved. This prompt covering may be accomplished in several ways: The animal may be trapped in quicksand or tar pits; it may bog down in a marshy place; it may fall or be dragged into a cavern in the rocks; volcanic dust or wind-blown sand may appear opportunely to cover its carcass; or it may become enveloped in flood-plain, river, or sea deposits. At best, the preservation of an animal skeleton is largely accidental, because so many factors enter into its accomplishment; and the absence of any one of these factors or its wrong association may be sufficient to bring about the total destruction of the skeleton.

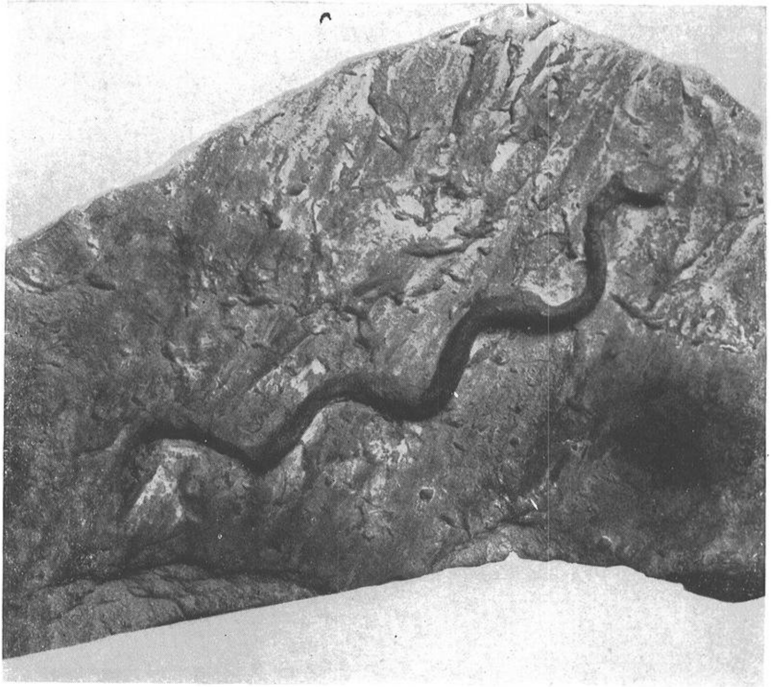
Once an animal remnant has become fossilized there is no assurance that it will remain in good condition until found by man, for even after being sealed up in the rocks there are still destructive agencies which attack it. The weight of superimposed strata sometimes flattens out fossils; rock movements during periods of upheaval or subsidence crack and twist them out of shape; and when again they are brought to the surface those same agencies that sought to destroy them before their entombment—rain, sun, snow, and frost—are ever ready to renew the attack and crumble the stony relics into fragments.

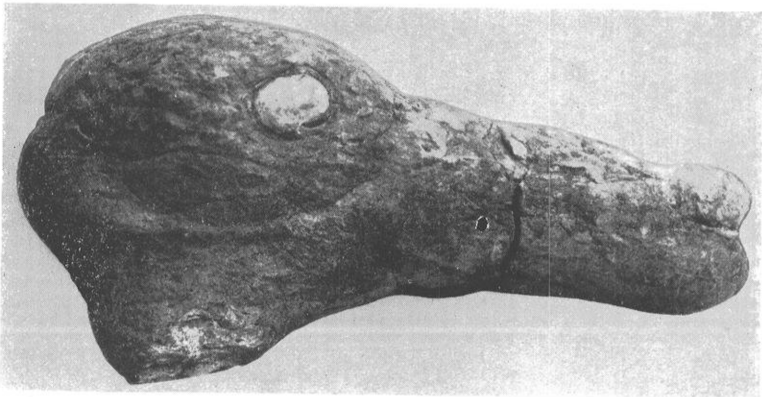
It is quite apparent, then, that for every specimen preserved innumerable ones have been destroyed, and this is why the paleontologist can never hope to obtain a complete chronologic series. Furthermore, it is only here and there that nature has made the fossil-bearing strata accessible by turning them up on edge, or by cutting through the more or less horizontal layers in the process of forming gullies, canyons, and valleys. The incompleteness of the fossil record is perhaps best illustrated by the birds. There are living today some 25,000 species, and in all the world only about 700 fossil species have been described.

The wonder of it all is, not that we know so little of the life of the past, but that we know as much as we do. We owe our knowledge largely to organized effort. Not so very long ago fossils were gathered only as accident revealed them; but with the advance of science, systematic search of the fossil-bearing rocks of the world has been undertaken by specially trained collectors. Accidental discoveries still bring interesting specimens to light, but systematic search deserves the credit for the recovery of those of the greatest import.

The collector of extinct animals, unlike the student of living forms, cares little for what is on the surface; his great concern is to see as much as possible of what may lie beneath. So he visits regions devoid of grass and trees, where the action of the wind and rain is carving gullies and canyons, thus exposing the bone-bearing layers in cross section. Ofttimes the only indication of fossils in the rock will be broken and scattered fragments that, when traced to their source, lead to the protruding end of a broken bone (Plate 64). Then the collector comes into his own.

In the early days of collecting, broken specimens were taken up piece by piece in the hope that they might again be fitted together in the laboratory. This was sometimes successful, but more often delicate structures and important processes were destroyed and lost—which added to the perplexities of the paleontologist when he undertook to identify the restored specimen. Today the searcher for extinct animals takes every precaution to prevent marring or damaging a fossil bone. In this connection it is of interest to recall my first season in the field under the tutelage of an early collector, a man of striking

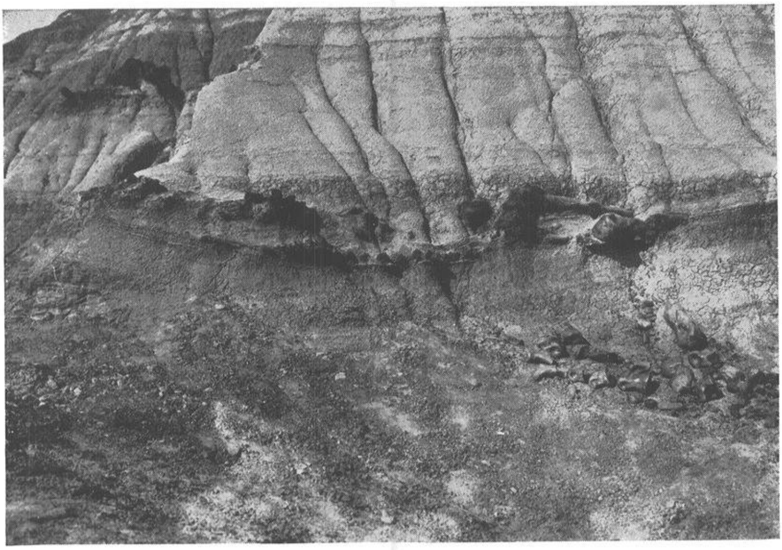


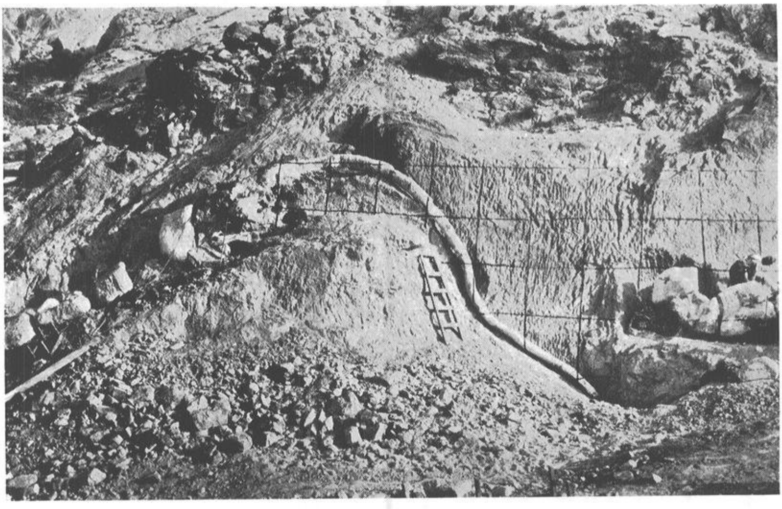


Upper: Pseudo-fossil snake. A peculiar result of wave or ripple work on soft mud or some form of vegetation. The finder thought it a fossil snake

Lower: Clay concretion. Supposed by the finder to be the petrified head of a reptile

PLATE 64





Upper: Dinosaur "prospect." Limb bones and ends of ribs protruding from the bank. Scattered parts of a hind foot in right foreground first drew attention to the specimen. Photograph by the Geological Survey of Canada

Lower: Dinosaur National Monument quarry, Utah, showing method of blocking out in squares for convenience in mapping. Tail of large dinosaur, plastered and ready to be removed. Photograph by the Carnegie Museum, Pittsburgh personal peculiarities. He would slam his heavy pick into the ground and bring forth a resounding clang as metal met stone. "Bone, by gosh!" For he claimed to be able to distinguish by the sound whether the object struck was fossil or rock; but I was never fully convinced of his discriminative skill. Being prone to exaggerate, this man—whom for convenience we will call Bill Smith—acquired such a reputation for stretching the truth that, when the inquiry was made as to who were the three biggest liars in Wyoming, the reply came that a certain sheriff in Rawlins was one, and that Bill Smith was the other two.

Experience has brought about refinement in the methods used to extract fossils from the rocks, resulting in the acquisition in recent years of better preserved and more perfect specimens than it was ever dreamed could be recovered. Modern technique in extracting and restoring fossils is described elsewhere in this series, but we may illustrate one phase of it here, to show the care exercised.

In those fossil-bearing rocks where the skeletons of many individuals are found commingled, the "general quarry" of the collector, it is the practice to lay the excavation off in squares of regular dimensions (Plate 64); and as the bones or skeletons are uncovered they are plotted to scale, thus making a diagram or quarry map covering the whole excavation. Each piece of bone is assigned a number or letter, so that later on the position of all the parts found can be shown exactly as they lay in the ground.

The uncertainty and chance in fossil collecting give the work quite as much zest as the quest for live game; for it has all of the elements of hope and failure, excitement and depression, that are found in the chase, with, as Osborn has observed, this very great difference—"that the hunter of live game, thorough sportsman though he may be, is always bringing live animals nearer to death and extinction, whereas the fossil hunter is always seeking to bring extinct animals back to life." The successful fossil collector must be primarily an enthusiast in his calling. He must also be ingenious enough to manipulate the large blocks of stone-inclosed fossils with the primitive means at hand, and to transport them long distances over rough, roadless country without injuring them. He must be willing to accept hardships—to suffer cold or intense heat and glaring sun, to drink alkali water, eat plain food, and endure the attacks of mosquitoes and other insect pests. All these things he accepts gladly, in the hope of finding some exceptionally well-preserved specimen, or of discovering some animal new to the scientific world.

Few museum visitors who view an articulated skeleton of a giant reptile can appreciate the time, energy, and skill given to the task of preparing it for public exhibition. Work on the skeleton of a *Diplodocus* now (in 1930) being mounted in the laboratory of the National Museum at Washington has already occupied three skilled preparators for a period of six years and the skeleton is still not entirely assembled. The large blocks of sandstone which contained the bones had a total weight of 50,000 pounds, or twenty-five tons, and five men spent nearly four months in quarrying them out. This great mass of rock was transported by teams 150 miles to the nearest railroad. The excavating was done in 1923, since which time the preparators have worked continuously at the arduous and tedious task of cutting the fossil bones out of the hard sandstone matrix. The final stage of the work consists in articulating the skeleton in a lifelike pose and making the iron and steel supports which hold the individual bones in their proper position. Is it any wonder that the number of mounted skeletons, in our public museums, of this largest of the huge reptiles can be counted almost on the fingers of one hand?

The specialist's first job is to classify his fossil. The system of zoological classification now in use is largely the invention of the Swedish naturalist, Linnaeus, and it is in this classification, originally established for living animals, that extinct animals, too, find their proper places.

Some extinct forms have their niches already provided because representatives of their kind are still living, notably the horse, camel, rhinoceros, lizard, and crocodile. But often whole groups of animals, such as the dinosaurs and pterodactyls, are found in the fossil state only, so that it becomes necessary to create places for them in the scheme of classification, determined by their relation to living groups. And as there are no vernacular terms for these animals that vanished from the earth long before the appearance of man, the paleontologist coins a name when a new species is found, devising a terminology drawn chiefly from the Greek and Latin. Since this plan has been adopted by all scientific men, of whatever nationality, it provides a universal language suited to their needs.

It may here be pointed out that the vertebrate paleontologist rarely deals with complete specimens, for, aside from the remains of fish and a few of the smaller reptiles and batrachians, a skeleton with every bone present is an exceptional prize. Usually the paleontologist must be content with the imperfect, a part of a skeleton—a limb, a foot, a skull, or perhaps only the dentition. We know many fossil animals, especially in the group Mammalia, only from the teeth; but because of the diagnostic characters to be found in teeth, their precise study is important. Fortunately we can often construct a nearly complete specimen from several imperfect ones, provided the parts belong unquestionably to the same species. Such composite skeletons become almost as useful as those in which all parts belong to a single individual.

Since Cuvier's time the belief has persisted that the paleontologist can reconstruct the skeleton of an extinct animal from a single bone or tooth. The absurdity of such an idea is clearly shown by the experience of competent paleontologists who have erred in their association of skeletal parts. More than one zealous worker has assigned a dissociated skull and foot to quite different groups of animals, only to realize his error with the discovery later of a skeleton having both these parts present. Thus it will be seen that the paleontologist is forever adding to and revising the recorded knowledge of the various extinct animals with which he deals, in the expectation and hope—a hope often realized—that eventually the true skeletal structure of each will be made known. The more intimately we know the skeletal structure of an animal the more precise will be our determination of its relationship to other animals, as well as its proper assignment in the general scheme of classification of the animal kingdom.

Another task of the vertebrate paleontologist—and to a certain extent a feasible one when once the skeleton of an extinct animal is known—is to make the bones live again, that is, to restore the animal to its probable appearance in life. Although the bones do not divulge what sort of coat the animal had, they do tell to what group it belongs; and if the restorer has a knowledge of the external form of living animals, certain probabilities are at once suggested. For example, no reptile would be covered with feathers, and if we may correctly judge from living reptiles, none of the extinct ones had coats of fur or hair. Various ridges, processes, and roughened areas on the bones indicate the points of attachment of essential muscles and ligaments, and to those competent to interpret these distinguishing marks in an extinct animal, much is learned about its musculature, which in life gave the animal its external form. If the animal to be restored has living relatives, distant though the kinship may be, the probability of error in the final restoration is much diminished. Folds, frills, and crests rarely leave a trace of their previous existence, so if they are to be introduced into the restoration, the reconstructor must trust to his imagination. Occasionally impressions of the animal's skin are found, but here again our knowledge is fragmentary and the imagination must be called upon to fill in the gaps. Silhouettes have even come to light showing a whole dinosaur or ichthyosaur, but so seldom as to make them the rarest of fossil trophies. As to the color of the coats of extinct animals, we have no information whatsoever, although it is usually assumed that the larger the creature, the more somber was its tint. Certain external appendages comparable to the ears, tail, and hump of the camel and the trunk of the elephant, must be restored from conjecture or analogy rather than from any precise evidence; for little or none is ever available.

Statuettes, paintings, and drawings depicting ancient animals as they may have appeared in life have played a large part in bringing about a better understanding of these long extinct creatures. A famous series of figures was made many years ago by Waterhouse Hawkins for exhibition in the Crystal Palace, London; but so little was known then of extinct animals that the creatures represented were almost purely imaginary. Within the past few years, however, Karl Hagenbeck has added to the collection of living specimens in his famous zoological gardens at Hamburg a number of life-sized models of dinosaurs and other extinct reptiles. These figures, modeled under the direction of the sculptor Pallenberg and approved by paleontologists of note, are probably as faithful representations of these ancient creatures as it is possible to produce in the light of our present knowledge. Mr. Hagenbeck's example in including in his exhibit both extinct and living specimens might well be emulated in other zoological parks, since it enables the visitor to observe at first hand the workings of evolution in animal forms.

But more valuable than restorations, perhaps, to acquaint the public with the striking creatures of past ages are the mounted fossil skeletons, posed in lifelike attitudes, which are found in many museums both in this country and Europe. Mention has already been made of the preparation for exhibit at this time by the National Museum of an eighty-foot skeleton of *Diplodocus*.

Such mountings, tedious and costly as they are, reveal the gigantic size and unfamiliar form of extinct animals more effectively than any painting or modeled restoration could hope to do. And in addition to their value as visual lessons to the layman, mounted fossil skeletons often greatly facilitate the work of the researcher. For it is far easier to compare the bones of these animals and determine structure and relationships when the huge skeletons are assembled than when they are but uncoordinated fragments. In consequence natural history museums everywhere are constantly adding to their collections of these exhibits.

CHAPTER VII

THE PLACE OF REPTILES AMONG VERTEBRATES

THE Reptilia, including turtles, crocodiles, lizards, and snakes, stand midway in the vertebrate scale. Seemingly descended from a primitive branch of the amphibians, reptiles in their turn may have given rise to both the birds and the mammals.

Certain small but constant characters distinguish the reptiles from their nearer relatives, the amphibians, as well as from their more remote kinsfolk, the fishes. Their scales, for example, are very different from those of most fishes. Fish scales grow out of the skin somewhat like finger nails and can be scraped off; but in the reptiles the scales, being horny folds of the skin itself, can not be separated from it. Another still more constant difference—for scales may be wholly absent in both classes—is found in the gills and gill slits, which are always present in fishes and never in reptiles.

The absence of gills serves also to distinguish the reptiles from the amphibians, which, as we have seen, usually have gills in the larval stage and sometimes throughout life. Reptiles differ from amphibians in various other anatomical structures, notably the tongue, the heart, and the ribs.

The tongues of reptiles vary greatly, but none are tied down only in front as are those of many amphibians. In snakes and in many lizards the tongue serves as an organ of touch.

The typical reptilian heart is three-chambered, but in some of the turtles this organ is really two-chambered, since only an incomplete partition divides the two receiving chambers (auricles). This tendency of the auricle to become divided, however, is also shared by the ventricle (pumping-out chamber) so that these turtles appear to be developing a four-chambered heart. But, so far, the

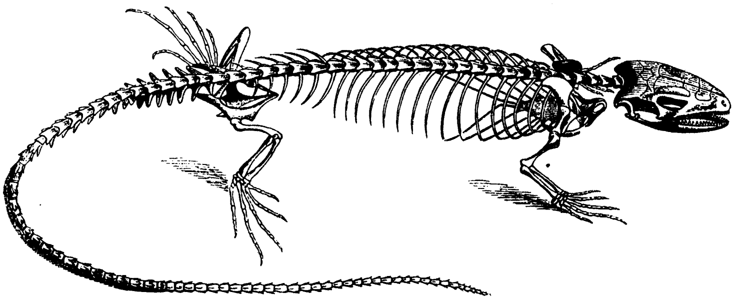


FIG. 77. Skeleton of a lizard, showing fully developed ribs attached to the breastbone. After Brehms

reptiles of only one order, the Crocodylia, have actually achieved a four-chambered heart and become, in part, warm-blooded.

In some reptiles we find, for the first time, fully developed ribs attached to the breastbone in front and operating as the mechanism of respiration (Fig. 77). In the turtles, except in the sea-going *Dermochelys*, however, the ribs are fastened to the upper shell, and these creatures breathe chiefly by pumping air from the mouth into the lungs after the manner of amphibians. Aquatic forms breathe to some extent, also, through the skin.

While the lungs of reptiles are usually better developed than those of amphibians, they range from mere sacs or pockets to asymmetrical organs, such as are found in the snakes and limbless lizards. In these forms, particularly in the snakes, one lung is always much reduced and is sometimes a mere rudiment, while the other extends almost the whole length of the body.

In turtles the lower shell takes the place of the breastbone. Snakes, too, lack a breastbone, and actually walk on their ribs, each of which is equipped with a separate active muscle and fastened to the lower surface of the body. The ribs of snakes are attached along the entire length of the backbone, which is supplied with numerous vertebrae—300 in the pythons. The articulation of the vertebrae gives snakes their wonderful litheness, so that, with a slight movement of ribs and scales they can climb, leap, swim, stand erect for a third their length, and run swiftly, without the aid of legs.

The modes of motion among reptiles are as various as are their adaptations to special environments. Nearly all swim with ease. Most of the land turtles, as well as many of the smaller lizards, can burrow into mud and soft earth. Lizards, whose bodies have an almost snakelike litheness, are often very rapid runners. The flying dragon —a tree lizard—possesses a gliding apparatus. Chameleons have opposable toes for grasping, as a special adaptation to their arboreal existence.

The complete skeleton of a lizard resembles somewhat closely that of a bird, with minor differences, however, that are easily recognized by the anatomist. In reptiles, as in amphibians, there is less centralization of the nervous system within the brain as compared with either birds or mammals. This must have been especially true of the extinct, monster dinosaurs. In *Stegosaurus* the skull is so small in proportion to the rest of the body that we can only suppose the brain to have been the center merely of the special senses. The motor function must have been controlled, as in present-day reptilian forms, by the nerve ganglions along the spinal column. It is this that makes the reptiles tenacious of life, even after the head has been cut off. A turtle is said to live for eighteen days after the brain has been removed, its movements then being governed by reflex action.

The senses of reptiles are somewhat better developed than are those of amphibians. They have an internal and a middle ear, the outside ear being represented in the crocodiles by the external fold or flap of skin that serves as a protection to the ear drum. Snakes have no external ears or ear openings. In many of the other reptiles the drum membrane lies exposed as in the frogs, but in some it is concealed by the continuation of the body scales.

Eyes are found in all reptiles, although in some burrowing forms they have become nearly functionless. They are usually equipped with two movable eyelids and sometimes with a third, known as the nictitating membrane. Some lizards, especially the skinks, have a transparent window in the lower lid to protect the eye from the sands of the desert, in which they burrow; in a few lizards the transparent lower lid is fused immovably to the reduced rim of the upper lid; while in all snakes the eyes are covered by a transparent immovable vestige of the nictitating membrane. Some reptiles show the remains of a third eye, called the pineal eye, situated in the top of the head, which the vertebrates have long since lost in the course of evolution.

The nostrils of reptiles are well devised for breathing, with various adaptations in the aquatic forms for keeping the water out. That some reptiles have a lively sense of smell is evidenced by the fact that the crocodilians secrete a powerful musk during the mating season.

Reptile eggs, large and usually free from each other, are covered either with a tough membrane or with a hard limy shell, and consist of yolk and white, like those of birds. In the reptilian embryo, for the first time in nature, we find two enveloping membranes, the *amnion* and the *allantois*, from which spring the digestive and the respiratory systems of the developing young. None of the reptiles pass through a larval stage as do the amphibians, but are hatched, or born alive, in the form of their parents.

Our present-day reptiles comprise four large orders. The most primitive group, the Rhynchocephalia, now represented by a single species, the tuatara of New Zealand, has preserved its line unbroken for ninety million years more or less, according to geological reckoning—straight from the most ancient reptiles which flourished in lower Permian times. The tuatara is distinctly lizard-like in form, but an examination of its anatomy reveals the fact that in structure it is truly a living fossil. Most paleontologists agree that the Rhynchocephalia represent the ancestral group which gave rise to crocodiles, dinosaurs, lizards, and snakes.

The crocodilians, composed of the crocodiles, alligators, and caymans, form a natural group having about twenty-three living species. Their fundamental structural character is the possession of a completely divided ventricle in the heart, in which respect they differ from all other reptiles.

The next order, the Testudinata, or Chelonia, including the land, fresh-water and marine turtles, is one of the easiest to distinguish, since in every one of its 250 species a bony shell incases the body. Some forms retract the head by turning it sidewise horizontally to protect it under the overhanging rim of the upper shell or carapace; others contract the neck itself into the shape of a perpendicular S.

The order Squamata comprises two closely related suborders: The Sauria (sometimes called Lacertilia) or lizards, and the Serpentes (otherwise known as the Ophidia) or snakes. Aside from their more obvious but sometimes variable characteristics, lizards and snakes may readily be distinguished from each other by a single point in their anatomy—the structure of the lower jaw. In lizards, as in most other animals, the two branches of the lower jaw are firmly joined by a suture; while snakes are provided with an elastic ligament which permits them to spread the jaw horizontally. The living species of lizards known today number over 2,500; of snakes, over 2,300; and every year the number of forms known to science slowly increases.

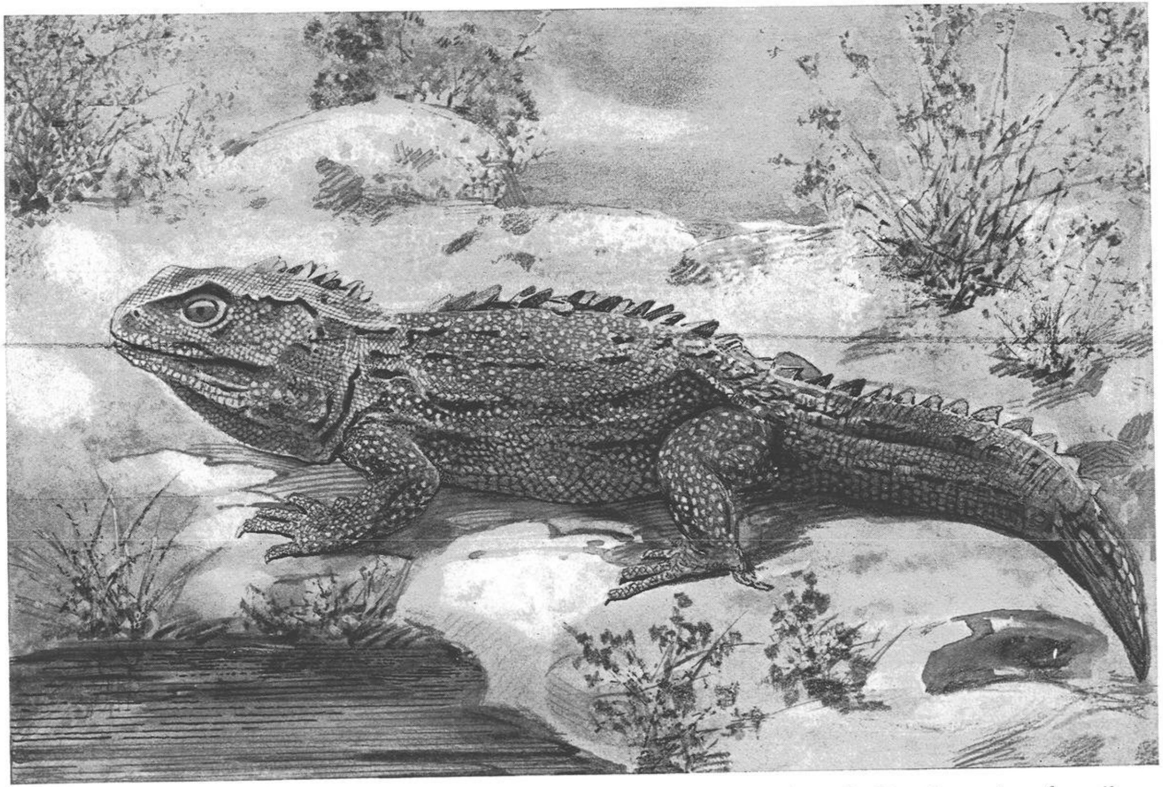
CHAPTER VIII

THE TUATARA

THE tuatara (*Sphenodon punctatum*), sole surviving member of the great Permian order Rhynchocephalia, is neither a lizard nor a crocodile, but in appearance something between, having four limbs, a short head, a heavy-set body, and a long tail. Living tuataras were first discovered in that land of oddities and weird survivals, New Zealand, *tuatara* being the Maori word for "having spines." With rapid colonization and the consequent cultivation of the land, the species has been killed off on the mainland of New Zealand, but is still found in a few outlying islands near by, where agriculture has not been so intensive.

In the summer of 1927, Dr. Frank N. Blanchard and his wife, Dr. Frieda Cobb Blanchard, sailed for New Zealand to see the tuatara in its native haunts. I quote some extracts from a letter by Dr. Frieda Blanchard:

> It [the tuatara] used to live all round the edge of New Zealand and on the islands off the coast, but the introduced animals, especially the pigs left by Captain Cook (so that the Maori would have something besides each other to eat) have all but exterminated them. There are thought to be none left now on the mainland, but they still occur on several islands which have been kept free of the pigs, mongoose, etc. They are strictly protected by the Government, and can be taken only with a special permit from the Department of Internal Affairs. . . .
>
> Sphenodon occurs particularly on the open slopes where the petrels nest; in fact it is right in the burrows of the birds, with them, that he is to be found . . . Their nests or burrows are frequently made under a rock, and many times in turning rocks we uncovered them. With every Sphenodon that we found there was a petrel and the men say that this is always the case.
>
> I will not describe the animal, for I hope that the pictures we took will be good. He is said to live largely on the "weta" which is a huge,



The tuatara, *Sphenodon punctatum*, a "living fossil," sole surviving member of a Permian order of reptiles. Confined now to a few islands off New Zealand

wingless, fiercely-jawed orthopteron. We found and collected many of the latter. . . . We got four Sphenodons to take back to the house to photograph. We could only keep one. There are plenty of them now on the island. . . . It is not taking them away that will exterminate them; the conditions are being changed and that will doubtless exterminate them as it has on the mainland. The stock wanders at large and destroys the undergrowth of the bush. This kills the trees in time. The bush is rapidly disappearing from the island.

The tuatara, which sometimes reaches a length of two and a half feet, resembles a stoutly built lizard with a line of yellowish, somewhat erectile spines extending from the top of the head along the back to the end of the tail, but interrupted on the neck. The dark olive-green skin is ornamented with small white or yellowish specks on the sides. The under surface is scaly, the rest of the body rather granular. The tail is thick and slightly compressed laterally. The large dark-brown eyes have vertical pupils.

Sphenodon sleeps during the day, preferably in the water, where he can remain submerged for hours without breathing. He lives wholly upon animals taken only when alive and moving about. The diet varies according to individual taste, and consists of small fish, insects, worms, and probably also crustaceans. *Sphenodon* is sluggish in movement, usually crawling slowly with both body and tail trailing on the ground, except in chasing prey, when he lifts the whole trunk off the ground. He can travel very slowly, only a few yards at a time, and is unable to jump the smallest obstacle. The female lays her eggs—white, hard-shelled, long, and oval—in the sands where they can be warmed by the sun. They do not hatch until about thirteen months old. Though sluggish and not aggressive, the adult *Sphenodon* will pluckily defend himself against dog or man by biting and scratching. As already explained, *Sphenodon* is usually found inhabiting burrows that he shares with various kinds of petrels. As soon as the sun has set he leaves his home to seek food. During the night, especially in the pairing season, he may be heard croaking or grunting.

It was only after careful dissection of the brain of *Sphenodon* that scientists discovered the true nature of the "pineal body," which is a small cone-shaped outgrowth found at the base of the brain of most of the higher mammals, including man himself (Fig. 78). In *Sphenodon* this body is greatly elongated and extends to the top of the head, where it ends directly beneath a little round hole in the skull, the pineal foramen. Distinct traces of an eyelike structure at this end prove that the pineal body is the only remaining vestige of a third and upward-looking eye which was undoubtedly possessed at one time by the ancestors of the mammals. Many of the recent lizards—notably the monitors—have more or less distinct traces of the "pineal eye" situated below the pineal foramen. In the monitors, the foramen is especially evident.

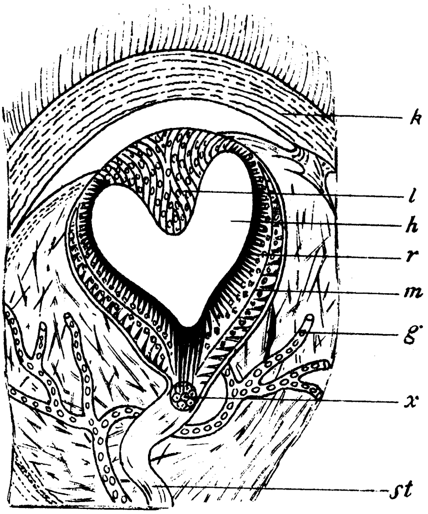


FIG. 78. The pineal eye, the remnant of a third and upward-looking eye, on the top of the tuatara's head. Well-developed in the very young, it degenerates as the reptile grows. k, capsule of connective tissue; l, lens; h, cavity of the eye filled with fluid; r, retina; m, molecular layer of the retina; g, blood vessels; x, cells in the stalk; st, stalk of the pineal eye.
After Baldwin Spencer

The tuatara, while interesting as a relic of a bygone age, seems to be of no especial economic value to mankind.

CHAPTER IX

CROCODILIANS

THE crocodilians, once a large and widespread order, are now reduced to some twenty-three living species, confined to the marshy lowlands of the tropics and semitropics. Although regarded as a single family, the Crocodylidae, they comprise four more or less distinct types—gavials, crocodiles, alligators, and caymans. These may be distinguished to a certain extent by the shape of the snout, ranging from an exceedingly long and narrow form in the gavial, through the sharp, slender, but triangular snout of some crocodiles and the broad, blunt, but also triangular form of others and of some caymans, to the very broad and bluntly rounded snouts of other caymans and of the two species of alligator (Fig. 79). Like their fossil prototypes, crocodilians are well supplied with teeth which are constantly renewed. In crocodiles, the fourth tooth on each side of the lower jaw is plainly visible when the jaws are closed; in alligators the fourth tooth is invisible. This difference constitutes a structural basis of distinction between the alligator and the crocodile.

All crocodilians have the back, and some both the back and the under parts, protected by a veritable coat of mail consisting of rows of sculptured bony scutes covered with horny scales. They resemble in bodily form gigantic lizards, since all have four strong but short legs and a laterally compressed tail. The smallest are probably at least a yard long, while one huge beast, twenty-nine feet long, was killed in the Philippines a century ago. As compared with some of their extinct forerunners, however, most modern crocodilians are mere pygmies. *Rhampho-suchus crassidens*, from the Pliocene deposits of India, reached the gigantic length of about fifty feet.

Being aquatic in their habits and depending upon what the water may bring them for food, crocodilians are best observed on the shores of the streams wherein they make their homes. A sandy bar detached somewhat from the shore itself especially attracts them, since there they may

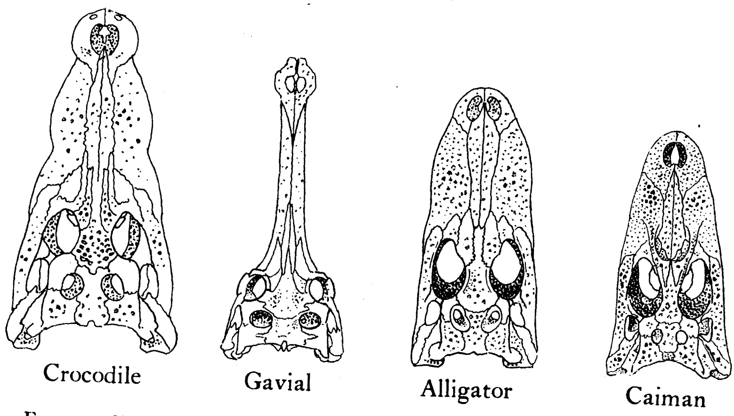


FIG. 79. Skulls of the four types of Crocodylidae viewed from above. After Charles C. Mook

the more readily observe whatever approaches; and there they lie in the warm sun, piled on top of one another in an absurd, sluggish heap. Nevertheless, if alarmed, they will lose no time in scrambling into the water.

During the mating season the scent glands of the crocodilians become most active. There are two pairs of these. One pair on the inner side, right and left, of the lower jaw, has a slitlike opening on the outside of the throat which is visible from below and leads into a pocket where the secretion from the glands is collected. This concentrated essence of musk, when obtained from the Nile crocodile, is much prized by the natives. The second pair of scent glands lies within the cloacal slit and is not visible from the outside. By means of these glands, which are possessed by both sexes, it is supposed that the animals are able to trace each other by the streak of scented water left behind each individual.

Undoubtedly the most striking feature of the crocodile is his capacious mouth fixed in a perpetual leering grin, as if in derision of the unhappy prey. The tongue is flat and thick and attached by its whole surface, so that it can be elevated but not protruded; over its surface are scattered the organs of touch and taste, in the shape of tiny wartlike elevations. By means of a transverse fold at the base, which meets a similar fold from the palate, the crocodile can close his throat completely and lie submerged in the water, except for his nostrils and wide-open mouth, thus comfortably breathing the while he

. . . welcomes little fishes in
With gently smiling jaws.

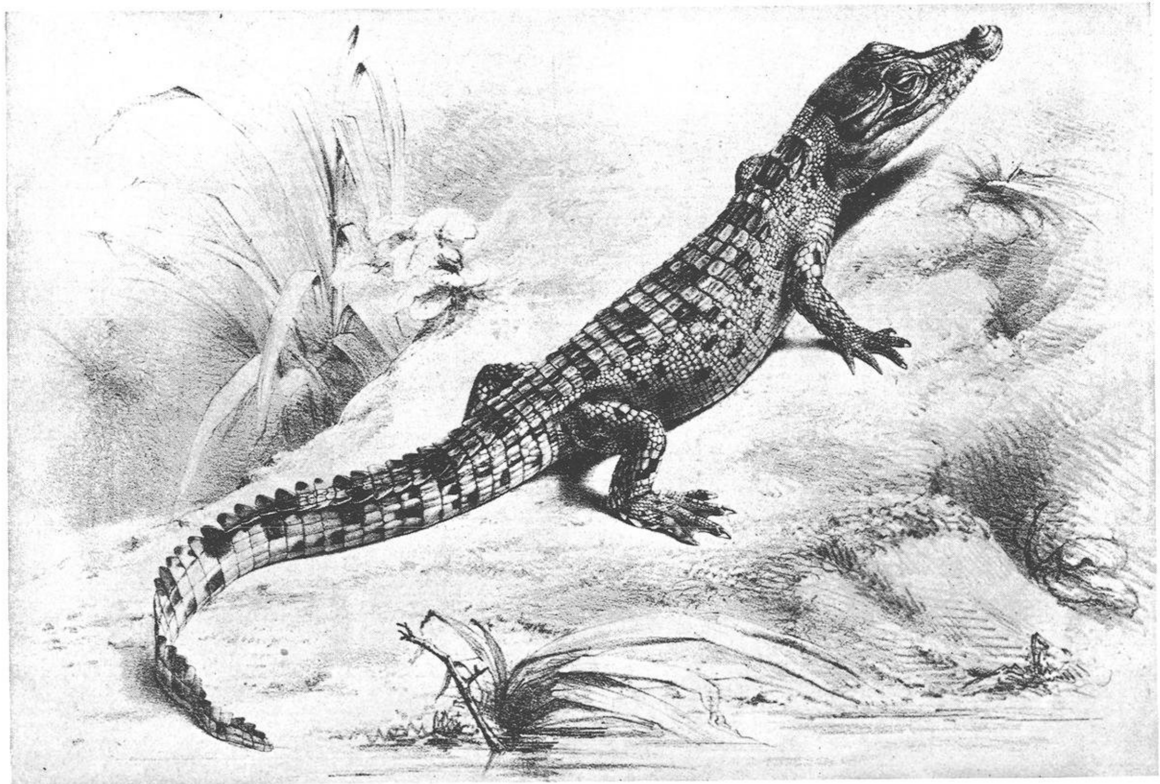
The Indian gavial (*Gavialis gangeticus*), which is one of the largest of living crocodilians, inhabits the Ganges and Brahmaputra rivers and their tributaries, extending westward along the Indus and its branches. Its extraordinarily long and narrow beak, with the knob at the end produced by the valvular nostrils and the interlocking slender teeth of needlelike sharpness, adapts it admirably to catch fish. Luckily this huge creature is seldom or never hostile to human beings. On the contrary, at sight of a man it will usually dash for the nearest water, raising its body from the ground and running on its short sturdy legs. If already in the water, with only its catlike eyes and the tip of its long snout visible, it will, when alarmed, sink noiselessly to the bottom, leaving no trace except a few bubbles on the surface. The female gavial lays her eggs in the sand. As soon as the young are hatched they can run with amazing rapidity and will bite before they are well out of the shell.

Of all the Crocodilia, by far the most celebrated is the fearsome African or Nile crocodile (*Crocodylus niloticus*), which sometimes reaches a length of fifteen feet and is found throughout Africa, except in desert regions, and swarms also in the inland rivers of Madagascar. Although abundant in many localities, the crocodile has been practically exterminated in lower Egypt; numerous mummies remain, however, to testify to its former abundance and to the reverence in which it was once held in this region. Only since the introduction of firearms has it been possible to cope successfully with this dangerous brute, bows and arrows, spears, and clubs being of little avail. It requires many men to drag out a full-grown specimen captured with hook and line. In some localities the natives use the hide as an effective armor against the primitive weapons of hostile tribes.

The Nile crocodile, which ordinarily lives in long subterranean burrows, deposits from twenty to thirty eggs in a specially constructed hollow, dug usually in white sand, laying half that number and covering them over with sand before depositing the remainder. The hole is then completely filled up so that no trace remains. The young before hatching utter a distinct piping sound which is said to be a warning to the mother, who habitually sleeps on the nest, to dig the eggs out from the enveloping sand. This she does, and then leads her newly hatched brood down to the water.

Larger than its cousin of the Nile, reaching a length of twenty feet or more, the salt-water crocodile (*Crocodylus porosus*), inhabits tidal waters and frequently goes to sea, so that it has a widespread distribution along the coasts of the Gulf of Bengal, southern China, and the Malay Archipelago southward to Australia and eastward to the Solomon and Fiji islands.

The American crocodile (*Crocodylus acutus*) is found in the West Indies and southern Florida and along the coasts of tropical North and South America, where it inhabits the salt-water marshes. Its greatest length is about four-



The salt-water crocodile, *Crocodilus porosus*, of southeastern Asia. It reaches a length of twenty feet. The Siamese consider it the most dangerous of wild animals. After Günther

teen feet and, while more vicious and active than the alligator, it does not bother human beings as some of its Old World relatives occasionally do. Where it still exists in settled areas, however, its voracity towards mammals, birds, and fish draws it distinctly into conflict with man, who also depends on these things for his food supply.

Our American alligator (*Alligator mississipiensis*), inhabiting the rivers and swamps of the Carolinas, southward through the Gulf States and westward to the Rio Grande, seems to display a good deal of parental solicitude in the care of its eggs. In the summer time the mother seeks out a damp, hot place on the solid ground, where she pushes together a great nest of roots and sticks and rotting vegetables. Here she deposits her eggs, in number anywhere from three to five dozen, then pulls some of the moist vegetation over them, packs the mass down, and leaves them to hatch. The eggs are white and ellipsoid in form—about the diameter of a hen's egg but more elongate—with a very thick solid shell of a peculiar pitted texture.

About two months later, when the baby alligators are ready to hatch, the mother is said by some to dig open the nest so they may scramble out of the débris and make immediately for the nearest shallows. It is a wise mother that knows her own children, and truly I doubt if she does, so much alike are these active eight-inch youngsters. Some authorities have it that the adults devour the young, while others state just as positively that the young are protected most carefully by the parent, who remains on the lookout for danger and rushes out with a fearful racket to attack anything that comes near the shallow water wherein the young 'gators are disporting themselves.

The rate of growth for alligators is probably variable, though not so slow as most people think. Doctor Ditmars, who reared some in captivity, found that for the first few years they grew with surprising rapidity. Just after hatching they were eight inches long and weighed one and three-eighths ounces. Five years from hatching they were five feet six inches long, on an average, and weighed fifty pounds. In the wild state, with an unlimited supply of fish, they probably reach maturity within four or five years. An alligator is sexually mature when less than eight feet long, and a female of this size has been known to deposit thirty-seven eggs. Growth continues long after sexual maturity is reached, though quite slowly, and a thirteen-foot specimen must be a true patriarch.

Now as to the food of our American alligator: Some records exist of its having actually attacked and eaten human beings; without doubt it is responsible for maiming a few. It devours a great many edible crabs and some of the larger fish, and will undoubtedly snap up any small mammal which is foolish enough to get within reach, while wading birds and wild ducks are greedily seized.

Besides its terrible jaws, the alligator possesses another weapon of defense—its powerful tail, a blow from which has been said to snap off a young tree. When surprised some distance inland, the alligator, like the gavial, will raise its body a foot or more from the ground and run toward the water with surprising agility for a creature ordinarily so sluggish and heavy. The alligator is exceptional among reptiles in having a loud voice. In the swamps, the bellowing of the males may be heard for over a mile.

In the lower Yangtze River in China lives the only other known species, *Alligator sinensis*, closely resembling ours in appearance, but dwarfed in size, no individual over five feet eight inches long having been recorded. It is quite rare, being limited to a narrow range, and as a source of hides it will never be of any moment commercially.

Five species of cayman (genus *Caiman*) inhabit Central America and tropical South America east of the Andes. They resemble alligators in general appearance, but differ from them in having a much heavier ventral armor composed of overlapping bony scutes, each of which is formed of two articulated halves.

The black cayman (*Caiman niger*) is said to grow to a length of twenty feet, which, if true would give it the distinction of being the largest of the New World crocodilians. It is found in the upper tributaries of the Amazon and resembles the alligator in general appearance and in some of its markings. The spectacled cayman (*Caiman sclerops*) occurs from Mexico through Central America and South America into Argentina. It takes its name from the heavy wrinkled eyelids that suggest a pair of spectacles. Sometimes the eyelids are developed into blunt horns.

The food habits of crocodilians as a group are such that man certainly does not benefit by them. Where man has brought his domesticated animals to a country long the domain of these voracious reptiles, he finds a continual toll taken of his pigs, calves, dogs, goats, or other livestock that may stray too near to the silent and motionless beasts which look like stranded logs lying on the river bank. In some places where very large crocodiles occur, as in the Malay Peninsula, certain old monsters are known to attack human bathers occasionally. Their fish-eating habits tend to bring them into conflict with man's interests, although this is probably not a serious item in tropical rivers where fish are usually abundant. As a source of leather, alligators and crocodiles have a distinct economic value, since the toughness and durability of their skins, when tanned, adapt them for use in the manufacture of many articles requiring a fine grade of leather.

CHAPTER X

TURTLES

THE order Testudinata, or Chelonia, comprises some 225 species of turtles, or tortoises as they are sometimes called. Little changed, except in size, from their Cretaceous ancestors, turtles are unique among living vertebrates in having their fore limbs attached inside the ribs, and in possessing a protective shell and a pair of horn-covered, toothless jaws. All have four stout limbs, more or less modified for swimming or for walking.

Besides possessing well-developed eyes and a fine sense of touch, turtles presumably are able to smell and to taste, since some species discriminate in the choice of food. They can not protrude their broad, flabby tongues. They have no very acute sense of hearing, and their voice is for the most part limited to a feeble piping during the pairing season.

All turtles lay white eggs, the shell of which varies from thin and flexible to thick, rigid, and well-polished. The eggs are buried in the ground, where they usually hatch after a few months. In some northern species, however, the development of the embryos is arrested during the winter, the little turtles not emerging until the following spring.

The turtle race is widely distributed and its representatives are found both on dry land and in most of the waters of the earth. Many varieties live in the mud of shallow ditches; some dwell in clear ponds or rivers; others spend most of their life in the sea. The land forms are distributed from north to south over both hemispheres where the cold is not too severe in winter.

In size, turtles range from the little mud turtles, measuring only four or five inches in length when fully grown, all the way up to the huge sea turtles; the leatherback, under favorable conditions, is a giant six or seven feet long. A fossil tortoise from northwestern India measured nearly twenty feet in length.

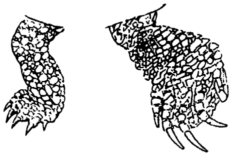
Owing to their build, no turtles are agile at climbing or running. The hard-shelled forms depend for protection on the heavy box of bone surrounding them; the soft-shelled species, on their razor-sharp jaws. With a few exceptions, however, turtles are notably unaggressive. They feed for the most part on anything and everything that is at all edible, although certain forms are strictly vegetarian.

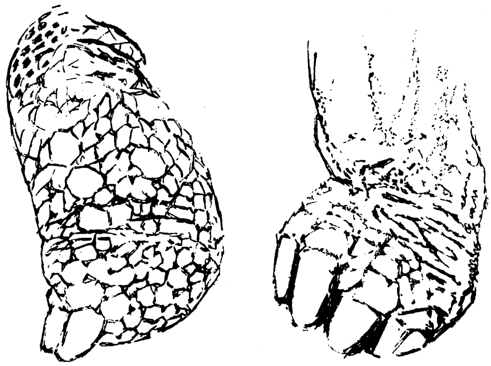
We may for convenience classify turtles as hard-shelled and soft-shelled; or again, according to habitat, as marine (turtles proper), fresh-water (terrapins), and land forms (tortoises). The systematist, however, usually ignores these more superficial distinctions and bases his classification solely on structure.

All living turtles with the exception of one species, the leatherback (*Dermochelys coriacea*), have the ribs solidly fused with the upper shell. *Dermochelys*, therefore, not only constitutes a separate family, the Dermochelidae, but by some authors is regarded as representing a distinct suborder, the Athecae. All other species are assigned to the suborder Thecophora, comprising ten families. These, again, are grouped into three superfamilies: The Cryptodira, including in its six families the Testudinidae, the most numerous of all, which embraces the greater number of the marine and fresh-water forms, as well as all the terrestrial species; the Pleurodira, mostly fresh-water forms, distributed among three families; and the Trionychoidea, soft-shelled turtles, comprising but a single family, the Trionychidae.

If we wish to distinguish between marine, fresh-water, and land turtles we must pay particular attention to the limbs (Fig. 80). In land turtles, both pairs of legs are pretty much alike, and in some of the larger species they bear a grotesque resemblance to an elephant's legs, especially when the heavy nails have become blunted by use. In fresh-water turtles the hind legs are larger and stronger than the fore legs and are chiefly used in swimming. In the sea turtles, the limbs are modified into flippers, the fore legs being the longer and serving as the principal swimming organs.

The obvious difference between the hard-shelled and soft-shelled turtles lies in the presence or absence of the characteristic horny shield. This, however, is quite distinct from the true bony skeleton which is found with certain modifications in all turtles, hard-shelled and soft-shelled alike (Fig. 81). The shell, which is made up of true bone covered usually with horny shields and





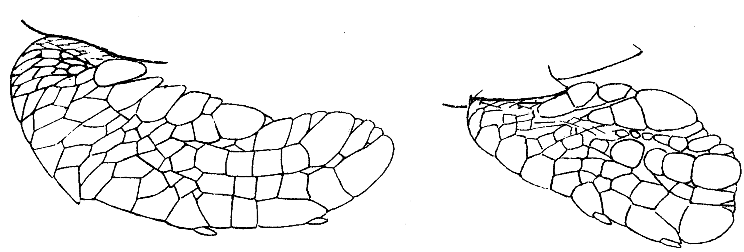


FIG. 80. Upper, smaller forefoot and larger hind foot of fresh-water turtle; middle, forefoot (side view) and hind foot of land turtle of the Galápagos Islands; lower, larger foreflipper and smaller hind flipper of marine hawksbill turtle

lined with a thin layer of subcutaneous connective tissue, consists of a dorsal portion, or carapace, and a ventral portion, or plastron, which are rigidly joined together on the sides. The horny epidermal shields do

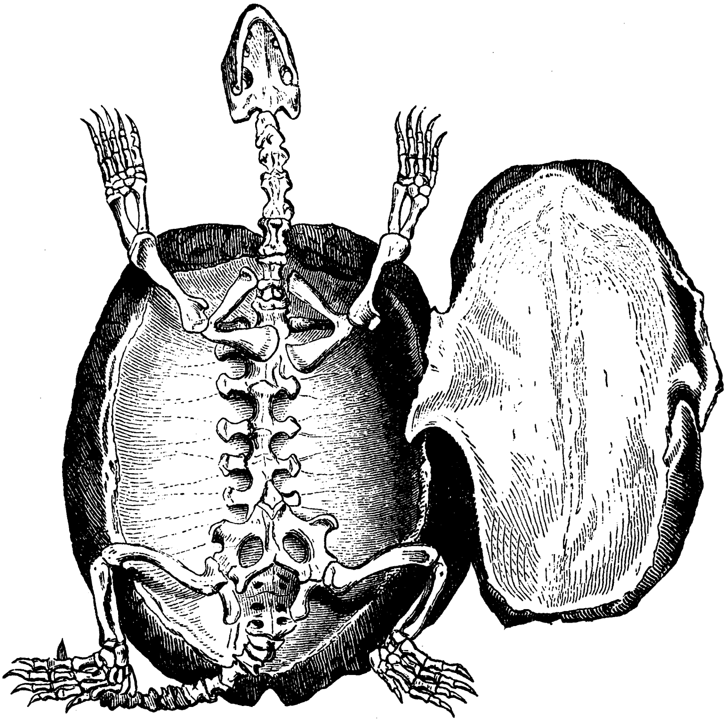


Fig. 81. Internal bony skeleton of a turtle, ventral view. The upper and lower shells consist of true bone covered (in most cases) with horny shields. After Brehms

not correspond exactly either in number or position with the bony plates of the shell, although there is a general resemblance in their arrangement. In the so-called soft-shelled forms, the bony plates are covered with skin instead of with the horny shields.

The "leatherback" (*Dermochelys coriacea*) represents a very aberrant group of marine turtles (Fig. 82). Its most striking characteristic is the tough, leathery body covering from which it takes its name and which is composed of a mosaic of hundreds of bony plates, embedded in and covered by the skin. Seven longitudinal ridges of the larger

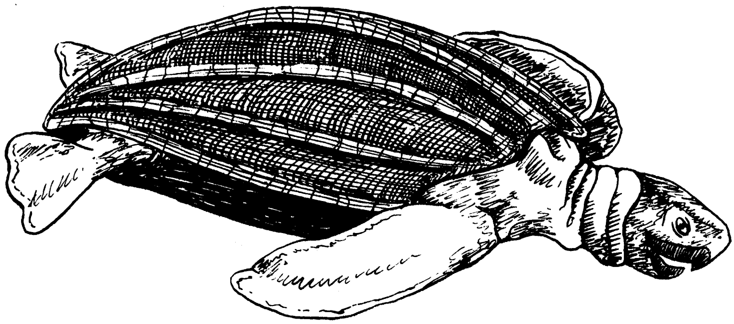


FIG. 82. The leatherback, *Dermochelys coriacea*, largest of living turtles, eight feet long and weighing 1,500 pounds

plates rise on the back and converge at the tail end of the shell, while five more ridges occur on the ventral portion. As noted, this is the only turtle which has the ribs and vertebrae free from the carapace.

The leatherback has the distinction of being the largest of living turtles, sometimes reaching a length of eight feet and weighing 1,500 pounds. In the sea it proves itself a most graceful and agile swimmer. It may be seen in shallow waters, poised, ready to swoop down on any morsel it may chance to spy on the sandy bottom, just as a vulture drops down from the sky to seize its prey.

Any marine turtle seen gliding a little below the surface of the water, with outstretched flippers, appears as swift and graceful as a bird soaring in the air on spread wings; while the same creature on shore will move so awkwardly and slowly that it may be overtaken and captured without difficulty. Fortunately for their safety, sea turtles spend their whole life in the water except at egg-laying time, when the females crawl out, usually at night, on to a sandy beach above high-tide line, to scoop a hole in the sand and deposit the eggs, which sometimes number many hundreds. The round white eggs, with their parchmentlike shells, look much like tennis balls. They contain valuable oil and prove very good eating, though somewhat musky. The eggs hatch in about two months, and as soon as the young turtles have scratched their way out through their blanket of sand they make with all speed down to the water, which they never voluntarily leave until they are fully grown. They have many enemies, as all the larger fish and even their own parents willingly swallow them, but by remaining in the warm shallow inlets, a small percentage of them reach their full size, and then they are safe except from man.

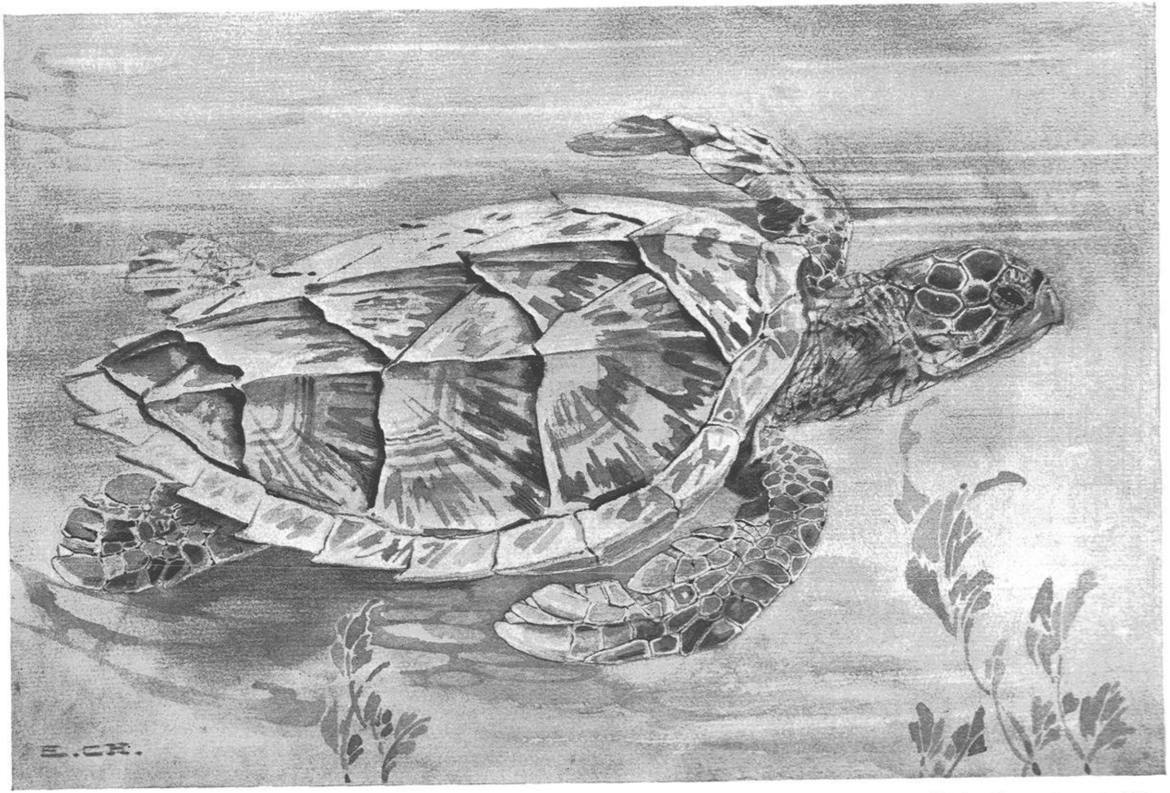
The Cheloniidae, a very important family of sea turtles, have paddles, or flippers, which show no separate fingers externally. In this family we find both the green turtle, renowned as an article of food, and the "hawksbill," which furnishes the valuable tortoise shell.

The green turtle (*Chelonia mydas*), so called because of the greenish hue of its fat, ranks first among the sea turtles as a food product. Some individuals may attain a weight of five or six hundred pounds, with a shell length of four feet, but those sold in the market seldom exceed 150 pounds, as the heavier ones are too tough for the general taste. The green turtle is herbivorous, feeding upon a certain marine plant called turtle grass; this it cuts near the roots to procure the most tender and succulent part, which alone is eaten, while the rest of the plant floats to the surface, where it spreads over large areas—a sure indication that the feeding ground of the green turtle is near. Turtle hunting takes place at all seasons of the year, but particularly at the breeding season. Much wanton destruction results from this practice, for at such times the females congregate on the seashore in great numbers, and may be secured by simply turning them on their backs, in which position they are helpless and unable to right themselves. As many more are turned than can be carried away, numbers are thus left to perish miserably.

The plastron, or lower shell, of these sea-going turtles is pliable and does not have to support the weight of the animal except in the brief trips shoreward at egg-laying time. Hence the custom of keeping the turtle in the markets rolled over on its back. If placed in the normal position when out of the water the animal's great weight presses the lungs and other internal organs down on the plastron, thus causing speedy death.

The hawksbill (*Eretmochelys imbricata*) is the smallest of the marine turtles and the only one whose shell is suitable for commercial purposes (Plate 67). It is distinguished from the other members of its family by the upper jaw, prolonged and hooked somewhat like the beak of a hawk. On the back there are thirteen large, horny plates constituting the tortoise shell. The twenty-four smaller marginal pieces which border the carapace, like the plates of the plastron, are of inferior value. The hawksbill feeds on seaweeds, crabs, mollusks, and fish, and grows to a length of about four and one-half feet, only rarely attaining a weight of 150 pounds. A good-sized hawksbill will yield eight pounds of shell.

The turtles of the family Testudinidae have well-developed, fingered feet and can withdraw the head and neck in an S shape under the shell. This family includes a number of interesting forms distributed over the temperate and warmer regions of the globe. Among them are land turtles which for countless centuries have maintained themselves in safety in desert strongholds only to fall at last victims to man's encroachment. Giant species occur on the islands of the Aldabra and Seychelles groups and a few others in the Indian Ocean near the coast of Africa; while still other giant forms once densely populated the Galápagos Islands, a volcanic group many miles



The hawksbill, *Eretmochelys imbricata*, smallest of the marine turtles, which provides all the "tortoise shell" of commerce

west of the mainland of Peru. Here the Spanish discoverers found great numbers of enormous turtles, which have since steadily diminished, until now they are gone from nearly every one of the many islands where formerly the crews of the whaling ships used to collect two hundred in a single day. The discovery of such a supply of delicious meat was of great importance to buccaneer and whaling ships, which would often stop at these desert islands and procure enough turtles to last them a year or more. The turtle meat was esteemed a great delicacy, and the fresh food was a godsend to the sailors, faced with the possibility of contracting scurvy, which an insufficiency of fresh vegetables or meats invariably brought on. The turtles were carried into the ship and laid on their backs in the dark hold, where they could not turn over. Here they lay for perhaps a year or more, alive and nourished on their own stored fat and on the peculiar storage pockets of fresh water in their necks. In fact, large turtles were sometimes killed solely to furnish from these reservoirs a drink of sweet water to the thirsty sailors. In this region, without wells or springs or natural fresh water of any sort excepting the rain, a wise provision of nature endows these creatures with a storage bag in their necks, so that when the equinoctial tempests come and the rain collects in every crevice of the lava rocks, the turtles may drink their fill before the water evaporates under the strong rays of the tropic sun. They are then able to do without another drink of water for a long period of time, living on what they carry about with them in the storage bag.

The precise maximum age which these animals can attain still remains to be determined. Some have lived for many years in zoological gardens. In 1766 a full-grown Seychelles Island tortoise was taken to Mauritius (then a French possession), where it was kept at Port Louis. When Mauritius was acquired by the British in 1810, the tortoise was especially mentioned in the conveyance and taken over, and was still living in the grounds of the garrison in 1901.

The brilliantly colored "painted terrapin" (*Chrysemys picta*) of the eastern United States, one of the smallest of fresh-water species, reaches a shell length of but six inches (Plate 68). Not only does this beautiful little creature possess a shell strikingly patterned in red, yellow, and black, but also displays delicate, bright yellow and red

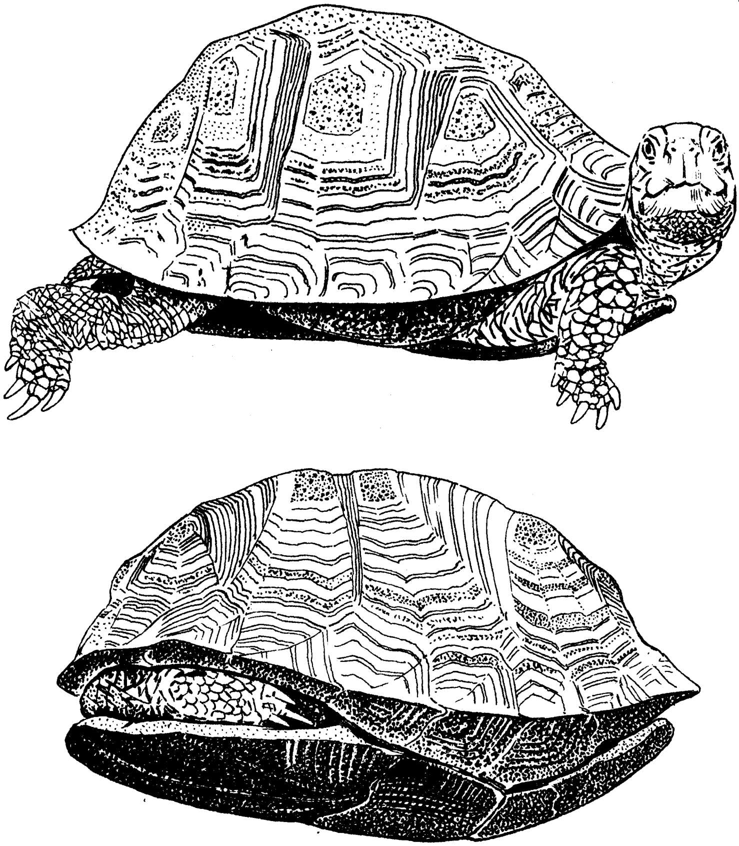
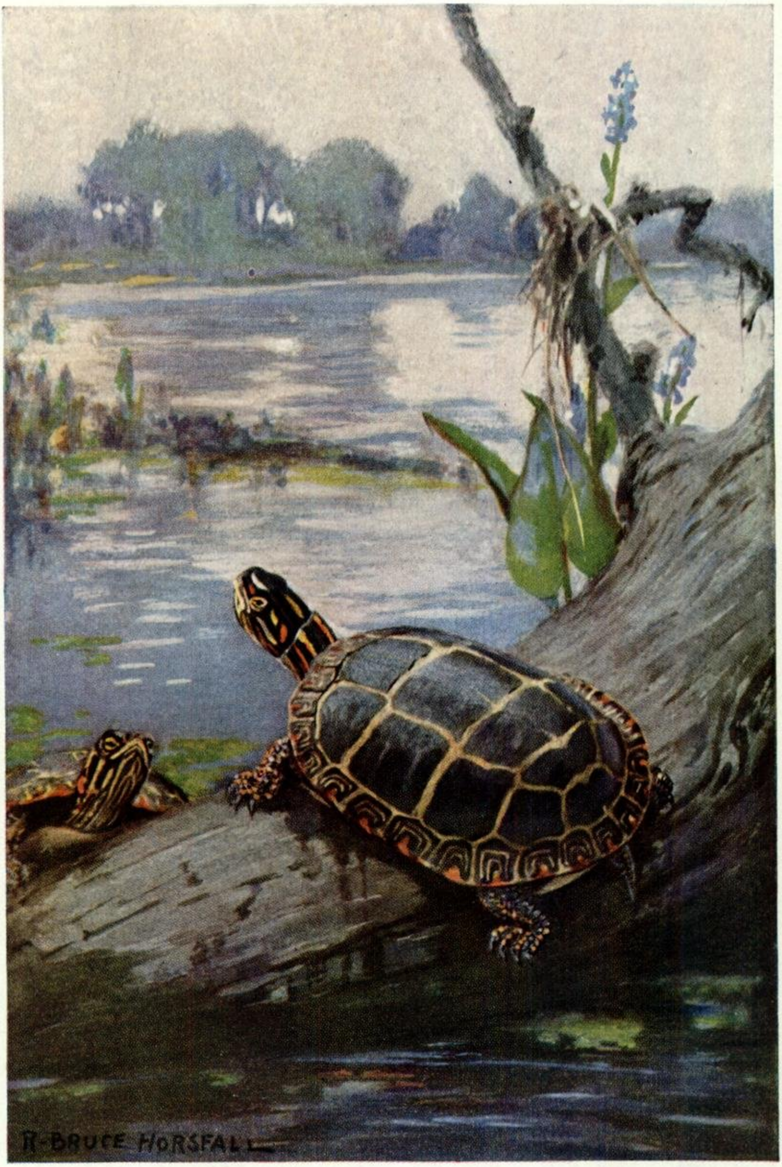


FIG. 83. The familiar American box turtle, *Terrapene carolina*, on the move and in retreat



The painted terrapin, *Chrysemys picta*, of the eastern United States

stripes on neck, limbs, and tail. Even the mouth appears painted with black and yellow stripes, while several bright yellow patches ornament the head. The painted terrapin has the unusual habit among turtles of shedding the outer layer of his horny dermal shields, so that after a few years his flattened carapace presents a perfectly smooth surface.

Most familiar of American tortoises is the box turtle (*Terrapene carolina*), so named from his habit, when annoyed or frightened, of withdrawing his head, legs, and tail entirely within his shell, the lower portion of which is hinged and movable and closes up so that the soft fleshy parts of the body are completely incased in a solid covering of bone (Fig. 83). Indeed, so tightly does the turtle shut himself into his armor that often there is no place where as much as a piece of paper could be pushed between the edges of the upper and lower shell, nor could any small prowling four-footed enemy make an opening. But the turtle does not remain "boxed up" indefinitely. If you watch him quietly for a few minutes the powerful muscles which effect the closure of the "lid" will begin to tire, and soon the animal will slowly thrust forth his head to find out if the coast is once more clear, and eventually he will waddle off as if nothing had happened.

Box turtles living in fields where a plentiful supply of wild strawberries or other succulent fruits may be found sometimes become so fat that they can not completely close both parts of the shell; if you happen to pick up one in this condition, it is amusing to watch him vainly trying to close the front entrance of his shell, while the back entrance is forced slightly open by his own too fat little legs. The musk turtles (*Kinosternon* and *Sternothaerus*) and the "semibox turtle" (*Emys blandingii*) are able to move the lower shell also. These may easily be distinguished, as they are aquatic and quite different in appearance from the box turtles. In Africa there is a kind of land turtle (*Kinixys*), much larger than our box turtle but probably similar in its habits, which has a partial hinge on the back portion of the upper shell, so that this upper part may be closed down to meet the rigid lower part, just the opposite of what happens in the closing of the box turtle's shell.

Our common box turtle (*Terrapene carolina*) is frequently found roaming in fields, woods, and pasture lands in the Eastern States. Another species inhabits the Southern States, and still others occur in the West, where they range well into Mexico. In our eastern box turtle, the high, rounded shell, which is almost a hemisphere, reaches a length of nearly six inches when the turtle is fully grown. These turtles are unfortunately addicted to traveling along the public highways, where many of them are crushed to death by passing automobiles. In fact, their extermination in regions bordering the busiest thoroughfares is a practical certainty.

When the reproductive season draws near, the female box turtle seeks a spot for depositing her eggs where the earth is soft and fairly dry. Some turtle eggs unearthed in a garden were brought to the Museum laboratory and placed at once in a pan of moist sand, so that the process of hatching might take place without further disturbance. Although thin and brittle when newly laid, the shell of the eggs just before hatching became leathery and quite pliable, so that the surface could be indented by a gentle touch, unlike that of a bird's egg, which, of course, is always quite rigid. That the shell was very strong and difficult to tear was proved by the length of time which it took the little turtles to work their way out. The first notice of their coming was the appearance of a small rip at one end of the egg. This was made by the "egg pip," which is a small, sharp, hornlike projection formed on the beak of the baby turtle, as well as on that of some birds, while it is still in the shell, and used only to rupture the imprisoning walls. The egg pip disappears shortly after the turtle or bird hatches, for it is never needed again.

The opening once made, the little turtle works almost continuously, moving his head from side to side, and even using the tiny claws of his forefeet to try to enlarge the opening. Several hours of mild kicking and struggling are usually needed to tear the shell down in ribbons, much as a banana peel separates from the fruit beneath. By the next day, following several periods of alternate rest and activity, the baby turtle has gained sufficient strength to free himself entirely and to crawl away from the remains of his prison. At this stage he is covered with a moist albuminous substance which very quickly dries on contact with the air. When turned over on his back, the placental suture in the lower part of the shell, through which the yolk of the egg once flowed to nourish the forming tissues, can easily be seen.

For a few days the main instinct of the newly hatched turtle is to hide completely away, no doubt because he is not yet able to move the hinge of the lower shell or to retract his head and legs to escape danger. It is not long, however, before the youngster can shut himself as nicely as you please into the little box of his own bones; but the hiding instinct remains a dominant one until he has actually reached maturity. Very few small or half-grown box turtles are ever found, even by careful searching, whereas a full-grown specimen may be met with often enough.

Very young turtles show no distinct markings, their shells being a dull brown with a light spot in the center of each scale. When half-grown, their coloration, while exceedingly variable, is much clearer than at any other period of life. An irregular or starlike pattern of yellow marks every scale of the back, and the under shell is yellow around the edges and dark brown in the middle. Often the yellow stars on the back are intensified to deep orange or almost to brick-red, and after a rain the little turtle looks very handsome in his brown suit with orange trimmings. In old turtles the color markings become very dull and faint, because of the hard wear on the surface of the scales.

The age of a young box turtle can be told quite accurately by counting the number of ridges on a scale from the center outward. At the time he is hatched the scales are already formed, and subsequent growth takes place around their margins. Each year at the approach of winter the box turtle finds a favorable spot of soft earth into which he begins to burrow until he is completely out of sight and also out of reach of the biting frost. Here in a state of absolute torpidity the turtle passes the winter in reptilian sleep. The heart very nearly stops beating, the circulation of the blood proceeds at a mere fraction of its usual rate, and breathing stops entirely. Growth also ceases, and when the spring sun at last brings a little warmth and renewed life to the box turtle in his subterranean retreat, he emerges to activity once more with the record of his winter's sleep etched upon his shell in the form of a little channel from which the new growth begins. On box turtles up to twenty years of age these ridges can usually be counted fairly easily; but many years of hard knocks and rough usage are apt to wear the ridges away so they can no longer be seen.

This species grows with comparative rapidity for a time, the length of three inches being reached in five years. But it requires from fifteen to twenty years for a box turtle to reach the fair size of six inches. No one knows just how long they can exist under favorable conditions, but some have been known to live over sixty years. The healthy adults are practically immune to danger from predatory animals owing to their hinged shell, but the eggs and the young turtles are hunted for food by skunks, raccoons, foxes, weasels and muskrats. Snakes also have been known to swallow young turtles, and undoubtedly a great number of them die every winter because they have not burrowed deep enough into the ground to escape freezing to death.

TURTLES

The ancient philosophers of Asia believed that this world rested on the back of a turtle and that this turtle himself stood upon nothing but his own dignity. The Indian aborigines of our country had a somewhat similar myth. Some believed that in the beginning of things there was nothing but a tortoise sleeping upon space; but after awhile he awoke and, becoming tired of his solitary existence, sank into the abysmal depths, whence he emerged finally with the earth upon his back. For lack of anything better to do, this tortoise has upheld the world ever since, but some day he will sink into the mud again, carrying the earth with him, and that will be the end.

CHAPTER XI

LIZARDS

LIZARDS and snakes are usually grouped together under the order Squamata, the lizards being known as the suborder Sauria (the Lacertilia of some authors), and the snakes as the suborder Serpentes, or Ophidia. As the frogs and toads are dominant among amphibians, so these two most variable and adaptable groups—lizards and snakes—are dominant today among living reptiles.

The 2,500 known species of lizards are found living under almost every conceivable condition of environment. On the cold Siberian plains, in scorching deserts, in moist lowlands, on high mountains, and on the seashore, lizards can make themselves at home, though most of them prefer the tropics and subtropics. Hibernating and aestivating through seasons of cold and heat, burrowing, running, climbing, swimming, even gliding through the air with specially devised parachutes, this plastic order has succeeded in adapting itself to every sort of habitat short of the regions of perpetual snow and ice.

Fortunately most of these creatures benefit mankind through their preference for insect food. None is aggressive toward man, although some will bite if they can not run away. Only the two species of the genus *Heloderma*, one of them our "Gila monster," are known to be venomous. Some lizards feed on small mammals, birds, and eggs, while the beach dwellers eat the smaller creatures cast up by the sea or living among the seaweed. A few, such as the chuckwalla, have taken to a vegetable diet.

Superficially, certain lizards may resemble their very distant cousins, the caecilians and salamanders, more than their nearer relatives, the snakes. Like the caecilians, some burrowing lizards are practically blind and limbless. They may be recognized, however, by their covering of external scales and by the tongue, which, unlike that of the caecilians, is long and slender and capable of being protruded. Similarly, the most salamanderlike lizards may be readily distinguished by their scaly bodies, very different from the smooth translucent skin of the true salamanders. The chief difference between lizards and the amphibians, however, consists in the manner of development. Lizards, in common with other reptiles, have no larval stage but are hatched as miniature likenesses of their parents. In some forms development progresses so far before the eggs are laid that the young make their appearance almost immediately afterward. A few species produce living young.

The typical lizard is, of course, easily distinguishable from any snake; in the limbless forms, however, we must look for the less obvious points of difference. Of these, the most distinctive characters are found in the structure of the lower jaw. In lizards, the two sides of the lower jaw are joined immovably in front; while snakes have an elastic ligament connecting the two bones, which permits them to expand the jaw in order to swallow their prey. Most lizards, too, have movable eyelids, while in snakes the lid has become transparent and immovably fixed over the cornea so that it merely functions as an outer membrane of the eye. An obvious external difference is the absence in all snakes of an outer ear opening, which is visible in most lizards. There are differences also in the skeleton and in the circulatory system.

A consideration of the formation of the tongue and teeth is of paramount importance in assigning the proper systematic position to any reptile, recent or fossil. The texture and shape of the tongue have long been considered important features in tracing relationships among the separate groups of lizards. Certain families, such as the Gekkonidae and Iguanidae, possess broad, fleshy tongues, which are partly covered with papillae and which can not be protruded very far. Such a tongue is obviously designed to help in the process of eating and has no extensive use as an organ of touch. Other families, well represented by the Varanidae, have a slender, forked, tubular tongue, which is heavily set with minute papillae and may be retracted into a basal sheath or extended to serve as an organ of touch as the lizard explores unusual surroundings, thus compensating for the heavy skin which prevents the delicate functioning of the ordinary sense of touch. The intermediate steps, from the fleshy tongue used in eating only to the delicate, highly sensitive one which serves also as a touch organ, may be found in the Lacertidae, Teiidae, and Anguidae, where the tongue performs both functions.

The teeth are sometimes attached by their bases to the edge of the jaw (acrodont form), and sometimes fixed by their sides to the inner surface (pleurodont). In no recent form of the lizard family are they embedded in sockets. In some of the lizard's predecessors, however, we find the thecodont dentition, in which the teeth are large, conical, hollow, rootless, and lodged each in its own socket, or alveolus, being replaced when worn out by a new one developed on the inner side. Sometimes, in living species, teeth occur on the palatal bones.

Lizards may be grouped into two main subdivisions—the Lacertilia Vera, or true lizards, world-wide in their range; and the Rhiptoglossa, comprising the Old World chameleons and their allies. Although no two systematic zoologists may agree as to exactly how many families there are, we may state broadly that there are about twenty in the first subdivision and only one—the Chamaeleontidae—in the other.

While we may consider that we know most of the species of lizards in certain intensively explored regions, other regions constantly yield unknown forms to expert collectors. The Old World family, Lacertidae, of which the wall lizard of Europe is a common example, has been assiduously studied by many scientists of ability; yet divergent forms of this family are still being collected in the sandy desert regions of Africa or on small rocky islets of the Mediterranean, where they have been cut off for centuries from their relatives on the mainland. The final

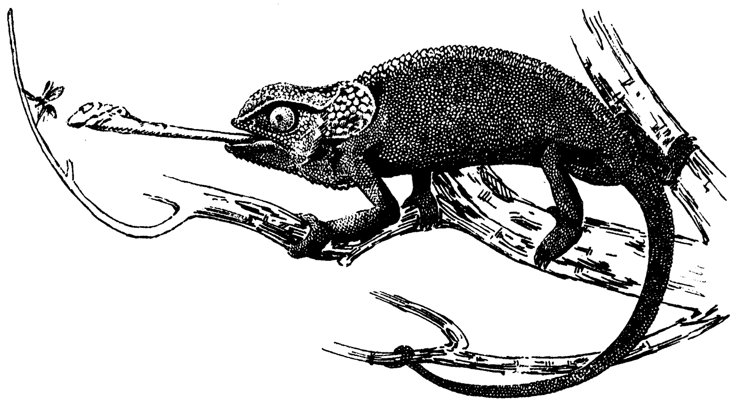


Fig. 84. The African chameleon, *Chamaeleon dilepis*, about eight inches long, shooting his tongue out a distance almost equal to his own length to catch an insect

word has not been said on any group of reptiles, and it is probable that many years will elapse before we know the lizards well enough to give a clear and complete picture of the relationships of all the families.

The Old World chameleons—not to be confused with our American "chameleon," so-called—have been variously ranked as a suborder of the Squamata distinct from both the lizards and the snakes, and as a subdivision or merely a family of the lizards. These curious creatures have been termed the most fantastic objects to be found among land animals today. The group is essentially African, about half of the fifty known species inhabiting Madagascar, a few extending into southern Asia, and one occurring in southern Spain as well as in the neighboring regions of north Africa.

These slow-moving denizens of the tree tops present a most grotesque appearance (Fig. 84). The common chameleon (*Chamaeleon vulgaris*) measures about eight inches from the tip of his nose to the end of his prehensile tail. The eyes project in startling fashion from the casquelike bony head. Each prominent eye moves independently, so that one may be directed straight ahead while the other is peering sidewise or backward through a small central opening in the enveloping movable eyelid.

Ordinarily one does not see the chameleon's tongue at all. But let a fly alight on a twig seven or eight inches in front of him, and a streak will dart from his mouth and the fly vanish as if by magic. Without his extremely long, flexible, sticky tongue, the chameleon would fare poorly indeed, being most deliberate, slow, and clumsy in all his movements.

Living as he does among the tree tops, the chameleon's feet are adapted for grasping rather than for walking. He has the five digits on both hands and feet separated into two groups of two and of three digits, respectively, tightly joined at the base and opposable. Moreover, both fingers and toes are provided with sharp little claws, so that, although the wind may rock the tree top where he clings, he will remain firmly anchored, with his tail wound around the branch for added safety.

The skin that covers the chameleon's laterally compressed body and long slender limbs is not scaly, but granular, and possesses an extraordinary power of changing its color and even its pattern. A chameleon will literally "turn green with fright," his usually dull greenish-blue skin becoming a vivid green under stress of strong emotion. Again he may appear a yellowish-gray or dirty brown. But you will be disappointed if you put him on a checkerboard, expecting him to imitate its colors and pattern. Aside from his emotions, the chief causes of a chameleon's color changes are light and heat. "Adaptation to their immediate surroundings," says Gadow, "takes place to a very moderate degree only, but as a rule they are brightest, especially in their green tints, when they are allowed to sit amongst green foliage. The introduction of a branch with fresh leaves generally has a brightening effect upon those which have previously been confined in a cage with dry twigs only. Cold does not necessarily make them pale, but they appear duller and the changes take place more slowly."

The geckos, found exclusively in tropical and semi-tropical countries, form another group of lizards distinctive enough to be regarded by some as a separate subdivision. Attaining a length of from one to fifteen inches, these creatures with soft flattened bodies and sprawling disklike toes make most unwelcome visitors on warm summer evenings, when they invade the houses, running over walls and ceilings in search of insects attracted by the lights. Sometimes, indeed, geckos become permanent guests in dwellings, hiding by day in the thatch of the roof, behind pictures, or in crevices of the walls, and emerging only at night to chase their insect prey.

Seen at close range, the typical gecko reveals a pair of large, lidless, staring eyes and a head that when silhouetted against a bright light appears to have a window in it. This is formed by a passage free from bony obstructions, which admits the light from ear to ear. Many geckos have an extraordinary development of the ear in the shape of a pair of large bags on either side of the neck containing the chalklike otolithic crystals usually found in the internal ear, which by vibrating in the surrounding lymph convey sound waves to the brain.

Geckos take their name from a characteristic call—little more than a soft cluck—which, when repeated resembles the word "gecko." Some species have taken up life in the desert, with resulting changes in structure and habits. Such forms have exchanged the typical catlike, elongated pupil of the eye for one that is round and suitable for daylight service; while the adhesive disks of the toes, so useful in running over smooth surfaces, have been replaced by

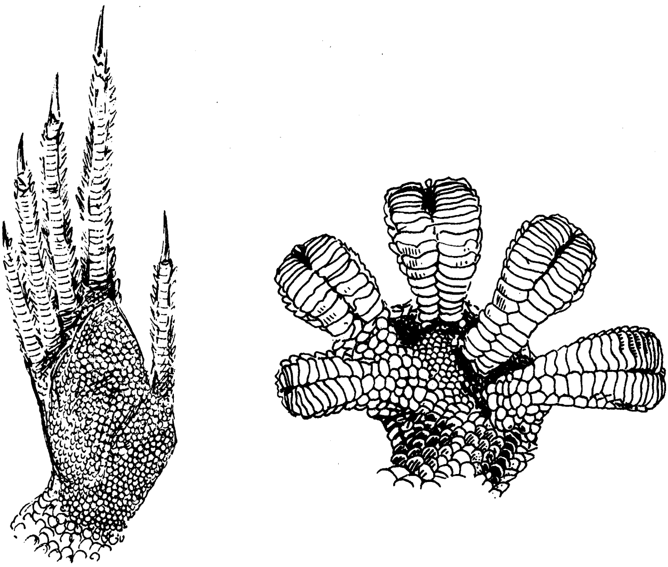


FIG. 85. The feet of two species of lizard compared, to show adaptations to environment. Left is the foot of an arboreal gecko, and right, of a lizard that lives on sandy deserts

fringes of scales that keep the creature's feet from sinking into the sand (Fig. 85).

Though capable of inspiring terror by its startling appearance and elusive habits, the gecko has no means of defense except its peculiar ability to escape by leaving its brittle tail in the grasp of the enemy. The stump soon produces a new tail differing from the old one only in the number and arrangement of the scales.

The Old World family Agamidae includes some of the most interesting of the lizards. The 200 species of this group vary greatly in form and habits, but all are acrodont, *i.e.*, they have the teeth set, not in sockets, but on the

The "flying dragon," *Draco volans*, of the Malay Peninsula, which glides from its home in the tree tops by the aid of membranes on each side of the body

edges of the jaw bones and more or less differentiated into incisors, canines, and molars. These agile, daylight-loving lizards have small keen eyes with round pupils and a complete set of movable eyelids. They wear no heavy armor of scales, the skin of most species being covered with a fine granular scalation, although some bear formidable spines on various parts of the body. The various species show adaptations to many kinds of habitat.

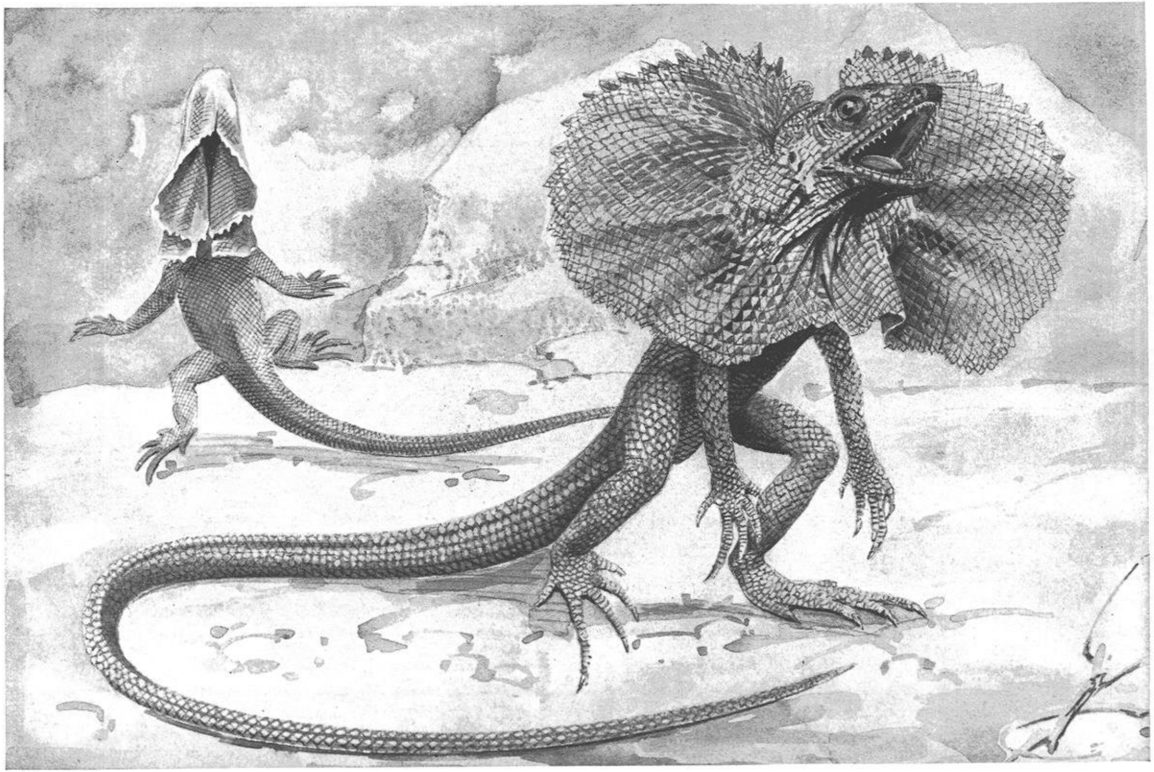
Draco, the little "flying dragon" found in the Malay Archipelago and in southern Asia, possesses a remarkable umbrella-like parachute, fashioned of a wide membrane on either side of the body, which may be folded or extended at will by means of five long, movable ribs, (Plate 69). These lizards travel in small companies, climbing to the top of a tree in search of ants, their favorite food, and then gliding down by means of their parachutes to the foot of the next tree. They can direct their flight for twenty yards or more, closing their parachutes as they settle down on the trunk of a tree. In flight they are as beautiful as the most gorgeous butterflies, the under surface of the semitransparent "wings" being usually ornamented with splashes of bright red, orange, or yellow, and sometimes decorated with lines and spots of deep blue or black. Even when at rest they resemble butterflies in their habit of opening and folding their pretty wings. Their vivid colors actually serve to conceal them by making them like the brightly colored flowers of the tropical trees on which they live.

Much more deserving of the name *dragon*, however, is the extraordinary "frilled lizard" (*Chlamydosaurus kingi*) of Australia, that vast island whereon nature has chosen to collect so many of her animal freaks (Plate 70). Even without the strange frills of skin around the neck, the creatures would be formidable looking, being strongly built, lithe, very active, and nearly a yard long, including the long, snakelike tail. The frill about the neck can be erected or lowered at will by muscles attached to long horny arches which extend into the flaps of skin somewhat like the ribs of an umbrella. When pursued, the lizard folds his frill, rears on his hind legs, and runs with extraordinary speed, his long tail curved over his back and his forelegs hanging in front, kangaroo fashion. Reaching a tree, which he can readily climb, he will turn at bay, spreading out the shield to its full extent, in the midst of which appears the wide-open, red, cavernous mouth armed with powerful teeth.

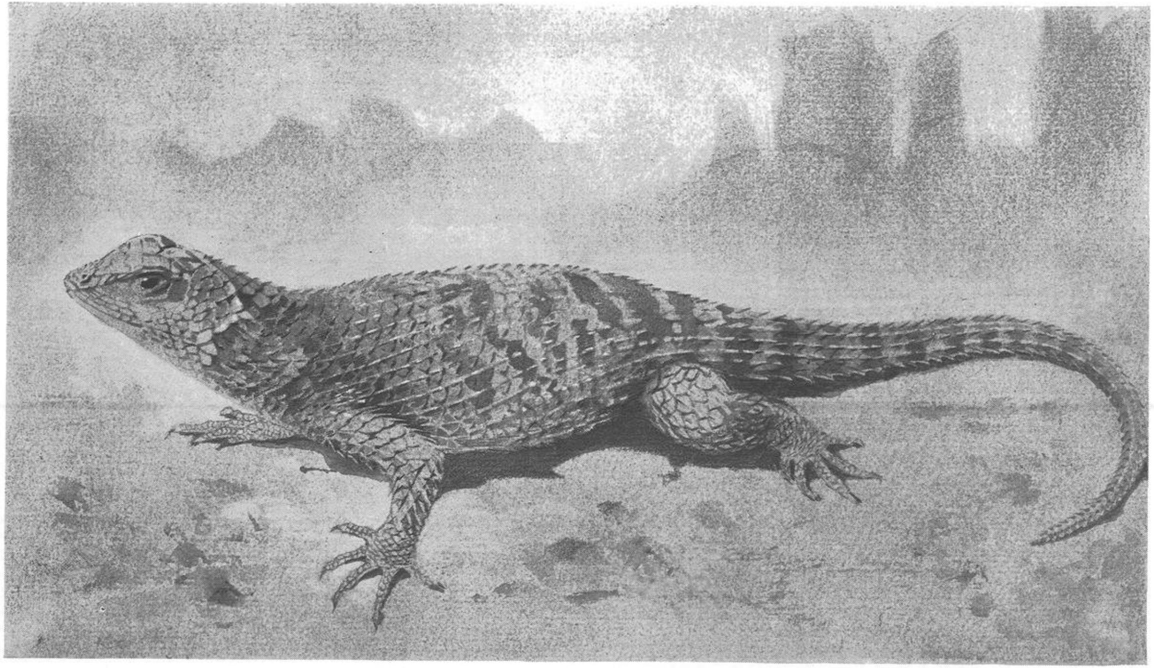
Another Australian member of the family Agamidae is the small but grotesque desert species, *Moloch horridus*, whose body is thickly studded with short, stout, prickly spines. This curious creature lives upon ants and is said to possess the power of absorbing quantities of water through the skin. It has no means of defense other than its spines.

The several species of the genus *Uromastix*, which inhabit the deserts of Asia and Africa, bear spines only on the tail and are appropriately known as the "spiny-tailed lizards." They live chiefly upon vegetable food—leaves, grass, and fruit—and can exist in practically waterless regions by absorbing dew through their skins.

An arboreal species of the Agamidae in Ceylon, *Lyriocephalus scutatus*, possesses so many of the characteristics of the totally unrelated chameleons, that it might easily be mistaken for one of the latter group. Another arboreal genus is *Calotes*, which resembles chameleons in its power of rapidly changing color. Because of this harmless trait *Calotes versicolor*, one of the commonest lizards of India, has been branded with the very misleading name of "bloodsucker." When excited or angered the lizard's brownish body turns yellow, the sides of the head, throat, and neck becoming a vivid red. Other startling color changes occur in this species, especially among the males during the breeding season. The species of the aquatic genus *Physignathus*, on the other hand, resemble crocodiles in their water-haunting habits and in their long,



The frilled lizard, *Chlamydosaurus kingi*, of Australia, nearly three feet long, capable of extending its frill at will



The spiny lizard, *Sceloporus orcutti*, of the southern United States. Large, overlapping, sharp-pointed scales give it a formidable appearance laterally compressed tails, topped with spiny crests. Then there is the very active desert species, *Agama stellio*, which is said to give offense to devout Moslems by nodding its head as if in prayer.

If we have dwelt at length on the various types of lizards to be found in the single, Old World family Agamidae, it is in order to emphasize sharply the extraordinary effect of environment upon development. For on the other side of the world, in the tropical and semitropical regions of the Americas, we find a totally distinct family, the Iguanidae, some of whose members, subjected to similar variations in environment, show a startling resemblance to the Agamidae.

The Iguanidae are distinguished from the Agamidae chiefly by their pleurodont dentition; that is, the teeth are attached to the lateral surface instead of to the edges of the jaws as in the Old World family. The Iguanidae are not wholly confined to the New World however, two genera occurring in Madagascar and one in the Fiji and Friendly islands. Among the 300 species we find arboreal, terrestrial, burrowing, and semiaquatic forms, and even one sea-going species, all differing as much in appearance as in habits.

Anolis, the largest genus of the Iguanidae, including no less than 200 species, is found in the southeastern United States, throughout Mexico, Central America, tropical South America, and the West Indies. These are the American "chameleons," so called from their rapidly changing colors, although neither in bodily form nor in specialized structures do they resemble the true chameleons of the Old World.

The best-known species, *Anolis carolinensis*, of the southeastern United States and Cuba, delights in running along fences or on the walls of buildings, like a big fly, aided by the disks on its feet. These adhesive pads are not placed at the end of the toe, as they are in the geckos, but along the middle part of each digit. The body is covered with minute granular scales, and the large blunt-nosed head has given to the animal the popular name of "alligator lizard." Not only is *Anolis* a famous climber; it can also hop from leaf to leaf of a tree as easily as any tree toad.

While *Anolis* does not depend on absorption through the skin to obtain its water supply, as does the spiny-tailed lizard, it would die of thirst as quickly if it had only a pan of water in its cage. In the wild state it laps up dew from leaves, and in captivity it looks for water supplied in a comparable manner. Sprinkling the cage will do the trick. For food it requires meal worms and flies.

The American "chameleon" almost equals the true chameleon of Europe as a colorist. The same causes influence his changes of hue—light, heat, and emotion, with the latter producing the most vivid effects, as can be seen when two males give battle. Then the throat fans distend and turn a vivid pink, while the bodies exchange the familiar dark brown of a sunny day for an emerald hue. An amusing ceremony of head nodding proceeds for a minute or two before the combat starts. These battles are not very serious in their outcome, for even if the vanquished one loses a tail in action, he goes away unconcernedly and grows a new one in a few weeks.

Most of the common, widely distributed lizards that go by the name of "swifts" belong to two important genera of the Iguanidae. The first of these, the genus *Uta*, including about sixteen species known as the small-scaled swifts, is found usually in the deserts of the southwestern United States and Lower California. These lizards live in rocky places, where they scamper with extraordinary speed after their insect prey or dart into crevices to hide. As a rule they are tiny creatures, dull-colored to match the rocks and sand of their desert home. But two species living in Lower California are an exception to this rule. One of these, the barred swift (*Uta thalassina*) reaches the length of two feet, and displays a back of rich, dark green crossed toward the head by three sooty-black bars.

The second genus, *Sceloporus*, includes about thirty-five species, known as the spiny swifts, distributed throughout the warmer parts of the United States and making their headquarters in Mexico and Central America. The bodies of these lizards bristle with large, overlapping, sharp-pointed scales, the needlelike tips of which on some species curl slightly outward, producing a very formidable appearance. The largest of all, the collared swift (*Sceloporus torquatus*) of Mexico, is so heavily armed with coarse, overlapping, spiny-tipped scales that it is sometimes called the "porcupine lizard."

The desert genus *Phrynosoma*, the so-called "horned toad," shows a startling likeness to the Australian *Moloch horridus* (Plate 72). Fabulous accounts—all equally unfounded—appear periodically affirming that this lizard can live a long time in an air-tight compartment. The "horned toad" gets its name from two rounded spines on the head pointing upward, in addition to three spines on each temple. Most species have certain distinctive color markings, usually a ribbon of yellow running down the back nearly to the tip of the tail and three brown spots on each side of the ribbon, each of which is bordered on one edge with yellow. Because of this coloring of mingled gold and brown these lizards are absolutely invisible at a distance of a few feet as they lie flat on the sand of the desert. The frill of horns around the back of the head serves merely to frighten their enemies and to make it more difficult for them to be swallowed. When disturbed they will on very rare occasions squirt a few drops of their own blood from near the eye at the aggressor. This strange reaction is said to result from the raising of the blood pressure due to fear or anger, until the fine capillaries near the corner of the eye actually burst.

Largest of the Iguanidae, attaining a length in some species of six feet, are the several genera known as iguanas, which occur from the southwestern edge of the United States southward throughout tropical South America. To the east they extend to the West Indies, while on the west we find two species in the Galápagos Islands, and another in the Fiji and Friendly islands. Iguanas have rather narrow, high bodies with a ridge of spines running down the back. Many species are eaten, the flesh being considered comparable to chicken meat.

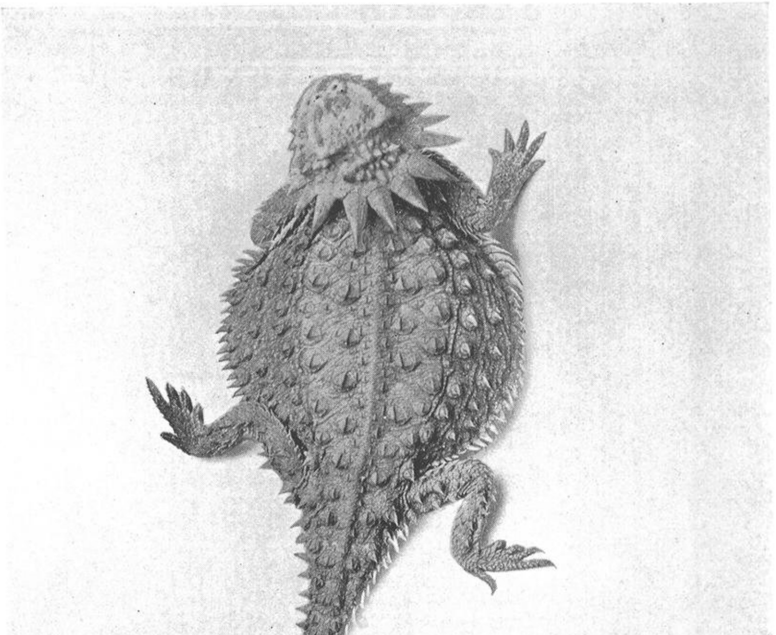
We find that the food habits of these lizards vary according to the environment in which they live. Arboreal species are quick to snap up crawling and flying insects, while the larger species are certainly not above filching birds' eggs, young birds, and probably also nest-building rodents. The forms living on the ground or around the trunks of fallen trees utilize as food almost any animal of suitable size. Ants, beetles, slugs, and earthworms probably are most readily obtained. Some forms have taken to a vegetarian diet.

The marine iguanas of the Galápagos Islands (*Amblyrhynchus cristatus*), gregarious lizards assembling in flocks of several hundred individuals, sometimes reach a length of four and a half feet (Plate 73). They are agile swimmers, apparently diving to a considerable depth to obtain the seaweed upon which they feed.

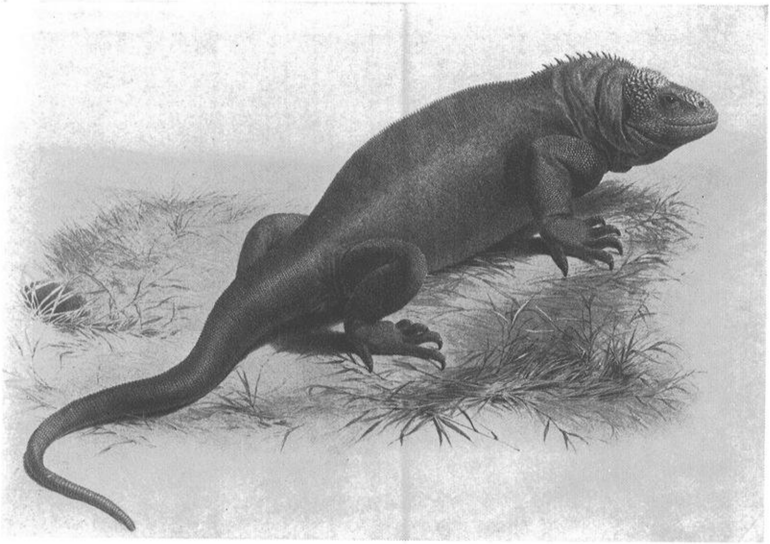
Strangely enough, one of the heaviest looking of the Iguanidae, the chuckwalla (*Sauromalus ater*) of the deserts of our Southwestern States, is the most delicate in its choice of food, which consists largely of dandelion flowers and very tender leaves.

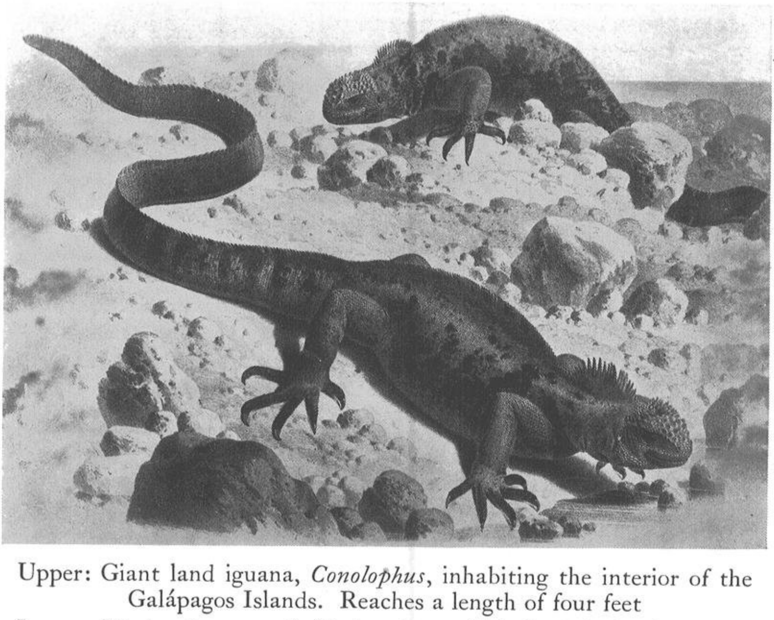
Of the half dozen lizards about to be described, representing different families and exhibiting widely varying characters and habits, all are of the pleurodont type except one, the tegu (*Tupinambis teguixin*); found generally in South America and in the West Indies.

Tupinambis belongs to an American family of lizards, the Teiidae, whose teeth are neither of the pleurodont nor acrodont type but, being solid and set almost on the edges of the jaws, are intermediate between the two types. The three species of the genus are all known as tegus,



The so-called horned toad, *Phrynosoma solare*, of our southwestern deserts. Seen from the top and side





Upper: Giant land iguana, *Conolophus*, inhabiting the interior of the Galápagos Islands. Reaches a length of four feet

Lower: Marine iguana, *Amblyrhynchus*, which lives in herds on the coasts of these islands. After Steindachner

Tupinambis teguixin representing the most common form. This tegu, the largest member of the whole family, reaches a yard in length, most of which is comprised in the round, tapering, snakelike tail. It presents a formidable appearance, with its heavy, thick-set body, stout active limbs, long, sprawling, clawed toes, and serpentine tail and head, the latter showing small glittering eyes, a quick-darting forked tongue, and big cheek pouches or jowls like those of an old crocodile. The general color of the animal is a dark bluish-black, ornamented with wide crossbars made up of small light-yellow spots on back, flanks, and tail. The under surface reverses this pattern, the ground color being reddish-yellow with irregular black bars. Tegus are swift runners and rapacious eaters, often destroying young chickens on farms and usually making their escape unless awaited with a gun or pursued by trained dogs. In many parts of South America they are themselves hunted for their flesh, which is said to be tender and of excellent flavor. The Teiidae are analogous to the typical Old World pleurodont family, the Lacertidae, or true lizards, which comprises over one hundred species widely distributed throughout Europe, Asia, and Africa.

A family of even wider distribution is that of the skinks (Scincidae) which are found in both the Eastern and the Western Hemispheres and include a great variety of forms, most of which, however, possess similar scales—large, rounded, smooth, and overlapping one another like extremely thin shingles. Most of the species have short limbs, but are fleet runners; some are snakelike and possess limbs in varying stages of degeneracy, while a few have lost them altogether. Typical of our American species having well-formed limbs is the blue-tailed skink (*Eumeces fasciatus*), which ranges from Massachusetts to Florida and westward to Texas. The most characteristic feature of this little lizard, which seldom reaches a length of more than ten inches, is its brilliant and varied coloration, showing a regular series of changes as the creature develops from youth to maturity. In this connection Doctor Ditmars says:

> Young and old examples are so entirely different, they were at one time, not far remote, thought to represent well-defined species. The immature specimens are jet black with five bright yellow stripes running lengthwise on the body; the tail of such individuals is of brilliant blue and in wonderful contrast to the colors of the body. As the lizard approaches maturity the body assumes a brownish tinge, the stripes become less distinct and upon the males disappear altogether, while the head takes on a fiery red hue. This phase is known as the red-headed lizard, or "scorpion" and for a time was technically called *Eumeces erythrocephalus*. It is thought by the negroes to be very poisonous. Female specimens retain the stripes; these, however, are less distinct against the brown body hue than with the young; the red tinge on the head of the female is never so brilliant as on the other sex. The complete color transformation takes three or four years.

Strange fables readily attach themselves to wild creatures which are a little mysterious to the casual observer because of their retiring habits and timid natures. Concerning the "glass snake" of the United States, the story has often been related in all good faith that this creature can break up its body into small pieces, put itself together again at its leisure and go on as good as new. It is believed to have magical powers of thus reassembling itself, such as no other animal possesses. The glass snake, however, is not a true snake at all, but a legless lizard, *Ophisaurus*, which means literally "snake lizard." This lizard no longer possesses legs: he has no further use for them, since he has taken exclusively to a burrowing life and lives by choice in loose earth, under decaying bark and in rich loam where plentiful supplies of insects may be found. It is a well-known fact that the legs of many burrowing lizards have disappeared altogether, or degenerated so that they are merely useless flaps of skin lying along the body, quite incapable of aiding in the creature's locomotion in any way whatsoever.

Now as to the contention that *Ophisaurus* can break himself into little pieces and then mend himself again!

When pursued by an enemy—usually a large king snake or small mammal—the lizard tries to slip away through the grass. But as his enemy may travel much faster than he himself can, he would be in danger of being caught except for a wise provision of nature. When cornered too closely, the glass snake can, with a sudden twist, cause his tail to snap completely off (Fig. 86). The dismembered tail thrashes about and wriggles and quivers for awhile with nervous twitchings as if alive, so that the enemy falls upon it, while the lizard himself glides off inconspicuously, and very shortly a new tail grows where the old one came off. But it never has the same color or shape as the old one. The original tail, long and tapering, perfectly matches in color the rest of the lizard's body—a metallic olive-green with a bronze stripe down each side. The new tail, always shorter and stubbier, presents a striking contrast, being cream-colored or light brown. Nor are the scales of the new tail as even as those on the old.

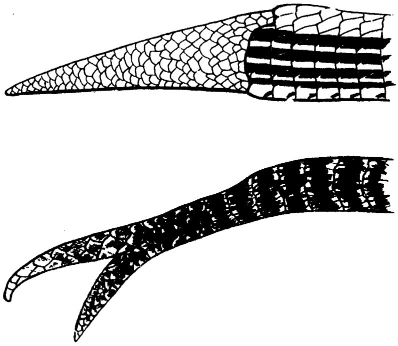
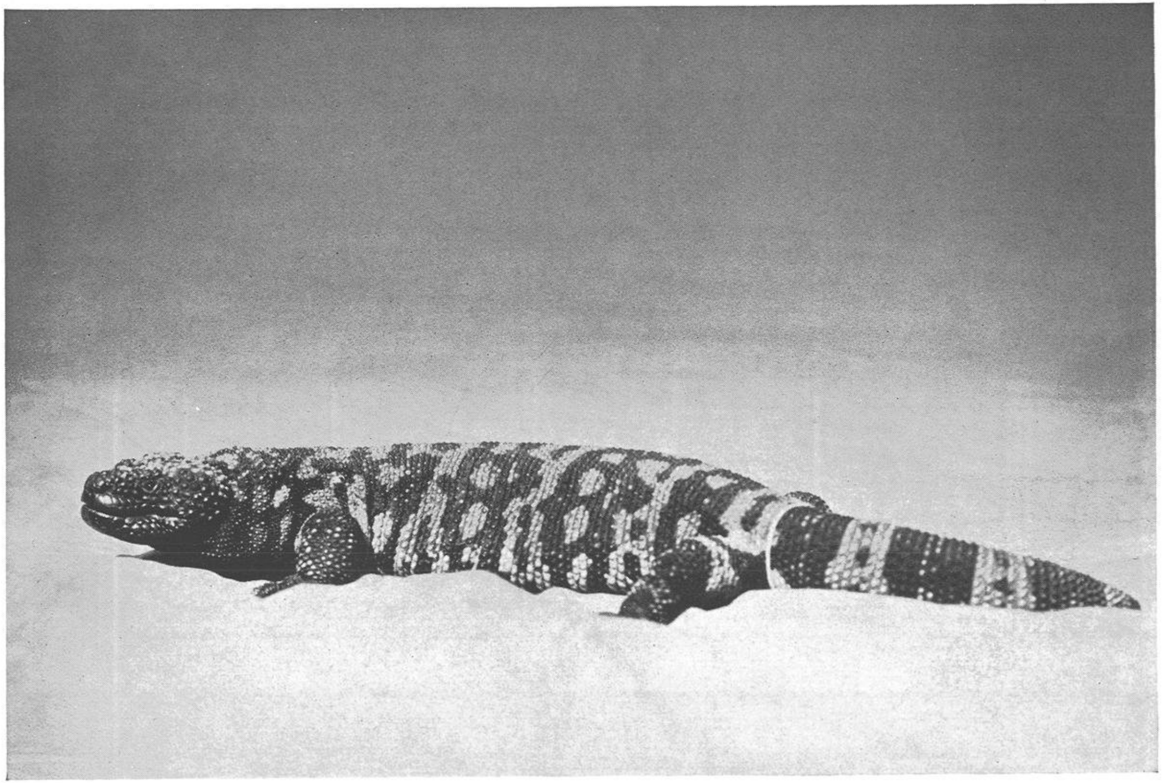


FIG. 86. New tails grown by the "glass snakes," *Ophisaurus ventralis*, after snapping off their original tails

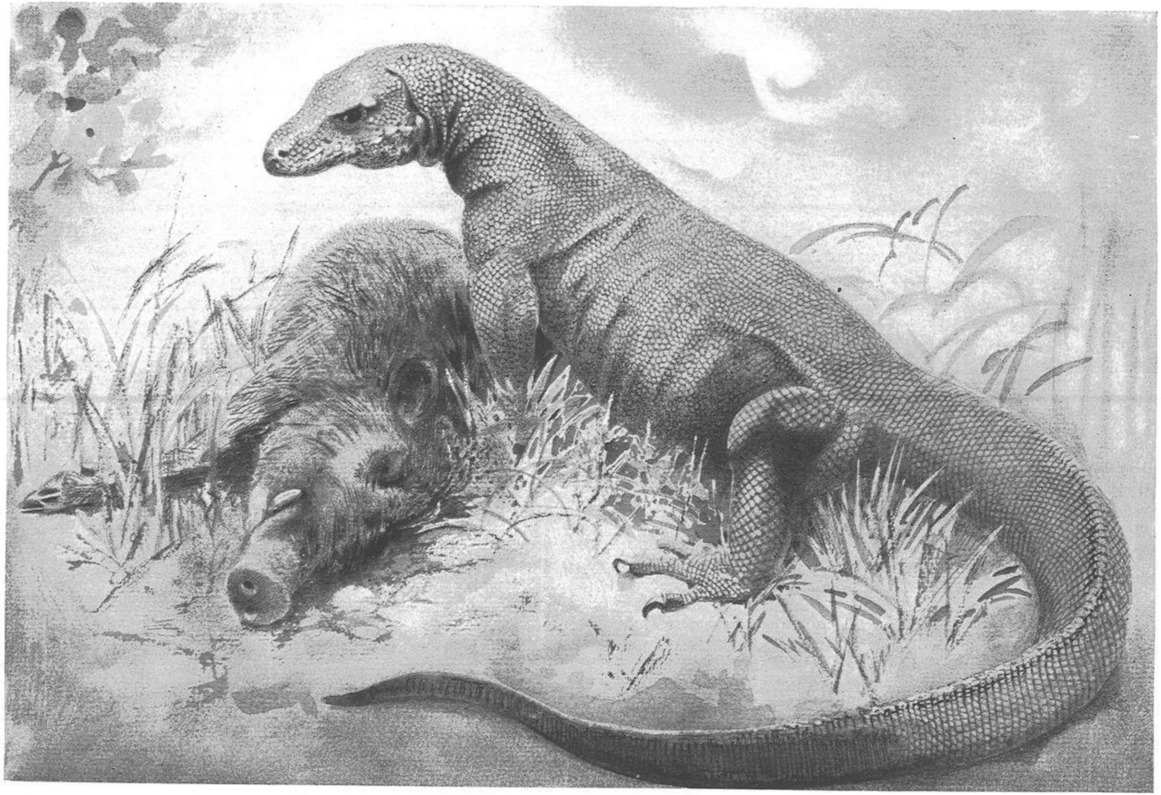
It is only the caudal appendage that has such regenerative power. If the body of the glass snake is accidentally broken in two, the lizard will, of course, die. The loss of a tail is seldom fatal to any reptile, and many other lizards besides the glass snake have the same power of regenerating the lost member. In fact, in the glass snake, as in other lizards, a very slight injury to the surface is sometimes enough to stimulate the production of a new growth, so that the injured tail heals while the new part continues to grow, until the tail eventually presents a perfectly forked appearance. I have seen lizards with as many as three tail tips.

Distantly related to the wormlike Anguidae, to which family the glass snake belongs, the Helodermatidae, or beaded lizards, comprise but the single genus *Heloderma*, with two species. One of these, *Heloderma horridum*, lives in Mexico. The other, *Heloderma suspectum*, is none other than the well-known and justly feared Gila monster of New Mexico and Arizona. These extraordinary beasts have a vivid combination of colors—pink and black, or yellow and black—forming an irregular pattern of blotches on the body and broad rings on the tail which, with the pebbly appearance of the skin, gives an effect precisely like that of Indian beadwork. Under the chin lie the poison glands, which pour out their venom onto the floor of the mouth between lips and gums. The teeth are grooved to help the insertion of the venom into the wound. The venom is about as deadly as that of a rattlesnake, and fatalities have been known to occur from it. The upper jaw emits a saliva which is nontoxic. The animal is not easily angered to the point of biting, yet when aroused it can move with considerable rapidity; and the strong jaws hold firmly whatever they have seized.

The monitors (family Varanidae), inhabiting southern Asia, Africa, and Australia, surpass all other modern lizards in size, several of the commoner ones attaining a length of eight feet, of which the tail makes up slightly more than half. The giant among monitors at the present time, *Varanus komodoensis*, lives on the island of Komodo (east of Java), where it is known to reach a length of nine feet, preying on native deer and wild hogs (Plate 75). In the past, giant monitors, perhaps even larger than those now found upon Komodo, appear to have been common in various places in the East Indies, where they were greatly feared by the natives. Indeed some accounts of the mythical dragon may have had a basis of fact in the appearance of these grotesque creatures. Despite the fear



The American Gila monster, *Heloderma suspectum*, one of the two known species of poisonous lizards. Photograph from the National Zoological Park



The giant among living lizards, *Varanus komodoensis*, a monitor living on the island of Komodo in the East Indies. Reaches a length of nine feet and preys on deer and wild hogs they inspire, the great lizards are eagerly sought as food by the natives of the regions they inhabit. Many are semi-aquatic, while others live exclusively on land, retreating at night to burrow under the rocks.

Varanus niloticus, the Nile monitor, whose long black body, decorated with a series of yellow spots across the back and tail, attains a total length of five and a half feet, has a long, angular head like that of a crocodile. This lizard is quite at home on the ground and in spite of its heavy body is a surprisingly swift runner, having very well-developed legs. Its toes are armed with great hooked claws with which it digs for the young of burrowing mice, its favorite food. It also preys on small lizards and eggs of snakes, its voracious appetite accounting for the destruction of vast numbers of harmful rodents as well as of the eggs of some of the poisonous serpents of Africa. It is known even to pursue fish and to feed on both the eggs and the young of crocodiles. Although more or less aquatic in its habits, it is frequently seen hunting for its food along the banks of the Nile and in irrigated fields, but never in the desert.

The lizards of the degenerate family Amphisbaenidae, almost world-wide in distribution, greatly resemble the amphibian caecilians, being worm-shaped with numerous rings formed by the soft skin. The eyes and ears are concealed and the limbs entirely lacking except in one genus, *Chirotes*, which has short fore limbs with claws and fingers. These lizards have a small, compact, bony head, to admit of burrowing in sand, and a long forked tongue, by which they may be at once distinguished from the caecilians.

The Florida worm lizard (*Rhineura floridana*), the sole species of the Amphisbaenidae found in the United States, is of a uniform pale-lavender color over which plays an iridescent bloom, and attains a length of about eight and a half inches. This species bores tunnels in soft ground and is turned up when the fields are plowed in the very circumscribed range in Florida where it occurs. Such forms may be of some aid to agriculture, in addition to the usual beneficial effects of the lizards' fondness for insects.

The economic value of lizards is due to the ever-growing use of their skins as leather and to their food habits, which are an aid to agriculture. Most of the smaller lizards are at least partially insectivorous, and the larger ones, in tropical countries, aid in destroying rodent pests. Moreover, lizards possess an especial interest for their beauty and grotesqueness, for their variety of form, and for their ingenious adaptations to environment.

CHAPTER XII

SNAKES

In many respects the most interesting because the most specialized group of reptiles, snakes have long suffered from an undeserved and widespread unpopularity. Few animals have been more persecuted or misrepresented than these timid and generally harmless creatures. The dread they inspire in most people, though genuinely deep-seated, is possibly not so much instinctive as it is the result of ignorance and superstition. Both for their attractiveness and for practical reasons, snakes, with the exception of a few harmful species, should be protected rather than destroyed. Their food habits are of real economic benefit to mankind, as they prey largely on insects and small mammals that are injurious to the farmer's crops.

Being extremely sensitive to cold, snakes living in northern countries can survive in winter only by burrowing into the ground below the frost line. Accordingly, we find most of the 2,300 species of the order Serpentes in tropical and semitropical countries. Despite their almost world-wide distribution, snakes have never been found in New Zealand, Hawaii, Iceland, and possibly Ireland.

Except for the absence of limbs, snakes appear in shapes almost as varied as do their cousins, the lizards. In size they range from the thirty-foot anaconda to a burrowing species only five or six inches long and of a twiglike slenderness. The body may be round and somewhat rigid, as in some burrowing snakes, or extremely flexible and often compressed, as in the tree snakes. The sluggish vipers and many desert-dwelling forms have flattened bodies. Aquatic snakes are often short and heavy, but some are slender, with the posterior part compressed.

The snake's mouth constitutes an important and interesting portion of his anatomy, since it is armed with a constantly renewed supply of teeth (including in some species the poison fangs) and possesses a sensitive organ of touch in the long, forked tongue which incessantly plays over every object in the reptile's path. Especially characteristic is the structure of the lower jaw and the part it plays in the process of swallowing the prey.

The loosely joined bones of the skull enable the snake to stretch his mouth so as to seize and swallow prey which would otherwise be much too large for him. The two halves of the lower jaw spread apart and work almost independently, resulting in a forward movement of one half, while the other remains stationary, with its sharply recurved teeth lodged like little hooks in the skin of the victim. By means of the alternating movement of the two sides of the lower jaw and a corresponding chewing motion of the teeth in the upper jaw, the food is slowly pushed into the cavity of the snake's throat, whereupon the extremely elastic tissues expand readily to allow its quick passage into the stomach. The ribs, not being attached ventrally, merely spread a bit to accommodate whatever the stomach receives.

Small animals may arrive in the snake's stomach without having suffered any great injury, as is illustrated by Gadow, who relates that one of his tame snakes, which was lying on a table, had just swallowed a frog when someone entered the room. The frightened serpent jumped to the ground, landing full on its belly and hurting the frog which squeaked loudly; whereupon the snake reversed its swallowing mechanism and the frog hopped away, none the worse for its terrifying experience. In order to assist the swallowing process, snakes secrete a great amount of saliva, which even in the most harmless species is said to be slightly toxic.

The fangs of the poisonous snakes are teeth more or less modified for the ejection of venom. The tongue has nothing whatever to do with the poison-ejecting mechanism and even in the deadliest species can inflict no injury. The most highly specialized development of teeth into poison ejectors occurs in the snake family to which the rattlesnake belongs, the Crotalidae. Their fangs are true hypodermic needles—very long, rigid, hollow teeth with an opening at the end—on either side of the upper jaw.

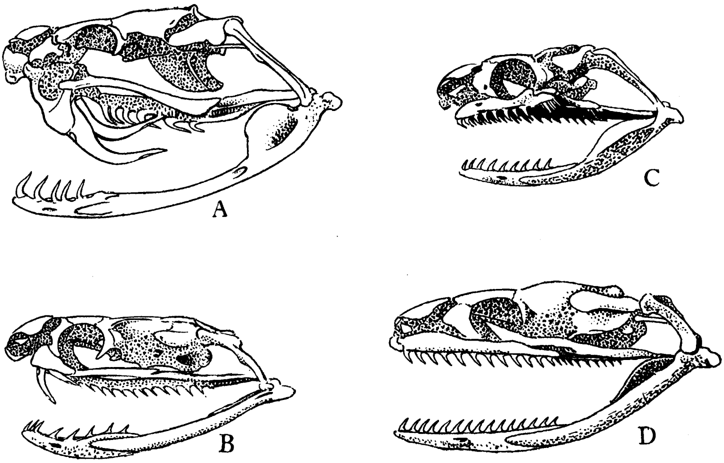


FIG. 87. Snake skulls showing the three types of poison fangs, and one skull with nonpoisonous dentition. A, rattlesnake, fangs solidly fixed in movable maxillary; B, cobra, fangs solidly fixed in immovable maxillary; C, tree snake, *Boiga*, grooved fangs in back part of upper jaw, not dangerous to man; D, solid-toothed snake, no fangs and nonvenomous

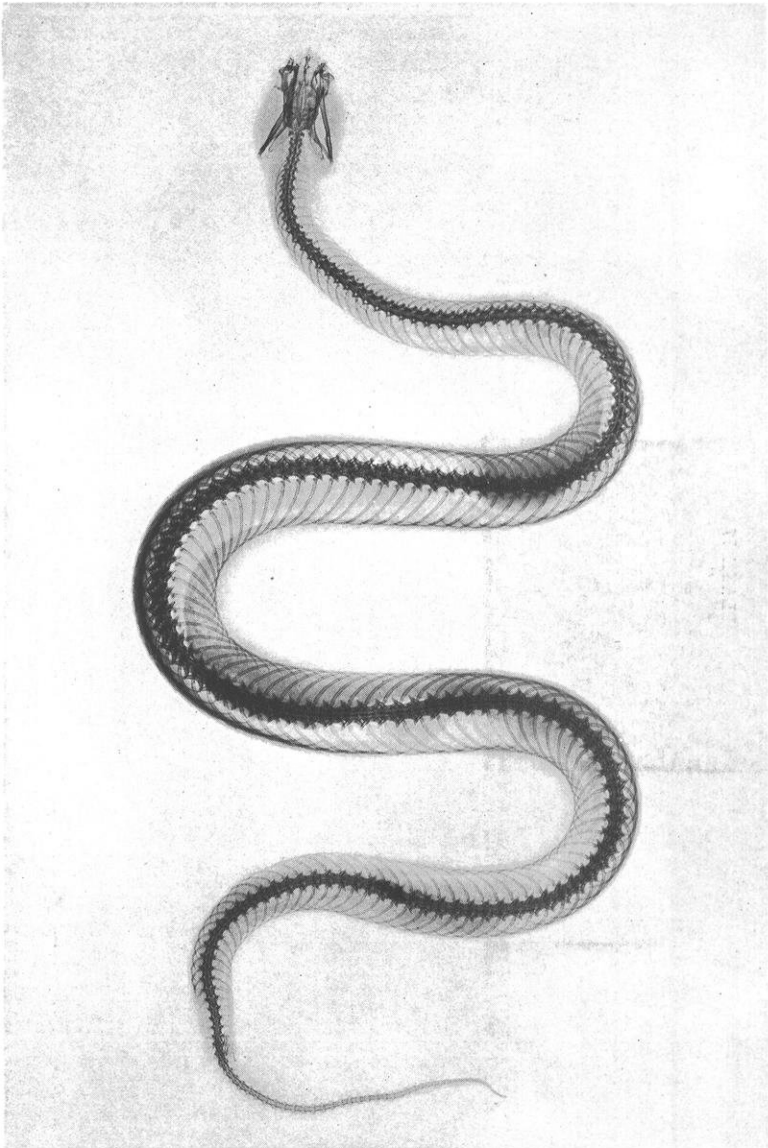
The poison comes from a gland back of the eye and passes through a canal to the base of each fang. Though the fangs are immovable, the maxillary turns, permitting them to be folded back when the jaw closes. In the group of poisonous snakes which includes the cobras and their allies (family Elapidae) as well as some of the sea snakes, we find a pair of short fangs in the forward part of the upper jaw (proteroglyphous), both fangs and jaw bone being immovable; these fangs may either be canaliculated or have an external groove.

Still another type of dentition is met with among poisonous serpents in which one or more pairs of venom fangs—grooved, not canaliculated—are situated in the rear of the upper jaw. The poison which they exude is apparently much less dangerous to man than that of the other two groups. Snakes with this type of fang differ widely in appearance and habitat. Some are sea or river dwellers and have valvular nostrils; some are highly adapted to arboreal existence, with small round heads merging into extremely attenuated necks, and long slender bodies. The only representatives of these back-fanged (opisthoglyphous) snakes to be found in the United States are confined to the southwestern portion and are small, inconspicuous, ground-dwelling forms.

That snakes possess any very keen sense of taste may be doubted from their manner of gorging and from the use of the tongue as a tactile organ. The nose, however, is well developed, and many snakes find their prey as much through the sense of smell as through that of sight. A transparent skin covers the otherwise lidless eyes and is shed periodically when sloughing occurs. In burrowing species the eye covering is so opaque that these snakes can perceive little besides light and darkness. All snakes appear to be deficient in the sense of hearing, since they have neither tympanums nor Eustachean tubes. Like other deaf creatures, they must receive sound vibrations through solid substances instead of through the air.

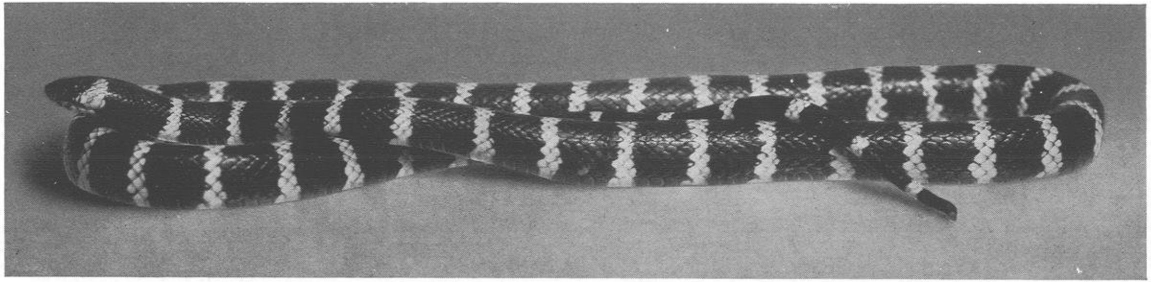
When one observes the smooth sinuous movement of a snake gliding swiftly and silently through the grass, it is hard to realize that the wormlike creature is actually a backboned animal and that he is in reality *walking on his ribs*, a pair of which are attached to each of his numerous vertebrae (Plate 76). Moreover, the lower surface of his body is provided with large transverse scales or shields,

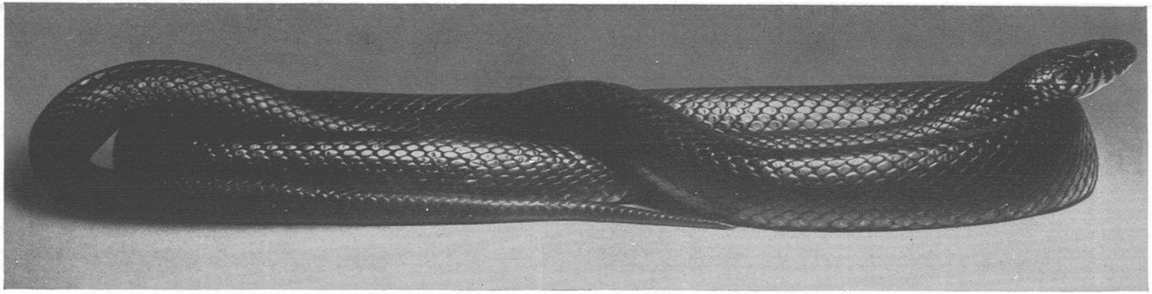
PLATE 76



Radiograph of a copperhead snake, showing the numerous ribs upon which the legless reptiles walk

PLATE 77





Two varieties of king snake, *Lampropeltis multicincta* (above) and *L. getulus niger*, inveterate enemies of poisonous snakes and rodents each scale corresponding to a pair of ribs. As the snake glides forward, these scales are partially erected in such a way as to take hold of the ground and enable the reptile to pull the rest of his length after him by means of his leglike ribs. In sea snakes and burrowing forms the ventral scales, not being required, are no longer present or are much reduced in size.

In some snakes vestiges of hind limbs are still to be seen; in the African *Python sebae* they appear as distinct claws. In no case, however, do they function as do the limbs of other reptiles. Tree snakes of the genus *Dendrophis* have a special modification for climbing—a pair of keels flanked by notches on the scales of the under side of the body. The additional hold on the bark thus obtained enables *Dendrophis* to glide along the branches in a nearly straight line, instead of in the sinuous course followed by other tree-climbing species.

A trait that all snakes seem to possess in common is that of shedding the skin at more or less regular intervals, discarding it entire and turning it wrong side out in the process.

While most snakes lay eggs, the young of many species are born alive. Poisonous species are provided at birth with fangs and venom glands, and are just as dangerous, in proportion to their size, as are the parents. The little ones are left to shift for themselves immediately after birth or hatching.

A favorite myth in regard to snakes which must be given up is that they are able to charm or fascinate their prey. Observations conducted in the menagerie of the Zoological Society of London led to the conclusion that birds and small mammals remain still when threatened by a snake because of curiosity associated with the power of attention. At a sudden or noisy movement they start off at once; but if the movement be slow, silent, and stealthy, they remain motionless, although intensely watchful. Snakes may take advantage of this curiosity if they are quick enough, but so may a human hand or a cat under the same conditions. Fascination has nothing whatever to do with the phenomenon, which may, however, be partly due to fear.

An absurd superstition has arisen to the effect that "milk snakes" suck milk from cows—hence their name. Such a feat on the part of this snake is obviously impossible, since the suction power required to obtain a flow of milk from a cow's udder is much greater than could be exerted by so slightly built a reptile. Moreover, a snake's sharp recurved teeth would inflict such injury on the cow that the would-be milker would soon have to flee for its life. Snakes seen around barns are there not for the purpose of sucking milk but to catch rats and mice.

The king snake, *Lampropeltis getulus*, close relative of the milk snake, reaches a length of five feet nine inches (Plate 77). We call it "king" because of its fearlessness in attacking and devouring other snakes, even the poisonous species. Like other members of this genus, these constricting snakes are expert in forcing their way into the burrows of the rats and mice on which they feed and in tracking down other snakes. The king snake is exceptionally friendly and gentle in its relations toward mankind, and should be protected, not only for its friendly offices in exterminating some of our worst enemies, but also for the beauty of its lustrous black body ornamented with a chain-like pattern of white or yellow lines because of which it is sometimes known as the "chain snake."

One of the most useful among our harmless serpents, the American black snake (*Coluber constrictor*) lurks in open, rocky places, foraging for small rodents, birds, frogs, and the young of other snakes. The typical form east of the Mississippi is a uniform pitchy black in color, with patches of white on the chin and throat. In the Central and Western States, the prevailing variety is greenish-gray, often bluish above, with a yellow abdomen—popularly called the "blue racer." Large specimens of the typical black snake are six feet long and an inch and a half in diameter at the thickest part of the body. The species is oviparous, and the young snakes just after hatching differ oddly from the parent, being pale-gray with brownish blotches on the back and irregular black spots on head and sides.

Far less liable to persecution than such forms as the king and the milk snakes are the burrowing species, whose habits protect them from observation. The rainbow snake (*Abastor erythrogrammus*) hides its beautiful body beneath sand and mud, inhabiting swampy, timbered areas all the way from the coastal plain region of the Gulf of Mexico north to Virginia. It reaches a length of nearly five feet, its scales being smooth and glossy, rich purplish-black above, with three stripes of dark red on the back, a band of pale-yellow on each side, and a checkered arrangement of blue-black and red spots beneath. In captivity it refuses to feed at all. Another burrower, also called rainbow and sometimes the "red-bellied" snake (*Farancia abacura*), grows to a length of six feet; it is purplish-black with large vermilion V-shaped blotches on its sides, matching its under surface. Its habits and range are much the same as those of the *Abastor erythrogrammus*. These two snakes never attempt to bite when handled, but will coil about one's arm to prevent themselves from falling. The tail of the red-bellied snake bears a terminal scale which is very short but sharp, and will sometimes make a slight scratch in the skin. Negroes acquainted with this snake are convinced that this is a "sting" which will cause certain death, wherefore they call this harmless, beautiful creature the "sting snake" and condemn it to death on sight. Still more absurd is their belief that these two species of snake roll along with their tails in their mouths. From this superstition comes the common name, "hoop snake."

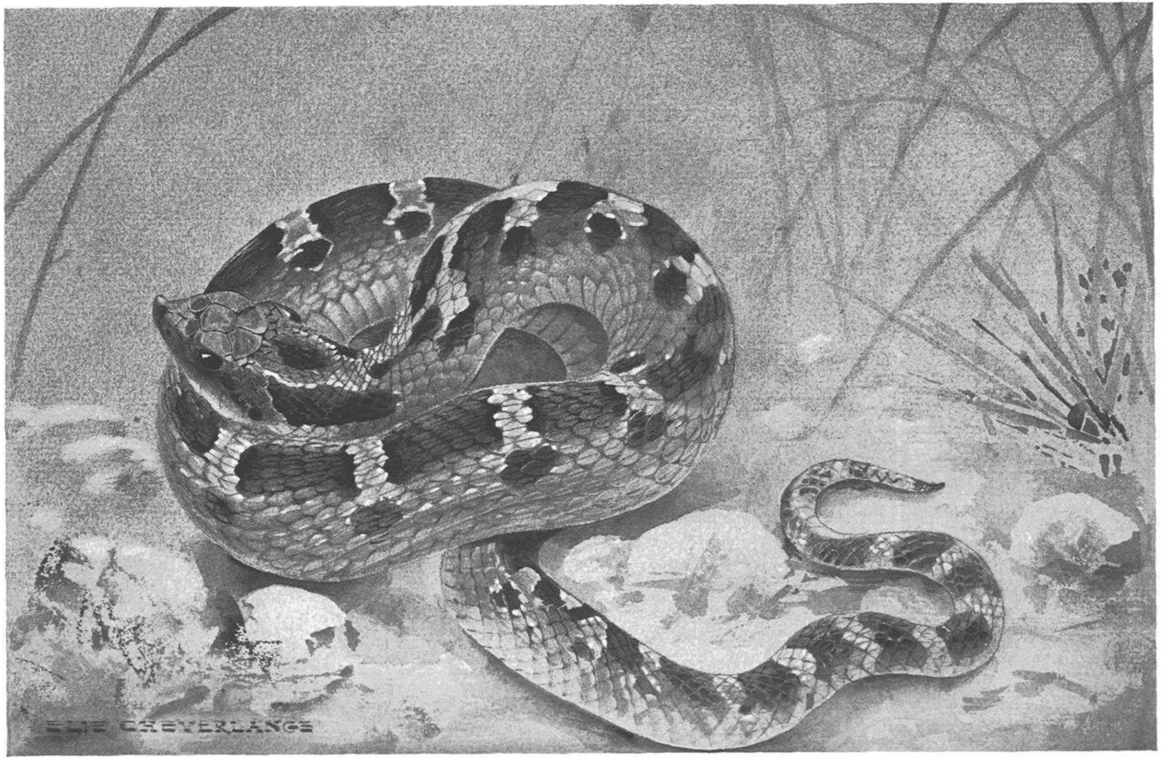
The trickster among our snakes is the hog-nose, puff adder, or spreading adder (*Heterodon*), as he is variously called, who camouflages an innocent and harmless disposition by the most startling display of viciousness (Plate 78).

The name puff or spreading adder has been given this snake because of his habit of spreading his forward ribs laterally, after the fashion of cobras. When roughly treated, a puff adder will go into a series of alarming contortions, writhing about and turning in circles as if in the death agony. Little by little his movements become slower, as if he were becoming weaker, and finally he lies on his back before us, his mouth half open, and his tongue hanging limply out, apparently a very dead snake indeed. But he is only playing 'possum, as we find when we try to right him, for he immediately turns on his back again, convinced that a snake to look realistically dead must be wrong side up. If we retreat a little way and remain quiet, the canny fellow will speedily come to and crawl away as fast as he can to the nearest shelter.

Most abundant of North American serpents is the common garter snake (*Thamnophis sirtalis*), which occurs in every part of the continent where snakes are to be found. Fortunately, this is an entirely harmless species and in captivity is said to show evidences of real affection for its human friends. Several varieties of the garter snake are recognized, and even the typical form of the species shows considerable variation. East of the Mississippi the garter snake appears as dark brown above, with three yellowish stripes separated by two well-defined rows of alternating spots; the under surface of the snake is greenish, or yellow. The larger specimens sometimes reach a length of about three feet and a diameter of one inch. The garter snake feeds principally upon frogs, toads, and earthworms—never upon warm-blooded prey.

Twenty-odd species of poisonous snakes are found within the borders of the United States, and these are grouped in two families, the Elapidae or harlequin snakes, and the Crotalidae, or pit vipers.

A single species of harlequin snake (*Micrurus fulvius*), sometimes called the "coral snake," occurs from North Carolina south through the Gulf States to Central America



The hognose, or puff adder, *Heterodon contortrix*, a harmless snake which pretends viciousness to frighten off opponents and, when that fails, plays dead

(Plate 79). The coral snake is beautifully banded with rings of red, black, and yellow, the end of its snout being always black. While only a few instances of this snake having bitten a human being are known, yet in about three-fourths of these death occurred. This, of course, was before the discovery of antivenin treatment. In eastern North America two distinct species of harmless snakes mimic the coral snake in color and pattern—the scarlet snake (*Cemophora coccinea*) and the scarlet king snake (*Lampropeltis elapsoides*). Neither of these has a black snout, and this distinguishes them at once from the coral snake. Other harmless species likewise resemble this snake, but in every case they may be distinguished from the poisonous species by a slight difference in the pattern. It will be noted that the poisonous species has single black rings bordered with a pair of yellow rings, while the harmless species reverses this scheme, wearing single yellow rings bordered with a pair of black rings; though actually to remember and observe such a distinction in an emergency would perhaps be asking too much of any but a skilled naturalist.

Among the pit vipers, or Crotalidae, we find both the copperhead (*Agkistrodon mokasen*) and the cottonmouth, or water moccasin (*Agkistrodon piscivorus*). This family, which includes also the rattlesnakes, takes its name from a deep pit between the eye and the nostril on each side of the head. True vipers—without head pits—are not found on the American continent.

The copperhead derives its name from the uniform coppery color of the head. Along each side against the paler brown of the ground color runs a series of chestnut-colored blotches, each of which resembles an inverted Y; when the tails of two Y's meet, the form suggests an hourglass. The color beneath is a dull yellow. The species occurs from central Massachusetts south to Florida and westward to southwestern Texas. A large specimen killed in the District of Columbia in 1893 measured thirty-eight inches.

Because it strikes without warning and is of a more aggressive nature, the copperhead is an enemy more frequently encountered than the rattlesnake. But its poison in proportion to the quantity injected is less virulent and its smaller size makes it a less terrible animal than is generally supposed. Authenticated cases of death from a copperhead bite are very rare.

The water moccasin, or cottonmouth, infests the lagoons and bayous of the Southeastern States. The stout, heavy body of dull olive, with wide, blackish, transverse blotches barely showing on the back but boldly defined on the sides, is topped by a large triangular head and ends in an abruptly tapering tail. The average length of these snakes is about four feet, but larger specimens are sometimes found measuring six feet or more. These—probably old individuals—appear a dingy brown or black with little trace of the usual marking. The young water moccasin has a pinkish body with red-brown, white-margined transverse bands and a sulphur-yellow tail.

Of all the poisonous serpents of North America the rattlesnake is undoubtedly the most feared; and justly so, not only for the deadly character of its venom, but also because of its wide distribution. No less than eighteen different species of rattlers exist within the boundaries of the United States, under the most diverse conditions of environment.

The water rattler (*Crotalus adamanteus*), better known as the diamond-back, haunts the neighborhood of water and is said to be a good swimmer; the pallid rattler (*Crotalus mitchelli*) prefers the desert; the prairie rattler (*Crotalus confluentus*) occurs on the Great Plains; while another form, *Crotalus horridus*, is limited to the woodlands of the Eastern States. While rattlesnakes do not habitually climb trees, there is no doubt that they occasionally do so, since a rough-barked slanting tree would be quite as easy to climb as the face of a rocky cliff where they sometimes find dens for winter retreat.

Two American poisonous snakes. On the rock is the copperhead, *Agkistrodon contortrix*, more aggressive than the rattlesnake but not so deadly; below is the coral snake, *Micrurus fulvius*, as deadly as the rattler but not so aggressive

Among the rattlesnakes described by Doctor Ditmars, the following may be cited as of especial interest:

Largest and most dangerous of the North American species, the Diamond-back Rattlesnake, *C. adamanteus*, confined to the southeastern portion of the United States, grows to a length of slightly over eight feet, while *it attains the greatest weight of any known poisonous serpent.* The bite of this terrible brute is usually fatal, often within less than an hour's time. The fangs are of greater length in proportion to the reptile's size than of any other North American poisonous snake.

. . . .

One of the most beautiful of the North American rattlesnakes occurs in the eastern portion of the United States from Vermont to northern Florida. This is the Timber or Banded Rattlesnake, *C. horridus.* In the North the majority of the males are black, and some of them are so intensely black the entire upper surface is without a suggestion of transverse bands, looking precisely like velvet. The females, to the contrary, are a beautiful sulphur yellow, ornamented with irregular brown or black transverse bands. Sometimes these bands assume the form of a chain of rhomb-like markings. A freshly-shed specimen is wonderful in the richness of its tints and no matter how strong may be the prejudice, few can fail to appreciate Nature's generosity in the distribution of her colors. . . . In the South, where the surroundings are quite different, the species assumes an entirely different phase—pinkish, with sooty black bands and a rusty red stripe on the back; this variety lives along the coastal region and is called the Cane-Brake Rattlesnake. The northern phase is essentially a mountain snake, haunting the immediate vicinity of ledges.

Our last species is a curious little snake of the deserts of the southwestern United States, the Horned Rattlesnake or Sidewinder, *C. cerastes.* Its length is seldom more than a yard. Over each eye is a blunt, upright horn. The coloration is in keeping with a desert life; pale yellowish or pinkish with obscure blotches, like the hues of the African desert vipers.

The method of getting over a yielding soil is exactly like that employed by the species of *Cerastes,* of Africa, already described ["throwing out lateral loops, one after another, in a fashion that imparts an agile *walking* motion"]. In snakes so widely separated in classification and *habitat,* this eccentric trail is an admirable example of Nature's trend toward perfect adaptation.

While most rattlesnakes are included in the genus *Crotalus,* two North American species belong to the genus *Sistrurus.* One of these, the pygmy rattlesnake (*Sistrurus* *miliarius*), known also as the ground rattlesnake, abounds in the Southeastern States. This little rattler, only twenty inches long, displays a row of jet-black saddles contrasting with its gray body and separated along the back by reddish interspaces. The tiny rattle can be heard only a few feet, and the bite, if the proper treatment is given promptly, is seldom followed by dangerous symptoms. A larger species of *Sistrurus*, the massasauga (*S. catenatus*) occurs in two varieties, one of which inhabits the Central States while the other extends into the Southwest.

Contrary to popular belief, a rattlesnake may acquire not one but several new rings on its rattle in the course of a year, since these constitute the unshed remnant of the old skin which all snakes must slough normally in the course of growth—sometimes at intervals of only a few months. The young rattler possesses but a single button at birth, and within a few days it sheds its skin and commences to feed. In about two months it sheds its skin for the second time, thus adding the first ring to the rattle. Each successive cap or ring of the rattle forms around a composite bone known as the "shaker," formed by the fusion of the last seven or eight vertebrae shortly after birth. The part of the skin covering the cap is not shed with the rest, but becomes loosened or dislodged from its place and moves backward to become an additional ring on the rattle.

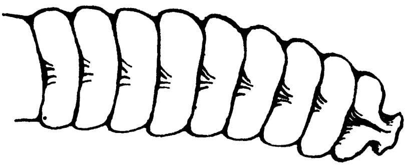


Fig. 88. Rattlesnake's rattle each ring after the first being the unshed remnant of an old skin

The ominous sound of the rattle serves as a warning or a threat to enemies and perhaps also as a call during the breeding season. It is a mistake to suppose that the snake can not rattle when its rattles are wet. Its tendency to rattle when disturbed undoubtedly results in the escape of many creatures that might otherwise become its prey.

The timber rattler has been known to keep up its clatter almost continuously for half an hour.

The bite of most rattlers is by no means certain death to man, since in many cases the full dose of poison does not enter the blood stream, but is delivered upon fatty tissue or upon clothing or shoe leather. In fact, recent figures tell us that it is fatal in only about ten per cent of the cases; and with antivenin injections the mortality is even less than that.

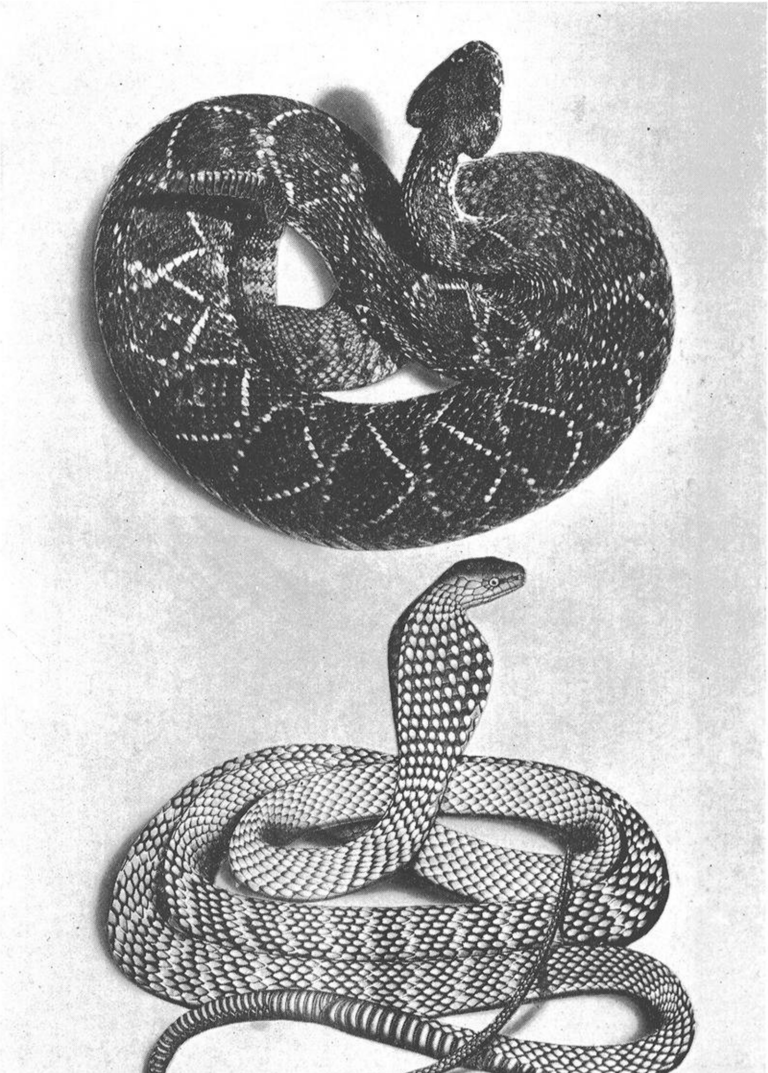
The preparation of antivenin is a real triumph for science. At the snake farm at the Butantan Institute, near São Palo, Brazil, Dr. Vital Brazil first collected the many South American species of pit vipers in sufficient numbers to enable him to prepare dried venom. The snakes are taken out of their pen as needed and with expert care are forced to bite through a piece of thin rubber stretched over a cup, leaving at each bite a drop or two of pure venom in the cup. This venom is dried and later is injected in very minute doses into the veins of strong healthy horses. Little by little the dose is increased, until the horses are able to stand far more than the ordinary lethal dose, having meanwhile developed a powerful antitoxin in their own blood. Some of the blood of the immunized horses is extracted and put through a process which separates the serous or colorless portion; and this is the antivenin, the injection of which is almost always successful in saving life.

In Asia, although poisonous snakes are far more plentiful and dangerous than in this country, relatively few are pit vipers. The little green bamboo snake is very common about the rice fields, where it feeds on frogs, but its bite is not much more feared by the natives than the sting of a bee. There is likewise a snake closely related to our copperhead, which is somewhat dangerous. The greatest toll of life, however, is taken by the cobra and its close relatives. The largest of the cobra family is the terrible hamadryad or king cobra (*Naja hannah*), which, though rather slender and slight, reaches eighteen feet in length. Like the king snake of our own country, this species receives its name through its ability to overcome and devour other snakes. It is one of the very few aggressive species, for it has been known to pursue human beings when disturbed. The reputation of the Indian cobra (*Naja naja*) is too well known to need mention here. The deaths from cobra bite in India each year number over 20,000. This, of course, is due to the fact that the cobras are sacred to the natives (which makes every one afraid to kill them); and also to the fact that the natives wear no covering on their feet, and very thin clothing on their bodies, so that the snake in striking penetrates directly to the veins or arteries.

Many slender, brightly colored tree snakes are to be found in the Malay Archipelago. They creep about in bushes seeking for lizards to devour, and move very briskly when disturbed. In fact, one genus, *Chrysopelea*, beautifully marked with a black network on a yellowish-green ground and having a row of clustered red dots, like a garland of flowers, down the center of its back, has an extraordinary and most unexpected way of gliding through the air from a high limb down to the ground by spreading its ribs and thus making a concavity of its under surface, somewhat like an elongated parachute.

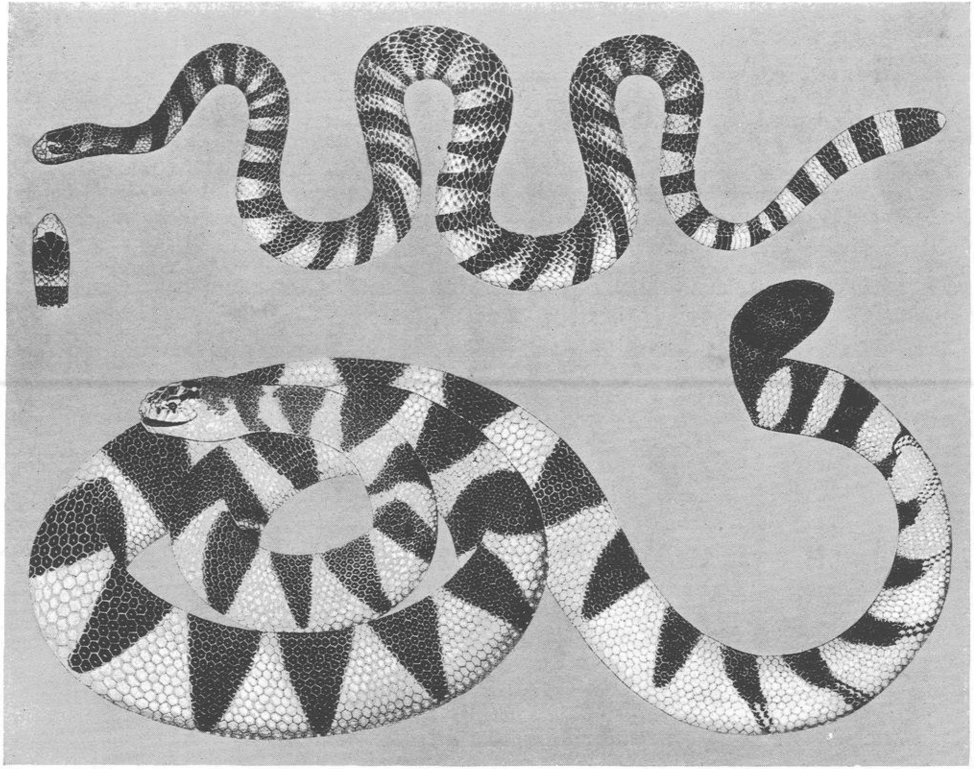
Another kind of tree snake, the large, heavy-bodied, constricting serpents, climb trees overhanging forest paths in order to intercept the deer and pigs coming to drink at the water holes. The boa constrictor of South and Central America is an excellent example of this kind of snake. The world's largest serpent, the anaconda, lives in the shallows of the Amazon. A specimen reaching the length of forty-six feet has been credibly reported by Doctor Amaral. Some of the Malay pythons are nearly thirty feet long.

The African pythons (*Python sebae*) are famous in story and fable for their size and their appetite. The reports of the length of these snakes are often much exaggerated.



Upper: The diamond-back rattlesnake, *Crotalus adamanteus*, largest and most feared of American poisonous snakes

Lower: The hamadryad, or king cobra, *Naja hannah*, largest of all poisonous snakes, reaching a length of eighteen feet, but slender of body. It inhabits southeastern Asia and preys exclusively on other snakes, though it will attack man if disturbed



Sea snakes (family Hydrinae) haunting the coasts of southern Asia and the Pacific islands. All are poisonous in varying degree

Probably twenty feet is the maximum which any ever attain nowadays. Possibly before the advent of the white man and his firearms, some old individuals may have attained the length of twenty-five feet; but in these times whenever the rumor spreads that an unusually large python is about, some white man with a zest for sport sets out to kill the monster, or capture it alive, for a circus or zoological garden will frequently pay a very good price for an unusually bulky serpent. The favorite haunts of pythons are rocky, wooded valleys, bordering a stream. They love water and delight to wallow in it, often lying submerged for hours, with only the nostrils above the surface. They climb trees easily, some by twisting their bodies like ropes, strand above strand, around the trunk, others, by progressing up rough-barked trees in wide, sinuous curves. Huge pythons often lie along the branches of trees with their stony-looking, unwinking eyes fixed upon the ground below. If something good to eat comes along, the snake simply drops upon it, and, still tightly gripping the branch with the end of its tail, envelops the prey with its folds and then proceeds to squeeze the life out of it. The skin of a living python shows a beautiful mosaic of bright, glossy hues, with tan, yellow, and brown as the basic colors, overlaid with a marvelous iridescent sheen of blue, green, and purple, which changes and sparkles as the body moves. This iridescence disappears at death, so that those who have looked at mounted skins of pythons in museums little realize the beauty of the living animal. Pythons are not poisonous, and become quite tame when kept in captivity, thriving on a diet of chickens and rabbits.

There are other African snakes, however, which it would not be safe to meet face to face. These are the spitting snakes (*Sepedon haemachates*), which really do have the ability to spit their venom in the faces of their foes, ejecting it from the poison fangs in two streams. The glass in front of a cageful of spitting snakes is always incrusted on the inside with this venom, for the snakes are usually very nervous and will eject poison whenever anyone approaches the cage. An actual bite would be fatal, unless serum could be administered at once.

Belonging to the same family group (Elapidae) as the spitting snakes, and considerably better known, are the African cobras (genus *Naja*). Several species inhabit Africa, where they take a heavy toll of human life. The cobra expands its hood not by puffing out the skin but by elevating the ribs in the region of the neck, where they are elongated, the length being graduated from the head downward so that they form a crescent on each side. The skin of the neck, being loose and elastic, contracts when the snake is at rest and the ribs depressed, so that no hood is visible. If the reptile is irritated or alarmed, it erects the head and fore portion of the body, raising the ribs in the neck region, which in turn elevate and spread the skin, thus forming the "hood." This is evidently intended by nature to aid the cobra in frightening off its enemies. With expanded hood and bright glistening eyes and skin, rearing amid the stubble and ready to strike, the snake is truly a terrifying sight.

The mamba (*Dendraspis angusticeps*), just as deadly and even more dreaded than its cousin the cobra, finds its favorite resting place in the branches of thickly leaved trees. Entwining themselves among the twigs, the snakes lie perfectly still. They frequently select trees along the Kafir paths which wind through the forests in various directions—paths made by the natives, who always walk in single file. Many a man has met his death by being bitten on the head, neck, or shoulders while passing under a branch in the foliage of which one of these venomous snakes lay concealed.

Along the coasts of southern Asia, Australia, and most of the Pacific islands, the fishermen often pull up in their nets real sea serpents (Hydrinae). These snakes are all poisonous; some are only slightly so, but others are deadly.

They feed entirely upon fish, and frequent the shallow, protected parts of the coast, being especially numerous in river mouths. They are graceful and rapid swimmers, possessing in their flattened rudderlike tail a powerfully developed swimming organ. The mother brings forth living young, two to eighteen at a time. Most of the species measure about four feet when fully grown, but a few attain a length of nine feet. On land they are practically helpless; in fact, most of them never go on shore at all. They are used as food in Tahiti, and in Hainan (China) they are chopped up and made into sausages.

Only one species (*Pelamydrus platurus*) ever travels far from the coast. It has been found hundreds of miles from land and is taken frequently off the west coast of Mexico and Central America. Most sea snakes are ringed with black and white, but this one is plain black above and brown below, with an intervening stripe of yellow.

Highly specialized for burrowing are the forms represented by the family Typhlopidae, found in tropical and semitropical countries, the sole surviving remnants, apparently, of the ancient type of serpents. *Typhlops*, the largest genus, contains nearly a hundred species, all very much alike—cylindrical, glassy creatures, more like worms than snakes, and resembling the legless burrowing lizards. As captives they are said to be most unsatisfactory, since they die unless provided with soil, and when so provided, at once bore their way out of sight.

Snakes in general may be considered beneficial to man, since they prey upon his enemies, the rodents and the insects, and among some savage races serve also as food. Snakeskin, moreover, has in recent years found favor as a material for the manufacture of women's shoes and other articles of wearing apparel. With a better realization of the snake's economic value has come a tendency to discriminate between the poisonous and the harmless varieties in order to save the latter from persecution and possible extermination.

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