90 SPECIATION

"Speciation" means formation of new species, whether of one new species to replace an old one or of two species by the gradual differentiation of one species into two. (In case you hadn't noticed before, the word "species" is both singular and plural. If you say "specie," you are using an old-fashioned word for "money.") Most of the time it is quite clear whether two groups of organisms are the same species or different species. We regard them to be the same species only if they interbreed freely and produce fertile offspring or are at least capable of such interbreeding. But a certain difficulty arises in some cases, as this plate will illustrate.

The Galápagos finches studied by Charles Darwin offer one of the clearest examples of speciation because their isolation from the mainland parental population was complete and the resulting species are quite distinct today. A more subtle example is provided by the leopard frog, which is found over the entire eastern half of North America, from southern Canada to northern Mexico. All leopard frogs have long been regarded as belonging to the same species, *Rana pipiens.* However, when the biologist John Moore did mating experiments with leopard frogs from different parts of that range, he found that as he mated frogs whose home territories were farther and farther apart in a north-south direction, he got many defective offspring and fewer and fewer eggs that survived to hatching. When he mated frogs from the extreme north and the extreme south, the eggs died. Clearly, the frogs from the two ends of the range have become different species, according to our customary definition. At the same time, frogs living somewhat closer together are still of the same species, although perhaps they are on the way to becoming different species.

Color the heading Frogs, title A, and the title Gene Pool. Color frog A and genes D through I in the related illustration, using a different color for each gene shape and a light color for A.

"Gene pool" is the term applied to the total set of genes in the entire population of a species at a given point in time. The box at the top of the plate symbolizes the *gene pool* of the *ancestral leopard frog* at whatever point in time it first became a separate species from other frogs. At that time, all the frogs of the species had to be close enough together to share a common gene pool, which we symbolize by the six shapes.

As the population of this new species grew and spread out to cover the eastern United States, there eventually came a time when sheer distance proved to be a barrier to free gene flow between northern frogs and southern frogs. It might not have been impossible for a frog in Florida to migrate to Minnesota to mate, but it certainly must have been a rather rare event.

With the passage of time, *natural selection* would have exerted its influence, and that would be a different influence in different places. Temperature is one factor that is obviously different between north and south, and John Moore did find that eggs from northern frogs would develop and hatch in water too cold to permit survival of eggs from southern frogs, while eggs from southern frogs would develop and hatch in water too warm to permit survival of eggs from northern frogs.

Color titles B and N, arrow N, frog B, and the symbols for the genes in its gene pool.

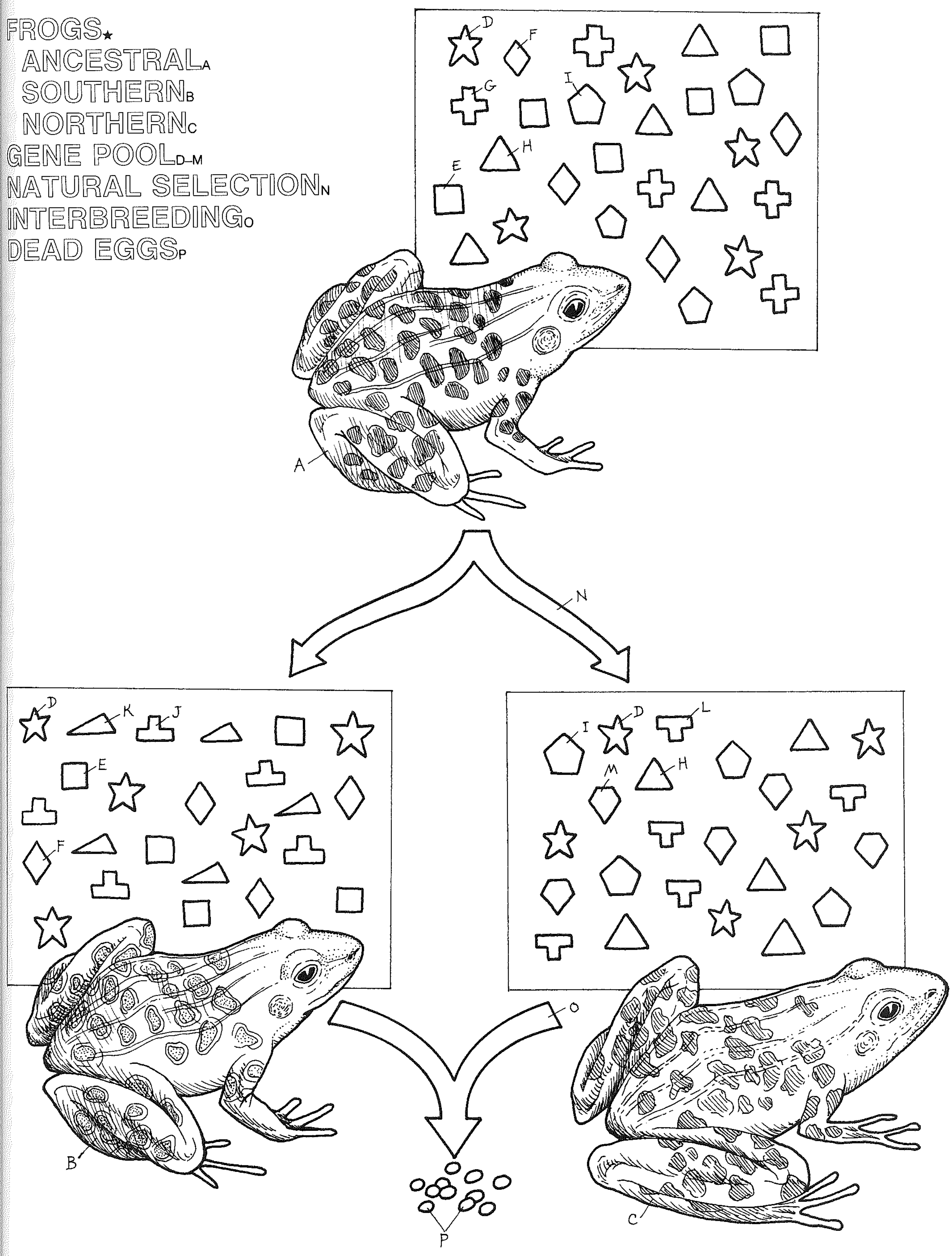
If you compare the genes of the *southern frog* with those of the ancestral frog, you will see that three kinds of genes are unchanged, two of them are somewhat changed, and one has been lost entirely. We know from genetic studies that mutations do occur in genes from time to time. Most of them are damaging, but occasionally one can occur that produces an improvement in the ability of the organism to survive. Suppose, for example, that gene G mutated to gene J, which allows eggs to develop and hatch more efficiently at warmer temperatures. For a southern frog, that is enough of an advantage that frogs with that mutation will tend to produce more surviving offspring than frogs without it. Eventually, gene G is eliminated from the southern population because the carriers of gene J are more efficient at reproducing. Similarly, if the mutation of gene H to gene K conferred some survival advantage, it would tend to replace gene H entirely. Gene I would produce some characteristic that is a disadvantage for survival in the south and hence be eliminated from that population.

Color frog C and the genes in its gene pool. Color the remainder of the plate.

A *northern* population of frogs would undergo the same kinds of changes in its gene pool as a result of natural selection in the north. Cooler temperature is one obvious factor in selection, but there would be many others. As with the southern frog, we show here two mutated genes and one entirely lost. With this much difference between the southern and northern populations, they may not be able to *interbreed* to produce offspring at all.

SPECIATION.

FROGS.★
ANCESTRAL A
SOUTHERN B
NORTHERN C
GENE POOL D–M
NATURAL SELECTION N
INTERBREEDING O
DEAD EGGS P



89
NATURAL SELECTION WE CAN SEE

Since Darwin's exposition of the principles of natural selection, biologists have found numerous examples of natural selection occurring in periods of time much shorter than the many thousands of years usually required. One outstanding example of this is what is known as industrial melanism (Greek: *melas,* "black"), the turning black of certain species in areas that were blackened with the soot of the coal-burning factories that sprang up in great numbers during the Industrial Revolution.

Color titles A, A^1, and B and the associated structures in the upper illustration. Use light gray or gray-green for A and A^1. Use black for B.

One of the best-studied cases of industrial melanism is the change in color of the peppered moths in the vicinity of Manchester, England. Nature study has been popular for centuries in England, so there are records of observations and insect collections going back several hundred years. In the vicinity of Manchester, a certain rather large moth *(Biston betularia)* was well known. It was called the *peppered moth* because it resembled a white moth on which pepper had been sprinkled. It was nocturnal in its habits and spent all the daylight hours resting on the trunks of trees, where it blended in almost perfectly with the *lichens* covering the tree trunks, since the lichens had the same "peppered" coloration. Only occasionally was a rare *black* member of this species spotted.

Color title B^1 and structures A, B, and B^1 in the lower illustration. Use black for B^1.

In the second half of the nineteenth century, however, more and more black moths began to show up. That change in the moths corresponded exactly with the progress of the Industrial Revolution. In that coal-burning part of England, the amount of *soot* put into the air by factories was so great that it *covered the tree trunks* in industrial areas, killing the lichens and turning the tree trunks black. Under those conditions, of course, the black moths were as well camouflaged as the peppered ones had been on the lichen-covered trunks. Eventually 98 percent of the moths of this species in industrial areas were black. This same change was observed in many dozens of other species of moths in similar industrial areas in England and the United States, wherever forests became polluted with soot. In unpolluted forests, the moths retained their light coloration.

The question then arose of just how this change was occurring. One hypothesis was that it must just be the results of natural selection, due to birds or other predators eating moths that didn't blend in with the background. But that left unanswered the question of how the first black moths appeared originally. Another hypothesis was that the moths ate or absorbed something in the soot that turned them black. Yet another hypothesis was that the moths had some sort of built-in reflex that caused them to turn themselves black whenever they sensed that their principal background had turned black. The English biologist H.B.D. Kettlewell decided to go out into the forests to investigate this problem thoroughly.

Color the remainder of the plate.

Kettlewell captured equal numbers of black and peppered moths, put identifying paint marks on their undersides where the marks wouldn't show when the moths were resting on a trunk, and released one set in an area with blackened tree trunks and another in an unpolluted area with trunks still covered with lichens. When he came back to recapture the moths, he recovered only half as many of the peppered moths as he did black moths in the soot-blackened forest, and in the light-colored forest he recovered only half as many black moths as he did peppered moths. He also examined the stomach contents of birds known to feed on the moths and found that in blackened forests they ate a disproportionately large number of light-colored moths and in light-colored forests the reverse was true. He also set up movie cameras and captured on film what is summarized in the illustrations of this plate. When a bird is zooming in toward a tree trunk looking for lunch, it is much more likely to see and therefore capture a black moth on a lichen-covered tree trunk or a peppered moth on a blackened tree trunk.

Kettlewell also found that geneticists had already established that the coloration of these moths was determined by a single pair of genes, with the peppered coloration recessive to black. Clearly, then, this was a case of natural selection in action. There was no "battle for survival" according to the "law of the jungle," as is sometimes mistakenly assumed to be a requirement for evolution. Survival or nonsurvival may depend on something as simple as the color of the background. Evolution, then, is simply the process of heredity, with all its lotterylike characteristics, extended over a long period of time, with the environment selecting which survive and which do not.

NATURAL SELECTION WE CAN SEE.

PEPPERED MOTH A
BLACK MOTH B•
LICHEN A¹
SOOT-COVERED TRUNK B¹•

PREDATOR C
CAPTURE PATH C¹