doesn't matter which fitness is picked as the standard; in each case the second alga has twice the relative fitness of the first, and the standard has a relative fitness of 1.00. Relative fitnesses compare all the various fitnesses in a population to one another.

Why do we need relative fitnesses? Darwin's theory is frequently and popularly phrased "survival of the fittest." We need relative fitnesses because "fittest" is a comparative word. Our first algal variety, with fitness 2, reproduces well and can survive in its environment. But the second variety reproduces even better, and so as you will see in a minute, the second will replace the first. Being fit is not enough; one must be fitter than one's competitors to survive for long.

SURVIVAL OF THE FITTEST

Assume that different phenotypes have different fitnesses and that fitness is at least partly inherited; then, in a stable environment, the average fitness of the members of a population is always increasing. That's it. The theory that revolutionized biology in 1859 still stands, improved only a little, explaining a lot. We shall devote the remainder of this chapter to explaining it, understanding what makes it a theory, and showing how it can be tested.

Notice first what the theory doesn't say. There is nothing in it about man evolving from gorillas. That hypothesis does not derive from the theory at all. It is an educated guess based on the anatomical similarity of men to apes and the fossil record of man. (In fact, you recall, modern paleontologists feel man probably evolved from a species of ape but not a modern one and certainly not a gorilla.)

Now notice how subtly the theory predicts that evolution will occur. If each phenotype has a different fitness, then an increase in the average fitness can only occur by a change in the mixture of phenotypes. In other words, the phenotypes we see now in the population aren't the same (on the average) as those we would have seen had we looked last year or ten years ago. This is the change of phenotype we've called evolution.

Last, notice that it not only predicts evolution, but provides a mechanism to explain it—the heritability of different fitnesses causing the accumulation of higher fitnesses in the population. This mechanism is called natural selection.

EVOLUTION: A THEORY?

When many people think about evolution, they pass over it superficially with the statement, "Oh, that's just a theory." Indeed, it is a theory, but the word "just" is out of place. People who use it are confusing the theory of evolution by natural selection with something else: the hypothesis, or educated guess, that evolution has occurred.

You have read Chapter 10 and seen that there is impressive evidence

that supports the occurrence of evolution. But you have also read the theory and seen that it is something else; it proposes the mechanism of evolution; it tries to explain how evolution is produced by life.

It is also very difficult to understand. No wonder Darwin took many years to develop it. "Just a theory" is hardly an appropriate phrase.

If you are willing to discipline yourself throughout this chapter and the next three, you will be able to do much better than Charles Darwin. You will come to understand this theory in only a week or two. And you will know why evolutionists are so sure of themselves.

WHAT IS A SCIENTIFIC THEORY?

What makes the theory of natural selection a theory? The answer lies in an examination of theories in general. That will lay bare the structure of the theory of natural selection and point out all the ways it could be wrong. It will, in other words, instruct us how to go about testing the theory. I begin with an artificial example.

The scientist from the planet Kimdumani had learned perfect English from everyday Americans. "I have a theory," he pronounced carefully, "that earthly life runs on energy supplied by their star, which they call 'sun.' I say this because I have measured their need for energy and the rates at which various sources supply it to them. And the sun's energy is the only source large enough to do the job."

Whether or not our fictional character is right (and, of course, he is), he does *not* "have a theory." He has a hypothesis, a word which really means "educated guess."

To scientists who work with them, theories are rather special. *A theory is a set of deductions derived from a set of assumptions.* For instance, if we assume $x+2=10$, then we may deduce that $x=8$; also that $x-4=4$; and that $x^2=64$. There is, in fact, an infinity of deductions which we can make from this assumption. There are also word theories. For example, assume that all members of the mammalian order Sirenia swim, and that manatees are Sirenia. Then "manatees swim" is our deduction. In this case it is hard to see any other possible deduction. Return to the discussion of natural selection and identify the assumptions and deductions in the theory of evolution.

DISPROVING THEORIES

Comparing deduction with reality. Every scientific statement is subject to disproof, and theories are no exception. In fact, theories have some subtle possible weak points which should be mentioned. One obvious way to disprove our Kimdumanian friend's hypothesis is to put some small sealed bit of life (say a terrarium) in a dark place. In most cases, its inhabitants would soon die and our friend's guess would not be disproved. We can (and should) do a similar thing with a theory, that is, compare its deductions with the real world. Go and look at a manatee. Does it swim? Measure something that you know to be x; is it 8? If not, there is something wrong.

Mistakes of logic. But even if the manatee swims, even if $x = 8$, the theory may be wrong. Suppose we had assumed $x + 3 = 10$ and deduced from this, $x = 8$. We measured x and it was 8, so we triumphantly announce the verification of our theory. But of course we have been victims of our inability to do algebra, followed by the unlucky accident that x is really 8. Every means of expression—language, math, geometry, even hand signals—has rules of deduction. By those rules, we made a mistake. If $x + 3 = 10$, then $x = 7$. Have you ever come up with the right answer for the wrong reason? That's what happened to us. Theories can be wrong, therefore, because their deductions are inaccurately drawn.

Since the rules of deduction are best worked out for number systems, theoreticians often use mathematics. Thus, they make their assumptions precise and their errors of deduction least likely. But being human, they still err, and the thinking man always insists that he be shown the logic.

Inaccurate assumptions. If the deductions of the theory are logically correct, why bother testing them? Because deductions correctly drawn from poor assumptions do not correspond to the real world, and it is measurable reality which concerns science. For instance, if x is really 8, and we assume $x + 3 = 10$, our assumption is wrong and our deduction useless. All assumptions must be tested.

Oversimplified assumptions. A more important cause (historically) of poor theories has been incomplete assumptions. The scientist dreads such systems, which he calls oversimplifications. The only way to defend against them is to test one's deductions again and again, until one gradually gains confidence that they do correspond to real life.

A famous biological example of an oversimplified system was arrived at by several men independently (Spencer, Volterra, and Lotka). The system involves exploitation in which one species (the predator) exploits another (the victim).

The deduction from this situation was that the numbers of victim and predator would constantly fluctuate—first rare, then common, then rare, then common again, and so on. Many have noticed that such fluctuations aren't usual in nature. Gause (and others) brought predation into the lab and showed that oscillations are hard to find there also.

The trouble with the theory was not its deduction process—this was perfect. The trouble was that theoreticians had ignored the fact that the prey are also alive and require nutriment, space, and energy themselves. This they omitted from their assumptions; they oversimplified their system

MacArthur and I have recently included this assumption and deduced that indeed fluctuations should be uncommon. We have also made many simplifying assumptions; only testing will tell whether they were oversimplifications or not. Properly deduced theories based on inaccurate or insufficient assumptions are often useless.

WHY THEORIZE?

Using theory to test assumptions. So far we have talked about theories whose main job is to make predictions about reality from known assumptions. Another important scientific use of theory is to work backwards—eliminate poor assumptions by testing their logical predictions.

Notice I was very careful to say "eliminate poor assumptions," not "establish good ones." As we have seen, a theory that doesn't work is wrong; if its deductions are logically produced, then its assumptions must be defective. But a theory that does make accurate predictions may also be wrong. Even if it has escaped all the perils mentioned, it may rest on a set of assumptions which is only one of many sets producing the same predictions.

Here we may cite Bergmann's rule as an example: homoiothermic (warm-blooded) species have members with larger bodies in colder regions (farther from the equator) and smaller bodies in warmer ones. For a hundred years evolutionists accepted the argument that this rule followed from the assumption that it is fitter for an animal in a cold climate to have a lower rate of temperature loss per gram of body weight. This is an interesting assumption, and it does yield a deduction which is correct.

About 20 years ago, the physiologist Scholander began to look at other deductions from the same assumption. He found them inaccurate. He feels that animals are protected from cold by other means, such as insulation (fur, fat, feathers). Today evolutionists have discovered that many other reasonable assumptions yield Bergmann's rule as a deduction. They don't yet know which of the assumptions is (are?) valid.

Since even a theory which has been successfully tested may prove to be wrong because a new set of assumptions arises which makes a more accurate set of predictions and a more complete explanation of known phenomena, each theory remains forever unproved. Science reserves the right to modify it or replace it tomorrow. Meanwhile, scientists patiently chip away at alternative assumptions, eliminating them and becoming more and more confident that such changes will not have to be made or, when made, will be minor. If you can't stand that kind of uncertainty, then science and the measurable world are probably not for you.

Importance of theory. If all those things can go wrong, why bother with theories?

First, because theories share many pitfalls with hypotheses. Hypotheses can also never be proved, only disproved; hypotheses also can be tested "successfully" because of carelessness or ignorance; hypotheses also can be replaced by others which are just as good at explaining the facts. The only special risks of theories are careless deduction and oversimplification.

These extra risks are braved because, second, it has been the experience of scientists that theories illuminate problems and answers in unique, rewarding ways. By indulging in simplification they point to generalizations; that is, they tell us what parts of the world are really most important to understanding it. By requiring precise statement of assumptions and deductions, they help to focus experiments on those things likely to be most important.

Third, theories often produce surprising results. When assumptions are combined in logical ways and then operated on by logical methods, their deductions are often totally unexpected. The scientist in effect was simply unaware *before* he worked on the theory, that the few assumptions he was aware of had anything to do with the deduction which theorizing produced. For example, Einstein's theory of relativity led him to predict that time runs more slowly for objects which are moving rapidly (see Bronowski). This theory, in turn, led to some entertaining science-fiction stories about starship crew members who, because of the high velocities of their craft, lived to see generations of the earthbound pass by, but experienced no sense of living longer lives. Recently this theory of Einstein has received its first experimental test; the test involved two highly accurate clocks, one kept on the Earth, the other sent on a space voyage; the test tended to conform to Einstein's serendipitous prediction.

Finally, many scientists simply enjoy working on theories. Nothing else affords them as much intellectual satisfaction.

PROBLEMS

Generating hypotheses

11-1. In New Mexico, a black-rock lava desert runs right next to a white-sand gypsum desert. A black population of the rock pocket mouse inhabits the black desert. A very pale, almost white population of the similar apache pocket mouse lives on the sand. (See Fig. 11-1.) Construct an hypothesis to account for the mouse distributions. (In simple English: "Guess why the mice live where they do.")

11-2. Can you imagine why skunks are conspicuously patterned?

11-3. A few acres of grassland in southeastern Arizona were once fenced, and cattle were excluded. This land hasn't changed. The surrounding grassland, under intense grazing, changed to a mesquite (a thorny bush) and weed desert. Can you guess why? Can you devise a test of your hypothesis?

Constructing theories

11-4. Assume that populations isolated from each other tend to become genetically dissimilar and that genetically dissimilar populations have difficulty in interbreeding. Now define a species as an interbreeding population. What should happen

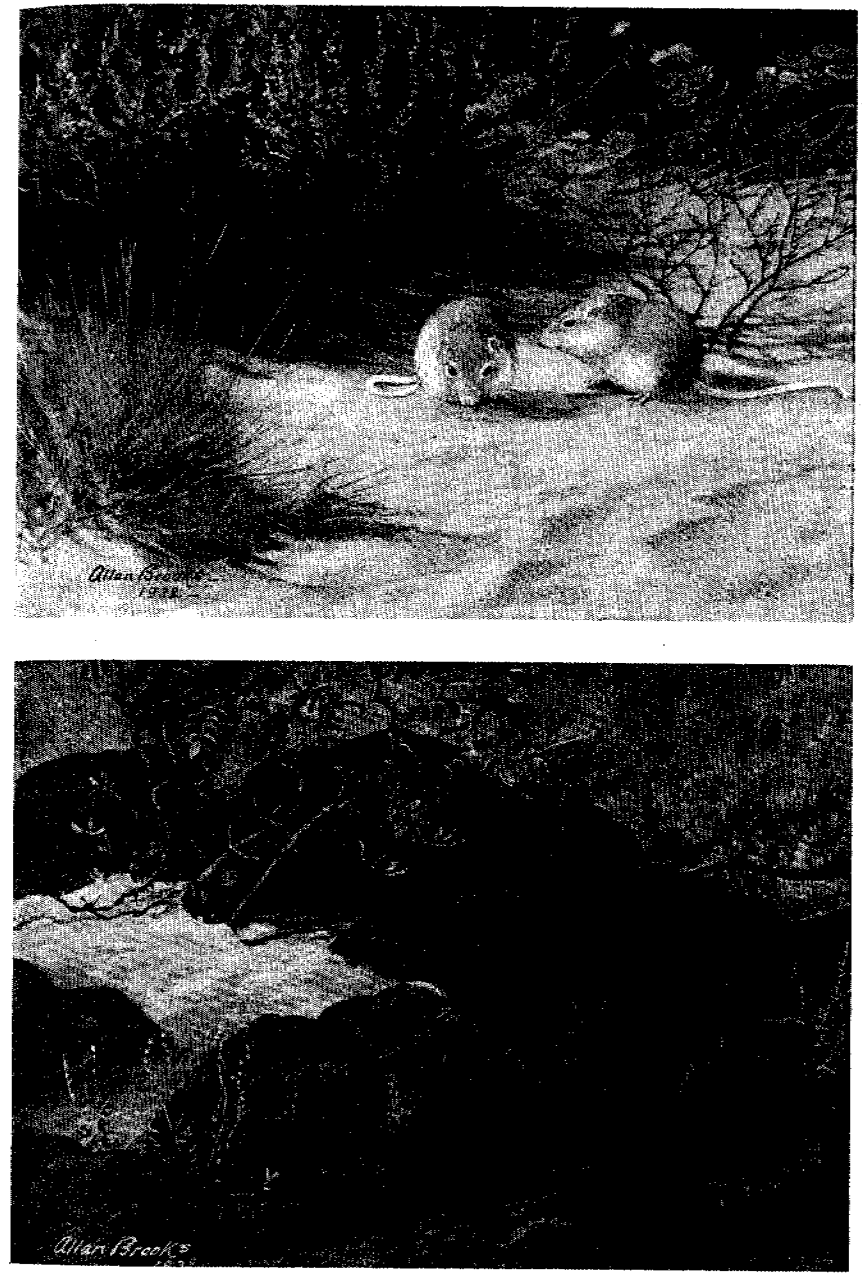

Fig. 11-1 The two deserts of south-central New Mexico and their pocket mice. (Courtesy of Museum of Vertebrate Zoology, University of California.)