

# 1 METHODS AND CONCEPTS IN BIOLOGY

## *Biology Revisited*

Buried somewhere in that mass of tissue just above and behind your eyes are memories of your first encounters with the living world. Still in residence are memories of discovering your hands and feet, your family, friends, the change of seasons, the smell of rain-drenched earth and grass. In that brain are memories of early

introductions to a great disorganized parade of insects, spiders, flowers, frogs, and furred things—mostly living, sometimes dead. There are memories of questions—“*What is life?*” and, inevitably, “*What is death?*” There are memories of answers, some satisfying, others less so.

**Figure 1.1** Think back on all you have known and seen. This is a foundation for your deeper probes into the world of life.



By observing, asking questions, and accumulating answers, you have built up a store of knowledge about the world of life. Experience and education have been refining your questions, and no doubt some answers are difficult to come by. Think of a young man whose brain is functionally dead as a result of a motorcycle accident. If his breathing and other basic functions proceed only as long as he remains hooked up to mechanical support systems, is he no longer “alive”? Think of a recently fertilized egg growing inside a pregnant woman, but currently no more than a cluster of a few dozen tiny cells. At what point in its development is it a definably “human” life? If questions like this have crossed your mind, your thoughts about life obviously run deep.

The point is, this book isn’t your introduction to biology—“the study of life”—for you have been studying life ever since information began penetrating your brain. This book simply is biology *revisited*, in ways that may help carry your thoughts to more organized levels of understanding.

Return to the question, *What is life?* Offhandedly, you might reply that you know it when you see it. To biologists, however, the question opens up a story that has been unfolding in countless directions for several billion years! “Life” is an outcome of ancient events by which nonliving materials became assembled into the first living cells. “Life” is a way of capturing and using energy and raw materials. “Life” is a way of sensing and responding to specific changes in the environment. “Life” is a capacity to reproduce, grow, and develop. And “life” evolves, meaning that details in the body plan and functions of organisms can change through successive generations.

Yet this short description only hints at the meaning of life. Deeper insight requires wide-ranging study of life’s characteristics.

Throughout this book you will come across many examples of how organisms are constructed, how they function, where they live, and what they do. The examples support certain concepts which, taken together, will give you a sense of what “life” is. This chapter provides an overview of the basic concepts. As you continue reading the book, you may find it useful to return to this overview to reinforce your grasp of details.

1. There is unity in the living world, for all organisms are alike in key respects. Their structural organization and functions depend on properties of matter and energy. They obtain and use energy and materials from the environment. They make controlled responses to changing conditions. They grow and reproduce, based on instructions contained in DNA.

2. There is diversity in the living world, for organisms vary immensely in body plans, body functions, and behavior. Evolutionary theories explain this diversity.

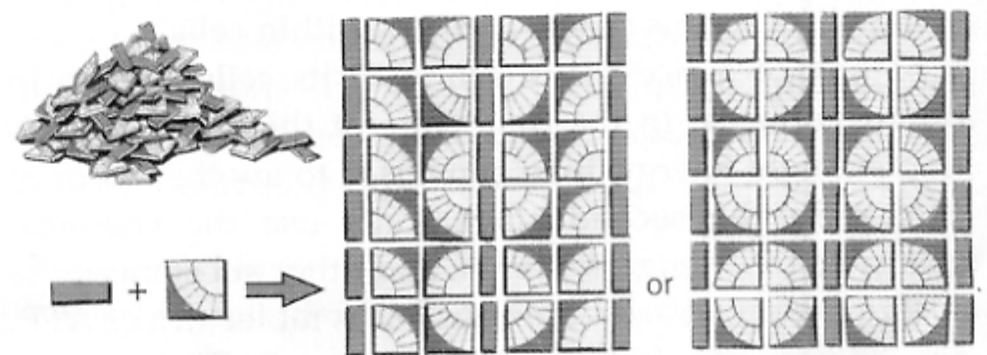
3. Biology, like other branches of science, is based on systematic observations, hypotheses, predictions, and relentless tests. The external world, not internal conviction, is the testing ground for scientific theories.

## 1.1 SHARED CHARACTERISTICS OF LIFE

### Energy, DNA, and Life

Picture a frog on a rock, busily croaking. Without even thinking about it, you know the frog is alive and the rock is not. At a much deeper level, however, the difference between them blurs. They and all other things are composed of the same particles (protons, electrons, and neutrons). The particles are organized as atoms, according to the same physical laws. At the heart of those laws is something called **energy**—a capacity to make things happen, to do work. Energetic interactions bind atom to atom in predictable patterns, giving rise to the structured bits of matter we call molecules. Energetic interactions among molecules hold a rock together—and they hold a frog together.

It takes a special molecule called deoxyribonucleic acid, or **DNA**, to set living things apart from the nonliving world. No chunk of granite or quartz has it. DNA molecules contain instructions for assembling new organisms from “lifeless” molecules that contain carbon and a few other kinds of atoms. By analogy, with proper instructions and a little effort, you can turn a disordered heap of ceramic tiles—even just two kinds of tiles—into ordered patterns such as these:



Similarly, life emerges from lifeless matter with DNA “directions,” raw materials, and energy inputs.

## Levels of Organization in Nature

Look carefully at Figure 1.2, which outlines the levels of organization in nature. The properties of life emerge at the level of cells. A **cell** is an organized unit that can survive and reproduce on its own, given DNA instructions and sources of energy and raw materials. In other words, the cell is the basic *living* unit. This definition obviously fits a free-living, single-celled organism such as an amoeba. Does it fit a **multicelled organism**, that has specialized cells organized into tissues and organs? Yes. You may find this a strange answer. After all, your own cells could never live all by themselves in nature. They must be bathed by fluids inside your body. Yet even human cells can be isolated and kept alive under controlled laboratory conditions. Researchers around the world routinely maintain human cells for use in important experiments, including cancer studies.

Referring to Figure 1.2, we find a more inclusive level of organization—the **population**. This is a group of single-celled or multicelled organisms of the same kind, such as a breeding colony of Emperor penguins in Antarctica. Next is the **community**, which includes all populations of all species (penguins, whales, seals, fishes, and so on) living in the same area. The next level, the **ecosystem**, includes the community and its physical and chemical environment. The most inclusive level of organization in nature is the **biosphere**. The word refers to all regions of the earth's waters, crust, and atmosphere in which organisms live.

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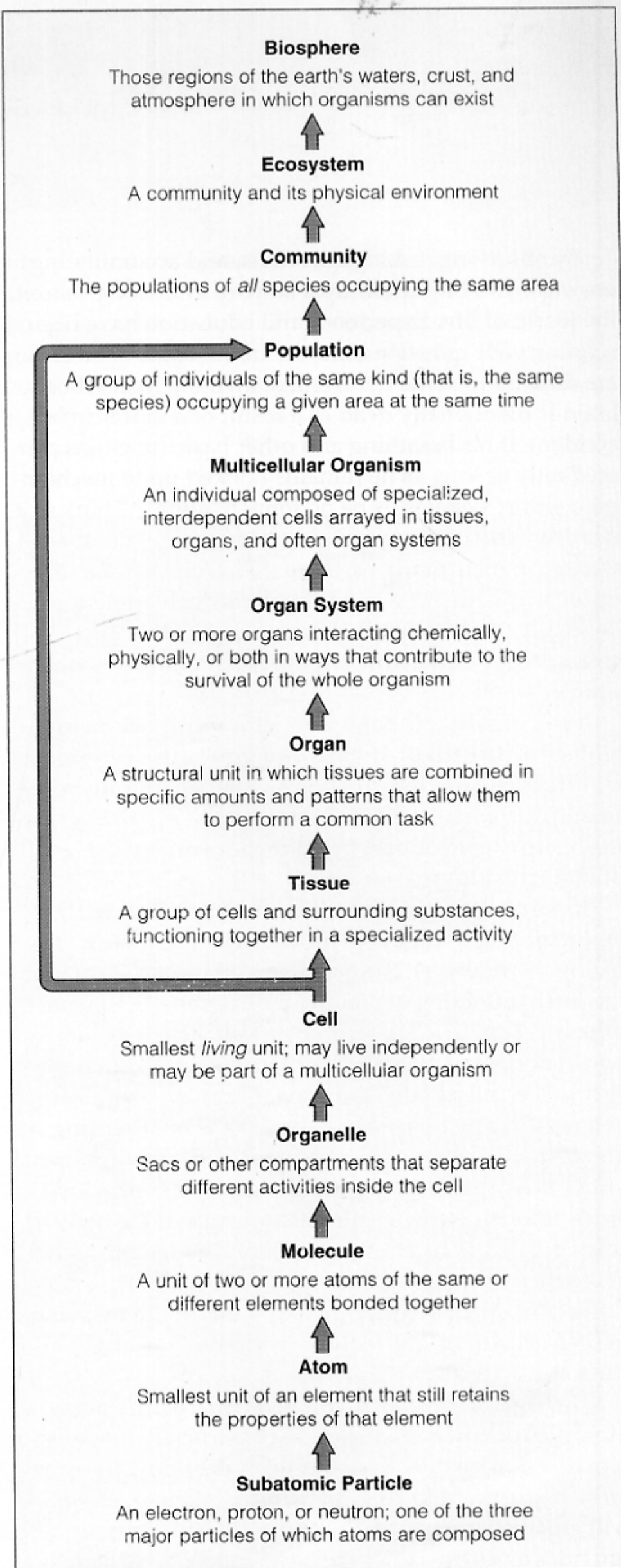
Within the hierarchy of organization in nature, the properties of life emerge at the level of cells. Cells emerge through a convergence of raw materials, sources of energy, and instructions contained in DNA molecules.

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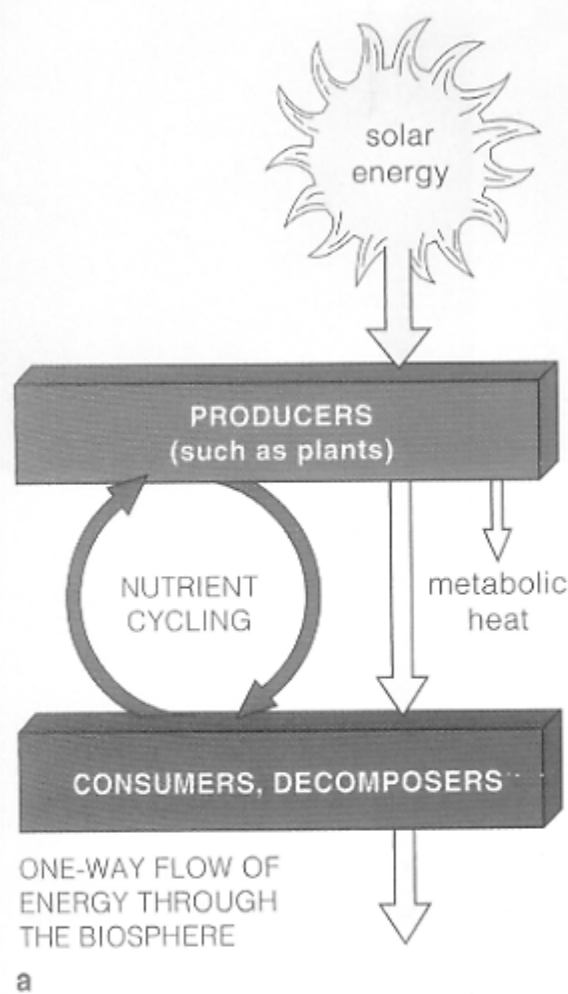
## Metabolism: Life's Energy Transfers

You never, ever will find a rock engaged in metabolic activities. Only living cells can do this. **Metabolism** refers to the cell's capacity to (1) extract and convert energy from its surroundings and (2) use energy and so maintain itself, grow, and reproduce. Simply put, metabolism means *energy transfers* within cells.

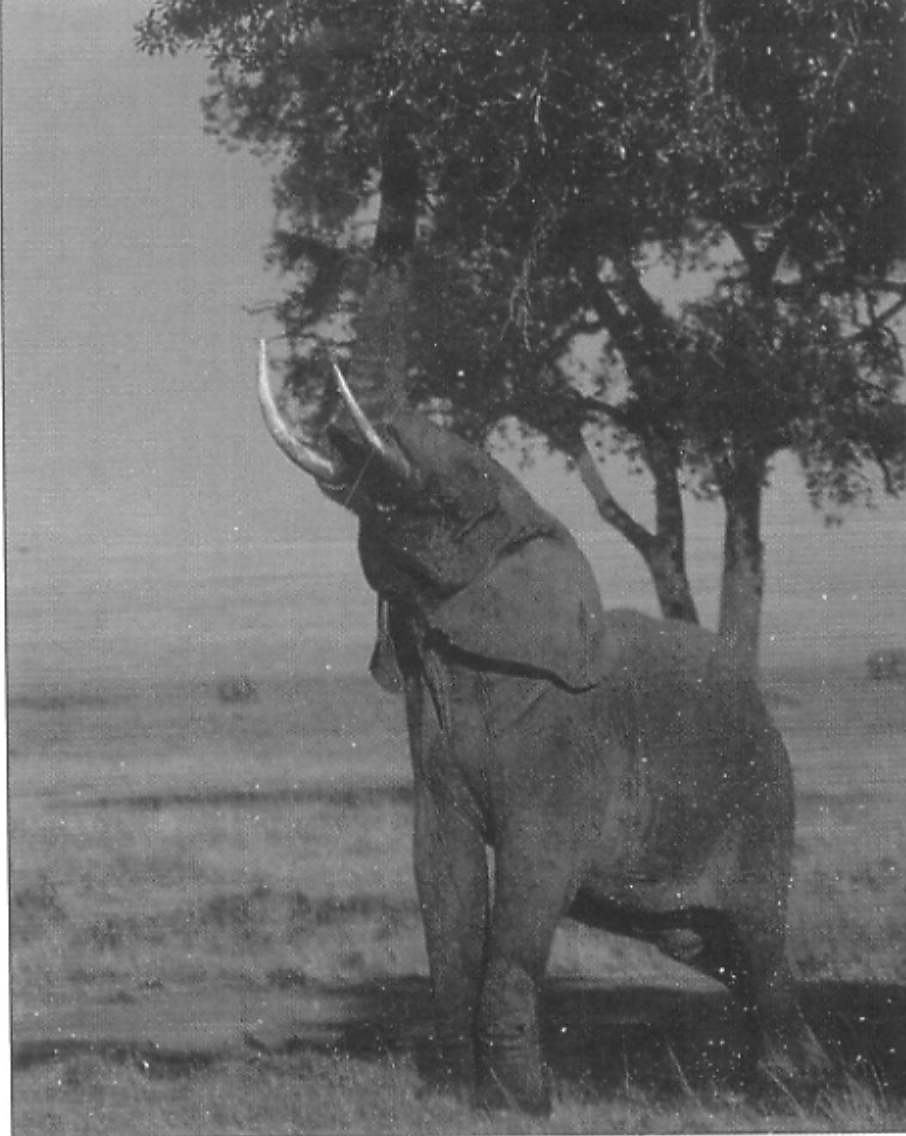
Think of a rice plant. Many of its cells engage in **photosynthesis**. In the first stage of this process, cells trap sunlight energy, then convert it to another form of energy. In the second stage, cells use the chemical energy to build sugars, starch, and other substances. As part of the process of photosynthesis, molecules of **ATP**, an "energy carrier," are put together. ATP transfers energy to other molecules that function as metabolic workers (enzymes), building blocks, or energy reserves.



**Figure 1.2** Levels of organization in nature. Cells represent the first level at which the properties of life emerge.



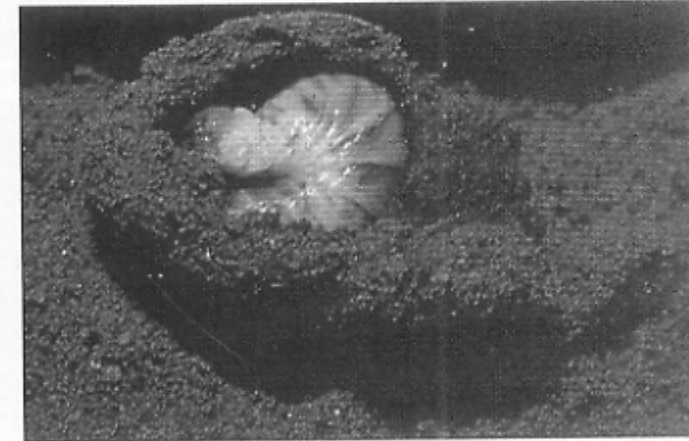
a



b



c



d

**Figure 1.3** (a) Direction of energy flow and the cycling of materials through the biosphere.

(b) Example of interdependency through nutrient cycling, although this cast of characters may seem a bit improbable at first. In the warm, dry grassland called the African savanna, we come across an adult male elephant. It eats huge quantities of plants to maintain its eight-ton self, and it produces huge piles of solid wastes—dung—that still contain some unused nutrients. Thus, although most organisms would not recognize it as such, elephant dung is an exploitable food source.

(c) And so we next have little dung beetles rushing to the scene almost simultaneously with the uplifting of an elephant tail. Working rapidly, they carve fragments of moist dung into round balls, which they roll off and bury in burrows. In these balls the beetles lay eggs, a reproductive behavior that assures forthcoming offspring (d) of a compact food supply.

Thanks to beetles, dung does not pile up and dry out into rock-hard mounds in the intense heat of the day. Instead, the surface of the land is tidied up, beetle offspring are fed, and leftover dung accumulates in burrows—there to enrich the soil that nourishes the plants that sustain (among others) the elephants.

In rice plants, some of the stored energy becomes concentrated in starchy seeds—rice grains. Energy reserves in countless trillions of rice grains provide energy for billions of rice-eating humans around the world. How? In humans, as in most animals and plants, stored energy is released and transferred to ATP by way of **aerobic respiration**, another metabolic process.

Living things show metabolic activity. Their cells acquire and use energy to stockpile, tear down, build, and eliminate materials in ways that promote survival and reproduction.

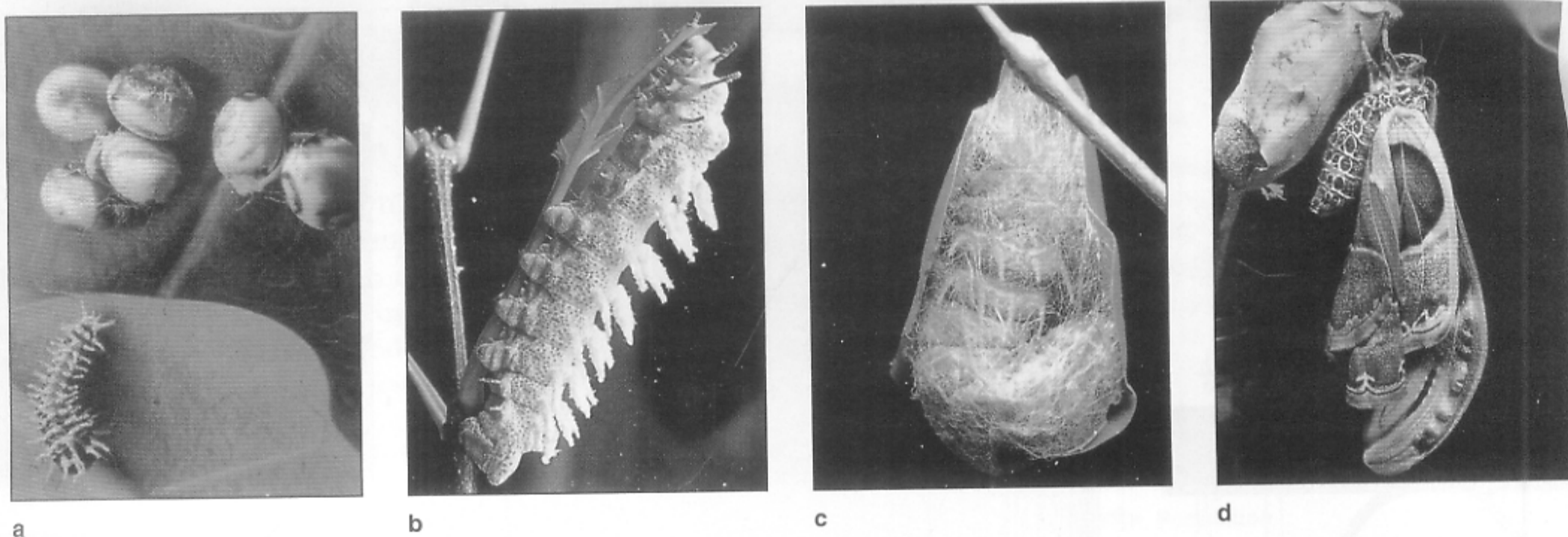
## Interdependency Among Organisms

With few exceptions, a flow of energy from the sun maintains the great pattern of organization in nature. Plants and some other photosynthetic organisms are the entry point for this flow. They are the food **producers**. Animals are **consumers**. Directly or indirectly, they feed on energy stored in plant parts. Thus zebras tap directly into the stored energy when they nibble on grass, and lions tap into it indirectly when they chomp on zebras. Many kinds of bacteria and fungi are **decomposers**. When they feed on tissues or remains of other organisms, they break down sugars and other biological molecules to simple raw materials—which can be cycled back to producers.

And so we have interdependency among organisms, based on a one-way flow of energy *through* them and a cycling of materials *among* them (Figure 1.3).

Such interactions among organisms influence populations, communities, and ecosystems. They even influence the global environment. Understand the extent of the interactions and you will gain insight into amplification of the greenhouse effect, acid rain, and many other modern-day problems.

**Webs of organization connect all organisms in nature, in that organisms depend directly or indirectly on one another for energy and raw materials.**



**Figure 1.4** “The insect”—a continuous series of stages in development. Different adaptive properties emerge at each stage. Shown here, a silkworm moth, from egg (a) to larval stage (b), to pupal form (c), to the splendid adult form (d,e).

## Sensing and Responding to Change

It is often said that only organisms “respond” to the environment. Yet a rock also “responds” to the environment, as when it yields to gravity and tumbles downhill or changes shape slowly under the battering of wind, rain, or tides. The real difference is this: *Organisms have the cellular means to sense changes in the environment and make controlled responses to them.* They do so with the help of **receptors**, which are molecules and structures that can detect specific information about the environment. When cells receive signals from receptors, they adjust their activities in ways that bring about an appropriate response.

Your body, for example, can withstand only so much heat or cold. It must rid itself of harmful substances. Certain foods must be available, in certain amounts. Yet temperatures shift, harmful substances may be encountered, and food is sometimes plentiful or scarce.

Think about what happens after you eat and simple sugar molecules enter your bloodstream. Blood is part of the body’s “internal environment” (the other part is the tissue fluid bathing your cells). When the sugar level in blood rises, cells of the pancreas step up their secretion of insulin. Most cells in your body have receptors for insulin, a hormone that prods the cells into taking up sugar molecules. With so many cells taking up sugar, the blood sugar level returns to normal.

Suppose you skip breakfast, then lunch, and the blood sugar level falls. Now a different hormone prods liver cells to dig into their stores of energy-rich molecules. Those molecules are broken down to simple sugars, which are released into the bloodstream—and again the blood sugar level returns to normal.

Usually, the internal environment of a multicelled organism is kept fairly constant. When conditions in the internal environment are being maintained within tolerable limits, we call this a state of **homeostasis**.

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Organisms have the means to sense and respond to changes in their environment. The responses help maintain favorable operating conditions inside the cell or multicelled body.

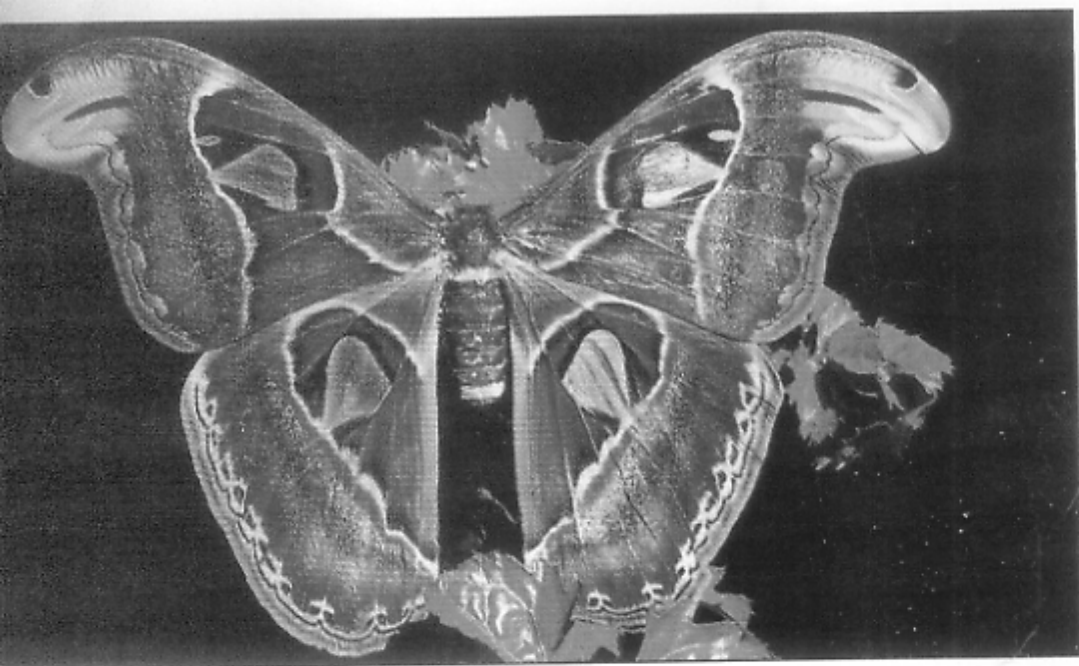
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## Reproduction

We humans tend to think we enter the world rather abruptly and leave it the same way. Yet we and all other organisms are more than this. *We are part of an immense, ongoing journey that began billions of years ago.* Think of the first cell produced when a human sperm penetrates an egg. The cell would not even exist if the sperm and egg had not formed earlier, according to DNA instructions passed down through countless generations. With those time-tested instructions, a new human body develops in ways that will prepare it, ultimately, for helping to produce individuals of the next generation. With **reproduction**—that is, the production of offspring—life’s journey continues.

Or think of a moth. Do you simply picture a winged insect? What of the tiny fertilized egg deposited on a branch by a female moth (Figure 1.4)? The egg contains the instructions necessary to become an adult. By those instructions, the egg develops into a caterpillar, a larval stage adapted for rapid feeding and growth. The caterpillar eats and grows until an internal “alarm clock” goes off. Then its body enters a so-called pupal stage of development, which involves wholesale remodeling. Some cells die, and others multiply and become organized in different patterns. In time an adult moth emerges. It has organs that contain eggs or sperm. Its wings are brightly colored and flutter at a frequency appropriate for attracting a mate. In short, the adult stage is adapted for reproduction.

None of these stages is “the insect.” The insect is a series of organized stages from one fertilized egg to the



e

next. Each stage is vital for the ultimate production of new moths. The instructions for each stage were written into moth DNA long before each moment of reproduction—and so the ancient moth story continues.

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Each organism arises through reproduction.

Each organism is part of a reproductive continuum that extends back through countless generations.

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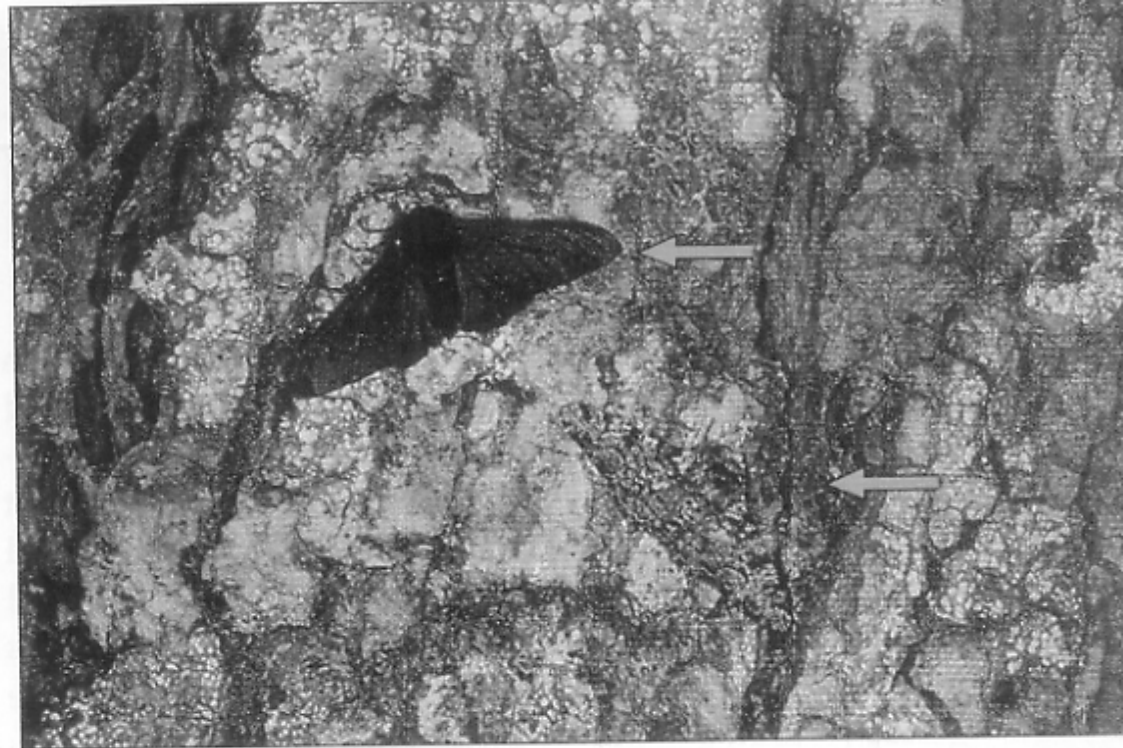
### Mutation: Source of Variations in Heritable Traits

Reproduction involves **inheritance**. The word means that parents transmit DNA instructions for duplicating their traits, such as body form, to offspring.

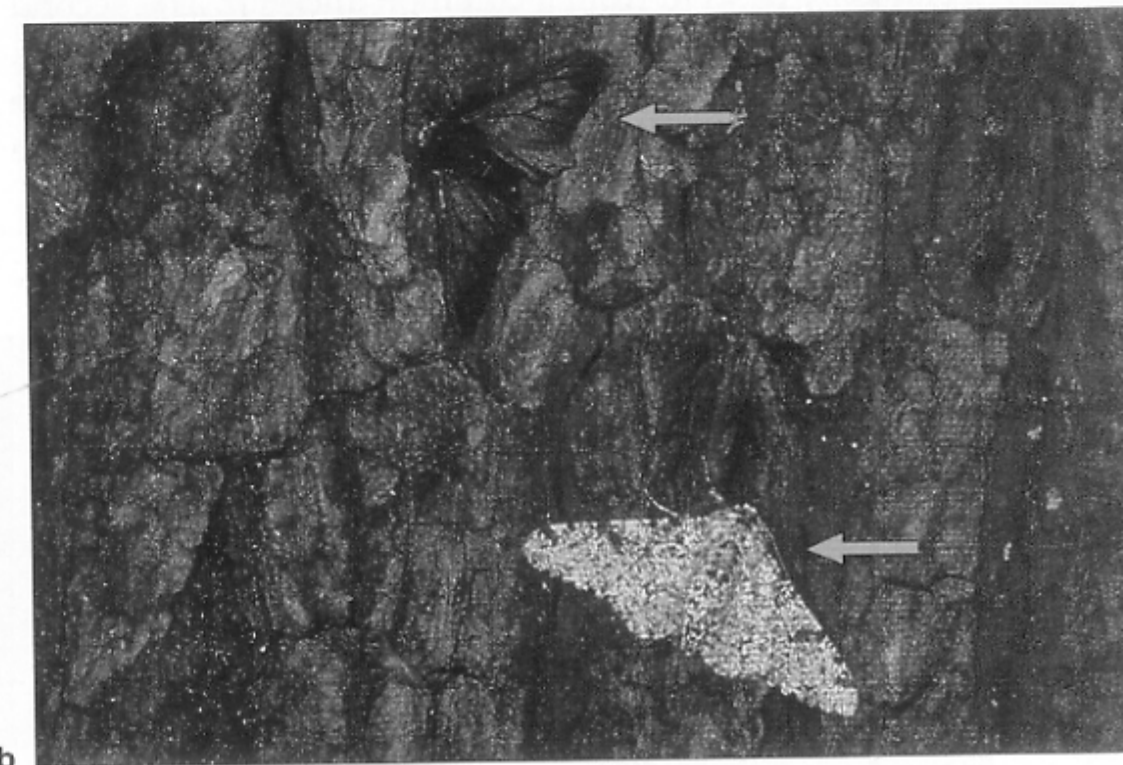
DNA has two striking qualities. Its instructions assure that offspring will resemble parents—and they also permit *variations* in the details of traits. For example, having five fingers on each hand is a human trait. Yet some humans are born with six fingers on each hand instead of five! Variations in traits arise through **mutations**, which are abnormal, heritable changes in the structure of DNA molecules.

Many mutations are harmful. A change in even a bit of DNA may be enough to sabotage the steps necessary to produce a vital trait. In *hemophilia A*, for example, a tiny mutation leads to an impaired ability to clot blood. Bleeding continues for an abnormally long time after even a small cut or bruise.

Yet some mutations are harmless, even beneficial, under prevailing conditions. A classic example is a mutation in light-colored moths that leads to dark-colored offspring. Moths fly by night and rest during the day, when birds that eat them are active. What happens when a light moth rests on a light-colored tree



a



b

**Figure 1.5** An example of how two different forms of the same trait (coloration of moths) are each adaptive under different environmental conditions.

trunk (Figure 1.5)? Birds simply don't see it. Suppose, as a result of heavy industry, light trunks in a forested region become soot covered—and dark. The dark moths are less conspicuous, so they have a better chance of living long enough to reproduce. Under sooty conditions, the dark form of the trait is more adaptive.

An **adaptive trait** simply is one that helps an organism survive and reproduce under a given set of environmental conditions.

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**DNA is the molecule of inheritance in organisms. Its instructions for reproducing traits are passed on from parents to offspring.**

**Mutations introduce variations in heritable traits.**

**Although many mutations are harmful, some give rise to variations in form, function, or behavior that turn out to be adaptive under prevailing conditions.**

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