

Preface

Beverly Rathcke planted the seed of this book in a lecture she gave in an ecology class during my first semester in graduate school. She told us about cotton farmers who tried to control an insect pest by spraying an insecticide. This strategy worked for a while, but then a couple of puzzling things happened. The first was that farmers found themselves battling more and more species¹ of insect pests as the years went by. The second was that their insecticide lost its ability to kill insect species that it once had clobbered. Farmers substituted a new type of insecticide, which worked for a while, and then it, too, failed. They kept replacing insecticides, and increasing the frequency of spraying, until they had no poisons left. With no way of halting crop destruction by insects, farmers had no choice but to abandon growing cotton on thousands of acres.

To understand why farmers battled ever more species of pests over time, Beverly explained, one had to bring ecology to bear. One of the central concerns of this discipline is explaining the abundance of organisms. In farm fields, one finds many species of insects. Some species live in such large populations, and eat so much of a farmer's crops, that we call them pests. Populations of dozens of other insect species also live in farm fields, but most pass without notice because they cause no measurable damage to crops. In some cases, they are not pests because they eat something other than the crop. In other cases, they do feast on the crop, but their populations are too small to cause measurable losses. Several factors keep populations of insect species small, including predation by other species of insects. (Picture ladybugs preying on aphids.) This means that from the farmer's point of view, some insect species in fields

are harmful (because they gobble up crops), but other insect species are beneficial (because they kill the insects that eat the crops).

A children's rhyme supplies an analogy. In the house that Jack built, Jack was like a farmer. The malt in the house that Jack built was like a crop. The rats that ate the malt in the house that Jack built resembled crop-eating insects. (Because we are talking about populations of animals rather than single individuals, we will make some species in the story plural.) The cats that ate the rats that ate the malt in the house that Jack built were predators akin to insects that prey on other insects. Now let us modify the story and add another species: the mouse. Mice lived in the house and ate the malt, but the cats killed them so efficiently that losses to mice were trivial. Mice resembled insect species living in farm fields in very small populations.

Now we have three species of mammals in Jack's house (not counting Jack) and a pair of predator-prey relations. One species, the rat, was numerous enough, and fond enough of malt, to qualify as a pest. A second malt-eating species, the mouse, inhabited the house in such low numbers one rarely noticed it and so it did not rise to pest status. A third species, the cat, benefited Jack by killing rats and mice. A similar cast of insect characters inhabited cotton fields – a large population of a crop-eating species (a pest), small populations of other crop-eating species, and populations of varying sizes of insect-eating (predatory) species.

Next imagine that Jack decided his losses to rats were unacceptably high. How might he respond? One way would be to import more cats. Another would be to poison the rats. Let us say Jack chose the latter route and scattered poison about the house. And let us say he chose a poison lethal to many mammalian species, including cats and mice, and these two species succumbed along with the rats. Furthermore, let us say other rats and mice lived in surrounding fields and migrated quickly into the house once the poison decayed. Cats, on the other hand, migrated in more slowly because they lived in the barns of distant neighbors. It would not be hard for populations of rats and mice to explode and for the mice to cause enough damage to join the rats as full-fledged pests. Now Jack lived in the house with lots of rats and mice but no cats. Ironically, in trying to kill one species, Jack accidentally helped a second species become a pest.

Insecticides had similar effects on insects in cotton fields. Many insecticides kill a wide range of insect species, beneficial as well as harmful. When spraying for one species of insect pest, farmers accidentally killed off populations of beneficial species of predatory insects, too. Freed from predation, populations of formerly rare plant-eating insect species

blossomed into full-blown pests. Spraying thus had the ironic effect of increasing rather than decreasing the number of pest species. (Enough insect species have become pests as a by-product of spraying that entomologists have a term for them: *secondary pests*.) Spraying did not create new species, but it helped populations of several species become plentiful enough to cause economic problems. This explained why the number of pest species attacking cotton fields increased over time despite regular doses of insecticides.

To solve the second puzzle – the failure of insecticides to kill species they formerly controlled – Beverly turned to evolutionary theory. Unwittingly, cotton farmers had been carrying out experiments in Darwinian evolution by natural selection. In *On the Origin of Species*, Charles Darwin summed up his theory this way: if “variations useful to any organic being ever do occur, assuredly individuals thus characterized will have the best chance of being preserved in the struggle for life; and from the strong principle of inheritance, these will tend to produce offspring similarly characterized. This principle of preservation, or the survival of the fittest, I have called Natural Selection.”²

Darwin would have little trouble applying his theory to insects in cotton fields. First, he would note that “variations useful” to individuals did occur. When spraying began, most individual insects of a given species in a given field (that is, a population) were susceptible to a given insecticide. A few individuals, however, were resistant to the insecticide because they happened to possess some biochemical machinery that detoxified the poison. So individuals varied in a “useful” trait. Second, Darwin would observe that this difference in traits influenced the “chance of being preserved in the struggle for life.” Resistant individuals *survived* spraying more often than susceptible individuals. In Darwinian terms, spraying *selected* for one trait (*resistance*) and against another (*susceptibility*). Third, because of “the strong principle of inheritance,” individual insects “produced offspring similarly characterized.” Susceptible parents produced susceptible offspring, and resistant parents produced resistant offspring. Today we attribute “the strong principle of inheritance” to the passing of genes (strings of DNA with instructions for how cells should operate) for traits from parents to offspring.

Puzzle solved. Insecticides did not lose their ability to kill insects because the poisons changed; they lost their ability because the target insect populations changed. When spraying began, susceptible individuals outnumbered resistant individuals in a cotton field by far, which made the insecticide effective. But each round of spraying acted as a selective

force, favoring the survival and reproduction of the resistant over the susceptible. Repeating this process over many insect generations increased the proportion of resistant individuals in the population until the insecticides failed to kill enough pests in the population to make it worth spraying. The insect population had evolved.

The encouragement of secondary pests and the evolution of resistance launched farmers onto something called the pesticide treadmill. In the short run, a pesticide worked, but in the long run, it failed. Farmers substituted a new insecticide, and the process repeated itself, *ad infinitum*. Beverly described this process as a **coevolutionary** arms race: insects evolved resistance, which led to a technological change by people, which led to more evolution for resistance, which led to more technological change, and so on. Farmers mimicked the Red Queen in *Alice in Wonderland*, running ever faster on the treadmill just to stay where they were.³

That evening, I gushed about Beverly's lecture to my wife as she was preparing dinner. (I think we were having burritos, but it could have been spaghetti. On our budget, we had one or the other most nights.) I have a feeling that even now, I have not identified all the reasons the story seemed so compelling, but I can point to some. It occupied the middle ground between the human and the natural. It showed reciprocal effects over time. It required the linking of tools from science (evolutionary ecology) and humanities (history) to understand events. You will see those same ideas in this book.