
WORLD MAP.
NORTH POLAR PROJECTION
SHOWING THE REGIONS OF
GEOGRAPHIC DISTRIBUTION OF LAND ANIMALS
AND THEIR DISPERSION FROM A NORTHERN CENTRE
EQUATOR
TROPIC OF CANCER
AUSTRALIAN REGION
AUSTRO-MALAYAN SUB-REGION
HOLARCTIC REGION
SONORAN SUB-REGION
MEDITERRANEAN SUB-REGION
ETHIOPIAN REGION
MALAGASY SUB-REGION
NEOTROPICAL REGION

THE SCIENCE-HISTORY OF THE UNIVERSE

FRANCIS ROLT-WHEELER
MANAGING EDITOR

IN TEN VOLUMES

THE CURRENT LITERATURE PUBLISHING COMPANY
NEW YORK
1910

THE SCIENCE-HISTORY OF THE UNIVERSE

INTRODUCTIONS BY

PROFESSOR E. E. BARNARD, A.M., Sc.D.,
Yerkes Astronomical Observatory.

PROFESSOR CHARLES BASKERVILLE, Ph.D., F.C.S.,
Professor of Chemistry, College of the City of New York.

DIRECTOR WILLIAM T. HORNADAY, Sc.D.,
President of New York Zoölogical Society.

PROFESSOR FREDERICK STARR, S.B., S.M., Ph.D.,
Professor of Anthropology, Chicago University.

PROFESSOR CASSIUS J. KEYSER, B.S., A.M., Ph.D.,
Adrian Professor of Mathematics, Columbia University.

EDWARD J. WHEELER, A.M., Litt.D.,
Editor of "Current Literature."

PROFESSOR HUGO MUENSTERBERG, A.B., M.D., Ph.D., LL.D.,
Professor of Psychology, Harvard University.

THE SCIENCE-HISTORY OF THE UNIVERSE

VOLUME VI

ZOOLOGY

By DR. WM. D. MATTHEW

BOTANY

By MARION E. LATHAM

INTRODUCTION

By DIRECTOR WM. T. HORNADAY

CONTENTS

PART I—ZOOLOGY

PART II—BOTANY

INTRODUCTION

UNDER favorable conditions, the study of animal life becomes not only profitable to mankind, but also as musical as Apollo's lute. To know the animal life of the world is to know the world. It is impossible for an intelligent mind to grasp the principal animal forms of a given country without at the same time acquiring a great store of knowledge of that country's topography, soil, climate and people.

The love of wild life springs eternal in the human breast. It is as natural for every child to be interested in animals as it is for every child to love the sound of music. Sad to say, however, that natural love for zoölogy often is completely stifled, or warped out of shape, by lack of opportunity. Those who by force of circumstances are compelled to grow up and live out their lives without knowing the satisfaction that is derived from an intimate acquaintance with at least one section of animal life, lose much pleasure to which they legitimately are entitled.

At no time in the history of the world has zoölogical knowledge been so vitally important to mankind as it is to-day. As animal life rapidly diminishes, its economic value to man becomes more apparent. Fifty years ago the edible fishes, lobsters, oysters and clams were so abundant that no one found it necessary to delve deeply into the life history of any one of those groups. To-day, and for the future, only the most careful conservation and cultivation, based on precise zoölogical knowledge, can preserve to man a continuous supply of those valuable and delicious foods.

For twenty-five years the nation and the States have been studying ichthyology earnestly and diligently, in pursuance of their costly and toilsome efforts to keep up the great food supply of the poor—the edible fishes. The demand in the United States for a flesh-food supply that is cheaper than mammalian meat now engages the efforts of more than 200,000 men, backed by $60,000,000 of capital; and the animal fish product has a value of about $50,000,000. Each year about 1,400 million fish eggs and live fishes are distributed by the United States Bureau of Fisheries. Verily, ichthyology is something more than a mere pastime for the angler or the student. To-day it is on the same basis of human necessity as is the growing of wheat and corn.

Fifty years ago few persons in America gave thought to the study of insects, save as a pastime. During recent years the ravages of insects have called forth a grand army of entomologists, first to study the destroyers, and then to fight them. To-day every farmer and fruit grower, every forester and every park superintendent is engaged in the great irrepressible conflict that is being waged between Man and the Insect World for the possession of the fruits, the vegetables, and the trees that are as necessary to this earth as is the air we breathe.

The monthly bulletins of the State Economic Zoölogist of Pennsylvania painfully bring home to us the appalling extent and the fierceness of the battle for the trees. Verily, the study of entomology has come to us to stay.

For twenty years the United States Government has been engaged in a continuous effort to inform all the people of the United States that the wild birds are man's most valuable friends and allies in his warfare against insect and mammalian pests.

Some communities hearkened gladly to the message, and responded with reasonable promptness to the efforts of the bird lovers in behalf of protective bird laws. A few States remained hostile to bird laws until the cotton-boll weevil and other pests sharply brought home to their people the fact that they needed the assistance of the birds.

Now that man's heedless and ignorant destructiveness has accomplished the extinction during our own times of a score of important animal species, and to-day is threatening to annihilate many others, zoölogical knowledge has suddenly become a practical necessity. Both to the statesman and the citizen the protection of wild life has become a solemn duty. Ignorance is dangerous alike to our forests and streams and to our wild life.

The time has long passed wherein it was necessary to justify by argument the existence of museums and the study of zoölogy. The nature-study courses in our secondary schools testify abundantly to the public recognition of the need for the dissemination of zoölogical knowledge.

Unfortunately, however, the workers in that field are as yet blindly groping for the methods by which they may impart to the school pupils of America the precise and practical animal lore that they need and desire. To-day the nature-study teachers elect to relegate to the background the great System of Nature in favor of a few actual objects in the classroom which the pupil can handle and dissect, and use as a foundation of original pupil philosophy. But the case is not wholly hopeless, for the present situation is so bad that it cannot long endure.

After long and unsatisfactory contemplation of study courses that mix together all sorts of living creatures in one chaotic mass, it is a pleasure to take up a scholarly work in which the methods of Nature are fully recognised and clearly set forth. Herein the foundation stones of Nature are assembled, and well and truly laid.

Fortunate is the young naturalist, and likewise the general reader of animal lore, who early acquires the habit of broad generalization. I am tempted to call it the bird's-eye-view habit. Had I but one chance to send a message to the young naturalists of the world, that message would be this: Lay out for yourselves a broad foundation of systematic knowledge, and after that each stone of the structure will find its own permanent place as joyously as running water seeks the lowest level.

It is impossible to insist too strongly upon the absolute, vital necessity of conforming all zoölogical studies with the great system of Nature. He who attempts to study any small group of animal forms without first gaining a bird's-eye view of the surrounding territory, and becoming familiar with the zoölogical grand divisions that lie around him, loses much. It is a mastery of the grand divisions—the orders, families and genera, in particular—that lends the greatest charm to the study of zoölogy. The librarian who expects to store ten thousand books in such a manner that each one may be instantly available, wisely provides twenty-five alcoves and two hundred and fifty shelves; and thereafter each new accession of books is a source of joy, because the place for each volume is ready. The young naturalist without a zoölogical foundation is like a librarian who has no shelves and must create a place for each new book.

But, after all, systematic zoölogical arrangement, or "classification," is only to be regarded as a ready means to the accomplishment of more important ends. To-day the world is keenly concerned in the philosophy of animal life, its whys and its wherefores. A well-thought-out exposition of the origin and relationships of animals offers an excellent foundation for studies of species, and of the habits and mental processes of individuals, that shall continue and furnish human interest as long as any wild life remains upon the earth.

The old question, "Where does the animal belong?" has now as a running mate the ever-present query, "What does it think and do?" The latter offers to every intelligent human being a delightful field of study and research. The new question, "Do animals reason?" is no longer a question, save with a very few persons to whom the animal kingdom is mostly unknown territory. All the men who are best acquainted with the living wild animals of the world assert, as one man, that all animals think and reason; that some think very little, others much;

and that some animals have reasoning faculties that are superior to those of some men.

During recent years the work of our paleontologists has been profoundly fruitful. In America the rocks of the Western bad lands have yielded an extinct fauna of a character so marvelous as to be almost incredible until the actual remains are seen. It is quite beyond the power of words to convey adequate conceptions of the reptilian giants that formed the group of dinosaurs. The Brontosaurus, the Diplodocus, the Triceratops, the Stegosaurus and the Tyrannosaurus all must be seen in order that the wonders of them may be appreciated.

The story of the Jurassic Age in North America, as told by those gigantic remains, is sufficient to awe the most frivolous mind.

In the presence of those vast skeletons, some of them so colossal that even the largest elephants of the present day seem small, the thoughtful observer finds a new realm of knowledge opening before him like a panorama. The animal kingdom takes on a solemn dignity and vastness never known before. Naturally, the mind reaches out, octopus-like, to fasten tentacles upon the Past and link it to the Present.

There is one result of zoölogical knowledge that no man can adequately set forth in words. It is the unending satisfaction, and at times the delight, that comes throughout the journey of life to every person who is able to recognise the most important animals that are met by the way. Except in mid-air, it is well-nigh impossible for man to travel so far that he leaves behind him all visible forms of animal life. I believe this has been accomplished only by the men who have pressed nearest to the poles, through the utmost cold. He who knows the wild animals of the world always travels among friends, and in every land he finds a welcome. To him the whole world is interesting. To his pleasure in life thousands of beasts, birds, and creeping things contribute. Nature's multitude of interesting forms stimulate his efforts to acquire knowledge, and her fields of research come the nearest to revealing the fountains of perpetual youth.

To-day, the life of the ardent nature lover is filled with activities. On the one hand there is the balance of Nature to preserve, and on the other that lost balance is to be restored. Those who are not engaged in fighting the noxious forms of animal life are commonly found on the firing-line of the army that is fighting the perpetual war with those who would, if let alone, exterminate all wild creatures from the whole earth. Let us hope that millions of intelligent Americans will learn to appreciate more fully the splendid fauna of this continent in time to save it from the forces that now threaten it with annihilation.

William T. Hornaday.

ZOOLOGY

CHAPTER I

FABULOUS ZOÖLOGY

THE beginnings of Zoölogy lie in the region of fable. In the earliest traditions and myths of primitive races the world is peopled with men and animals, some real, some half-real, some entirely fabulous. Natural and supernatural are mingled together and a religious or superstitious significance attaches to both real and unreal beings seen or imagined by primitive man. His ready imagination and uncritical belief made the creations of his fancy seem as real as those of his observation and experience. With the increase of knowledge of the real, the unreal became more and more relegated to the domain of folklore and fable. Some of it has been preserved in the traditions and myths of different races, some crystallized in the fanciful animals of decorative sculptures, paintings and heraldry. Most of it has been forgotten.

It has been well observed that the imagination of man does not really enable him to create anything new, but only to recombine or rearrange what he has seen. He may combine the body of a reptile with the wings of an eagle; he may combine the head and shoulders of a man with the body and legs of a horse or attach to a human form the white wings of a swan. He may in fancy enlarge a mouse to the size of an elephant or conceive of a serpent large enough to encircle the whole world; he may support the universe upon the back of an elephant of appropriate size. But all these are not new creations; they are objects known to his experience, but recombined or altered in proportions. It is only as he comes to realize with wider knowledge that certain combinations of parts, certain relations of size do not occur in nature, that these imaginary beings become improbable or impossible. He is accustomed to supply the missing parts of half-seen animals from his previous observations. He sees the head of a deer projecting from the leafy wall of the forest and all unconsciously pictures the rest of the quadruped from what he has seen before; he sees a distant eagle perched upon a crag and knows well enough that when it starts to fly it will stretch out a pair of broad wings now closely folded against the body and invisible in the distance. If then he sees dimly outlined in the clouds a human form, what more natural than to supply it with the long feathered wings that belong to the birds of the air, or if at night with the wings of the bats that infest his cave dwelling? Nearly all of the fabulous monsters of zoölogy belong to this early period. They have been handed down conventionalized in form and degenerated into fable, but originally they were just as real as the rest of the half-seen, half-imagined world in which primitive man existed.

Perhaps the most familiar and universally known of these fabulous animals is the dragon. It appears in all the older myths of the Western nations in serpent form, usually winged, often with fiery or pestilential breath, the deadly enemy and scourge of man. It is equally prominent among the Eastern peoples, and probably received from them its conventional form, the long hind legs, the great eagle claws, the body covered with glittering armor scales, the writhing tail and bat-like wings. Among the Mediterranean nations it appears first as a sea monster and comes up out of the sea; wings were a later addition. In the Northern myths it is at first a "worm"—*i.e.*, a serpent of gigantic size—and the conventional form is borrowed later from the East.

The fabulous Dragon had a real counterpart, singularly close in some respects, in the extinct carnivorous Dinosaurs of the Age of Reptiles. These gigantic reptiles were not winged, indeed, but in the proportions of body, limbs and tail, in the huge head and sharp teeth, the enormous, sharp, eagle-like claws, possibly even in the glittering scaly armor, some of them at all events might have sat for a very tolerable portrait of the dragon of mythology. It is a tempting explanation to suppose that some tradition of these real monsters, handed down from primitive ancestors, was the basis of the dragon legends so widely scattered among all races of men. But this theory must be regretfully abandoned when the perspective of the geologic record is examined. The last of the Dinosaurs became extinct at the end of the Cretaceous Period, some three million years ago at a moderate estimate, before the evolution of the various races of modern quadrupeds had begun, long before monkeys and apes had evolved out of the primitive lemur-like animals from which they are derived and long, long before the evolution of man. The remote ancestors of the human race in the days of the Dinosaurs were tiny shrew-like animals, inferior in intelligence to almost any living quadrupeds, and millions of years were to elapse before they slowly evolved a higher intelligence and finally became capable of articulate speech. So it is utterly impossible that a tradition could have been handed down from the time when Dinosaurs really existed.

Nor is it to be supposed that the dragon myths are based upon discovery of their fossil remains, for in the millions of years that have elapsed since their time the sand and mud in which their remains were buried have been converted into hard sandstone and shale and the bones so thoroly petrified that they appear much like the rock itself. They would not easily be recognised as bones at all, and it would be quite out of the question for primitive man to get any correct notion of the kind of animals they represented if they happened to come across a few fragments unearthed out of the rock. Dinosaur bones might conceivably pass for bones of giants, but the concept of the dragon could not possibly be founded upon them. There remains a third explanation, that in some region of the world Dinosaurs might have survived until more recent times and have been seen by primitive men. But from what is known of the geological history of life, this supposition is so exceedingly improbable as to amount to an utter impossibility. One is obliged to conclude that the dragon is wholly a creation of the imagination of man, its source being probably among the races of Eastern Asia. How and why it came to assume its present conventional form would require a broad knowledge of the early history and mythology of these races to discern.

In the traditions of the Northern races the dragon legends are engrafted upon the myth of the giant serpent, the "Worm," which in the old Norse story encircles the earth, lying at the bottom of the surrounding ocean. This same myth, in another form, is handed down as the Sea Serpent. Sea serpents, however, are easier to credit than dragons, partly because less is known about the inhabitants of the sea than those of the land, partly because among the multitudinous forms of ocean life there are many that correspond more or less with the preconceived idea of what a sea serpent ought to be like. So that while the dragon is confined to legend and no one professes to have really seen one, there be many, down to the passengers on modern ocean liners, who have testified to seeing a sea serpent of approved type. Sometimes it may be one of the large sea snakes, sometimes a ribbon fish or a school of porpoises following one another as they leap out of the water so as to give the impression of the rolling coils of a great serpent. Sometimes a long streamer or tangle of seaweed may look like the giant serpent with its maned neck which all expect to see. Possibly among the unknown inhabitants of the great deep some such animal may really exist. But until it is captured and its remains deposited in some museum of natural history it must be ranked among fabulous monsters.

The Unicorn of classical writers was a real animal; the great one-horned Rhinoceros of India, well known to Eastern writers and not unfamiliar to the patrons of the Greek or Roman circuses. In medieval Europe it suffered a curious transformation. The Northern artist had never

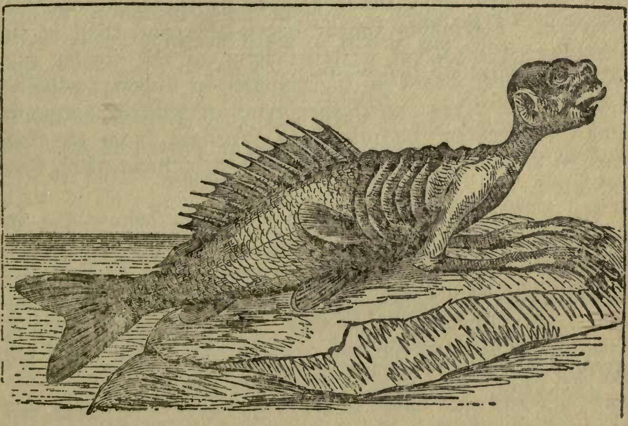


Fig. 1 —Supposed 'Merman.'
Long exhibited in Agassiz Museum, Boston, as an authentic specimen.

seen a rhinoceros nor talked with any one who had. He knew that it was a great four-legged beast with a long horn on its forehead and the traditional foe of the lion. So he grafted the twisted tusk of a narwhal on the forehead of a horse and in this form it was conventionalized in heraldry, its source not recognised when, centuries later, the rhinoceros was reintroduced to the knowledge of Western nations.

The various composite monsters of the mythology of different races—the Centaurs and Sirens of the Greeks, the Mermaids and Swan-maidens of Western Europe, the winged bulls of Assyria or the eagle-headed gods of Egypt—have all a more or less definite religious significance and are theological rather than zoölogical myths. Some of them have survived in zoölogical lore, supported, like the sea-serpent, by the occasional sight of animals more or less resembling what the observer expected to see and their described appearance colored by the traditional description. Mermaids appear every now and then in the accounts of medieval writers; some of the stories may well have been based on the manatee or dugong, while in more recent years actual specimens of stuffed mermaids, manufactured by the ingenious Japanese from the fore part of a monkey and the tail of a fish, have often been exhibited.

To another class of zoölogical myths belong the innumerable fanciful stories told of the characters and habits of real animals; of the transmutation of men into animals and vice versa, and of the transformation of one species of animal into another. Real metamorphosis of form, as of the tadpole into the frog or of the larva into the perfect insect, is well known to modern natural history, but however much or little a primitive ancestry may have known about it, there seems to be no good reason to believe that the enchantment-transformations of mythology originated in any real observations of metamorphosis in nature. Dream experiences imperfectly separated from the recollections of waking hours had probably much to do with their conception. Hence it would seem that while Natural History possesses relations which may throw its beginnings to the fabulous monsters of ancient times, the same cannot be said for the Science of Zoölogy, which as a science requires evidence, and having classified that evidence is loth to admit therein such mythical creatures who are undoubted aliens.

CHAPTER II

DEVELOPMENT AND DISTRIBUTION

THE animal kingdom includes a vast variety of organisms whose common basis of life is the cell. They are, like plants, an organized community of cells. The various members of this community are adapted to perform different services, and many groups have specialized, each for its particular function, so that the individual cells are no longer capable of a separate life. The animal or plant is thus not a mere aggregate of living cells, but an organism. In the successive classes and orders of animals, from lowest to highest, there is a progressive complexity in the organism, a more and more absolute and exact limitation of the cells or groups of cells to special functions. This progressive specialization is the key to the life history of the individual organism, the development or 'ontogeny' of the animal; and to the life history or 'phylogeny' of the race.

All animals are to be regarded, then, as organized communities, the units of these communities being protoplasm cells, originally identical in structure and capable of all the necessary activities of life, but specialized to perform particular functions. The first steps in the plan of organization as they appear in the development of the individual are identical in all animals.

The cell divides and re-divides until it forms an aggregate of numerous small cells, the 'blastula.' This aggregate, continuing to subdivide, then takes on a thimblelike form, the 'gastrula,' one layer of cells lining the cavity, the other being external. This cavity is primarily to contain and digest food, and the cells lining it naturally take on the functions of nutrition, while the outer cells, in contact with the outside world, take on the functions of sensation, of offense and defense, and procuring food. The living sponges and hydroids illustrate this stage of development, more or less modified.

The next important stage in development is the formation of a third intermediate layer of cells between the inner layer or endoderm and the outer layer or ectoderm. From this intermediate layer are developed in the higher animals the muscles, circulatory system and various glands and organs, the alimentary system with its glands being developed from the endoderm, the skin, the nervous system and the organs of sensation from the ectoderm. From this point onward, fundamental differences are to be found in the plan of organization of the principal types of animals, and the organs, adapted to serve the same purposes, are often developed from different parts and in a different manner. It is upon these fundamental differences in organization that the classification of the animal kingdom is based.

These lower animals are derived from the same stock as the higher ones. They persist to-day because they are perfectly adapted to their habitat and mode of life, or because they had gotten into a groove of evolutionary progress which did not allow them to advance so fast or so far as the higher types, or because of arrested development from obscure causes. Some of the factors which have limited their evolution are clearly seen, others are and perhaps always will be difficult to trace.

Life originated in the ocean, or at all events in water; but the dry land environment has stimulated a higher evolution, the obvious cause being the more abundant supply of oxygen, admitting of more active life. In order to preserve the form and relations of their parts, all animals of any considerable size have been compelled to develop a rigid framework or skeleton of some kind; the material and position of this skeleton, and its further use for purposes of offense and defense, have profoundly influenced the further development of the race. In the lower animals the skeleton is generally external; and the insects may be considered as representing the highest possibilities of a development based upon an external skeleton. In the vertebrates the skeleton at first was mainly external, but this became gradually replaced by an internal structure; and the higher possibilities of development with the internal skeleton form one leading cause for the higher development and greater size attained by vertebrated animals.

The third and perhaps the most important factor in causing or arresting evolution is in the nature of the environment, whether constant from age to age, or subject to slow secular or periodic change during geological time. If an animal is fitted to its mode of life and the conditions of its immediate surroundings remain unchanged, the organism has no occasion to vary, and tends to become fixed and unprogressive. But if the conditions are slowly changing, the race must become adapted to fit its new environment, and will retain or acquire a variability which through the influence of selection will lead to greater progressiveness.

The uniform and unchanging conditions of the deep sea have not been favorable to progress; the theater of evolution of marine organisms has been the ever-changing littoral region, the shores of the ocean, advancing and retreating through successive geological periods, widely varied in character, ranging from rocky coasts to sandy shoals, or from muddy flats to the still, clear water of protected inlets. Some of the deep-sea organisms, such as protozoans and sponges, have remained unchanged, so far as is known, from the earliest geological periods down to the present day. Others, like the crinoids, or sea-lilies, long since extinct in the littoral region, have found in the ocean depths a refuge where they still survive. Others again, like the deep-sea fishes, originally adapted to the life of the shore, have become curiously modified to suit the conditions of the ocean's depths.

Easily evident, likewise, is a corresponding difference between fresh-water and land animals. There can be no doubt that all terrestrial life was ultimately derived from an aquatic ancestry; those animals which have solved the problem of the utilization of the more abundant oxygen supply of the air instead of the limited amount available in the water having been able to assume a higher development and greater progressiveness, and the snails among mollusks, the insects among arthropods, and the reptiles, birds and mammals among vertebrates are the highest types in their respective classes. The fresh-water animals, more limited in possibilities of development, and subject to less change and variation in their conditions of life, are of inferior type, and as in the deep sea, among them may be noted survivals of very ancient and primitive organisms and higher types developed upon the land, but readapted to aquatic life. Having once acquired the capacity to use the oxygen of the air, however, they are careful not to lose it again, and remain air-breathers, however far their adaptation to aquatic or marine life may be carried in other respects.

It will have been noted that reference has been made to the ancient forms of life, thousands of varieties of which passed out of existence long before the existence of Man, and it is natural to ask by what means their nature is learned. To reply "By fossils" without determining what a fossil is would be to beg the question. The term fossil, which originally meant merely things dug out of the ground, has come to have a much more definite and restricted meaning in the language of modern science. Fossils are the remains of animals or plants or indications of their former existence, found buried in the soil or enclosed in the rock.

In general, only the hard parts of animals are preserved, the shells of mollusks and crustaceans and the bones of the vertebrate animals, while the fact that they are preserved at all is due to a combination of favorable circumstances. Usually when an animal dies, the flesh or soft parts decay or are devoured; the hard parts last longer, but gradually disintegrate into formless dust or mud under the influence of the atmosphere or the air-bearing waters of the surface. But if the animal is buried in a swamp, a river bottom, lake or estuary, where sediment is being piled up by the action of the rivers or of the sea, its hard parts may be covered up in time to escape destruction and get below the zone of atmospheric influence. In this case the remains will be subject only to the influence of the mineralized waters that permeate the soil and rocks beneath the surface.

The action of these waters is to dissolve particle by particle the organic matter of the fossil, and to replace it with mineral matter. In this process, known as petrifaction, usually the structure is preserved, as well as the external form. The bone or shell is thus converted wholly into stone, solid and permanent like the sediment in which it was buried, now converted by the same agencies into rock. This is the ordinary process by which fossils are made. There is nothing mysterious about it—it is merely the natural result that water seeping upward toward the surface, loaded with mineral matter and destitute of organic matter, tends to dissolve any organic matter it finds on its way and deposit mineral matter in all the minute cavities left, until they are filled and the porous mud or sand becomes solid impermeable rock.

Fossils, then, preserved in this manner, constitute the record of the history of life on the earth. It is an incomplete record. Long periods of time are unrepresented, because the sediments then deposited have been washed away or deeply buried, or the fossils in them destroyed by crystallization. A large proportion of the past life of this planet is imperfectly recorded or altogether lost because the animals had no hard parts to be preserved. The vast majority of the records are undiscovered or inaccessible because they are still buried far beneath the surface, and, moreover, the interpretation of the records is often doubtful.

Yet the importance of paleontology, or the study of fossil remains, is great, and its teaching positive because the evidence is direct. No one to-day would venture to question that the fossils of the rocks are the actual remains of animals which lived and died in former ages; and the scientist's knowledge of existing animals and plants is now complete enough for him to be able to declare positively that the animals which formerly inhabited the world were different from those of to-day, and that in proportion as research is pushed backward in time, the earlier forms were more and more diverse from their modern successors. Furthermore, it is seen that the lowest and simplest groups of animals were of the earliest introduction to the past life of the world, and that the higher groups have successively appeared in order of their complication and specialization in physical and mental structure.

Throughout the geological record there is evidence of 'annectant' or intermediate types, linking together groups of animals now widely separated; and the earliest appearing members of each group are more or less 'generalized,' that is to say, their bodily structure conforms to the general type of the whole group, but shows a combination of characters which are now found scattered among the various modern members of the group, but seldom or never all combined in one animal. These generalized characters also are apt to be annectant, and link the group to other groups.

For example, the birds and reptiles are now wide apart, the birds being toothless, feathered, adapted to flight, walking or hopping when on the ground, and with the tail (exclusive of feathers) reduced to a little rudimentary stub, while the reptiles possess teeth and scales, and are crawling or swimming, with long vertebrated tails. But all the earliest birds had true teeth like reptiles, and the oldest of them, the Archæopteryx, a long vertebrated tail feathered on the sides like the head of an arrow. And on the reptilian side are found the Dinosaurs among the more ancient reptiles resembling birds in many details of their bony structure, and especially in their long legs, adapted to walking instead of crawling; and the Pterodactyls, a group of flying reptiles, the latest of them tailless and toothless, with horny beaks like the birds.

Again, there is a great gap among modern animals between fishes and four-footed animals of the land. But the most ancient fishes are precisely those which come nearest in structure to the higher vertebrates, and from which these might most readily have been derived. Through all the invertebrate groups the same conditions appear.

Thus in a broad way the discoveries of paleontology tend continually to break down the sharp lines of distinction between the great modern groups and classes of animals, and do so in just such a way as must follow if the doctrine of evolution be true.

If the various species, genera, orders and classes of animals are derived from a common ancestry through the evolutionary process it should be possible to trace the successive steps in the evolution and differentiation of each race by the fossil remains of its ancestral stages in the successive geological epochs. This has been done, precisely and in detail, in many instances; that it has not been done in all, is due to the imperfection of the geological record, to a peccable knowledge of it, and especially to the vastness of the problem and the limitations, in means, facilities or insight, of those who are laboring to solve it. Broadly and approximately, the course of the evolution of animal life has been traced out from the indirect evidence of structure and individual development, and the more direct but less complete evidence of paleontology. The task of working out and proving it in detail is as yet far from complete. But among the thousands of workers who are devoting their lives to the study of fossils and their meaning, not one has been led to deny the truth of evolution or to doubt the theory of descent. Difference of opinion among scientific men is as to the method, not as to the fact.

Closely allied to the nature of the animals of the past is the question of their habitat in early times, involving the problem evoked by their present geographical distribution.

There are very few species of animals which inhabit more than a portion of the world; most of them are limited to quite a small part of the land or water areas. Man is perhaps the most cosmopolitan of all land animals. He inhabits every considerable land area of the globe, except the antarctic continent and a much smaller area around the North Pole. Most animals, however, are limited in their distribution by uncongenial climate or by barriers which the species has not found means of crossing. With land animals these barriers may be broad stretches of ocean, extensive deserts, high mountain ranges, or great rivers. With sea animals they may be continental barriers, uncongenial stretches of coast, and sometimes the volumes of fresh water poured out by great rivers. But the limitations imposed by climate and temperature are the most efficient barriers to the worldwide distribution of either land or sea animals.

Animals are dependent directly or indirectly upon plants for their food, and the abundance and rapid growth of vegetation in the tropics affords opportunity for a corresponding development of animal life. The profusion and variety of life in the tropics cannot fail to impress an observer from the temperate zone. The struggle for existence everywhere going on is perhaps somewhat different in character. It is an internecine war, a strife for survival among the animals themselves rather than a combat against an unpropitious climatic environment. In the temperate and especially in the arctic regions the element of struggle against the untoward conditions of outside nature is superadded to the ever-present war against other animals, which, scattered over a wider space, is less apt to impress the observer, altho its influence on the development of the race may be no less powerful. Here, perhaps, in the double struggle—against animals and against nature itself—lies the reason for the dominance of temperate and northern types when brought into competition with the more abundant but less severely selected races of the tropics. This fact is familiar in the case of man, but it is equally true among animals. The tropic regions, with their abundant food and easy life, are the refuge of inferior races, succumbing and driven forth before the sterner competition of the north.

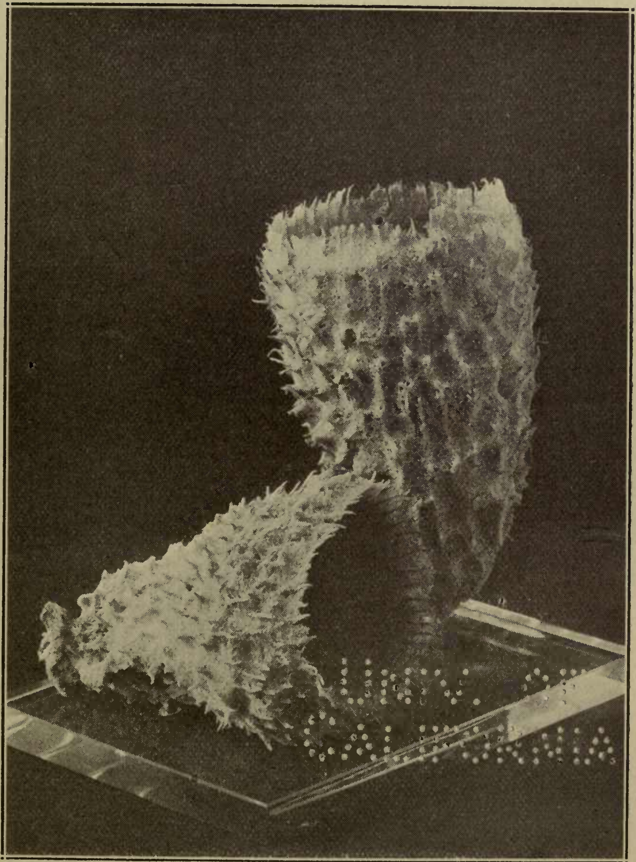
The zoölogical realms and provinces of the world correspond broadly with the geographic divisions, and even to some extent with the political divisions, since geographic and climatic barriers have conditioned the distribution of the races of men and thus largely influenced their governments. In the land fauna it is observed that the great land mass of the northern continents forms one great zoölogical realm, the Holarctic; South America a second, the Neotropical; Africa south of the Sahara a third, the Ethiopian; and Australia a fourth, the most isolated of all. The various islands partake more or less of the character of the mainland adjoining, but there are marked differences which point to a different distribution of land and water in former times than now.

Thus the animals of the British Islands are almost identical with those of Continental Europe, while the animals of Madagascar are widely different from those of Africa.

The simplest explanation, obviously, is that the former have been connected with the mainland of Europe since the present species of animals came into existence, the latter has been separated from the mainland since remote ages. Geological considerations support this view.

The marine provinces correspond in part with the great oceans, but are more influenced by zones of temperature than those of the land. So far as shore animals are concerned, their lines of distribution will be along the coast lines, and a broad area of deep sea is as much a barrier to most of them as is a land barrier. Like the land animals, however, they give convincing evidence of former differences in the distribution of land and water. There is a considerable proportion, for instance, of identical species on the two sides of the Isthmus of Panama not found on the Asiatic or European coasts. Hence there must have been communication between Atlantic and Pacific oceans, either at the Isthmus of Panama or elsewhere, since these species came into existence. They could not have gone around the Horn, because they are tropical species and are not found on the shores of temperate South America.

The geographic distribution of animals, present and past, together with the geological record of the evolution of each race, furnishes a most important line of evidence on the past history and geography of the globe, and under the name 'paleogeography' a branch of study is being built up which is of great scientific importance as well as of transcendent interest. Its scope and vastness of purview are readily recognised when it is remembered that an intimate knowledge of Zoölogy and of Geology (each of them vast and comprehensive) is a prerequisite. Especially is this true of the lower orders of life, which, despite their simplicity, afford the most fascinating realms of investigation.



A Horny Sponge, from the American Coast. (A. M. N. H.)

CHAPTER III

THE LOWER INVERTEBRATES

FROM the earliest times, when Sponges were believed to be but solidifications of the foam of the sea, they have been an element of curiosity to Man. They have been declared to be animal, to be vegetable and to be mineral; ancient naturalists quarreled over the question whether they could move or no, and Aristotle's decision that they were animal because they shrank when moved from their rock bases provoked a storm of dissent. Even so keen an observer as Lamarck believed the apertures on the surface of a sponge to be the mouths of small cells inhabited by polyps, and he expended no little wonder over the question why a polyp never was to be found in his cell. Peysonnel, on the other hand, declared that sponges were created by a giant sea-worm, and held that the sponge itself was "mere nidus and excretion."

It is now known, however, that the ordinary sponge of bathtub importance is the horny skeleton of one of the simplest kinds of animals. In life this horny framework is lined with an inner and an outer layer of cells. It is fast to a rock or coral block; its movements consist only in inducing a current of water through the pores by means of tiny whip-lashes attached to the inner cells, and by a certain amount of contraction and expansion of the entrances to the pores. The cells absorb and digest any food matter that is brought by the currents of water passing through the pores. Most of the growth is by budding; bisexual reproduction does occur, however, alternately with the giving off of gemmules, or independent buds; these gemmules, produced in the autumn, develop into male and female forms, and the ova from the one, fertilized by spermatozoa from the other, give rise to a summer generation of sponges, which in turn produce gemmules. This alternation of generations is not uncommon among lower animals.

There is a great variety of sponges, some with a calcareous skeleton, others with horny or siliceous skeletons. They are nearly all marine, and the best known kinds are tropical. The commercial sponges, of which the best come from the Mediterranean and Indian seas, are found in clear water at moderate depths. The fishermen locate them by looking through a glass-bottomed bucket, and pull them up with a pair of hooks on the end of a long pole. They are left upon the shore to die and decompose and then washed and bleached. Among the siliceous sponges some, like the Venus' Flower Basket, are exquisitely beautiful in the form and structure of the skeleton. These live at great depths and are obtained by dredging.

Fossil sponges are found in the most ancient rocks. Professor Cayeux has discovered the spicules of siliceous sponges in the Archaean rocks of Brittany, which would make them the oldest fossils known; and they are common in the oldest fossiliferous formations of other parts of the world. So that the testimony of the rocks appears to confirm what would be expected, that the sponges are the most ancient, as they are the simplest of the Metazoa, or many-celled organisms.

The Corals and Sea-anemones, Hydroids and Jellyfish, grouped under an order 'Cœlenterata,' are but little less simple in form. In all these animals the structure consists simply of a body cavity with a fringe of tentacles around the edge. The tentacles are stinging and sensitive cells which serve to capture the food; the body cavity is lined with digestive cells which serve to digest it, and is sometimes partially divided up by partitions extending inward from the outer wall; and the outer layer of cells may secrete a calcareous shell which serves as a protection. The jelly-fish are free-swimming organisms; the hydroids and sea-anemones are fixed to the bottom; and

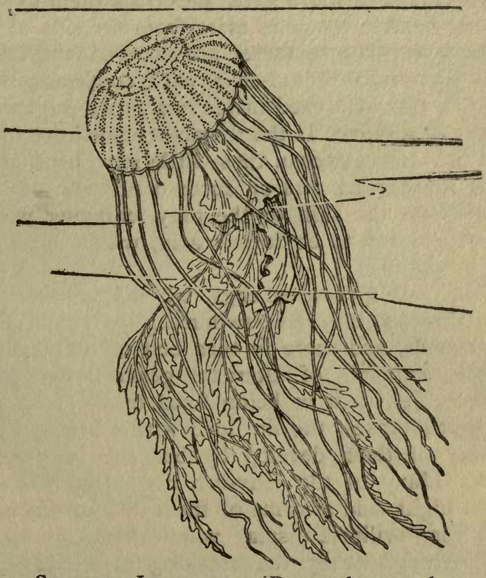


Fig. 2 —Speckled Jellyfish. (Drawn from a photograph.)

the corals are great colonies of individuals which secrete a calcareous shell.

The translucent milky umbrella-like disk of the jelly-fish, lazily opening and closing as it floats along the tide, is familiar to every one. Beneath the disk hangs a circle of long tentacles, stinging cells which serve to kill or paralyze small fishes or other minute animals that may come in contact with them, and are floated into the body cavity by a current of water produced by the lashing of cilia, or whip-cells, in the same way as in sponges. Many jelly-fish can inflict a sting sufficient to cause severe pain to the incautious hand which touches them. The structure of the stinging tentacles is very curious. A. G. Mayer, in his 'Sea-shore Life,' describes them as follows: "The long flexible tentacles arise from the side of the bell near the rim. The tentacles are covered with wart-like clusters of minute thread-cells, each containing a coiled tube which can be turned inside out as we might do with the finger of a glove. If the tentacles come in contact with a small fish or crustacean these little stinging threads are instantly discharged, and on account of their minute size they penetrate the skin of the prey, carrying with them a poison, believed to be formic acid, which quickly paralyzes the victim."

The jelly-fish produces eggs, which, however, do not develop directly into free-swimming jelly-fish, but into fixed hydroids, and these in turn bud off jelly-fish. This is another example of alternate generations. Hydroids differ from jelly-fish in being fixed to the bottom; they are like little vases, the lip lined with stinging tentacles, and many of them develop by budding into compound colonies. Many of the jelly-fish are strongly phosphorescent at night, and swarms of them floating in the water make a very brilliant display when stirred up by a boat passing through or by the breaking of waves upon the shore.

It may seem strange that such an animal as the jelly-fish should leave any traces of its presence in the rocks. Nevertheless, under certain favorable circumstances they may be buried in the sand and converted into siliceous casts without much loss of shape, and these fossil casts, known as 'star-cobbles,' are found in the most ancient rocks of the Cambrian period in Alabama and elsewhere. So it appears that jelly-fish were among the inhabitants of the seas at the dawn of recorded geological history.

"A sea-anemone," says Mayer, "is a barrel-shaped animal. The bottom of the barrel is fastened to some rock or other firm anchorage, while the upper end bears a slit-like mouth which is encircled by a fringe of tentacles. The mouth leads into a simple tube-like throat, which

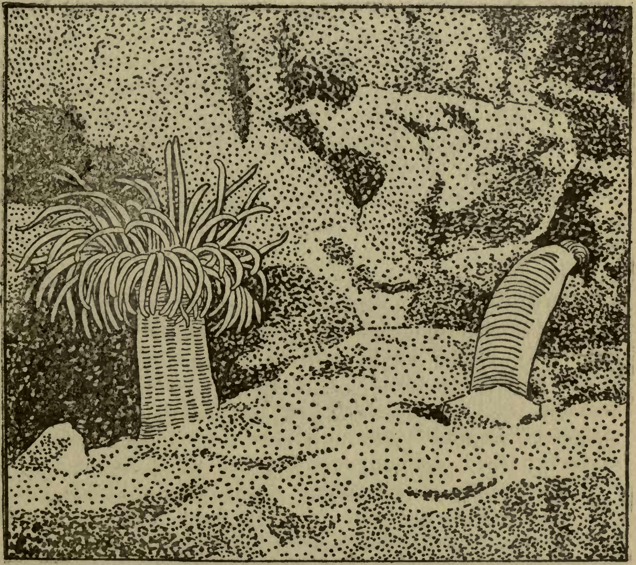


Fig. 3 —White-armed Anemone; Expanded and Contracted. (Drawn from a photograph.)

is bound to the inner sides of the barrel by means of radiating partitions.

"The throat-tube is, however, only about one-half as long as the height of the barrel, so that the radial partitions in the lower half of the barrel cavity do not meet at the center, but leave an open space which is the 'stomach' of the anemone. Sea-anemones are among the most attractive of marine animals, beautiful both in form and color. They vary in size from that of a pin's head to several feet across, and they live at all depths and in a great variety of situations.

"A Coral Polyp is only a sea-anemone which deposits a plate of lime salts at the base of its barrel-like body and between the radial partitions of the stomach cavity. These lime salts form a stony skeleton or substance which we commonly call 'coral.' It is well to remember that the coral animals are not 'insects,' but are merely sea-anemones which form stony skeletons. Altho sea-anemones and Coral Polyps resemble beautiful flowers when fully expanded, they quickly contract into a mere dome-shaped mass when disturbed. In this way the coral polyps are protected by withdrawing into their stony cup-shaped bases.

"The Coral Polyps are glassy white and translucent, and have each from eighteen to twenty-four long tapering tentacles which end in a white knob and are speckled over with white warts. These are the stinging organs which enable the coral to capture its prey of small marine animals. When fully expanded the polyps are about one-eighth of an inch wide and three-eighths high, but when disturbed they suddenly contract so as to become practically invisible. The colony starts with a single polyp, but soon others bud out from its base, and the cluster increases by further budding from the bases of the older polyps until it may be several inches in diameter.

"The Fleshy Coral is found from the eastern end of Long Island to the Gulf of St. Lawrence. It is rarely seen in shallow water, but is common upon rocks at depths greater than twenty feet. When first brought up from the bottom it appears as an ugly, tough gelatinous mass covered with dull yellowish-pink finger-shaped processes. If placed in water, however, the whole mass soon appears studded with beautiful star-shaped polyps, which expand so as to give the appearance of a stump covered with delicate pink flowers. Each of these polyps has a terminal mouth surrounded by eight tentacles, the sides of which are bordered with rays giving a feathery appearance. The whole colony of polyps develops through constant budding from the sides and bases of the older parts of the colony.

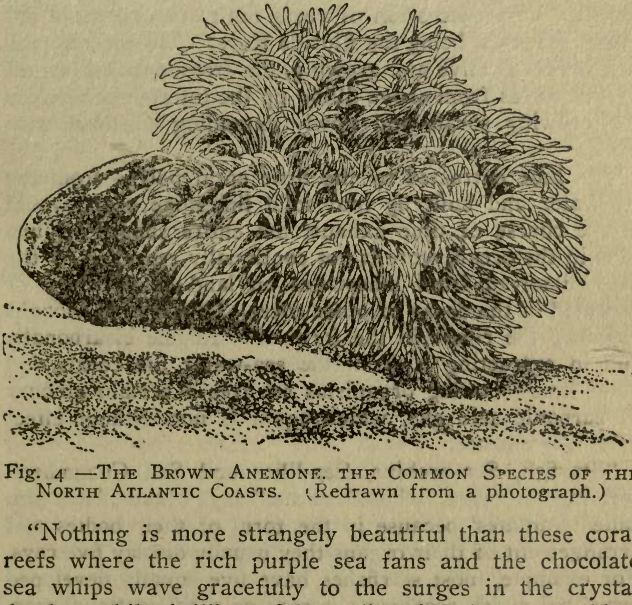


Fig. 4—The Brown Anemone, the Common Species of the North Atlantic Coasts. (Redrawn from a photograph.)

"Nothing is more strangely beautiful than these coral reefs where the rich purple sea fans and the chocolate sea whips wave gracefully to the surges in the crystal depths, while brilliant fishes glistening in green, blue, purple and yellow glide in and out among the shadows of the coral caverns. The precious coral of the Mediterranean is allied to the Sea Whips. Its polyps are brilliant white, and have each eight feathered tentacles; while the internal axis of the colony is red and stony."

The Stony Corals, especially the reef-building kinds, have played an important part in the building up of the continents. They flourish in a warm temperature and clear water. In the West Indies, the Red Sea and Indian Ocean, the northeast coast of Australia, and especially in the islands of the Pacific, coral reefs to-day are building out the land on a gigantic scale; and their influence has been even more important at times in the past history of the earth. The lower part of the peninsula of Florida consists of a succession of reefs built out one after another, the latest being the Florida Keys. The outer border of the reef is alive and growing, the fragments broken off by the waves from above filling up the interstices between the growing corals and slowly extending the bank seaward.

The lime extracted by the little coral polyps from the sea-water and built up into solid limestone reefs would in the course of time exhaust the entire supply of lime salts in the ocean, were it not continually recruited by the lime dissolved from limestones on land by the rain or liberated in the decay of other rocks. This lime is brought down by the rivers in the form of a soluble bicarbonate, and in extracting it from the sea-water the corals and other lime-secreting organisms set free a certain amount of carbonic acid gas, which again is not without effect upon the climate.

"Starfish, Sea-urchins, Sea-lilies and Sea Cucumbers, forming the order Echinodermata," says Mayer, "are also called 'radiates' because in the form of their bodies and arrangement of their organs they usually display five rays. For example, most starfishes have five equally developed arms, 72° apart, recalling the rays of a conventional star. In the Echinoderms the skin usually contains a skeleton composed of calcareous plates of definite shapes, all hinged together in an orderly manner, so as to make a veritable armor which gives rigidity to the body and protects the soft organs of the interior. In the living starfish one will see hundreds of little tubular feet which arise from the grooves on the lower side of the arms. When the starfish is turned over upon its back these feet stretch out to a remarkable length and wave about, seeking to fasten upon something in order to right the animal. It is then we may see that each of these feet is a hollow tube ending in a cup-shaped sucker.

"Similar tube-feet will be seen in five double lines along the sides of the sea urchins. The mouth of the starfish is at the center of the lower surface. On the upper side, and a little away from the center between two arms, one will see a spongy-looking area. This is called the madreporic plate, and is the sieve-like entrance to the water-tubes of the starfish, which extend down the arms and give rise to little bladder-like vessels one above each tube-foot. The contractions of these little bladders cause the tube-feet to elongate by pressing water out into their cavities. The upper surfaces of most of the starfishes are covered with spines, but these are much better developed in the sea urchins, where, in addition to spines, are found calcareous pincers mounted upon rods, which are used to remove any injurious foreign substance that may fall upon the body of the urchins.

"The sea cucumbers, or Holothuria, are worm-like in appearance, but are nevertheless closely related to starfishes and sea urchins. They have no spines and their skeleton is often reduced to minute anchor-shaped spicules within the skin. The mouth is at one end of the worm-shaped body, and is surrounded by feathered or branching tentacles. In some species there are five double rows of tube-feet down the sides of the body, but in others these are absent. When disturbed sea cucumbers have the curious habit of casting out their viscera and afterward regenerating them. They are sluggish creatures, and either live within the sand or under rocks or crawl slowly over the bottom, feeding upon minute organisms that are contained in the sand or mud which they swallow.

"Sea urchins, or Echini, may be compared to starfishes without arms. They are usually provided with a skeleton made for the most part of six-sided plates fused or rigidly joined together. They have five sharp-edged teeth with which they gnaw off minute seaweeds from the rocks. Some species can even gnaw away the rock itself, and in many parts of the world the sea urchins have literally honeycombed the rocks; indeed, a sea urchin is often

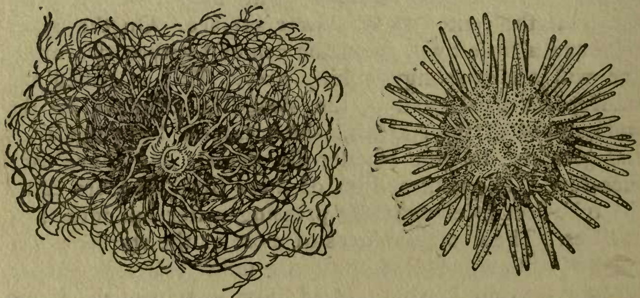


Fig. 5 —Basket Star (left) and Sea-urchin (right). (Drawn from photographs.)

found living in a cavity whose opening is too small to allow of the animal's escape. The common sea urchin of Europe is sold in the markets during the season when it is full of eggs.

"The Sea Lilies, or Crinoidea, may be compared to a starfish mounted upon a long stem which arises from the middle of its back and anchors it to the bottom of the sea. The mouth is turned upward, and is surrounded by branching arms which sweep gracefully to and fro in search of prey.

"The Echinoderms live only in salt water, but they are found at all depths and in all oceans, from the tropics to the poles. The vast majority crawl over the bottom, but at least one holothurian swims through the water, and was at first mistaken for a jelly-fish. Most of them cast their eggs out into the water, and the larvæ develop bands of waving cilia, which enable them to swim about for a considerable time. Suddenly the body of the Echinoderm begins to develop with the larva, and most of the old larval body is absorbed or cast off.

"Starfishes feed upon almost any kind of mollusk, but will also devour barnacles, worms, and occasionally sea urchins or even the young of their own species. It is estimated that in one year starfishes destroyed $631,500 worth of oysters on the beds of Connecticut alone. In the mode of feeding the starfish folds its arms over the clam or oyster, and hundreds of the sucker-like tube-feet fasten themselves to the valves of the shell, so that finally the mollusk yields to the constant pull of the starfish and the shell gapes open. Then the starfish turns its stomach inside out and engulfs the mollusk. It has been found by experiment that a large starfish can exert a steady pull of over two and one-half pounds, and that this is sufficient in time to open the valves of a clam or mussel.

"The eggs of the starfish are discharged into the water in greatest abundance during the last three weeks of June, altho they are also to be found throughout the summer, and occasionally even in winter. These eggs soon develop into little transparent larvæ covered with tortuous lines of waving cilia, and provided with long, flexible tubercles. They swim slowly about near the surface, and feed upon minute organisms until they grow to be about one-eighth of an inch long. Then the upper and lower halves of the star begin to develop upon both sides of the stomach, and in a few hours all of the anterior part of the larva and the tubercles are absorbed, and only a minute star about as large as a pin's head is seen upon the bottom of the ocean.

"Myriads of these little stars settle upon sea weeds and eel grass, and begin at once to devour the young clams which also begin life in the same places. Professor Mead found that one of these little stars devoured over 50 young clams in 6 days. The starfishes grow rapidly, and in one year they may have arms 2½ inches long and be ready to spawn."

Besides the common five-pointed starfish there are many others more or less familiar. The Serpent-stars have long, slender, flexible arms and are much more active; in the Basket-stars the arms are branched and forked into a multitude of slender interlaced tips upon which the animal moves about with the body lifted above the ground.

The prickly sea urchins abound along rocky coasts; along the sandy shores they are replaced by the sand-dollar, flattened out into a thin plate covered with minute brown spines. Sea cucumbers are familiar to every one who has explored the tide-pools of rocky coasts at low water, but other kinds are common on sandy, muddy or gravelly beaches, living just below low-water mark. In China a species of sea cucumber is prepared and eaten as a delicacy. Sea lilies, or Crinoids, are now rare and confined to deep water, but in the early periods of geologic time they were very abundant and varied, shore forms as well as deep-water species. The oldest of them, dating back to the Cambrian Period, suggest a sea urchin which has lost its spines and is mounted upon a jointed stalk; in the Crinoids proper the body has developed branching arms which wave in a feathery plume above it. The fossil crinoids, or 'stone-lilies,' are sometimes preserved in wonderful perfection in the Paleozoic limestones, and are one of the most attractive of fossils. Great numbers of them have been obtained in the limestones of Crawfordsville, Indiana, and elsewhere in the United States.

"The title 'Worms,'" says Professor Thomson, "is hardly justifiable except as a convenient name for a shape. The animals to which the name is applied form a heterogeneous mob, including about a dozen classes whose relationships are imperfectly known. But the zoölogical interest of the diverse types of worms is great. For amid the diversity we discern affinities with Cœlenterata, Echinoderms, Arthropods, Mollusks and Vertebrates.

"Moreover, it is likely that certain worms were the first to abandon the more primitive radial symmetry, to begin moving with one part of the body always in front, to acquire head and sides. And if one end of the body constantly experienced the first impressions of external objects, it seems plausible that sensitive and nervous cells would be most developed in that much-stimulated, over-educated head region. But a brain arises from the insinking of ectodermic (skin) cells, and its beginning in the cerebral ganglion of the simplest 'worms' is thus in part explained."

Most of the creatures which fall into this group are of little interest to the general reader. Many of them are parasitic; some, like the Tape-worms, Thread-worms, Flukes and Trichinæ, are unpleasantly familiar in this connection. The simpler Unsegmented Worms are those which most nearly represent the remote ancestors of mollusks and of vertebrates; the higher Segmented Worms, or 'Annelids,' follow more definitely along the line of crustacean and insect evolution. In them may be found an arrangement of organs and plan of bodily construction which serves to explain how the organization of the crustaceans and insects has been developed.

The Common Earthworm is the most familiar of the annelids, and its anatomy is much more interesting and complicated than might at first be supposed. The surprise is great that awaits the man who first dissects an Earthworm. With proper cleaning and dissection he will be able to see a complex and wonderful structure, a plan of organization wholly different from that of the higher animals (vertebrates), yet subserving to a large extent the same purposes, and beautifully adapted to the needs of the Earthworm's life and habitation. To tear up that delicate mechanism on the prongs of a fishhook is likely afterward to appear to him a sort of disregard of proportions, much like throwing a gold watch at a stray cat.

Of the anatomy a detailed account cannot be given here.

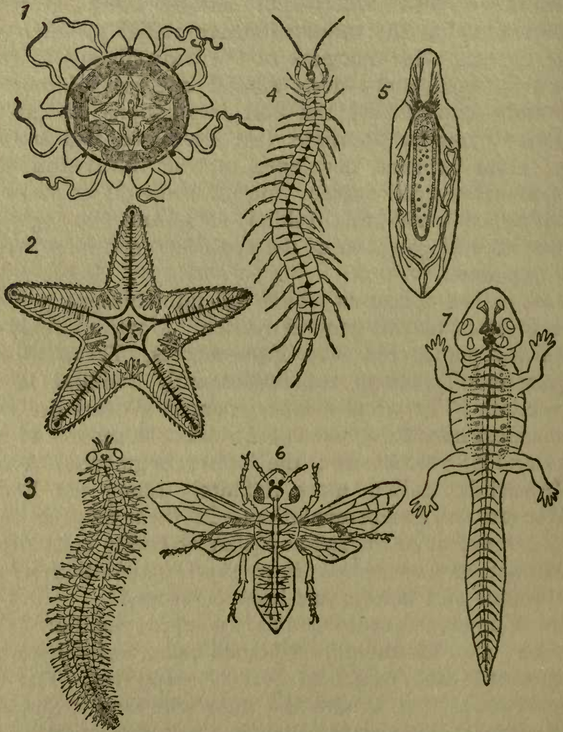


Fig. 6 —Nervous System in Various Phyla.
1., sea anemone; 2., starfish; 3., worm; 4., centipede; 5., clam; 6., honey-bee; 7., salamander.

It must suffice to say that it has a straight alimentary canal stretching from the mouth at the front end to near the hinder end of the body, the front end of the canal being provided with a muscular ring and with glands which aid it in swallowing and digesting the earth which forms its food. There is a circulatory system, consisting of a slender tube along the mid line of the back and others along the under side, joined by several cross veins encircling the throat, which by expanding and contracting enable the colorless blood to circulate through the body. It possesses also a nervous system consisting of a cord corresponding to the spinal cord of higher animals, but situated on the under side of the body along the middle line, and double instead of single, with little knot-like expansions or ganglia at every segment, which correspond to the brain of the higher animals, and with a separate pair of ganglia on the dorsal (upper) side of the head united with the front pair of ganglia of the under side by a pair of cords encircling the gullet. There are no eyes or other specialized sense organs, no special organs of respiration; yet the worm is aware of the approach of enemies or of light and darkness through a general sensitiveness of the skin, and the blood is aerated through the skin. There are, however, the beginnings of organs of excretion, to remove waste matter from the circulation, and the reproductive system is quite elaborate, the animal being hermaphrodite—that is, combining both sexes in one individual, but so arranged that the eggs of one Earthworm must be fertilized by another.

The chief economic importance of Earthworms is as principal agents in forming the mantle of humus, or soil, which covers the dry land in all parts of the world, and buries the hard rocks and sterile soil beneath it. Earthworms abound in all parts of the world; they eat their way through the soil and come out at night to the surface, where they forage around for leaves and stray bits of vegetable matter, which they drag to their burrows to be nibbled and swallowed at leisure. Their castings, composed of the earth and comminuted vegetable matter which they have swallowed and digested, are deposited on the surface, and in the course of their lives they bring up a good deal of the sterile under soil, mix it thoroly with particles of vegetation from the surface, and deposit it in their castings. These, accumulating year after year and century after century, form the layer of humus, or top-soil, in which vegetation chiefly thrives and on which the gardener and farmer depend for the successful growth of their crops.

Not all the humus is due to Earthworms—insect larvæ play some part, and to a large extent it is merely due to natural decay of surface vegetation and its mixture with soil by rain and the dust brought by the winds. But the investigations of Darwin showed that the Earthworm plays an important part in its formation. Thus as the tiny Coral Polyp is ever helping to form the continents on which man can live, and perhaps also to control the climate and moderate the extremes of temperature, so also the Earthworm is rendering efficient aid in covering the land with rich and fertile soil, enabling vegetation to flourish and making the earth habitable for the human species.

The name 'mollusks,' or soft-bodied animals, covers an immense number and variety of invertebrates, the Clams, Oysters and other shellfish, the Snails and Slugs, the Octopus and Squid, and many less familiar types. All of them have soft bodies, usually with an external calcareous shell, but with no internal skeleton except in the Squids and their relatives. They are much more highly organized than the Coral or Starfish groups. The arrangement of the organs shows a bilateral symmetry, unlike the radial symmetry of Coral or Starfish. That is to say, the organs and parts of the body are arranged in pairs on each side of the middle line, so that there is a front and a hinder end to the body. On the other hand, the body is not divided into successive segments as in the worms, crustaceans and insects. Most of the mollusks are sluggish animals, many of them attached to stones or other objects on the bottom, but the Squid and Cuttlefish are swift and active.

"The lower surface of the body," says Mayer, "consists of a thick muscular 'foot' used in creeping. In front of the foot is the head, which may have a pair of eyes and tentacles; while the mouth lies on its lower surface and is often provided with numerous horny, rasping teeth. A flap-like fold of the body extends outward from the sides. This fold is called the 'mantle,' and its free edge and upper part secretes the shell which usually covers the back of the mollusk. The feathery gills arise from the sides and lie in the space between the lower side of the mantle and the side of the body. The intestine is coiled and opens typically at the posterior end of the body, behind the foot. There is a paired digestive gland or 'liver' which pours its secretion into the mid-gut. The three-chambered heart lies above the hind gut and pumps blood from the gills to other parts of the body." In addition, it may be noted that the mollusks show well-defined muscles and nervous system.

The latter consists of a number of ganglia, knots or nodes of 'gray matter,' corresponding in function more or less to the brain of higher animals, connected by cords of nerve fibers which may be said to correspond roughly to the spinal cord in higher animals. From these ganglia nerves are given off to the various parts of the body. This concentration of the nervous system into a few defined ganglia connected by cords is a great advance upon the condition in the lower invertebrates, where the nerve cells are diffused and scattered over the surface of the body. It makes possible a much more exact and definite correlation of the movements and actions of different parts of the body. It is like the establishment of a central executive bureau to control and order the activities of some great and complex organization.

The great majority of mollusks are marine, chiefly shore-living, altho some are adapted to a deep-sea life. But many inhabit fresh-water lakes, rivers and streams, and one group, the Land-snails, has become adapted for terrestrial life, breathing air instead of water.

The principal groups of mollusks are: (1) The Bivalves, or Lamellibranchs, comprising clams, oysters, mussels and other shell-fish in which the shell consists of two valves, right and left; (2) Snail-shells, or Gasteropods, including snails, whelks, periwinkles, limpets and others in which there is a single valve, mostly spirally coiled; the symmetry of the animal is obscured in this group by development of one side; in the Slugs the shell has degenerated to a small, horny scale buried in the body; (3) Squids and Cuttlefish, or Cephalopods, including also the octopus, nautilus and a host of extinct forms; they are free-swimming, active animals with a ring of muscular tentacles around the mouth and part of the 'foot' modified into a funnel, the 'siphon,' through which water can be forcibly expelled from the mantle cavity, driving the animal backward; these are considered the highest development of molluskan life, on account of their active habits and more concentrated nervous system.

The Lamellibranchs feed upon minute organisms, both animal and vegetable, which they sift out from the sea water by the aid of gills. The gasteropods are more generally carnivorous, feeding upon other mollusks, which they attack by boring a hole in the shell by means of a ribbon-like tongue, the 'radula,' armed with many small, sharp, horny, rasping teeth, and then sucking out the juices of their victims. This unique little implement appears to be very efficient for its purpose, and is said to be aided by a secretion of sulphuric acid. Other gasteropods, such as the periwinkles and the fresh-water and land snails, feed upon plants, but all of them possess the radula. The cephalopods also are carnivorous, the Octopus lying in wait for unwary fish or crustaceans which may come within reach of the long tentacles, the Squids capturing their prey by darting rapidly backward, swinging quickly to one side and seizing the victim in their sucker-bearing arms.

The mollusca include an immense number and diversity of animals. In the Gasteropoda alone there are over fifteen thousand living species; the Lamellibranchs are hardly less numerous. Many of them are edible, a few are important articles of food. The oyster fisheries in the United States alone are estimated to yield $16,600,000 annually. The soft-shell clam of the North Atlantic, the scallop and the round clam or quahaug of the Middle Atlantic States, are important articles of commerce, while mussels, whelks, periwinkles and land snails also are largely eaten in Europe. The pearl oysters of the Indian and Pacific oceans and the fresh-water pearl-clams of the United States are likewise of importance, not only for the pearls, but for the much larger industry in mother-of-pearl obtained from the shells and manufactured into buttons and pearl ornaments. The pearl fisheries in the Persian Gulf alone are said to be worth $2,000,000 annually.

The noxious activities of mollusks are slight. A few species commit depredations upon oyster-beds; the damage done by the teredos to timber under water is more serious. The gruesome tales of attacks upon man by the devil-fish or octopus are mostly fanciful. An octopus, if large enough, no doubt could and would attack a man if he came within reach. And once in a while he might catch him at a sufficient disadvantage to overcome and destroy him. But the chances for such an encounter with such a result are exceedingly small. Members of this group of mollusks do attain a gigantic size, however. These huge forms are deep-water organisms, and are very rarely seen by man, altho they form an important part of the food of marine mammals such as the seals and sperm-whales.

During the whole of recorded geologic time mollusca have been an important element in the marine fauna;

fresh-water mollusks are probably equally ancient, and land mollusks are known to have appeared as far back as the Coal Era. Their hard, indestructible shells are the most abundant of fossils, often making up the entire mass of limestone strata. Lamellibranchs, gasteropods and cephalopods were all distinct as early as the Cambrian Period; their evolution from a common stock must date far back into the unrecorded beginnings of geologic time. The shelled cephalopods, related to the modern nautilus, attained great size and abundance early in geologic time, and were then the dominant type of marine life. In Orthoceras the shell is sometimes seven feet long, straight instead of coiled as in the nautilus. During the Age of Reptiles the cephalopods were again very abundant marine forms, the Ammonites, Baculites, etc., coiled, partly coiled or uncoiled, being probably more nearly related to the squid and octopus than to the nautilus.

But the majority of fossil shells are related to the modern lamp-shells and their allies, the Brachiopoda, which, altho mollusk-like, are not true mollusks, the plan of organization of the animal being wholly different. The shell may be distinguished by the fact that its valves are dorsal and ventral, instead of right and left, with respect to the symmetry of the animal. These Brachiopoda are considered a class apart, or grouped with Bryozoans into the 'Molluscoidea.' Their relations are about as close with worms as with mollusks, but not very near to either. The living brachiopods are rare deep-water organisms, crowded out from shallow water by competition of the more highly organized mollusks; but in early geologic times they were the common shells of the sea-shore.

With the Crustaceans begins the Arthropod series of invertebrates, characterized by a segmented body, jointed limbs and an outside skeleton. The name (arthro-poda, jointed feet) points to the distinction that separates them from the worms; but their plan of organization is evidently derived from that of the segmented worms or Annelids. The crustaceans are adapted to aquatic life and breathe by gills; the insects are adapted to terrestrial life and breathe by tracheæ; the spiders and their allies include both land and aquatic types, differing from either insect or crustacean in their plan of organization.

The lobster and crayfish are the most typical crustaceans, the first marine, the second living in fresh water. In comparison with the worm, it is observable that while the body is segmented, the segments are not all alike, but are divided into two regions, the head-and-thorax and the abdomen. Likewise the appendages are not mere bristles as in the worms, but jointed, and specialized to serve different purposes. The most anterior ones, antennæ and antennules, are organs of touch and smell, enabling the lobster to feel his way about; next come six pairs which serve chiefly to aid in biting and chewing the food; then the large forceps to seize the prey; then four pair which are used in walking; and six posterior pairs used mainly for swimming purposes. Altogether there are nineteen pairs of appendages. The stalked eyes are not classed as appendages, being of different origin. The segments and appendages are enveloped in a tough, horny covering, flexible at the joints, hardened elsewhere by lime salts into a rigid armor.

The internal organs of the lobster are much more elaborate than in the worm, but their general plan is much the same. The nervous system is more concentrated; the muscles are distinct and well developed; the alimentary system consists of, first, a gizzard with a complex mill for grinding up the food, then a mid-gut stomach with a large digestive gland which takes the place of liver, pancreas, and in part the stomach glands of higher animals; and finally a long straight hind-gut, which takes but small part in the digestive process. The colorless blood enters the heart from the gills through valves which admit of entrance but not of exit. Thence it is pumped through well-defined arteries to the tissues of the body, from which it returns through ill-defined channels to the gills. The gills are feathery structures of a rather complex nature, presenting a large surface to the current of water which the animal keeps going through them by paddling with part of the fifth pair of appendages. There is also a distinct excretory system (kidney), and the reproductive organs are more elaborated than in the worm, the sexes being separate. It is thus a much higher type of animal than the earthworm, but the plan of organization is the same, as it is also in the insect. The mollusk and the vertebrate are organized upon entirely different plans.

The lobster occasionally attains great size, and one specimen, three feet and six inches long and 30 pounds in weight, was captured off the New Jersey coast in March, 1897.

The Snapping Prawns are little lobster-like crustaceans of the American coast. The largest are not more than one and three-quarters inches long. One claw is much larger than the other, and is provided with a sharp-edged blade which is normally held out at right angles to the claw. At the least alarm this blade is closed with a sharp snap, reminding one of the explosion of a small torpedo. These little creatures live in crevices of coral reefs, under shells and stones and fairly swarm in sponges; so that when a sponge is lifted from the water it crackles as if filled with minute firecrackers. The Shrimps are similar in many ways, but are free swimmers.

A Crab is essentially a lobster with its tail turned in under its body. It is the highest of the Crustacea, and the species is widely distributed and varied, extending from the combative edible or blue crab to the parasitic hermit crab; ranging in size from the tiny oyster crabs which live with the gill cavity of the oyster to the giant spider crab of Japan, which attains a span of twelve feet; including deep sea crabs which never come to the surface and the land crabs of the tropics which rarely enter the water, and which, like the robber crabs, climb trees and live on cocoanuts.

Barnacles, while mollusk-like in appearance, are really crustaceans which have affixed themselves to rocks or floating objects and are enclosed in a hinged calcareous shell. As Huxley put it, "They are fast to a rock by their heads and kick the food into their mouths." The stalked barnacle, or 'goose-barnacle,' was believed by writers of the Middle Ages to undergo a metamorphosis into a species of goose—the 'barnacle-goose'—and this transformation was repeatedly asserted in the most positive terms down to the time of Linnæus or even later.

"Being encased in a natural armor," says Mayer in 'Seashore Life,' "crustaceans cannot grow at a uniform rate, but enlarge suddenly at the periods when the shell is shed. This occurs at fairly regular intervals, and the entire shell is shed, even the coverings of the eyes and part of the lining of the stomach being cast off. The creature is then soft and helpless, and usually remains hidden in some safe retreat until the body has expanded and the new shell hardened."

Owing to their hard outer armor and their aquatic life, remains of crustaceans are very common as fossils, and there is a fairly complete record of their evolution. The higher types, such as crabs and lobsters, did not appear until after the Coal Period. But the more primitive, mostly minute crustaceans known as Ostracods and Phyllopods have been traced as far back as the Cambrian, nearly to the beginning of recorded geological history.

The Trilobites, familiar to every geologist, were a primitive group of crustaceans which flourished during the older geologic periods, becoming extinct in the Coal Period. They are very abundant and characteristic fossils in Paleozoic strata. Many of them attained considerable size, the largest up to two feet in length.

CHAPTER IV

THE HIGHER INVERTEBRATES

It seems natural to think of a spider or scorpion as an insect. But in fact they are not true insects, altho they belong to the Arthropod series of invertebrates. All insects have three pairs of legs and breathe by tracheæ. Spiders and scorpions have four pairs of legs and breathe by "lung-books," an apparatus like modified gills. And in all the details of their anatomy spiders and scorpions are as different from insects as they are from crustaceans. All insects (excepting, perhaps, a few unimportant primitive kinds) have wings or have had them at a former period in the development of the race; altho in many groups the wings are degenerate or lost. Scorpions and spiders appear never to have developed wings at all.

In short, the insect class may be regarded as an adaptation of the Arthropod invertebrates to aerial life; the spider class to terrestrial life; the crustaceans to marine life. Each, in its own element, has had a long and more or less successful career; each has made attempts to invade the territory of the others. For in the West Indies and other oceanic islands are crabs which pass their life mostly on dry land; and the spider swinging in air from a slender thread, and even in some cases traveling through the air on a long film of unattached gossamer, is emulating the habits of the flying insect. But the insects alone have invaded the alien habitats with any great success, and so far as terrestrial life is concerned they have crowded the spiders and scorpions to the wall.

Scorpions are found only in tropical countries, and are distinguished by the elongate tail with venomous tip and the large-clawed grasping legs in front. They have four pairs of walking legs like spiders. In the old natural history books they are credited with committing suicide when unable to escape by stinging themselves to death Unfortunately for the story, aside from the argument that the mental processes of the lower animals are not very likely

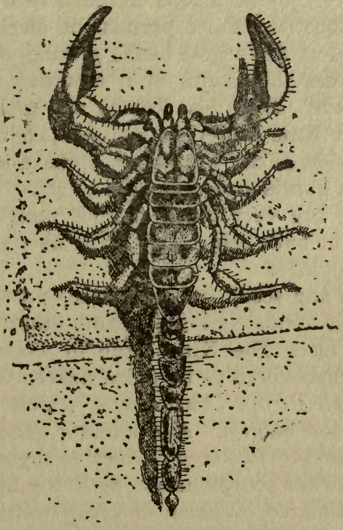


Fig. 7 —A Scorpion.

to lead them to deliberate suicide, the feat is anatomically impossible, and if it were possible the poison would have no effect.

Spiders are common everywhere, and, like scorpions, they are all carnivorous, sucking the juices of insects which they capture. Many of them, but not all, form webs, and the construction of the web is a remarkable piece of engineering, which must involve highly elaborated instincts comparable only to those of the higher insects.

The material of the web is a liquid silk secreted by the spinning glands and forced through the fine tubes of the "spinnerets," hardening immediately on exposure to the air. The spun threads are used also to line the nest, to envelop the cocoon, and to assist the spider in his aerial gymnastics.

The Spiders are by no means confined to webs, but certain of them construct more permanent dwellings. Thus the Mason Spiders dig a hole in the ground, and then spin across and across the mouth of it a woven door with a hinge at one side. Even less known and more curious is the work of a little water-spider, who, not desiring to forego the power of air breathing, spins a silken diving bell, wherein is imprisoned a globule of air.

Male spiders are very much smaller than the females, the difference in bulk being sometimes as 1,300 to 1, and more brightly colored.

With spiders and scorpions are classed various parasitic insects, such as mites and ticks, and other minute and degenerate forms. The King Crab or Horseshoe Crab has also been discovered to be more nearly related to the Arachnoids than to the Crustaceans, which it resembles in appearance and habitat. And another group of aquatic animals, the Eurypterids, now extinct, is regarded as most nearly related to the scorpions among living animals. The Eurypterids inhabited brackish or fresh water during the Paleozoic era, and some of them attained a length of six or seven feet, a truly formidable size for that ancient period.

The numbers and variety of insect life are far beyond those of any other animals, at least upon the land. More than half the described species of zoölogy are insects—more than three-fourths of the land animals belong to this class. And the innumerable hosts of some sorts make them, despite their small size, the most dreaded and dangerous enemies with which man has to contend. The seriously noxious insects are indeed a small minority—most are indifferent so far as man's welfare is concerned—a few are actively beneficial. But as a class, it must be affirmed that the harmful activities of insects outweigh their beneficial action. They are rivals with man for the possession of the fruits of the earth, and if to the damage on this score be added their activities as carriers of infectious diseases, they may well be regarded as the most formidable enemies of man in the animal kingdom.

The insect is an evolution from the primitive worm or annelid type, adapted to terrestrial life as the crustacean is to marine life, and the structure and plan of organization is much the same in both. There are two most important differences. The first of these is that the crustacean breathes by gills, the insect by tracheæ, branching tubes which ramify into every part of the body, and by expanding and contracting take in fresh and expel vitiated air, as do our lungs. The second difference is that the insect has wings, generally four of them. The arrangement of the nervous system, the circulation, the appendages and mouth parts, the sense organs and the alimentary system are much as in crustaceans.

In comparison with higher vertebrates of the land, the insect shows a fundamentally different plan of organization. Thus, in a vertebrate the principal nervous system is along the dorsal, in an insect along the ventral side of the animal. In a vertebrate the jaws open up and down, and the teeth are originally modified scales; in an insect the jaws open sideways and the teeth are modified legs. In a vertebrate the skeleton is internal, in an insect it is external. The heart of a vertebrate is in its thorax, the stomach in its abdomen; in an insect the position is reversed. The vertebrate pumps vitiated blood from the tissues to the lungs to be aerated; the insect pumps fresh air to freshen the vitiated tissues directly. The wings of a bird or a bat are modified legs; the wings of an insect are outgrowths from the skin of the back. And so on throughout. The resemblances between insects and land vertebrates are mostly superficial; their plan of organization is wholly different, and the similarity is due to both being adapted to live on land. The resemblances between insects and crustaceans indicate relationship; their plan of organization is fundamentally the same, the differences being due to adaptation to terrestrial life in the one, to aquatic life in the other.

Note that there are water insects and likewise land crustaceans. But the land crustaceans still breathe by gills, a method evidently adapted for water-breathing. And the water insects are dependent upon air for breathing, so that they have to come to the surface from time to time at least.

The most important feature of the development of the higher orders of insects is the metamorphosis or change of form from larval to adult. The egg hatches into a larva wholly different from the adult in form, internal organs, and manner of life, and the larva in changing to the adult form undergoes a metamorphosis which involves the almost complete breaking down of all the structures of the body into a mass of formless tissue, and the rebuilding out of this formless tissue the organs and parts proper to the adult.

This extraordinary change takes place in from two or three days to several weeks, and the insect undergoing it is called a pupa. In the lower orders of insects there is no metamorphosis or a very incomplete one. The meaning of this change and the object of it in furthering the interests of the insect is not very clear. Obviously the wingless crawling larva may be regarded as having once represented the ancestral type from which the insect is descended, but as now greatly altered to fit the requirements of its own (juvenile) habits and environment. And it is possible to explain the breaking down of the old tissues into a formless mass of cells by supposing that larva and adult have each proceeded so far on their divergent specializations of structure and form in adaptation to the needs of each, that it has become cheaper, so to speak, to break down the old tissues and build anew, rather than to modify the old into the new tissues along the lines of natural development.

Setting aside certain primitive wingless insects, the three orders Ephemerida, Plecoptera and Odonata (May-flies, Stone-flies and Dragon-flies) are given lowest rank among insects because of their incomplete metamorphosis. All of them haunt the fresh-water ponds, rivers or streams wherein their larvæ dwell, and are not seen far away from water. The larvæ are at first wingless, provided with gills instead of spiracles, so that they are not obliged to come to the surface. They develop rudimentary wings during their larval life, and change to the adult form by a succession of molts like crustaceans, without any breaking up of the internal structures.

The dragon-flies "are unexcelled among insects," says Kellogg, "for swiftness, straightness and quick angular changes in direction of flight. The successful maintenance of their predatory life depends upon this finely developed flight function, together with certain structural and functional body conditions which might be said to be accessory or auxiliary to it. All have four well-developed wings. The body is long, smooth and subcylindrical or gently tapering. This clean, slender body offers little resistance to the air in flight and serves as an effective steering oar. The wings are long and comparatively narrow, fore and hind wings being much alike. . . . The head is unusually large, and more than two-thirds composed of the pair of great compound eyes. More than 30,000 facets have been counted in the cornea of certain dragon-fly species. For accurate flight and successful pursuit of flying prey, the dragon-fly has full need of good eyes. The jaws are strong and toothed, and obviously well adapted for tearing and crushing the captured prey.

"When the prey is come up with, however, it is caught, not by the mouth but by the 'leg-basket,' and then held in the fore legs while being bitten and devoured. The internal anatomy is specially characterized, as might well be imagined, by a finely developed system of thoracic muscles for the rapid and powerful motion of the wings and the delicate and accurate movements of the legs. The respiratory system is also unusually well developed.

"The prey of the dragon-fly may be almost any flying

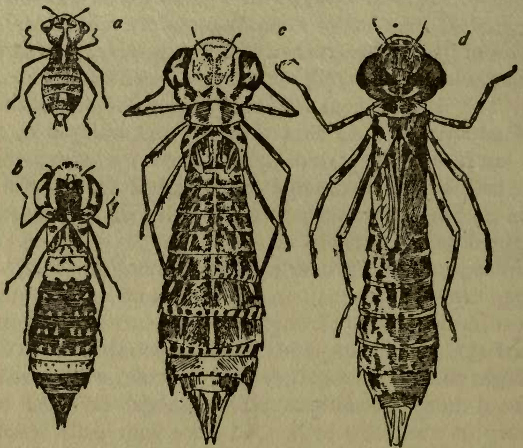


Fig. 8 —Young of Giant Dragon-fly in Different Stages of Development, Slightly Enlarged. (Needham.)

insect smaller than itself, altho midges, mosquitoes and larger flies constitute the majority of the victims. The good that is done by dragon-flies through their insatiable appetite for mosquitoes is very great. Now that we recognise in mosquitoes not only irritating tormentors and destroyers of our peace of mind, but alarmingly dangerous disseminators of serious diseases (malaria, yellow fever, filariasis), any enemy of them must be called a friend of ours."

Dragon-flies are a very ancient race of insects. They tenanted the strange antique forests of the Coal Period, and some were, for an insect, of gigantic size, one having a spread of wing of nearly two feet. Others are found in the still older forests of the Devonian. And indeed it is to the ancient life and ancient land that dragon-flies seem peculiarly appropriate. The dark, somber tropical swamp-forests of those early days, their trees gigantic club-

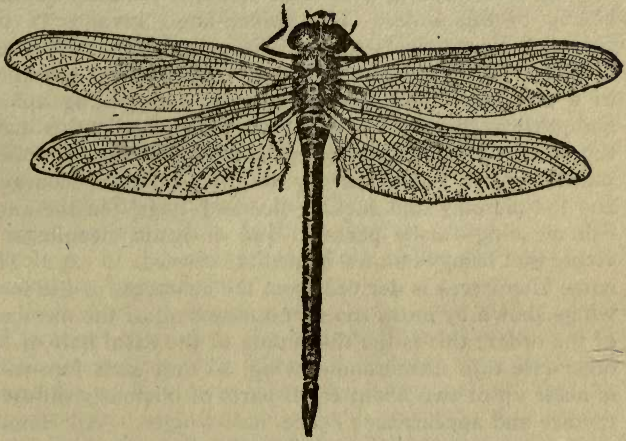


Fig. 9 —The Giant Dragon-fly. About Five-sevenths Natural Size. (Kellogg.)

mosses, ferns and horse-tail rushes, before the appearance of flowers, of broad-leaved trees, of land vertebrates, seem peculiarly fit to be tenanted by insects which to-day are associated with similar life-conditions, and which have no relations with flowering plants or with the higher developments of insect life.

The various kinds of bugs, scale-insects and plant-lice which make up the order of the 'Hemiptera,' or Bugs, have the mouth parts modified into a sucking beak. They feed upon the juices of living plants or the blood of living animals, and include the worst of insect scourges. Owing to their sucking habits, they are more difficult to combat than the biting insects, and their fecundity is enormous.

"The order Hemiptera," says Kellogg, "includes over 5,000 known species of North American insects, representing a large variety and a great economic importance. Some of the most destructive crop pests and most discomforting insect scourges of man and the domestic animals belong to this order. The chinch-bug's ravages in the corn and wheat fields of the Mississippi Valley offer effective evidence to the dismayed farmers of the workings of a displeased Providence; the tiny sap-sucking aphids and phylloxera and insignificant-looking scale-insects make the orchardist and vine-grower similar believers in supernatural moral correction by means of insect scourges; and the piercing and sucking lice and 'bugs'—in the English meaning—make personal and domestic cleanliness a virtue that brings its own immediate reward. . . . The name Hemiptera is derived from the character of the fore-wings shown by most, tho by no means all of the members of the order; this is the thickening of the basal half of the otherwise thin membranous wing, so that each fore-wing is made up of two about equal parts of obviously different texture and appearance; hence 'half-winged.' All Hemiptera (except the male scale-insects) have an incomplete metamorphosis, the young at birth resembling the parents in most essential characteristics except size and the presence of wings. By steady growth, with repeated moltings and the gradual development of external wing pads, the adult form is reached, without any of the marked changes apparent in the insects of complete metamorphosis. With similar mouth parts the young have, in most cases, similar feeding habits, preying upon the same kinds of plants or animals that give nourishment to the parents.

"The extent of the injuries done by various members of this order to farm and orchard crops, to meadows and forests, and to our domestic animals is enormous. Of the other insects the order of beetles includes numerous crop pests, and the caterpillars of many moths and a few butterflies do much damage; locusts have a healthy appetite for green things, and many kinds of flies could be lost to the world to our advantage, but perhaps no other order of insects has so large a proportion of its members in the category of insect pests. The single Hemipterous species Blissus leucopterus, better known by its vernacular name of chinch-bug, causes an annual loss to grain of twenty millions of dollars; the grape phylloxera destroyed the vines on 3,000,000 acres of France's choicest vineyards; the San José scale has in the last ten years spread from California to every other State and Territory in the United States and become a menace to the whole fruit-growing industry. So despite their small size and their general unfamiliarity to laymen, the Hemiptera are found by economic entomologists, in their warfare against the insect scourges of the country, to be one of the most formidable of all the insect orders."

Remedies for sucking insects are not readily found. Kerosene emulsion is the one chiefly employed. Fumigation or spraying with tobacco is effective on a small scale, and for scale insects when the leaves are off the trees, hydrocyanic acid fumigation or lime-sulphur-salt spraying are used. The orange-scale has been successfully held in check by importing and fostering a lady-bird beetle which feeds upon it; and the chinch-bug by introducing a parasitic fungus which kills the bugs by wholesale when the weather conditions favor its spread.

The order 'Orthoptera' includes the cockroaches, locusts, grasshoppers and crickets, all familiar types of insects, many of them of large size, and several ranking among the important noxious insects. On the other hand, their active leaping and noisy flight, their cheerful trilling and chirping lend a variety and interest to outdoor life which one might sadly miss if deprived of their companionship. Their music is rather instrumental than vocal, since it is made by rasping the wings against each other or against the roughened inner surface of the thighs.

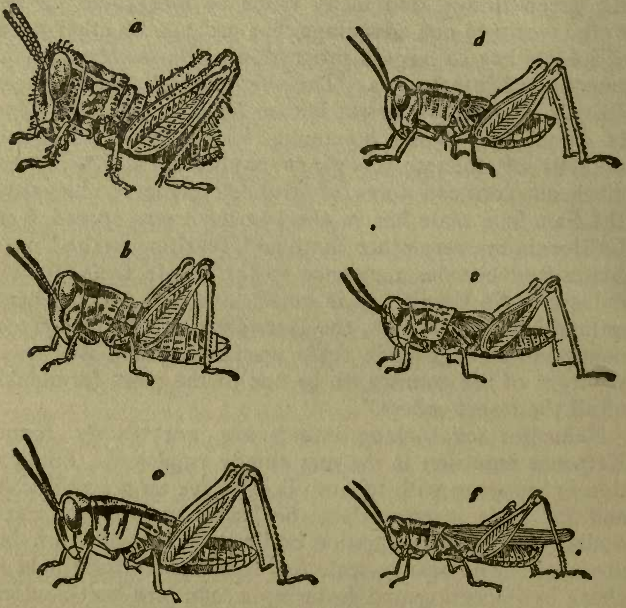


Fig. 10 —Development of the Grasshopper. The Younger Stages Much Enlarged. (Kellogg.)

In all this order the mouth parts are modified for biting, and they mostly live on vegetable food, especially upon green leaves. In the grasshoppers, locusts and crickets the hind limbs are modified for leaping; the cockroaches, praying insects and walking-sticks are walking or running types. The roaches are one of the most ancient and persistent groups of insects. They shared with the dragon-flies the dominance of the ancient forests of the Coal Period, and are to-day a familiar household pest, especially in tropical countries and aboard ships. The mantis or praying-insect is a carnivorous type, feeding upon flies or other insects which may come within reach, and its curious attitudes have caused a variety of fanciful or superstitious legends to gather around it. To kill a mantis is very generally considered sinful or unlucky, and among the quaint monkish legends is one of St. Francis Xavier, who, "seeing a mantis moving along in its solemn way, holding up its two fore legs as in the act of devotion, desired it to sing the praise of God, whereupon the insect caroled forth a fine canticle."

The most singular of the Orthopterous insects are the walking-sticks, which mimic the green twigs and stalks of grass among which they live, in form, color and characteristic attitudes, so closely that they are one of the best examples of "protective mimicry."

The swarms of locusts which from time to time descend upon cultivated agricultural regions, devouring every green thing in their path, and bringing ruin and desolation to the farmer, are now known to be normally inhabitants of the high-lying grassy plains, driven from their accustomed feeding grounds by exceptionally dry seasons which have withered and destroyed the grass of the high plains. They cannot maintain themselves permanently in the moist climate of the low-lying valleys; and for their periodical incursions there is little remedy except to fight them in the high dry plains which are their natural home.

The Termites, or White Ants, are quite unrelated to the true ants, and quite unlike them in appearance. They belong to the lower orders of insects; the young are like the adult from the time they emerge from the egg, and do not undergo any metamorphosis. But, like the ants, they have an elaborate social organization and live in great colonies, mainly composed of sterile workers of several castes. Among the ants, bees and wasps these sterile workers are always females; with the termites they are of both sexes. The colony is presided over by a "royal pair" whose functions are confined to egg-laying. As with the ants, the workers are wingless, and the fertile males and females are winged only during the swarming season, when they leave the nest to found new colonies.

Termites live upon dead wood and are abundant mainly in tropical or sub-tropical regions, where they are fearfully destructive to all wooden buildings, furniture, etc., except they be constructed from some of the few kinds of wood that are immune to their attacks. The great hillock nests which they construct are a prominent feature of the landscape in some parts of tropical Africa. Their habits and complex social organization are almost as remarkable as those of the ants, but the communal instinct is not quite so strongly developed.

With the Beetles, or 'Coleoptera,' begins the series of higher insects with complete metamorphosis. That is to say, the young develop from the egg into a larva, quite unlike the adult in form, structure and habits, wingless and more or less worm-like in appearance and habits. After a period of active growth the larva becomes quiescent, wrapping itself up usually in a cocoon or protective case, and undergoes a remarkable change, the organs and tissues of the body being largely broken down and reformed, and finally the completed insect, or imago, issues from the cocoon or cell, perfect in form and widely different from the larva not merely in its external form, but in the whole internal structure as well. This extraordinary change, which has often been used as an apt natural illustration of ethical regeneration, is one of the most striking and wonderful features of insect life. It is completely carried out in the beetles, moths and butterflies, the lace-winged flies, the two-winged flies, and in the ants, bees and wasps. The lower orders of insects exhibit various degrees of approximation toward it, but in none of them is it complete.

The beetles include a vast multitude of different species and genera—12,000 species are known from the United States and Canada alone. All of them are distinguished by the hard, horny fore-wings which serve as a sheath for the membranous hind wings, these alone being used for flight. The body is compact in form, covered by hard, horny skin, and the mouth parts are adapted for biting, the jaws often strong and large. Some beetles are predaceous, others, and these the great majority, are plant eaters, and some of them are notorious pests. Among the noxious beetles may be especially noted the "potato-bug," wire-worms, white grubs and other beetle larvæ, fruit and grain weevils, apple-tree borers, and a host of less important ones. The predaceous beetles, on the other hand, are actively beneficial by destroying quantities of noxious insects.

Among the handsomest members of the order are the tiger-beetles and the various predaceous ground-beetles, active, alert, many of them of bright metallic color patterns. Many beetles, like the fireflies and glow-worms, are luminous at night; some of the tropical fireflies emit light enough to read by when a few of them are placed under a glass. The stag-beetles and rhinoceros-beetles are among the largest of a group (Lamellicornia) notable for the huge mandibles and various peculiar horn-like processes developed in the males of many of the species. The numerous kinds of wood-boring species, some of them of giant size, do serious damage to orchards and forests. The little round ladybird beetles or ladybugs, with their "polka-dot" pattern of red and black, on the other hand, are a great help to the gardener and fruit-raiser, as they feed upon plant-lice and scale-insects. In the large group which includes the curculios, weevils and snout-beetles, the front of the head is prolonged into a long beak, at the tip of which are the small, sharp jaws; many of these also are serious insect pests.

The 'Diptera,' or Two-winged Flies, includes gnats, mosquitoes and the innumerable kinds of true flies, an immense group, including some fifty thousand species, many of them familiar from the annoyance they inflict on men and animals, and in recent years more seriously considered as carriers of disease. The mouth parts in all are adapted for sucking and piercing, and they have but two wings, the hinder pair being converted to little structures which are used to balance or direct the fly in his flight.

The mosquitoes are familiar from the tropics to the poles, but it is only in recent years that their relations to three serious diseases of man have been suspected and proved. It has been shown beyond question that the germs of malaria, yellow fever and filariasis are transmitted from man to man through the agency of mosquitoes. The life history of the malaria germ has been quite thoroly investigated. Malarial fever, which is the most deadly disease of the tropics, is caused by a minute amœba-like one-celled organism, parasitic in the blood-corpuscles. These grow and multiply asexually in the human blood, but their sexual multiplication occurs within the stomach-cavity of the mosquito 'Anopheles.' Thence they make their way to the poison-gland of the insect, and are so introduced into the body of the next person bitten by this species. The 'Anopheles' is the mosquito with spotted wings, fortunately less common than the gray-winged or brindled-winged mosquitoes of the genus 'Culex.' Another mosquito, 'Stegomyia,' is responsible for the dissemination of yellow fever and of filariasis, the life history of the germ proceeding along much the same lines as with the malaria germ, so far as it has been investigated. The destruction of mosquitoes, especially of the 'Anopheles' and 'Stegomyia,' and protection from their attacks, have consequently been recognised as a most important safeguard to health, especially in tropical countries. Protection is chiefly to be had by extensive and thoro screening of houses and porches; destruction of the mosquito larvæ can be effectively accomplished by draining swamps and stagnant pools in which they chiefly breed, and where draining is impossible by periodically covering the surface of the water with a thin film of kerosene. Standing water in cisterns or rain-barrels should be carefully screened. By these methods of prevention the mortality from malarial fever and yellow fever in tropical regions has been greatly reduced when, as in the construction of the Panama Canal, they have been systematically and thoroly applied.

Fig. 11 —A Blow-fly; Larva, Pupa and Adult.
This fly lays its eggs on fresh or decaying meat. (Kellogg.)

The smaller gnats and midges are nearly related to the mosquitoes, and are equally a pest throughout the world from their bloodthirsty habits.

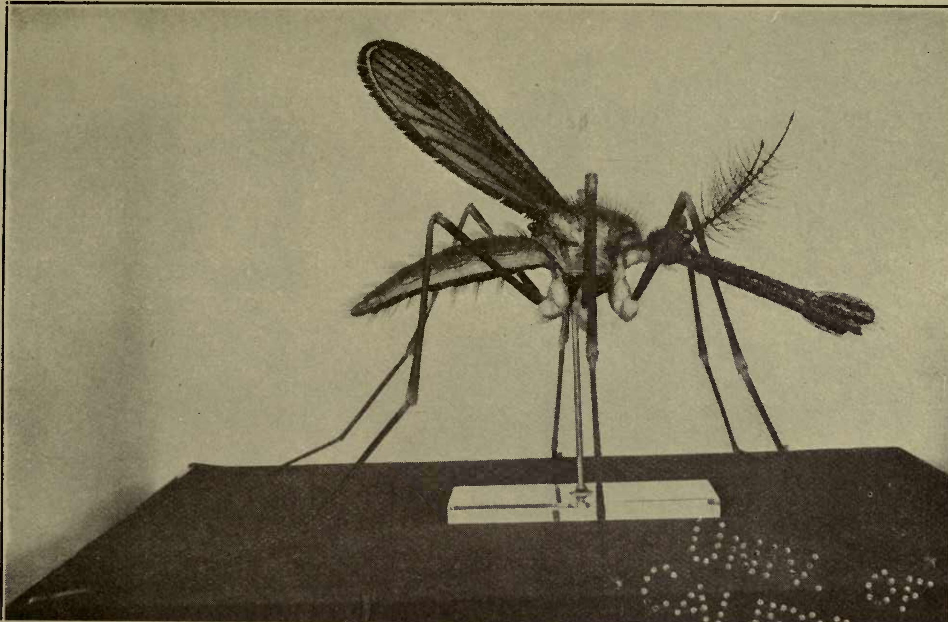
The compact heavy-bodied flies, with short antennæ, are a much larger group than the mosquitoes, and many of them attain large size. The great majority are harmless to man, a few beneficial as they prey upon noxious insects; but some do serious injury to growing crops, the larvæ or maggots feeding upon the leaves or roots of the plants;

a few, such as the bot-flies, are parasitic upon animals or man; and others, like the house-flies, blow-flies and their allies, are annoying and disgusting pests and dangerous spreaders of disease. The agency of the house-fly in disseminating typhoid fever in cities and camps has been properly appreciated only in recent years. Doctor L. O. Howard has recently suggested that in view of its activities in this direction it might most appropriately be called the "typhoid fly." This fly breeds in stable-manure and other decaying matter, and thoro cleanliness and sanitation has already accomplished wonderful results in reducing the death-rate from diseases which are largely spread through its agency.

Related to the flies, altho given a separate ordinal rank, are the fleas, degenerate blood-sucking parasites of mammals and birds which likewise take part in the dissemination of certain diseases. They are wingless, with peculiarly compressed bodies and mouth parts adapted for piercing and sucking.

"The Moths and Butterflies (order Lepidoptera) are the insects," says Kellogg, "most favored of collectors and nature lovers; a German amateur would call them the 'Lieblings-insekten.' The beautiful color patterns, the graceful flight and dainty flower-haunting habits, and the interesting metamorphosis in their life history make them very attractive, while the comparative ease with which the various species may be determined, and the large number of popular as well as more technical accounts of their life which are accessible for information, render the moths and butterflies most available, among all the insects, for systematic collecting and study by amateurs."

This great group of insects ranks with the beetles and flies in abundance and variety. Between six and seven thousand species are found in North America alone, but they are even more numerous and varied in tropical regions. They attain their greatest size and beauty of color



The Malaria-bearing Mosquito. (From enlarged model, A. M. N. H.)

and pattern in the equatorial forest regions, especially in South America.

The exquisite color patterns are due to the covering of minute scales over wings and body. The scales, which are

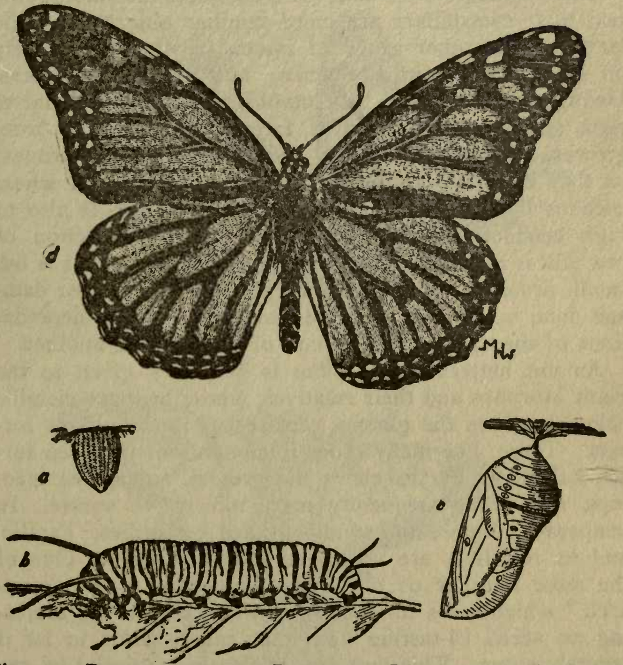


Fig. 12 —Development of a Butterfly, Illustrating Complete Metamorphosis.

A., egg (greatly magnified) ; B., larva or caterpillar; C., pupa or chrysalis; D., imago or adult butterfly. (Jordan and Kellogg.)

to be regarded as modified hairs, vary in shape and size (from $^1/_{350}$ to $^1/_{80}$ inch) and their brilliant metallic colors are mainly due to diffraction of light from their finely striated surfaces, while the black, brown, yellow and dull red colors are due to pigment-color in the scale itself. In this group are to be found the most striking examples of protective coloration, of warning colors, of mimicry, and other more obscure phases of adaptive coloration.

The Lepidoptera all undergo a complete metamorphosis, and their caterpillars are more familiar objects than the larvæ of any other group of insects, as they live mostly on green leaves and are active and voracious feeders. Owing to their habits and numbers, many of the larvæ rank among the plagues of farmer, gardener or tree-grower. The adults, mostly nectar-sipping, are harmless as they are often beautiful. The silk-moth, from whose cocoons the world's supply of silk is obtained, is also of high economic importance. The annual production of raw silk is estimated at over $100,000,000. Yet this is but small, probably, compared with the total amount of damage done to gardens, orchards and fields by the depredations of the various caterpillars of one kind or another.

Among butterflies the palm is generally given to the giant Morphos and their relatives, whose brilliant metallic colors brighten the gloomy recesses of the Brazilian forests. These, like many other inhabitants of the deep forest, habitually fly far above the ground, among the tree-tops, and are consequently more difficult to secure. In temperate climates the swallow-tailed butterflies, 'Papilio' and its relatives, are the most widely admired. One of the most familiar of the larger butterflies is the "monarch," which owes its success in life partly to its secreting an acrid, ill-tasting fluid that causes birds to let it severely alone. This butterfly is closely mimicked by another, the "viceroy," which is not ill-tasting, but doubtless profits by this resemblance in escaping the attacks of birds.

The order Hymenoptera, in which are included Ants, Bees and Wasps, is the most interesting group among all the lower animals, because many of its members have a highly complicated and elaborated communal life. The study of these great insect societies, of their social life, habits and instincts, is one of the most interesting subjects in the whole range of natural history. From the days of Solomon the tireless industry and frugality of the ant

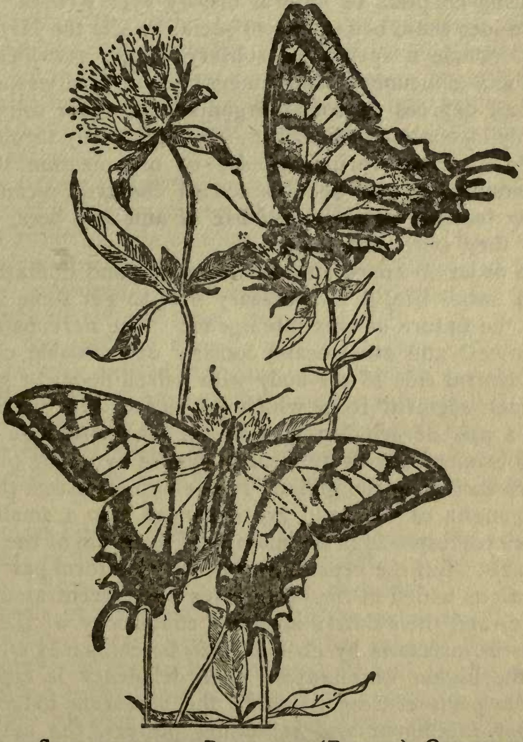


Fig. 13 —Swallow-tailed Butterfly (Papilio), One-half Natural Size. (Kellogg.)

have been proverbial. The busy ways, the complicated and orderly activities of the bee, are familiar to every one, and Maeterlinck's brilliant and sympathetic description of the life of the great bee communities in his 'The Life of the Bee,' altho perhaps too much tinged with the natural tendency to interpret it in terms of human reason and sensations to be wholly reliable, is one of the most fascinating chapters of natural history ever written.

Besides these better known social insects the Hymenoptera include a variety of solitary forms, saw-flies, gall-flies and ichneumons, and among the bees and wasps there are all degrees of social organization, from solitary to highly elaborated social types. It is especially through the study of these various grades of organization that an understanding can be obtained of the true meaning of many features of the social life of ants and bees, and of how they were developed.

In order to appreciate the character and limitations of their social life, it is necessary first to get some insight into the nature of this intelligence. The nervous system in insects and crustaceans consists of a double cord on the ventral side of the body with paired nodes or ganglia at each segment from which the nerves are distributed, and a pair of principal ganglia on the dorsal side of the head connected with the ventral system by a ring of nerve fibers encircling the gullet. In the higher insects the dorsal ganglia of the head are expanded into a small mass which corresponds in the main with the brain of the higher animals. But the ventral ganglia also perform part of the functions which in the vertebrates are concentrated in the brain, and the relative size and complexity of the brain mass in insects is by no means to be compared with any of the higher vertebrates. The deficiency is especially in the parts corresponding to the cerebrum lodging the higher intelligent and reasoning powers, the automatic and instinctive acts being governed mainly by the enlarged ventral ganglia.

So far as can be judged, the nervous system of an insect is that of a very elaborate and perfect animal automaton, but not much more. It is natural to suppose, on seeing the complex and varied activities of an ant or bee community, that these insects must possess an intelligence comparable with that of man rather than of the lower animals; and ideas of their life are apt to be colored by this view. But the most eminent modern authorities on their psychology, among whom Professor Forel may be especially mentioned, believe that, while not devoid of intelligence, their actions are in the main instinctive and automatic, and that even their intelligent action degenerates into habit—that is, tends to become automatic—much more rapidly than in higher animals.

The extreme complexity of these instincts can be better understood if it is remembered that the insects are a very ancient group. Little of their early history has been definitely ascertained, but the lower orders of insects, at least such as cockroaches and dragon-flies, appeared far back in the age of invertebrates, almost as early as the beginning of the geologic record; and the higher orders are known to have existed at a time when highest vertebrates had not advanced beyond the modern salamanders and newts. During the millions of years since that time, while the vertebrates were slowly developing an intelligent brain, the higher insects were elaborating an instinct brain.

The most serious difficulty in understanding the actions of insects is that their senses are so different from those of Man. Broadly speaking, indeed, they make use of the same media of communication with the outer world. All of them have organs sensitive to ether rays of light and heat, corresponding to human eyesight and to the sense of heat and cold. Most of them have apparatus to sense the waves of sound, altho less developed than the ears of vertebrates, and different in mechanism. All of them have organs for perception of solid bodies and of the minute particles given out from them, corresponding to the senses of touch, taste and smell, but differently situated and combined, and generally much more elaborated. The antennæ of insects are sensitive to touch and odor, and in most of the higher insects are highly specialized organs. In the ants especially they usurp the place which in most animals is taken by the eyes.

"Picture to yourself," says Forel, "an olfactory sense—*i.e.*, a chemical sense effective at a distance and, like our sense of smell, capable of receiving impressions from particles of the most diverse substances diffused through the atmosphere—located not on your nostrils but on your hands. For of such a nature is the position of the olfactory sense on the antennal club of the ant.

"Now imagine your olfactory hands in continual vibration, touching all objects to the right and to the left as you walk along, thereby rapidly locating the position of all odoriferous objects as you approach or recede from them, and perceiving the surfaces both simultaneously and successively as parts of objects differing in odor and position. It is clear from the very outset that such sense organs would enable you to construct a veritable odor-chart of the path you had traversed and one of double significance: (1) A clear contact-odor chart, restricted, to be sure, to the immediate environment, and giving the accurate odor-form of the objects touched (round odors, rectangular odors, elongate odors, etc.), and, further, hard and soft odors in combination with the tactile sensations; (2) a less definite chart which, however, has orienting value for a certain distance, and produces emanations which we may picture to ourselves like the red gas of bromine which we can actually see.

"If we have demonstrated that ants perceive chemical qualities through their antennæ both from contact and from a distance, then the antennæ must give them knowledge of space, if the above formulated law is true, and concerning this there is little doubt. This must be true even from the fact that the two antennæ simultaneously perceive different and differently odoriferous portions of space. They must therefore also transmit perceptions and topographically associated memories concerning a path thus touched and smelled. Both the trail of the ants themselves and the surrounding objects must leave in their brains an odor-image of immediate space, and this must render associated memories possible. Thus an ant must perceive the forms of its trail by means of smell. This is impossible, at least for the majority of the species, by means of the eyes."

It will appear therefore that this antennal sense, which Forel designates as topographical, is the principal means by which the brain of the ant is placed in communication with the outside world, supplying the space and form perceptions in the same way that a vertebrate's eyes do. Light and darkness are indifferent to an ant, so far as getting about is concerned. Many of the species use their eyes, but do not depend primarily on them; others are blind or nearly so. This topochemical sense is present in other insects to a varying extent. In Bees and Wasps it is well developed, altho not to the exclusion of sight as in Ants. In Flies and Dragon-flies and in most of the lower insects it is more or less rudimentary; they depend chiefly upon the eyes.

There are other wide differences in the external sense organs of the various insects from man and from each other. Insects see colors differently; they hear sounds to which the human ear is not sensitive, while they are deaf to tones that it perceives. Their world of perceptions is so different in its nature and its limitations that it is difficult to enter very far into the psychology even of their simplest sensations. For the most part the facts can only be related as they appear; the ever-present temptation to interpret the actions of an insect in the terms of the observer's sensations is almost sure to lead him astray.

In most of the lower animals the young are well able to take care of themselves. In general they develop from the egg with little or no help from their parents. But in the Hymenoptera, as in birds and mammals, the young are helpless larvæ, unable to forage for themselves, and requiring to be supplied with food, or fed directly, by the adults. This is the most important fact in the life history of these insects. It differentiates them as of distinctly higher type than any other invertebrates, and it is around the care of the young that their social life chiefly centers. It has been well observed that in man the duration and helplessness of infancy is in direct proportion to the progress of civilization. It is equally true of the lower animals, that those in which the young require and obtain the help of their parents in their early life are thereby enabled to reach a higher stage in development than those in which the young can and do shift for themselves from the time they emerge from the egg.

All of the Hymenoptera make provision in one way or another for their young, and the extent to which this care is carried is the index of development in the different groups.

The Saw-flies, the lowest member of the group, merely place the eggs in favorable spots on the stems of plants, where the larvæ can feed readily upon the juices of the plant. These larvæ are little more helpless than true caterpillars and feed in much the same way.

The Gall-flies show the next stage in progress; the eggs are laid in the leaves or stems of various plants in such a position that the irritation of their presence stimulates the plant to develop abnormal growths or galls, which are utilized as food by the larvæ.

The Ichneumon-flies lay their eggs in the bodies of caterpillars, and the larva develops at the expense of its unfortunate host. A great variety of the lower Hymenoptera are parasitic in this way upon other insects of various orders, and the parasitism has entailed more or less degeneracy. The life histories of these various parasitic forms form a very curious and interesting chapter in natural history.

CHAPTER V

INSECT SOCIAL COMMUNITIES

THE study of the habits of Solitary Wasps and Bees and the transitional forms between these and the social kinds gives the clue to the method of development of these great insect societies and helps to explain many features of their life otherwise incomprehensible. In the first place, it is evident that their activities center largely around the care for the young. The larva develops from the egg as a helpless footless maggot, unable to forage for itself, unable to protect itself from enemies. It is dependent among Bees and Wasps upon the food supply stored up in the cell with the egg; among Ants it is fed directly by the workers by regurgitation from their crops.

Solitary Wasps form a group to be considered by themselves. Thus the Digger-wasp ('Sphex') does not live in communities, but the females make separate nests, one for each egg, provisioning them with insect prey which they sometimes kill, but more generally merely paralyze beforehand by stinging them. J. H. Fabre describes their habits in his 'Insect Life' as follows:

"The nests may be of mud and attached, for shelter, under leaves, rocks or eaves of buildings, or may be burrows hollowed out in the ground, in trees or in the stems of plants. The adult wasp lives upon fruit or nectar, but the young grub or larva must have animal food, and here the parent wasp shows a rigid conservatism, each species providing the sort of food that has been approved by its family for generations, one taking flies, another bugs, and another beetles, caterpillars, grasshoppers, crickets, locusts, spiders, cockroaches, aphids or other creatures, as the case may be.

"The Solitary Wasps mate soon after leaving the nest in the spring or summer. The males are irresponsible creatures, aiding little, if at all, in the care of the family. When the egg-laying time arrives the female secures her prey, which she either kills or paralyzes, places it in the nest, lays the egg upon it, and then in most cases closes the hole and takes no further interest in it, going on to make new nests from day to day. In some genera the female maintains a longer connection with her offspring, not bringing all the provisions at once, but returning to feed the larva as it grows and only leaving the nest permanently when the grub has spun its cocoon and become a pupa.

"The egg develops in from one to three days into a footless maggot-like creature which feeds upon the store provided for it, increasing rapidly in size and entering the pupal stage in from three days to two weeks. In the cocoon it passes through its final metamorphosis, emerging as a perfect insect perhaps in two or three weeks, or, in many cases, after the winter months have passed and summer has come again. Probably no Solitary Wasp lives through the winter, those that have come out in the spring or summer perishing in the autumn."

"The habit common to almost all of the Solitary Wasps," says Kellogg, "of so stinging the prey, caterpillars, spiders, beetles, flies, bugs, or whatever other insects are used to provision the nests, as not to kill but only to paralyze it, is perhaps the most amazing part of all the interesting behavior of all these wasps. The advantage is obvious: killed, the prey would quickly decompose, and the hatching carnivorous wasp larva would have only a mass of, to it, inedible decaying flesh, instead of the fresh live animal substance it demands. But if stored unhurt, the prey would, if a cricket or spider or similarly active animal, quickly escape from the burrow, or if a caterpillar or weak bug, at least succeed, albeit unwittingly, in crushing the tender wasp egg by wriggling about in the underground prison cell.

"More than that, unhurt, some insects could not live without food the many days that are necessary for the development of the wasp larva, especially in the face of the frantic and exhausting efforts they would be impelled to in their attempts to escape. But paralyzed, there is no

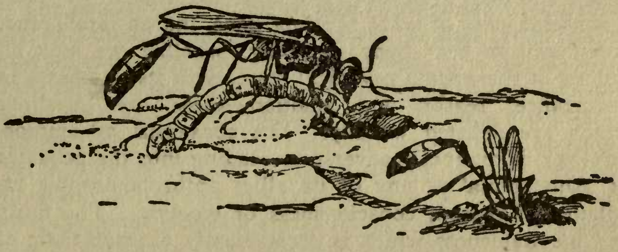


Fig. 14 —Ammophila.
Solitary wasps, stocking their burrows with paralyzed insects as food for their young. (Kellogg.)

exertion; metabolism is slight, and life without food is capable of being prolonged many days. The paralysis is due to the stinging by the Wasp of one or more of the ganglia (nerve centers) of the ventral nerve cord. The amazing expertness and accuracy displayed in plunging the sting into exactly those spots where injury will give rise to exactly that physiological phenonenon in the prey that will make it available for the special conditions attending the wasp larva's sustenance—this adroitness and this seeming knowledge of the structure and the physiology of the prey have led some entomologists to credit the Solitary Wasp with anthropomorphic qualities that are quite unwarranted. The whole behavior is probably explicable as a complex and advantageous reflex or instinct, developed by selection.

"Similarly, the whole course of the nest building and provisioning is an elaborate performance wholly for the sake of the young, which the mother will likely never see; and these young in turn will, if females, do the same thing, perfectly, and in essentially, if not exactly, the same manner, without ever previously seeing such remarkable processes performed. All these complex and altruistic habits have naturally led to much speculation concerning their origin and their relation to psychical conditions. Whether a consciousness of what is being done and an intelligence is brought to bear upon its doing; whether we may attribute to the wasp a psychical state, with its attributes of cognizance, reason and emotion—these are questions which are debated warmly. The consensus of opinion, however, is distinctly adverse to reading into the behavior of 'Ammophila' or any of its allies anthropomorphic attributes of reason, consciousness or emotion. The fixity and inevitableness which is preëminently characteristic of the behavior of the wasps, and the fact that each female is 'ab ovo' adequate to carry through the complex train of actions without teaching, experience or opportunity for imitation, practically prove all this seeming marvel of reasoned care for the future young to be an inherited instinct incapable of essential modification except by the slow process of selection through successive generations."

The Social Wasps—Hornets, Yellow-jackets and such —live in great communities of males, females and a third caste, the neuters or workers. These last are in reality sterile females, taking no part in the reproduction of the race, but take charge of the building and caring for the nest of the community, bringing food and rearing the young.

The life-history of a community in general outline is given by Kellogg as follows: "In the early spring, fertilized females (queens) which have hibernated (as adults) in sheltered places, as crevices in stone walls, under logs, stones, etc., come out from their winter hiding places and each makes a small nest, containing a few brood cells. In each cell an egg is laid, and food, consisting of insects, killed and somewhat masticated, is hunted for and brought to the larvæ throughout their brief life by the queen. The larvæ soon pupate in the cells and in a few days issue as winged wasps. They are exclusively workers. These workers now enlarge the nest, adding more brood cells in which the queen deposits eggs. The bringing of food and the care of the young now devolve on the workers.

"The new, or second, brood also is composed of workers only, and these immediately reinforce the first brood in the work of enlarging the nest and building new brood cells. Thus, through the summer, several broods of workers are reared until in the late summer or early fall a brood containing males and females as well as workers appears. The community is now at its maximum, both as regards population and size of nest. In the species 'Vespa,' which make the great ball-like aerial nests, the community may grow to number several thousand individuals. The males and females mate (presumably with members of other communities), but no more eggs are laid, and with the gradual coming on of winter the males and workers and many of the females die. There persist only as survivors of each community a few fertilized females. These crawl into safe places to pass the winter. Any Social Wasp found in winter time is thus almost certainly a queen. Those of the queens which come safely through the long winter found the communities which live through the following season.

"The Social Wasps of the genus Vespa, the familiar Yellow-jackets and Hornets, are the ones which build the large subspherical nests familiar to all outdoor observers and related to much boyish adventure. Inside the great globe are several horizontal combs of brood cells in tiers, all enclosed by several layers of wasp-paper. The large bald-faced Hornet, 'Vespa maculata,' is the best known builder of the globe nests. The smaller Yellow-jackets ('Vespa germanica,' 'Vespa cuneata') build in hollows in stumps or stone fences or underground. Such protected or underground nests are not as thoroly or thickly enveloped in paper as are the exposed arboreal globe nests. The miniature queen nests of the 'Vespa,' with the single little brood comb inside, may often be found by careful searching in the spring.

"The long-bodied, blackish Wasps of the genus 'Polistes' build single exposed horizontal combs out of wasp-paper (chewed wood), which are attached to the under side of porch roofs, eaves, ceilings of outbuildings, etc., by a short central stem. The little comb made by the queen may contain but half a dozen cells, but after the workers hatch many other cells are added around the margin. But the nest and workers never compare in size and numbers with the large communities of 'Vespa.'"

Among all the Wasps the adult feeds upon nectar of flowers, but the larva is fed on insects, paralyzed or freshly killed. The Solitary kinds store up food and place it in the cell with the egg; the Social Wasps do not, but the queen at first and afterward the workers forage for insects, which they bring in constantly and feed to the larvæ in a killed and partially masticated condition.

Bees differ from Wasps in that the young larva, as well as the adult, is fed upon the nectar and pollen of flowers. converted into honey and bee-bread, instead of upon insect food as in the Wasps. The structure of the mouth parts and the instincts of the Bee differ accordingly. There are a great many kinds of Solitary Bees, but the Social Bees, the wild Bumblebee and the Hive-bee are by far the most familiar. In the Solitary Bees there are only males and females; in the Social Bees, as in Social Wasps, there are males, females and workers. The Bumblebees nest underground, occupying and enlarging a mouse-hole or small burrow, and the life-history of the community is much like that of the Wasps. They do not make honey cells, but mix pollen and honey to a pasty mass, deposit a few eggs upon the mass, and in the later stages of the nest build waxen cells for the larvæ to pupate in.

The Honey Bees ('Melipona' and 'Apis') have a much more elaborated community life, and unlike the Wasps and Bumblebees, this does not terminate with the summer, but is continuous from season to season. The Meliponas are tropical bees, stingless or nearly so, living in immense communities whose life-history is not completely known. The better known Hive-bees ('Apis') are native to the Old World, but domesticated and introduced everywhere. The habits and life-history of the great Hive-bee communities have been more carefully studied than any other phase of insect life. Yet there are many unsolved problems, especially in regard to the interpretation and meaning of their behavior.

A well-written and reliable account of the life of the Hive-bees is given in Jordan and Kellogg's 'Evolution and Animal Life,' from which the following may be quoted:

"An interesting series of gradations from a strictly solitary through a gregarious to an elaborately specialized communal life is shown by the bees. Altho the Bumblebee and the Honey Bee are so much more familiar to us than other bee kinds that the communal life exemplified by them may have come to seem the usual kind of bee life, yet, as a matter of fact, there are many more solitary bees than social ones. The general character of the domestic economy of the solitary bees is well shown by the interesting little Green Carpenter Bee, 'Ceratina dupla.' Each female of this species bores out the pith from five or six inches of an elder branch or raspberry cane, and divides this space into a few cells by means of transverse partitions. In each cell she lays an egg, and puts with it enough food—flower pollen—to last the grub or larva through its life. She then waits in an upper cell of the nest until the young bees issue from their cells, when she leads them off, and each begins active life on its own account.

"The Mining Bees, 'Andrena,' which make little burrows in a clay bank, live in large colonies—that is, they make their nest burrows close together in the same clay bank,

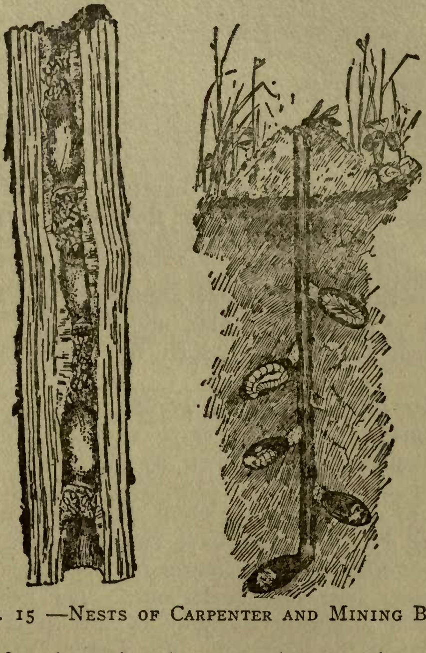


Fig. 15 —NESTS OF CARPENTER AND MINING BEE.

but each female makes her own burrow, lays her own eggs in it, furnishes it with food—a kind of paste of nectar and pollen—and takes no further care of her young. Nor has she at any time any special interest in her neighbors. But with the smaller Mining Bees, belonging to the genus 'Halictus,' several females unite in making a common burrow, after which each female makes side passages of her own, extending from the main or public entrance burrow. As a well-known entomologist has said, " 'Andrena' builds villages composed of individual homes, while 'Halictus' makes cities composed of apartment houses."

"The Bumblebee, however, establishes a real community with a truly communal life, altho a very simple one. The few Bumblebees which we see in winter time are queens; all others die in the autumn. In the spring a queen selects some deserted nest of a field mouse, or a hole in the ground, gathers pollen which she molds into a rather large irregular mass and puts into the hole, and lays a few eggs on the pollen mass. The young grubs or larvæ which soon hatch feed on the pollen, grow, pupate, and issue as workers—winged bees a little smaller than the queen. These workers bring more pollen, enlarge the nest, and make irregular cells in the pollen mass, in each of which the queen lays an egg. She gathers no more pollen, does no more work except that of egg-laying. From these new eggs are produced more workers, and so on until the community may come to be large. Later in the summer males and females are produced and mate. With the approach of winter all the workers and males die, leaving only the fertilized females, the queens, to live through the winter and found new communities in the spring.

"The Social Wasps—as with the bees, there are many more kinds of solitary wasps than social ones—show a communal life like that of the Bumblebees. The only Yellow-jackets and Hornets that live through the winter are fertilized females or queens. When spring comes each queen builds a small nest suspended from a tree branch, or in a hole in the ground, which consists of a small comb enclosed in a covering or envelope open at the lower end. The nest is composed of 'wasp-paper,' made by chewing bits of weather-beaten wood taken from all fences or outbuildings. In each of the cells the queen lays an egg. She deposits in the cell a small mass of food, consisting of some chewed insects or spiders. From these eggs hatch grubs which eat the food prepared for them, grow, pupate, and issue as worker wasps, winged and slightly smaller than the queen. The workers enlarge the nest, adding more combs and making many cells, in each of which the queen lays an egg. The

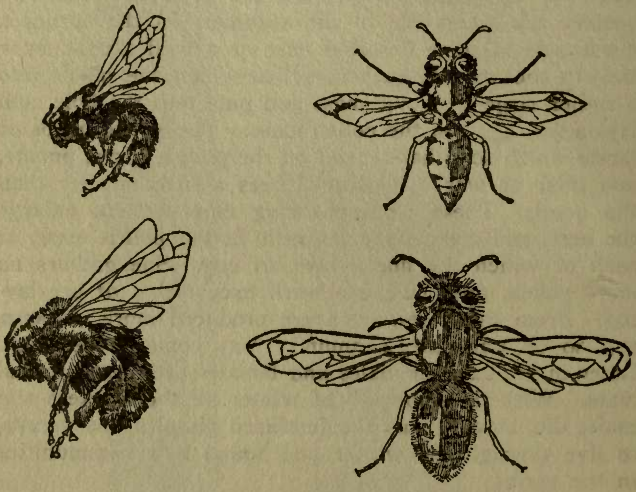


Fig. 16 —Bumblebee and Hornet.
Upper figures, workers; lower figures, queens.

workers provision the cell with chewed insects, and other broods of workers are rapidly hatched. The community grows in numbers and the nest grows in size until it comes to be the great ball-like oval mass which we know so well as a hornets' nest, a thing to be left untouched. When disturbed, the wasps swarm out of the nest and fiercely attack any invading foe in sight. After a number of broods of workers has been produced, broods of males and females appear and mating takes place. In the late fall the males and all of the many workers die, leaving only the new queens to live through the winter.

"Honey Bees live together, as we know, in large communities. We are accustomed to think of Honey Bees as the inhabitants of beehives, but there were bees before there were hives. The 'bee tree' is familiar to many of us. The bees, in nature, make their home in the hollow of some dead or decaying tree-trunk, and carry on there all the industries which characterize the busy communities in the hives. A Honey Bee community comprizes three kinds of individuals—namely, a fertile female or queen, numerous males or drones, and many infertile females or workers. These three kinds of individuals differ in external appearance sufficiently to be readily recognisable. The workers are smaller than the queens and drones, and the last two differ in the shape of the abdomen, or hind body, the abdomen of the queen being longer and more slender than that of the male or drone. In a single community there is one queen, a few hundred drones, and ten to thirty thousand workers.

"The number of drones and workers varies at different times of the year, being smallest in winter. Each kind of individual has certain work or business to do for the whole community. The queen lays all the eggs from which new bees are born; that is, she is the mother of the entire community. The drones or males have simply to act as royal consorts; upon them depends the fertilization of the eggs. The workers undertake all the food-getting, the care of the young bees, the comb-building, the honey-making—all the industries with which we are more or less familiar that are carried on in the hive. And all the work done by the workers is strictly work for the whole community; in no case does the worker bee work for itself alone; it works for itself only in so far as it is a member of the community.

"How varied and elaborately perfected these industries are may be perceived from a brief account of the life history of a bee community. The interior of the hollow in the bee tree or of the hive is filled with 'comb'—that is, with wax molded into hexagonal cells and supports for these cells. The molding of these thousands of symmetrical cells is accomplished by the workers by means of their specially modified trowel-like mandibles or jaws. The wax itself, of which the cells are made, comes from the bodies of the workers in the form of small liquid drops which exude from the skin on the under side of the abdomen or hinder body rings. These droplets run together, harden and become flattened, and are removed from the wax plates, as the peculiarly modified parts of the skin which produce the wax are called, by means of the hind legs, which are furnished with scissor-like contrivances for cutting off the wax.

"In certain of the cells are stored the pollen and honey, which serve as food for the community. The pollen is gathered by the workers from certain favorite flowers and is carried by them from the flowers to the hive in the 'pollen baskets,' the slightly concave outer surface of one of the segments of the broadened and flattened hind legs. This concave surface is lined on each margin with a row of incurved stiff hairs, which hold the pollen mass securely in place.

"The 'honey' is the nectar of flowers which has been sucked up by the workers by means of their elaborate lapping and sucking mouth parts and swallowed into a sort of honey-sac or stomach, then brought to the hives and regurgitated into the cells. This nectar is at first too watery to be good honey, so the bees have to evaporate some of this water. Many of the workers gather above the cells containing the nectar and buzz—that is, vibrate their wings violently. This creates currents of air which pass over the exposed nectar and increase the evaporation of the water. The violent buzzing raises the temperature of the bees' bodies, and this warmth given off to the air also helps make evaporation more rapid. In addition to bringing in food, the workers also bring in, when necessary, 'propolis,' or the resinous gum of certain trees, which they use in repairing the hive, as closing up cracks and crevices in it.

"In many of the cells there will be found, not pollen or honey, but the eggs or the young bees in larval or pupal condition. The queen moves about through the hive, laying eggs. She deposits only one egg in a cell. In three days the egg hatches, and the young bee appears as a helpless soft, white, footless grub or larva. It is cared for by certain of the workers, that may be called nurses. These nurses do not differ structurally from the other workers, but they have the special duty of caring for the helpless young bees. They do not go out for pollen or honey, but stay in the hive. They are usually the new bees—*i.e.*, the youngest or most recently added workers. After they act as nurses for a week or so they take their places with the food-gathering workers, and other new bees act as nurses. The nurses feed the young or larval bees at first with a highly nutritous food called bee jelly, which the nurses make in their stomach and regurgitate for the larvæ. After the larvæ are two or three days old they are fed with pollen and honey. Finally, a small mass of food is put into the cell, and the cell is 'capped' or covered with wax. Each larva, after eating all its food, in two or three days more changes into a pupa, which lies quiescent without eating for thirteen days, when it changes into a full-grown bee. The new bee breaks open the cap of the cell with its jaws and comes out into the hive, ready to take up its share of the work for the community.

"In a few cases, however, the life history is different. The nurses will tear down several cells around some single one, and enlarge this inner one into a great irregular vase-shaped cell. When the egg hatches, the grub or larva is fed bee jelly as long as it remains a larva, never being given ordinary pollen and honey at all. This larva finally pupates, and there issues from the pupa not a worker or drone bee, but a new queen bee. The egg from which the queen is produced is the same as the other eggs, but the worker nurses by feeding the larva only the highly nutritious bee jelly make it certain that the new bee shall become a queen instead of a worker. It is also to be noted that the male bees or drones are hatched from eggs that are not fertilized, the queen having it in her power to lay either fertilized or unfertilized eggs. From the fertliized eggs hatch larvæ which develop into queens or workers, depending on the manner of their nourishment; from the unfertilized eggs hatch the males.

"When several queens appear there is much excitement in the community. Each community has normally a single one, so that when additional queens appear some rearrangement is necessary. The rearrangement comes about first by fighting among the queens until only one of the new queens is left alive. Then the old or mother queen issues from the hive or tree followed by many of the workers. She and her followers fly away together, finally alighting on some tree branch and massing there in a dense swarm. This is the familiar phenomenon of 'swarming.' The swarm finally finds a new hollow tree, or in the case of the Hive-bee the swarm is put into a new hive, where the bees build cells, gather food, produce young, and thus found a new community. This swarming is simply an emigration, which results in the wider distribution and in the increase of the number of the species. It is a peculiar but effective mode of distributing and perpetuating the species. The community, it is important to note, is a persistent or continuous one. The workers do not live long, the spring broods usually not over two or three months, and the fall broods not more than six or eight months; but new ones are hatching while the old ones are dying, and the community as a whole always persists. The queen may live several years, perhaps as many as five. She lays about one million eggs a year."

The Ants may fairly be regarded as the highest group of invertebrate animals. They excel in the variety and complexity of their instincts and the elaborateness of their social organization, and their abundance and wide distribution marks them as one of the most successful and dominant types produced by evolution.

There are no solitary ants. All of them have a highly complex social life, live in large communities composed of males, females and workers. The workers (sterile females) are the principal part of an ant colony; only at the mating season do males and females appear in any considerable numbers. The workers are wingless and much smaller than the males and females; the latter are winged only for the mating or swarming season, when they leave the nest. After mating the males die and the females or queens, throwing off their wings, proceed each to found a new colony.

Aside from their mating flights, Ants are all strictly terrestrial. Their nests are a maze of underground galleries and chambers tunneled out by the workers and serving as a retreat for the adults, a nursery for the young, a granary for stored-up food, and in one group of Ants as a vegetable garden as well. The colony consists usually of a queen-ant, or in some instances several queens, whose duties are confined to egg laying, of a great number of workers of two or more castes, worker-minors, worker-majors and sometimes soldiers, and at certain seasons of the winged males and females ready to issue from the nest, mate and form new colonies. The duties of the different castes of workers vary; to the youngest and smallest ones are assigned the care of the eggs and feeding of the larvæ; the larger workers forage for food; while the soldiers, large-headed and with powerful jaws, apparently do little besides protecting the nest in case of attack.

Ants are primarily carnivorous; they subsist on other insects or upon sweet juices exuding from flowers, leaves or stems or secreted by insects. They are extremely fond of the 'honey-dew' secreted by the plant-lice, or Aphids, which with many of the common species forms an important part of their food. On every plant infested by Aphids one is pretty certain to see a number of Ants in attendance, stimulating the excretion of the honey-dew by deft stroking. Many are the stories that have been told of the curious relations between Ant and Aphis, but many of them need to be verified by more careful investigation. Nevertheless it is certain that the Ants do take care of their 'cows,' as Linnæus called them, in a way that is at least suggestive of domestication. If the various Ants attending Aphids on one plant are observed, they will be found to be all of one species and apparently all from one nest. One might assume from this, but probably quite incorrectly, that Aphids were considered as personal (or rather municipal) property among the Ants. Again, certain Ants build a sort of tent of mud or vegetable fiber over parts of branches or stems infested with Aphids or scale insects, and this tent serving to protect and shelter both the Ants and their 'cows' from rain or from incursions of enemies or other ants, may fairly be regarded as a stable. Furthermore, in at least one common species of Ant, the workers have been seen to take the newly hatched Corn-root Aphids and carefully place them upon the roots of certain species of knotweed, guard and protect them there until the corn-roots were sufficiently advanced and then to remove the Aphids to feed upon the corn. There can be no question that the mere presence of such bold, active and efficient fighters as the Ants must serve to keep away enemies from the slow and helpless Aphids; but to what further extent the Ants actively protect their charges is not so clear.

The most familiar traditional aspect of ant life, the storing up of grain for a winter supply, is illustrated in the Harvester or Agricultural Ants, whose nests are conspicuous in open grassy places and especially in arid or nearly desert regions. They bring into their nests great quantities of grain and grass seeds, and have been even credited with deliberate planting for harvest of certain kinds of grass seed, of which they are very fond; this last, however, is discredited by Wheeler.

The Ecitons, or Foraging Ants, are fierce predatory insects, well known in West Africa and tropical America. They are nomadic, having no fixed habitations, but travel mostly by night in enormous armies which seek out and destroy every living animal in their path. The approach of these great columns strikes terror and confusion into all the varied life of the tropical forests. Beast, bird and man hasten to get out of their path. Dwellings are promptly vacated on notice of their appearance, and they swarm through the house, seek out every cranny and crevice, attack and tear to pieces insects, mice, rats and vermin of every kind, and retire, loaded with booty, to their nests, which are mere temporary camps excavated beneath stones or other convenient shelter.

They are blind or nearly so, and traveling chiefly by night, are guided by their antennal sense, which, as in most other ants, practically takes the place of sight in higher animals. Travelers in the forest whose camps are in the line of march of an army of Driver Ants find themselves suddenly covered by swarms of big black insects, biting fiercely at every unprotected spot, and have to run for their lives, abandoning camp baggage and clothing for a time to the mercies of their savage assailants. Their household visitations are regarded as a blessing, for the dwelling is clear of vermin, dead or alive, when they get through with it, and a temporary eviction is a small price for the owners to pay where vermin swarm as they do in the tropics.

The Saübas, or Leaf-cutting Ants, are among the most remarkable of all the social insects. They are abundant in tropical America and species of this group are found as far north as New Jersey. In South and Central America they build enormous nests with vast ramifications of galleries and passages which extend for many yards and are even said to tunnel under considerable rivers. Their curious habit of cutting out little pieces of leaves and carrying them to their nests was noticed by early explorers and is referred to even in some of the Indian legends. But it was long a mystery what they did with the leaves. Ants generally are dependent for food upon other insects, animal matter or upon sweet juices which they obtain in various ways. They do not usually eat ordinary vegetation, and while the Saübas might be supposed an exception to the rule, there was no evidence that they ate the leaf fragments which they so carefully conveyed to their homes. Professor Bates, who saw their work in the Amazon Valley, was of the opinion that they used the leaves to thatch their galleries and protect them from the heavy tropic rains. The true explanation was suggested in 1874 by Thomas Belt.

The leaves are used as manure in which they grow and cultivate a peculiar species of fungus on which they feed. Within the nests, several feet below the ground, they excavate large cavities, often a foot in diameter, which are veritable underground gardens, tended, weeded and manned by different grades of workers. The little leaf fragments are brought to these cavities, cut, crushed and manipulated into small round pellets, and planted in the surface of the garden, to serve as nutriment for the fungus to grow upon. Under the care of the ants the fungus is not allowed to produce spores, but only to grow in thread-like filaments, from which clusters of transparent globules bud off, these latter forming the food of the ants. All other kinds of fungus growth are carfully kept down, and the temperature and moisture of the fungus garden is regulated by opening or closing the openings at the top of the nest, which seem to be chiefly ventilation holes, the

Ants issuing and returning by other openings more or less distant.

"These insects," observes Wheeler, "in the fierce struggle for existence everywhere apparent in the tropics, have developed a complex group of instinctive activities which enables them to draw upon an ever-present, inexhaustible food supply through utilizing the foliage of plants as a substratum for the cultivation of edible fungi. No wonder, therefore, that, having emancipated themselves from the precarious diet of other ants, which subsist on insects, the sweet exudations of plants and excrement, the Attii have become the dominant invertebrates of tropical America."

The nests are guarded by large soldier-workers, with massive heads and powerful jaws. Smaller workers of several different sizes have assigned to them the various tasks of collecting leaves, of excavating the tunnels and galleries, of cultivating, manuring and weeding the fungus and of feeding the young, helpless larvæ, the nurse-girls of the colony being the smallest and youngest of the workers. Upon leaving the nest for the foundation of a new colony, the female carries with her a small pellet of the fungus, which is carefully tended and manured until the new colony has become established.

The Saüba Ants are not the only fungus-growing insects. Among the Termites, which, altho not true Ants, resemble them in appearance and social habits, there are certain kinds that also cultivate a species of fungus which they use for food. The worker sex, however, is said to feed upon dead wood and to receive no share of the fungus which it spends so much time in cultivating. Among the wood-boring beetles the Ambrosia Beetles also cultivate and feed upon certain kinds of fungus, growing it on the walls of the galleries which they excavate.

The Honey Ants ('Myrmecocystus') are a unique group. These curious little Ants store up honey like the Bees, but in a very different way. Instead of building cells of wax, they store it up in the bodies of certain of the workers, in which the abdomen becomes enormously distended, so that they are veritable living casks. These individuals do not leave the nests, but are fed by the active workers, and when replete, hang from the roof of enlarged chambers in the runways. In seasons of scarcity they are able in turn to feed the rest of the community by the same method of regurgitation. They inhabit the arid southwestern United States and were studied and described by Professor McCook from the Garden of the Gods in Colorado. Leading a rather precarious existence in a region where food is abundant only for a short season in the year, the advantage of this habit can readily be seen, and there are certain advantages about living casks in being more readily removed from danger than the fixed storehouses of the Bees.

A curious development of the social life of Ants is seen in the so-called Slave-making Ants. Two of these, the Sanguinary Ant, or Red Slave-maker, 'Formica sanguinea,' and the Amazon Ant, 'Polyergus,' are well known, and their habits have been carefully studied, the most recent studies and interpretation being by Wheeler. The Sanguinary Ant makes raids upon the nests of other ants, but in particular upon the smaller brown species, 'Formica fusca,' killing the workers, carrying off eggs and larvæ to its own nest. Most of the larvæ are used for food, but a part of them are reared and brought up in the nest of their captors. They become loyal members of the new community and take part in the multifarious activities of the nest, going out in search of food, caring for the eggs, feeding the larvæ, excavating or extending the nest and so on. It does not appear that they take part in the raids on other ant nests, but probably this is merely because such raids are conducted by the larger and more powerful workers only in any ant community.

The resemblance here to slave-making in the human race is more superficial than real. Worker-ants are never captured in these raids, and the larvæ reared in the nest of the captors are not an unwilling and inferior race forcibly held in subjection and treated as an inferior caste. The nest is rather to be considered as a mixed community, in which the division of labor is based on the capabilities of the individual, but not on his race. Nevertheless, if it is considered that it is only the worker larvæ of the smaller species that are reared, and that they help to rear and care for the young of an alien race instead of their own, this slave-making does involve the exploiting of the weaker for the benefit of the more powerful race.

In the Amazon Ant a further development of the slave-making instinct appears, which may serve to show where the weak point lies in this method of exploitation. In this species the workers have become largely dependent upon the captured race, not only for the care of the nest and rearing of the young, but for food as well, so that they are unable to feed or groom themselves. Under these conditions the continuance of the Amazon Ant communities obviously becomes dependent upon the prosperity and abundance of colonies of the smaller species. The slave-making race cannot prosper at the expense of the other beyond a certain limit, and its relations tend to become analogous to those of parasitic animals.

In several kinds of ants the female, instead of depending upon her own progeny to start a new colony, may seek out a small existing colony of her own or some other species and persuade or compel the workers to adopt her. This process has been carefully observed by Wheeler and distinguished from the slave-making habits with which it might readily be confused. Both result in mixed communities in which the larger species is more or less dependent upon the smaller in its household and personal activities. But the slave-making results from the carrying off of larvæ from raided nests; the social parasitism from the adoption by an ant community of a queen of alien race. It is not wholly clear, in spite of the careful observations of Wheeler and others, how the invading queen manages to overcome the strong instinct of antagonism in the workers to an ant of another community or race. But this parasitism is carried in some species so far that the invading race has no workers, only males and females, and is wholly dependent upon its host for sustenance.

There is a great variety of parasitism, social and individual, to be seen in ant communities, and the careful study of its nature has thrown much light on the nature and limits of the intelligence of these insects. There are several kinds of smaller ants that live in mixed communities with larger forms, but construct separate galleries opening into the larger galleries of their hosts, but too small for the larger ants to traverse. Among these some, like the Thief Ant, 'Solenopsis,' prey upon the larvæ and pupæ of the larger form, while others merely levy toll upon the supplies brought in by the larger workers.

Again there are various insects of other orders, flies, bugs and spiders, which make their homes in ant nests. Some are harmless, or even beneficial in the life of the community, but others are ravenous and destructive enemies of the ants, preying upon the eggs or larvæ, laying their own eggs within the ant-larvæ to develop at their expense, and in various ways seriously interfering with the prosperity of the nest. Yet the eggs and larvæ of these parasites are as carefully tended and reared by the ants as their own, and the adults are evidently tolerated by the workers, either because they are unobserved, or because they are regarded as nest-mates, or for some other reason still obscure.

CHAPTER VI

THE VERTEBRATES—I. FISH

THE vertebrates, or backboned animals, including fish, amphibia, reptiles, birds and mammals (with man), are markedly differentiated in their plan of organization from the radiates, mollusks or arthropods. This new plan of organization, leading to a higher plane of development, has made the vertebrate the dominant type of animal life, not indeed in numbers of individuals or species, as some naturalists would interpret dominance, but as individually higher types, better fitted for success in the struggle for existence. They have further opened the way, in the development of man, for the inception of a new era, the Psychozoic Era as it has been aptly called by Leconte, in which intellect becomes the principal factor in the evolution of life, controlling its environment, guiding its development, and leading to results which we can but dimly foresee, even as to those immediately before us.

In a brief review of the plan of organization of the vertebrates it will appear wherein these advantages lie. In all vertebrates there is an internal skeleton, of which the central feature is the backbone, originally developed from the 'notochord,' a segmented strip of cartilage later converted into bone, forming the nucleus of the spine. This internal skeleton, as against the external skeleton of most invertebrates, affords certain marked mechanical advantages in giving the muscles a better purchase and enabling them to control the action and movements of body and limbs more powerfully. Now it is a fundamental fact of mechanics that with every doubling of the dimensions of a structure the relative strength of its materials is reduced by one-half. So that larger constructions, to perform what is relatively the same work, must be more massively proportioned, or made of stronger material than smaller ones. This is equally true of animals. The larger an animal is the more powerful and strongly constructed must it be, in order to have the same amount of activity and obtain its proportional amount of food. It is a common saying that if a flea were the size of an elephant he could jump over the spire of the highest cathedral in Europe. But any engineer can see the absurdity of this statement. If a flea were the size of an elephant, he would in fact be unable to lift his body off the ground. His proportionate strength would be $^1/_{4820}$ of what it is, and in all probability would not hold his body together. His apparent strength is merely due to his minute size. If vertebrates and invertebrates of equal size be compared the greater strength and activity of the vertebrate is immediately perceived.

Now size is a very important factor in the dominance of an animal, and the superior organization of the vertebrates which has enabled them to attain much larger size is in no small degree due to their having an internal skeleton. Many vertebrates have also developed for protection an external skeleton of scales or plates, and the most ancient of fossil vertebrates were well armored externally, while the internal skeleton was still composed of cartilage not yet hardened into bone.

The nervous system of vertebrates consists of a spinal cord along the back just above the notochord, and a brain developing at the front end of the notochord. The brain is more concentrated into a single mass than in invertebrates, where its functions are partly distributed among ganglia in different parts of the nervous cords. This naturally makes for more centralized and better correlated control of the different parts and organs of the body, and facilitates the development of intelligence and reasoning powers. In the highest invertebrates there is a marvelous development of accurately coördinated automatic action and complexity of instinct, but they seem to be unable to attain high intelligent or reasoning powers. In vertebrates, while the instincts are less elaborate and complex, the observer is impressed with the relatively intelligent character of their activities, with their ability to respond to new sensations, and accommodate themselves to new conditions of life. This is to be connected with their more concentrated brain, and from the first the nervous system appears to have been more concentrated in vertebrates than in any of the invertebrate groups.

All vertebrates breathed primarily by gills, the water which aerated the gills entering through the mouth and making its exit through gill-slits on each side of the throat. Fishes and tadpoles still breathe this way, but land animals have become adapted to breathing air by means of the lungs. Rudimentary lungs are present in many primitive fishes, serving to assist the gills in aerating the blood when, as in stagnant ponds, the supply of oxygen in the water was not sufficient for the needs of the fish. In the more typical modern fish this rudimentary lung has been converted into the so-called swim-bladder, serving to adjust the weight of the body to the water around by compressing or expanding the air contained in it, and perhaps for adjusting the amount and quality of air in the blood. It is interesting to observe that the embryos of all land mammals, including man, pass through a stage in which they possess gill-slits, altho these serve no purpose in the life of the young animal.

All vertebrates except certain very lowly types possess paired appendages—fins, limbs or wings. These consist always of two pairs, never more, and originate in an entirely different way from those of arthropods, as folds of skin along the side of the body, becoming concentrated into fins or paddles and thence converted into limbs. In birds, bats and pterodactyls the fore limbs are converted into wings.

The alimentary or digestive system consists at first of a long straight canal near the under side of the body and is elaborated into a very complex affair by the development of various glands to assist in digestion, and by the lengthening and coiling of the alimentary canal. The circulatory system is much more elaborated than in the lower animals and progressively so in the higher vertebrates. A marked difference from insects lies in the fact that air is conveyed from the lungs or gills to the tissues by medium of the blood corpuscles, whereas in insects the air reaches the tissues of all parts of the body directly through the tracheæ. The circulation of the blood is thus a much more important function of the life of vertebrates than of insects.

In the development of the skeleton it is to be noted that the spinal cord soon becomes arched over by segments of bone and the brain enclosed in a bony capsule; that the under side of the body is supported by arches of cartilage from each segment of the notochord, which are converted into bony ribs; that the gill-arches are also supported by bony arches, of which the front pair is later converted into a part of the lower jaw; that the teeth develop originally as scales on the skin of the mouth; that the segmented limb-bones retain even among mammals many suggestions of their former fin-ray construction. Various additional bones are formed in the skin of the head which coalesce with the more internal bones of brain capsule and jaw to form the solid skull of the higher vertebrates. In fishes the various bones of the head are more or less separate, as also in the young of higher animals.

The eyes are in general highly developed and are the most important of the sense organs; the hearing organs are also very elaborate and complicated. The sense of

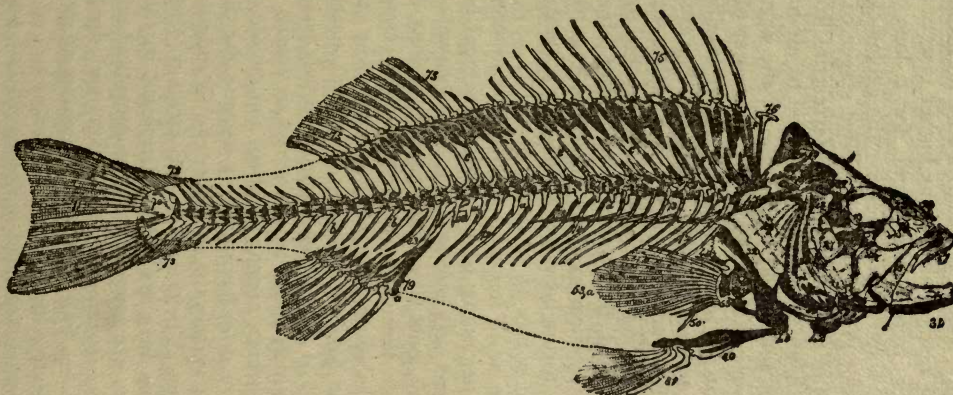


Fig. 17 —SKELETON OF THE PERCH.

Illustrating the internal skeleton of the vertebrata, of which the backbone is the central feature. The skull is composed of numerous separate plates of bone; there is no neck, and the paired fins (pectoral 53, ventral 80-82) are set far forward on the body. The fin supports (74) grow inward from the skin, meeting the outwardly growing spines of the backbone (c. c.).

smell, altho usually well developed, has by no means the importance that it reaches among the higher insects.

The vertebrates were, at first and for a long time, adapted to live in water. In reviewing the geological history of the different groups, the successive stages of their invasion of the land and adaptation to terrestrial life will appear. Having once become well adapted to air-breathing and the more active and varied life of the dry land, the vertebrates were enabled, through their better plan of organization, to attain larger size and higher intelligence than the insects, spiders and land snails which were their predecessors as land animals. Their internal instead of external skeleton, their more concentrated nervous system, and it might be added, their more concentrated breathing system (for the tracheæ of insects may be regarded as lungs distributed throughout the whole body) were probably the principal points of advantage.

Vertebrates are much less ancient than the invertebrate groups. At the beginning of recorded geological history the several groups of invertebrates already were well specialized. They must have had a long previous era of evolution of which there is no record, partly because the most ancient rocks containing it are so altered by crystallization that their fossils have been destroyed, partly because many or all of these most ancient animals possessed no hard points which could be preserved as fossils. But the earliest vertebrates, appearing about the middle of the Paleozoic era, are only beginning to assume the distinctive characters of vertebrata, so far as can be judged from the fossil remains. They were in the dawn of their development; and as they are followed upward in the geologic column, they are found putting on more and more of the characteristic features of vertebrata, and finally, at the end of the long Paleozoic era, becoming adapted, at first very imperfectly, for active land life.

The earliest vertebrates had a notochord but no bony internal skeleton; but some of them had a very complete bony armor. The notochord was gradually replaced by a true backbone in the land vertebrates, but more or less of it still remains in modern fishes, and it was not until the beginning of the Age of Reptiles that it disappeared among the land vertebrates.

Among these most ancient of vertebrates may be mentioned two groups, the Ostracoderms, covered with bony armor (or sometimes with only the head armored), first found in the Old Red Sandstones of Scotland, of whose "griesly fisch in the laithly flood" Hugh Miller has given such lively and fascinating descriptions. These animals at first glance resemble crustaceans or scorpions, but they are considered as vertebrata, altho not true fishes. True fishes appear a little later, in the primitive sharks and related types which are preserved, sometimes in great perfection, in the Devonian shales of Ohio and elsewhere.

In the sharks and rays the internal skeleton is still composed of cartilage, as it was in the primitive ancestral vertebrates. The gill-slits are also of a very ancient type. They consist of a number of separate slots along the outer surface of the side just behind the head. In all the higher fishes they are covered by a flap of bone and skin called the operculum, or gill-cover.

To the bather in tropical waters, to the shipwrecked seaman clinging to a raft or afloat in a leaky overloaded boat, the appearance of sharks is the danger most to be dreaded. Swift, powerful and voracious, many of them huge in size, they are the terror of the warmer seas. Indiscriminate in their appetite, they are fortunately less dexterous than many other fish in seizing their prey at the surface, and may often be frightened away by splashing and disturbance of the water, which their low intelligence does not allow them to understand. It is probable indeed that the number of swimmers actually devoured by sharks is by no means in proportion to their reputation.

The largest and most voracious of the man-eating sharks is the great white shark, found in all tropical seas, but fortunately not very common. This species reaches a length of 30 feet, and is quite capable of swallowing a man whole. It is, according to Linnæus, the 'great fish' which swallowed Jonah. "Jonam Prophetum ut veteris Herculem trinoctem, in hujus ventriculo tridui spateo bæsisse, verosimile est." Gesner relates that the bodies of men have been found entire in sharks, on one occasion, at Marseilles, a man in complete armor; and over a hundred similar cases "have since been recorded."

Huge as is the living white shark, it was far surpassed by some of its extinct relatives. The fossil shark teeth common in the phosphate beds of South Carolina and in other Tertiary and Pleistocene formations are sometimes six inches long and five wide, three times as large as in the largest white sharks, and the animal, if of proportionate size, must have attained a length of ninety feet, equaling or exceeding the largest whales. It is possible that sharks of this size still exist, altho they have never been reported on good authority, for teeth of similar dimensions have been obtained in deep-sea dredging. A restoration of the jaws of this gigantic extinct shark with the (original) teeth all in position has recently been placed on exhibition in the Natural History Museum in New York. The gape of the jaws is nearly seven feet, so that this monster could almost have swallowed a small vessel, crew and all, and the traditional Jonah could easily have walked down his throat if opened for the purpose.

Closely related to the white shark are the mackerel sharks, porbeagles and salmon-sharks, not attaining such giant size, but equally swift and voracious. The high triangular back-fin and the mackerel-like tail are characteristic features of this group. The basking shark is the largest of the family and the largest of all true fishes, attaining a length of thirty-six fe and an enormous bulk. Unlike its relatives, it is a dull, s ggish animal, and does not pursue large prey.

The blue sharks, tiger-sharks a d cub or harbor sharks are much more common and familiar than the white shark and its allies, and almost equal it in swiftness and ferocity, and sometimes in gigantic size. The dorsal fin is not so high and triangular, and the lobes of the tail are very unequal, the upper lobe projecting far backward, while the lower lobe is small. The blue shark, so commonly seen following ships, and the cub-shark, common around the waters of tropical harbors, are usually credited with the dangerous ferocity of the white shark, which they hardly deserve.

The rays and skates are related to the true sharks, but have the body flattened out and the pectoral fins extended in a thin, continuous flap along the sides, so that the animal has the shape of a flounder or halibut. They are bottom feeders, living on shells and crustaceans, and harmless, except for the sting rays, which can deliver a severe wound by a slash of the spiny tail, and the torpedoes, which have an electric organ capable of giving a severe benumbing shock to an enemy. The sea-devils are gigantic rays, the great wing-like fins expanding twenty feet.

Most modern fishes have a bony internal skeleton, and in various respects are higher types than the sharks. There are various partly intermediate forms between sharks and true bony fishes, but their relationships need not be considered here.

The perch and bass are usually considered the most typical of this group, and from this type as a center they vary into an endless diversity of form structure and habit. Most of them are marine, but many inhabit fresh-water lakes, rivers and brooks. In the ocean they are abundant everywhere, from shore to far out at sea, from the surface to great depths. Nowhere are they so varied or brightly colored as around the coral reefs of tropical seas; but they are equally abundant in the colder waters of the northern oceans. They form an important part of the food of all maritime peoples; the value of the herring fishery alone is over thirty-seven million dollars annually.

The most ancient type of true bony fish are the soft-finned fishes, allies of the herring and the trout. The herring, running in immense "schools" in all the northern seas, is more used for food than any other fish, and "its spawning and feeding grounds have determined the location of cities." Closely allied to the herring is the shad, highly prized as a food fish in the United States, and the menhaden, caught chiefly for its oil and as a manure for fields. The much larger tarpon of the South Atlantic is a favorite game-fish, reaching a length of six feet or more and affording exciting sport to the angler. Extinct allies of the tarpon in the Cretaceous seas (Portheus) reached a length of twelve feet.

The trout and salmon live partly or wholly in fresh water, the salmon ascending rivers from the sea to spawn, while the trout live entirely in fresh water, running streams or lakes, and the whitefish inhabit the great fresh-water lakes of North America. The Pacific salmon enters the rivers only for spawning, takes no food during its desperate struggle up to the headwaters of the stream, and dies when the spawning is completed, the young returning to the sea at the next high water. The Atlantic and European salmon, much more closely related to the trout, spend a much larger part of their lives in fresh water, while on the other hand several species of trout descend for a time to the sea, and others live partly or wholly in fresh-water lakes and ponds. Salmon and trout are the chief of game fish. In beauty and variety of color, in delicacy of flavor, in fighting qualities and in wariness, they rank with any fish.

If the trout and salmon are the favorites of the fresh-water fisherman, eels are perhaps the most heartily disliked. Their long, snaky form, ugly color, slimy skin, and their unpleasant addiction to "swallowing the bait" would be causes enough, but in addition they are one of the worst enemies of the game fishes. The spawning of the fresh-water eel was long a mystery, only very recently solved.

The truth is that they descend to the sea to spawn, reversing the habits of the salmon.

The carp family includes a great many fresh-water fish, mostly small and less active than the salmon group. Both carp and salmon families are found only in the northern temperate regions. The carp and chub, dace and roach, minnow and shiner, are familiar in our brooks and streams, none of them gamy, none very good eating, but passable

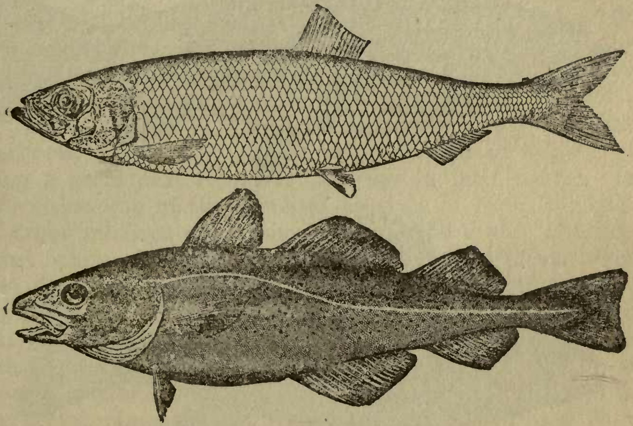


Fig. 18 —Herring and Cod.
The two greatest food fishes of the world. (Jordan.)

in absence of better fish. The carp and the nearly related goldfish are natives of China, domesticated there for centuries and introduced into Europe about 300 years ago.

Another familiar group of fresh-water fishes is the catfish family. They derive their name from the barbels or feelers around the mouth, which suggest the "smellers" of a cat. They are not scaly, but often head and parts of body are armored with bony plates. Their especial home is in South America, but they are common also in the northern continents and a few in Africa. They are all carnivorous gamy fish, fair to good eating, and most of them are found in river channels or muddy streams. Similar in habits but more graceful in form are the pike and

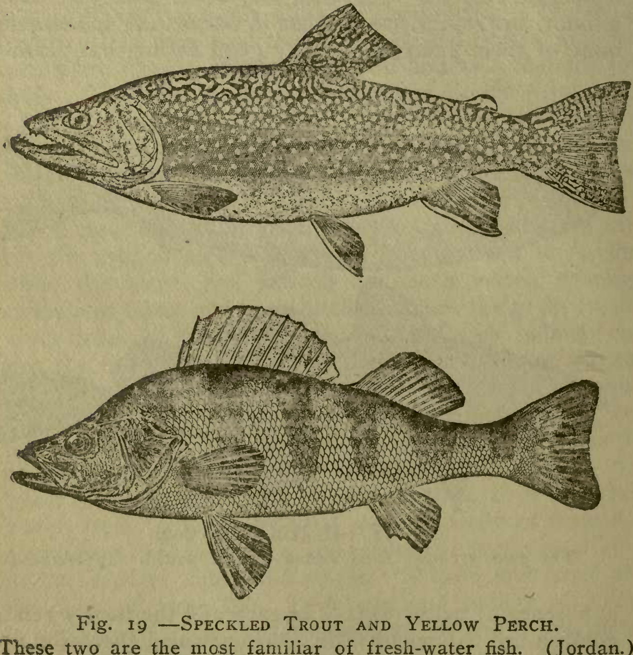


Fig. 19 —Speckled Trout and Yellow Perch.
These two are the most familiar of fresh-water fish. (Jordan.)

muskallonge, the first living in fresh-water streams of all the northern continents, the second in the Great Lakes.

In the south temperate zone, where there are no true trout, their place is taken by a distinct group of fishes of the same habits. They are the "trout" of New Zealand, Australia, Tasmania, Patagonia and the Falkland Islands, and of South Africa. It has been supposed that these fresh-water fish, living in the isolated continents of the south, and unknown in equatorial or northern regions, must have spread from one to another region by way of an antarctic continent now submerged. It has recently been found, however, that these fish are able to live in salt water as well as fresh, so that they may have been distributed by sea.

The largest and most typical of the great groups of bony fishes are the spiny-rayed fish, typified by the perch and mackerel. Numerous fresh-water and more abundant marine fish are included in this order; only a few of the best-known kinds can be mentioned here.

The mackerel of the North Atlantic runs in great schools, estimated to contain many millions of fish, varying a great deal from year to year in their course. It furnishes one of the principal fisheries of New England. Larger relatives of the mackerel are the tunny, albacore and bonito of the warmer seas, and the Spanish mackerel of the West Indies. All these are swift, graceful, handsome fishes. The mackerel are preyed upon by their larger relative, the swordfish, which follows the schools to the New England coasts. Its presence is a sign that there are mackerel about. It is one of the swiftest of fishes; the graceful, compact body, forked tail and pointed head with long, sword-like upper jaw are all peculiarly fitted for speed. The swordfish frequently attacks ships or boats, driving its sword through a heavy plank without difficulty.

The bluefish is another well-known predaceous fish of the North Atlantic. It is said to be the most destructive of all fishes in the waters it inhabits, pursuing the schools of smaller fish and killing far more than it requires for food. Professor Baird has estimated that during their stay on the New England coast the bluefish destroy upward of twelve hundred million million of smaller fish.

The order of perch-like fish includes a great variety of familiar fishes, fresh-water and marine—the perch, bass, darters and sunfish of the still streams and lakes of the north temperate zone; the sea bass and their relatives which in Australia, South America and South Africa have invaded the rivers and take the place and name of perch; the bright-colored groups of tropical seas. The parrot-fish, damsel-fish and angel-fish of the coral reefs, the

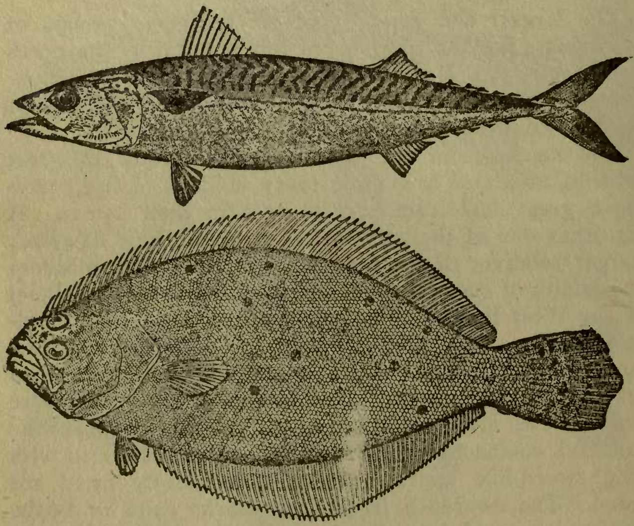


Fig. 20 —Mackerel and Flounder.
Illustrating swift-swimming and bottom-feeding types of adaptation among sea-fish. (Jordan.)

sculpins and gurnards are more or less nearly related. The flat fishes are a curious offshoot of the sping-rayed fishes. The body is very deep and narrow, but the fish swims on its side, one eye being twisted around from its normal position so that both of the eyes are on the side which lies uppermost. This side is also darker colored than the under side. In some flatfish it is the right, in others the left side which lies uppermost and shows the eyes and darker coloration. The flounders, soles, halibut, turbot and plaice are the best known of the flatfish. All are excellent food fishes.

The codfish family—codfish, pollock, haddock and va-

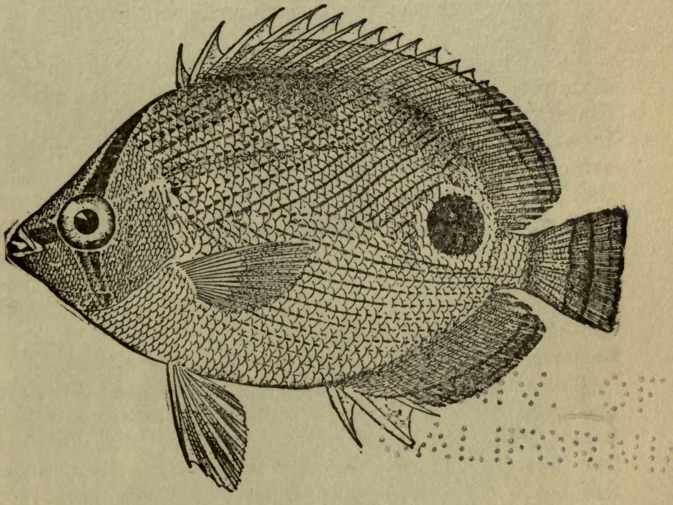


Fig. 21 —The Butterfly-fish.
One of the gorgeously colored fishes which live among the coral reefs. (Jordan.)

rious smaller species—are more remotely related to the spiny finned fishes, and are of great importance as a food fish. For four centuries the Banks of Newfoundland have been the chief center of the cod fishery. Among the fishing vessels all nations are represented, and in succession have come the Basque, Dutch, English, American and Scandinavian fishermen.

CHAPTER VII

THE VERTEBRATES—II. AMPHIBIA AND REPTILES

The Frogs, Toads, Efts and Salamanders are intermediate between aquatic and terrestrial vertebrates, between fishes and reptiles. In early life they are tadpoles, living in water, breathing by gills, having no true limbs, but a fringe of fin like the median fins of many fishes. Later they undergo a metamorphosis, bud out true limbs with feet, lose their gills and develop lungs, and become adapted to live on land. They are to some extent intermediate between fishes and reptiles, but are in fact much closer to reptiles if we compare the adult animals. Altho fish-like in their early development, there is a wide gap between them and any true fishes, living or extinct.

There are two living groups of amphibians, the frogs and toads, tailless; and the efts and salamanders with long, heavy tails. The efts or newts and salamanders look very like lizards, but may be distinguished by their broad, flat heads. They frequent damp woods and borders of ponds, and may often be found by overturning stones or logs in such places. Most of them are quite small, but the giant salamander of Japan ('Cryptobranchus') reaches a length of five feet, and the closely related hellbender is sometimes eighteen inches long. The smaller efts are common in all the northern continents, and a few are found in North Africa and along the Andes Mountains as far south as Argentina. Some of the tailed amphibians retain their gills throughout their life, especially if the conditions favor their continued aquatic life.

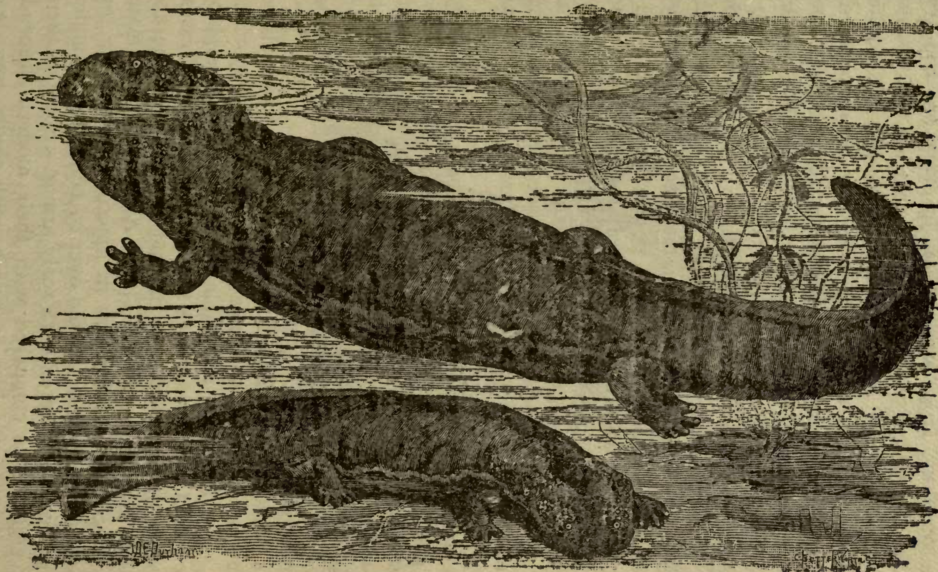


Fig. 22 —The Giant Salamander of Japan. (Gadow.)

The toads and frogs are familiar to every one and are found in all parts of world, except in some of the oceanic islands. Toads are harmless creatures, helpful to the gardener from the quantities of insects they consume, many of them curiously interesting in their mating and egg-laying habits, and it is hard to see why they should be regarded with such general aversion. Like most Amphibians, there is a poisonous secretion in the skin which protects them from the attacks of more active animals, but this is not exuded from the surface save in extremity, and they can be handled with perfect safety, the poison acting only internally. There is no ground for the notion that warts on the skin are the result of handling toads. A curious myth found in early books on natural history and embalmed by Shakespeare in a quotation familiar to all, credits the toad with bearing a "precious jewel in his head."

The frogs, less poisonous than toads, are protected by their greater activity and more amphibious habits. The tree-toads are protected by their genius at concealment, and altho every one has heard their loud trilling, it is surprising how few persons have seen the little green chap with sucker-like disks on the tips of the toes who is responsible for it.

The modern amphibians are diminutive and specialized descendants of what was once a numerous and important race. The Primitive Amphibians or Armored Amphibians of the Coal Period were the first of land vertebrates, and were the dominant type of land animals until the appearance of the reptiles. These Armored Amphibians were much like salamanders in appearance, but the top of the head was solidly roofed over by bone and the under side of the body covered with scaly armor. Some of them were gigantic as compared with their modern descendants, ten or twelve feet in length, with skulls two feet long and a foot and a half wide. From some of these ancient amphibians were probably descended the reptiles, birds and mammals of later geologic ages.

The class of reptiles includes several very diverse kinds of animals—the snakes, lizards, crocodiles and turtles. Superficially they have not much in common except for the scaly skin, and that they (mostly) lay eggs and (all)

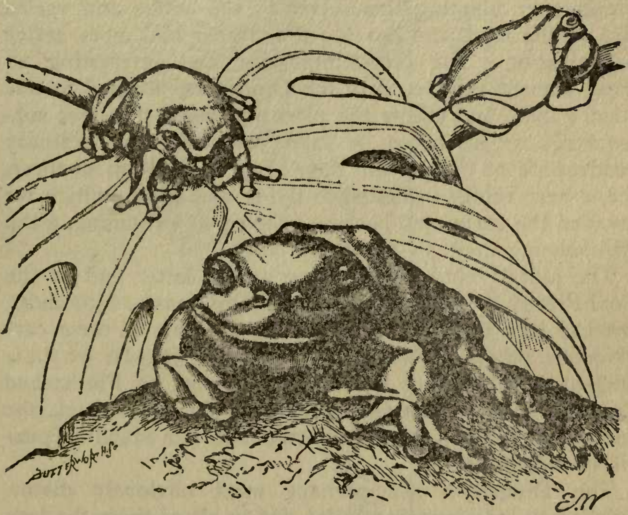


Fig. 23 —An Australian Tree Frog.
Note the adhesive discs of the toes and the inflated vocal sac.

breathe by lungs throughout their lives. The construction of the skeleton and the various details of internal organization show that they are in fact related to each other, tho not very closely, and geological history shows that they art the scattered and specialized survivors of a class of vertebrates which for countless centuries was the dominant type of land animal. The Age of Reptiles is estimated to have endured for some nine millions of years;

the Age of Mammals, which followed it and culminated in the appearance of man, for three millions of years. Compared with these vast periods the duration of historic time shrinks into insignificance.

The reptiles evolved from the Primitive Amphibians of the Coal Period, and the earliest reptiles are with difficulty distinguished from them. But they were more progressive in adapting themselves to the active and varied life of the land, and developed a higher and more active organization. The most important and interesting of these ancient reptiles were the Dinosaurs, adapted to live on dry land, and taking the place in nature that was subsequently to be taken by land mammals, the ordinary quadrupeds of the present day. But in addition to these, there were reptiles adapted to flying and others which re-invaded the ocean and became adapted to swimming, altho still keeping their air-breathing habit.

The oldest reptiles, appearing at the latter end of the Coal Period, were clumsy, heavy-bodied beasts, with short, crooked legs like crocodiles or turtles, some of them carnivorous, others herbivorous. The most singular of these ancient reptiles were the Pelycosaurians, or Fin-backed Reptiles, with an enormous rigid bony fin on the back, the purpose of which, unless for ornament, is a standing puzzle to zoölogists.

The Dinosaurs are perhaps most obviously distinguished as long-legged reptiles, for in all of them the legs are long and straight as in modern land quadrupeds, instead of short and crooked as in modern reptiles. They were the characteristic land animals during the whole of the Age of Reptiles, comprising the Triassic, Jurassic and Cretaceous Periods, and many of them reached a gigantic size, rivaling the largest of living animals. Besides these gigantic forms, there were numerous smaller, lighter, more agile kinds, many of them known only by their footprints preserved in the ancient tidal flats of the Connecticut Valley and elsewhere. And there is reason to believe

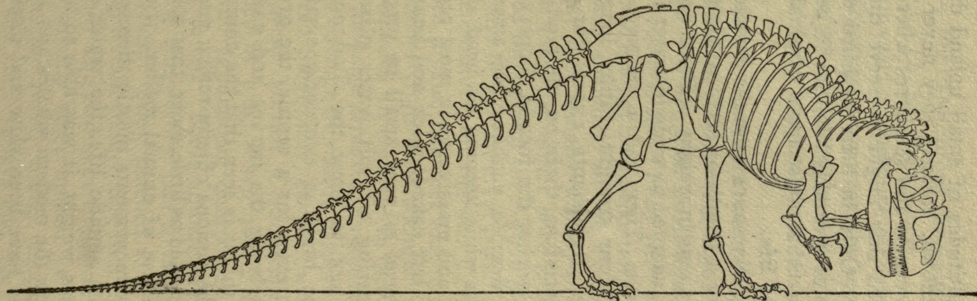


Fig. 24 —A. Carnivorous Dinosaurs (Allosaurus).

Jurassic Period, Age of Reptiles. This skeleton, 36 feet in length, is mounted in the American Museum of Natural History, New York.

that there were multitudes of small upland dinosaurs of which nothing is known, because they never frequented the river-bottoms, swamps and seashores where sediments were being deposited that might preserve their remains to the present day. Only in their modified descendants, readapted to swamp or riverside life, can be perceived the traces remaining of what must have originally been an adaptation to upland life.

The hugest of the Dinosaurs were the Brontosaurus and Diplodocus, reaching a length of sixty to eighty feet and a mass of over thirty tons in weight. These were probably amphibious animals, adapted to wade in water from twenty to fifty feet in depth. They had a massive elephantine body, supported on four straight, rather long legs, with feet very like those of elephants, except for large, blunt claws, one on the fore-foot, three on the hind-foot, which may have served to anchor the foot in slippery mud. The neck was long and flexible, enabling the animal to wade to considerable depth while keeping his head above water; the tail long, heavy and massive as in most reptiles. The skin was not scaly, but naked, thick and heavy like that of a whale. The head is very small in proportion, the teeth adapted to tearing off soft water plants or other such material, but not to chew the food nor to attack other animals. The brain is extremely small, and was of low organization even for a reptile, the great mass of the nervous system being the nerves and ganglia of the spinal cord. From this it is seen that the animal was slow and unintelligent, the actions chiefly reflex, and the Brontosaurus may be regarded as little more than a huge automaton, a vast storehouse of animal matter, with but little intelligence, and its movements mostly directed by reflex action. Through its aquatic life, the water buoying up most of its enormous weight, it was able to attain a size comparable only with the modern whales and sharks. But its movements must have been slow and clumsy, and on land it would be utterly helpless; it was protected from its chief enemies, the carnivorous dinosaurs, by being able to wade to a depth beyond their reach.

Skeletons or casts of skeletons of some of these gigantic amphibious dinosaurs have recently been mounted in several of the larger museums in America and Europe and are among the most impressive records of the past history of the world.

The carnivorous dinosaurs were very different in appearance and habits. They were biped reptiles, with long hind limbs and bird-like feet, small fore limbs, large, sharp claws, short neck and large head with sharp-pointed, saw-edged teeth, and a long, lizard-like tail. Tracks of this type of dinosaur are abundant on the Connecticut sandstones and show that they usually walked or ran on the hind-limbs, seldom touching either fore-limbs or tail. These dinosaurs lived throughout the Age of Reptiles, both small, agile species and large, powerful ones. The most gigantic was the Tyrannosaurus of the late Cretaceous, forty feet in length, with a skull five feet long and teeth projecting four to six inches from their sockets. This animal must have nearly equaled an elephant in bulk and was adapted to prey upon the huge armored dinosaurs.

Other types of huge dinosaurs discovered in recent years are the armored Stegosaurs, covered with bony plates and spines, the great horned Ceratopsians with enormous skulls defended by long, sharp horns, and the duck-billed Trachodon and Iguanodon, unarmored, and with broad, horny, duck-like bill. These animals were all herbivorous, and except the Stegosaurs, had a fairly effective battery of grinding teeth. They reached a length of twenty to thirty feet and a bulk comparable to a hippopotamus or an elephant. They also had numerous smaller relatives, more agile and apparently more upland in their habitat, since their skeletons are rarely found complete in the ancient sediments of the river valleys and marshes of the Age of Reptiles. Mostly they are known to science only by the scattered bones and fragments brought down by the rivers from higher levels.

The Flying Reptiles, or 'Pterodactyls,' were contemporaries of the Dinosaurs and equally remarkable, altho less gigantic in size. These "dragons of the prime" had the fore limbs converted into bat-like wings by the extension of the little finger into a long, slender-jointed rod supporting a membrane wing like that of bats. The tail is rudi-

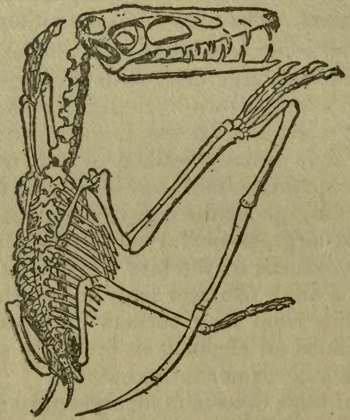


Fig. 25 —Pterodactyl or Flying Reptile.
Jurassic Period, Age of Reptiles. Note the greatly elongated fifth digit of the fore foot, from which the wing membrane stretches back to the hind foot and body. (Zittel.)

mentary or converted into a long steering blade, and the skeleton throughout is very light and fragile, the bones being hollow and pneumatic (filled with air) as they are in birds. Most of the Pterodactyls were small, from six inches to three feet expanse of wing, but in the late Cretaceous appeared large forms (Pteranodon), some twenty feet from tip to tip of the wings, with large, straight, toothless beaks, adapted apparently to spearing fish. The Pteranodon skeletons are found in marine formations deposited far out at sea, while the small Pterodactyls, with shorter wings, lived near the land. All of them were apparently adapted for soaring rather than fluttering, and they may be regarded as nature's nearest approach to a modern aeroplane.

In the rivers and swamps of the Age of Reptiles might be found crocodiles and turtles not very unlike those of the present day, and a variety of extinct reptiles more or less resembling them. In the seas lived several kinds of marine reptiles, some of gigantic size. These, like the cetaceans, seals and sirenians of the present day, were derived from terrestrial ancestors, but had re-invaded the sea, where they competed to advantage with the finny autochthones by reason of their superior organization and air-breathing habit.

The Plesiosaurs were long-necked, with compact bodies and long, turtle-like flippers. The Ichthyosaurs were very fish-like in outward appearance, with short necks, long, slender jaws and shark-like tail, and were evidently adapted to swift swimming like the mackerel-shark or the dolphin. The Mosasaurs were more nearly related to the lizards, but with flipper-like feet, large heads, with powerful jaws and sharp, stout teeth and long, compressed tails. Some of the Mosasaurs and Plesiosaurs reached a length of forty feet; the Ichthyosaurs were somewhat smaller. All these great marine reptiles had become extinct by the end of the Cretaceous Period, and their place in the world was taken by marine mammals, ancestors of the Cetaceans of our modern seas.

The world must have appeared strange from a modern viewpoint during the Age of Reptiles. The imagination must picture dry land and swamps populated by long-legged reptiles, many of them fantastic and bizarre in appearance and all utterly unlike any living animals. The vegetation would be less strange, but its tropical aspect and the absence of many of the more abundant higher types of plants could hardly fail to impress the observer. In place of birds were the Pterodactyls, soaring through the air or hanging bat-like from trees or projecting rocks. Along the seashore we might find many familiar invertebrates, corals, starfish, sea urchins, crustaceans and mollusks, and with them swarms of nautilus-like ammonites and squid-like belemnites. Along the shores and far out at sea, besides the numerous types of fishes more or less like those of the present day, would be found numbers of the huge voracious marine reptiles, Plesiosaurs and Ichthyosaurs and (in the Cretaceous Period) Mosasaurs, rulers of the deep, as the Cetaceans are to-day.

The keynote of the Age of Reptiles, as compared with the world of to-day, was the dominance of brute force. The varied types of reptilia which ruled land and swamp, sea and air were but little inferior in size and not greatly inferior in mechanical organization, in strength and speed to the higher animals which have taken their place. But they were notably inferior in type of brain, with the intelligence, adaptability and agility which it entails. Their disappearance at the end of the Cretaceous Period is to be ascribed partly to their being unable to adapt themselves to changed conditions of life brought about by changes in climate and geography of the world which they inhabited, partly to the competition of the more intelligent and adaptable mammals and birds that were being evolved to compete with them. There may have been other important factors in causing their extinction; several have been suggested, many more might be suggested. But these are known causes and must have played an important part in the process; the others are mostly guesswork.

At the end of the Age of Reptiles there were a few surviving groups which have persisted to the present day with but little change. They were the turtles, crocodiles, lizards and snakes, which on account of their habits and environment came less directly into competition with the higher quadrupeds and birds or whose surroundings were not altered by changes in geography and climate. These are the reptiles of to-day, a small and despised remnant of a class which ruled the world for millions of years, and for gigantic and formidable beasts has hardly since been equaled.

The Turtles and Tortoises, 'Chelonia,' form a well-armored group. The slow-moving tortoise is one of the most thoroly protected of four-footed animals. Give him a chance to withdraw his head, legs and tail within his shell and close the lids, and no enemy can molest him unless it be large and powerful enough to crush his whole shell between its jaws. He lives upon snails, slugs, caterpillars, earthworms, etc., with a considerable addition of vegetable food, usually hibernates in winter, and continues his leisurely, untroubled existence for a long period of years, perhaps even for centuries. It is only in his younger days that he has much to fear from enemies. But the eggs and young are toothsome morsels for carnivorous animals, and in spite of the care with which the mother conceals her eggs in the sand, burying them and effacing all marks which might serve as guide to their location, probably very few survive to be adult.

Land tortoises are found everywhere except in the Australian region and are found on several isolated oceanic islands, where, unmolested by higher quadrupeds, they are very abundant and reach large size. Their aquatic relatives, to which the name "turtle" is usually restricted, are of several different groups similar in general appearance, but not very closely related. They are generally more active, less completely protected by shell, and with the feet more or less completely converted into flippers for swimming.

The pond-tortoises, or marsh-turtles (Terrapins), are nearest to the true land tortoises, but have a flatter shell. One of the prettiest among them is the Painted Terrapin

(Chrysemys), with its handsome pattern of red and yellow on a background of dull greenish black, but most of them are dull colored. The Diamond-back Terrapin, noted as the finest of all edible turtles, frequents the salt marshes of the Atlantic coast, especially in the Southern States, but is rapidly becoming scarce except where artificially protected. The snapping turtles and mud turtles are more aquatic and less completely protected by bony shell. The sea turtles are wholly marine, mostly confined to tropical seas and valued not only as food but for the tortoise shell manufactured from the outer layer of the carapace. The largest of these marine turtles is the green turtle (Chelone), inevitably connected, in song and story, with aldermanic banquets and other such civic functions. A near relative is the hawksbill turtle, the chief source of the tortoise shell of commerce.

The Side-necked Turtles, abundant in the rivers of all the southern continents, are rather distantly related to those we have mentioned. Altho much alike superficially, the construction of the carapace is different, and in withdrawing the head into the shell they bend the neck sideways, while the others bend it vertically in an S-shaped curve. Vast numbers of these turtles live in the South American rivers.

The soft-shelled river turtles (Trionyx) of the northern continents on the one hand, and the marine leathery turtles on the other, are ancient offshoots of the main chelonian stock which have endured with little change since the Reptilian Age.

Like the turtles, the crocodiles are a race of ancient lineage. During the Age of Reptiles they infested both seas and rivers in all parts of the world. Since then their range has been gradually restricted. The marine forms long ago became extinct; the river crocodiles have disappeared from most temperate regions and are common only in tropical or subtropical rivers. The living species are grouped as alligators, crocodiles and gavials, differing in the width of the skull and to some extent in their food habits. The narrow-snouted gavials of the East Indies feed chiefly upon fish; the broad-headed alligators (chiefly new-world) and the crocodiles (chiefly old-world), with heads of medium width and muzzles notched at the sides near the front to receive a large tooth in the lower jaw, lie in wait for land animals which come down to the rivers to

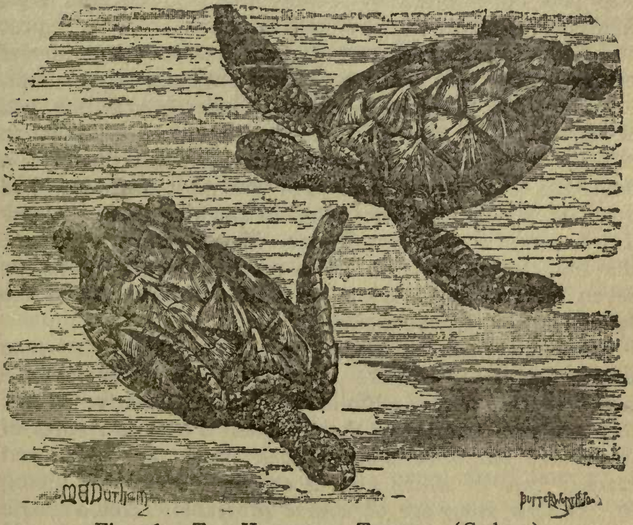


Fig. 26 —THE HAWKSBILL TURTLE. (Gadow.)

drink or attempt to cross. These also live partly on fish. They are said to dig burrows in the banks of the rivers where they dwell, and like turtles they lay their eggs in a nest in the dry sand or earth of the river bank, usually covering them up and leaving them to hatch by the heat of the sun.

The crocodile, with its covering of armor scales, its powerful jaws and tail, is still formidable in modern tropical rivers, and to primitive man, armed only with spears and arrows, it must have been almost unassailable. One cannot wonder at the superstitious respect in which it was held in ancient Egypt. The caimans of South America are closely related to the alligators.

In contrast with the slow-moving armored turtles and crocodiles the lizards are mostly quick, active, small in size and unprotected by armor, the skin covered with small horny scales. They are wholly terrestrial, most abundant in arid or desert regions, but they live almost everywhere except in the cold temperate and arctic zones. Their small size, quick movements, dexterity in hiding, and ability to live in rocky and desert places, enable them to compete very well with small mammals, and they are a numerous and varied race. For the most part they live upon insects and are very adept in catching them. A few lizards attain a considerable size. The monitors of Africa, the East Indies and Australia reach a length of six or seven feet; in the tropical parts of the New World the Iguanas attain an equal size.

Among the smaller kinds, the geckos, skinks and true lizards are most familiar. Professor Gadow describes the habits of the Gecko as follows: "In their native haunts they are very regular in their habits. Favorite resorts of theirs are old olive trees or oak trees, the rough and cracked bark of which affords excellent places for hiding in. Hollow trees are of course preferred. Not a single specimen is seen during the early hours of the morning or in the forenoon, but when the sun has become broiling hot and our own shadow passes over the stem of a tree we become aware of flitting little shadows which jerk over its surface. These are Geckos which had been basking, motionless, very dark gray, almost blackish, just like the color of the gray bark upon which the last season's wet moss has been scorched to a black cinder. It is difficult to espy a Gecko while it is glued on to such a tree. Only the little beady eyes betray it, watching you carefully.

Nothing appears more easy than to catch that motionless thing. You put out your hand and it is gone; like a flash it has moved a foot higher up or down, to the right or to the left, just where you least expected it to go, and there it clings motionless as before. It does not seem to run; it glides along, dodging over to the other side of the stem and back again. There is system in its motions, since, taking a last leisurely look around, it gently disappears in a rent or hole. Toward the evening, or when the shadows become longer, the Geckos become lively. One after another appears on the surface, upon the tree or at the entrance of the cave, and they all move about in their peculiar rushing jerks. Spiders, flies, mosquitoes, moths form the principal diet, and the hunting goes on well into the night. Where a gecko has been seen once it is sure to reappear the next day at the same hour. Those which take up their abode inside a house become almost domesticated. They are strange sights when hunting for flies, running up and down the papered walls; but we fairly gasp when they come to the upper corner, calmly bend over and with the next jerk slide along the whitewashed ceiling. We are accustomed to flies performing such feats, but at animals five inches long, supple and fat, we are inclined to draw the line. However, that is the way of Geckos, and—be it confessed—the more we ponder over the mechanism of their fingers and toes, the less we comprehend how such little vacua can support or suspend such heavy creatures from a dry and often porous surface."

Among the fifteen hundred species of true lizards many are of very odd appearance and interesting habits. The "flying dragons" of the East Indies have wing-like membranes shaped very like the wings of a butterfly when extended, supported by long extensions of the ribs, and used as parachutes in long leaps from tree to tree. They are not much larger than a large butterfly, so that the name "dragon" is rather a misfit as to size. Another remarkable type is the Chlamydosaurus, or Frilled Lizard, of Australia, with very long, slender legs and tail and a large frill around the neck, which it erects when brought to bay. It runs ordinarily on its hind legs, the fore legs hanging down, the long tail balancing the body. In shape the frill has an absurd resemblance to the great bony neck frills of the Horned Dinosaurs, and the long legs and biped gait are also singularly like certain Dinosaurs. It is said to

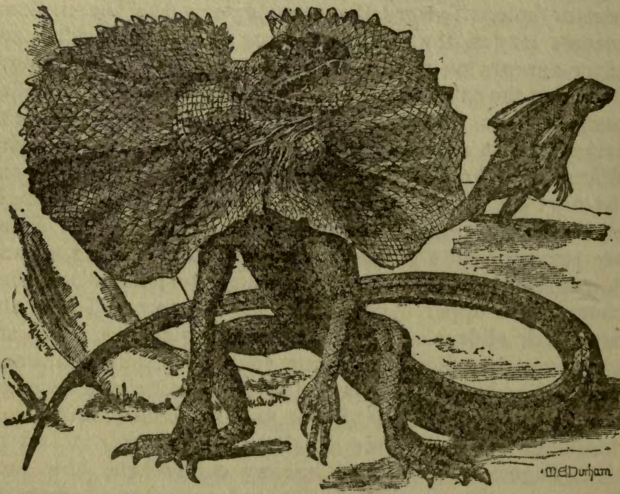


Fig. 27 —The Frilled Lizard of Australia. (Gadow.)

reach a length of two or three feet. The quaint little "Horned Toads" (Phrynosoma) of the Western United States, too, suggest some of the extinct Armored Dinosaurs. The ugly, poisonous Gila Monsters of the same region, brightly colored in orange and black, are a well-known example of warning coloration, the colors enabling the hungry bird or coyote to recognise and avoid them.

The Chameleons are found chiefly in Africa, altho they range into Spain and India as well. They are very odd and interesting little lizards in their habits, and their color changes have been carefully watched and studied. The head is high and narrow, the body compressed sideways, unlike most lizards, and the feet are very peculiar, two toes in each foot being opposed to the other three. The tongue is very peculiarly constructed and the club-shaped sticky tip can be shot out suddenly to a distance of seven or eight inches, annexing the insect which the chameleon is stalking. They are extremely slow and cautious in their movements. The changes in color are only partly protective, chiefly related to the excitement or quiescence of the animal, or to heat and cold, as was long ago stated by Linnæus. Some of the Madagascar chameleons reach a length of two feet, but they are mostly only a few inches long.

No reptiles are so familiar, and yet so much maligned, as snakes. Most people regard a snake with horror, or at least with strong aversion. It is nasty, slimy, venomous; it kills chickens, it "fascinates" and devours little song-birds, and its bite is deadly poison to man. It is a thing to be killed on sight, but from a good distance and with stones or sticks, lest it attack you. Almost every small boy and the great majority of grown folk will kill any snake they see, feeling that it is the natural and proper thing to do.

As a matter of fact, snakes are not at all slimy. Their skin is perfectly dry and scaly; they are quite as clean to handle as any dog or cat. There are a few poisonous snakes, but one may readily learn to recognise and avoid them. Most snakes (except in Australia) are perfectly harmless, and are a great help to the farmer, as they devour quantities of mice and insects. Snakes do not fascinate birds—the fluttering, apparently helpless bird is simply trying its best to entice the snake away from its nest.

No snake, poisonous or non-poisonous, will pursue a human being; their chief anxiety, if they see one, is to

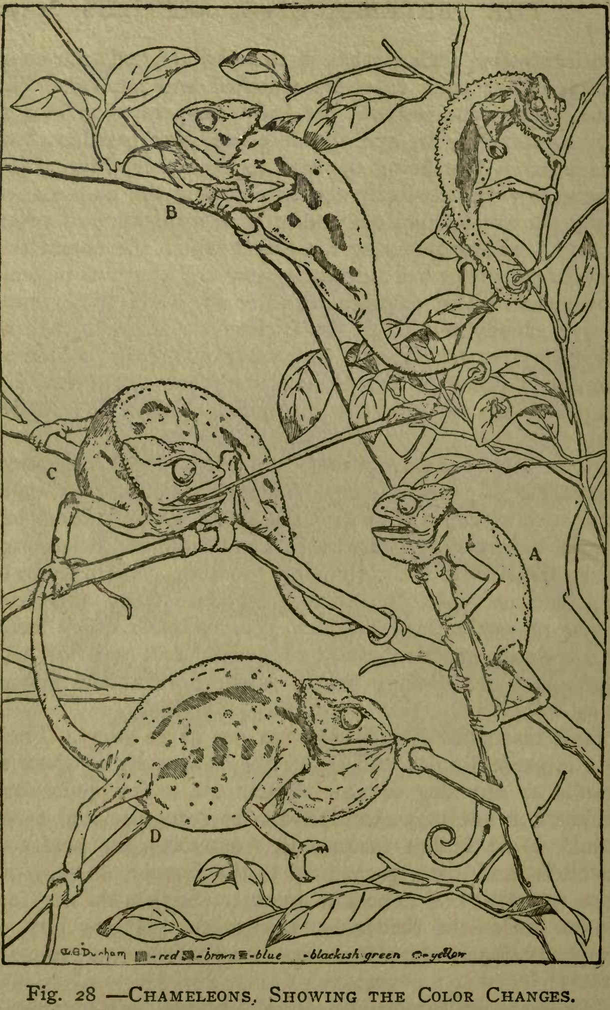


Fig. 28 —CHAMELEONS, SHOWING THE COLOR CHANGES. Note also the slender extensile tongue, with sticky, club-like tip. (Gadow.)

get away as quickly as they can to a place of safety. When cornered or suddenly disturbed without a chance to escape they will hiss and strike with the fore part of the body—a snake's striking distance is from a third to a half its length—but all this demonstration is entirely harmless unless the snake is a poisonous one and strikes some part of the body where its fangs can get through the clothing to the skin. For all the popular fear of snakes, actual recorded cases of death from the bite of a poisonous snake in the United States are extremely rare. In India and in other tropical countries the case is different. The mortality from snake-bite is large, partly because venomous serpents are more common, chiefly because the natives habitually travel barefoot through the jungle. The deaths from snake-bite in India are officially estimated at 22,000 a year—about one in fifteen thousand of the population. It is probably less in other tropical regions.

It is commonly said that poisonous snakes may be distinguished by their broad flat heads from the non-poisonous kinds. This is only partly true. The poisonous snakes of the viper family, including the viper, puff-adder, copperhead, water moccasin, fer-de-lance and rattlesnake, do have wide short heads; so do several kinds of non-poisonous snakes. But in the coral snakes and cobras, the deadliest of all venomous serpents, the head is of the same shape as the common harmless garter-snake or blacksnake.

Snakes are the most highly specialized of the reptilia. Altho undoubtedly descended from four-legged walking reptiles, no traces of the limbs remain except for some vestiges in the boa and python; the body is much elongated and adapted to crawling. The peculiar loosely hung double-jointed jaws and the very elastic throat and neck admit of extraordinary stretching so as to swallow the prey whole, so that the snake literally gets outside of his victim by alternately setting forward the upper and lower jaws with their sharp little recurved teeth. The poisonous snakes have one pair of teeth in the front of the jaw enlarged, and provided with a groove or canal through which the poison is injected into the wound. In the cobras and coral snakes the poison fangs are fixed; in the vipers they lie back against the roof of the mouth in repose, and are erected only when the snake opens its mouth to strike. The great majority of the species live on dry land, hiding at night, and in cold countries hibernating through the

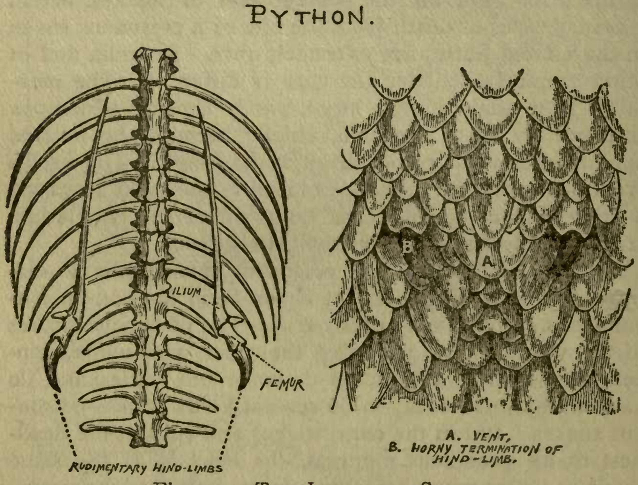


Fig. 29 —The Legs of a Snake.

winter in crevices among rocks, in burrows made by rodents, or any other convenient shelter. Many snakes live partly or wholly in fresh-water streams or ponds; a few are marine. Some species lay eggs; others bring forth their young alive.

The largest snakes are the boas and pythons of tropical countries, which are said to reach a length sometimes of thirty feet, and kill their prey by crushing it between their coils—whence the name constrictor. Nine-tenths of the living species of snakes belong to the harmless colubrine group, of which the pretty striped garter-snakes are the most familiar kind. The blacksnakes, bullsnakes and hog-nosed snakes are well known in North America; many

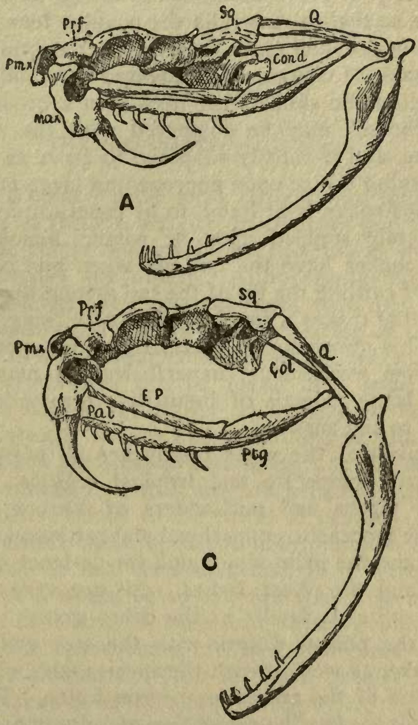


Fig. 30 —Skull of Rattlesnake, Showing the Poison Fang. A., when the mouth is partly closed; C., when it is open.

others, under various names, take their place in other continents. Some of these colubrine snakes constrict their prey, others swallow it without the formality of previously killing it.

Related to the colubrine snakes are the cobras of the Old World and coral-snakes of the New, all tropical or sub-tropical, and the most deadly of poisonous serpents. The majority of Australian snakes belong to this venomous group, so that in Australia the popular fear and hatred of snakes is justified more than in other continents. The peculiar habit of cobras, when angered and ready to strike, of expanding the skin of the neck into a broad, brightly marked "hood," may be compared with the rattle of a rattlesnake, and is usually supposed to serve as a warning signal, serving notice upon approaching large animals that a poisonous snake is at hand, to be carefully avoided and not carelessly stepped upon or eaten. Some perfectly harmless snakes have the custom, when one comes close to them, of rattling the tip of the tail among the dry leaves in a way that makes a fair imitation of a "singing" rattlesnake. This quivering of the tail may be—probably is—simply from excitement; nevertheless, it may serve to scare off large animals of inquisitive disposition, and so be useful to the snake.

The snakes of the viper family are all poisonous, and inhabit both temperate and tropical regions. They include the vipers and puff-adders of Europe, Asia and Africa, the moccasin, copperhead and rattlesnake of North America, and the palm-vipers and fer-de-lance of Tropical America and the West Indies. All are very poisonous, altho not quite so deadly as the cobra group. The virulence of the poison differs with the size and condition of the snake, as well as with the species, and with the size and stamina of the animal or person bitten. The bite of the fer-de-lance has the reputation of being most generally fatal to man.

CHAPTER VIII

THE VERTEBRATES—III. BIRDS

Birds as a class are the most attractive of animals. In intelligence, in restless activity, in compact graceful form, in handsome colors and markings, in musical voices they equal or surpass any others. Altho egg-laying like the lower vertebrates, they give far more care and attention to the incubating of the eggs and the rearing of the young. Family life is well developed among them, whereas among the lower vertebrates can be found only some scarcely recognisable beginnings of it. It is easy to understand and appreciate the actions and sensations of a bird where those of an ant are strange and foreign to the mental attitude of the human. Birds, too, are peculiarly the friends of man in his relations to the world of nature. They are the great natural check upon the multiplication of his insect enemies. It has been said that if it were not for birds the world would be so overrun with insects that all crops would be destroyed, successful farming would be impossible, and in consequence civilized man could no longer maintain his existence. This assertion greatly overrates their importance to civilization, in regarding them as indispensable to its continued existence. For, besides the birds, there are other important natural checks upon the indefinite multiplication of noxious insects, aside from the artificial checks devised by man, or which would be devised if the need for them were sufficiently urgent. Yet the services rendered by birds to the farmer are truly of immense value, far outbalancing the occasional toll taken from his seed-corn or his chicken-yard, even by those birds which are most generally counted as his enemies.

"A bird," says Gadow, "may be known by its feathers" —for all birds have feathers and no other animal possesses them. In other ways they form the most compact and readily distinguishable of the four groups of land vertebrates. They are all surprisingly alike in construction of skeleton and in the anatomy of the soft parts. With all their wide diversity in size and form and habits of life, it is singularly difficult to distinguish the bones of the different groups. The reason for this would seem to be that successful flight, in an animal as large as a bird, involves a high degree of specialization and mechanical perfection of skeleton and muscles, and limits the variations that may occur within rather narrow lines. The wide diversity of form and structure that exists among the mammals is not here found. Yet birds are an equally ancient group and have had ample time to assume diversity of form in relation to their diversity of habits hardly less than that of terrestrial quadrupeds. On the other hand, they show much more variety and brilliancy of color.

The high degree of specialization of birds appears throughout their organization. The fore-limbs are modified to serve as wings, the neck is long, the tail short and rudimentary so far as the skeleton is concerned. The heart is four-chambered and the circulation rapid and strong. The body is kept constantly at a temperature of 100°, instead of being only slightly higher than the temperature of the surrounding medium, as it is in the "cold-blooded" vertebrates. The lungs are large, and respiration is further aided by air-sacs which expand from the bronchial tubes into parts of the body cavity and the hollow bones. The muscles, as in mammals, are more distinct and sharply defined than in the lower vertebrates. The brain is of much higher type than in reptiles, and is comparable to the mammalian brain. All in all, the birds represent a development of the vertebrate stock ranking with the mammals as the highest type of animals, inferior in certain phases of intelligence but superior perhaps in activity and perfection of mechanism.

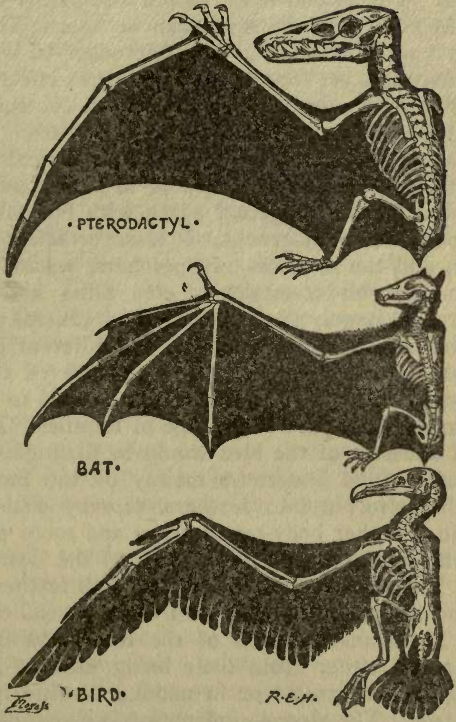


Fig. 31 —SPECIALIZED ADAPTATIONS FOR FLIGHT.

The feathers of a bird serve two essential purposes. In the first place they are bad conductors of heat, and prevent the body-heat from escaping, just as does the hair of mammals. Thus the bird and mammal are enabled to maintain a high bodily temperature, impossible to the scaly or naked-skinned reptiles, amphibians and fish. The high bodily temperature and rapid circulation are essential to the higher development and more active life of bird and mammal. The second essential purpose of the feathers is to aid in flight. While flight can be accomplished, as it is in bats or insects and was in pterodactyls, without the aid of feathers, yet they furnish the most effective mechanism that nature has devised for perfect control of movement in the air with animals as large as birds.

The classification of birds is a most difficult problem. The older arrangements, according to habits and external characters, do not altogether agree with the natural relationships of different groups. It is nevertheless very convenient, and the division into perchers, waders, birds of prey, marine birds, ostriches, etc., altho known to be unnatural, is largely used in default of general agreement as to the natural relationships of the different groups.

It may be assumed that birds are derived from some early type of primitive reptile, nearly related to the Dinosaurs, in the early part of the Age of Reptiles. This hypothetical ancestor of the bird would be distinguished from the small upland Dinosaurs mainly by the fact that its scales had evolved into feathers, thereby enabling it to maintain a higher body-temperature and more active life. Its habits would be much like those of the Ostriches, but the tail long, vertebrated, lizard-like, with feathers on each side, and the jaws provided with teeth instead of a horny beak. The transformation of the fore-limbs into wings might result either from their being used as an aid to running on the ground or in making soaring leaps from tree to tree. The second explanation is generally regarded as most probable.

The oldest known fossil bird, the 'Archæopteryx' of the Jurassic Period (middle part of the Age of Reptiles), appears to be in this transitional stage. It was about the size of a crow and had the toothed jaws and long vertebrated tail of a reptile, feathered like the shaft of an arrow. Its wings were short and small, and in the opinion of some authors at least could hardly have served for true flight, but might enable it to flutter from bough to bough.

The remains of a few birds of the Cretaceous Period have been found. The two best known are the 'Hesperornis' and 'Ichthyornis,' both provided with teeth, but the tail is of the usual Bird type. 'Hesperornis' was a marine diver, allied to the Loons and Grebes and fully as large, but more primitive in various details of the skeleton. 'Ichthyornis' was a flying bird, allied to the gulls. These three genera, 'Archæopteryx,' 'Hesperornis' and 'Ichthyornis,' are the most important fossil birds as regards the evidence they offer toward the problem of the course of evolution of the birds and the relations of the various modern orders. They are a long way, however, from clearing up the problem. Most of the remaining fossil birds are very imperfectly known, and a remarkably large proportion of the more familiar kinds are large, flightless ground birds. This does not mean, as might be thought, that ground birds were formerly more abundant than now, but rather that on account of their size and habits their bones are more likely to be preserved and noticed by collectors than those of the smaller fragile-boned flying birds.

All that can be concluded as to the early evolution of the class is that they were derived from long-legged bipedal reptiles probably inhabiting the upland regions of the great land mass of the northern continents; that they developed feathers from scales primarily for warmth, secondarily for flight; that they subsequently lost their tails, and later on their teeth; but that at a very early period in their evolution they had become differentiated into various habits—perching, running, diving, soaring. Since the center of dispersal of their early evolution was the upland regions of the north, it is reasonable to expect to find the highest and most typical birds in that general habitat. Remnants of primitive bird-races, archaic survivals, we should expect to find in the most remote southern regions, or among marine or diving birds, or especially among the flightless ground birds. To a certain extent these expectations are carried out. But the birds are a race of ancient development and their strong and sustained flight gives them great powers of distribution over distances and across barriers that impede or baffle the migration of terrestrial animals. The bird life, therefore, of southern continents and tropical islands is much less peculiar and archaic than the mammalian life. The very primitive races have long ago been swept out of existence by competition with more progressive invaders. The apparently primitive survivals, such as the ground birds which to-day inhabit Australia, South Africa and South America, and others which have become extinct; such as the Penguins of the Antarctic region, the Loons and Grebes of northern lakes, the Auks and other apparently primitive types—all these must be regarded not as true primitive survivals, but as cases of at least partial reversion, of readaptation to ancestral habits from various stocks of more progressive and typical flying birds, where the conditions of their environment favored the development of types of birds similar in habits to early ancestors of the bird class.

The Ostrich is distinguished from all other ground birds by having only two toes. It is native to the African continent, but has been introduced in other arid regions with success and is the largest of living birds. A full-grown male stands over eight feet high and can outrun a horse. The handsome tail feathers have long been used for ornament, and the value of the annual output in South Africa is estimated at five million dollars, mostly derived from the large ostrich farms where the birds are semi-domesticated. The Rhea of southern South America, the Emus and Cassowaries of Australasia and the Kiwi of

New Zealand are similar in habits to the Ostrich, but of smaller size and with toes of the normal bird type.

Among the extinct flightless birds the Moas, which inhabited New Zealand in quite recent geologic times, were related to the Kiwi, but reached a much larger size than the Ostrich, the largest being estimated at twelve feet in height. The extermination of these birds by the Maori natives dates not more than four centuries ago. Equally recent is the disappearance of the great Æpyornis of Madagascar, upon which, it is said, the Eastern legends of the 'Roc' are founded. The Roc, as it is described in the Arabian Nights, is exaggerated and distorted into a flying bird of impossibly gigantic size; but it may have been founded upon the eggs of these great ground birds, some of which are still in existence and large enough to hold two gallons of liquid.

These great flightless birds are usually grouped into a sub-class, Ratitæ, altho they are very probably degenerate descendants of several stocks of flying birds. There are other large extinct flightless birds in which the relationship to different groups of flying birds is more clearly seen. Such are the 'Dodo' and 'Solitaire' of Mauritius, related to the Pigeon, and exterminated only two centuries ago; the 'Phororhachos' of the Miocene epoch in Patagonia, related to the modern Seriema or Crested Screamer; the 'Gastornis' of the European Eocene, related to the Ducks.

The most primitive—or degenerate—of marine birds are the Penguins of the Antarctic regions, flightless, active swimmers and divers, with the wings modified into paddles. In Penguins the three metatarsal bones of the hind foot are partially separate, more primitive than in any other bird. They are known to have inhabited the Antarctic seas at least as far back as the early Tertiary, and are probably a very ancient group. If future explorations should succeed in discovering fossil remains of the fauna which inhabited the old Antarctic continent during the

Age of Mammals, it is very probable, in the present writer's opinion, that its higher land vertebrates will prove to have been, not mammals, but great ground birds of which the modern Penguins are a solitary marine survival.

The Divers and Grebes are the most primitive of the modern flying birds. Aquatic or marine in their habits, they are mostly heavy and awkward in flight or on land, but excellent swimmers and divers, using the webbed or lobed feet very effectively in swimming. The Divers are Arctic, the Grebes cosmopolitan in distribution.

The Petrels and Albatrosses and their allies are strong-flying ocean-birds, worldwide in distribution, but most abundant in the desolate wastes of the Southern oceans. Beyond all other birds they are at home on the ocean, resting and sleeping on the surface of the waves, resorting to land only for breeding purposes, and nesting on the rocky ledges of wild, inaccessible sea-cliffs.

A much larger group of water birds is represented by the Storks and their allies, mostly wading birds inhabiting fresh water, but some marine, like the tropic-birds, Gannets, Cormorants and Frigate-birds. The Storks, Ibises, Herons and Bitterns, the Flamingoes and Pelicans are the most familiar wading types, various in size and proportions, in habitat and nesting habits, feeding upon fish, frogs and other denizens of the marshes and rivers. Many of the birds of this group are distinguished by their large size, handsome colors and decorative plumes.

The Ducks and Geese are a still more familiar group of birds, aquatic in their habits, and mostly fresh-water dwellers, but swimming and diving rather than wading, more omnivorous in their feeding habits than the wading birds. They are cosmopolitan, but most abundant in the northern continents. The domesticated species are of large economic importance, and the wild species form a considerable proportion of the common game birds.

The Eagles, Hawks and Vultures are widely different in appearance and habits from the preceding groups. They constitute the "Birds of Prey," excluding the Owls, and are all carnivorous, mostly predaceous, living on land, and preying upon smaller birds and mammals, or upon carrion, sometimes upon fish, occasionally upon insects. In accordance with their habits they are swift and powerful in their flight, the bill is adapted to seize and tear their prey, the claws are sharp, strong and curved. The Condor of the Andes is one of the largest of flying birds. While to some extent Eagles and Hawks merit the hostility of man by their slaughter of smaller birds, their depredations upon the poultry-yard and their occasional attacks upon larger domestic animals, yet most of the hawks, at least, prey largely or chiefly upon rodents and, with the owls, are an important natural check upon their increase. As a class they undoubtedly do far more good than harm to the farmer, and their persecution is often followed by a terrifying increase in the numbers of noxious rodents.

The Domestic Fowl and their allies are the most familiar of birds and the most important economically. To this order belong, besides the domestic fowl, peacock, turkeys and guinea-fowl, the pheasants, partridges, grouse and quail, the curassows and hoatzin of South America and many less known birds. In the pheasant group are included the greater number of game-birds. The birds of this order are generally polygamous and the majority handsomely colored, especially the males.

The Rails, Cranes and Bustards are a second wading group, similar in habits to the storks and their allies, but not closely related. Another order of very varied habits is formed by the plovers, sandpipers and curlews, the gulls and auks and the pigeons, very diverse in outward form, but connected by common characters in the skeleton.

The Cuckoos and the Parrot family, comprising the Parrots, Parrakeets, Macaws and Cockatoos, are distinguished by having two of the toes reversed, instead of one as in most other birds, an especial adaptation for climbing and grasping branches.

A much larger order includes the Night-jars, swifts and humming-birds, the Owls, Kingfishers and woodpeckers, the trogons, toucans, hornbills and various other more or less familiar birds. They are all land-birds, of arboreal habits, with short legs, the majority nesting in holes in trees or similar places, and the young hatch out blind and peculiarly helpless. Their feeding habits are various, the owls being predaceous, pursuing small mammals and birds and mostly nocturnal; the kingfishers feed upon fish, the woodpeckers especially upon boring beetles, the swifts and night-jars upon insects, the humming-birds upon the nectar of flowers, while the large toucans and hornbills are mainly fruit-eaters. The owls by their destruction of noxious rodents render aid to the farmer that far more than counterbalances the toll they levy on his chickens.

By far the largest order of birds is the Passeriformes, including the song-birds and their allies. It contains some 5,500 species, more than half the whole class. To this great order belong all the true singing birds, besides many which do not sing. They are mostly of small size, of high intelligence, as shown in their habits, their nest-building and in the care of their young. They are all land birds, terrestrial or arboreal in their nest-building, the feet adapted for perching, with one reversed digit and three in normal position; their powers of flight moderate or highly developed. A large proportion of them are seasonal migrants, traveling thousands of miles in their annual flights. They inhabit every region of the world, continents and islands; they range from seacoast swamps to above the snow-line in the mountains—forest, plain and desert, all have their special types of song-birds, adapted in habits and plumage to the requirements of their surroundings. Their numbers and variety are immense, and even in large ornithological books their mere enumeration is lengthy and cumbersome.

CHAPTER IX

THE VERTEBRATES—IV. MAMMALS

THE mammals form the highest and most important group of the vertebrata. Broadly speaking, they correspond to the popular term of 'quadruped,' but also include man himself, and the whales, seals, and manatees. As reptiles have scales, and birds feathers, mammals have hair as their most obvious character. But the skin is often partly, rarely wholly, naked; and in a few mammals scales or bony plates are also present, covering the surface more or less completely. The young are born alive and suckled by the mother; this is the primary distinguishing character. They are warm-blooded, air-breathing, the heart with four chambers, and lungs and heart are separated from the abdominal organs by a muscular diaphragm.

The sense organs are more highly developed than in other vertebrates, the brain larger and more complex, the skull more consolidated. Teeth are nearly always present, and usually elaborated into various and often complex structures adapted to the various food requirements of the animal. The limbs and feet show an equally wide diversity in adaptation to various habits and modes of life.

The Tertiary Period is often called the Age of Mammals. During that time the mammals assumed the dominant position among animals, previously held by reptiles, and evolved, mostly from small ancestors of uniform type, into the diverse and often gigantic species of the present day. Ancestral mammals had first evolved from primitive reptiles long before, probably before the close of the Age of Amphibians, and these small primitive ancestors had been living side by side with the gigantic Dinosaurs during all the Age of Reptiles. They were rare and of minute size, probably tree-living animals, and it is not unlikely that their arboreal life, with its continual demands on intelligent action and readiness to grasp opportunities, stimulated the much higher grade of intelligence to which the mammals had attained when they first appear in numbers at the opening of the Tertiary Period.

These primitive ancestral mammals were small, long-tailed animals which might be compared to the modern tree-shrews. They had flexible limbs and feet, slender body, moderately long neck, slender skull, and long jaws with teeth adapted to insect-eating. The number of teeth was forty-four in all. The toes were five on each foot, the digits flexible, clawed, the inner digit to some extent opposable, and with one less joint than the others.

Fossil mammals have been found in great numbers and variety in the formations of successive epochs of the Tertiary Period, and it is possible to trace the successive stages through which they evolved from these small primitive types into the various kinds of modern quadrupeds. Conversely, when the ancestral series of any modern quadruped is traced back it is found leading down in every case toward this identical small primitive type; and when one examines and compares the structure and anatomy of any modern animal it is seen that it is most easily explained as a modification from this common primitive type in adaptation to one or another habit of life.

Some races have become herbivorous, others carnivorous, others fruit-eating, and the teeth have been modified in accordance. Some have remained arboreal, others have become terrestrial, aquatic, or fossorial; some have remained small, others have become large, or even gigantic in size; and the limbs and feet have been modified to suit their various habits and size.

In herbivorous mammals the cheek teeth are used for crushing and grinding vegetable food, the front teeth for cropping. The true molars are enlarged, and complicated into a more or less elaborate pattern of crests or crescentic ridges which serve to chop or grind the food. The premolars either degenerate or become like the molars. The canines are sometimes enlarged into tusks for fighting, sometimes degenerate and disappear. The incisors are converted into spadelike teeth for nipping off food, into large gnawing teeth, or degenerate and disappear. In carnivorous animals, on the other hand, the pointed canines, used for seizing and holding the prey, are large, sharp and strong; the premolars, used for cutting the food, are well developed; while the molars, used for grinding, tend to degenerate or disappear, or to become more like the premolars, and to be used chiefly for cutting up the food. In frugivorous animals the cheek teeth are used for crushing fruit or nuts, and become flat-topped; the premolars often degenerate; the front teeth, used for biting off the food, are converted into a row of little spade-shaped teeth. Animals of more mixed diet show various combinations of these characters in the dentition.

The animals which have remained arboreal have retained and perfected the adaptation of limbs and feet to this purpose, but have departed less than any others from the primitive type. Among terrestrial mammals are found a variety of adaptations. Some have developed speed, to escape from their enemies or pursue their prey. For this purpose they have taken to walking or running upon the fingers, or even upon the tips of the claws, instead of, as at first, upon the flat of the foot. In consequence, the lower limbs and feet are lengthened, the joints of the feet made stronger and more compact, the side toes tend to degenerate and the middle toes bear the weight of the body, and the claws are converted into broad, strong hoofs which finally support the whole weight. Other terrestrial races have depended upon their fighting capacity rather than upon speed; they have increased rapidly in size, developed horns, tusks, armor plates or spines, for attack or defense, and the limbs have become adapted to bearing enormous weights, with heavy bones, massive muscles, short, heavily padded feet. Fossorial mammals have developed short and exceedingly powerful limbs and great digging claws upon the feet. In aquatic mammals the feet become webbed, and are finally converted into paddles; or in such as developed a powerful swimming tail the hind limbs have degenerated and disappeared. Finally one group of aerial mammals appears, the bats, in which the fore limbs are converted into wings, by lengthening the fingers and developing a web between them and the sides of body and tail. Various arboreal mammals also have weblike expansions of the skin, which they stretch as parachutes in leaping from bough to bough.

The quadrupeds are less dependent upon temperature and climate than most of the lower animals, while they are more strictly limited in their migrations by the boundaries of the continents and islands which they inhabit. Moreover, they are not so ancient as the invertebrates and lower vertebrates; their evolution and dispersal over the world has mostly occurred during the Tertiary Period, when the distribution of land and water was not so very different from what it is at present. We find that the present general arrangement of the land areas, with a great central northern land mass and isolated peninsular continents stretching down into the southern hemisphere, is the key to the geographical distribution of mammals. They have spread out in successive waves of migration from one part or another of the Holarctic region, and each new wave of higher stages of evolution in the different races has driven its more primitive predecessors before it toward the remotest confines of the southern continents and islands. This general tendency has been limited by the land connections with the southern continents and islands.

The connection with South America was interrupted during a part of the Tertiary, and during that interruption the South American animals evolved independently into races which were quite different from those of the northern world. When connection was resumed, the northern animals invaded South America, while some of the southern races invaded North America; but the superior quality of the animals evolved on the great northern land mass enabled them to overcome and displace those of South American origin, which have nearly all become extinct. In Africa and in peninsular India the connection was also interrupted for a time and then restored, with the same results; but the interruption did not last so long. Australia and the adjoining islands have been separated since before the Tertiary Period, and the higher mammals have never been able to reach those regions. In consequence, the more primitive mammals which reached there at an earlier period have evolved and specialized into a large and varied mammal fauna paralleling the higher mammals of the northern world.

Some of the East Indian islands, now separated from the mainland only by shallow seas, have been united with it during the Tertiary Period, so that the great land animals could invade and occupy them. Other oceanic islands, like Celebes, Madagascar, the West Indies, New Zealand, and many smaller islands, are separated by deep oceans from the mainland. In these it is noted that land mammals are generally absent, or are peculiar types different from those of other regions, and probably developed on the islands themselves from such small mammals as might once in a long while reach their shores on floating rafts drifted out from the mouths of rivers on the mainland. Small mammals, such as rodents, insectivores, or small lemurs, might once in a while gain a footing on the isolated island in this way, and once established, in the absence of competition would evolve into a variety of larger races, as the Marsupials did in Australia. In this way can be explained why Madagascar possesses none of the elephants, rhinoceroses, zebras, antelopes, dogs, cats, etc., of the adjoining coast of Africa, but does have a great number of lemurs not found elsewhere, a number of insectivores of a family (Centetidæ) peculiar to the island, two or three carnivores, related to the civets but of very exceptional character. The bush-pigs may have been brought there by man; the pigmy hippopotami found fossil on the island may have reached it by swimming. But the absence of practically all the mainland animals, together with the presence of peculiar types which seem adapted to take their place, can scarcely be explained except by supposing that the island has been separated from the African mainland for a very long period. The problems of geographical distribution are a most fascinating branch of zoölogy and have attracted a large share of the attention of scientific men, especially in recent years.

In the arrangement of this class of vertebrates first must be set aside the Egg-laying mammals of Australia as an exceedingly archaic type, to a great extent a connecting link between mammals and the primitive reptiles from which they are descended. As might be expected, these most ancient of mammals are found on the very outskirts of the mammalian domain, Southern Australia and Tasmania, most remote from the main center of Mammalian evolution in the north. These form the subclass Prototheria.

The rest of the mammals may be divided again into a small and a large group, the Marsupials, or Pouched Mammals (Metatheria), in which the young are born alive, but very immature, and are carried for some time in a pouch on the under side of the mother's body until they are able to shift for themselves; and the Placental

Mammals, 'Eutheria,' including all the rest. In the placentals the young are more mature when born, and are never carried about in a pouch. Either they are able to follow the mother about, or she remains with them, in some suitably protected spot, until they are well grown.

There are, of course, numerous distinctions in the skeleton and soft anatomy to support this division of the mammals into Prototherians, Metatherians and Eutherians; but from a modern point of view it is well to lay weight on these differences in the care of the young. For, as has been seen among invertebrates, the progressively greater care of the young, the prolongation of infancy, appears to be, more than anything else, the key to the possibilities of higher development. Among insects it is patent that the higher life of the social wasps and bees centers mainly about the care of the young. It is no less true among vertebrates. The most prominent feature in the life of birds and mammals is the care that they take of their young; and in the higher orders of mammals the period of infancy becomes progressively longer until it reaches its maximum in man.

The Mammalia are further divisible into twenty-three orders as generally accepted in recent years. Their arrangement is as follows:

I. Sub-Class Prototheria. Egg-laying Mammals.
  1. Order Monotremata, Ornithorhynchus and Echidna.

II. Sub-Class Metatheria. Pouched Mammals.
  2. Order Marsupialia. Opossums, Kangaroos, etc.

III. Sub-Class Eutheria. Placental Mammals.
  3. Order Insectivora. Hedgehogs, Moles, etc.
  4. Order Edentata. Sloths, Armadillos, etc.
  5. Order Cetacea. Whales, Dolphins, etc.
  6. Order Sirenia. Manatee and Dugong.
  7. Order Perissodactyla. Horses, Rhinoceroses, Tapirs.
  8. Order Artiodactyla. Pigs and Ruminants.

9. Order Proboscidea. Elephants.
10-16. Orders Condylarthra, Amblypoda, Toxodontia, Litoptema, Arsinoitheria, Embrithopoda, Astrapotheria. Extinct Hoofed Mammals.
17. Order Hyracoidea. Conies.
18. Order Rodentia. Rats, Mice, Rabbits, etc.
19-20. Orders Tillodonta and Tæniodonta. Extinct Clawed Mammals.
21. Order Carnivora. Dogs, Cats, Weasels, Civets, etc.
22. Order Chiroptera. Bats.
23. Order Primates. Lemurs, Monkeys, Apes, Man.

The Egg-laying Mammals, therefore, must be treated first. These two little animals, the 'Ornithorhynchus,' or Duck-bill, and the 'Echidna,' or Spiny Anteater, inhabit Southern Australia and Tasmania. They are the most archaic of all mammals, and from their geographic location may be regarded as the vanguard of the great mammalian dispersion which has spread out in successive waves from the northern continental land mass. They are classed with mammals because of their hair-covered skin, solid skull, jaws all of one piece, and various features of their anatomy, but they retain numerous characters in the skeleton approaching those of the primitive reptiles of the Coal Period from which the mammals are believed to be descended. Like the Marsupials, these animals are provided with a pouch, to which the eggs are transferred after they are laid. The eggs are hatched in the pouch, and the young animal remains there for some time, nourished by a secretion from the skin of the mother.

The Ornithorhynchus lives in burrows along the margin of ponds and streams, feeding upon fresh-water clams, crustaceans, etc. "During the Australian winter," says Doctor Semon, "from June till the end of August, when the nights are cold, you may be sure to find the animals in the river at sunrise and sunset. If you are near the river early enough to watch the rising of the sun, you will see something flat, one or two feet in length, floating on the water, like a plank, as soon as the first sunbeams strike the river surface and allow you to discern single objects. Sometimes it lies motionless for a while, then it disappears, to reappear again after a few moments in quite a different place. This is an Ornithorhynchus seeking its breakfast in the mire of the river."

The Echidna, or Spiny Anteater, is a shy, nocturnal, burrowing animal, living in the dense, impenetrable scrub and wild, rocky parts of the country. "On its nightly expeditions," says Semon again, "the anteater seeks worms and insects of all kinds, which it extracts from their hiding places in earth holes, between stones, and in rotting bark, by means of its long, wormlike tongue. Its principal food, however, consists of ants, which it captures like other anteaters, by thrusting its tongue into the anthill, waiting till it is covered with ants, and then drawing it in quickly.

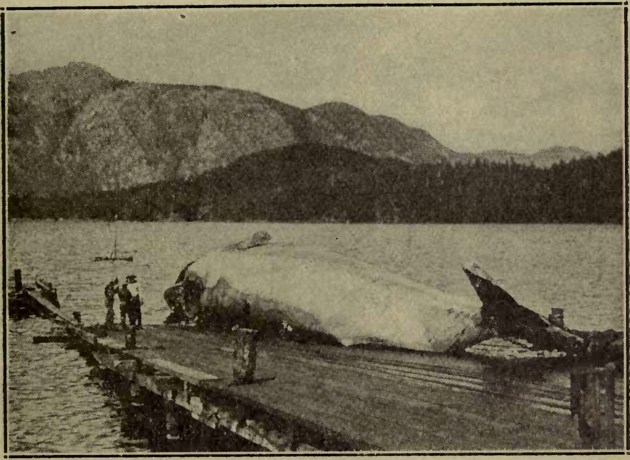
It is interesting to note that the Pouched Mammals have a lower and less constant body temperature than any of the higher mammals. In this respect also they approach the reptiles and other "cold-blooded" vertebrates.

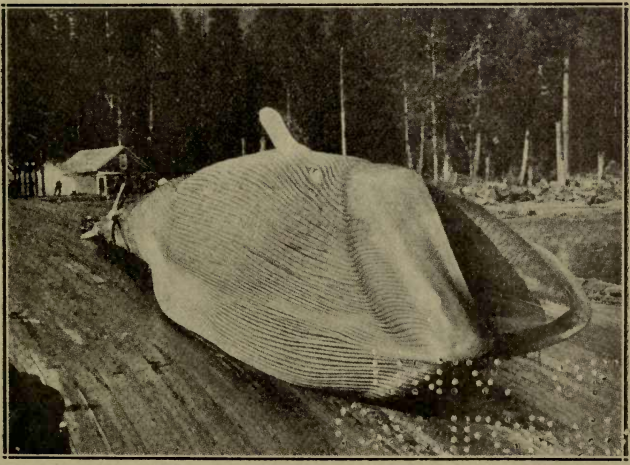
The Marsupials are more or less intermediate between the Monotremes and the placental mammals, but decidedly nearer in all respects to the latter. They lack a placenta, that particular internal organ which enables the young to be brought to a maturer, more perfected state before birth. In consequence they are born in a very rudimentary condition, and are usually transferred to a pouch on the under side of the mother to complete their development. Teats are present, as in the higher mammals, and the little animal is suckled within the pouch.

Marsupials are to-day chiefly found in Australia and the adjacent islands. The opossums of South and Central America, of which one species ranges northward into the

United States, and a rare little animal (Cænolestes) recently discovered in the Andean highlands, are the only living representatives of the order outside of Australasia (except that a few of the Australian marsupials also range northward into the East Indies). Formerly the Marsupials were worldwide in their distribution. It is probable that most, if not all, of the tiny, shrew-like mammals which have been referred to as contemporaries of the gigantic Dinosaurs during the Age of Reptiles were Marsupials, or at least equivalent to them in their stage of evolution. But with the advent of the higher placental mammals at the beginning of the Tertiary Period, the Marsupials gradually disappeared from the northern world. A few survivors have been found among the early Tertiary mammals of Europe and North America, and they were abundant in South America until the latter part of the Tertiary Period, when a great invasion of the northern mammals swept them out of existence save for the opossums and 'Cænolestes.'

In Australia, however, they were undisturbed by northern competitors, as this continent remained isolated throughout the Tertiary Period. "They were allowed," says Semon, "to thrive unhindered, to regard the bush forests, the river banks, the rocks and mountains, the grassy pastures, as their undisputed domain, adapting themselves more and more to the characters of their surroundings. Some feed on the grass of the bush, like kangaroos and wallabies; others dig for roots and bulbs, like the kangaroo-rats; still others seek their food on eucalyptus trees, like Phascolarctus, the Australian opossum, and the flying Marsupials. Bandicoots (Peramelidæ) and the shrewlike bush rats and bush mice (Phascologale, Antechinomys) are mostly insectivorous; the native cat, the Tasmanian devil, and the pouched wolf carnivorous, with teeth strongly reminding us of those of Placentalia. As different as their food are the dwellings, the habits, and the modes of locomotion in all these animals. Like





An Eighty-foot Sulphur-bottom Whale. (A. M. N. H.)

jumping mice, the kangaroos hop over the level country, some of them—for instance, the rock-wallabies—being able to execute their leaps also in mountainous country with the cleverness of a chamois, while the tree-kangaroo (Dendrolagus) performs real climbing antics in the crowns of the highest trees. We see the Australian opossum and the Cuscus climb with the agility of squirrels; Petaurus flits from tree to tree, and is therefore erroneously called by the Australians 'flying squirrel'; Phascolarctos, however, climbs along as lazily as any sloth. Slinking is the gait of the native cat, and trotting that of the pouched wolf.

"In the grass, in rocky caves, on the ground, or on trees, we find the hiding places and lairs of the marsupials. Like rabbits, the wombats dig long and deep burrows in the ground, and quite subterranean are the life and habits of the blind Notoryctes typhlops, which latter has but recently been discovered in the deepest interior of Australia, and the mien and habits of which strongly remind us of our mole; and still all these animals have nothing to do with moles, squirrels, flying-squirrels, rats, jumping-mice, shrew-mice, cats and wolves. All of them are marsupials, and related much more closely to each other than to any of the placental mammals which they resemble as to looks, movements or habits, and from which they derive their popular names. Further, we must not imagine that the placental beasts of prey have sprung from similar marsupial beasts of prey—the genuine jumping-mice from kangaroos, moles from Notoryctes, and so on. It is more probable that the transition from marsupials to placentals took place only once, and from a less specialized group of marsupials than now exists. The original group of placentals that arose thence has differentiated into distinct series, like insectivora, rodents, hoofed animals, beasts of prey, lemurs, apes and men. The outer resemblance between certain groups of marsupials and placentals is a phenomenon of convergence, and is produced by adaptation to similar conditions of life. It ought to be judged like the resemblance between wood lice and centipedes, fishes and whales, birds and bats. Outer resemblance is not always a proof of blood relationship. Echidna, porcupine and hedgehog are no wise related, much as they resemble each other, since the former is related to Ornithorhynchus, the second to the chinchilla, and the last to the mole."

The Marsupials are divided into two main groups. In the Polyprotodonts, mostly carnivorous or insectivorous, the canine teeth are sharp and strong, the incisor teeth small and set in a transverse row, and the cheek teeth adapted to cutting flesh or insect food. In the Diprotodonts, mostly herbivorous or frugivorous, the canine teeth are minute or absent, and one or two pair of the incisor teeth are enlarged somewhat as in rodents, while the cheek teeth are fitted for crushing or chopping vegetation, fruit or nuts. In the first group the feet have usually five separate well-developed toes; in the second the toes are usually reduced in number, the fourth digit enlarged, the others enclosed in a common integument.

Of the Carnivorous Marsupials, or Polyprotodonts, the American opossums and the Thylacine, or Tasmanian "Wolf," the Tasmanian Devil (Sarcophilus) and Dasyure, or "Native Cat" of Australia, are the best known living types. In the Australian regions these take the place of true placental Carnivora of other continents, which are unknown there, except for the Dingo, or Wild Dog, probably introduced by man. But even in the short time that the dingo has been present on the main continent of Australia, his superiority as a hunter over his marsupial competitors is shown by the fact that the Thylacine and "Devil," abundant in Australia in prehistoric times, have disappeared from the mainland and survive only in Tasmania, where dingos have not been introduced. In South America during the Tertiary Period, while it was an island continent, there were, likewise, no true Carnivora, and there, too, the carnivorous marsupials developed into large wolf-like, lion-like and smaller cat-like or civetlike forms, to prey upon the various herbivora. When, toward the end of the Tertiary, the continent was united with North America, true carnivores invaded it from the north, and soon caused the extinction of all the carnivorous marsupials, except the opossums, whose arboreal habits and more omnivorous or insectivorous diet enabled them to survive to the present day. The fossil remains of these extinct South American marsupial carnivores discovered in recent years show so much resemblance to the Thylacines that they have been referred to the same family, and supposed to have migrated from Australia to South America by means of land connections with the Antarctic continent. In the present writer's opinion the resemblance is better explained as due to similar adaptation from primitive opossumlike marsupials, originally derived, with the rest of the South American and Australian mammals, from those primitive mammals which lived during the Age of Reptiles in the Northern continents.

These primitive marsupials, ancestors of the various living marsupials, and from which, at a somewhat earlier period, the remote ancestors of the higher, or placental, mammals had branched off, are pretty closely represented in the living opossums. So that one may, without very great straining of facts, place the 'possum in the gallery of ancestral portraits, and picture from him the sort of animal from which Man, in common with all the quadrupeds, is remotely descended. Little ratlike or shrewlike animals, with long, prehensile tail, with opposable thumb and great toe, insectivorous, living in trees, and venturing out from their hiding places mainly by night, alert and intelligent above their fellows of the Reptilian Era, but not by the higher standards of modern quadrupeds—such, as far as can be judged, were the remote ancestors of the mammals; and such are the opossums to-day.

The Thylacine is a much larger animal, with teeth specialized for flesh-eating and feet for running. Its superficial resemblance to a wolf is well shown in the illustration; the striped rump suggests the tiger, also, while the long, stiff tail is an opossum character. It is now limited to the mountains of Tasmania, as is also the related "Tasmanian Devil," but both are found fossil in Australia. The Dasyures are smaller, civetlike animals of Australia and Tasmania which take the place of the smaller predaceous carnivora of other parts of the world. The Bandicoots are small omnivorous or insectivorous marsupials, with teeth like those of the carnivorous group, but feet more like those of the herbivorous group. In the Wombats the reverse is the case, the teeth being of the "diprotodont" type, while the feet have five well-developed toes with strong claws. These animals, in their heavy, clumsy build, short, stubby tail and shuffling walk, very much resemble small bears, and are commonly known as "native bears." The Phalangers are small squirrellike marsupials, arboreal in their habits, and found throughout Australasia, ranging as far north and west as Amboyna and Celebes among the East Indian islands.

The largest living Marsupials are the Kangaroos, which in Australia take the place of the hoofed quadrupeds of other continents. "These animals," says Semon, "will always hold their own as the most characteristic feature of Australia. Every one who has observed them in zoölogical gardens and menageries will have remarked that there exist larger and smaller kinds of this animal, but we are apt to lose sight of the many and considerable differences between the various species and genera in the simple fact that the general quaintness of their aspect, the peculiar structure of their extremities and tail, and the queer manner of their locomotion, lead us to overlook everything else. Nevertheless, these animals, apparently so uniform in structure, show an astonishing variety in their more minute features, their habits and their distribution. If we reckon only the genuine Macropodidæ without the kangaroo-rats, we have to admit seven genera, comprizing forty-three species; and of these, twenty-three belong to the genus Macropus, the real kangaroo. The Australian colonists call all the larger kinds 'kangaroos' . . . the smaller kinds they call 'wallabies.'" The kangaroos "for the most part prefer the open bush, the level or undulating ground of which gives them occasion to exercise their splendid leaping powers, besides of-

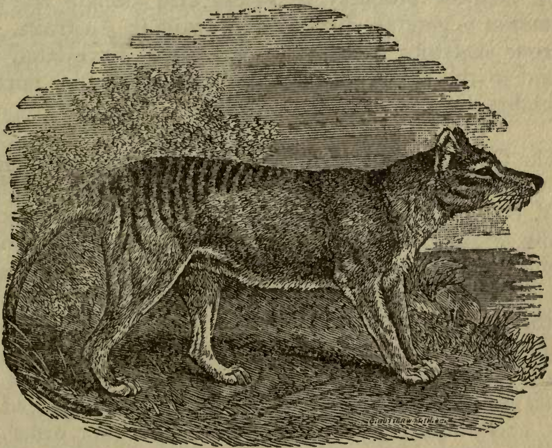


Fig. 32 —The Tasmanian Wolf or Thylacine. (Flower and Lydekker.)

fering them a rich pasture. The leaps of the bigger kinds have generally a length of several yards. When chased they heighten the extent of a single leap to ten yards or more. The jerk is produced by the hind legs without assistance from the tail, as some think. This is easily proved by observing the track the animals' leaps imprint upon the ground. The tail is flourished at every leap, but hardly touches the earth. It seems to help the leaping animals to steer, and to support its weight when resting."

While the Kangaroos are the largest of living Marsupials, the extinct Diprotodon and Nototherium, which inhabited Australia during the Pleistocene Epoch, were gigantic animals, equaling the Indian Rhinoceros in bulk, and curiously resembling the modern elephant in the long, straight, massive postlike limbs and short, rounded, stubby feet. They were related to the Wombats, and may, in fact, be regarded as a sort of gigantic development of this race, adapted probably to a less arid climate and more abundant vegetation than now prevails in Australia. Numerous skeletons of these extinct giants have lately been found in the dried-up lakes of West Australia, north of Adelaide.

The Cetaceans are mammals which have become adapted to marine life and assumed a fishlike form, lost their hair, converted the fore limbs into paddles, lost the hind limbs entirely, and converted the tail into a swimming organ. They are only superficially like fish. The skeleton and internal organs, the quality of the muscles, the teeth, are all those of land mammals, and widely different from fish. They are warm-blooded, bring forth their young alive, and nurse them after the manner of land quadrupeds. The brain is far superior to that of any fish, and the intelligence is of a much higher order than that of fishes. The intelligence of the dolphin seems to have been noticed by men in prehistoric times, for it appears in Greek mythology as the friend and active helper of man.

The Cetaceans include the largest of known animals, living or extinct, the whalebone whales and sperm whales, and the numerous smaller active species of which the dolphins and porpoises are most familiar. The order is divided into two groups.

The Whalebone Whales (Mysticetæ) are toothless, and provided with fringed plates of whalebone which act as a sieve to catch and retain in the mouth the minute crustaceans, etc., upon which the animal feeds. There are several kinds of these whales, all of gigantic size. In the "Right" Whales, 'Balæna,' the head is more arched and the whalebone plates and fringes longer. In the Rorquals, 'Balænoptera,' the whalebone plates are smaller, and the animal is longer-bodied, the head less gigantic, there is a dorsal fin, or hump, not present on the right whales (whence the names of "finner" and "hump-back" applied to different species), and the throat has a series of longitudinal furrows. The species of Balæna reach a length of 40 to 70 feet, with an enormous bulk. The rorquals, tho somewhat less massive, attain even greater size. A large "sulphur bottom" whale will reach 75 to 85 feet in length and weigh about 75 tons. A skeleton in the Museum of Christchurch, New Zealand, is reported as measuring 87 feet in total length, the skull alone being 21 feet long. The danger and romance of whaling are departed, and it has become a merciless butchery, which bids fair soon to extinguish utterly the largest and most magnificent of living animals. The whalebone, which is now the only practical object of the pursuit, seems a pitifully inadequate compensation for their extinction.

The Toothed Cetaceans (Odontocetes) have no baleen plates, but the jaws are set with sharp-pointed recurved teeth, adapted to seize and hold the fish and other swift-swimming marine animals on which they prey. The sperm whale, or Cachalot, attains a size almost rivaling the Whalebone Whales; 55 to 60 feet is a conservative estimate of the length, and of this nearly a third is the gigantic, blunt-snouted head. In the cavities of the skull are stored vast quantities of fluid fat, the spermaceti of commerce. From the sperm whale is also obtained the rare and valuable substance ambergris, used in the preparation of perfumes.

Unlike the whalebone whales, which are confined to the cold temperate and Arctic seas, the sperm whale chiefly inhabits the tropical oceans. Its food is chiefly cuttlefish, and it is said to especially seek the gigantic octopus, which lives far beneath the surface of the deep seas, and has so rarely been seen by man that it was, till recently, regarded as a fabulous monster. Bullen, in the 'Cruise of the Cachalot,' has given a fascinating account of a combat between these giants of the deep. The spermaceti, oil and ambergris of the cachalot are the objects of a considerable fishery, which, however, does not at present threaten the extinction of the animal. The first two products are found in the other toothed cetaceans, but in smaller quantities.

The dolphins and porpoises, and their allies, are common in all parts of the world, mostly marine, but some of them inhabiting the great tropical rivers. The largest of the dolphin group is the grampus, or killer, a fierce predaceous species which reaches a length of thirty feet. The Killer preys upon seals and porpoises, and several will combine to attack one of the larger whales. Another remarkable form is the Narwhal, in which the teeth are reduced to a single long, twisted tusk, projecting forward from the head to a length of six or seven feet. The purpose of this twisted tusk is not certainly known.

Among the numerous fossil cetaceans, the most interesting are the Zeuglodonts, a primitive group which serve to connect the cetacea with the land quadrupeds of the early Tertiary, especially with primitive carnivora or carnivorous insectivores. Altho marine, and fishlike in form, the teeth and skull characters approach more nearly to those of early carnivorous land mammals, from which they were, no doubt, derived. They have been found in the Eocene formations of Alabama, and, more recently, in Egypt.

Among the living relics of prehistoric animals preserved to this day in the isolated southern continents, the so-called Edentates are not the least interesting. The tree-sloths are sluggish, stupid creatures, covered with long, greenish-brown hair, which inhabit the Brazilian forests, hanging upside down from the trees by their long, curved claws, feeding upon leaves, and moving slowly and cautiously from bough to bough, and protected by their likeness in color and appearance to the mossy-green, lichen-covered branches around them. The armadillos are covered by bony plates embedded in the skin, forming a rigid buckler at each end of the body, with bands of movable plates between, so that the animal can roll up into an armor-covered ball. They are fossorial animals, active diggers, and are found in all parts of South America, and as far north as southern Texas. The anteaters, also South American, are covered with long, shaggy hair, toothless, with long snouts and slender, protrusible tongue, and powerful claws to tear down the nests of the ants on which they are especially adapted to feed. These creatures are all of moderate size, the largest being the Great Anteater, seven feet in length, including the long, bushy tail. The term Edentates, or 'toothless animals,' applies strictly to the ant-eaters only; the others have teeth, altho they lack enamel. The living edentates are the remnants of a race which flourished greatly in South America during the Age of Mammals, while that region was an island continent, protected by ocean barriers from the incursions of the more highly developed mammals of the northern world. Some of the extinct edentates, the great Ground Sloths and Glyptodonts, attained gigantic size. The Megatherium almost rivaled an elephant in bulk, and was extraordinarily massive in skeleton; its allies, the Mylodons, were somewhat smaller. These huge animals were nearest to the tree sloths in structure, but were much too large to have lived in trees. They are supposed to have used their gigantic claws in digging up and uprooting trees upon whose foliage they fed. The Glyptodonts, or Tortoise-Armadillos, were covered with armor, a massive solid carapace, without the movable bands of the armadillo, and the feet hoofed instead of clawed. They had very efficient grinding teeth, and were presumably grazing animals. Some of them equaled a rhinoceros in bulk. Certain of these gigantic animals appear to have survived in Patagonia almost to historic time and to have been actually domesticated by the Indians of that region. The native legends tell of gigantic animals which correspond—not very accurately—with the Mylodon as it must have appeared in life; and in a cave at Last Hope Inlet, in Patagonia, there were recently found parts of the skin, well preserved and almost fresh, together with droppings of the Mylodon, and chopped grass, on which it is supposed to have been fed; the indications being that the animals were kept confined in a part of the cave.

The Order Insectivora includes the Hedgehogs, Moles, Shrews and many less familiar animals. The living Insectivores are the scattered remnants of an ancient race of mammals from whose earlier members were evolved the higher and more intelligent races which have mostly displaced them in the struggle for existence. The survivors are protected by spiny armor or nauseous taste or by burrowing habits, or else inhabit remote fringes of the continents or large islands, where they have escaped from the competition of higher types. All the insectivora are small or minute animals, with teeth adapted to a diet of insects, which form their principal food.

The best known of the insectivores are the hedgehogs, covered with a prickly coat, and, like the armadillos, able to roll themselves up into a ball which defies the assaults of any ordinary beast of prey; the moles, strictly subterranean, and almost blind, the fore limbs converted into very powerful and efficient digging instruments; and the shrews, less specialized for burrowing, but protected by their nocturnal habits and nauseous taste. Few birds or animals will touch a shrew—the owl is almost the only one that preys upon it. Hedgehogs, moles and shrews inhabit the northern continents, hedgehogs being restricted to the Old World. Various other insectivores, more or less related to these, but mostly less specially protected, are found in South and West Africa, in the East and West Indies, and in Madagascar, and one species, at least, formerly existed in South America. In the early part of the Age of Mammals the Insectivores were far more numerous, and some of larger size, and they had not then

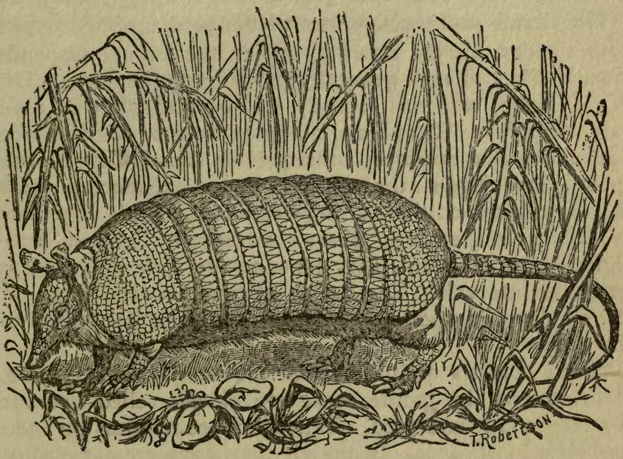


Fig. 33 —The Peba Armadillo.
An antique type of armored mammal inhabiting South America.

developed the various extreme specializations by which the surviving members of the order have managed to prolong their existence. The higher mammals, in the opinion of Huxley, were probably derived from some of these very primitive unspecialized Insectivores.

The Bats, Order Chiroptera, are usually regarded as related to the Insectivores, but they are the most isolated and highly specialized of all mammals in relation to their habits of flight. In adaptation to this purpose the fore limbs, and especially the fingers, are greatly elongated, the hind limbs reduced and slender, twisted around so that the knee projects backward, and a thin, flexible wing membrane extends from the sides of the body to the tips of the fingers and from the front of the fore arm to the hind limbs and usually to the tail. The pectoral muscles which move the wings are greatly enlarged, as they are in flying birds.

The thumb and the five toes of the hind foot are tipped with slender, curved claws by which the animal suspends himself when at rest, generally hanging upside down. Dr. W. L. Hahn, who has recently studied the habits of cave bats, observes: "They have no nests, dens or fixed homes. They have few enemies; consequently fear is little developed. About five-sixths of a bat's entire existence is spent in a dormant condition; a large amount of fat is favorable to torpor. In the caves, where conditions of light and temperature are constant, bats come to the cave entrance at irregular intervals. The length of time between these intervals depends upon the amount of surplus fat stored in the body.

"Food consists of insects that are caught on the wing. Hearing and the tactile sense are chiefly relied upon to perceive and locate food. Bats are more helpless on their feet than most birds. In the air they have greater agility. They can check their momentum very quickly. In flight they can secure hold of a surface only slightly rough with a single thumb or with one foot. Neither sight nor the external ears are necessary for the perception of obstacles during flight; such are perceived chiefly through the sense organs located in the internal ear; but the body hairs have probably a sensory function as well. Perception is probably due to the condensation of the atmosphere between the moving animal and the object which it is approaching. It is difficult to explain how they find their way by means of the five senses familiar to us. The presence of a sixth sense, that of direction, will explain all the facts, but it has not been conclusively shown that such a sense exists."

There are two principal groups of bats. The large Fruit-bats inhabit the East Indies, Africa and Madagascar, Australia and many of the Pacific islands, feeding upon fruit and hanging from branches of trees when not on the

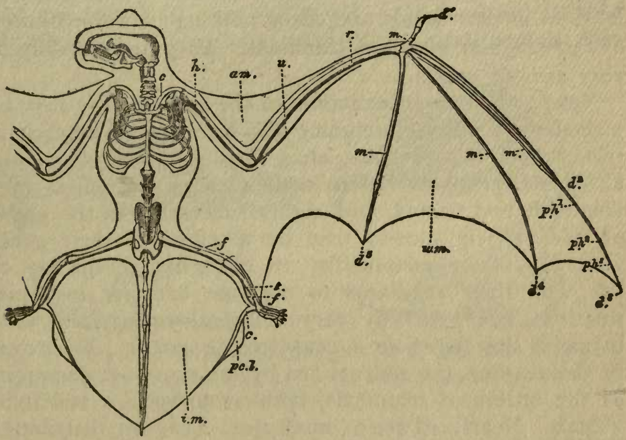


Fig. 34 —Skeleton of a Bat, Showing Bones of Wing. r., radius; u., ulna; d1., d2., d3., d4., d5., the five digits or 'fingers.'

wing. The smaller insectivorous bats are much better known and are cosmopolitan in their distribution. The ears are large and complex, and many kinds possess peculiar leafy outgrowths from the nostrils which aid in perception of objects around, somewhat as do the antennæ of ants, save that it is the sense of touch that is elaborated, instead of that of smell. While most of them live on insects, a few are frugivorous or carnivorous, and the South American Desmodus, the true Vampire Bat, is a blood-sucker, fastening upon men or animals during sleep and inflicting severe wounds, with serious loss of blood, without awakening the sleeper, by means of its keen-edged front teeth.

The cave-haunting habits of modern bats are familiar, and their fossil remains have been found in ancient cave and crevice formations as far back as the early part of the Tertiary Period. All the extinct species are closely related to modern kinds and show nothing of the evolution of this singular group of mammals. They are probably of very ancient origin.

Next above the Insectivores in the scale of life may be placed the Rodents, including the Rats and Mice, Squirrels, Porcupines, Rabbits, etc. This group of mammals, altho comparatively low in scale of organization, is very abundant and varied, and highly successful in the battle of life. Their success may be ascribed to their great fecundity, their adaptability to changing conditions of life, and their readiness to combine together in social relations, not generally very complex, yet each serving to assist the others to a considerable extent. Whatever be the reasons, the rodents are by far the most numerous of the orders of mammals, both as to species and individuals. Nearly all are of small size. They are distributed all over the world, a few even reaching Australia, and are terrestrial, arboreal, fossorial or amphibious in their habits. None of them is marine and none is able to fly, altho some have membranous expansions of the skin which can be stretched like parachutes in taking long, soaring leaps from tree to tree. The limbs and feet are mostly of primitive type, five-toed, tipped with claws, and the animal walks on the sole of the foot. The teeth are peculiar in the conversion of one pair of incisors in each jaw into gnawing teeth, and disappearance of all the other front teeth; the cheek teeth are adapted to crushing or grinding. Rodents live mainly upon seeds, roots, nuts, fruits, or upon grasses or the bark of trees; but they are by no means averse to insect or animal food.

More than half the living species of mammals belong to this order. It is divided into four groups, of which the squirrels, porcupines, rats and rabbits serve as types.

The squirrel group includes the squirrels, marmots, beavers, pocket-gophers, and their allies. The arboreal squirrels are the most intelligent and attractive of rodents, and are found all over the world, save in Australia and Madagascar. Their long, bushy tails, neat, smooth fur,

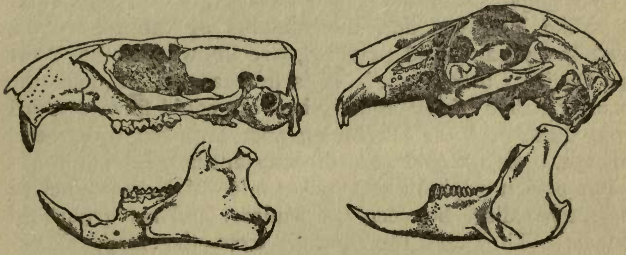
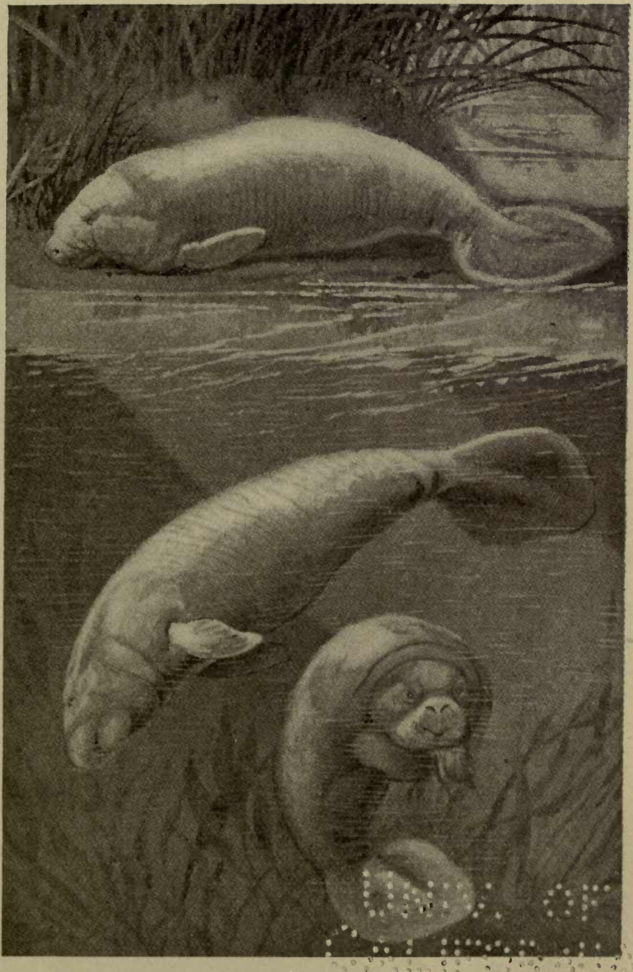


Fig. 35 —Skulls of Prairie Marmot (left) and Rabbit (right). Illustrating the rodent type of teeth, with enlarged gnawing incision. (Flower and Lydekker)

and often handsome coloring, and their restless activity and chatter, offset their occasional depredations on birds' nests. The marmots (woodchucks, gophers, prairie-dogs, etc.) are nearly related to the tree squirrels, but terrestrial and more or less burrowing in habit, adapted to live in open country and in temperate or arctic climates. The beavers are more distantly related; they are a small group, of highly specialized habits, large-brained and intelligent for rodents. There are only two living species, the European and American beaver. As is well known, they live in colonies, in artificial lakes which they construct by damming streams with logs, brush and mud, each family making a nest or burrow in or beside the shallow waters of the pond, accessible by an underwater entrance. Both species have been hunted almost to extinction for their fur. A large extinct relative of the beaver, Castoroides, lived in North America during the Glacial Epoch, equaling the black bear in size, but nothing is known of its habits, except that its remains are mostly found in ancient swamps and pond bottoms. During the Tertiary Period small animals related to the Beaver (Steneofiber) were common both in Europe and North America, but their habits were like those of the modern prairie dogs. They constructed elaborate winding, corkscrewlike burrows, and the remains of these burrows, filled in by sand and petrified, are known in the West as "Devil's Corkscrews." It is not easy to see how the peculiar habits of the aquatic beavers could have evolved from those of these burrowing ancestors, but they were, perhaps, a side branch, not directly ancestral.

The pocket gophers and pocket mice of North America are intermediate between the squirrel and rat groups of rodents. They get their name from the large cheek-pockets in which they carry food and transport earth from their burrows. The pocket gophers are completely subterranean, equaling the mole in their digging powers, but living on vegetable food. The pocket mice are terrestrial, and some of them active leapers. The jerboas and their relatives are also specialized for leaping rather than running, but are more nearly related to the rats and porcupines than to the squirrels. They inhabit the northern continents and Africa, mostly living in open plains or desert regions.

The most abundant of the rodent groups are the rats and mice and their relatives. These are found all over the world; a few have even penetrated to Australia, and to various oceanic islands which few or none of the other mammals have contrived to reach. They are nearly all of small size, living upon all kinds of plant food, and



Manatee, Living Form of Once Numerous Species.

often more or less omnivorous, adapting themselves very readily to varying conditions of life and endowed with great fecundity. Their depredations upon crops, upon stored grain, upon household supplies, the damage they do by girdling trees for the edible inner bark, cause enormous losses in various fields of human activity, so that they rank with noxious insects in their economic importance. Birds of prey are their chief natural enemies, more efficient in general than any artificial check on their increase.

The porcupine group of rodents are represented by two or three large, spiny-coated species in the northern continents, but their headquarters are in South America, where they include the cavies and chinchillas, viscachas, agoutis, capybaras, and many others, of which the largest, the capybara, reaches the size of a pig. Quite a number of this group of rodents inhabit Africa, and during the Tertiary Period they were the only rodents in South America, and one extinct genus is estimated to have attained the size of an ox, much beyond that of any other rodent.

The last group of rodents are the hares, rabbits and picas, worldwide in distribution, but most familiar and abundant in the north temperate and sub-arctic regions. In Australia and New Zealand they have been introduced by the white settlers, and have thriven and multiplied exceedingly, so as to be a serious pest in the absence of their natural enemies. Their limbs and feet are more specialized for speed than in most rodents, altho the rabbitlike cavies and chinchillas of South America show a corresponding adaptation.

Under the name of Hoofed Mammals, or Ungulata, are commonly grouped together several orders of mammals which are not in fact nearly related to each other. They are all herbivorous, adapted to terrestrial life, using the feet only for walking or running, and in all of them the claws have been thickened and broadened into hoofs, serving for support, but useless for grasping or climbing. So far as can be judged, they are derived from several stocks of primitive clawed ancestors, in each of which

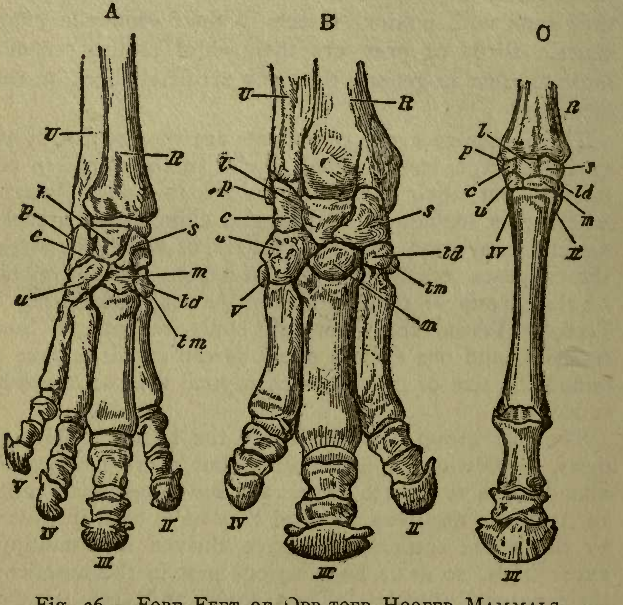


Fig. 36 —Fore Feet of Odd-toed Hoofed Mammals.
A., the tapir; B., the rhinoceros; C., the horse. The line of symmetry passes through the middle of the third digit. (After Flower.)

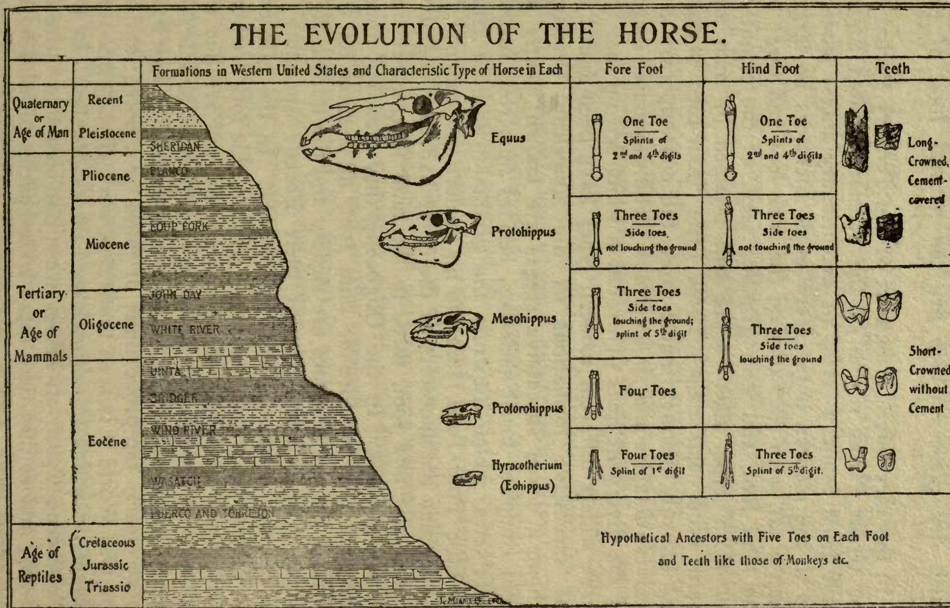
the hoofs have been independently evolved in adaptation to similar habits of life. The horses, tapirs and rhinoceroses are derived from one primitive stock, the pigs and ruminants from another, the elephants from a third, while there are several extinct races of hoofed mammals derived from still other primitive stocks. The Ungulates are all medium to large-sized mammals, many of them gigantic, none of them very small. Their brains are mostly of high type, and in intelligence they rank with the Carnivora, decidedly above any of the orders that we have considered, except the Cetacea, and exceeded only by the higher Primates (Monkeys, Apes and Men). The two most important groups are the Perissodactyls, or Odd-Toed, and Artiodactyls, or Even-Toed Hoofed Mammals. In the former the number of toes, in the hind foot at least, is three or one, the axis of symmetry passing through the middle digit. In the latter the number of toes is four or two, the axis of symmetry passing between the two middle digits. There are numerous other points of difference in the structure of teeth, skeleton and soft anatomy, which show that these two groups are distinct; that while animals so different as the horse and rhinoceros are derived from a common ancestral stock, the tapir and the pig, or the rhinoceros and the hippopotamus, are derived from different primitive stocks of placental mammals. These relationships are fully confirmed by what is known of the geological history of the various races of ungulates. Owing to their large size and comparative abundance, fossil hoofed mammals are more common and better known than any of the other groups, and the geological history and evolution of many of the ungulate races is quite fully known.

"The Horse," wrote the small boy in his essay, "is a square animal with a leg at each corner," a definition that might perhaps be improved upon. But in fact the horse needs no definition to bring it before the eye of man, woman or child. Its graceful proportions, compact, well-knit body, long head and arched neck, its flowing mane and tail, its slender limbs and one-toed feet tipped each by a broad, solid hoof—these are the ideal proportions of the swift-running hoofed mammal, designed to cover long distances at a high rate of speed.

True horses are practically unknown in a wild state, the so-called wild horses being, for the most part, descended from animals which have escaped from domestication. The Przewalsky horse of the deserts of Central Asia is, however, believed to be a truly wild species. The closely related asses and zebras occur in the wild state in Western Asia and in Africa; they differ from the horse chiefly in size and color pattern, and all are included in the genus 'Equus.' In a broad way all of them may be called horses.

The structure of the feet and teeth in the horse, using the word in this broader sense, is unique among modern animals. The foot has but a single toe, corresponding to the middle or third digit of man, but the second and fourth digits are represented by small rudiments, "splint-bones," which lie closely pressed against the back of the cannon-bone (corresponding to the third metacarpal bone of the palm in the human hand or the third metatarsal bone of the instep in the foot). These rudiments are all that is left of the second and fourth toes; of the first and fifth there is no trace at all.

The cheek teeth are equally peculiar. They are long, square columns, growing at the base and pushing up from the jaw as they wear off at the surface in grinding the food. They are composed of enamel, dentine and cement; the enamel, which forms the covering of the usual type of mammal tooth, is infolded into a complicated pattern, its worn edges supported on one side by the dentine which underlies the enamel in the normal mammal tooth and on the other by cement, a special substance slightly softer than the dentine, deposited on what is at first the outer side of the enamel before the tooth pushes up through the gum. By this means the grinding surface of the tooth at any stage of wear is composed of a complex pattern of hard enamel ridges braced on either side by the somewhat softer dentine and cement. This forms a most efficient instrument for grinding and triturating the


THE EVOLUTION OF THE HORSE.
Formations in Western United States and Characteristic Type of Horse in Each
Fore Foot
Hind Foot
Teeth
Quaternary or Age of Man
Recent
Pleistocene
Tertiary or Age of Mammals
Pliocene
Miocene
Oligocene
Eocene
Age of Reptiles
Cretaceous
Jurassic
Triassic
SHERIDAN
BLANCO
LOUP FORK
JOHN DAY
WHITE RIVER
UINTA
BRIDGER
WIND RIVER
WASATCH
PUERCO AND TORREJON
Equus
Protohippus
Mesohippus
Protorohippus
Hyracotherium (Eohippus)
One Toe
Splints of 2nd and 4th digits
One Toe
Splints of 2nd and 4th digits
Three Toes
Side toes, not touching the ground
Three Toes
Side toes not touching the ground
Three Toes
Side toes touching the ground; splint of 5th digit
Three Toes
Side toes touching the ground
Four Toes
Four Toes
Splint of 1st digit
Three Toes
Splint of 5th digit.
Long-Crowned, Cement-covered
Short-Crowned, without Cement
Hypothetical Ancestors with Five Toes on Each Foot and Teeth like those of Monkeys etc.

hard, dry grasses which are the natural food of the horse.

In the successive formations of the Tertiary Period in the Great Plains region of the Western United States have been found a series of evolutionary stages leading up to the modern horse from small ancestors no larger than a cat, with four toes on the fore foot and three on the hind foot, and with grinding teeth of the primitive 'bunodont' type, such as are still retained by man and many other mammals These little "four-toed horses" are scarcely distinguishable from the contemporary ancestors of tapirs and rhinoceroses. The successive stages of the divergent lines of evolution which led up into the three widely different modern types have been found in the successive formations of the American Tertiary. About a dozen successive stages are known, nearly all from complete fossil skeletons, besides numerous incomplete ones, which illustrate the gradual transition from the little 'Four-Toed Horse' to his modern descendant. In the Eocene the ancestors of the horse had four complete toes in the fore foot, three in the hind foot, all resting on the ground. In the Oligocene they had but three complete toes on fore or hind foot, all resting on the ground, but the side toes are slender and the middle digit larger. The outside toe of their Eocene ancestors is represented by a rudiment or "splint." In the Miocene the central toe is more enlarged, and the side toes are very slender and no longer touch the ground, but are like the "dew-claws" of a dog or deer. In the Pliocene the side toes are still more slender and the bones of the middle digit have more clearly the proportions of those of a horse; and in the Old World it is seen that there were already one-toed horses, in which the dew-claws had disappeared. In the Pleistocene Epoch all horses were one-toed like those of to-day, and at that time there were species of wild horse in Europe, Asia, Africa, North and South America. Since that time the geographic range of horses has been much restricted. They disappeared wholly from the New World, to be reintroduced by European settlers in North and South America. They are no longer found in a wild state in Europe, nor in most parts of Asia, and the zebras and wild asses are rapidly disappearing. The domesticated breeds, which are believed to be crosses of Asiatic, North African and perhaps native European wild horses, have been introduced everywhere that civilized man has made his home; and feral races, escaped from domestication, have repeopled the high plains of both Americas.

The evolution of the Horse is to be regarded as an adaptation to changing conditions of climate and geography which favored more and more the development of swift-running types in open grassy plains. At the beginning of the Tertiary Period the plains of Western America lay near to sea-level, had a moist sub-tropical climate, and were heavily forest-clad. Throughout this period they were being slowly elevated above sea-level, the climate was becoming colder and more arid, and the forests were disappearing, to be replaced by extensive grassy plains. Of the original population of animals some retreated southward with the changing climate, and their descendants are to-day to be found in the tropical forests. Some became extinct, and are known to us only from their fossil remains. Some, like the horses, were able to adapt themselves to the changing conditions, and their descendants, much changed in form and habits, still survive. Hand in hand with the changes in foot structure adapting them to swift running, went changes in the teeth adapting them to feed upon the hard, dry upland grasses. The steady increase in size is a common feature in many races of animals, especially of ungulates.

The Tapirs afford an example of a race which has followed the climate southward instead of altering its habits and structure. Tapirs to-day inhabit the forests of tropical America and the Malayan peninsula. They retain the primitive construction of the feet, four toes in the fore foot, three in the hind foot, and their teeth are not greatly changed from the primitive type of the Eocene ancestors of horses, tapirs and rhinoceroses. Except for increased size and bulk and the development of a short flexible proboscis they have changed but little. During the early part of the Tertiary Period tapirs inhabited all the northern continents, but their range was gradually restricted further and further to the south.

The history of the Rhinoceroses is much the same as of the Tapirs. In the early Tertiary their ancestors had four toes on the front foot, three on the hind foot, and primitive short-crowned 'bunodont' teeth. Like the early horses, these ancestral rhinoceroses lost the outer digit in the fore foot, and began to lengthen out the crowns of the teeth, making them more efficient grinders. But they got no further than these first steps, and then, like the Tapirs, they followed the changing climate southward, in preference to adapting themselves to new conditions of life. Rhinoceroses were common in Europe, Northern Asia and North America as far north as Canada during the early and middle Tertiary, but by the end of the Tertiary they had disappeared from the northern regions, except for a few survivors in Europe and Asia; and to-day they are found only in the tropical regions of the Old World, in India and some of the East Indian islands, in Africa as far south as Cape Colony. In the New World they have become wholly extinct.

Other races of the early Perissodactyls have become entirely extinct. Such were the Titanotheres of Tertiary North America, huge, massive rhinoceros-like animals with humped back like the bison, and paired bony horns at the front of the solidly built skull; the Palæotheres of the European Tertiary, smaller, hornless, tapir-like in size and proportions, but with only three front toes; and most peculiar of all the Chalicotheres, an odd combination of horse and rhinoceros in proportions, but with the hoofs reconverted into large, powerful claws, used probably to dig around trees and uproot them in order to feed upon their foliage.

In reviewing the historical development of the Perissodactyls it must be deemed an order that has passed its prime and is tending toward extinction. It was represented during the Tertiary Period by a great number and variety of members, both small and large. Its living representatives are few in number, of large size, scattered, widely diverse in form and habits, and, except for the horses, confined to tropical regions. Even the horses, the most successful in adapting themselves to modern conditions of life, do not appear to maintain themselves in competition with their numerous and varied rivals of the ruminant group, which are by far the most abundant among modern hoofed mammals.

The order Artiodactyla includes two principal groups, first the non-ruminants (pigs, peccaries and hippopotami), with the primitive bunodont type of teeth and with four separate digits in each foot, altho the side toes are sometimes much reduced; second, the ruminants (camels, deer, antelopes, sheep and cattle), in which the cheek teeth are adapted for grinding, altho with a wholly different pattern from the grinders of horses or rhinoceroses, and there are only two complete digits on each foot, the metapodials of which are fused into a single "cannon bone," altho the toes remain separate, and the side toes are rudimentary "dew-claws" or altogether absent. The first group retain more nearly the ancestral characters of teeth and feet, and have survived owing to certain unusual habits of life or special means of defense which have protected them against competition. The second group is the progressive and dominant group of herbivorous mammals.

The pigs of the Old World and the Peccaries of the New are provided with bristly hair, thick skin, and very efficient canine tusks. They are compact-bodied, bold and active fighters, dangerous adversaries whom their carnivorous enemies or herbivorous rivals may well hesitate to attack. Nevertheless, their rangs and numbers have been much decreased since the Middle Tertiary. Several large kinds of peccary inhabited North America as far north at least as the Canadian border up to the Pleistocene Epoch; there is now but a single genus which ranges from

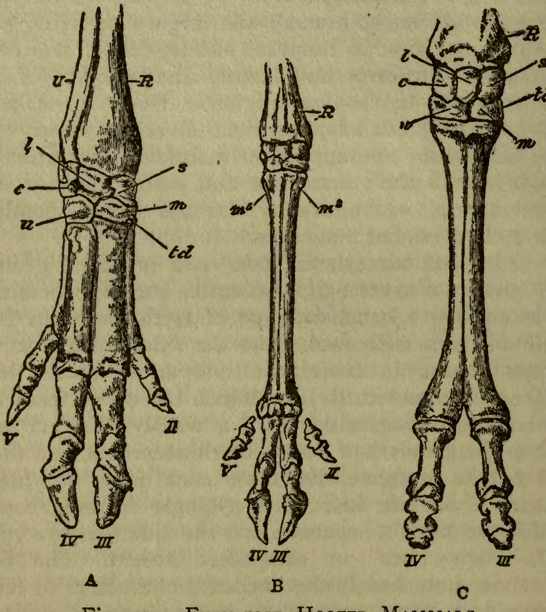


Fig. 37 —Even-toed Hoofed Mammals.

A., the pig; B., the deer; C., the camel. Note that the axis of symmetry of the foot lies between the third and fourth digits. (Flower.) In the pig the side toes are complete; in the deer only dew-claws remain; in the camel they have wholly disappeared.

Southern Texas to Brazil. In Europe there were also a number of true pigs, some of large size, during the later Tertiary; the wild boar is the only surviving type in temperate regions, but in tropical Africa and the East Indies there are several others, the Wart-Hog, Red River Hog, Babirussa and a number of species of pigs. The pigs, like the tapirs and rhinoceroses, have followed the tropical forest and climate southward in its gradual disappearance from the temperate zone.

The Hippopotamus is among the largest of living quadrupeds, thick-skinned, almost hairless, its broad, short feet with four toes of nearly equal size, its huge jaws and long, heavy tusks adapted to root in the mud of river bottoms. Chiefly aquatic in its habits, it can remain under water for some time before coming up to breathe. It is found today only in the rivers of Central Africa, but had formerly a much wider range, inhabiting Madagascar and Southern Asia and ranging northward into Europe.

Nine-tenths of the hoofed animals belong to the Ruminants, a section of the Artiodactyls. They are distinguished especially by the peculiar complexity of the stomach which enables them to chew the cud. It is divided into four chambers, the first and largest, or paunch, serving to contain the hastily swallowed food, which is later returned to the mouth, thoroly masticated at leisure, and passes to the other divisions of the stomach for digestion. The advantage of this habit of "chewing the cud" to an herbivorous animal whose food requires thoro chewing are very considerable. Food can be obtained hastily where rich and plentiful, while the necessary mastication can be continued while en route from the feeding grounds or during rest, or deferred till a place of safety is reached. The limbs and feet of ruminants are highly specialized both for speed and endurance, almost if not quite as much as in the horse, while the "divided hoof"—really two separate hoofs closely paired—gives them a better footing on rough or irregular ground.

Among living ruminants the camels and llamas stand apart as a primtive and peculiar race, specialized for desert life. The long, loose-jointed limbs and padded feet lack the speed adaptation of the higher races, but are well fitted to traverse the loose desert sand; the stomach is less complex but peculiarly specialized to carry a supply of water which enables the animal to go without drinking for several days at a time. Altho the camels are now found only in the Central Asian and North African deserts and the llamas in the arid regions of South America, they were during the Tertiary period a peculiarly North American family, and the evolution of the race has been traced almost as completely as the evolution of the horse, back to little ancestors no larger than a cat, with four separate digits on each foot. They disappeared from North America before the appearance of civilized man, like the native American horses, and the preservation of camels in the Old World is perhaps, like the preservation of the Asiatic Horse, due to their being domesticated by man. It is doubtful whether any truly wild camels exist either in Asia or Africa. If these domesticated races be set aside it will be found that camels and horses have both disappeared from the northern continents, where they were abundant during the Age of Mammals, but are preserved in the outlying southern continents, the peculiarly American camels in South America, the cosmopolitan horses in Southern Africa. Looking at the matter in this way, it may reasonably be supposed that they were driven into the outlying southern regions through their inability to contend with the more perfected ruminants whose center of dispersal was in the great northern land mass. Both camels and llamas have been domesticated by man and used as beasts of burden; the Bactrian or two-humped camel in Central Asia, the dromedary in North Africa; the llama was the only beast of burden in ancient Peru, while the smaller alpaca was kept for its fleece and meat. The wild races of these two species still exist in the high plains of South America under the names of guanaco and vicuña.

Before taking up the typical ruminants, or Pecora, allusion may be made to the chevrotain of the dense forests of the East Indies, and the water-chevrotain of the equally dense forests of West Africa, both regions the refuge of many primitive survivors of the Tertiary fauna. These two genera are grouped together because of the less per-

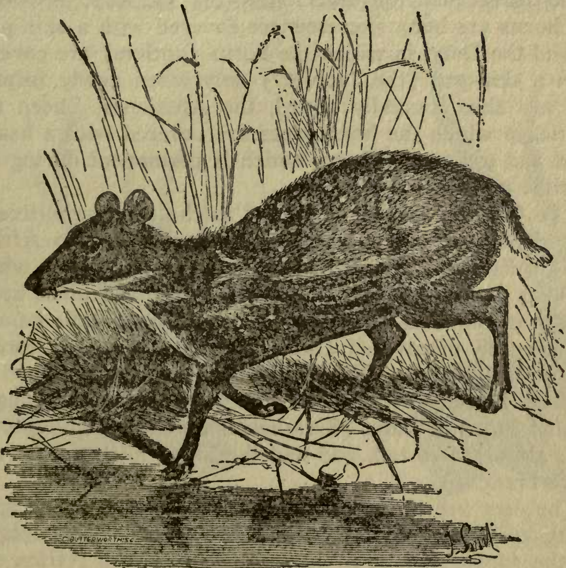


Fig. 38 —THE WATER-CHEVROTAIN OF WEST AFRICA. Primitive type of the Ruminants. (Flower and Lydekker.)

fected foot-structure and lack of horns, and represent quite nearly the early Tertiary stage in the evolution of the ruminants, as it is found fossil in Europe and North America.

The true ruminants or Pecora are undoubtedly the dominant group of herbivora to-day. They are a group of comparatively recent evolution geologically, and first appear in the Middle Tertiary, developing out of primitive artiodactyls mainly in the Old World. Their center of diffusion was apparently Northern Asia, whence they spread to Europe on one hand, to North America on the other, reaching Africa and South America at a later date, probably toward the end of the Tertiary period. They include three main sections; first the Giraffes, in which the horns are bony excrescences covered with a skin-pad; second the Deer, in which the horns (antlers) are covered with a skin-pad (the "velvet") only when newly formed, and are shed annually; third, the Antelopes, Sheep and Cattle, in which the horn cones are covered with a heavy, solid and tough true horn, which is permanent during the lifetime of the animal.

The Giraffes may be regarded as the most primitive of these three sections. They are to-day limited to Africa, the giraffe being adapted to the semi-desert plains, where its long neck enables it to feed upon the succulent upper foliage of mimosas and other thorny bushes; while its ally, the recently-discovered Okapi, inhabits the deep forests of Central Africa. Fossil giraffes have been found in the late Tertiary of Asia and Southern Europe, and nearly related forms in India (Sivatherium, etc.) were of greater bulk altho not so tall, and had the horns much larger and more branched.

The deer are especially adapted to forest life, the teeth short crowned and suited for browsing. They inhabit all the forest regions of Europe, Asia, North Africa and the two Americas, but have been prevented from reaching the Ethiopian region by the wide stretch of the Saharan desert and the arid mountainous country to the east of it. The largest and most progressive of the deer are found, as one might expect, in the Arctic and cold temperate zones of the North, the wapiti and red deer, the reindeer and caribou, the moose and (European) elk being the highest development of the family. The smallest and most primitive members live in Southern Europe, in Southeastern Asia, the East Indies and in Central and South America. The earliest deer were of small size, at first hornless, like the modern musk deer of the Himalayas and water-deer of China, or the fawn of any of the larger deer; then with a single spike, like the Central American "brockets," or the second year of the larger deer (to which the term brocket originally belonged); then with two,

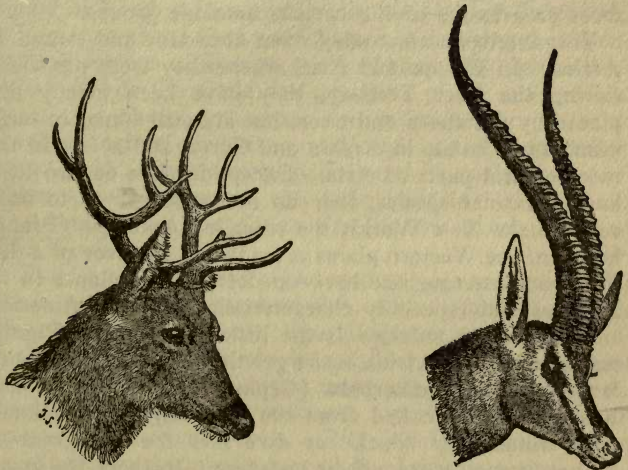


Fig. 39 —Heads of Deer and Gazelle, Showing the Antlered and Hollow-horned Types of Ruminant. (Sclater, Brooke.)

three or more times, all the stages being paralleled both by the adults of different species of modern deer and by the annual changes in the young of the larger northern deer.

The antelopes, sheep and cattle are primarily adapted to living on open plains. The teeth are mostly long-crowned, and in many of them the grinding edges of the enamel are braced by a heavy deposit of cement, as in the horses. They are thus suited to feed upon the hard, dry plains grasses, which require very thoro chewing before their nutrition becomes available. "Antelopes" is a broad term that covers all the various races except two—the sheep and goats, and the cattle—which on account of their domestication by man are of especial importance and have received especial names. From the zoölogical point of view they are not more different from antelopes than the different races of antelopes are from each other. But they may fairly be considered as the highest and most progressive of the various antelope groups.

The antelopes are to-day most abundant and varied in Africa. In Europe and Asia, where they were numerous during the later Tertiary, they have been mostly displaced by the sheep and oxen, but are still found in large numbers in India, in Arabia and Syria, and a few in the more central parts of Asia. Except for one or two little known extinct species, they do not appear ever to have reached the New World; the so-called Antelope (Pronghorn) of the Western plains is a solitary survivor of a distinct race intermediate between deer and antelopes in its affinities and especially characteristic of North America.

The smallest antelope is the little Madoqua or Pigmy-antelope of East Africa, no larger than a hare. Not much larger are the Duikerboks (Cephalophus) of South and East Africa, so called from the dexterity and quickness with which they "duck" or dive into the tall grass or bushes to escape from their pursuers. In these the horns are small, straight spikes. The gazelles, with longer, ringed horns, delicate head with large, soft eyes, slender neck and long limbs, are generally admitted to be the most graceful of the hoofed quadrupeds and unsurpassed in speed. In the larger antelopes the horns are either ringed or spirally twisted, mostly projecting upward with a slight backward curve, but in the gnu they are depressed on the side of the head, as in the sheep. Some of the larger antelopes, such as the African eland or Indian nilghai, have nearly the size and proportions of domestic cattle.

The goats, sheep and cattle are the latest of the antelope groups to appear in geological history, and the wild species are to-day predominantly Asiatic in their distribution. The cattle, however, are widely distributed throughout Africa, India and the East India islands, and in North America are represented by the bison and musk-ox. The big-horn and mountain goat of northwestern North America are the only New World representatives of the sheep and goats; a single species of wild sheep is found in North Africa; otherwise they are all Palæarctic, a few, such as the Ibex and Chamois, inhabiting the mountainous regions of Europe, most of them the highlands of Asia. While the cattle are especially plains and lowland types, the sheep and goats are preëminently mountain dwellers, active climbers, sure-footed, and able to endure severe cold. The domesticated species of cattle, sheep and goats are of enormous economic importance, and have contributed very largely to shaping the development of Old World civilization.

Besides the ancestors of the modern pigs and ruminants, there were various races of this order of hoofed animals that have not survived. The Elotheres were large animals with huge skulls, cheek teeth like those of pigs, front teeth more like carnivorous mammals, feet strictly two-toed as in camels and ruminants, but the metapodials not united into a cannon-bone. They inhabited the northern continents in the middle part of the Tertiary period. The skull of the largest of them, 'Dinohyus,' is over three feet long, the animal as large as a hippopotamus but with much longer legs and short, massive body proportioned more like the bison. The Oreodonts, very abundant in North America at the same time, have been called "ruminating hogs," as they combined the four-toed feet of the pigs with a ruminating type of teeth. They must have resembled peccaries in appearance and habits, but with shorter snout. The contemporary Anoplotheres took the place of the Oreodonts in the Old World; the Anthracotheres, pig-like in proportions, with teeth partly intermediate between those of pigs and ruminants, are regarded as more or less directly ancestral to the hippopotamus.

The Elephants are the most gigantic of living quadrupeds and the most singular in appearance. The elongation of the snout into a long, flexible trunk, serving much the same purposes as the hands in man, sets them apart from all other ungulates as, in this respect at least, a higher mechanical adaptation. For there can be no doubt that the development of the hand into an effective organ of prehension, released from the functions of locomotion, has played an important part in the evolution of intelligent life in man; and in the elephant we see an entirely different organ serving the same purpose almost as effectively. To find the elephant ranking as the most intelligent of hoofed animals, then, is what might be expected. The limbs are long, straight and massive, the feet short, rounded, heavily padded, with five small hoofs on each. This construction is best adapted to support the gigantic weight of the body—five to fifteen thousand pounds—and all very large land animals approach it more or less nearly.

The teeth are very highly specialized. One pair of upper incisors is enlarged and lengthened into tusks; all the other front teeth have disappeared. Of the cheek teeth only the molars remain, and these are high crowned, composed of alternating transverse plates of enamel, dentine and cement. The three molars come into use one after another, dropping out as they wear down to the roots, and in a fully adult elephant only one grinding tooth is left on each side of upper or lower jaw. Four grinders and two tusks constitute the entire adult dentition, and even the tusks are absent in the female. The skull and jaws are extremely short, and large in proportion, giving room for the attachment of the powerful muscles necessary to wield the trunk and tusks and grind the food—leaves, twigs, fruits and forest grasses. Unlike other long-limbed animals (excepting man) the neck is very short, as the trunk makes it unnecessary for the head to reach the ground.

The average height of elephants is from eight to ten feet, but the African species at least, sometimes reaches twelve feet in height. Jumbo was eleven feet high, his weight six and a half tons. The Indian species is more massive, but not so tall as the African one; its forehead is higher and grinders larger, with more numerous and closely set plates; the tusks are smaller and often absent in males as well as females.

Elephants have been tamed since the days of the ancients, both the Indian and African species. Those brought by Hannibal from Carthage must have been African elephants; but the Greeks and Romans were more familiar with the Indian species.

The two modern species of elephants are the last survivors of a race widely distributed in prehistoric times. The mammoths were simply a species of elephant; the mastodons were a nearly related genus, but with shorter crowned and more numerous teeth, and other primitive characters. These during the Pleistocene epoch ranged over all the northern continents. Mammoth remains have been found in all parts of Europe and in Asia northward to the Liakhof Islands i.. the Arctic Ocean, where vast quantities of their tusks and bones are preserved in the frozen soil. In America the mammoths of different species ranged from Siberia to Mexico. The Mastodons were of even wider range, penetrating into South America as far as the Argentine plains. The Arctic species of elephants were covered with a shaggy coat of reddish brown wool, mingled with longer black hairs. In Siberia and Alaska carcasses of these animals more or less complete have been found preserved in the frozen soil. The southern mammoths were more probably naked-skinned like the modern elephants, which they somewhat exceeded in height and bulk. A skeleton in the Paris Museum is slightly over three meters (thirteen feet) in height. The mastodons were also partly covered with hair. The tusks in some of these mammoths and mastodons were of enormous size, curling inward and crossing at the tips. Some of these fossil tusks measure thirteen feet in length and nine inches in thickness. Like the tusks of modern elephants they are composed of ivory or dentine only, the enamel being lacking.

During the latter half of the Tertiary Period Primitive Mastodons (Gomphotherium) inhabited Europe, Asia and North America. They were much smaller than the Pleistocene Mastodons and Elephants, with tusks in both upper and lower jaws, and shorter limbs, longer skull, and much shorter trunk. The lower tusks are short and straight, or in the earliest forms curving slightly downward, and with a strip of enamel on the face of the tusk. In a related genus, 'Dinotherium,' the upper tusks were absent, the lower ones large and curving downward; and in this animal the grinding teeth were more numerous, five on each side of each jaw, while the 'Gomphotherium,' like the true Mastodon, had but three.

A complete series of intermediate stages between the Primitive Mastodons and the modern elephants is found in the successive formations of the later Tertiary in Europe and Asia. The early history of the Proboscideans was unknown until very recently, when the explorations in the Fayûm district of Egypt disclosed an early Tertiary fauna which included, among other large quadrupeds new to science, the early stages in the evolution of mastodons and elephants. These carried back the ancestry of the elephant to a small animal (Mœritherium) about as large as a cow, with a nearly complete series of teeth, short crowned grinders, one pair of incisors, enlarged and somewhat like the gnawing teeth of rodents, with long head, no trunk, and short limbs. Palæomastodon was intermediate between this type and the primitive mastodons.

Reference has been made to the various extinct relatives of the Perissodactyls, Artiodactyls and Proboscideans.

But during the Age of Mammals there were a number of groups of hoofed mammals not related to any of the living orders, and some of remarkable proportions and gigantic size. In North America, during the Eocene epoch, lived the 'Uintatherium' or 'Dinoceras,' a huge creature larger than an Indian rhinoceros, with elephantine limbs and feet, its head armed with three pairs of bony horns and great, saber-like upper tusks. In Africa, about the same time or a little later, lived the 'Arsinoitherium,' equally huge and elephantine in limbs and feet, and with a pair of great, sharp horns at the front of the skull. South America, during the long period that it remained an island continent, developed a great variety of hoofed mammals, unrelated to those of the northern continents, but sometimes paralleling them to a remarkable extent. In the South American Eocene is found a great elephantine quadruped, the 'Pyrotherium,' singularly like the ancestral mastodons in many respects, but probably not closely related to them. In the Miocene lived another huge beast, the 'Astrapotherium,' again with elephantine limhs and feet, and apparently provided with a shorter trunk; but with tusks like those of pigs and peccaries only of larger size, and with grinding teeth that bear a general resemblance to those of the rhinoceros. At the same time lived smaller animals, the 'Nesodons,' proportioned somewhat on the lines of a small hornless rhinoceros, and little Typotheres, rabbit or coney-like in size and proportions, but in fact related to the Nesodons.

The most interesting members of this Miocene fauna of South America were the Litopterna, some of which paralleled the horses in their foot-structure with extraordinary closeness, altho not at all horse-like in the skull or teeth. The side-toes were reduced to "dew-claws" as in the later three-toed horses, and finally disappeared, leaving only the central toe with a rudimentary nodule of bone to represent each side toe, like the splint of the modern horse. The form of the foot bones throughout becomes singularly like that of the true horses. Other Litopterna retained three well-developed toes like the rhinoceroses, but their limbs had rather the shambling build of the camel than the more compact proportions of rhinoceros or tapir. At the end of the Tertiary still other gigantic ungulates developed in South America. The Nesodons gave rise to the huge massive 'Toxodon,' exceeding a rhinoceros in size; the three-toed Litopterna to the camel-like 'Macrauchenia.'

All these extinct groups of Ungulates were evolved in North America, in South America and in Africa during epochs when these regions were cut off from the main center of diffusion of mammals, the great land mass of Northern and Central Asia. The corresponding forms evolved in this larger central region were subject to severer and wider competition, were more advanced, intelligent, active or hardy than the quadrupeds evolved in the smaller isolated areas. Consequently, when these areas were joined to the central land mass, its fauna invaded them and swept out of existence all the competing autochthonic types.

The Manatee and Dugong are the remnants of a group of herbivorous mammals, nearly related to the ancestors of the elephants. Like the Cetacea, they have adopted an aquatic life, and become more or less fish-like in form, losing the hind limbs, developing the tail into a swimming organ, and the fore limbs into fin-like paddles, and entirely losing the hair. Unlike cetaceans they are sluggish, slow-moving bottom feeders, living on the aquatic vegetation of tidal rivers or upon sea-weeds. The Dugong of the Rea Sea and East Indies, and the Manatee of the Atlantic coasts are the only survivors. A larger form, Steller's Sea Cow, inhabited some of the Aleutian Islands until 1758; and in the Tertiary formations of Europe and North Africa various ancestral stages have been discovered. The name Sirenia may seem singularly inappropriate for such peculiarly ugly animals, yet it is not unlikely that some of the older reports of mermaids were based upon the dugong, owing to the custom of the parent holding the young to her breast with her flippers, the round heads of both being raised out of the water.

The 'Carnivora' are the Beasts of Prey, specially adapted for flesh-eating and predaceous habits. For the most part they are exceptionally active, strong and restless, of high intelligence and perfect bodily mechanism. In so far as perfection consists in mechanical adaptation to an active and varied life, the carnivora may indeed be regarded as the highest of living animals. Man indeed, in respect of

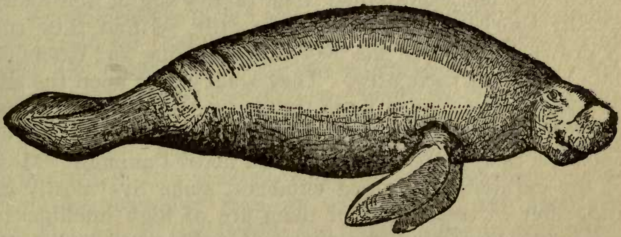


Fig. 40 —The Florida Manatee. (Flower and Lydekker.)

his mental powers, stands far above the rest of creation, but as an all-round athlete he must yield the palm to the Carnivores.

Besides the land carnivora this order includes the Seals and Walruses, adapted to a marine life, and again partially assuming a fish-like form, altho they have retained their furry covering, and in the absence of a heavy tail the hind limbs have been converted into a propelling organ, instead of disappearing as they have done in cetaceans or sirenians. The fore-limbs are converted into flippers, and the teeth mimic those of the early toothed whales in their adaptation to fish-eating. But seals and walruses are not as helpless on land as are dolphins or whales; their adaptation to marine life is not so complete. The great "rookeries" in which seals congregate for breeding purposes, and the long migrations which they undertake each season, are remarkable features of their life.

The terrestrial carnivora are more numerous and familiar. Their teeth are specialized for seizing their prey and for cutting flesh. The canine teeth are large, sharp and strong, one pair of cheek teeth is enlarged and converted into stout shearing blades which act like a pair of scissors; these are termed carnassials, and the cheek teeth in front of them are usually of cutting type, while the molars behind are used for crushing or are entirely absent. The feet have either four or five digits, the claws usually sharp and sometimes retractile, so that they can be drawn back out of the way while walking and extended only in seizing their prey. They walk either upon the entire sole of the foot or upon the under surface of the toes, the sole or palm being held free of the ground; but never upon the tips of the toes, as do the hoofed animals. Most of the carnivora are good climbers; some live mostly or altogether in trees. All of them are of high intelligence and keen perceptions, the senses of sight, smell and hearing very highly developed. They are divided usually into seven families:

1. 'Canidæ'—Dogs, wolves, foxes and jackals. Partly omnivorous, adapted to swift running and very often hunting in packs. Cosmopolitan.

2. 'Procyonidæ'—Raccoons, omnivorous and arboreal. Found only in the New World.

3. 'Ursidæ'—Bears, omnivorous, terrestrial, and all of large size. Cosmopolitan except Australian region.

4. 'Mustelidæ'—Weasels, martens, skunks, badgers and otters. Mostly predaceous and of small or medium size, found everywhere except in the Australian region.

5. 'Viverridæ'—Civets, mongooses, etc. Mostly predaceous and of small or medium size, confined to the Old World exclusive of Australasia. The few species of Carnivora in Madagascar all belong to this family.

6. 'Hyænidæ.—Hyenas. Predaceous and of large size, found only in Africa and Southern Asia.

7. 'Felidæ'—The cat family, including the lion, tiger and various smaller cats. Strictly predaceous, large or of medium size. Cosmopolitan except Australasia.

The dog family are more adapted for speed than any other carnivora, and the larger species often hunt in packs and run down their prey in the open. They are equally expert in tracking their prey, the sense of smell being very highly developed. Unlike most carnivora, the claws are blunt and are used only for locomotion; and they are quite unable to climb trees. Their range extends from the Arctic regions to the equator, and southward to Patagonia and the Falkland Islands. The true wolves and foxes are mostly found in the northern continents; the jackals are Oriental and African; while the South American canids belong to a somewhat primitive group known as dog-foxes. The dingo is the only member of the carnivora which has entered Australia, but whether introduced by primitive man or naturally is not certainly proven. All of the family are much alike in structure, differing mainly in size, color and habits. They are all included in the genus Canis except four or five species inhabiting India, Africa and South America.

The Raccoons of the New World are more or less related to the dogs, but arboreal, forest-living, nocturnal and omnivorous. The "coon" has a well-deserved reputation for cleverness and cunning, qualities shared by the less known members of the family, the coati, caxomistle and kinkajou of the Central and South American forests. The last-named is the most strictly arboreal of the carnivora; its tail prehensile like the monkeys, which it resembles in habits and food.

The Bears are the largest of the carnivora. They are omnivorous, or rather frugivorous, feeding mostly upon roots and berries. They are long limbed, almost tailless, walk upon the sole of the foot, and the large, sharp claws are used in digging out roots, bulbs, insects and honey, of which last they are extremely fond. Their main subsistence in the summer is upon berries. In the north they hibernate through the winter season of scarcity and cold, coming out in the spring hungry and ravenous, ready to seize and devour anything they can find. In general, however, bears are easy-going, good-natured animals, rarely attacking man, and generally doing their best to escape when attacked, dangerous only when cornered or wounded, when hungry, or when their cubs are endangered. Perhaps an exception should be made of the Polar bear, which is entirely carnivorous, living upon seals, fish, or occasional land animals, and correspondingly savage in temperament.

The bears are chiefly a northern race, but are found in India and the East Indies, in Algeria and in the Andes mountains. The largest species are the huge Kadiak bears of Alaska; the polar bear is almost as large.

The weasel and civet families are mostly small but bloodthirsty and fierce beasts of prey, with long tails, rather short legs, and usually slender "vermiform" bodies. Most of them are terrestrial or partly arboreal, but the weasel family includes also fossorial (badgers) and semi-aquatic types (otters). The largest member of the Mustelidæ is the Glutton or Wolverene of the boreal zone in both Old and New World. The Old World Viverridæ are chiefly found in the Oriental region and in Africa; two or three have reached Madagascar, where they are the only carnivorous animals. The Mustelidæ, on the other hand, are more northern in their distribution, altho found in all the great continents except Australia.

The Hyenas are large Old World carnivores related to the civets, but living in more open country and preying upon larger game. They are commonly called carrion-eaters, but are in fact more like the dogs, tracking and running down live prey or feeding upon carcasses, pretty much as opportunity offers. They are, however, gross and indiscriminate feeders, contrasting in their manner of eating with the more dainty habits of the cats; and the teeth are massive, heavy, usually much worn on the edges. They now inhabit India, Southwestern Asia and Africa, but formerly ranged all over the northern parts of the Old World, never having reached the New. Teeth and bones of hyenas and their prey are the most abundant fossil remains in the "bone-caves" of England and Northern Europe.

The Cats are the most strictly predaceous group of carnivora. They are especially distinguished by the retractile claws—but the claws are slightly retractile in some of the Viverrids—and the teeth are sharper, the shearing action of the carnassials more perfect, the crushing teeth more reduced than in any of the other families. The limbs, especially the fore-limbs, are very flexible and powerful, and they afford perhaps the finest mechanical adaptations for combined strength and agility to be found in the whole animal kingdom. Altho capable of great speed for a short spurt, they are not able to maintain it over long distances; they never run down their prey, but track or lie in wait for it and spring upon it unawares. If they fail to overtake it in the first few bounds they abandon the chase. Cats are all dainty eaters, and among the thousands of skulls in large museum collections it is rare to find one with the teeth much worn, except among the desert species, which must needs encounter considerable loose sand with the food. It is not true, however, that they will not devour an animal which they have not themselves killed.

The largest cats are the lion and tiger, the one inhabiting Africa and Southwestern Asia, the other India and Eastern Asia. The lion is especially an inhabitant of desert or arid countries, and his color matches his surroundings; the brilliant vertical stripes of the tiger are said to be equally effective for concealment in the deep jungles and forests of Southeastern Asia. Both are mainly nocturnal in their habits, as are all the cats.

In the New World, the puma and jaguar correspond to the Old World lion and tiger, but are of smaller size, not exceeding the leopards of the Old World. The lynxes or bob-tailed cats are especially boreal in range, inhabiting the arctic and cold-temperate regions of the northern continents. Various other smaller cats range down to the size of the domestic species, inhabiting all the continents except Australia.

During the latter part of the Tertiary Period lived various carnivora, ancestral or related to the modern kinds. Perhaps the largest of them are the Amphicyons, related to the dogs but equaling the largest bears in size, and apparently similar to them in habits. Unlike bears, they were provided with extremely long and heavy tails, exceeding those of the great cats, while the limbs were rather short.

But the most remarkable of the extinct carnivora are the Saber-toothed Tigers or 'Machaerodonts,' related to the true cats, and similar to them in general proportions and habits, but with the upper canine enlarged into a great compressed fang, slightly curved and with sharp, serrate edges. The jaws were peculiarly loose-hung and could be opened wide enough to allow full play for the action of the tusks, and powerful muscles at the back of the skull enabled the animal to drive them down with tremendous force into the body of an enemy. The legs were short, the muscles exceptionally heavy and powerful. In all respects the Saber-toothed tigers appear to have been especially adapted to prey upon large, thick-skinned, slow-moving quadrupeds. The largest species equalled a grizzly bear in size, the smallest were about as large as a lynx.

In the earlier part of the Tertiary Period there were numerous kinds of carnivores, with much smaller brains than the modern kinds and more primitive in various respects. These are grouped in a distinct sub-order, Creodonta. Some of them were ancestral to the various families of modern carnivores; others have left no descendants. In habits and general appearance these extinct races were much like modern beasts of prey, but the various peculiar features of the several modern races are found in different combinations.

The order Primates includes Lemurs, Monkeys, Apes and Man. In this order are the animals of greatest interest on account of their near relationship to the human race. Cuvier, it is true, placed Man in a separate order of Mammals, Bimana, but almost all other zoölogists, ancient and modern, are agreed in including him in the Primates.

Taken as a whole, this order is preëminently the arboreal group among the Mammalia. Its members are more completely and thoroughly specialized for this mode of life than any other group. The long, slender limbs, flexible joints, opposable thumb, long toes capped with nails instead of claws, the long, powerful and often prehensile tail, are all peculiarly adapted to dwelling among the branches of the forest, as the teeth are to eating the fruits and berries which it affords. The highest primates, however, have departed from the typical habits of the order and become partially or completely terrestrial.

It is probably to the stimulus of arboreal life that the Primates owe the beginnings of that higher intelligence which distinguishes them. Travel among the branches of trees affords more continuous opportunities for the exercise of intelligent choice in determining every successive movement than does the more uniform and safer progression upon the surface of the ground or in the water, or the violent but unvarying exercise of flying. One finds that arboreal animals usually rank high in intelligence, as, for instance, the squirrels among rodents, the raccoons among the carnivora, the tree-shrews among insectivora, the opossums among marsupials. In addition, the opposable thumb gives to the primate especial facility in touching and handling objects, and enables him to obtain readily a more exact and complete knowledge of them.

In their skeleton structure this order has departed less from the primitive mammal type than most others. As

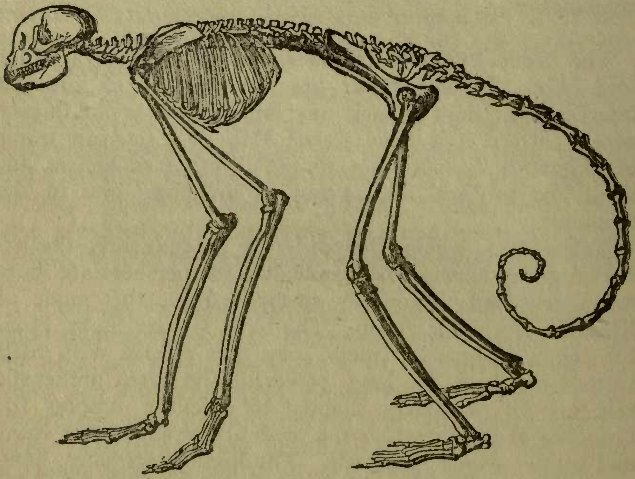


Fig. 41 —Skeleton of the Spider-Monkey.

A type of mammal peculiarly fitted to live among the tree-tops. Note the long, delicate limbs, the flexible five-toed feet, the strong prehensile tail, the short but flexible neck, the large brain. (Flower and Lydekker.)

has been pointed out, the earliest mammals were probably arboreal, and the primates have retained and perfected their adaptation to this mode of life. The most notable lines of progress are in the shortening of the face and enlargement of the brain.

The living primates are divided into two groups—the more primitive lemurs, and the more progressive monkeys, apes and man. The lemurs are chiefly found in Madagascar, but a few of them inhabit Central Africa, India and the East Indies. They have a rather long face, with less reduction in the number of teeth than the higher groups, and in all except the Tarsier the lower incisors project forward instead of upward. The brain also is decidedly smaller and less complex, and they are very noticeably inferior to monkeys in intelligence and activity. They are in fact the little altered survivors of the ancestral primates of the early Tertiary. Some of these ancestral primates gave rise to the more progressive higher types, while others retreated southward to the fringes of the Asiatic continents, or crossed into Africa, and thence reached Madagascar. In the last-named island they found their most congenial home, free from the rivalry or pursuit of the higher types of mammals, and developed into a remarkably large and varied fauna, the largest and most remarkable of which have very recently become extinct. The modern Malagasy lemurs are all arboreal, small or of moderate size, but in the late Pleistocene, probably just before man gained a foothold on the island, there were large lemurs of terrestrial adaptation, paralleling some of the ungulate mammals in their skull, teeth and skeletons; and others with remarkably short face and large brain, paralleling the higher apes. These last, one may suppose, would in the course of time have evolved into creatures paralleling man himself, had not their evolution been cut short by the irruption of the more progressive races developed upon the great northern land mass, in particular by the invasion of early races of man. It should be pointed out that a higher invading race destroys first those inferior races which come most directly into competition with it, while those among the native races, which are of different adaptation and habits, survive, as they do not interfere with the higher race. Man invaded the Malagasy region probably during the Pleistocene (Glacial) epoch; the monkeys have never reached the island. Hence the highly intelligent ground-lemurs, native to the island, which came in competition with him, became extinct; the less intelligent and smaller tree-lemurs have survived, because they did not interfere with man, and had not to compete with monkeys.

Of the higher or Anthropoid section of the Primates, the South American monkeys are the most primitive. All of them are strictly arboreal, one family, Cebidæ, with prehensile tails and opposable thumbs; the other, Hapalidæ, including only the little marmosets, in which the opposability of the thumb has been lost. The marmosets are squirrel-like in size and habits; the Cebidæ are of larger size, but not as large as the Old World monkeys and apes. In all the South American monkeys the nostrils are separated by a broad cartilage, and their apertures look outward. In the Old World monkeys, as in man, the cartilage septum is much reduced, the apertures close together and facing downward.

The Old World monkeys and baboons are united into a single family, but are very various in proportions and appearance. The tail is sometimes long, sometimes short, and many of them are more or less terrestrial, especially the baboons. They inhabit all the tropical parts of the Old World, but except for a species of Macaque that lives on the Rock of Gibraltar, none are found in Europe; nor do they live in Northern Asia north of the Altii Mountains. The Macaques (Macacus) are short-tailed, rather short-faced, Asiatic in range with one species in North Africa and Gibraltar. The Langurs (Semnopithecus) are long-tailed, arboreal monkeys of southern and eastern Asia. The Maugabeys (Cercocebus) are West African, the Guenous (Cercopithecus) are also African, but more widely distributed. Both genera are long-tailed. The baboons (Cynocephalus) are distinguished by the projecting snout with heavy canine teeth; they are mostly of large size, live in herds, and are more omnivorous and ferocious than any other primates.

They are all African or Arabian, except one species from Celebes, and inhabit rocky and mountainous districts, living chiefly upon the ground.

The last group of the Primates to be considered are the Anthropoid Apes of the family Simiidæ. These are of large size, of higher intelligence than any other primates, tailless, and closely allied to man in all respects. They are of arboreal habits, walking when on the ground in a semi-erect position, the long arms reaching the ground but not supporting the main weight of the body, and resting on the back of the fingers instead of the palms as in all lower animals. The skin is partly naked. The jaws, especially in the adult males, are much larger and more projecting than in man, and the brain capacity somewhat less than half that of man, making allowance for the size of the body in different species. The four living types are the Gibbons of Southeastern Asia, the Gorilla and Chimpanzee of the West African forests, and the Orang-Utan of Borneo and Sumatra. It is from some unknown Tertiary members of this family of Apes that the ancestry of Man must be derived. On account of this relationship the Anthropoid Apes have been very carefully studied and described, and their appearance, habits and structure are familiar to every one.

Remains of monkeys allied to the modern South American genera have been found in the Miocene formations of Patagonia. In the Miocene of Europe have been found remains of various monkeys and lower apes of the Old World. Both are probably derived from the Eocene lemurs of Europe and North America. So far as the direct ancestry of the higher apes and man is concerned, the geological record is very incomplete. The most interesting of recent discoveries is the Pithecanthropos of Java, founded upon a part of a skull and a femur which probably (but not certainly) belonged to the same individual, and indicated an animal walking upright like man, but in brain capacity intermediate between man and the higher apes. This species, however, according to the latest investigations, was of Pleistocene age, contemporary with fully developed men, so that it cannot be regarded as a direct ancestor in a genealogical sense.

Since the modern species of anthropoid apes live in Africa and Southern Asia, and the most primitive races of man are also found around the shores of the Indian Ocean, the theory has been advanced that it is to some part of this region that we should look for the discovery of fossil remains of the primates ancestral to man. But in this brief review of the evolution and geological history of the lower races of mammals it has been seen that while in the southern continents and around the southern fringes of the great northern land mass are found numerous primitive survivals of ancient races, yet the main theater of the evolution of most races of mammals, their chief diffusion center, has always been the great land mass of the three northern continents, united more or less completely during a large part of the Tertiary Period. West Africa and southeastern Asia, with the East Indian Islands adjoining it, contain many primitive survivals of races whose evolution center was in the Palæarctic region.

In the present writer's opinion the geological evidence of the ancestry of man and the most direct phylogmy of many mammals will be discovered when the Tertiary formations of Central and Eastern Asia are adequately and thoroly searched for remains of fossil vertebrates. At present they are practically unknown. From the observations of pioneer explorers it is very probably inferred that fossiliferous formations of Tertiary age exist in some parts of this immense region. The revealing of the evidence which they should afford of the true evolutionary history of the higher mammals and of man is the task for the scientific explorers of the twentieth century.

BOTANY

MARION E. LATHAM

BOTANY

CHAPTER I

EARLY DEVELOPMENT

"WHAT is the content and scope of the science of botany?" asks Prof. Herbert Maule Richards, in a recent lecture, and his reply is very true. "Popular opinion," he says, "will answer somewhat easily: Botany consists in the gathering of plants, and the dismembering of them, in connection with the use of a complicated terminology. That is the beginning and end of botany as it is understood by the majority; there is nothing more to be said. In consequence, the employment of the botanist seems so trivial, so very remote from important human interests that no second thought is given to it. The conception formed in ignorance is continued in ignorance. Even the zoölogist is at an advantage, for the public is finally forced to admit that it does not know what he is about, while it understands the botanist very well. He is quite hopeless, for, while flowers may be pretty things to pick, they should not be pulled to pieces, and if he does not happen to be interested in dissecting flowers he is not a botanist but simply a fraud.

"Under botany we have to consider all the questions as to the form, functions, the classification and the distribution of those organisms that are called plants. In the beginning all that was known about plants might be readily comprehended under the simple caption, Botany, but in modern times the rapid accumulation of facts has demanded a segregation of different lines of work. Thus have arisen the divisions of botanical activity, which, for our purposes, may be classed under three heads. First, the taxonomic, or as more commonly called, the systematic side, which has to do with the classification, mainly as established by gross morphology. Second, the morphological field which concerns itself with the outward and inward form and structure and the development thereof, which may or may not have direct relation with taxonomic work. Third, there is the domain of physiology which treats of function.

"Any folk which had so far emerged from the stage of savagery as to stop to notice the world about it would perforce pay some attention to plants. A discrimination of the medicinal uses of plants is often noticeable even in primitive peoples, and with such observation goes also the discrimination of difference in form, the prototype of morphological research.

"In our own civilization we can trace back the history of botany to Aristotle, who affords us some record of the plant forms known at his time, tho the influence which his philosophy wielded, even down to the middle of the last century, was of vastly greater importance than any contribution which he made to botany itself. Theophrastus gave a fuller account of plants, and later came the inquiring and ever curious Pliny. Dioscoridės, however, in the first or second century of our era, was one of the first to investigate plants with any attempt at thoroness even from the standpoint of the knowledge of the time. As is shown especially by Dioscorides' work, the study of plants was largely from their use as drugs, and they were described simply to facilitate their recognition. Any real knowledge of them was naturally meager, and false ideas that clung for a long time, some until comparatively recently, prevented any proper conception of form and function.

"The contributions become of less and less value as we approach the middle ages, the botanical writings of which time were full of the wildest fantasy and superstition. In the sixteenth century in northern Europe, particularly Germany, there was a movement toward the real study of plants from the plants themselves as evidenced by the

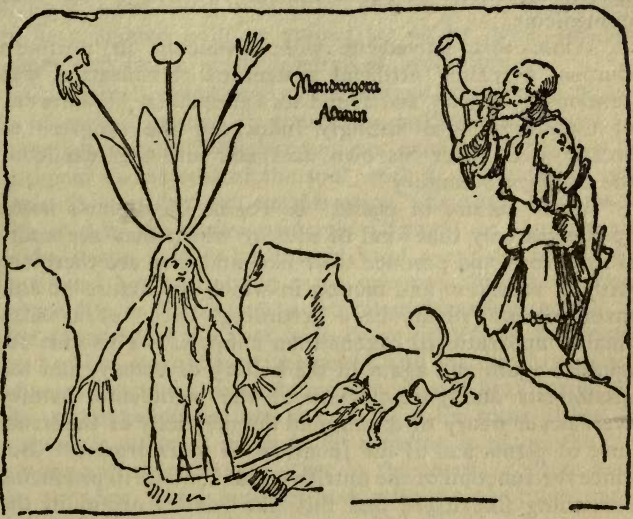


Fig. 1 —The Mandrake.

Medieval drawing, showing fear of fabulous human plant. Dog is pulling out root, as to do so by the hand of man meant loss of immortality. Horn is blown to drown supposed shrieks which caused eternal deafness.

works of the herbalists, but no attempt at classification was made. Here there was an attempt at the enumeration and illustration of plants from living specimens, and confused and empirical as this work was, it was actuated by an honest endeavor to record, as accurately as possible, actual forms, and not fanciful abstractions which never did and never could have existed. All the descriptions were detached from one another and little or no attempt was made at classification, tho by the repeated study of many similar forms the idea of natural relationship began to dawn in a vague way. The actual purpose of all this plant study was the recording of the officinal plants, for special knowledge of plants was still confined to their uses in medicine.

"While this movement was advancing in northern Europe, a mainly artificial system of classification was developing in Italy and found its culmination in the work of Cæsalpino, who strongly influenced the progress of botany, even after his own time and into the middle of the eighteenth century."

"As the nature of plants," so begins Cæsalpino's book, "possesses only that kind of soul by which they are nourished, grow, and produce their like, and they are therefore without sensation and motion in which the nature of animals consists, plants have accordingly need of a much smaller apparatus of organs than animals." This idea reappears again and again in the history of botany, and the anatomists and physiologists of the eighteenth century were never weary of dilating on the simplicity of the structure of plants and of the functions of their organs. "But since the function of the nutritive soul consists in producing something like itself, and this like has its origin in the food for maintaining the life of the individual, or in the seed for continuing the species, perfect plants have at most two parts, which are, however, of the highest necessity; one part called the root by which they procure food; the other by which they bear the fruit."

This conception of the upright stem as the seed-bearer of the plant, which is in the main correct, also was long maintained in botany. It should be observed also that the production of the seed is spoken of as merely another kind of nutrition, a notion which afterward prevented Malpighi from correctly explaining the flower and fruit, and in a modified form led Kaspar Friedrich Wolff in 1759 to a very wrong conception of the nature of the sexual function. The next sentence in Cæsalpino leads into the heart of the Aristotelian misinterpretation of the plant, according to which the root answers to the mouth or stomach, and must therefore be regarded in idea as the upper part altho it is the lower in position, and the plant would have to be compared with an animal set on its head, and the upper and lower parts determined accordingly.

Cæsalpino's discussion of the seat of the soul in plants is of special interest in connection with certain views of later botanists. "Whether any one part in plants can be assigned as the seat of the soul, such as the heart in animals, is a matter for consideration," he says, "for since the soul is the active principle ('actus') of the organic body, it can neither be 'tota in toto' nor 'tota in singulis partibus,' but entirely in some one and chief part, from which life is distributed to the other dependent parts. If the function of the root is to draw food from the earth, and of the stem to bear the seeds, and the two cannot exchange functions, so that the root should bear seeds and the shoot penetrate into the earth, there must either be two souls different in kind and separate in place, the one residing in the root, the other in the shoot, or there must be only one, which supplies both with their peculiar capabilities."

"It may be remarked here," says Julius von Sachs in his 'History of Botany,' "that the point of union between the root and the stem, in which Cæsalpino placed the seat of the plant-soul, afterward received the name of root-neck (collet) ; and tho the Linnæan botanists of the nineteenth century were unaware of what Cæsalpino had proved in the sixteenth, and did not even believe in a soul of plants, they still entertained a superstitious respect for this part of the plant, which is really no part at all; and this, it would seem, explains the fact that an importance scarcely intelligible without reference to history was once attributed to it, especially by some French botanists."

The theoretical introduction to his excellent and copious remarks on the parts of fructification may supply another example of Cæsalpino's peripatetic method: "As the final cause, 'finis,' of plants consists in that propagation which is effected by the seed, while propagation from a shoot is of a more imperfect nature, in so far as plants do exist in a divided state, so the beauty of plants is best shown in the production of seed, for in the number of the parts and the forms and varieties of the seed-vessels the fructification shows a much greater amount of adornment than the unfolding of a shoot; this wonderful beauty proves the delight, 'delitas,' of generating nature in the bringing forth of seeds. Consequently as in animals the seed is an excretion of the most highly refined food-substance in the heart, by the vital warmth and spirit of which it is made fruitful, so also in plants it is necessary that the substance of the seeds should be secreted from the part in which the principle of the natural heat lies, and this part is the pith. For this reason, therefore, the pith of the seed (that is, the substance of the cotyledons and of the endosperm) springs from the moister and purer part of the food, while the husk which surrounds the seed for protection springs from the coarser part. It was unnecessary to separate a special fertilizing substance from the rest of the matter in plants, as it is separated in animals which are thus distinguished as male and female."

This last remark and some lengthy deductions which follow are intended to prove, after the example of Aristotle, the absence and indeed the impossibility of sexuality in plants, and accordingly Cæsalpino goes on to compare the parts of the flower, which he knew better than his contemporaries, with the envelopes of the ova in the fetus of animals, which he regards as organs of protection.

"The doctrine of metamorphosis," suggests Von Sachs, "appears in a more consistent and necessary form in

Cæsalpino than in the botanists of the nineteenth century before Darwin; it flows more immediately from his philosophical views on the nature of plants, and appears therefore up to a certain point thoroly intelligible. We see in Cæsalpino's doctrine of metamorphosis without doubt the theory of the flower afterward adopted by Linnæus, tho in a somewhat different form." That Linnæas himself regarded the theory ascribed to him on the nature of the flower as the opinion of Cæsalpino also, is shown in his 'Classes Plantarum,' where in describing Cæsalpino's system he says: "He regarded the flower as the interior portions of the plant, which emerge from the bursting rind; the calyx as a thicker portion of the rind of the shoot; the corolla as an inner and thinner rind; the stamens as the interior fibers of the wood, and the pistil as the pith of the plant."

But, to do Cæsalpino justice, it would be necessary to give a full account of his very numerous, accurate and often acute observations on the position of leaves, the formation of fruits, the distribution of seeds and their position in the fruit, of his comparative observations on the parts of the fruit in different plants, and above all of his very excellent description of plants with tendrils and climbing plants, of those that are armed with thorns and the like. Tho there is naturally much that is erroneous and inexact in his accounts, yet in the chapters on these subjects may be seen the first beginning of a comparative morphology, which quite casts into the shade all that Aristotle and Theophrastus have said on the subject. But the most brilliant portions of his general botany are those in which he gives the outlines of his views on the systematic arrangement of plants.

All that Cæsalpino says on systematic arrangement shows that he was perfectly clear in his own mind with regard to the distinction between a division on subjective grounds, and one that respects the inner nature of plants themselves, and that he accepted the latter as the only true one. He says, for instance: "We seek out similarities and dissimilarities of form, in which the essence, 'substantia,' of plants consists, but not of things which are merely accidents of them, 'quæ accidunt ipsis.'" Medicinal virtues and other useful qualities are, he says, just such accidents. Here the path is opened, along which all scientific arrangement must proceed, if it is to exhibit real natural affinities, but at the same time there is a warning already of the error which beset systematic botany up to Darwin's time; if in the above sentence he substituted the word idea for that of substance, and the two expressions have much the same meaning in the Aristotelian and Platonic view of nature, will be recognised the modern pre-Darwinian doctrine, that species, genera, and families represent 'ideam quandam' and 'quoddam supranaturale.'

The next great figure in botanical science was Joachim Jung. He was born in Lübeck in the year 1587, and died after an eventful life in 1657. He was a contemporary of Kepler, Galileo, Vesal, Bacon, Gassendi, and Descartes. After having been already a professor in Giessen, he applied himself to the study of medicine in Rostock, was in Padua in 1618 and 1619, and there, as may confidently be believed, became acquainted with the botanical doctrines of Cæsalpino, who had died fifteen years before. He occupied himself with the philosophy of the day, in which he appeared as an opponent of scholasticism and of Aristotle, and also with various branches of science, mathematics, physics, mineralogy, zoölogy, and botany. In 1662 his pupil, Martin Fogel, printed the 'Doxoscopiæ Physicæ Minores,' a work of enormous compass left in manuscript at the master's death, and another pupil, Johann Vagetius, the 'Isagoge Phytoscopica,' in 1678. Ray, however, states that a copy of notes on botanical subjects had already reached England in 1660. He was the first who objected to the traditional division of plants into trees and herbs as not founded on their true nature. But how firmly this old dogma was established is well shown by the fact that

Ray at the end of the century still retained this division, tho he founded his botanical theories on the 'Isagoge' of Jung. Jung was in advance of Cæsalpino and his own contemporaries in repeatedly expressing his doubt of the existence of spontaneous generation.

"The 'Isagoge Phytoscopica,' a system of theoretical botany," says Von Sachs, "very concisely written and in the form of propositions arranged in strict logical sequence, was a more important work and had more lasting effects upon the history of botany. The first chapter of the 'Isagoge' discusses the distinction between plants and animals. A plant is, according to Jung, a living but not a sentient body; or it is a body attached to a fixed spot or a fixed substratum, from which it can obtain immediate nourishment, grow and propagate itself. A plant feeds when it transforms the nourishment which it takes up into the substance of its parts, in order to replace what has been dissipated by its natural heat and interior fire. A plant grows when it adds more substance than has been dissipated, and thus becomes larger and forms new parts. The growth of plants is distinguished from that of animals by the circumstance that their parts are not all growing at the same time, for leaves and shoots cease to grow as soon as they arrive at maturity; but then new leaves, shoots, and flowers are produced. A plant is said to propagate itself when it produces another specifically like itself; this is the idea in its broader acceptation. We see that here, as in Cæsalpino, the idea of the species is connected with that of propagation.

"The second chapter, headed 'Plantæ Partitio,' treats of the most important morphological relations in the external differentiation of plants; here Jung adheres essentially to Cæsalpino's view, that the whole body in all plants, except the lowest forms, is composed of two chief parts, the root as the organ which takes up the food, and the stem above the ground which bears the fructification. Jung's theory of the flower suffers, as in Cæsalpino, from his entire ignorance of the difference of sexes in plants, which is sufficient to render any satisfactory definition of the idea of a flower impossible."

While Cæsalpino, Kaspar Bauhin, and Jung stand as solitary forms each in his own generation, the last thirty years of the seventeenth century are marked by the stirring activity of a number of contemporary botanists. While during this period physics were making rapid advances in the hands of Newton, philosophy in those of Locke and Leibnitz, and the anatomy and physiology of plants by the labors of Malpighi and Grew, systematic botany was also being developed, tho by no means to the same extent or with equally profound results, by Morison, Ray, Bachmann (Rivinus), and Tournefort. The works of these men and of their less gifted adherents, following rapidly upon or partly synchronous with each other, led to an exchange of opinions and sometimes to polemical discussion, such as had not before arisen on botanical subjects; this abundance of literature, with the increased animation of its style, excited a more permanent interest, which spread beyond the narrow circle of the professional adepts.

Carl Linnæus, called Carl von Linné after 1757, was born in 1707 at Rashult in Sweden, where his father was preacher. Linnæus is commonly regarded as the reformer of the natural sciences which are distinguished by the term descriptive, and it is usual to say that a new epoch in the history of our science begins with him, as a new astronomy began with Copernicus and new physics with Galileo. "This conception of Linnæus' historical position," Von Sachs points out, "as far at least as his chief subject, botany, is concerned, can only be entertained by one who is not acquainted with the works of Cæsalpino, Jung, Ray and Bachmann, or who disregards the numerous quotations from them in Linnæus' theoretical writings. On the contrary, Linnæus is preëminently the last link in the chain of development represented by the above-named writers; the field of view and the ideas of Linnæus are substantially the same as theirs; he shares with them in the fundamental errors of the time, and indeed essentially contributed to transmit them to the nineteenth century. But to maintain that Linnæus marks not the beginning of a new epoch, but the conclusion of an old one, does not at all imply that his labors had no influence upon the time that followed him."

If the works of the earlier botanists are compared with Linnæus' 'Fundamenta Botanica' (1736), his 'Classes Plantarum' (1738) and his 'Philosophia Botanica' (1751). it becomes evident that the ideas on which his theories are based are to be found scattered up and down in the works of his predecessors. Further, whoever has traced the history of the sexual theory from the time of Camerarius (1694), must allow that Linnæus added nothing new to it, tho he contributed essentially to its recognition. But that which gave Linnæus so overwhelming an importance for his own time was the skilful way in which he gathered up all that had been done before him; this fusing together of the scattered acquisitions of the past is the great and characteristic merit of Linnæus.

Cæsalpino was the first who introduced Aristotelian modes of thought into botany; his system was intended to be a natural one, but it was in reality extremely unnatural; Linnæus, in whose works the profound impression which he had received from Cæsalpino is everywhere to be traced, retained all that was important in his predecessor's views, but perceived at the same time what no one before him had perceived, that the method pursued by Cæsalpino could never do justice to those natural affinities which it was his object to discover, and that in this way only an artificial tho very serviceable arrangement could be attained, while the exhibition of natural affinities must be sought by other means.

As regards the terminology of the parts of plants, which was all that the morphology of the day attempted, Lin-

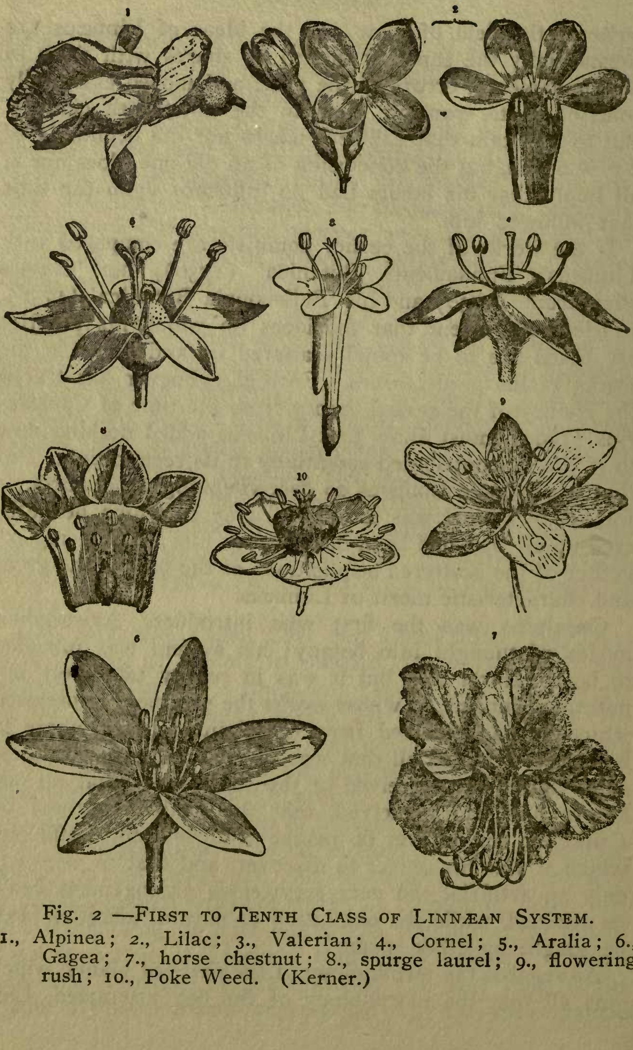


Fig. 2 —First to Tenth Class of Linnæan System.
1., Alpinea; 2., Lilac; 3., Valerian; 4., Cornel; 5., Aralia; 6., Gagea; 7., horse chestnut; 8., spurge laurel; 9., flowering rush; 10., Poke Weed. (Kerner.)

næus simply adopted all that was contained in the 'Isagoge' of Jung, but gave it a more perspicuous form, and advanced the theory of the flower by accepting without hesitation the sexual importance of the stamens, which was still but little attended to; he thus arrived at a better general conception of the flower, and this bore fruit again in a terminology which is as clear as it is convenient. But there was one great misconception in the matter, which has not a little contributed to increase Linnæus' reputation. He called his artificial system, founded on the number, union and grouping of the stamens and carpels, the sexual system of plants, because he rested its supposed superiority on the fact that it was founded upon organs the function of which lays claim to the very highest importance. But it is obvious that the sexual system of Linnæus would have the same value for the purposes of classification, if the stamens had nothing whatever to do with propagation, or if their sexual significance were quite unknown. For it is exactly those characters of the stamens which Linnæus employs for purposes of classification, their number and mode of union, which are matter of entire indifference as regards the sexual function.

Linnæus distinctly declared it was his view that the highest and only worthy task of a botanist was to know all species of the vegetable kingdom exactly by name, and his school in Germany and England adhered to it so firmly that it established itself with the general public, who to the present day consider it as a self-evident proposition that a botanist exists essentially for the purpose of at once designating any and every plant by a name. Like his predecessors, Linnæus regarded morphology and general theoretical botany only as means to be used for discovering the principles of terminology and definition, with a view to the improvement of the art of describing plants.

"The most pernicious feature in scholasticism and the Aristotelian philosophy is the confounding of mere conceptions and words with the objective reality of the things denoted by them," says Von Sachs upon this point. "Men took a special pleasure in deducing the nature of things from the original meaning of the words, and even the question of the existence or non-existence of a thing was answered from the idea of it. This way of thinking is found everywhere in Linnæus, not only where he is busy as systematist and describer, but where he wishes to give information on the nature of plants and the phenomena of their life. Linnæus cared little for experimental proof; he expends all his art on a genuine scholastic demonstration intended to prove the existence of sexuality as arising necessarily from the nature of the plant."

On the whole the superiority of Linnæus lay in his natural gift for discriminating and classifying the objects which engaged his attention; he might almost be said to have been a classifying, coördinating and subordinating machine. He dealt with all about which he wrote in the way in which he dealt with objects of natural history.

"In any attempt to estimate the advance which the science owes to the labors of Linnæus," says the former writer, "the chief prominence must be assigned to two points: First to his success in carrying out the binary nomenclature in connection with the careful and methodical study which he bestowed on the distinguishing of genera and species; this system of nomenclature he endeavored to extend to the whole of the then known vegetable world, and thus descriptive botany in its narrower sense assumed through his instrumentality an entirely new form. The second merit is that while he framed his artificial sexual system, he exhibited a fragment of a natural system by its side and repeatedly declared that the chief task of botanists is to discover the natural system. Thus he cleared the ground for systematic botany."

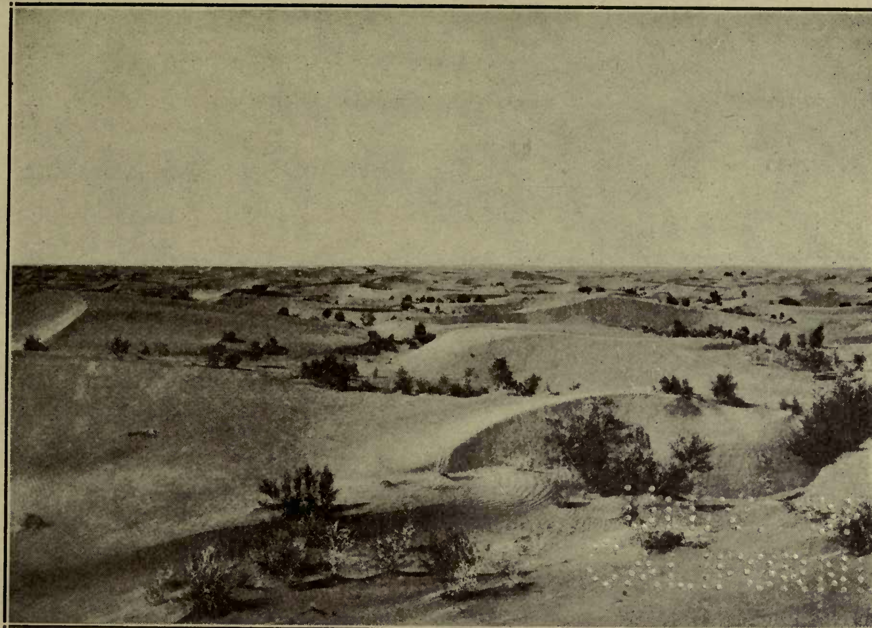
The main features of Linnæus' theoretical botany can best be learned from the 'Philosophia Botanica,' which may be regarded as a text-book of that which Linnæus called botany and which far surpasses all earlier compositions of the kind in perspicuity and precision and in copiousness of material, and indeed it would be difficult to find in the ninety years after 1781 a text-book of botany which treats what was known on the subject at each period with equal clearness and completeness. The vegetable world, says Linnæus, comprises seven families, Fungi, Algæ, Mosses, Ferns, Grasses, Palms and Plants. All are composed of three kinds of vessels, sap-vessels which convey the fluids, tubes which store up the sap in their cavities and tracheæ which take in air; these statements Linnæus adopts from Malpighi and Grew.

The parts in the individual plant which the beginner must distinguish are three: the root, the herb and the parts of fructification, in which enumeration Linnæus departs from his predecessors, by whom the fructification and the herb together are opposed to the root. In the central part of the plant is the pith, enclosed by the wood which is formed from the bast; the bast is distinct from the rind, which again is covered by the epidermis; these anatomical facts are from Malpighi; the statement that the pith grows by extending itself and its envelopes is borrowed from Mariotte.

The root, which takes up the food, and produces the stem and the fructification, consists of pith, wood, bast and rind, and is divided into the two parts, 'caudex' and 'radicula.' The 'caudex' answers pretty nearly to the modern primary root and rhizomes, the 'radicula' to what is now called secondary roots. The herb springs from the root and is terminated by the fructification; it consists of the stem, leaves, leaf-supports ('fulcrum') and the organs of hibernation ('hibernaculum'). Then follow the further distinctions of stem and leaves, the terminology, still partly in use and resting essentially on the definitions of Jung, is here set forth in great detail. Linnæus, however, does not mention the remarkable distinction between stem and leaf which Jung founded on relations of symmetry. In this course of mixing up morphological and biological relations of organs he was followed by botanists till late into the nineteenth century.

Linnæus goes far beyond his predecessors in distinguishing and naming the organs of fructification. The fructification, he says, is a temporary part in plants devoted to propagation, terminating the old and beginning the new. He distinguishes the following seven parts: (1) The calyx, which represents the rind, including in this term the involucre of the Umbelliferæ, the spathe, the calyptra of Mosses and even the volva of certain Fungi, another instance of the way in which Linnæus was guided by external appearance in his terminology of the parts of plants; (2) the corolla, which represents the inner rind (bast) of the plant; (3) the stamen, which produces the pollen; (4) the pistil, which is attached to the fruit and receives the pollen; here for the first time the ovary, style and stigma are clearly distinguished. But next comes as a special organ (5) the pericarp, the ovary which contains the seed. Nevertheless Linnæus distinguishes the different forms of fruit much better than his predecessors had done. (6) The seed is a part of the plant that falls off from it, the rudiment of a new plant, and it is excited to active life by the pollen. The treatment of the seed and its parts is the feeblest of all Linnæus' efforts; he follows Cæsalpino, but his account of the parts of the seed is much more imperfect than that of Cæsalpino and his successors. (7) By the word 'receptaculum' he understands everything by which the parts of the fructification are connected together, both the 'receptaculum proprium,' which unites the parts of the single flower, and the 'receptaculum commune,' under which term he comprises the most diverse forms of inflorescence (umbel, cyme, spadix).

He concludes with the remark that the essence of the flower consists in the anther and the stigma, that of the fruit in the seed, that of the fructification in the flower and the fruit and that of all vegetable forms in the fructification, and he adds a long list of distinctions between the



Desert Vegetation, Russian Turkestan.

organs of fructification with their names; among these organs appear the nectaries, which he was the first to distinguish.

From Linnæus the advance was more rapid, and, while most of the study in plants centered on the work of classification, there were unmistakable signs of other interests. The ideas of the classified were still hampered by the dogma of the constancy of species, which continually clashed with the insistent and undeniable evidences of the genetic relationships of organic forms. Despite the movement in favor of the idea of the development of species from previously existing forms, despite the views advanced by Lamarck and others at about that time, despite, indeed, the more strictly botanical investigations in the morphological field which were brought forward during the first half of the nineteenth century—despite all these things, the botanist was unable to break away from the concept of groups of plants as abstract ideas.

It was not until 1859 that the publication of Darwin's 'Origin of Species' drove biologists to a different point of view. Then the rational idea of the evolution of organic forms explained in a similar rational fashion the observed genetic relationships of groups of plants. "No longer," says Richards, "did the classifier hesitatingly admit the possibility of the evolution of species and deny that of genera and higher groups, no longer did he maintain his artificial groups, which had no more relation to each other than successive throws of dice, but he admitted the whole great scheme implied by the evolution of organic forms from preëxisting types."

"The natural system was rightly appreciated by Linnæus," says Asa Gray in his 'Structural Botany,' "who pronounced it to be the first and last desideratum in systematic botany; and he early attempted to collocate most known genera under natural orders, but without definition or arrangement. In his later years he was unable to accomplish anything more." The difficult problem was taken up by Linnæus' contemporary and correspondent, Bernard de Jussieu. His pupil, Adanson, published in 1763, in his 'Familles des Plantes,' the first complete system of natural orders. Adanson himself thus defines his idea of species: "The moderns define a species of plant as a collection of several individuals which resemble each other perfectly, yet not in everything, but in the essential parts and qualities, without, however, giving attention to the differences caused in these individuals either by sex or accidental varieties.

Antoine Laurent de Jussieu, nephew of Bernard, followed Adanson. "He has been called the founder of the natural system of Botany," says Asa Gray, "and to him more than to any other one person this honor may be ascribed. In his 'Genera Plantarum secundum Ordines Naturales disposita,' 1789, natural orders of plants, one hundred in number, were first established and defined by proper characters, and nearly all known genera arranged under them."

The next great systematist was Auguste Pyrame de Candolle. Reversing the order of Jussieu, who proceeded from the lower or simpler to the higher or more complex forms, De Candolle began with the latter, the phenogamous or flowering plants, and with those having typically complete flowers. De Candolle's interest was perhaps more from a morphological point of view, altho he is to be regarded as a systematist, and from that standpoint it will be seen later that his work was of the first importance.

John Lindley in successive attempts (between 1830 and 1845) variously modified and in some few respects improved the Candollean arrangement. Robert Brown, next to Jussieu, did more than any other botanist for the proper establishment and correct characterization of the natural orders. Stephen Ladislaus Endlicer, of Vienna, a contemporary of Lindley, of less botanical genius but of great erudition and aptness for classification, brought out his complete 'Genera Plantarum secundum Ordines Naturales disposita' between the years 1836 and 1840. The 'Genera Plantarum' of Bentham and Hooker adopts in a general way the Candollean sequence of order with various emendations, divides the class of Dicotyledons into two subclasses, Angiosperms and Gymnosperms, with still further divisions in the Angiosperms.

In this country botanists have to thank the labors of John Torrey and Asa Gray for the firm foundation upon which the knowledge of American flora is built. Of the two, Asa Gray was by far the broader in his interests and is regarded by many as the father of American botany. He had considerable knowledge of other fields than that of mere systematic botany of the higher plants and was perhaps the ablest protagonist whom Darwin had in this country. He wrote numerous papers in defense of the then new theory of the origin of species. His main work, however, was the taxonomic study of the flora of North America.

Discussion of the definition of species, how much a species includes and of what constitutes a variety is at present a foremost question among taxonomists, and the effort seems to look toward simplification and lessening of the numbers already formed. Linnæus tells in his 'Philosophia Botanica' (1751): "We enumerate as many species as different forms were originally created." He also says, "There are as many species as the Infinite Being originally produced different forms, and these forms, following the laws of reproduction imposed upon them, have produced more, but always similar to themselves. Therefore there are as many species as there are different forms or structures met with to-day."

The idea of a species set forth by Lamarck is thus defined: "In botany as in zoölogy a species is necessarily constituted of the aggregation of similar individuals which perpetuate themselves, the same, by reproduction. I understand similarity in the essential qualities of the species, because the individuals which constitute it offer frequently accidental differences, which give rise to varieties and sometimes sexual differences, which belong, however, to the same species, as the male and female hemp, in which all the individuals constitute the common cultivated hemp. Thus, without the constant reproduction of similar individuals, there could not exist a true species."

De Candolle and Sprengle say that "by species we understand a number of plants which agree with one another in invariable marks. No doubt there were in the preceding state of our globe other species of plants which have now perished and the remains of which we still find in impressions in shale, slate-clay and other floetz rocks. Whether the present species, which often resemble these, have arisen from them; whether the great revolutions on the surface of the earth, which we read in the Book of Nature, contributed to these transitions, we know not. What we know is that from as early a time as the human race has left memorials of its existence upon the earth the separate species of plants have maintained the same properties invariably.

"To be sure, we frequently speak of the transitions and crossings of species; and it cannot be denied that something of this kind does not occur, tho without affecting the idea of species which we have proposed. We must, therefore, understand this difference. Species only appear to undergo transitions when we have considered an organ or a property as invariable, which is not so.

"All properties of plants which are subject to change form either a sub-species or a variety. By the former we understand such forms as continue indeed during some reproductions, but at last, by a greater difference of soil, of climate and of treatment, are either lost or changed." John Lindley in his 'Introduction to Botany' defines species as "a union of individuals agreeing with each other in all essential characters of vegetation and fructification, capable of reproduction by seed without change, breeding freely together and producing perfect seed from which a fertile progeny can be reared."

To Asa Gray "species in biological natural history is a chain or series of organisms of which the links or component individuals are parent and offspring. Objectively a species is the totality of beings which have come from one stock, in virtue of that most general fact that likeness is transmitted from parent to progeny.

"The two elements of species are (1) community of origin and (2) similarity of the component individuals. But the degree of similarity is variable, and the fact of genetic relationship can seldom be established by observation or historical evidence. It is from the likeness that the naturalist ordinarily decides that such and such individuals belong to one species. Still the likeness is a consequence of the genetic relationship, so that the latter is the real foundation of species.

"Varieties are forms of species marked by characters of less fixity or importance than are the species themselves. They may be of all grades of difference from the slightest to the most notable; they abound in free nature, but assume particular importance under domestication and cultivation, under which variations are prone to originate, and desirable ones are preserved, led on to further development and relatively fixed."

Charles Darwin, whose work has done so much to put all natural sciences upon their present basis of experimental observation, does not commit himself to an actual statement. He says that "no one definition has satisfied all naturalists; yet every naturalist knows vaguely what he means when he speaks of a species. The term variety is almost equally difficult to define, but here community of descent is almost universally implied, tho it can rarely be proved."

"All the individual plants which resemble each other sufficiently to make us conclude that they are all or may have been all descended from a common parent" are included in one species by George Bentham. "These individuals may often differ from each other in many striking particulars, such as the color of the flower, size of the leaf, etc., but these particulars are such as experience teaches us are liable to vary in the seedlings raised from one individual. When a large number of the individuals of a species differ from the others in any striking particular, they constitute a variety." Britton and Brown consider that "a species is composed of all the individuals of a kind capable of continuous successive propagation among themselves."

"Nature produces individuals," declares Charles E. Bessey, "and nothing more. She produces them in such countless numbers that we are compelled to sort them into kinds in order that we may be able to carry them in our minds. This sorting is classification-taxonomy. But right here we are in danger of misunderstanding the matter. We do not actually sort out our individuals. We imagine them sorted out. It is only to a very slight extent that the systematic botanist ever actually sorts out individuals.

"So species have no actual existence in nature. They are mental concepts and nothing more. They are conceived in order to save ourselves the labor of thinking in terms of individuals, and they must be so framed that they do save us labor."

"It should be borne in mind," ably summarizes Asa Gray, "that the natural system of botany is natural only in the constitution of its genera, tribes, orders, etc., and in its grand divisions; that its cohorts and the like are as yet only tentative groupings, and that the putting together of any or all these parts in a system, and especially in a lineal order, necessary as a lineal arrangement is, must needs be largely artificial. So that even the best perfected arrangements must always fail to give of themselves more than an imperfect and considerably distorted reflection of the plan of the vegetable kingdom or even of our knowledge of it."

CHAPTER II

PLANT STRUCTURES

THE work of the earlier botanists was given over to two main objects, the classification of species and varieties in a manner that should most readily account for the entire system, and the determination of a true basis for such a taxonomic classification, requiring a somewhat close study of the morphology and the physiology of the plant. The later botanists, beginning mainly from the bases laid down by Linnæus, developed the Science of Botany into a study of no little complexity; and questions arose, of intense interest in themselves, but which took for granted a basic knowledge of these simpler matters of structure and of classification. As it would be difficult to carry the development of botanical thought up to its modern complexity without an assurance that the reader was conversant with the general outline, it is thought wiser to touch on it briefly here.

Plants are differentiated from each other by certain variances of their parts, which again reveal causes deeper still. Wherefore an understanding of the nature of these parts should precede a statement of their differences.

Just as the man has various members, by which he sees, hears, feels, so have the plants several kinds of organs. The advantage of this to the plant becomes plain by using the common illustration of the difference between a tribe of savages and a civilized community. Several kinds of organs in a plant mean to the plant just what division of labor means to the community; it results in better work and more work.

All the work done by plants comes under two heads: nutrition and reproduction. This means that every plant must care for two things, (1) the support of its own body (nutrition), and (2) the production of other plants like itself (reproduction). To the great work of nutrition many kinds of work contribute, and the same is true of reproduction. In a complex plant, therefore, there are certain organs which specially contribute to the work of nutrition and others which are specially concerned with the work of reproduction.

The plant is extremely dependent upon its surroundings, more so because of its lack of locomotion. For example, it must receive material from the outside and get rid of waste material. Therefore, organs must establish certain definite relations with things outside of themselves before they can work effectively; and these necessary relations are known as life-relations. For example, green leaves are definitely related to light—they cannot do their peculiar work without it; many roots must be related to the soil; certain plants are related to abundant water; some plants, such as parasites, are related to other plants. Each organ, therefore, must become adjusted to a complete set of relations, and a plant with several organs has many delicate adjustments to care for. Three conspicuous organs, root, stem and leaf, are concerned with nutrition; and most of these plants have at some time also another structure, the flower, which is concerned with reproduction.

On examining an ordinary leaf, the blade is seen to consist of a green substance through which a network of veins is distributed. The larger veins that enter the blade send off smaller veinlets that are invisible. This is plainly shown by a skeleton leaf, wherein it appears that the vein system or venation of leaves is exceedingly diverse, altho all forms can be referred to a few general plans.

In some leaves a single very prominent vein known as the midrib runs through the middle of the blade. From this all the minor veins arise as branches, and such a leaf is said to be pinnately veined. In other leaves several large veins (ribs) of equal prominence enter the blade

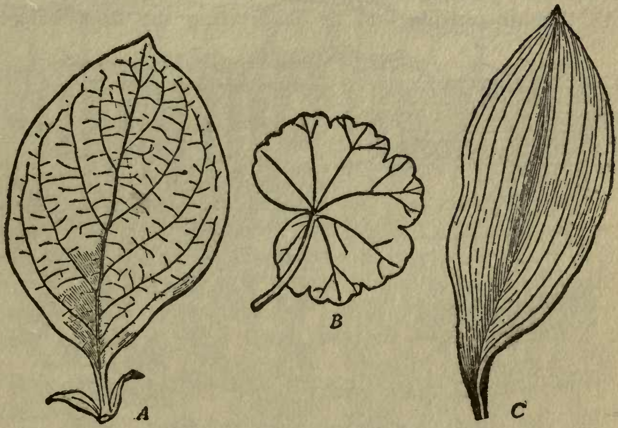


Fig. 3 —Types of Venation.
A., pinnately veined leaf of quince; B., palmately veined leaf of geranium; C., parallel-veined leaf of lily of the valley.

and diverge, each giving rise to smaller branches. Such a leaf is said to be palmately veined. In still other leaves all the visible veins run approximately parallel from the base of the blade to its apex, such leaves being parallel-veined, as distinct from the two preceding, which are both net-veined.

The upper and the under surface of a leaf is covered by a delicate transparent skin (epidermis), which generally shows no green color. "Examined under the compound microscope," says John M. Coulter, "it is seen to be made up of small units of structure known as cells. Each cell is bounded by a wall, and in the epidermis these cells fit closely together, sometimes dovetailing with one another. Characteristic openings in the epidermis also will be discovered, sometimes in very great numbers. The whole apparatus is known as a stoma. These numerous openings are the stomata, which give passageway into the interior of the leaf, putting the internal cells into communication with the air outside and so facilitating the interchange

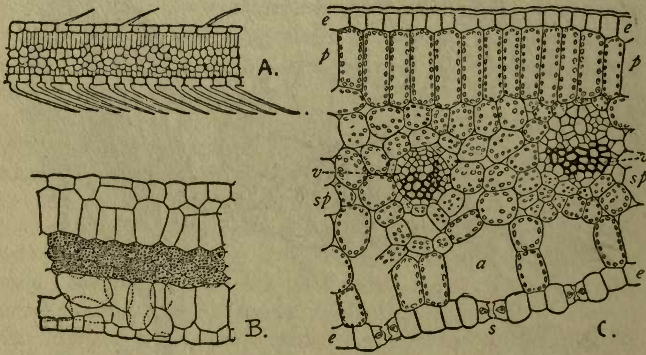


Fig. 4 —Cross-sections of Leaves.
A., bush clover; B., begonia; C., lily.

of gases. The size of these apertures may vary under different conditions.

"Between these two epidermal layers is the mass of green tissue making up the body of the leaf, and known as mesophyll. This comprises cells containing the numerous small green bodies (chloroplasts) that give color to the whole leaf. Usually the mesophyll cells are arranged differently in the upper and lower regions of the horizontal leaf. In the upper region the cells just beneath the epidermis are elongated at right angles to the surface of the leaf, and stand in close contact, forming the palisade tissue. In the lower region of the leaf the cells are irregular in form, and so loosely arranged as to leave air space between the cells, the whole region forming the spongy tissue. The air spaces communicate with one another, thus forming a labyrinthine system of air chambers throughout the spongy mesophyll. It is into this system

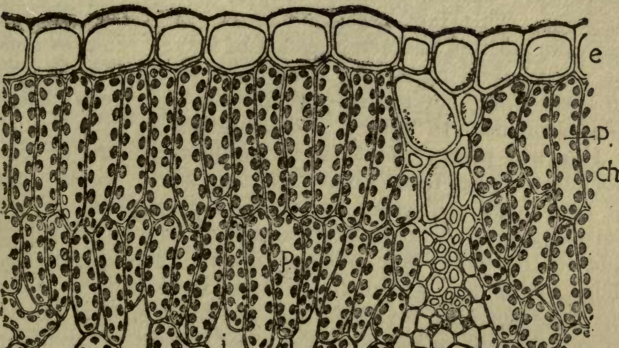


Fig. 5 —Upper Layers of Lilac Leaf.
e., epidermis; p., palisade mesophyll; ch., chloroplast; sp., spongy mesophyll; i., intercellular spaces; v., small vein cut across; l., end of vein; col., collecting cells; s., stoma. (Hanson.)

of air chambers that the stomata open, and thus what may be called an internal atmosphere is in contact with all the green working cells, and this internal atmosphere is in free communication, through the stomata, with the external atmosphere."

"In general," says G. F. Atkinson, "the function of the foliage leaf as an organ of the plant is five-fold: (1) That of carbon-dioxide assimilation; (2) that of transpiration; (3) that of the synthesis of other organic compounds; (4) that of respiration; (5) that of assimilation proper or the making of new living substances."

The importance of the work of leaves is apparent, but this work cannot be done unless the leaf is exposed to light. This fact explains many things in connection with the position and arrangement of leaves. Leaves must be arranged to receive as much light as possible to help in their work, but too intense light is dangerous; hence the adjustment to light is a delicate one.

If green plants should stop the manufacture of carbohydrates the food supply of the world would soon be exhausted. All other forms of food are derived from carbohydrates in some way, and only green plants can add to the stock that is being drawn upon continually. This means that green plants must manufacture carbohydrates not only for their own use but also for the use of animals, and of plants that are not green. Since leaves are chiefly expansions of green tissue, they are conspicuous in the manufacture of carbohydrates.

It must be remembered that the manufacture goes on wherever there is green tissue, whether it is found in leaves or not. A very conspicuous fact about this manufacture is that it cannot go on unless the green tissue is exposed to light. This explains why leaves are adjusted in so many ways to obtain light.

It also gives name to the process, photosynthesis, the name indicating that the work is done in the presence of light. The process demands that carbohydrates shall be made from raw materials common in nature and easily obtained by plants, and in photosynthesis two such substances are used. One of these is water, which in the plants commonly thought of is absorbed by the roots from the soil. The other substance is carbon dioxide, a gas present in small proportion in the air (really in the form of carbonic acid gas), but one which is being constantly renewed as it is used, so that it is always available. Water is made up of one part of oxygen and two parts of hydrogen, while carbon dioxide consists of two parts of oxygen and one part of carbon. These are just the elements that enter into the structure of a carbohydrate.

In photosynthesis the elements of water and carbon dioxide are separated, and recombined to form a carbohydrate, and in this process oxygen is a waste product and is given off by the working cells. Therefore, in the sunlight a leaf is absorbing carbon dioxide and giving off oxygen, and this gas exchange is the superficial indication that photosynthesis is going on.

"Such an important organ as the leaf," says Coulter again, "with its delicate active cells necessarily in communication with the air, is exposed to numerous dangers. Conspicuous among these dangers are drought, intense light and cold. Perhaps the most common danger to most plants is an excessive loss of water, and when a drought prevails the problem of checking transpiration is a most serious one. As the leaves are the prominent transpiring organs, the chief methods of protection concern them.

The epidermis may be regarded as an ever-present check against transpiration, for without it the active mesophyll cells would soon lose all their water. In some plants of very dry regions what may be regarded as several epidermal layers appear. The cuticle which is often developed upon the epidermis is one of the best protections against loss of water. It is developed by the exposed walls of the epidermal cells, and being constantly renewed from beneath, it may become very thick and many-layered. In dry regions, or in any much exposed place, the cuticle is a very constant feature of plants.

"In many leaves," remarks Atkinson, "certain of the cells of the epidermis grow out into the form of hairs or scales." They may form only a slightly downy covering or the leaf may be covered by a woolly or feltlike mass so that the epidermis is entirely concealed. In dry or cold regions the hairy covering of leaves is very noticeable, often giving them a brilliant silky white or bronze look.

In dry regions each leaf endeavors to expose as small a surface in proportion to substance to the drying air and intense light. That this reduction in size holds a direct relation to the dry conditions is evident from the fact that the same plant often produces small leaves in a dry region and larger ones in moist conditions. In the case of the cactus, a large group in the dry regions of

Fig. 6 —Day (A.) and Night (B.) Positions of a Clover-like Plant.

the Southwest, the leaves have become so much reduced that they are no longer used in photosynthesis, and this process is carried on by the green tissue of the globular, cylindrical, or flattened stems. The rosette habit is a very common method of protection used by small plants growing in exposed situations, as bare rocks and sandy ground. The clustered, overlapping leaves form a very effective arrangement for resisting intense light or drought.

There are leaves which can shift their positions according to their needs, directing their flat surfaces toward the light, or more or less inclining them. Such leaves have been developed most extensively in the great family to which peas and beans belong, the most conspicuous ones being those of the so-called sensitive plants. The name has been given because the leaves respond to various external influences by changing position with remarkable rapidity. A slight touch, or even jarring, will call forth a response from the leaves, and the sudden application of heat gives striking results.

Insect-devouring plants usually grow in swampy regions, the leaves forming small rosettes upon the ground. In one

Fig. 7 —Sensitive Plant Before and After Shock.

form of sundew the blade is round and the margin is beset by prominent bristle-like hairs, each with a globular gland at its tip. Shorter gland-bearing hairs are scattered also over the inner surface of the blade. All these glands excrete a clear, sticky fluid, which hangs to them like dewdrops, and which, not being dissipated by sunlight, has suggested the name sundew. If a small insect becomes entangled in one of the sticky drops the hair begins to curve inward, and presently presses its victim down upon the surface of the blade. The famous 'Venus Flytrap' is found only in certain sandy swamps in North Carolina.

The leaf-blade is constructed so as to work like a steel trap, the two halves snapping together, and the marginal bristles interlocking. A few sensitive hairs, like feelers, are developed on the leaf surface, and when one of these is touched by a small flying or hovering insect the trap snaps shut and the insect is caught. Only after digestion, which is a slow process, does the trap open again.

The stem is distinguished as that part of the plant which bears the leaves. "It has for its chief function," says C. C.

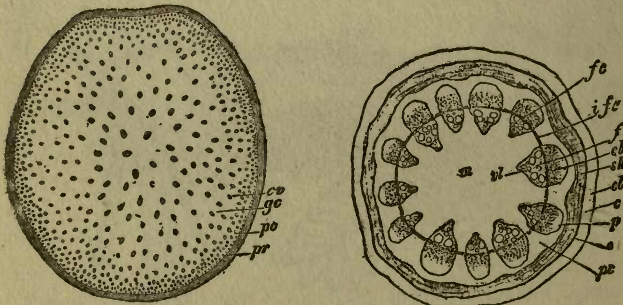
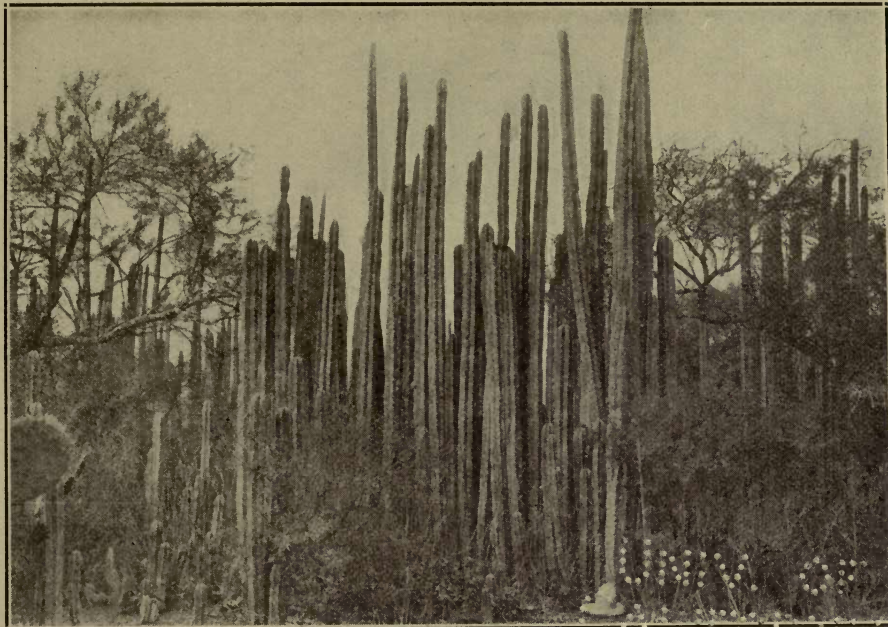


Fig. 8—Transverse Sections of Stems, Primary and Secondary. (Strasburger.)

Curtis, "the production and display of the leaves and roots and the conduction of the materials which these organs are especially concerned in handling. It serves as a connection between them, carrying up the material absorbed by the roots and distributing the various substances received from the leaf." The stem may be compared to a system of transportation carrying building material for new cells and arranging for the bearing away of that which is waste.

The stem best adapted for the proper display of leaves is generally upright, for they can be spread out on all sides and carried upward toward the light. To maintain the



Cactus and Agave Vegetation, Mexico.

erect position is not a simple mechanical problem, and in large, woody stems it involves an extensive development and arrangement of supporting tissues. Other stems lie along the ground bearing leaves only on the free side, while a third great group is that of the climbers, which use other plants as supports. The great lianus of South America belong to this class.

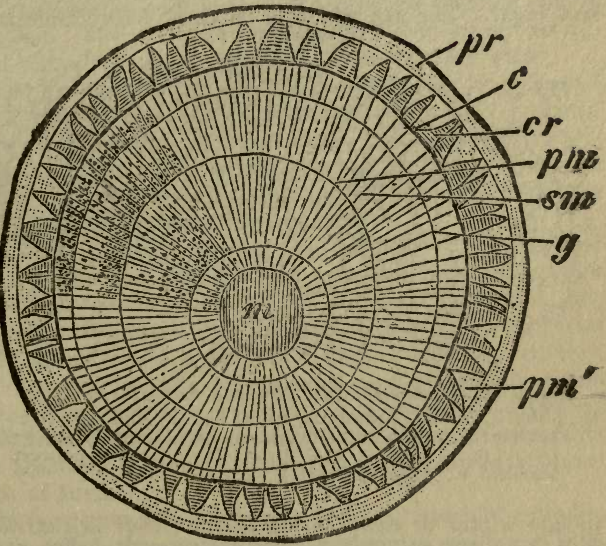


Fig. 9 —Transverse Section of Woody Stem.
pr., primary cortex; c., cambium ring; cr., bast; pm., primary medullary ray; pm'., expanded extremity of a primary medullary ray; sm, secondary medullary ray; g., limit of third year's wood. (Strasburger.)

It has been shown that the stem is in a sense a transportation system, and it becomes immediately evident that the material transported must be largely in soluble form. This liquid is known as sap. "It is important to notice," say J. Y. Bergen and C. M. Davis in their 'Principles of Botany,' "that sap is by no means the same substance everywhere and at all times. As it first makes its way by osmotic action inward through the root hairs of the growing plant it differs little from ordinary well water. The liquid which flows from the cut stem of a tree just before the buds have begun to burst in the spring is mainly water often with a little dissolved organic acids, proteids and sugar. The sap which is obtained from maple trees

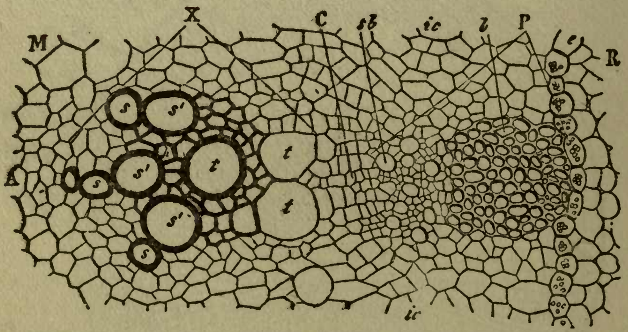


Fig. 10 —Cross-section Through Sunflower Stem.
M., pith; X., xylem, containing spiral (s., s.') and pitted (c., e') vessels; C., cambium; P., phloem, containing sieve vessels (sb.); b., a mass of bast fibers; ic., pith rays between the bundles; e., starch sheath; R., cortex.

in late winter or early spring is far richer in nutritious material, while the elaborated sap which is sent so abundantly into the ear of the corn at the time of its filling out contains great stores of food to support plant or animal life."

Most root-forms are adapted for growth in the soil, but there are many of which this is not true. Thus many of the orchids have aerial roots which fasten the plants to the branch of a tree and absorb moisture from the heavy humid air of a tropical forest; others are adventitious, like the ivy, which cause the plant to cling to a wall; others again, like the mistletoe and the dodder, are parasitic and are adapted to prey upon their host, while another large group of roots are adapted to life in the water, such as the duck-weed.

The length of roots is rarely realized. Thus winter wheat has been found to extend to a depth of seven feet, and the average root stretch of a plant of common oats is 154 feet. The Mexican mesquite has been known to extend sixty feet below ground in the search for water.

The growing tip of each root and rootlet is protected by a cap of cells called the root-cap. This root-cap consists of several layers of cells, the outer ones gradually dying or being worn away as the tip of the root pushes through the soil, and being replaced by new layers which are continually forming beneath.

A short distance behind the root-cap the surface of the root becomes covered by a more or less dense growth of hairs, known as root-hairs. These hairs are outgrowths, sometimes very long ones, from the superficial cells, a single cell producing a single root-hair. In fact, the root-hair is only an extended part of the superficial cell. The root absorbs water and materials dissolved in it from the soil, and the root-hairs enormously increase the absorbing surface. Thousands may occur on a square inch of surface.

In the center of a young root is a solid vascular cylinder, often called the central axis, sometimes enclosing pith. Investing the solid vascular cylinder of the root is the cortex, which often can be stripped from the central axis like a spongy bark.

The wood (xylem) and the bast (phloem) of the vascular cylinder do not hold the same relation to each other as in the stem. The vascular cylinder, instead of being made up of vascular bundles, with wood toward the center and bast toward the outside, as in stems, is made up of wood and bast strands alternating with each other around the center. The wood strands radiate from the center like the spokes of a wheel, and the bast strands are between these spokes, near their outer ends. This

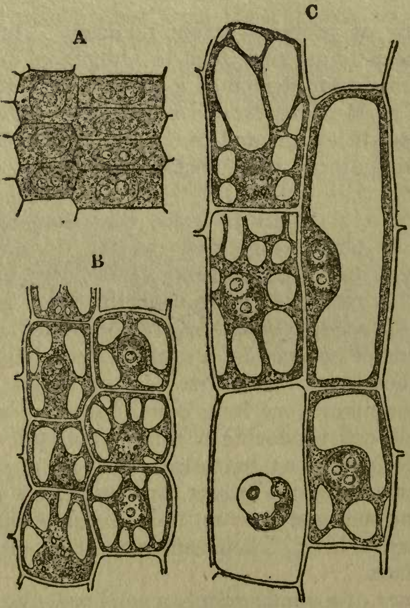


Fig. 11 —Cells from Root-bark.

A., embryonal stage; B. and C., elongating or growing stages. (Giesenhagen.)

arrangement of wood and bast is peculiar to roots. The vascular bundles of the root connect with those of the stem, and these in turn with those of the leaves, so that throughout the whole plant there is a continuous vascular system.

CHAPTER III

REPRODUCTION STRUCTURES

The root, the stem, and the leaf being the three principal organs in the nutrition of a plant, the matter next of importance is a consideration of the manner of its reproduction. Usually this is popularly supposed to be by a flower, but a large division of plants are flowerless and reproduce in many diverse ways. As, moreover, the mode of reproduction often constitutes a means of differentiating between various species, it will be treated therein, but certain main principles may be laid down.

Thus the earliest form of reproduction is that of mere cell division, which cell, so far as can be seen, is not marked out from other cells; indeed, all the cells are capable of division. Next comes the setting aside of a certain cell which is called a spore; and what seems strange in the vegetable world, certain of these, by the lashing about of filaments, are able to swim, and are called 'swimming spores.' So far all has been without sex, and is called 'ásexual.'

But, still very early in the plant kingdom, two cells very like the swimming spores, yet different in action, are produced, which are called 'gametes'; these have an affinity for each other, come together, fuse or fertilize, and, thus fertilized, are called "zygospores," and from these are thrown off spores which can produce new plants. These two gametes at first are very similar, but in higher forms become strongly dissimilar, and are called sperms and eggs. The organ producing the sperms is called the 'antheridium,' that producing the egg is known as the 'oögonium,' in still higher types the 'Archegonium.' The last stage in this type of reproductive process is that in which different plants (sometimes different stems) produce sex organs which may be termed respectively male and female. The highest and the vast division of the Plant Kingdom, known as 'Spermatophytes,' or seed-bearing, is so called because of its development of seeds and reproduction thereby. The gymnosperms, of which pine trees are the best known, produce no flowers, but the Angiosperms have the sexual system very fully developed in the flower.

A flower is a highly modified stem peculiarly adapted for perpetuation. The stem-like nature of the flower is very noticeable before it opens, at which time a series of leaves protects the delicate parts within. These green leaves are known as the calyx, each leaf of which is separately distinguished as a sepal. "As the bud opens," says Curtis, "a number of organs are disclosed; particularly noticeable are a set of variously colored leaves known as the corolla, each leaf of which is called a petal. Within the perianth (which is the calyx and corolla together) are two kinds of organs, the pistils and the stamens, collectively known as sporophylls, since their special work is to produce certain cells called spores." The anthers discharge pollen, which is carried in various ways to the pistil, where the ovules are situated. It is by the fertilization of the female nucleus of the egg-cell at the apex of the embryo sac in the pistil by the male nucleus from a pollen grain that plants arise.

The transfer of the pollen to the pistil.—This transfer—*i.e.*, pollination—is effected in many Angiosperms by insects, altho in some cases the wind serves to carry pollen, as it does in the Gymnosperms. This mutually helpful relation between flowers and insects in some cases has become so intimate that they cannot exist without each other. Flowers are modified in many ways in relation to insect visits, and insects are variously adapted to flowers.

"The pollen," Coulter points out, "may be transferred to the stigma of its own flower, 'self-pollination,' or of some other flower of the same kind, 'cross-pollination.' In the latter case the two flowers concerned may be upon the same plant or upon different plants, which may be quite distant from one another. Since flowers are very com-

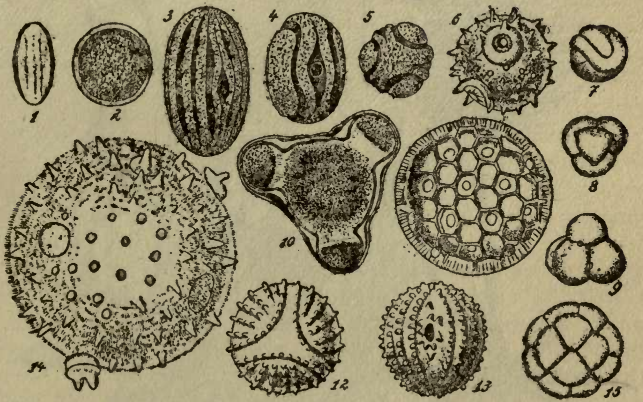


Fig. 12 —Various Forms of Pollen Granules. (Wettstein.)

monly arranged to secure cross-pollination, it must be more advantageous in general than self-pollination.

"The advantage of this relation to the insect is to secure food. This the flower provides in the form of either nectar or pollen; and insects visiting flowers may be grouped as nectar-feeders, represented by moths and butterflies, and pollen-feeders, represented by the numerous bees and wasps. The presence of these supplies of food in the flower is made known to the insect by the display of color, by odor, or by form. Moreover, the flower not only must secure the visits of suitable insects but also must guard against the depredations of unsuitable ones."

Cross-pollinating flowers may be illustrated under three heads, distinguished from one another by their methods of hindering self-pollination; but it must be understood that almost every kind of flower has its own way of solving the problems of pollination. The following illustra-

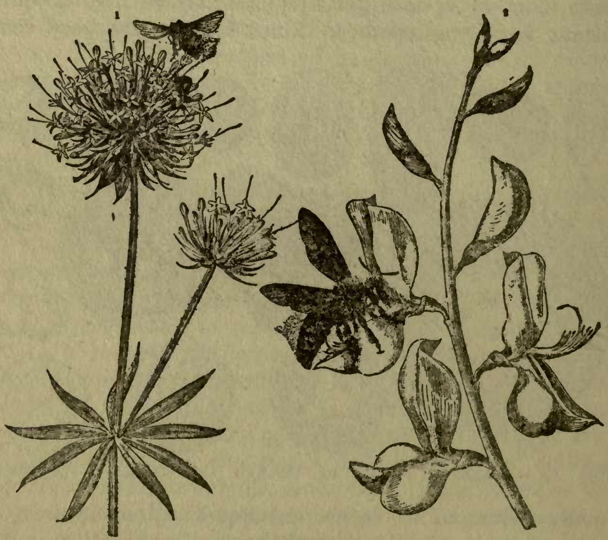


Fig. 13 —Explosive Pollination.

1., insect, touching style, bursts open flowers with a cloud of pollen; 2., bee's weight releasing keel, style and stamens spring up with a jerk, ejecting pollen. (Kerner.)

tion will serve to show one of the processes, that dependent upon position. In this case the pollen and the stigma are ready at the same time, but their position in reference to each other, or in reference to some conformation of the flower, makes it unlikely that the pollen will fall upon the stigma.

In the family Leguminosa, to which the pea, bean, etc., belong, the several stamens and the single carpel are in a cluster enclosed in a boat-shaped structure, 'keel,' formed

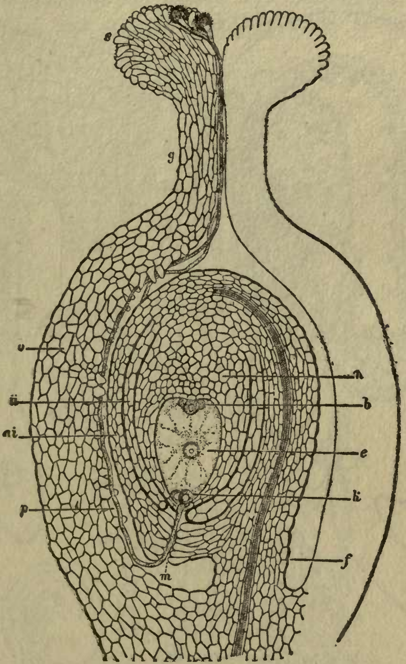


Fig. 14 —Diagrammatic Section of Ovary and Ovule.
At the moment of fertilization in angiosperm. The track of the pollen tube is shown down through the style and the walls of the ovary to the micropylar end of the embryo sac.

by two of the petals. The stigma is at the summit of the style and projects somewhat beyond the pollen sacs, some of whose pollen lodges on a hairy zone on the style below the stigma. While the stigma is not altogether secure from receiving some pollen, the position does not favor it. The projecting keel is the natural landing place for a bee visiting the flower; and it is so inserted that the weight of the insect depresses it and the stigma comes

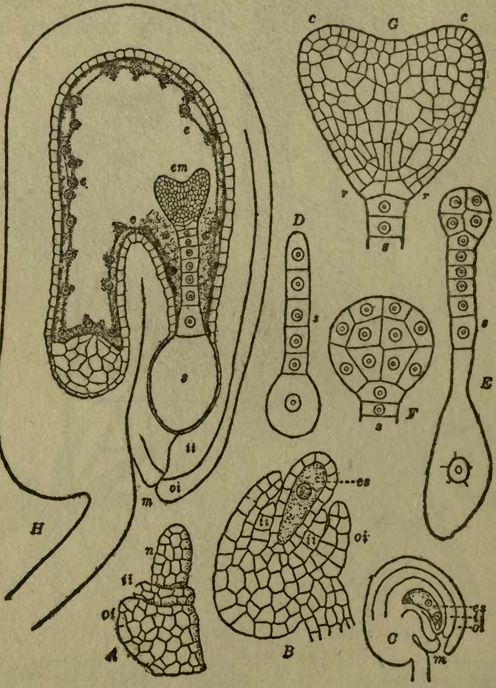


Fig. 15 —Development of the Ovule and Embryo of the Shepherd's Purse.

A., young ovule; B., outer integument (oi.) growing beyond inner (ii.), showing young embryo sac (es.); C., diagram showing mature ovule; D., development of the suspensor (s.); E., early divisions of terminal to form embryo; F., later stage of same; G., later stage showing two cotyledons (c.) and root region (r.); H., longitudinal section of ovule; em., embryo sac; s., suspensor; e., endosperm; ii., inner integument; m., micropyle. (Bergen and Davis.)

in contact with its body. Not only does the stigma strike the body, but by the glancing blow the surface of the style is rubbed against the insect; and upon this style, below the stigma, the pollen has been shed, and is rubbed off against the insect. At the next flower visited the

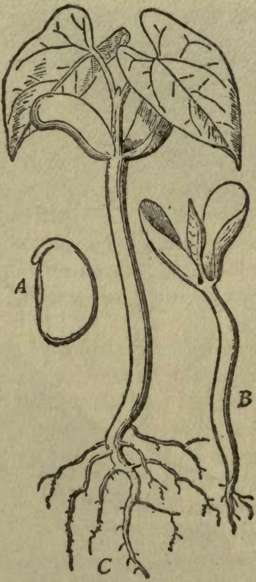


Fig. 16 —Seedling of Bean.

A., embryo removed from testa; B., young seedling, showing hypocotyl, cotyledons and epicotyl; C., older seedling, showing the first internode and leaves of the stem. (Gray.)

stigma is likely to strike the pollen obtained from the previous flower, and the style will deposit a new supply of pollen.

But in the general flower, as visited by the insect, the pollen grains that reach the stigma, the specially prepared surface for receiving them, begin to put out pollen tubes. These tubes grow through the stigma and enter the style; grow down the style and enter the cavity of the ovary; reach the ovules and enter their micropyles; and finally penetrate the ovule to the egg. Throughout

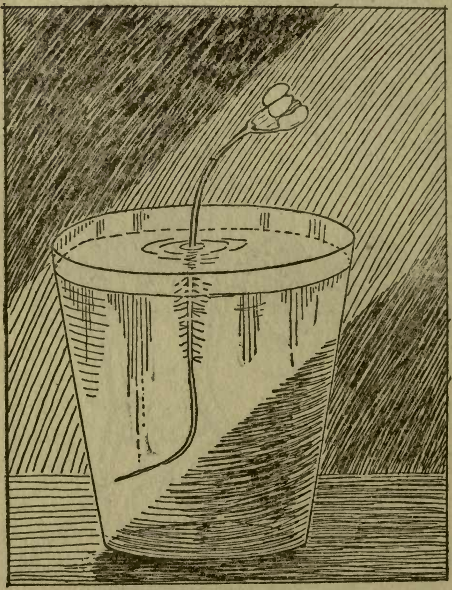


Fig. 17 —Seedling of White Mustard, Showing Positive Phototropism of Stem and Negative Phototropism of Root.

this progress of the tube the male cells are in its tip, and when the egg is reached they are discharged from the tube and one of them fuses with the egg. This is the act of fertilization, and through it the egg becomes an oöspore.

An important difference between Gymnosperms and

Angiosperms should be noted here. In Gymnosperms the pollen reaches the ovules, for they are exposed, but in Angiosperms the pollen reaches only the surface (stigma) of the pistil that encloses the ovules.

The oöspore, lying in the midst of the ovule, at once begins to germinate, and forms a young plant, or embryo. When the embryo is forming, the ovule develops a hard coat outside, and a seed is the result.

The seed coats are varied in many ways, as in the pea and the Brazil nut, but their internal anatomy follows the same general pattern, and they nearly all contain food for the embryonic plant. It is this food in grains and in nuts which is used as foodstuff by man. The three kinds of food stored in seeds are starch, oil and albuminous substances called proteids. The young seedling does not push its way straight out of ground, but sends up an arched part of the steam, known as the hypocotyl, and when the surface of the ground is broken the stem straightens and the cotyledons appear.

The lower elongating tip of the hypocotyl directs its growth downward—that is, toward the earth—even if it has to curve about the seed to do so. It is exceedingly sensitive to surrounding influences, a condition that is called irritability, especially so to gravity, a condition that is called geotropism, the root being said to be geotropic. If the same stimulus and response that directs the root-tip toward the soil continues to direct it within the soil it continues to grow directly downward and becomes a tap-root. When such a root, having entered the soil, begins to send out branches, these do not respond to the stimulus of gravity as does the tap-root, for they extend through the soil in every direction. It is likewise sensitive to light, the stem being attracted and the root repelled. With the establishment of roots in the soil, and the exposure of green leaves to the light and air, germination is over, for the plant is able to make its own food.

CHAPTER IV

TAXONOMIC BOTANY

THE first great division of the plant kingdom comprises the Algæ and Fungi, grouped under the term 'Thallophytes, meaning plants wherein such special vegetative organs as leaves and roots are either lacking or rudimentary.

The Algæ grow in the water, and hence their habits are adapted to a water environment. They are often called sea-weeds, but altho they are very abundant along sea-coasts they are also found in fresh waters. Some of them are so small that the individual bodies are visible only under the microscope, but others are large, the sea-kelp having been known to have a stem nine hundred feet long.

Altho all algæ contain chlorophyll, and hence are able to make their own food, they do not all appear green, for in many of them the chlorophyll is obscured by other coloring matters. The four great groups of Algæ are named from the general color of their bodies.

The Blue-Green Algæ, or the 'Green Slimes,' form blue-green or olive-green patches on damp tree trunks, rocks and walls. The name of the group refers to the fact that in addition to the chlorophyll the cells contain a characteristic blue coloring matter which does not mask the green, but combined with it gives a bluish-green tint to the plants when seen in masses. Not all the blue-green Algæ are bluish-green in tint, however, for the presence of other substances may disguise it, and the color may be yellow, or brown, or even reddish. The color of the Red Sea, which has given it its name, is due to the presence under certain conditions of immense quantities of one of the blue-green forms.

The green algæ are so named because the green of the chloroplasts is neither modified nor obscured by other colors, and the plants have a characteristic grass-green

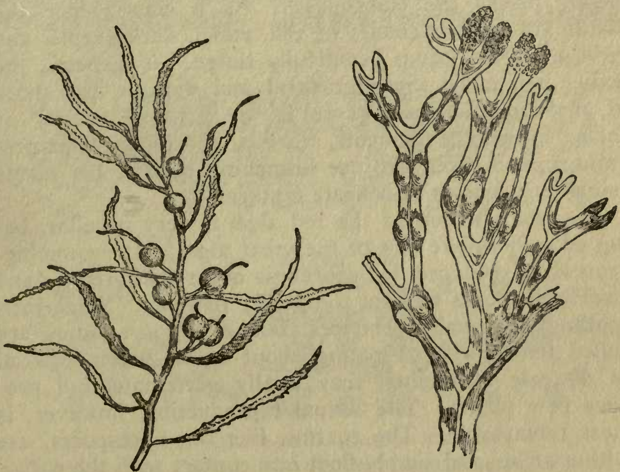


Fig. 18 —Two Types of Marine Algæ, Gulf-weed and Rock-weed, 'Fucus.' (Luerssen.)

color. Some of the green algæ are associated with the blue-green algæ in the pollution of water reservoirs.

The brown algæ, of which the giant kelp of the Pacific coast, with a length of 900 feet, is the largest, are all anchored plants, chiefly marine. The first great group of brown algæ, of which a small form, Ectocarpus, is a well-known representative, is distinguished by its swimming spores and its similar gametes. The smaller group, besides the common "rock-weed" or Fucus, contains the famous gulf-weed, or Sargasso weed, which makes a floating bank of dense weed in the North Atlantic, known as the Sargasso Sea. These differ from the first group in producing no swimming spores, and in its dissimilar gametes (eggs and sperms).

The red algæ are mostly marine forms, and receive their name from the fact that a red coloring matter completely masks the chlorophyll. As a consequence the plants are various shades of red, violet, dark purple, and reddish brown, often beautifully tinted. In general, the bodies are much more graceful and delicate than those of the brown algæ. There is the greatest variety of forms, branching filaments, ribbons, and filmy plates prevailing; and often profuse branching occurs, the plants resembling mosses of delicate texture.

The reproduction of the red algæ is very peculiar, being entirely unlike that of the other algæ. No swimming-spores are produced, but sporangia occur that produce and discharge spores without the ability to swim. Since each sporangium usually produces four such spores, they are called tetraspores. Floating about in the water, instead of actively swimming, they finally germinate and produce new plants. The sexual reproduction, however, is most remarkable. The sperms, like the tetraspores, are without cilia, and simply float into contact with the carpogonium, whose form is like that of a flask with a long, narrow neck. In the bulbous base of the carpogonium the female cell is developed. In a very simple case the floating sperm comes in contact with the long neck, the two walls become perforated at the point of contact, the contents of the sperm enters and passes to the carpogenic cell, and thus fertilization is accomplished. As a result of fertilization there appears on the plant a spore-containing structure like a little fruit. The spores it contains produce the alga plants again.

The Fungi do not contain chlorophyll, and this fact forms the sharpest contrast between them and the algæ.

The presence of chlorophyll enables the algæ to be independent of any other organism, since they can manufacture food out of carbon dioxide and water. The absence of chlorophyll compels the Fungi to be dependent upon other organisms for their food. This food is obtained in two general ways: either (1) directly from living plants and animals, or (2) from organic waste products or dead bodies. In case a living body is attacked

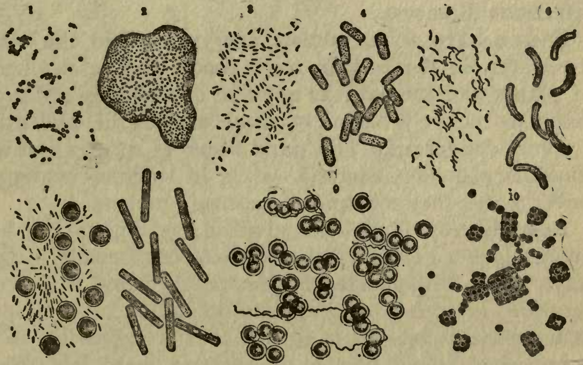


Fig. 19 —MICRO-ORGANISMS OF BACTERIA.
1., 'blood-portent' (found in 'red' rains); 2., the same, in zooglea form; 3., the vinegar fermentation; 4., the same, highly magnified; 5., Asiatic cholera; 6., the same, highly magnified; 7., anthrax and red-blood corpuscles; 8., the same, highly magnified; 9., relapsing fever; 10., sarcina ventriculi. (Kerner.)

the attacking fungus is called a 'parasite,' and the plant or animal attacked the host. In case the food is obtained in the other way the fungus is called a 'saprophyte.' For example, the rust that attacks wheat is a parasite, and the wheat is the host; while the mold which often develops on stale bread is a saprophyte.

Bacteria include the smallest known living forms of fungi, some of which are spherical cells only $^1/_{25000}$ inch in diameter. It is estimated that 1,500 of certain rod-shaped forms, placed end to end, would about stretch across the head of an ordinary pin. Even to distinguish ordinary bacteria, therefore, the highest powers of the microscope are necessary. However, they are so very important to man, on account of their useful and destructive operations, that every student should have some information about them. Public attention has been drawn to them chiefly on account of the part they play in many infectious diseases.

Bacteria are found almost everywhere—in the air, in the water, in the soil, in most foods, and in the bodies of plants and animals, as regular inhabitants. Many of them are entirely harmless, some are useful, and others are very dangerous. The 'pure' water of springs and wells contains abundant bacteria, while in stagnant water and sewer water they swarm in immense numbers.

Reproduction is by cell division, as among the blue-green algæ, a group which the bacteria resemble in many ways. This cell division is remarkably rapid in bacteria, resulting in such prodigious multiplication of individuals in a comparatively short time that it is impossible to imagine what would happen if bacteria were left free to reproduce to their full capacity. Bacteria have been observed to reproduce themselves in fifteen to forty minutes after their formation; that is, a single generation of such bacteria is that length of time. It would be interesting to determinate the number of progeny from a single bacterium at the end of twenty-four hours if such a rate were maintained.

Yeasts are much larger than bacteria and have a more complex cell structure, for there is present a clearly defined nucleus. The cells reproduce in a peculiar method called 'budding.' This consists in a cell putting out one or more projections which gradually enlarge and finally become pinched off. Often the cells thus produced cling together in short, irregular chains. The chief interest in connection with yeasts is the important part they play in the fermentation of sugar solutions, "splitting" the sugar into alcohol and carbon dioxide, a process also induced by certain bacteria, but chiefly by the yeasts.

Fermentation by yeasts is employed on a large scale in the manufacture of beer, wine, and spirits, and in the making of bread. In the last-named process the dough is

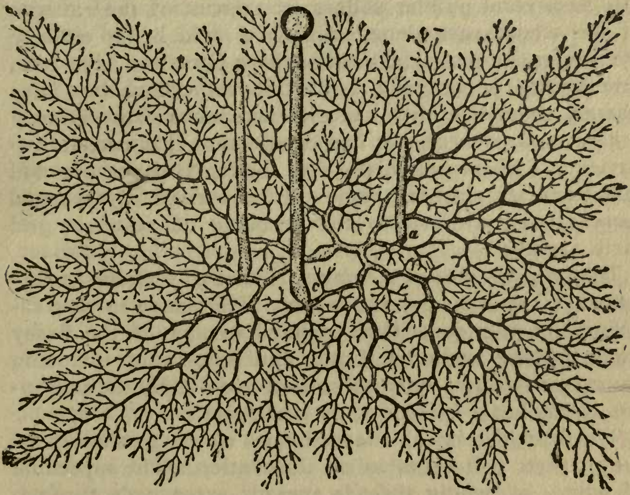


Fig. 20 —DIAGRAM OF BREAD MOLD. (Mucor.)
a., b., c., three sporophores; c., mature.

inoculated with yeast plants and placed in a sufficiently warm temperature to induce rapid growth. The plants begin to reproduce actively by budding, the sugar in the dough is split into alcohol and carbon dioxide, and the latter, a gas, expands and puffs up the dough, making it light and porous; that is, causing it to "rise."

One of the most common of the Mucors, or 'bread molds,' forms white, furry growths on damp bread, preserved fruits, manure heaps, etc. It may be grown easily by keeping a piece of moist bread in a warm room under a glass vessel. The sources of its food supply indicate that it is a saprophyte.

Rusts are destructive parasites that attack almost all seed plants, but those that attack the cereals are of special importance. Wheat, oats, rye and barley all have their rusts, and in the United States there is a yearly loss of several million dollars on account of the ravages of the wheat rust alone, scarcely a field being entirely free from the pest. Naturally, these parasites have been investigated persistently, but while very much has been learned about their life histories and behavior no remedy has been discovered. It has been found that certain varieties of wheat resist the rust better than others and that varieties ripening early escape serious injury; and these facts may lead to the breeding of resistant and early races.

The popular idea of a fungus is that of a fleshy, colorless form, such as the mushroom. This name is very indefinite, being sometimes applied to any of the fleshy fungi of the umbrella form, and sometimes including among such forms only those that are edible, the poisonous forms being spoken of as toadstools.

The life history of the ordinary edible mushroom of the markets will serve as an illustration. The mycelium of white, branching threads spreads extensively through the substratum of decaying organic material, and by those who grow mushrooms is called spawn. This mycelium, altho the least conspicuous part of the mushroom, is, of course, the real vegetable body. Upon this underground mycelium little knoblike protuberances arise (buttons), growing larger and larger until they develop into the umbrella-like structures commonly spoken of as mushrooms. This umbrella-like structure, however, corresponds to the sporophores that arise from the mycelia of other groups of fungi, except that it includes a large number of sporophores organized into a single large body. Therefore, the real mushroom body is a subterranean mycelium, upon which the structures commonly called mushrooms are the spore-bearing branches. In pulling up a mushroom, fragments of the mycelium may often be seen attached to it, looking like small rootlets.

The puffballs are fleshy fungi that differ from the mushrooms in having the spores enclosed until they are ripe. There is a subterranean mycelium, as in the mushrooms, but the spore-bearing structure is a fleshy, globular body containing irregular chambers lined with the spore-producing layer. When young this body is solid and white, but as the spores mature it becomes yellowish and brownish, gradually dries up, and finally is only a brown, parchment-like shell containing innumerable exceedingly small spores that are discharged by the breaking of the shell. Some of the puffballs become very large, reaching a diameter of twelve to eighteen inches.

Lichens are abundant everywhere, forming splotches of various colors on tree trunks, rocks, old boards, etc. They have a general greenish-gray color, but brighter colors also may be observed. The great interest connected with lichens is that they are not single plants, but that each lichen is formed of a fungus and an alga living together so intimately as to appear like a single plant. In other words, a lichen is not an individual, but a firm of two individuals very unlike one another. If a lichen be sectioned the relation between the two constituent plants may be seen. The fungus makes the bulk of the body with its interwoven mycelial threads, in the meshes of which lie the algæ, sometimes massed. It is these enmeshed algæ, showing through the transparent mycelium, that give the greenish tint to the lichen. It has been found that the lichen-alga can live quite independently of the lichen-fungus. On the other hand, it has been found that the lichen-fungus is completely dependent upon the algæ, for the germinating spores of the fungus do not develop far unless the young mycelium can lay hold of suitable algæ. Artificial lichens also have been made by bringing together wild algæ and lichen-fungi. Lichens, therefore, are really combinations of a parasitic fungus and its host, the parasitism being peculiar in that the host is not injured. The fungus lives upon the food made by the alga, and the relation suggested is that the alga is enslaved by the fungus.

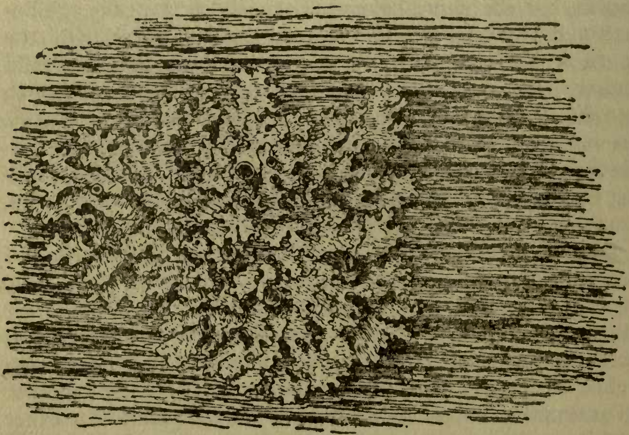


Fig. 21 —Foliose Lichen Growing Upon a Board. (Coulter.)

With the Liverworts a new division of the Plant Kingdom is entered, known as the Bryophytes, possessing 'archegonia,' but no vascular system. Among these the simplest of the archegonia forms are found.

Mosses are very abundant and familiar plants. They grow in all conditions of moisture; many of them can endure drying out wonderfully, and hence they can grow in very much exposed situations, as do many lichens. In fact, lichens and mosses, being able to grow in the most exposed situations, are the first plants to appear upon bare rocks and ground, and are the last plants seen in climbing high mountains or in going into very high latitudes.

Mosses have great power of vegetative multiplication, new leafy branches putting out from old ones indefinitely, thus forming thick carpets and masses. Bog mosses often completely fill up bogs or small ponds and lakes with

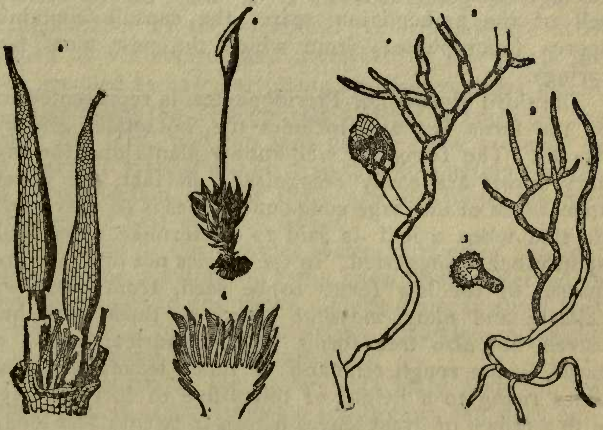


Fig. 22 —Mosses.
1., germinating spore; 2., protonema; 3., bud from protonema; 4., section of tip of male shoot with antheridia; 5., tip of female shoot with archegonia; 6., developed sporogonium. (Kerner.)

a dense growth, which dies below and continues to grow above, so long as the conditions are favorable. These quaking bogs, or "mosses," as they are sometimes called, furnish very treacherous footing unless rendered firmer by other plants.

The conspicuous part of an ordinary moss plant consists of a more or less erect and usually branching stem bearing numerous delicate leaves. The plant is evidently able to make its own food, and it is anchored to its substratum by hairlike rhizoids. Its power of vegetative propagation has been described. At certain times there appears at the end of the main stem, or at the end of a branch, a rosette of leaves, often called the moss flower. In the center of this rosette there is a group of antheridia and archegonia, sometimes both kinds of organs in a single rosette, sometimes only one kind. From the fertilized egg cell of the archegonium arises the capsule containing spores (sporophyte), from which the new moss plant springs.

The third division, or Pteridophytes, is represented first by the ferns, but also includes the 'horsetails' and club mosses. The ferns are well-known plants and the ordinary forms are easily recognised; in fact, the general appearance of the large compound leaves is so characteristic that when a leaf is said to be fernlike a particular appearance is suggested. In the tropics not only are great masses of the low forms to be seen, from those with delicate and filmy, mosslike leaves to those with huge leaves, but also tree forms with cylindrical trunks encased by the rough remnants of fallen leaves, and sometimes rising to a height of thirty-five to forty-five feet, with a crown of great leaves fifteen to twenty feet long.

If an ordinary fern be examined it will be discovered that it has a horizontal underground stem or rootstock, which sends out roots into the soil and one or more large leaves into the air. These leaves, appearing to come directly from the soil, were once supposed to be different from ordinary leaves, and were called fronds; but altho the name is still used in connection with fern leaves it is neither necessary nor accurate. These leaves are usually compound, branching either pinnately or palmately. There are two peculiarities about fern leaves that should be noted. One is that in expanding the leaves seem to unroll from the base, as tho they had been rolled from the apex downward, the apex being in the center of the roll. When unrolling this gives the leaves a crozier-like tip. The other peculiarity is that the veins fork repeatedly. This combination of unrolling leaves and forking veins is very characteristic of ferns.

"Probably the most important fact about the fern body," says Coulter, "is that it contains a vascular system. The appearance of this system marks some such epoch in the evolution of the plants as is marked among animals by the appearance of the backbone. As animals are often grouped as vertebrates and invertebrates, so plants are often grouped as vascular plants and non-vascular plants, the latter being the Thallophytes and the Bryophytes, the former the ferns and the seed plants. The presence of this vascular system means a special conducting system, and in connection with it there are developed the first roots and the first complex leaves.

"On account of the vascular system, and other resistant structures, the remains of ferns have been preserved in great abundance in the rocks. These records show that the ferns are a very ancient group, occurring in special abundance during the Coal-measures.

"Another striking fact about this leafy body of the ferns is that it never produces sex organs, but does produce spores abundantly. This means that it is the sporophyte in the life history of the fern, and when it is contrasted with the sporophyte of Bryophytes the differences are remarkable. Among the liverworts and the mosses the sporophyte is a leafless structure attached to the gametophyte, and dependent on it, while the gameophyte is the leafy body doing chlorophyll work. Among the ferns, however, the sporophyte is an elaborate leafy structure and entirely independent. Therefore, when one ordinarily speaks of a moss and a fern, the gametophyte is referred to in the former case and the sporophyte in the latter. This means that in passing from mosses to ferns plants have transferred the chief work of food manufacture from the gametophyte to the sporophyte, which has thus become the conspicuous generation.

"The sharp and easily marked distinction between the prothallus (gametophyte) and the fern plant itself

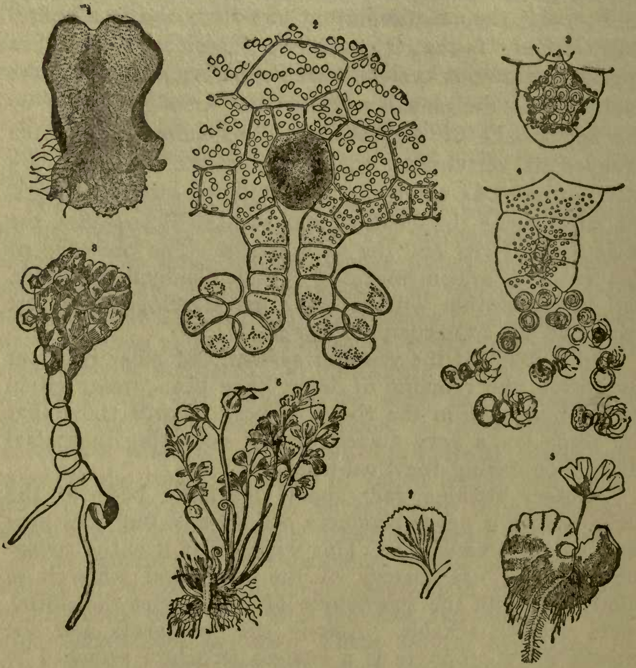


Fig. 23 —Life History of a Fern.

1., a fern prothallium seen from under side; 2., section of archegonium; 3., antheridium; 4., escape of spermatozoids; 5., young sporophyte; 6., complete sporophyte; 7., under surface of pinnule of (6.); 8., a young prothallium. (Kerner.)

(sporophyte) has led certain writers on "biology" to consider the fern as a typical plant for the purpose of comparison with certain typical animals which are assumed to represent a similar stage of evolutionary development. Aside from the dangers which arise from such an assumption, it must be said that in many respects ferns are not typical. They should not be regarded as the ancestors of the present flowering plants, but as a

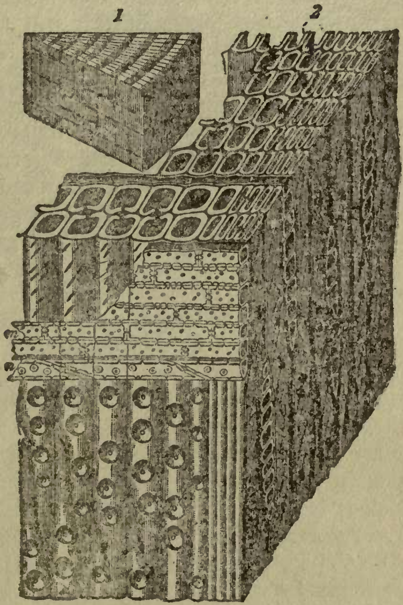


Fig. 24 —Normal Secondary Growth of Conifer Wood.
1., Wedge-shaped section, showing ten years' growth; 2., enlarged portion, showing the anatomical characters of a year's growth.

somewhat highly specialized offshoot from the main line of descent which at the present geological age is not "biologically successful" in competition with the seed-bearing forms."

The Gymnosperms are one of the two groups of seed plants, the most familiar ones in temperate regions being pines, spruces, hemlocks, cedars, etc., the group commonly called evergreens. It is an ancient group, for its representatives were associated with the giant club mosses and horsetails in the forest vegetation of the Coal-measures. Only about four hundred species exist to-day as a remnant of its former display, altho it still forms extensive forests. Gymnosperms are very diverse in habit. They are all woody forms, but they may be gigantic trees, trailing or straggling shrubs, or high-climbing vines. There are two prominent living groups of Gymnosperms.

Cycads are tropical forms with large fernlike leaves. The stem is either a columnar shaft, crowned with a rosette of large compound leaves, with the general habit of tree-ferns and palms, or they are like great tubers, crowned in the same way. The tuberous stems are often more or less buried. In ancient times cycads were very abundant, but now they are represented by about eighty species, scattered through the Oriental and Occidental tropics. They are especially interesting in their resemblances to ferns, and some of them might be mistaken for ferns did they not bear large seeds.

Conifers are the common Gymnosperms, often forming great forests in temperate regions. Some of the forms are widely distributed, as the pines, while some are now very much restricted, as the gigantic redwoods, 'Sequoia,' of the Pacific slope. The habit of the body is quite characteristic, a central shaft extending to the very top. In many cases the branches spread horizontally, with diminishing length at the top, forming a conical outline, as in the firs. This habit gives the conifers an appearance very distinct from that of the other trees.

The large cone of the pine is made up of sporophylls that become very thick and hard, and that are packed closely together until they spread apart to let out the seeds. On the upper side of each sporophyll, near its base, there are two sporangia, in each one of which there

Typical Tropical Palm Foliage.

is a single large spore (megaspore). So large is the spore that it looks like a conspicuous cavity in the center of the sporangium. These structures also bear old names that may be used. The sporangia were called 'ovules,' and the sporophyll bearing them was called a 'carpel.' The large spore was regarded only as a cavity in the ovule. The cone, therefore, is a group of carpels, and to distinguish it from the staminate cone it may be called the 'carpellate cone.'

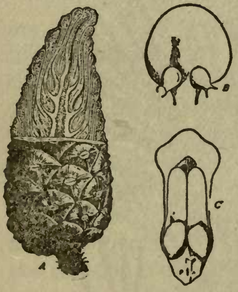


Fig. 25 —Carpellate Cone of Pine.
A., partly sectioned; B., young carpel with two ovules; C., old carpel with mature seeds.

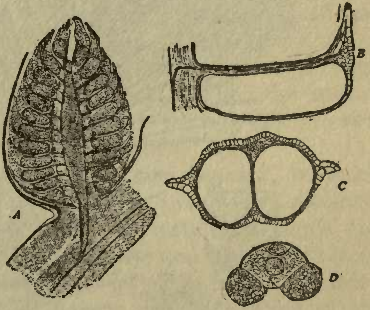


Fig. 26 —Staminate Cone of Pine.
A., section of cone, showing sporophylls bearing sporangia; B., section of stamen, through one pollen sac; C., cross-section of stamen, showing both pollen sacs; D., the winged pollen grain. (Strasburger.)

It is evident that the pine tree, bearing these sporangia, is the sporophyte in the life history; that is, it is the sexless generation. The sporophyte has now become so prominent that it seems to have become the whole plant. The pine being heterosporous, there are male and female gametophytes. The small spores (pollen grains) germinate and produce very small male gametophytes. Only a few cells are formed, and these remain in the pollen grain. The single large spore within the ovule is peculiar in never leaving it; it is never shed, but produces a female gametophyte which lies embedded in the center of the ovule. The reason, therefore, why the gametophytes of such plants are not ordinarily seen is that one is within the pollen grain and the other within the ovule.

"Before fertilization can take place," remarks Coulter,

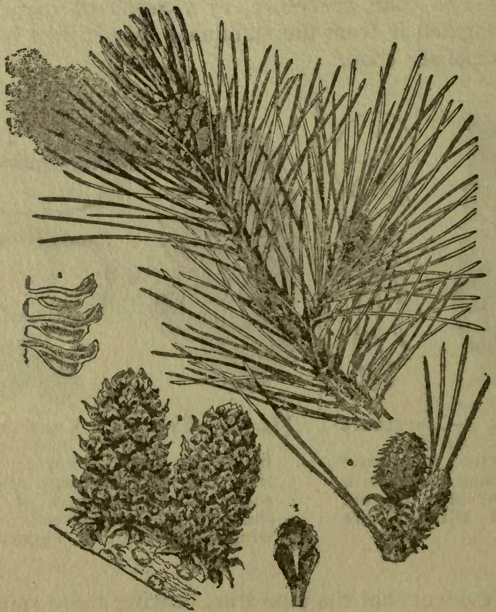


Fig. 27 —Cones of Mountain Pine.

"the pollen grain, which develops the male gametophyte with its sperms, must be brought to the ovule, which contains the female gametophyte with its archegonia. The pollen grains (microspores) are formed in very great abundance, are dry and powdery, and are scattered far and wide by the wind. In the pines and their allies the pollen grains are winged, so they are well organized for wind distribution. So abundant is the pollen of conifers that it sometimes falls like a yellow shower, and the occasionally reported "showers of sulphur" are really showers of pollen from some forest of conifers. Some pollen must reach the ovules, and to insure this it must fall like rain. To aid in catching the falling pollen the scale-like carpels of the cone spread apart, and the pollen grains, sliding down their sloping surfaces, collect in a little drift at the bottom of each carpel, where the ovules are found.

"In this position each of the most favorably placed pollen grains begins to put forth a tube (pollen tube). This tube, containing the two sperms in its tip, grows through the ovule and reaches the archegonia. Then the sperms are discharged, and when they reach the egg fusion takes place and fertilization is accomplished."

The Angiosperms are the flowering plants. In many flowers there is no regularity in the number of members in each set. For example, in the water lily petals and stamens occur in indefinite numbers, and in the buttercup the same is true of stamens and carpels. In most flowers, however, definite numbers appear either in some of the sets or in all of them. When these definite numbers are present they are prevailingly either three or five; that is, there are either three or five sepals, petals, stamens and carpels; altho it is very common to have two sets of stamens, in which case they number six or ten. These numbers appear so constantly in great groups that the two grand divisions of Angiosperms, called Monocotyledons and Dicotyledons, are characterized by them, the former having the parts of the flower in threes, the latter in fives. This does not mean that all flowers of these two divisions have one or the other number, but that these are the prevailing numbers in case there is a definite number at all. Not a few Dicotyledons have flowers with the parts in threes, and a still larger number have them in fours.

In many cases stamens and pistils are not found together in the same flower. In such cases there are staminate flowers—that is, those without pistils; and pistillate flowers—that is, those without stamens. These two kinds of flowers may be borne upon the same plant, which is then said to be monœcious (one household); or upon dif-

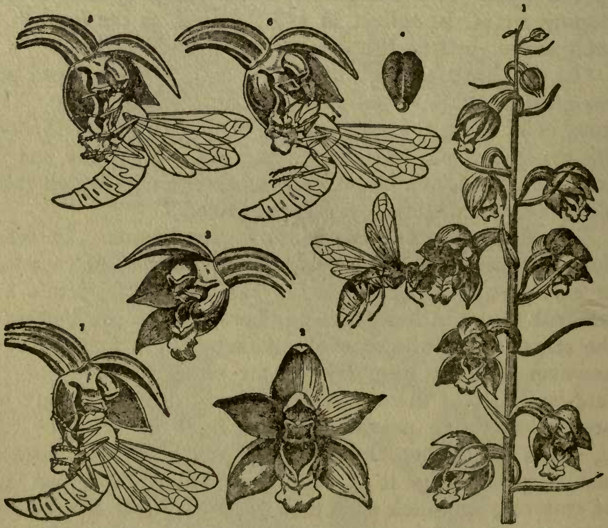


Fig. 28 —Pollination of an Orchid.

1., wasp alighting; 2., front view of flower; 3., side view with part of perianth cut away; 4., two pollinia; 5., wasp, licking honey, touches pollinia; 6., wasp leaving flower with pollinia attached to his head; 7., wasp visiting another flower, causing pollinia to touch stigma. (Kerner.)

ferent plants, which are then said to be diœcious (two households). These terms are applied indifferently to the plants or to the flowers, either the plants or the flowers being spoken of as monœcious or diœcious. About forty monocotyledonous families are recognised, containing numerous genera and about twenty thousand species.

The Dicotyledons are a much larger group than the Monocotyledons, containing more than 200 families and about 100,000 species. Most of them are easily recognised by the floral number five or four, the net-veined leaves, and the arrangement of the vascular bundles of the stem in a hollow cylinder.

In the lower stretches of the Dicotyledons there are a number of small families that include the most common hardwood or deciduous trees, and this assemblage of conspicuous forms may be considered together without selecting any special family. They include elms, sycamore, walnuts, hickories, oaks, chestnuts, willows, poplars, cottonwoods, birches, beech, etc. These trees are all characterized by their simple and inconspicuous flowers, which are usually wind-pollinated.

Passing from these forms, which, in the older terminology, are not inaptly described as "apetalous," there is the very large group of plants which have distinct and separate petals which are well described by the adjective polypetalous. It would be impossible in the space at command to adequately describe or even name the important plants which come under this head. As a type one might perhaps take the flower of the flax, the parts of which are regular and symmetrical, and show, except in the ovary, no fusion. But there may be wide departure from forms like these, and the habit of considering any one flower as a type and the other forms as deviations from that type is one which the modern botanist eschews.

It is not unreasonable to suppose, however, in a general way that the irregular flowers, like the sweet pea, for example, have, in the evolutionary sense, been the result of later development than the simpler and symmetrical forms. One potent factor in the development of partial fusions and of flowers which are not radially symmetrical is probably that of the relation of the flower to insect visitation for the furthering of cross-pollination. A tendency is found in general toward modifications which, as they can be interpreted, make for the restrictions of the movements of insects or parts of insects among the floral organs and thus render more probable the carrying of pollen from one flower to another.

The culmination of this tendency, along with condition known as epigyny (the insertion of the calyx, corolla and stamens on the ovary), is seen in the sympetalous dicotyledonous type. In the sympetalous or gamopetalous flower the petals are fused into a bell or tube, a condition which may or may not be accompanied by other fusions. It is conceded that the Compositeæ (Sunflowers, Daisies, Asters), which are of this sympetalous type, represent the final and highest development of the dicotyledonous flower. Composites are found everywhere, but are most numerous in temperate regions, where they are usually herbs. The name of the family suggests the most conspicuous feature, namely, the organization of the numerous small flowers into a compact head which resembles a single flower, formerly called a compound flower.

So common are the Composites that the general structure of the head should be understood. Taking the head of Arnica as a type, the outermost set of organs consists of more or less leaflike bracts or scales, 'involucre,' which resemble sepals; within these there is a circle of flowers with conspicuous yellow corollas, 'rays,' which are split above the tubular base and flattened into a strap-shaped body, and much resembling petals; within the ray-flowers is the broad expanse called the disk, which is closely packed with very numerous small tubular flowers known as 'disk-flowers.' If a disk-flower be removed it will be discovered that the ovary is inferior, and that arising from it, around the tubular corolla, there is a tuft of delicate hairs, 'pappus,' which represent the sepals. This pappus surmounting the akene in Composites may be lacking.

CHAPTER V

DEVELOPMENT OF MORPHOLOGY

"We owe the term morphology to Goethe," to quote from Goebel. He says: 'Scientific men in all times have striven to recognise living bodies as such, to understand the relations of their external, visible, tangible parts, and to interpret them as indications of what is within, and thereby in some measure to gain a comprehensive notion of the whole. . . . We find therefore in the march of art, of knowledge and of science many attempts to found and construct a doctrine which we may name the morphology.' It is quite evident then that morphology does not deal merely with the distinction and the naming of the outer parts of plants, altho this, which really belongs to terminology, has been in part incorrectly called morphology. Morphology does demand the knowledge of the different appearances of the members of the plant body, but only as a means to an end; it requires not isolated facts, but the relation of facts to one another.

"Terminology can be based on the study of dried plants, but morphology has, as Goethe stated, to do with "living bodies," which are involved in changes of a fixed character and are subjected to the influences exercized upon them by the outer world; it has, in other words, to do with that part of life phenomena which finds expression in the external configuration.

"In nature the form and function of an organ stand in the most intimate relation to each other. Herbert Spencer says: "Everywhere structures in great measure determine functions and everywhere structures are incessantly modifying structures. In nature the two are inseparable co-operators, and science can give no true interpretation of nature without keeping their coöperation constantly in view. An account of organic evolution in its more special aspects must be essentially an account of the interactions of structures and functions.

"The first question to which we have to find an answer is, How came it that the functions of organs were entirely divorced from morphology?" continues Goebel. "It is, and rightly so, one of the fundamental declarations of this study that the function of an organ tells nothing of its 'morphological significance,' or, in other words, the same function may be performed by organs of very different morphological value; 'homologous' organs must be distinguished from 'analogous' ones. The tendrils of the vine and of the passion-flower, for example, are shoot axes whose leaves are entirely or almost entirely suppressed, but the tendrils of the Leguminosæ and of other plants, altho alike in form and function to those of the vine and passion-flower, are transformed leaves. The tendrils in the two cases are analogous; they are not homologous.

"This knowledge is one of the weightiest acquisitions of morphology, but it has been the cause of an incorrect generalization. Because organs of like morphological significance may take on different functions, the functions which they perform have been considered as of subordinate importance and therefore of no moment in the determination of the characters of the organs. Hence it has been concluded that they must be entirely neglected in the grouping of the different members of plants in general categories.

"This conclusion is erroneous. It has led to an untenable position, especially in that fundamental problem of morphology which from the time of Goethe has been styled the 'Doctrine of Metamorphosis.' By this we understand the fact that manifold as are the organs of plants, they can be referred back to a few 'fundamental forms' through whose 'transformation' the many and different members of the plant body have arisen. •

"When we inquire how these primary forms and their transformations have been represented to us, we meet with different conceptions on the part of those authors who have taken pains to reflect upon the idea with which they dealt. In the idealistic morphology, as it was expounded by Goethe, A. Braun and Hanstein, the doctrine of metamorphosis concerned itself with an essentially theoretical construction. Goethe himself has plainly stated his view as follows: 'That which according to our idea is equal may in reality appear either as equal or as similar or, indeed, as completely unequal and dissimilar; this is the essence of the pliant life of nature.' In somewhat other form this idealistic notion has been preserved, inasmuch as the history of development was raised by the labors of K. F. Wolff, R. Brown and Schleiden to the rank of one of the most important aids to organography. The view which I have called the 'Differentiation Theory' is based, as indeed the whole of the doctrine of metamorphosis, on the study of the transformation of leaves, the manifold character of which is well known. The differentiation theory assumes that at the vegetative point of the shoot indifferent primordia arise which are capable of development according to the needs of the plant in manifold ways, but have this in common—they are leaves. The other view assumes a real transformation of a primordium in such a way that, for example, the primordium of a foliage leaf, instead of developing actually into a foliage-leaf, can become in the mature condition a leaf of quite a different character."

That the study of morphology should not have developed as rapidly as that of systematic is not to be wondered at, and other than the passing references which will be found it would be purposeless to dilate upon the crude ideas of the earlier writers. While it cannot be said that he was by any means the first to consider morphological problems, in many ways De Candolle's work afforded a sounder foundation for proper morphological conceptions than most of his predecessors.

"The efforts of Jussieu, De Candolle and Robert Brown were directed to the discovery of the relationship between different species of plants by comparing them together," says Sachs. "The doctrine of metamorphosis founded by Goethe set itself from the first to bring to light the hidden relationship between the different organs of one and the same plant. As De Candolle's doctrine of symmetry derived the different species of plants from an ideal plan of symmetry or type, so the doctrine of metamorphosis assumed an ideal fundamental organ, from which the different leaf-forms in a plant could be derived. The stem came into consideration only as carrying the leaves; the root was almost entirely disregarded. As the resemblance of nearly allied species of plants suggests itself naturally and unsought to the mind of the unbiassed observer, so also does the connection between different organs of a leafy nature in one and the same plant.

"Goethe's conception of the matter was from the first much less clear and chiefly because he was never able to bring the abnormal into its true connection with the normal or ascending metamorphosis. In the first sentence of his 'Doctrine of Metamorphosis' (1790) he says, 'that it is open to observation that certain exterior parts of plants sometimes change and pass into the form of adjacent parts, either wholly or in a greater or less degree.' In the cases of which Goethe is here thinking a distinct meaning can be affixed to the word metamorphosis; if, for example, the seeds of a plant with normal flowers produce a plant which has petals in place of stamens, or in which the ovaries are resolved into green expanded leaves, it is actually the case that a plant of a known form has given rise to another plant of a different form; in other words, a change or metamorphosis has really taken place. But we cannot reason in this way in the case of that which Goethe calls normal or ascending metamorphosis. For the plant taken as constant, the idea of metamorphosis has only a figurative meaning; the abstraction performed by the mind is transferred to the object itself, if we ascribe to it a metamorphosis which has really taken place only in our conception. The case would be different if we could assume that the stamens and other organs of the plants lying before us were ordinary leaves in their progenitors. So long as this assumption of an actual change is not even hypothetically made, the expression change or metamorphosis is a mere 'idea.' This distinction Goethe has not made; he did not clearly see that his normal ascending metamorphosis can only have the meaning of a scientific fact, if a real change is assumed to take place in the course of propagation in this case as in that of abnormal metamorphosis or misformation."

"In the years immediately before and after 1840 a new life began to stir in all parts of botanical research, in anatomy, physiology and morphology. Morphology was now specially connected with renewed investigations into the sexuality of plants and into embryology, and attention was no longer confined to the Phanerogams, or flowering plants, but was extended to the higher and later on to the lower Cryptogams, or flowerless plants (the old division of Linnæus). These researches into the history of development first became possible when Von Mohl had restored the study of anatomy and Nägeli had founded and elaborated the theory of cell-formation about the year 1845. The success of both these inquirers was due to the previous development of the art of microscopy; it was the microscope which revealed the facts on which the foundations of the new research were laid, while its promoters at the same time started from other philosophical principles than those which had hitherto prevailed among botanists.

"Serious attention to microscopy was one of the causes which introduced the best observers to the practice of inductive inquiry and gave them an insight into its nature, and in a few years' time when the actual results of these investigations began to appear and when a wholly new world disclosed itself to botanists, especially in the Cryptogams, then questions arose on which the dogmatic philosophy had not essayed its ancient strength. The facts and the questions were new and untouched and presented themselves to unprejudiced observation in a purer form than those which during the first three centuries had been so mixed up with the old philosophy and with the principles of scholasticism. "Von Mohl, who only occasionally occupied himself with morphological subjects," says Sachs, "was a firm adherent of the inductive method, and was bent on the establishment of individual facts rather than of general principles; but the founders also of the new morphology, Schleiden and Nägeli, started from philosophical points of view which, different as they were in the two men, had yet two things in common, a demand for severely inductive investigation as the foundation of all science and the rejection of all teleological modes of explaining phenomena, in which latter point their opposition to the idealistic nature-philosophy school was most distinctly manifested.

"They had indeed one very important point of contact with this school, the belief in the constancy of organic forms; but this belief, not being connected with the Platonic doctrine of ideas, was with them only a recognition of everyday observations, and was therefore of less fundamental importance, being felt merely as an inconvenient element in the science. Treating the question in this way, and influenced by the results of the new researches, they either inclined to entertain the idea of descent before the appearance of Darwin's great work or gave a ready assent to the principle of the new doctrine, tho they expressed some doubts respecting matters of detail. Hofmeister's researches in morphology and embryology threw an entirely new light on the relations of affinity between the great groups in the vegetable kingdom, and were leading more and more to the view that there must be some special peculiarity in the question of the constancy of organic forms."

"But the idea of evolution in the vegetable kingdom was brought more distinctly home to men's minds by paleontological researches. Unger especially, while advancing the knowledge of the structure of cells and of vegetable anatomy and physiology and generally taking a prominent part in the development of the new botany, applied the results of its investigations to the examination of primeval vegetation and showed the morphological and systematic relations between past and existing floras. After twenty years of preliminary study he declared distinctly in 1852 that the immutability of species is an illusion, that the new species which have made their appearance in geological periods are organically connected, the younger having arisen from the elder. In the year that Darwin's book on the origin of species appeared Nägeli wrote: "External reasons, supplied by the comparison of the floras of successive geological periods, and internal reasons given in physiological and morphological laws of development and in the variability of the species leave scarcely a doubt that species have proceeded one from another."

"Tho these words might not contain a theory of descent capable at once of scientific application, yet they show that the latest researches and candid appreciation of facts were compelling the most eminent representatives of the botany of the day to give up the constancy of forms. At the same time in the genetic morphology which had developed itself mainly under Nägeli's guidance since 1844, and still more in embryology, which in Hofmeister's hands was leading to results of the greatest systematic importance, there lay a fruitful element destined to correct and enrich Darwin's doctrine of descent in one essential point. That doctrine in its original form sought to show that selection, the result of the struggle for existence, combined with perpetual variation, was the sole cause of progressive improvement in organic forms. But Nägeli, relying on the results of German morphology, was able as early as 1865 to point out that this explanation was not satisfactory, because it leaves unnoticed certain morphological relations, especially between the large divisions of the vegetable kingdom, which scarcely seem explainable by mere selection in breeding.

"While Nägeli allowed that Darwin's principle of selection was well adapted to explain fully the adaptation of organisms to their environment and the suitableness and physiological peculiarities of their structure, he pointed out that in the nature of plants themselves there are intimations of laws of variation which lead to a perfecting of organic forms and to their progressive differentiation independently of the struggle for existence and of natural selection. The importance of this result of morphological research has since been recognised by Darwin. Thus Nägeli supplied what was wanting in the theory of descent and gave it the form in which it is adequate to explain the problem already recognised by the systematists of the old persuasion—namely, how it is possible for the morphological affinity of species in the system to be in so high a degree independent of their physiological adaptation to their environment. The modern teaching on vegetable cells, modern anatomy and morphology and the improved form of the theory of selection are the product of inductive inquiry since 1840. It is one of the characteristic features of this period of botany that morphology enters into the closest connection with the doctrine of the cell, with anatomy and embryology, and that researches, especially into the process of fecundation and the formation of the embryo, form to some extent the central point of morphological and systematic investigations.

At this time, when there was such necessity for general critical coördination and attack on the methods of the day, Schleiden began his writing. In all his work were to be found side by side with facts of real importance reflections of the man himself and generally coarse polemic, coupled with a free praise or blame of other workers.

Schleiden's greatest contribution was his establishment of the true nature of the cell and the propounding of what may be called the cell doctrine of the structure of plants. This was published in 1848, a year before the appearance of a similar contribution by Schwann as regards animal forms. Both of these investigations mark a new epoch in the study of the structure of organic forms, and from that time the researches into the inner morphology of plants made rapid progress.

"Schleiden's mode of dealing with the natural system must be reckoned among the good services which he rendered to method; not because his classification of the vegetable kingdom presents any specially interesting features or brought to light any new affinities, but because we see an attempt made for the first time to give detailed characters drawn from morphology and the history of development to the primary divisions, and because by this means the positive and distinct nature of the Cryptogams was from the first clearly brought out. The old way of treating morphology, as tho there were only Phanerogams in the world, and then having recourse to unmeaning negatives in dealing with the Cryptogams, was thus set aside, much to the profit of the immediate future, which directed its attention specially to the Cryptogams.

"Soon after Schleiden first stirred the scientific world a man of a very different character of mind began to address himself to the great task. This was Carl Nägeli, whose researches from this time onward laid the foundations of knowledge in every department of botany. Like others, he felt the necessity of first determining his position with respect to the philosophical principles of the investigation of nature, but he did not proceed to give a general exposition of the inductive method as opposed to the dogmatism of the idealistic school. He went straight to the application of the laws of induction to the most general problems of organic nature and specially of vegetation.

"It is easy to say," remarks von Sachs, treating of his work, "that the task of natural science is simply to deduce conceptions and laws from the facts of experience by aid of exact observation. Many considerations present themselves as soon as the attempt is made to satisfy this demand, for it is not enough merely to accumulate individual facts. The point to which the inductive inquiry is to lead must be kept constantly and clearly before the mind. Nägeli insisted that it is only in this way that facts and observations have any scientific value; that the one important thing is to make every single conception obtained by induction find its place in the scheme of all the rest of our knowledge. Since in nature everything is in movement, and every phenomenon is transitory, presenting itself to us in organic life especially as the history of development, all due regard must be paid to this condition of constant motility in forming scientific conceptions. The history of development is not merely to be treated generally as one of various means of investigation, but as identical with investigation into organic nature."

"Nägeli set himself in earnest to meet the demands of inductive inquiry, such as he had himself described them. Moreover, he connected his own morphological investigations, as fas as possible, with the lower Cryptogams, extending them afterward to the higher Cryptogams and to the Phanerogams—that is, he proceeded from simple and plain facts to the more difficult, thus not only introducing the Cryptogams into the field of systematic investigation, but making them its starting-point. In this way morphology not only secured a foundation in exact historical development, but it assumed a different aspect, inasmuch as the morphological ideas hitherto drawn from the Phan-

Wind-riven Foliage of Pike's Peak. Tropical Forest Showing Lianas.

erogams were now examined by the light of the history of development in the Cryptogams.

"This was one innovation; the second, closely connected with it, was the way in which Nägeli made the new doctrine of the cell the starting-point of morphology. Both the first commencement of organs and their further growth were carried back to the formation of the separate cells, and the remarkable result was to show that in the Cryptogams especially, whose growth is intimately connected with cell-division, precise conformity to law obtains in the succession and direction of the dividing walls and that the origin and further growth of every organ is effected by cells of an absolutely fixed derivation. The most remarkable thing was that every stem and branch, every leaf or other organ has a single cell at its apex, and that all succeeding cells are formed by division of this one cell according to fixed laws, so that the origin of all cell-tissue can be traced back to an apical cell."

While important fragments as to their life-histories and structures were described, they had little connected scientific value, save perhaps the discovery that the fertilization in certain Cryptogams as in animals was effected by spermatozoids. As to the flowering plants, the true function of the pollen tube and of the development of the embryo was not at all understood.

"This important question was set at rest by Wilhelm Hofmeister. He showed that the egg-cell is formed in the embryo-sac before fertilization, and that it is this which is excited to further development by the appearance of the pollen-tube and produces the embryo. Hofmeister had observed the organization of the ovule, the nature of the embryo-sac and of the pollen-grain and the formation of the embryo from the fertilized egg-cell step by step and cell by cell, and his account of these processes was aided by the light which Nägeli's theory of the cell and his reference of all processes of development to the processes of cell-formation had thrown upon the history of development. He went on to apply the same method to the study of the embryology of the Mosses and the Vascular Cryptogams, and followed the development of the sexual organs cell by cell in a large number of species. The intimate connection between such different organisms as the Liverworts, the Mosses, the Ferns, the Horse-tails, the Club-mosses, the Conifers, the Monocotyledons and Dicotyledons could now be surveyed in all its relations with a distinctness never before attained. Alternation of generations, lately shown to exist tho in quite different forms in the animal kingdom, was proved to be the highest law of development and to reign according to a simple scheme throughout the whole long series of these extremely different plants. It appeared most clearly in the Ferns and Mosses, tho at the same time with a certain difference in each; in the Ferns and allied Cryptogams a small inconspicuous body grows out of the asexually produced spore and immediately produces the sexual organs. From the fertilization of these organs proceeds the root-bearing and leafy stem of the Fern, which in its turn again produces only asexual spores. In the Mosses, on the other hand, a much differentiated and usually long-lived plant is developed from the spore, and this plant proceeds again after some time to form sexual organs, the product of which is the so-called Moss-plant. The first generation that arose from the spore, the sexual, is in the Moss the vegetative plant, while in the Ferns and their allies the whole fulness of vital activity and of morphological differentiation is unfolded in the second generation which is asexually produced.

"Here all was at once clear and obvious, but Hofmeister's researches also showed that the same scheme of development holds good in the Rhizocarps and Selaginellæ, where two kinds of spores are formed; and it appeared plainly from their case that the recognition of the true relation between the production of spores and sexual organs is the guide to the morphological interpretation. When the processes in the large female spore of the most perfect of the Cryptogams was known, the formation of the seeds in the Conifers was at once understood; the embryo-sac in these answered to this large spore, while the endosperm represented the prothallium and the pollen-grain the microspore. The last trace of alternation of generations, so obvious in the Ferns and Mosses, was seen in the formation of the seed in the Phanerogams. The changes which the alternation of generations passes through from the Mosses upward to the Phanerogams were, if possible, still more surprising than the alternation of generations itself.

"The reader of Hofmeister's 'Vergleichende Untersuchungen' was presented with a picture of genetic affinity between Cryptogams and Phanerogams, which could not be reconciled with the then reigning belief in the constancy of species. He was invited to recognise a connection of development which made the most different things appear to be closely united together, the simplest Moss with Palms, Conifers and angiospermous trees and which was incompatible with the theory of original types. The assumption that every natural group represents an idea was here quite out of place. The notion entertained up to that time of what was really meant by the natural system had to be entirely altered; it could as little pass for a body of Platonic ideas as for a mere framework of conceptions. But the effect of the work was great in respect to the system also; the Cryptogams were now the most important objects in the study of morphology; the Mosses were the standard by which the lower Cryptogams must be tried; the Ferns were the measure for the Phanerogams.

"Embryology was the thread which guided the observer through the labyrinth of comparative and genetic morphology; metamorphosis now received its true meaning, when every organ could be referred back to its parent-form, the staminal and carpellary leaves of the Phanerogams, for example, to the spore-bearing leaves of the Vascular Cryptogams. That which Haeckel, after the appearance of Darwin's book, called the phylogenetic method, Hofmeister had long before actually carried out, and with magnificent success. When Darwin's theory was given to the world eight years after Hofmeister's investigations, the relations of affinity between the great divisions of the vegetable kingdom were so well established and so patent that the theory of descent had only to accept what genetic morphology had actually brought to view.

"But the Algæ, Fungi and Lichens presented a chaotic mass of obscure forms in contrast with the well-ordered knowledge of the Mosses and Vascular plants. There was a difficulty in drawing the boundary-line between the lower animals and plants. The difficulty was solved by classing all objects capable of independent movement with animals. Thus whole families of Algæ were claimed by the zoölogists, and when the swarmspores of a genuine Alga were seen for the first time in the act of escaping, the phenomenon was described as the changing of the plant into an animal.

"Such was the condition of affairs with respect to the Algæ about the year 1850, when Hofmeister made the formation of the embryo in the Phanerogams, the Vascular Cryptogams and the Mosses the central point of investigation in morphology and systematic botany. He made it clear that a perfect insight into the whole cycle of development in the plant and into its affinities can only be obtained in making its sexual propagation, the first commencement of the embryo, the starting-point of the investigation. It was natural to expect as happy results from the embryology of the Algæ as had been obtained in the case of the higher plants. It was important, therefore, that the observer should no longer rest satisfied with a knowledge of the sexual multiplication of the Algæ. He must inquire into their asexual propagation, and by its aid discover the complete history of their development. Former observations suggested the probability that here too sexual propagation is the prevailing rule. A splendid result appeared in 1853 in Thuret's account of the fertilization of the genus Fucus; this was a simple process as a matter of embryology, but the sexual act was so clear and even open to experimental treatment that it threw light at once upon other cases more difficult to observe. Then followed discoveries by different workers of sexual processes in rapid succession. Pringsheim, however, was not content with carefully observing the sexual act. He gave detailed descriptions of growth in the same families in its progress cell by cell, of the formation of the sexual organs and the development of the sexual product. The asexual propagations which are intercalated into the vegetation and embryology were shown in their true connection. Processes were recognised which often recalled the alternation of generations in the Muscinæ; it was shown that very different forms of sexuality and of general development occur in the Algæ, and these led to the formation of systematic groups, quite different from those founded on the superficial observation of collectors. From the confused mass of forms not before understood Pringsheim brought out a series of characteristic groups, which, thoroly examined and skilfully described in words and by figures, stood out as islands in the chaotic sea of still unexamined forms and threw light in many ways on all around them. The Algæ offer at present a greater variety in the processes of development than any other class of plants. Sexual and asexual propagation and growth work one into the other in a way which opens entirely new glimpses into the nature of the vegetable world.

"Some useful observations also had been accumulating for some time on the Fungi. As early as 1729 P. A. Micheli (1679-1737) had collected the spores of numerous Fungi, had sown them and obtained not only mycelia but also sporophores (fructifications). Yet Rudolphi and Link at the beginning of the last century ventured to deny the germination of the spores of Fungi. Persoon in 1818 thought that some Fungi grow from spores, others from spontaneous generation.

The study of the lower fungi presented many difficulties, but by the method of carefully working out complete life-histories, or at least attempting to do so, progress was being made. To the brothers Tulasne belongs the credit of first breaking ground in this direction.

"But mycology owes its present form to none more than to Anton de Bary. With a correct understanding of the only means which can lead to sure results in this difficult branch of study, De Bary made it his first endeavor to perfect the methods of observation, and not only sought for the stages of development of the lower Fungi in their natural places of growth, but cultivated them himself with all possible precautions, and thus obtained complete and uninterrupted series of developments. By these means he succeeded in proving that parasitic Fungi make their way into the inside of healthy plants and animals, and that this is the explanation of the remarkable fact that Fungi live in the apparently uninjured tissue of other organisms, a fact which formerly had led to the supposition that such Fungi owe their origin to spontaneous generation or to the living contents of the cells of their entertainers. Pringsheim had already observed these occurrences in 1858 in the case of an unusually simple water-fungus (Pythium). De Bary showed that the intrusive parasite vegetates inside the plant or animal which is its host and afterward sends out its organs of propagation into the open air, and that at a given time the organism attacked by the fungus sickens or dies. These investigations were not only of high scientific interest to the biologist, but they produced a series of results of the greatest importance to agriculture and forestry and even to medicine.

"With the Fungi even more than with the Algæ the chief difficulty in making out a complete series of developments in the history of each species arose from the frequent intercalation of the asexual mode of multiplication into the course of its development and in the further peculiarity that the several stages of development in some cases could only be completed on different substrata. One of the most important tasks was to find the sexual organs, the existence of which was rendered probable by various analogies, and after De Bary had observed the sexual organs in the Peronosporeæ in 1861 he succeeded in 1863 in proving for the first time that the whole fruit-body of an Ascomycete is itself the product of a sexual act which takes place on the threads of the mycelium.

"But the most important result remains to be told. It is that the two classes of Algæ and Fungi, hitherto kept strictly separate, must obviously be now united and an entirely new classification adopted in which Algæ and Fungi recur as forms differing only in habit in various divisions founded on their morphology.

"A few words must be given here to the Lichens. They are the division of the Thallophytes whose true nature was last recognised, and that only in modern times. Till after 1850 scarcely more was known of their organization than Wallroth had discovered in 1825—namely, that green cells, known as gonidia, are scattered through the fungus-like hyphal tissue of the thallus. After Mohl's investigations in 1833, it was known that free spores were formed in the tubes of the fructifications (apothecia) and that a dust collected from the thallus and consisting of a mixture of gonidia and hyphæ was in a condition to propagate the species. The genetic relation between the chlorophyll-containing gonidia and the fungus-like hyphæ long continued to be obscure, till at last, after 1868, it was shown that the gonidia are true Algæ and the hyphal tissue a genuine Fungus and that therefore the Lichens are not a class coördinating with the Algæ and Fungi, but a division of Ascomycetes which have this peculiarity, that they spin their threads round the plants on which they feed and take them up into their tissue.

CHAPTER VI

ORGANOGENY AND ADAPTATION (ECOLOGY)

REFERENCE has already been made to the service which Schleiden did in promulgating the idea of the cell as the morphological unit of plant structure. As will be seen, he was not, indeed, the first to observe them, tho he was the first to properly understand their significance. Since the cell is the ultimate unit to which morphological discussions must necessarily hark back, it is well to examine a little more closely just what these cells are.

"A thin cross-section from the stem or leaf of any plant shows, when magnified, a network of cells not unlike those of the honeycomb. This fact was first discovered in 1667 by Robert Hooke, an Englishman, who happened to take such a section to test the improvements he was making on the microscope. The first real study of cell structure was made by Malpighi, an Italian, in the year 1671. The section thus examined appears to be divided into small chambers or cavities, separated from each other by a common wall. The single cavity with its enclosing wall, like a room in a house, received the name of cell. The origin of these cells, or elements of plant structure, was at first supposed to be similar to that of air bubbles in a somewhat viscous liquid, but this supposition was soon found untenable, as in no young growing tissues was there found any indication of the liquid in which the bubbles were supposed to form.

"At a much later period it was discovered that the wall, or membrane, which gave the name to the cavity which it surrounds, was really the less important part and that the cell contents were the only necessary element. This is shown by the fact that the wall is a product of the contents and that at certain periods of the plant's life the cell may exist without it. Discoveries of this kind gave rise to an entirely different conception of the nature of the plant-cell. It is now known that this, in its simplest or least differentiated condition, consists of a small portion of the viscous liquid known as protoplasm, in which, under ordinary magnification, no structures are visible. It is in this general sense that Reinke defines a plant-cell as follows: "An individualized, not farther divisible structure, consisting of or containing protoplasm which either shows life processes or has shown them."

"In studying the anatomy of a plant-cell," says E. L. Gregory in 'Elements of Plant Anatomy,' "it will be necessary to consider one in its ordinary condition of development—that is, as an element of any plant, differentiated sufficiently to perform the ordinary functions of plant-cells. Such cells are usually considered as consisting of two parts, wall and centents, or as it is frequently stated, wall and protoplasm, the latter including a nucleus and one or more vacuoles. Before taking up the study of these parts separately, it may be well to examine the cell as a whole in reference to several features—namely, size, form, mechanical and physiological principles, and finally to discuss briefly certain theories concerning organized structures in general. By far the greater number of plant-cells are microscopic, but they vary greatly in size. The smallest occur among the organisms known as bacteriă. Some of these are spherical in form and measure from seven-tenths to one micro-millimeter (.001 millimeter) in diameter.

"Cells vary as much in form as in size; those without a membrane incline to the spherical shape, since the protoplasm composing them is in a half-liquid state. Many swarm-spores are pear-shaped, but they generally assume a spherical form on coming to rest. The forms of some naked cells are subject to rapid change.

"In all the higher plants new cells are formed by the growth of walls across the cavities of the old cells. The new walls join the old at certain angles, and when the cells are young they are inclined to a hexagonal form. As growth continues the form is liable to change in various

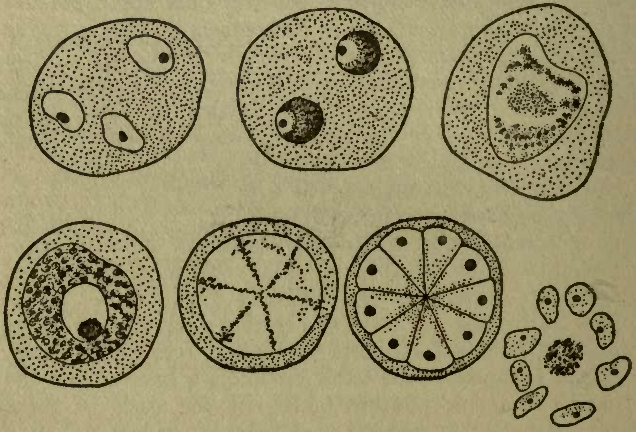


Fig. 29 —Various Types of Cells.

ways. If the cell should grow equally fast in all parts it would tend to retain its original form. This very rarely happens, and even when it does, the shape of such a cell is influenced in a greater or less degree by the manner of growth of those surrounding it, as the growing wall is flexible and its shape easily changed by pressure or traction from without.

"The individuality of the cell is shown by the fact that each has its own predetermined manner of development. All young cells of any plant are, at first, nearly similar in form and size, but later on each cell is seen to follow certain laws of growth which are, to a certain extent, independent of all external forces. From these laws, together with various mechanical causes, arises the great variety of form in the cells of ordinary plants. The peculiar forms common to certain unicellular plants illustrate even better than those of higher ones the inherent tendency of cells to grow in a certain manner.

"From the small size of the average cell two advantages result to the plant: First, strength and solidity; secondly, the greatest possible amount of surface for the transfer of cell contents. The first insures mechanical support; the second is connected with those changes in the chemical nature of the cell contents by which the life processes of the plant as a whole are carried on."

Herbert Spencer included a consideration of plants in his scheme of the "Principles of Biology." However some of his deductions may be regarded at the present time, the fact remains that he summed up in at least a convenient form the ideas of morphological differentiation as influenced by the idea of Evolution. It is true that Spencer's knowledge of plants was much of it second-hand, but his treatment of the subject was a philosophical one and in the main sound.

The problems of Morphology fall into two distinct classes, answering respectively to the two leading aspects of evolution. "Evolution," says Spencer in his 'Principles of Biology,' "implies insensible modifications and gradual transitions, which render definition difficult—which make it impossible to separate absolutely the phases of organization from one another. Thus, on inquiring what is the morphological unit, whether of plants or of animals, we find that the facts refuse to be included in any rigid formula. The doctrine that all organisms are built up of cells, or that the cells are the elements out of which every tissue is developed, is but approximately true. There are living forms of which cellular structure cannot be asserted; and in living forms that are for the most part cellular, there are nevertheless certain portions which are not produced by the metamorphosis of cells. Obviously, the earliest forms must have been minute, since, in the absence of any but diffused organic matter, no form but a minute one could find nutriment. Obviously, too, it must have been structureless, since as differentiations are producible only by the unlike actions of incident forces, there could have been no differentiations before such forces had had time to work. Hence distinctions of parts like those required to constitute a cell were necessarily absent at first. And we need not therefore be surprised to find, as we do find, specks of protoplasm manifesting life and yet showing no signs of organization.

"A further stage of evolution is reached when the imperfectly integrated molecules forming one of these minute aggregates become more coherent, at the same time as they pass into a state of heterogeneity, gradually increasing in its definiteness. That is to say, we may look for the assumption by them of some distinctions of parts, such as we find in cells and in what are called unicellular organisms. They cannot retain their primordial uniformity, and while in a few cases they may depart from it but slightly, they will, in the great majority of cases, acquire a decided multiformity; there will result the comparatively integrated and comparatively differentiated Protophyta and Protozoa. The production of minute aggregates of physiological units being the first step, and the passage of such minute aggregates into more consolidated and more complex forms being the second step, it must naturally happen that all higher organic types subsequently arising by further integrations and differentiations will everywhere bear the impress of this earliest phase of evolution.

"From the law of heredity, considered as extending to the entire succession of living things during the earth's past history, it follows that since the formation of these small, simple organisms must have preceded the formation of larger and more complex organisms, the larger and more complex organisms must inherit their essential characters. We may anticipate that the multiplication and combination of these minute aggregates or cells will be conspicuous in the early developmental stages of plants and animals, and that throughout all subsequent stages cell production and cell differentiation will be dominant characteristics. The physiological units peculiar to each higher species will, speaking generally, pass through this form of aggregation on their way toward the final arrangement they are to assume, because those primordial physiological units from which they are remotely descended aggregated into this form."

Goebel more recently, naming Spencer along with Hofmeister and Sachs as one who has contributed in a special degree to the science of organography, has proceeded along somewhat similar lines, tho with a far wider knowledge of the actual facts. In discussing the question of the elaboration of the plant body, his introductory statements are illuminating.

"It is manifest," he says, "that the distinction of organs must have originally been based upon differences of outer form. The word 'blade' indicates that the original conception of a leaf was that of a flat organ which was distinguished by this character from the usually cylindric stem; under the designation root all subterranean organs were reckoned. It is, however, now generally known that there are leaves which have all the appearance of shoots, and the converse is also the case.

"External form is closely connected with function and with anatomical structure. In the vegetative organs the form may change, accompanied by a change in anatomical structure; 'metamorphosis' may take place, and a flower-leaf is the homologue of a foliage-leaf, notwithstanding that it has quite a different form.

"The history of development of the stem of the leaf is usually different. In the first place the duration of development is unlike; leaves have limited growth, shoots have unlimited growth. But there are many shoots which normally exhibit limited growth; for example, the short shoots, or spur-shoots, of many conifers and broad-leaved

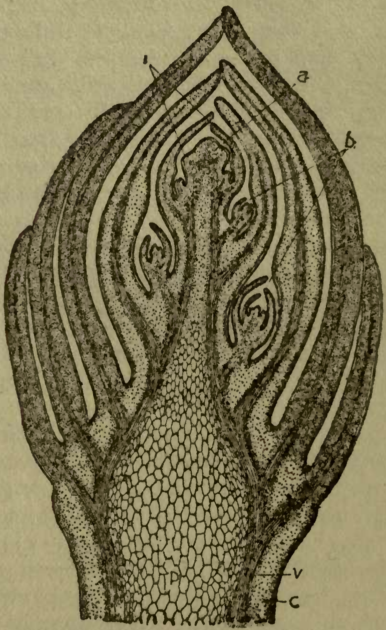


Fig. 30 —DIAGRAM OF TIP OF STEM IN LONGITUDINAL SECTION. a., formative region; lb., leaves and branches in various stages of development; v., vascular bundles; c., cortex; p., pith. (Curtis.)

trees. These, however, may under certain conditions become shoots of unlimited growth and be transformed into long shoots.

"A striking illustration is furnished by species of the genus Utricularia, which are among the most remarkable plants in the world. In this genus the floating 'shoots' of the water-form, as well as the creeping 'stolons' of the land-form, are homologous with leaves, but the difference between stem and leaf has entirely disappeared. The organs which are homologous with leaves produce flowers and other shoots and exhibit unlimited growth, and that they are really leaves with prolonged apical growth is only to be determined by a careful comparative study. Every distinction then that we may draw between shoot and leaf is only relative, is not fundamental.

"There is, however, this point still to notice: Leaves are in most cases outgrowths of shoot-axes and they arise on their vegetative point as lateral members; nevertheless terminal leaf-organs—organs arising from the end of a shoot-axis—are known. They occur in the flowers of many plants; the cotyledon in many monocotyledonous plants is terminal in the embryo. There are also monocotyledonous embryos upon which leaves arise, altho no vegetative point of the axis is visible, and a similar condition is also found in Isœtes. Further, the vegetative body of Lemna is nothing else than a leaf producing leaves; it is not a leafless twig, as is commonly assumed.

"A plant-body in which the shoot-axis does not exhibit differentiation into stem and leaf is termed a thallus. The expression thallus, which signifies nothing more than shoot, was first used by Acharius in describing the lichens, and subsequently it was extended to the Algæ, the Fungi and the thallose liverworts. There is no sharp limitation between a thallus and a leafy shoot.

"The external relationships of configuration of the bodies of plants are determined by the peculariarities of their living substance, the protoplasm, which in the higher plants is enclosed within the numerous cells which compose the plant; it is only among the lower plants that we find unicellular bodies. In land-plants the cellular structure is general and the several cell-chambers are separated from one another by firm walls."

Here Goebel speaks of Sachs' definition of the energid as the unit of cell structure, quoting Sachs, who says: "By an energid I mean a single nucleus with the protoplasm which it dominates." Thus he distinguishes the monergic type of plant, which is unicellular and has but a single nucleus—*i.e.*, is a single energid—and the polyergic forms which have many energids that are usually separated into individual cells by cell walls, tho in some of the lower forms they may not be.

"It has been possible," he continues, "in a large number of cases to discover a relationship between their forms and their life-functions. We see this, for example, among diatoms. The monergic cells of fixed species have a different construction from that which obtains in the actively moving or floating species. It is also clear that the pear-like form of most swarm-spores is especially favorable for their movements. In other cases, however, we know so little regarding the special life-relationships of the plants that we are quite unable to speak with certainty. We cannot, for example, say whether the rod-like or sickle-like desmids have relationships of a kind different from those of the plate-forms.

"The degree in which the single energids are united with one another may be more or less intimate. A polyergic plant is either an energid colony or cœnobium (cellular or non-cellular), in which a division of labor between the several energids has not yet appeared and each energid is capable of living for itself, or the energids exhibit a division of labor, and, altho in unison with one another, are therein different from one another; they form an energid dominion. This is what has come to pass in the majority of the polyergic plants. There are, of course, many transitions between these two conditions, and their separation is in a measure artificial, being based upon extreme relationships.

"In the higher plants the shoot is differentiated into shoot-axis and leaf in all cases except in some degenerate parasites. There are, it is true, leafless shoots of limited growth, but these are quite exceptions. In the lower forms of plant-life such a differentiation of the shoot may also take place. The sexual generation of many liverworts and of the whole of the mosses shows an evident division into shoot-axis and leaf, and, as has been above explained, this condition is reached among the liverworts in the most different cycles of affinity, which have developed quite independently one of the other. That the leaves of the sexual generation of mosses are not homologous with those of the asexual generation of the Pteridophyta is sufficiently clear, but terminology is only a means to an end, and I have no hesitation in calling the leaf-like organs which we find in many Thallophyta 'leaves.'"

The development of morphology, both as it applies to cell and tissue structure alone and as it applies to the study of life-histories, has made rapid advances in the last few decades. There have been and are numerous keen investigators covering all morphological fields. The present knowledge of the structure of the individual cell has greatly increased, and the store of information regarding the embryology of the higher plants, tho founded on the classic work of Hofmeister, is well-nigh a new science. The study of life-histories in as complete a way as possible is now the aim of morphological investigators.

"The morphologist," says H. M. Richards, "who devotes his time to the study of life-histories is engaged in the work of tracing the race history of plants from the comparison of the individual development of more or less nearly related forms. Thus the homologies which have been traced among the flowering plants and their nearest allies among the ferns and other forms indicate to us the probable race history of these groups. It is true that the beginning of this work dates back some decades, but it is still, to a large extent, an open field, and numerous investigators are actively prosecuting research along these lines. For example, the alternation of a sexual and nonsexual generation of plants which has long been known as characteristic of the life-histories of higher forms has recently been established among the lower groups, and thus a much clearer view of the whole series of the plant kingdom is being obtained."

The branch of botanical research known as ecology is one of the most inclusive. It may be regarded as an attempt to grasp the full meaning of the morphological and physiological manifestations of the living plant not only as they concern itself, but also in their relation to all factors of its environment, whether with other organisms or with purely physical agents. It is evident that the problem is a stupendous one, and in the present state of knowledge both of physiology and morphology it cannot be expected that necessarily permanent results are to be obtained. Nevertheless it serves a highly important end in calling attention to and insisting upon the fact that environmental factors must influence the individual; that no organism, even a plant, is a free agent in determining its career or the career of its progeny.

Ecology is the application in a broad and more philosophical way of the methods of the physiological anatomist coupled with those of the taxonomist; but, in addition, the work of the botanist touches the field of the physiographer and geologist. "Ecology," says H. M. Richards in his 'Botany,' "is the endeavor to uncover the plan of nature as it governs the relations of the different plant forms in a given area, to understand the why and the wherefore of the association of very different forms in one locality. The keynote of the philosophical development of this topic rests on the conception of the constant struggle of individuals or groups of individuals to maintain themselves against other forms, which leads to a balanced relation of the different species in a given flora."

From the beginning one of the greatest of ecological problems has been that of the origin and significance of adaptations. "In other days," remarks Henry C. Cowles in his 'Trend of Ecological Philosophy,' "the solution was sought in special creation, one of the most unscientific of all theories, because altogether subversive of experiment. The entire question was prejudged at the outset. The theory of special creation, however, has not been especially harmful, because it has generally seemed so unlikely as to have received but little support among scientific men. Perhaps the most baneful of all ecological theories has been the Lamarckian theory of direct adaptation.

"The theory of natural selection has worked great harm in the ecological study of plant structures. Thorny plants have been supposed to be selected by reason of animal incursion, and such complex things as floral structures have been supposed to be the result of parallel selection on the part of flowers and insects. There is no adequate evidence, experimental or otherwise, for views of this character. Such experimental work as has been done appears to show that the success or failure of a plant rarely depends upon this or that little advantage, upon which natural selection may be supposed to work, but rather that its perpetuation depends for the most part upon other things than its so-called adaptations.

"Few more perfect adaptations for their function can be thought of than the digestive glands of insectivorous plants, and yet there is no evidence in support of the idea that such plants have been able to survive by reason of these glands. The evolution of such a complex flower as that of the orchid along lines that are parallel with the evolution of the mouth parts of a special insect requires a nicety of operation that seems staggering, and all the more because the flower, at least, seems to have evolved so far along the lines of zygomorphy as to be a source of disadvantage rather than of advantage, an impossible idea to the natural selectionist.

"The facts of regeneration show that plants and animals are often in a position to make an instant new reaction to conditions unlike those to which they have ever been accustomed and that these reactions may or may not be advantageous. In any case, natural selection can have no possible connection with their origin. The trend of the time, especially among botanists, is unmistakably toward the abandonment of natural selection as a theory of evolution, but ecological work is finding a dominant place for it as one of the controlling factors in succession. The student of vegetation dynamics, more perhaps than any other, finds displayed before him an incessant struggle for existence; in the changing conditions the fitness of an old species to remain or of a new species to displace it is commonly a matter of profound importance in the vegetative change produced.

"To the working ecologist the necessary consequences of the abandonment of the idea of adaptation and of natural selection as a causative factor are most vital. First and foremost there comes the possibility of disadvantageous trends in evolution. To some extent such tendencies will be checked by the destructive operation of natural selection, so that only such new species as are most fit are likely to survive and have progeny. But in view of the ideas that have generally prevailed in past years, it cannot be emphasized too strongly that plants may retain useless structures and even structures that are moderately harmful and yet live on if they also possess other structures or habits that are sufficiently advantageous. This conception at once relieves ecologists of one of the most arduous of their former duties, the establishment of an advantageous function for every organ and of a benefit in every function."

CHAPTER VII

PHYSIOLOGY OF PLANTS

"Every living organism has the power of producing offspring which inherit the characteristics of the parent stock," says Pfeffer in his 'Physiology of Plants.' "The fact that the acorn always produces an oak, a fungus spore the same specific fungus, is sufficient proof that it is the inherent properties of the living substance of the embryonic organism which primarily determine the shape, character and indivdual peculiarities of the adult organism. In the young plant the full development of such characters takes place only through interaction with the external world, and not unless certain necessary conditions are fulfilled. Thus, if the plant is deprived of nourishment it finally dies of hunger, while vital activity and growth are only possible in the presence of water and within certain limits of temperature. It is evident that the absence of any one of the necessary conditions must invalidate the remaining ones, so that if the amount of water is insufficient, or if the temperature sinks too low, the vital activity of the organism is depressed or completely arrested, and similarly at a high temperature death ultimately supervenes. Hence Physiology is primarily required to determine the powers and possibilities of individual organs and cells and their various interactions.

"The manifestations of life when traced back to their ultimate origin are always found to originate in the protoplasm, an undifferentiated mass of which constitutes the substance of the simplest living elementary organism. Hence one of the tasks of Physiology is to throw light on the manner in which the inherent nature of the protoplasm is responsible for the chemical and physical changes to which it gives rise. It is as impossible to picture a regular continuance of life otherwise than by the coöperation of different organs and biological elements as it is to imagine a watch which could still keep time after the removal of certain of the wheels.

"The chemical nature of the living organism, with its indissolubly connected chemical and mechanical properties, is of much greater importance than that of a machine; for in the changes which take place in the self-regulating protoplasmic mechanism chemical nature and affinities are, in all cases, of fundamental importance. Hence progress in Physiology necessarily goes hand in hand with progress in Chemistry. From a physiological standpoint it is hardly possible, for example, to overestimate the importance of a complete knowledge of the chemical constitution of the proteids, which take so prominent a part in building up the living protoplast, especially in view of the possibility that each particular species may be characterized by a specific variety of living proteid.

"There is no reason for regarding life as the product of an extraordinary and mystical natural force; it is to be treated simply as a special and peculiar manifestation of energy. Moreover, since we can only guess at the evolutionary history of the organism, it is only possible for us to deal with the physiological and other properties which it now possesses, and however clearly we may be able to explain the peculiarities of a given plant as being due to characters and tendencies inherited from its parents, we shall still be unable to determine with certainty the evolutionary origin of that particular species.

"The production and hereditary transmission of variations are connected in many ways with the general physiological problems with which we are immediately concerned. When any variation takes place an alternation in the structure or nature of the protoplast must have previously occurred, provided the variation is not merely a temporarily induced one, but is one capable of hereditary transmission to the offspring. This is true for the lowest as well as the highest plants, and whether the variation is perpetuated by sexual asexual reproduction. The conclusion that a change of this kind necessarily indicates an alteration in the arrangement or character of the protoplasmic constellation is, indeed, a logical necessity, even tho it is impossible to determine exactly how the given variation arises or is induced.

"The reproduction of hybrid forms is evidently due to the combination of two different kinds of living substance. There can be no doubt that if it were possible to interchange the nuclei of two separate and distinct protoplasts, assuming that the strange nuclei and protoplasts could live and grow together, two new organisms would be produced differing from one another and from the original protoplasts. These special characteristics of the new organisms would be preserved so long as the union and coöperation between the parts of the new protoplasts were maintained. This would also be the case if, for example, a bacterium existed in intimate and permanent symbiotic union with the protoplast, as a chloroplastid does, and were transmitted from generation to generation in the ovules.

"It is, as a matter of fact, not inconceivable that the existence of certain species, as such, depends upon protoplastic or symbiotic unions of similar character to the above. Nor is the possibility excluded that the tiny symbiont might be too small to be visible, or might be unable to continue an independent existence outside of the protoplast. Comparatively recently lichens were regarded as distinct organisms, altho we now know that they are the products of a synthetic union of two distinct plants, and that by the artificial synthesis of various algæ and fungi new forms, or forms similar to those already known, may be produced with relative ease.

"Nevertheless, as is well known, variation capable of hereditary transmission may arise without the help of foreign protoplasm, and certain bacteria afford especially instructive examples of these. Thus in many bacteria the power of forming either spores or certain metabolic products may be inhibited by a particular mode of treatment, and in some cases this inhibition is permanent, so that even under normal cultural conditions a reversal never takes place. The variety thus produced will hence remain constant in a neutral environment, altho there always remains the possibility that by the action of other agencies a return to the original condition may be induced. Accidental reversions are, as is well known, by no means uncommon in the higher plants.

"Saltatory variations often do appear in organisms, and may arise under precisely similar external conditions in particular individuals only, or may even affect these in different manner or degree. It has previously been stated that Physiology must necessarily seek an explanation of all vital processes in the developmental and formative powers of the protoplast. Our knowledge on this point is still in its infancy, and we must be content if we can gain here and there a glimpse into the internal protoplasmic mechanism. Even tho our knowledge with regard to the structure of protoplasm were to be enormously increased we should still see, not the causes and forces which are acting, but only the results which they produce. The most perfect mental picture of the plant or of the protoplast must necessarily fail to reveal the hidden and invisible causes which make it assume its specific form.

"Above all, it must be remembered that the simplest protoplast is an organism of very complex structure, and that its various activities result from the interactions of its component parts and organs. The particular result which any given cause produces is due to the special nature of the given protoplast. Every plant must therefore necessarily have certain special protoplasmic characteristics which are peculiar to it alone. At the same time, protoplasts of similar origin may temporarily or permanently acquire special properties by a progressive differentiation of labor and by adaptation to special aims and purposes. Nevertheless, the plant protoplast, so long as it remains living, retains all the general features which characterize a typical vegetable cell.

"In order to attain certain ends the organism forms parts which are not living or capable of life. One such organ is the cell-wall which the protoplast constructs as a protective mantle in which it may live and work; indeed, the protoplast living inside its cell-wall may be compared to a snail in its shell. In certain cases the protoplasmic contents may escape from the cellulose investment as a naked swarmspore, which later may build for itself a new domicile.

"In the protoplast, just as in a snail, the internal structure and functional importance of the component parts require to be studied. Within the protoplast are spaces having considerable functional value, which are surrounded by living substance, but whose contents are not living. Such are the vacuoles, which subserve a variety of functions. They may serve for the storage of reserve food material, while the dissolved substances which they contain give rise to the osmotic properties of the cell and preserve these properties during growth. As the vacuoles increase in size the cell becomes much larger, but the amount of protoplasm which it contains undergoes no increase, or but little, so that finally it is reduced to a thin primordial utricle or bag, closely adpressed to the cell-wall, and containing a single large central vacuole. Vacuoles are laboratories in which food may often be digested or building material prepared for use, while at the same time they are utilized in translocation.

"The body of the protoplast, the protoplasm as we may call it, is built up of organs and elemental structures. The nucleus is an organ of very general importance, and, indeed, a separation into nucleoplasm (karyoplasm) and cytoplasm probably occurs in all protoplasts. On the other hand, chromatophores, including chlorophyll corpuscles, are organs of special character and are absent from fungi. When such special organs are present they may be given the general name of plastids.

"Like all living substance, the plasmatic organs are of considerable complexity. This is readily perceptible in the resting nucleus, and is admirably shown when the latter divides; while the chromatin fibers, which are then so markedly visible, may also be seen to have a definite structure of their own. Besides the plastids already mentioned, the cytoplasm may contain minute bodies, often in great numbers, which, regardless of their morphological and physiological nature, may be termed microsomes or microsomata. They may be composed in some cases of non-living substance, but in other cases may be minute living plastids.

"In a small cell, or one of the organs of such a cell, the component units must necessarily be still smaller, and yet have positive dimensions; while the smaller and more numerous these units are the more varied and complicated will the possible combinations be. At the same time a relatively greater surface area is correlated with the smaller size, and this is a factor of the utmost importance; for bacteria teach us what remarkable powers are conferred by extreme minuteness and what extraordinary processes it renders such organisms capable of performing.

"The various operations which are continually going on in the body of the plant involve the execution of a considerable amount of work. This is very evident in the enormous development of a large tree from the relatively small seed. Such a process of construction has involved the preparation of a vast quantity of highly complex material from very simple chemical substances. The processes incident to life also, tho they may not lead directly to the formation of such substances, cannot be conducted without involving a considerable amount of work, whether the plant is a minute body consisting of a single protoplast, or an organism of a much higher degree of complexity."

"If we turn now to consider the sources of the plant's energy," continues J. Reynolds Green in his 'Introduction to Vegetable Physiology, "it is evident that they must be in the first instance of external origin. . . . The radiant energy of the sun, indeed, is the only possible source which can supply it to normal green plants. The rays which emanate from the sun are generally alluded to as falling into three categories: those of the visible spectrum, those of the infra-red, and those of the ultra-violet. The second of these are frequently spoken of as heat rays and the last as chemical.

"The greatest absorption of energy appears to take place in consequence of the peculiarities of chlorophyll. This substance, whether in the plant or when in solution in various media, absorbs a large number of rays in the red and in the blue and violet regions of the spectrum, together with a few others in the yellow and the green. The solar spectrum, after the light has passed through a solution of chlorophyll, is seen to be robbed of rays in these regions, and hence to present the appearance of a band of the different colors crossed by several dark bands. The greater part of the energy so obtained in the cells which contain the chloroplasts is at once expended, partly in constructing carbohydrate food materials and partly in evaporating the water of transpiration, the latter process being much the more expensive."

Speaking of these carbohydrate food materials, H. M. Richards says: "It is evident that the starch, which is the first substance that we readily recognise, is not the first substance which is formed. Modern research points more and more to the conclusion that it is the simplest of carbohydrates that is produced, a substance known as formaldehyde. But what is especially interesting is that it seems not impossible that this primal reaction may not, after all, be a function of the living protoplasm, but a chemical reaction that can be carried on outside the cell through the agency of chlorophyll. It is in the further elaboration of this first substance formed that the living protoplasm is apparently necessary. At any rate, we know that the energy demanded for the process must be

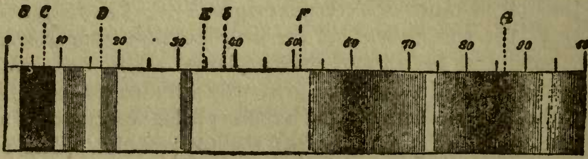


Fig. 31 —Absorption Spectrum of an Alcoholic Solution of Chlorophyll Extracted from Foliage Leaves.

The broad black on the left indicates in what portion of the spectrum—namely, the red-orange—the greatest absorption takes place.

afforded by the particular rays of sunlight which the chlorophyll absorbs."

"There is plenty of evidence," continues Green, "of the power of plants to avail themselves of the heat rays. Not only can the air rob the plant of heat by radiation, but when its own temperature is high it can communicate heat to it in turn. Indeed, its absorption by the leaves would be a source of considerable danger to the plant were it not for the cooling effect of transpiration, which dissipates 98 per cent. of it during bright sunshine. No doubt this dissipation is one of the chief benefits secured by transpiration.

"It is evident, however, that in the general economy of the plant something further must be at work in connection with the supply of energy. The absorption of these external forms must take place at the exterior of the plant, while many the processes of expenditure are carried out in parts which are more or less deep-seated. We are obliged to turn our attention, therefore, in this connection as in that of the construction and utilization of food, to processes of accumulation, distribution and economy.

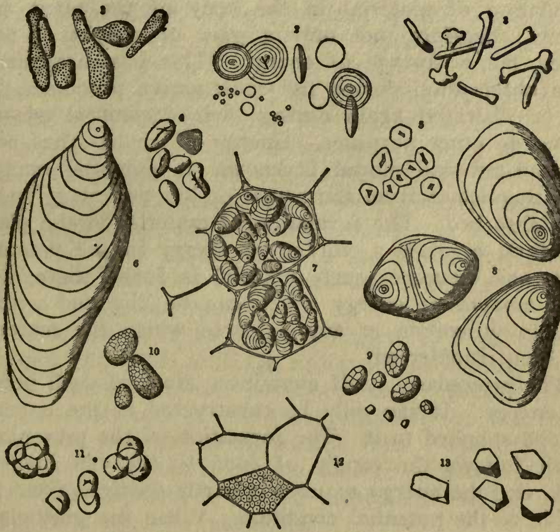


Fig. 32 —Forms of Starch Grains.

1., from corn-cockle; 2., from wheat; 3., from spurge; 4., from bean; 5., from Indian corn; 6., from canna; 7., from potato; 8., from potato (highly magnified); 9., from oats; 10., compound grain from seed of a grass; 11., from meadow saffron; 12., from rice; 13., from millet. (Kerner.)

"What is the immediate fate of the energy absorbed? It enters the plant in what is known as the kinetic form. A very considerable part of the kinetic energy of the sun's rays, we have already seen, is devoted at once to the evaporation of the water of transpiration, but some of it is employed by the chloroplasts to construct some form of carbohydrate. The energy so applied can be again set free by the decomposition of this formed material. If the latter were burned its combustion would be attended by the evolution of a certain definite amount of heat. This heat would represent the energy that had been applied to the construction of the material so burned. Any accumulation of material in the body of the plant represents, therefore, not only a gain of weight or substance, but a storage of energy. This has disappeared from observation during the constructive processes, but can be liberated again during their decomposition and applied to other purposes. Energy which has thus been accumulated and stored is known as potential energy, to distinguish it from the actual or kinetic energy originally absorbed. The formation of material in the plant, therefore, involves a storage of energy in the potential form, and wherever such material is found there is in it an amount of energy which can be liberated with a view to utilization at any point to which the material has been transferred.

"The protoplasm itself contains a store of such potential energy. It can only be constructed at the expense of food supplied to it. The formation of the protoplasm which follows the supply of food to the cell involves work, and the energy so used is partly changed from the kinetic to the potential condition. When the protoplasm undergoes what we have called its self-decomposition, which is continually taking place, a certain amount of this potential energy is liberated and can be observed and measured in various ways. When destructive metabolism is active there is usually a rise of temperature, as in the processes of the germination of seeds. A certain amount of the liberated potential energy in this case manifests itself in the form of heat. A vegetable cell which obtains no direct radiant energy from without can, consequently, obtain the energy it needs from within itself by setting up decomposition, either of its own substance or of certain materials which have been accumulated within it.

"The transformation of potential into kinetic energy is associated with decomposition just as the converse process is bound up with construction. Destructive metabolism in the cell is then the means by which its energy is made available. The processes of this katabolism go on in the interior of each cell. Each liberates at least as much energy as it requires for the maintenance of its life and the discharge of its particular functions. The processes associated with the utilization of the stored energy are, then, chemical decompositions in which various constituents of the cell are involved. These are of two kinds, in the first of which the protoplasm itself takes part, and which comprize the processes in which its own breaking down takes place; in the second it effects the splitting up of other bodies without a necessary disruption of its own molecules.

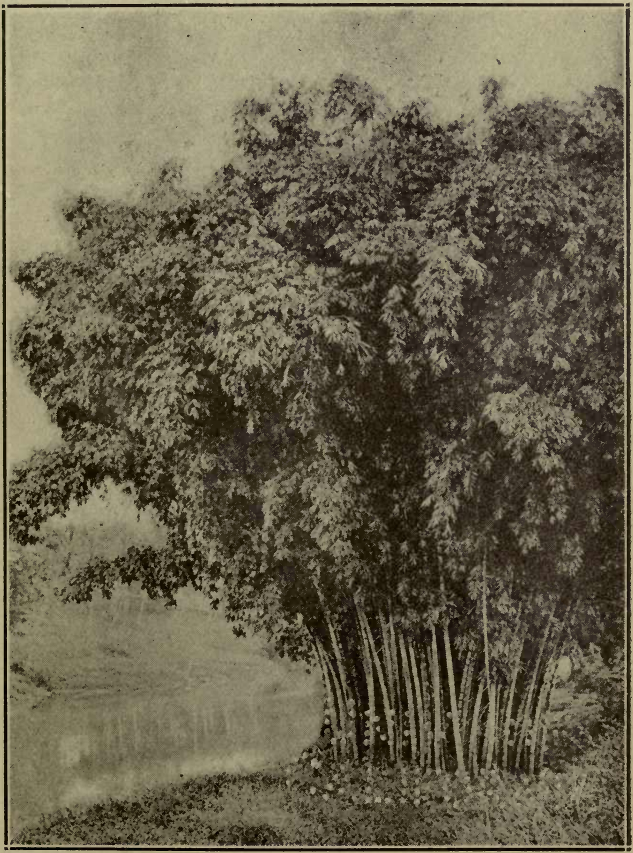
"Respiration is to be looked upon as a process very largely connected with the utilization of the store of energy which each cell possesses, and perhaps primarily to be concerned in the transformation of that energy from the potential to the kinetic form. The oxygen appears to be necessary mainly for the purpose of exciting those decompositions of the protoplasm which are so dependent upon its instability."

CHAPTER VIII

GROWTH AND VARIATION

"In studying the growth of plants," says Reynolds Green, "the relation which it bears to the processes of metabolism must be borne in mind. The constructive processes are much greater than those which lead to the disappearance of material from the plant-body. The result of this is that there is a conspicuous increase in the substance of the plant as well as an accumulation of potential energy which can be made use of by the plant through various decompositions which its protoplasm can set up. The great permanent accumulation of material is what we associate with the processes of growth. Mere increase in weight in an organ does not, on the other hand, necessarily imply any growth.

"Growth," he continues, "is in the strict sense always associated with the formation of new living substance, and is very generally accompanied or immediately followed by additions to the framework of the growing cells or organs. It is in nearly all cases attended by a permanent change of form. This is perhaps not so evident in the case of axial organs as it is in that of leaves and their modifications, tho even in them it can be detected to a certain extent. It is much more conspicuous in the case of leaves, for the latter, as they expand from the bud, have usually a different shape from that of the adult ones, and the assumption of the mature form is a gradual process, taking place as the age of the leaf in-



Giant Bamboo (compare size of man at foot).

creases. Growth may, in the light of the considerations just advanced, be defined as permanent increase of bulk, attended by permanent change of form.

"Growth in the lowliest plants may be coextensive with the plant-body. In all plants of any considerable size, however, it is localized in particular regions, and in them it is associated with the formation of new protoplasts. In the sporophytes of all the higher plants there exist certain regions in which the cells are merismatic; that is, which have the power of cell multiplication by means of division. In such regions, when a cell has reached a certain size, which varies with the individual, it divides into two, each of which increases to the original dimensions and then divides again. As these growing regions consist of cells, the growth of the entire organ or plant will depend on the behavior of the cells or protoplasts of which its merismatic tissues are composed.

"The growth of such a cell will be found to depend mainly upon five conditions: (1) There must be a supply of nutritive or plastic materials, at the expense of which the increase of its protoplasm can take place, and which supply the needed potential energy. (2) There must be a supply of water to such an extent as to set up a certain hydrostatic pressure in the cell. (3) The supply of water must be associated with the formation of osmotic substances in the cell or it cannot be made to enter it. In the absence of the turgescence which will be the result of the last two conditions no growth is possible, for reasons that will presently appear. (4) The cell must have a certain temperature, for the activity of a protoplast is only possible within particular limits, which differ in the cases of different plants. (5) There must be a supply of oxygen to the growing cell, for, as we have seen, the protoplast is dependent upon this gas for the performance of its vital functions, and particularly for the liberation of the energy which is demanded in the constructive processes. This is evident also from the consideration that the growth of the cells is attended by the growth in surface of the cell-wall; and as the latter is a secretion from the protoplasm—a product, that is, of its katabolic activity—such a decomposition cannot readily take place unless oxygen is admitted to it.

"Growth, so far as it implies only the formation of living substance, is thus a constructive process. It is,

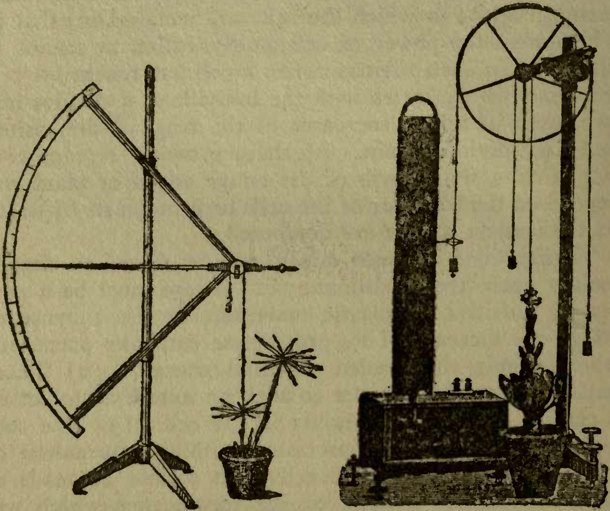


Fig. 33 —Apparatus for Measuring Growth. (Giesenhagen.)

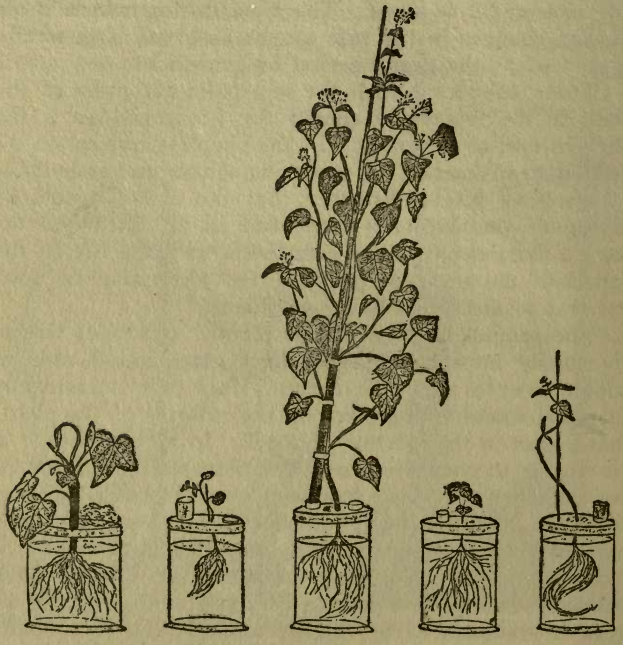
however, intimately associated with destructive metabolism or katabolism, the latter being involved in the construction of the increased bulk of the framework of the cell or cells, and being essential to supply the energy needed for the constructive processes.

"The process of the growth of a cell is limited in its extent, tho the limits vary widely in different cases. In some, cells grow only to a few times their original dimensions; in others they may attain a very considerable size. In any case, however, we can notice that the rate of growth varies regularly throughout the process; it begins slowly, increases to a maximum, and then becomes gradually slower till it stops. The time during which these regular changes in the rate can be observed is generally spoken of as the grand period of growth."

Closely connected with the metabolic activities of the plant in the release of energy for life processes is the phenomenon of digestion. In the simplest conception digestion means merely the rendering soluble and assimilable of insoluble food substances; but the active agents of digestion—the enzymes—may, and in all likelihood do, have a far more intimate connection with the life of the cell than the mere preparation for absorption of food exterior to the actual living substance.

"The process of digestion in plants," continues Green, "is chiefly intracellular, and takes place in all cells in which reserve materials occur. It is only occasionally that it is found taking place on the exterior of the plant; that is, not in the interior of a cell. In a few cases it is carried on in connection with the absorption of nitrogenous or protein food, as has been already shown. Digestion, tho most generally associated in plants with the utilization of reserve materials, may thus occasionally be met with in connection with the absorption of food from without, when it is a process precisely similar to the digestive processes of the higher animals, tho it is somewhat simpler in the details of its mechanism. The intracellular digestion of plants agrees very closely with that of many of the humbler animals, and corresponds also with such processes in the higher forms as the utilization of the glycogen of the liver and the fat of various regions.

"Absorption of food from without, after preliminary digestion, is much more frequently observed when we study the nutritive processes of the Fungi. Not only protein, but also carbohydrate and fatty substances are thus digested outside the body of the plant, and the products of the digestion are subsequently absorbed.



4 3 1 2 5

Fig. 34 —Plants of Buckwheat Cultivated in Various Nutritive Solutions.

1., normal solution containing all necessary salts; 2., solution with potassium compounds omitted; 3., with sodium salts omitted; 5., with nitrogen compounds omitted.

"The protoplasm of the cell, among its many properties, no doubt has the power of setting up these decompositions, and probably in many of the very lowly plants, in which the whole organism consists of only a few protoplasts or perhaps a single one, the work is altogether effected by its instrumentality. The protoplast, in fact, carries out all the various processes of life by the interactions of its own living substance with the materials absorbed by it, aided in the constructive processes by the chlorophyll apparatus, if it possesses one. In such a protoplast we may observe at times the storage of such a reserve material as starch, and its digestion at the appropriate period.

"Even in more complex plants it is certain that the living substance of every protoplast is in a constant state of change, initiating many decompositions in which its own substance takes part, as well as others into the course of which it does not itself enter. Among these decompositions we must include the various intracellular digestive processes. Tho all protoplasm has this power, it is not usual in plants, any more than in animals, to find it exclusively relying on it. The work of digestion, at any rate, is generally carried out by peculiar substances which it forms or secretes for the purpose. We have in plants a large number of these secretions, which are known as enzymes, or soluble ferments.

"The action of these enzymes is not at all completely understood. They appear not to enter into the composition of the substances which are formed by their activity, and they seem to be capable of carrying out an almost indefinite amount of such work without being used up in the process. They are inactive at very low temperatures, but effect the decompositions they set up freely at the ordinary temperature of the plant. As the temperature at which they are working is raised their activity increases up to a certain point, which varies slightly for each enzyme, and is called its optimum point. This usually ranges between 30° and 45° C. If the temperature is raised above the optimum point the enzyme becomes less and less active as it rises, and at about 60-70°

C. it is destroyed. The exact point, however, varies a good deal in the cases of different enzymes.

"Enzymes work most advantageously in darkness or in a very subdued light; if they are exposed to bright sunshine they are gradually decomposed, the violet and ultra-violet rays being apparently most powerful in effecting their destruction. They are often injuriously affected by neutral salts, alkalies or acids, tho in this respect there exists considerable diversity throughout the group.

"The enzymes are manufactured by the protoplasm of the various cells in which they occur, being produced from its own substance in a manner somewhat similar to that of the formation of the cell-wall. Usually their presence is accompanied by a marked granularity of the protoplasm, due to the formation in it of an antecedent substance known as a zymogen, which is readily converted into the enzyme. This granularity does not, however, always occur, tho we have reason to suppose that the secretion of the enzyme always takes place by successive stages. The zymogen has not, however, been definitely detected in all cases."

While, as has been stated, the digestion of substances within the cell is the most common occurrence, there are not a few cases, even among the highly developed plants, where digestive ferments are excreted and act upon materials exterior to the cell itself. The absorption of food material stored in the seed is often an instance of this, but more strikingly is it seen in the so-called carnivorous plants, such as the sundew, etc., that were so carefully investigated by Darwin. In the latter case these plants can actually utilize the available nitrogenous material presented in the form of animal substance; in short, meat.

This process of extracellular digestion is, however, more especially the attribute of the strictly parasitic or saprophytic plants, notably the lower fungi and the bacteria. Of necessity they must digest from the substratum on which they grow the necessary food material, unless it happens to be presented to them in soluble and diffusible form, a circumstance of rare occurrence. The Bacteria are the most important as well as familiar of such plants, and as producers of enormously vigorous fermentation for their size there are no organisms which approach them. Their fermentative power has long been made use of in many industries, and at the present time is the especial study of preventive medicine in endeavoring to fully understand and guard against the deleterious effects of disease-breeding bacteria on the human organism. Associated with bacteria, in a purely physiological sense, and no other, are the highly degenerate fungi known as yeasts, the power of which in producing extracellular alcoholic fermentation has been known in a purely empirical way since prehistoric times.

Ptomaines, toxins, indeed some of the poisons associated with so-called toadstools and snake venoms, are all enzymatic or fermentative in their nature, and a very small quantity of them is capable of producing relatively enormous changes in the substances on which they act, and come under the general physical class of catalytic agents. The present aim of bacteriological research, as applied to disease organisms, is to discover the best mode of combating the toxins, and that has been found in the antitoxins, which have the power of uniting the toxins and rendering them harmless, altho it must be said that the manner in which they do this is not fully understood.

The study of all classes of enzymatic substances in the living organism, plants as well as animals, is at present the field which promises more than any other to elucidate the mysteries of life processes, and with the aid of modern physical chemistry the next few decades may mark a striking advance in man's knowledge of what living protoplasm really consists.

"The life of every plant is of limited duration," to quote from the Text Book of Botany by Strasburger, Nott, Schenck and Karsten. "Death ensues sooner or later, and the decayed remains form a part of the surface soil. All existing vegetable life owes its existence to the capacity inherent in all organisms of reproducing their kind. Reproduction is accordingly a vital power which must be exercized by every existing plant species. It is also evident from the very nature of reproduction that in the production

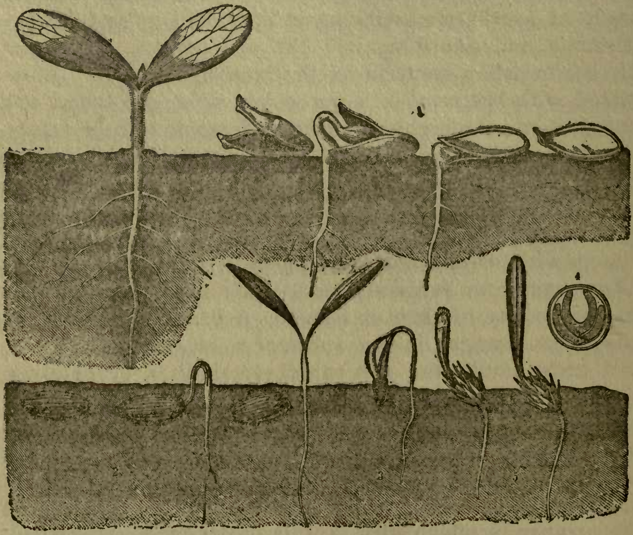


Fig. 35 —Cotyledonic Liberation Variation.
1., Gourd; 2., Asaptida; 3., Immortelle; 4., cross-section of (3.); 5., Cardopatium. (Kerner.)

of new organisms a process of rejuvenation continually is being carried on. The descendants commence their development at a stage long since passed over by the parents.

"The physiological significance of sexual reproduction is not at once apparent. In many plants the vegetative mode of reproduction is sufficient to secure the necessary multiplication of the species, so that plants are able to continue without sexual reproduction. Since monogenetic reproduction is sufficient for the preservation of the species, sexual reproduction must answer some purpose not attained by the vegetative mode of multiplication, for otherwise it would be altogether superfluous that the same plant, in addition to the vegetative, should also possess the sexual form of reproduction, which is so much more complicated and less certain.

"What makes digenetic reproduction essentially different from monogenetic is the union of the substances of the parents and the consequent transmission and blending of the paternal and maternal properties. It is in this qualitative influence that the chief difference between sexual and vegetative reproduction is shown. And this may be regarded as the special advantage of sexuality. By vegetative reproduction the quantitative multiplication of the individual is secured, while by sexual reproduction a qualitative influence is exerted. The vegetatively produced progeny consist of unmixed descendants; the sexually produced offspring, on the other hand, are the result of a blending of the parents.

"In vegetative multiplication the complex of properties unfolded in the descendants does not, as a rule, differ from that possessed by the parent form. The sexually produced offspring, on the other hand, endowed with the properties of the father, can never be identical with the mother plant, but possess the properties of both parents. When these are divergent they frequently play very different parts in the descendants, some (dominant) characters appearing conspicuously, while others (recessive characters) become less marked or remain completely latent. In this way the descendants do not exhibit a uniform mean between the parents, but some may resemble the father, others the mother. These relations determine the character of the sexually produced descendants. Variations appearing in single individuals will, unless they are of an absolutely dominating character, become modified and ultimately lost by crossing with ordinary individuals. In such a case sexual reproduction tends to maintain the constancy of the species. In other cases, as when one parent possesses new and dominant characters, or when both parents tend to vary in the same direction, the deviation from the ancestral form may be maintained or increased by sexual reproduction.

"The great tendency to variation commonly exhibited by hybrids illustrates how the equilibrium of the complex properties of a sexually produced individual is affected by divergent parental tendencies. But even as a result of ordinary fertilization not only small and readily disappearing variations (fluctuating variations) but sometimes more striking ones occur, in which the offspring differs so strongly from the parents in characters which can be inherited that it appears to be a new species or sub-species. In such sudden variations (the occurrence of which Von Kölliker, and with him Korschinsky, term heterogenesis, while De Vries more recently calls it mutation) these authors seek the starting points of the origin of new species. This would occur when a particular species passes, from unknown causes, into a period of mutation such as De Vries demonstrated experimentally in Œnothera Lamarckiana. The fluctuating variations which largely determine the valuable characters of economic plants—*e.g.*, the high percentage of sugar in the Sugar Beet—are in contrast to the mutations not fixed on inheritance. Careful and continued selection of the varying progeny is thus necessary to maintain the required standard of the race."

Hugo de Vries himself says, in writing on this matter of variability: "Before Darwin, little was known concerning the phenomena of variability. The fact that hardly two leaves on a tree were exactly the same could not escape observation; small deviations of the same kind were met with everywhere, among individuals as well as among the organs of the same plant.

"Darwin was the first to take a broad survey of the whole range of variations in the animal and vegetable kingdoms. His theory of Natural Selection is based on the fact of variability. His main argument is that the most striking and most highly adapted modifications may be acquired by successive variations. The direction of the adaptations will be determined by the needs in the struggle for life, and natural selection will simply exclude all such changes as occur on opposite or deviating lines. In this way it is not variability itself which is called upon to explain beautiful adaptations, but it is quite sufficient to suppose that natural selection has operated during long periods in the same way. Eventually, all acquired characters being transmitted together would appear to us as if they had been simultaneously developed.

"Correlations must play a large part in such special evolutions. Darwin repeatedly laid great stress on this view, altho a definite proof of its correctness could not be given in his time. Such proof requires the direct observation of a mutation. . . . The new evening primroses which have sprung up in my garden from the old form of Œnothera Lamarckiana, and which have evidently been derived from it, in each case by a single mutation, do not differ from their parent species in one character only, but in almost all their organs and qualities.

"Some authors have tried to show that the theory of mutation is opposed to Darwin's views, but this is erroneous. On the contrary, it is in fullest harmony with the great principle laid down by Darwin. In order to be acted upon by that complex of environmental forces which Darwin has called natural selection the changes must obviously first be there. The manner in which they are produced is of secondary importance, and has hardly any bearing on the theory of descent with modification.

"A critical survey of all the facts of variability of plants, in nature as well as under cultivation, has led me to the conviction that Darwin was right in stating that those rare beneficial variations which from time to time

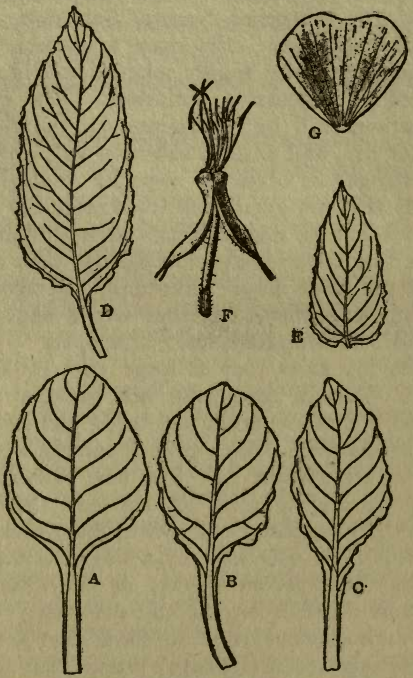


Fig. 36 —Parental Form of Mutants ('Œnothera Lamarckiana').

A., B., C., leaves from rosette; D., leaf from middle of flowering stem; E., bract; F., flower with petals removed; G., petal.

happen to arise—the so-called mutations—are the real source of progress in the whole realm of the organic world.

"The origin of new species, which is in part the effect of mutability, is, however, due mainly to natural selection. Mutability provides the new characters and new

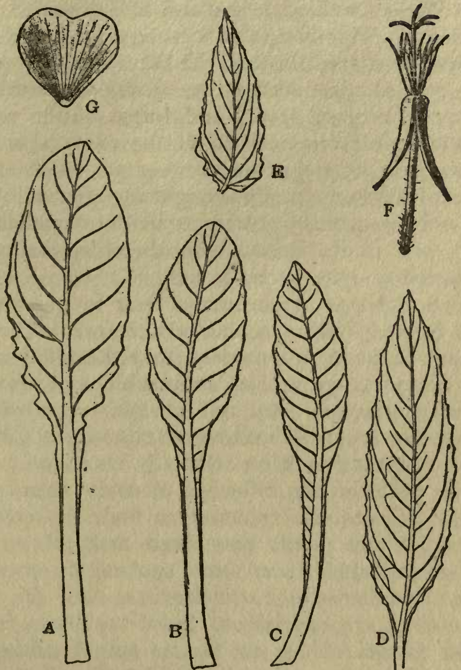


Fig. 37 —A Mutant of De Vries (Evening Primrose).

elementary species. Natural selection, on the other hand, decides what is to live and what to die. Mutability seems to be free, and not restricted to previously determined lines. Selection, however, may take place along the same lines in the course of long geological epochs, thus directing the development of large branches of the animal and vegetable kingdoms. In natural selection it is evident that nutrition and environment are the main factors. But it is probable that while nutrition may be one of the main causes of mutability, environment may play the chief part in the decision ascribed to natural selection."

Dr. Daniel T. MacDougal in a lecture published in 1905 tells us that "scattered through the literature of botany and horticulture of the last century are scores of records of the sudden appearance of sports and forms of the aspect of species which fully support all of the conclusions drawn from the observations on the evening primroses. An examination of the facts, easily brought together, allows us to see that certain general principles in the organization of the plant, and in its behavior in these breaks or saltations in heredity, may be made out.

"The first and most important of these is one which was advanced by De Vries speculatively, before he began his experiments in heredity—namely, that the plant is essentially a complex group of indivisible unit-characters. These unit-characters may not always be expressed or recognisable in external anatomical characters, since they may be in a latent condition or totally inactive.

"Popular belief in the influence of environment and the inheritance of acquired characters finds its commonest expression in 'that plants have been changed by cultivation.' Domesticated races are spoken of as 'garden forms' by botanists and horticulturists, with the implication that they are specialized types resulting from the effects of tillage. Now, so far as actual cultivation is concerned, this assumption is without foundation, since at the present time no evidence exists to show that the farm, garden or nursery has ever produced alterations which were strictly and continuously inheritable, or were present, except under environic conditions similar to those by which the alterations were produced, altho vague statements and erroneous generalizations to the contrary are current. It is true, of course, that structural and physiological changes may be induced in a strain of plants in any generation, which may persist in a share to the second, or even in some degree to a third, but no longer. Some very important operations of the market gardener and the farmer are dependent upon this fact."

"The matter of general scientific agriculture opens an immense field," says H. M. Richards. "The scientific care of our forests, for trees may be regarded as a crop, and their culture agriculture, is a question to which we, in this country, are awakening none too soon. Forestry, as practiced in Europe, demanding as it does expert botanical knowledge, perhaps not by the foresters themselves but by those who direct their labors, has saved what were the fast diminishing wooded areas."

"The scientific rotation of crops, the use of fertilizers, and the study of the physical and chemical condition of the soil in connection with the living plants," continues Professor Richards, "involve certain questions which may mean the success or failure of much farming. These questions can only be settled by careful investigations which take into consideration the nature of the plants themselves as well as the physical conditions of their environment. Some may say that knowledge along this line has been satisfactorily handed down from father to son; that the farmer knows his business better than does the scientist; but it is a patent fact that this is not so. For instance, many a farm which has been damaged for a long period of years by the overliming of the soil might have been spared had the farmer of fifty years ago had the knowledge which we now have of the relation of lime to the other mineral substances needed by the plant, of when to apply it and when to withhold it. It is the difference between merely empirical knowledge and that which is based on scientific principles.

"When the contest comes between virgin soil and long-tilled land, the latter, no matter how rich it may once have been, must needs be cultivated more intensively if it is to hold its own. Intensive cultivation requires the aid of special information, and it is here that scientific agriculture comes into play. Few people realize that without artificial fertilizers, the direct outcome of highly theoretical work on the raw foodstuffs of plants, much of the farming of to-day would be almost impossible; and the proper use of fertilizers is but one of many questions.

"We are coming now, in this country, to a stage in its development when scientific agriculture must be seriously considered. Fortunately, it is being so considered, and the federal and State establishments devoted to the investigation of these agricultural questions may confidently be expected, I think, to help in the solving of the practical economic questions that must arise in the competition of our own agriculture with that of other lands. The way it must be done is by the introduction of improved methods, based on carefully conducted scientific research, that often find their stimulus in the highly theoretical investigations of the pure scientist. Thus must the so-called impractical devotee of science come in contact with the practical man of affairs, and furnish him knowledge that can be used for the benefit of all."