BORRADAILE'S

# MANUAL OF ELEMENTARY ZOOLOGY

*THIRTEENTH EDITION*

*Revised by*

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# PREFACE

THE twelfth edition of Borradaile, the first major revision since the book was published forty-five years ago, has on the whole been well received both by reviewers and by readers. Complaint was commonly made of the illustrations, both old and new, and with some justification. The necessity for a new edition less than two years after the edition was published has allowed the replacement of some forty-three of these, and I hope that in future editions more will be treated in the same way. I am grateful to all those who have pointed out misprints or *lapsus calami*, all of which have been corrected. I thank also those who have reported errors; if a reviewer finds that any of these remain uncorrected it is because, after consulting the best authorities available to me (including, in two instances, the animal itself) I have come to the conclusion that what I originally wrote was nearer to the truth. I have also tried to remove a few ambiguities, and statements throughout the book have been corrected to accord with new knowledge.

The interest that the book has aroused is very pleasing, but there is one respect in which I cannot agree with some of my critics, who would have liked to see the old morphological basis entirely abandoned. While I agree completely with them on the importance of physiology and ecology, I believe that there is still good reason for not trying to force on students a fusion of the morphological, physiological and ecological aspects of the subject, which, at the level for which this book is written, few of them will understand. I have retained the type-system not, as one reviewer said, because I have never known any other, but because I have seen, as a teacher, as an examiner, and as an attender at scientific meetings, the bad results of attempts to be 'synthetic' or 'comparative' before the student knows the basic facts of morphology. They simply do not work. The sections in this book on parasitism (now put as a separate chapter) and on the cœlomate body, and those on vertebrates at the end, read after those on the relevant types, will give the student of sixteen to nineteen or so, enough on which to exercise his mind (I hope he will do so critically). I originally intended to include a general chapter on physiology, and may still do so in a later edition. But, with some experience of reducing the whole range of physiology to small compass, I am not sure that such extreme compression can usefully be done.

W. B. Y.

STOURBRIDGE,
*August* 1957.

# CONTENTS

1

# INTRODUCTORY: THE ANIMAL ORGANISM

## BIOLOGY

ZOOLOGY, the science of animals, is a branch of biology, the science of living beings. Of such beings there are various kinds besides the animals; but all the kinds have important features in common. Rightly to understand any animal is therefore to comprehend properties which it shares with non-animal living beings as well as its purely animal characters. Thus at the outset of our study of zoology it is desirable that we should spend a little time in considering the nature in general of living beings.

## LIVING AND LIFELESS

Out of the multitude of material objects that surround us, we distinguish some, as alive, from the rest, which are lifeless —that is, either are dead or have never been alive. It would be helpful if we could set down in precise terms the properties on which we base this distinction.

The commonsense view is that a living being, such as a cow or a tree, grows and reproduces, while a non-living thing, such as a stone or a piece of wood, does not, but a little reflection will show that no precise distinction can be made in these terms. A cow may be capable of reproduction, but for a variety of reasons, such as absence of a bull or infection by a parasite, may not in fact produce offspring; an ox can never reproduce, but is nevertheless alive, and if it be objected that an ox is in an artificial state through the interference of man, there is the parallel example of the worker bee, which is sterile by nature. It is a matter of common observation that growth, in the ordinary sense of the word, ceases in man relatively early in life, and in old age it becomes negative, if the expression may be permitted. In some of the lower animals, too, 'degrowth' is known; thus, if a pond flatworm is starved it decreases in size and appears to reverse its normal trend.

No better definition of life can be made from any of the other properties which have from time to time been proposed for the purpose. Neither irritability, nor self-preservation, nor respiration is at all times characteristic of things which are called living, and one or more of these properties (as well as growth and reproduction) may at times be found in things which are called non-living. In the limit, it remains a matter of opinion whether the viruses (small particles which cause a number of diseases such as smallpox and measles) should be considered as living or non-living.

In spite of the impossibility of making a definition, there are certain properties which are generally found in things which men tacitly agree to call living, and which are seldom found in things which they do not so call. We will now briefly consider the more important of such properties.

## GROWTH

Growth means the increase in quantity of material in a body, and is usually measured, for biological purposes, as increase in dry weight (this word being used incorrectly for mass), that is, weight after free water has been driven off at 105° C. It thus excludes mere addition of water, which may be so rapid and temporary as to be meaningless, and differs fundamentally from increase in size, which may occur by absorption of water or even air. It depends on an uptake of matter from the surroundings, and on this more is said below.

## REPRODUCTION

An animal or plant may, by itself or in co-operation with another, produce a new living thing, a process known as reproduction. In a sense reproduction is a consequence of growth, for growth without reproduction would lead to an impossible expansion in size ; this connection is seen at its clearest in an animal like *Amœba* which simply divides into two when it reaches a certain size, but in the higher animals the connection is obscured. The division of a cell of a higher organism (p. 688) though it may take place by a similar mechanism, is philosophically distinct from the reproduction of *Amœba*.

Reproduction always includes, though it may be much more than, the fission or division of an existing body. Whatever may have been its origin, all the evidence suggests that under the conditions which now exist life never starts anew, but is always passed on from one living being to another which arises from it. A living being which divides to produce others is a parent; those which it forms are offspring. These are always at first unlike the parent. There are certain creatures, like *Amœba*, mentioned above, in which the only evident difference between the offspring and the individual by whose division they arose is the necessary

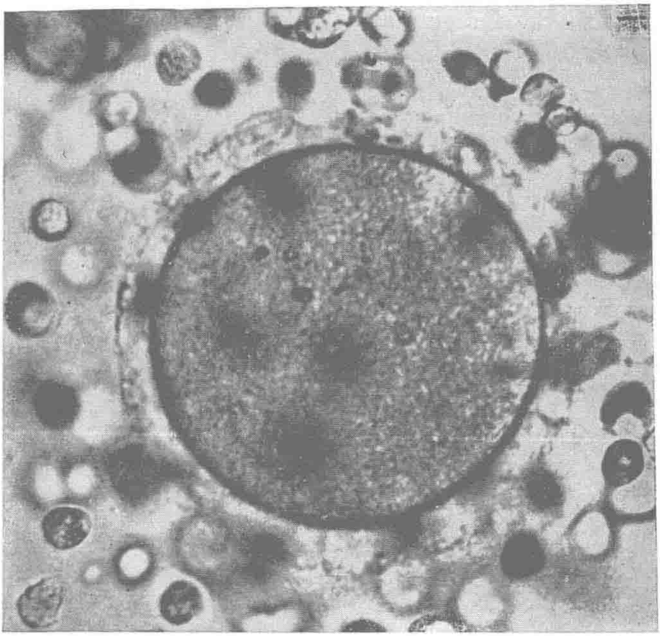


FIG. 1.—Human ovum from the uterus. × 480.—From Hamilton, Boyd and Mossman, *Human Embryology*, 1945. Heffer and Sons, Cambridge.

one of size, but in the great majority of cases there is also an obvious difference in form, the offspring being at first very unlike the parent in structure. This difference is obscured in the case of man and some other animals, where the offspring (Fig. 1) undergoes changes in the womb before birth, but it is seen unmistakably in animals which are born in the condition of an egg. In their immature condition the offspring are known as reproductive bodies.

In spite of this unlikeness at starting, the offspring become in time like the parent or parents from which they arose, though they never resemble them in every detail. The succession of changes which brings this about is called development, and is sometimes straightforward, or direct, sometimes, as in the well-known case of the butterfly, very roundabout, or indirect. In reproduction by budding (Chap. 9) development may take place partly or mainly before fission. Thus the life of an animal or plant is a cycle, in which it passes through a series of stages, beginning with the small and simple reproductive body, and ending with the larger and usually more complex adult, ready to undergo fission again. Every individual goes through the same cycle of changes as its parent, resembling in each stage a similar stage passed through by the latter, till it reaches the likeness of the individual that produced it, that is, it shows the property known as heredity. Thus, in the strict sense of the word, reproduction includes the whole life cycle and consists of two distinct processes—fission, and the development of the reproductive body into the adult—for until this cycle has been completed the parent is not reproduced. From this point of view, growth is that part of the process of development by which the reproductive body reaches the size of the adult. At the same time, usually, and perhaps always, the growing individual is undergoing the changes in structure to which we have alluded.

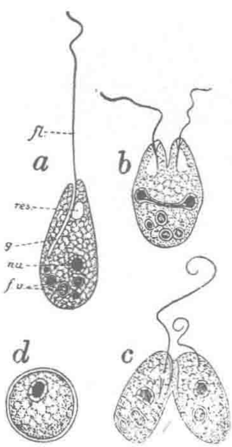
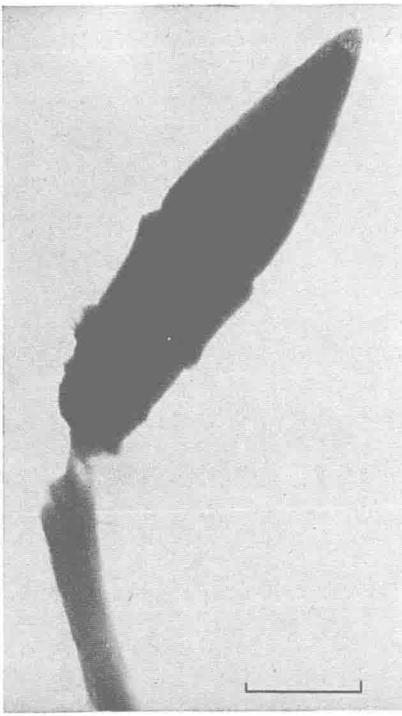



FIG. 2.—*Copromonas*, a minute inhabitant of dung.—After Dobell.

*a*, Adult individual ; *b*, the same in fission ; *c*, two adult individuals in syngamy; *d*, the zygote, enclosed in a cyst.
.v., Food vacuole; *fl.*, flagellum; *g.*, gullet; *nu.*, nucleus; *res.*, reservoir of contractile vacuole (see p. 41).

## SYNGAMY

Here must be mentioned a process which is an essential part of reproduction in many organisms and in all the higher animals. In such organisms the reproductive bodies are of two sorts, each produced only by one of the sexes, and neither sort can develop except after fusion with one of the other sort. That fusion is an example of the process known as a syngamy, union of two distinct living bodies, which occurs from time to time in nearly all species of animals and plants. The bodies which unite are known as gametes, and that which results from their fusion as a zygote. In some of the smallest living beings (Fig. 2) syngamy is the union of fully-grown adults, but in other such creatures (Fig. 8), and in all large and complex animals and plants, syngamy takes place only between the reproductive bodies, which are generally unable to develop without it, so that it becomes a necessary part of the reproductive process. In these creatures the reproductive bodies are of a kind known as germ cells, distinguished from other reproductive bodies (free buds, etc.) by their small size and the simplicity of their structure. The germ cells of such creatures are usually of two sizes which unite larger with smaller (Fig. 8*C*). In all large and complex animals



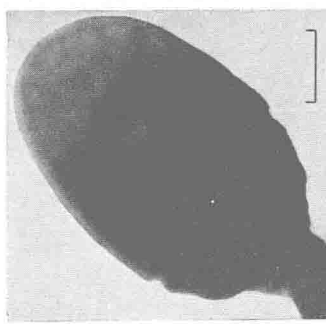


FIG. 3.—Heads of human spermatozoa, in side and face view. Electron photomicrographs. The scale is one micron.—From Friedlander *Proc. roy. Soc. B.*, 1952, 140.

(and in some of the smallest) the gametes differ in form and behaviour as well as in size (Figs. 1 and 3). One is larger and passive, and is called the female gamete, or, in large animals, the egg or ovum. The other is smaller and active, and known as the male gamete or spermatozoon or sperm ; it has usually a tail (flagellum) with which it swims in the fluid in which it is borne, and thus it moves to the egg and enters the latter (Fig. 4). This process is known as the fertilisation of the ovum. After it the fertilised ovum proceeds to develop. Ova and spermatozoa are usually formed by different adults, known respectively as female and male, but in some animals both kinds are formed by one individual, which is then known as a hermaphrodite. If sperms are formed before ova, a hermaphrodite is said to be protandrous; if the ova are formed first, it is protogynous. In some aquatic animals the gametes are set free, and syngamy takes place outside the body of the parent. In others, however, and in all land animals, the ova are kept within the body of the mother, and the male gametes are transferred in the seminal fluid by the male to the body of the female and there fertilise the ova. This transference is known as coition or copulation. Reproduction in which syngamy is necessary before the reproductive bodies can develop is known as sexual reproduction; that in which the reproductive bodies are not gametes is asexual.

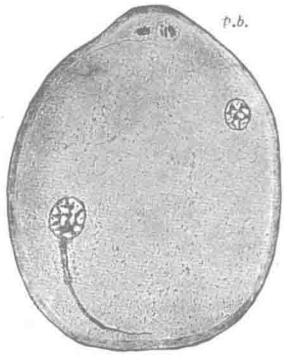



FIG. 4.—The ovum of a bat, after the entry of the spermatozoon.—From F. H. A. Marshall, after van der Stricht.

*o.n.*, nucleus of the ovum; *p.b.*, 'polar bodies' (see p. 620); *spn.*, spermatozoon.

In some animals there is a kind of reproduction (parthenogenesis) in which a female germ cell (ovum) develops without syngamy. This kind is best regarded as an aberrant form of sexual reproduction.

The terminology of these processes is in some confusion. Syngamy is the fusion of two cells (p. 498), nucleus with nucleus and cytoplasm with cytoplasm, though one of the two may have little cytoplasm and possibly sometimes has none. The union of nuclei—which is by far more important than that of the cytoplasms—is karyogamy; the union of cytoplasm is plasmogamy. The term conjugation has been used as a synonym for syngamy but is best restricted to the peculiar procedure by which syngamy is accomplished in the Ciliata (Chap. 5).

## ACTIVITY

Most familiar animals, and some plants, may be said to be active in a way in which a stone is not, although machines have a certain type of activity which simulates that of living things. The activity may be the result of the receipt of a stimulus, that is a change in the external environment, or it may occur without apparent cause. The first, examples of which are the shaking of the head of a dog when the hairs in its ear are touched and the folding and falling of the leaf of a sensitive plant when it is knocked, has been called irritability, and the second, which may be illustrated by the beating of the heart, automatism. In many cases a distinction is difficult. Irritability differs from mere mechanical change produced by external circumstances, such as the melting of ice, in that the magnitude of the response, as measured by the energy involved, bears no relation to the magnitude of the stimulus. It follows from this, and from the first law of thermodynamics, that the energy for the response must come from within the organism.

## ABSORPTION AND ASSIMILATION

Growth requires the intake of new material, and response needs energy, which depends on the breakdown or conversion of chemical substances. The incorporation of food is therefore characteristic of living matter. Two distinct processes may be recognised in incorporation—absorption and assimilation. Before it can be absorbed the food of animals has generally to undergo a preliminary process of digestion, whereby solid or indiffusible nutriment which it contains is made soluble and diffusible. The food must always contain the following materials: (1) water, which is of the highest importance both as an essential constituent of the living matter (protoplasm) and also because it is used in the body for transporting substances in solution, as in the blood and urine, (2) certain inorganic ions, such as chloride and phosphate and those of sodium, potassium, and calcium, (3) the very complex compounds known as proteins. A protein is a colloid substance consisting of carbon, hydrogen, oxygen, and nitrogen, with sometimes small quantities of sulphur and phosphorus. A familiar example is the albumen which, mixed with water, forms white of egg. Proteins are very complex linkages of amino-acids, that is, compounds which contain both the basic radicle $-NH_2$ and the acid group $-COOH$. A simple example is aminoacetic acid or glycine, $CH_2.NH_2.COOH$. Thus in the complicated chemistry of the body proteins are able to exercise the power, which amino-acids have, of uniting either with acids or with bases; and on final disintegration they always yield their nitrogen in a form related to ammonia. The proteins of the body are many, and even those of similar parts in different animals are slightly different. That the food does not consist of proteins identical with those of the body it is entering does not matter, since in digestion proteins are resolved into the amino-acids of which they are composed and the animal so recombines these as to meet its own needs. The food must, however, supply the right amino-acids in sufficient quantities. It is found, for instance, that mice fed upon a diet in which the only protein present is zein, the protein of maize, which does not contain the important constituent tryptophane, are unable to support life. Proteins are important in the food of all animals, because, while, like other substances that we shall mention below, they can be oxidised to provide energy, it is normally they alone that can make good the protein matter that every living body contains and loses by wear and tear and also that can provide such material for growth. When they are to be used for fuel the nitrogen is discharged from their molecules as ammonia. This is deamination ; it is the ultimate source of most of the nitrogenous compounds which are mentioned below as forming part of the excreta.

Besides these substances the food usually contains (4) carbohydrates (sugars, starches, and related substances), (5) fats. It is chiefly these two classes of substances that are oxidised to provide energy. Both contain carbon, hydrogen, and oxygen. In carbohydrates the oxygen is present in exactly the proportions to oxidise the hydrogen, as in cane sugar and malt sugar or maltose, which both have the formula $C_{12}H_{22}O_{11}$, grape sugar or glucose, $C_6H_{12}O_6$, and starch $(C_6H_{10}O_5)n$. In fats there is relatively less oxygen ; therefore they require for complete combustion more of that element than is needed to oxidise the carbon, and their potential energy is greater than that of carbohydrates. In digestion, insoluble carbohydrates, such as starch, are dissolved by conversion into glucose or other simple sugars, and fats are partially split into soluble components—fatty acids and glycerol.

Both these processes, and also the digestion of protein, are hydrolyses—decompositions into smaller molecules with the aid of water taken up. Thus :

$$\underset{\text{(Starch)}}{2(C_6H_{10}O_5)n} + nH_2O = \underset{\text{(Maltose)}}{nC_{12}H_{22}O_{11}}$$

$$\underset{\text{(Maltose)}}{C_{12}H_{22}O_{11}} + H_2O = \underset{\text{(Glucose)}}{2C_6H_{12}O_6}$$

and again :

$$(C_{17}H_{35}COO)_3C_3H_5 + 3H_2O = 3C_{17}H_{35}COOH + C_3H_5(OH)_3$$
(the fat Stearin) (Stearic acid) (Glycerol)

They are all initiated by organic substances called enzymes (p. 444), which take part in the reaction but are restored at the end. Enzymes are named by the addition of the suffix *-ase* to the name of the substrate on which they act.

Since proteins, carbohydrates, and fats are among the compounds known as 'organic', which, in nature, are found only in the bodies of plants and animals and in their remains, such bodies are a necessary part, and the chief part, of the food of all animals. From the same source animals must also obtain (6) other organic substances needed in small quantities. These include the vitamins. These substances, originally manufactured by plants, are transmitted to herbivorous animals, and so to the carnivores, and though needed in very small quantities, are essential to life. When, for instance, young rats are fed upon an artificial liquid containing the protein, sugar, and fat of milk in the usual proportions, they fail to grow, but the addition to their diet of a very small quantity of fresh milk (which contains the vitamins) causes them to grow in a normal manner (Fig. 5). The structure and mode of action of many vitamins are now known. They are nearly all required to enable some particular reaction to go on ; thus both $B_1$ and $B_2$ (riboflavin) are concerned in cell oxidations.

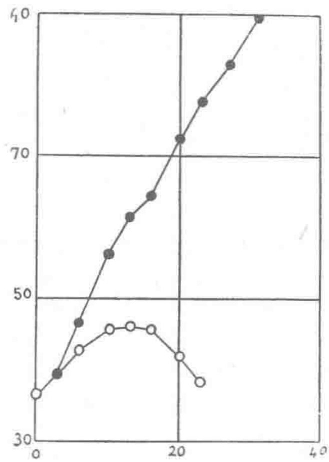



FIG. 5.—Curves showing the effect of vitamins on the growth of rats.—From Hopkins.

Lower curve (white circles), rats fed on artificial milk alone. Upper curve (black circles), rats fed on artificial milk and 2 c.c. of cow's milk daily. Average weight in grams, vertical. Time in days, horizontal.

The digested materials undergo absorption into the substance of the body, leaving the indigestible matter to be cast away as the dung or fæces. Incorporation, however, is not brought about simply by the absorption of digested matter. Neither before nor after digestion is the food of the same composition as the substance