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evolutionary HISTORY:

PROSPECTUS FOR A NEW FIELD

IT WAS, evolutionary biologist Theodosius Dobzhansky wrote in 1937, "probably the best proof of the effectiveness of natural selection yet obtained."[1] If we were guessing what Dobzhansky had in mind, we might nominate some of the classic examples from evolutionary biology and paleontology. Charles Darwin's tortoises in the Galapagos Islands? The rise and extinction of the dinosaurs? Fossils from the Burgess shale? The answer to all these suggestions is no. Dobzhansky's proof was the evolution of insects resistant to insecticides.

In the early twentieth century, fruit growers in the western United States noticed that, over time, some insecticides "lost" their ability to kill scale insects in orchards. Most entomologists blamed people. Manufacturers produced defective insecticides, they reasoned, or farmers applied legitimate products incorrectly. A few entomologists, however, noticed that their data contradicted this explanation. Insecticides lost their potency in areas where farmers bought the most reliable insecticides and sprayed them most carefully, rather than the reverse. Perhaps, these scientists ventured, some insects carried Mendelian genes for resistance to sprays. But the reason why resistant individuals should be common in heavily sprayed areas remained a mystery for the next two decades.[2]

In the 1930s, Dobzhansky solved this puzzle by discarding an unspoken assumption. Entomologists had assumed that insect species stayed constant (or evolved so little that change was trivial) in historical time. Dobzhansky suggested the opposite. Spraying was a form of natural selection, he argued. By chance, a few individuals within a species carried genes conferring resistance to insecticides. Insecticides killed off susceptible individuals and left the resistant ones behind to reproduce. Resistant individuals passed on their genes for resistance to their offspring. Every time farmers sprayed, they increased the ratio of resistant to susceptible insects in their orchards. Eventually, so few susceptible individuals remained that insecticides appeared to have lost their potency. This deceptively simple explanation solved a pair of biological puzzles: why genes for

resistance should become more common over time, and why resistance should be most common in areas sprayed most heavily. It also solved an economic puzzle: why crop losses to insects should rise despite ever-greater doses of insecticides. Further, it provided the paradigmatic example for a new approach to biology, the modern (neo-Darwinian) synthesis that united evolutionary theory with genetics.[3]

Dobzhansky's findings challenged several ideas about evolution that remain common today. Many of us think of evolution as something that happened in the distant past, took eons to occur, and was done by nature. Resistant insects, however, evolved recently rather than long ago, quickly rather than over eons, and under the influence of humans rather than nature alone. Many of us think of evolution as speciation, but populations of insects evolved resistance without budding into new species. Many of us think of a species' genes as fixed in historical time and space, or as varying so little that differences are trivial. But members of insect species carried different versions of genes before insecticides arrived, and spraying increased the proportion of genes for resistance in certain parts of species' ranges enough that resistance became an economic problem. Many of us think of evolutionary ideas as tools for biologists, not humanists. But humans have shaped the evolution of countless species for millennia, reshaping human experience as well as the genes of other species.[4]

Few historians, however, have incorporated evolution into their work. Until we do, the historicism project will remain incomplete. A signal contribution of environmental history has been to historicize ways of thinking about and interacting with other species. The most visible sciences of this effort have been ecology and public health, which have helped us understand changes in the distribution, abundance, and health of organisms. We have largely ignored, however, the impact of ecological changes and public health measures on the constitutions of other species. By changing the environments in which organisms live, we have changed the selective regimes in which they evolve. In some cases, the resulting evolution has forced humans to interact with versions of those species in very different ways. The 1950 versions of orchard insects differed from 1900 versions of the same species, which forced farmers to use a new generation of technology to control them. To reach a full understanding of the history of life on earth, then, we must join hands with evolutionary biologists and paleontologists to historicize organisms themselves.

In making the case for an evolutionary historiography, this essay focuses on genetic evolution in non-human species. For the most part, it sets aside the role of human evolution. One reason is to emphasize the value of evolution for understanding the distinctive concern of environmental history—nature. Organisms have changed in historical time; those changes have mattered to human beings; and evolution offers the only cogent explanation for such change. The second reason is to emphasize that one can practice evolutionary history with a limited agenda. Studying human evolution is not necessary (or even sufficient) for evolutionary history. The third reason is to encourage a focus on aspects of evolution sometimes obscured by controversial issues, such as sociobiology and evolutionary psychology. This essay is not a brief for those fields

or for biological determinism. Humans and other species have engaged in a complex dance in which genes in non-human species, along with a variety of other human and natural forces, have played roles. Nor is evolutionary history an effort to make history a subdiscipline of evolutionary biology. It is an effort to tap some of the most powerful ideas of the past 150 years to create a fuller understanding of history.

This essay begins by making a case for the importance of anthropogenic evolution. A review of the literature documents the limited role of evolution in environmental history, hypothesizes reasons for its low profile, and surveys uses of evolution in other disciplines in the humanities and social sciences. Drawing on existing works, the next section demonstrates the potential for evolutionary history to revise accounts of events as disparate as international relations, industrialization, and the collapse of natural resources. Finally, the essay suggests that evolutionary history has the potential to inform not just our understanding of the past, but a future in which biotechnology plays an increasingly important role.

ANTHROPOGENIC EVOLUTION

ANTHROPOGENIC EVOLUTION has played a venerable role in the development of evolutionary theory. Although better known for his travels in the Galapagos Islands than for his trips to English farms, Darwin drew on domestication to understand and explain evolution in the wild. The first chapter of *On the Origin of Species* is about variation and selection under domestication. Only after putting that framework in place does Darwin turn in chapter two to natural selection, which he introduces as "applying the principles arrived at in the last chapter to organic beings in a state of Nature." Darwin described another of his books, the two-volume *Variation of Animals and Plants under Domestication*, as providing "facts on which the conclusions in [*Origin*] were founded."[5]

Today's understanding of Darwinian evolution is, at heart, simple. It requires three things: variation, inheritance, and selection. *Variation* means that individuals in a population differ in some trait. It could be any trait, visible or invisible to the eye: speed, size, tolerance of drought, metabolic efficiency, and so on. *Inheritance* means that these traits pass from parent to child. Today, evolutionary biologists focus on genes as the units of inheritance. *Selection* means that variation in traits enables some individuals to contribute more offspring to the next generation than do others.[6]

The term for which Darwin is most famous, natural selection, derived from domestication. Darwin believed the term was less than ideal because it implied "conscious choice" on the part of nature. But the advantages outweighed the disadvantages, for "it brings into connection the production of domestic races by man's power of selection, and the natural preservation of varieties and species in a state of nature." In Darwin's day, "selection" referred to what breeders did. Darwin needed a modifier to create the new meaning, the analogous process in nature–hence, "natural" selection.[7]

Today, the meaning has all but reversed. Evolutionary biologists often use "selection" and "natural selection" synonymously, and they use "artificial selection" (Darwin's occasional phrase) to refer to what people do. This essay uses "selection" to include natural and artificial selection and attaches an adjective when necessary to draw a distinction. Artificial selection—and thus anthropogenic evolution—has been unintentional and intentional. Evolution of resistance to insecticides was unintentional. Recent plant and animal breeding has been intentional. Breeders have worked on species whose individuals varied in some inherited traits. They selected some individuals to mate and prevented others from doing so. If all went well, the next generation included relatively more individuals with the desired trait and fewer individuals lacking it. The new generation had evolved from the generation before.[8]

Artificial selection could not change frogs into princesses, but it transformed animals so radically that it seemed magical. Working hard on the heels of a revolution in animal breeding, Darwin learned that breeders imagined a perfect animal and then set out to create it. William Youatt, whom Darwin quoted approvingly, said the breeder's "principle of selection" was "that which enables the agriculturists, not only to modify the character of his flock, but to change it altogether. It is the magician's wand, by means of which he may summon into life whatever form and mould he pleases." Even farmers without such imagination, Darwin believed, transformed their stock as radically (if more slowly) simply by picking the best animals to breed over long periods.[9]

This conception of evolution allows evolution to happen quickly, to result from human actions, and to result in changes short of speciation. Breeders have not exaggerated, then, when they have described themselves as "helping evolution." One such breeder took advantage of a mutant, featherless strain of chicken. ("We call them naked chickens," he said, "just because they are naked.") This strain, the breeder thought, might solve a problem arising from the spread of enclosed, mass-production chicken raising to tropical countries at the end of the twentieth century. Conventional feathered chickens often died of heat in such enclosures. Naked chickens might dissipate heat more efficiently than their feathered cousins did. As in most evolution, however, there was a tradeoff. Naked chickens might thrive in hot, enclosed spaces, but a stroll in the sun knocked them into a stupor.[10]

The contrast between sheds and the open air, and between chickens suited to each, illustrates the inseparability of selection from environment. Organisms have not evolved toward some universally better (much less best) state. Natural selection, as Darwin put it, "acts exclusively by the preservation and accumulation of variations, which are beneficial *under the organic and inorganic conditions to which each creature is exposed* at all periods of life." "Better" makes sense only in the context of specific environments, and then it only means that some individuals are more likely to reproduce than are others.[11]

We can measure the significance of anthropogenic evolution in several ways. To lead with the trump card: Without it, our profession would not exist. Jared Diamond's *Guns, Germs, and Steel* argues that humans directed the evolution of nearly all domesticated species. Archaeological and genetic evidence suggest that

humans have been domesticating organisms since the Neolithic revolution, about 12,000 years ago. Intentionally and unintentionally, humans selected for sweeter fruit, non-shattering seed pods, less aggressive animals, and fatter cows. These modifications in turn created the agricultural surplus necessary for settled societies, social hierarchies, bureaucracies, armies, contagious diseases, complicated technology, international conquest, and writing (thus our profession). More seriously, the point is not that our profession would not exist; it is that nearly everything historians study, which by definition we consider significant, would not have occurred without domestication.[12]

Another way to measure the significance of anthropogenic evolution is to tally the taxonomic range of species that humans have domesticated. This number suggests the enormous effort humans have poured into this endeavor for thousands of years. The animals have included mammals (dog, ass, horse, cow, sheep, goat, reindeer, camel, buffalo, rabbit, elephant, ferret, mongoose, yak), birds (chicken, turkey, pheasant, quail, pigeon, falcon, goose, duck, pelican, cormorant, crane, canary, ostrich), insects (silkworm, honeybee), and fish (eel, carp, goldfish, paradise fish).[13]

The list of domesticated plants is even longer. The plants thought to have originated in the Near East alone include cereals (oats, barley, rye, wheat), pulses (chickpea, lentil, fava), tubers (beet, turnip, carrot, radish), oil crops (rapeseed, mustard, safflower, olive, flax), fruits and nuts (hazelnut, melon, fig, walnut, palm, almond, apricot, cherry, pear, apple, grape), vegetables and spices (onion, garlic, leek, cabbage, coriander, cucumber, cumin, anise, purselane), fiber plants (hemp, flax), forage crops (bentgrass, rye, clover, vetch), and drug sources (belladonna, digitalis, codeine). Making use of some of these animals and plants has depended in turn on domesticating microorganisms. Bacteria turn milk into yogurt, and yeast is essential for making leavened bread, wine, and beer.[14]

A third way to judge the importance of anthropogenic evolution is to estimate economic effects. One expensive arena is agriculture. The process Dobzhansky analyzed, the rise of resistance to pesticides, has led American farmers to spend $1.6 billion per year to apply extra insecticide. This cost has risen each year as the number of resistant species has grown. By 1986, some 450 species of insects and mites, 100 species of plant pathogens, and 48 species of weeds had evolved resistance to pesticides. In some cases, resistance has forced the abandonment of enterprises altogether. In the 1960s, farmers had to stop growing cotton on 700,000 acres because insecticides no longer controlled a major pest, the tobacco budworm.[15]

Another expensive arena is medicine. By 2000, tuberculosis infected one-third of humanity and caused two million deaths each year. Strains of tuberculosis resistant to the major drugs infected 11 percent of the new cases. (Like insects treated with insecticides, pathogens treated with antibiotics have evolved resistance as susceptible individuals died off and resistant individuals survived to reproduce.) Fallback medicines were more expensive than the drugs of first choice. Overall, antibiotic resistance cost Americans $30 billion each year.[16]

A fourth way is to measure the cost in lives. The United States Centers for Disease Control and Prevention estimated in 1995 that sixty thousand people died each year in the United States from hospital-acquired infections. Pathogens resistant to antibiotics caused a large percentage of those deaths. The combination of insect resistance to pesticides and pathogen resistance to medications fueled distressing increases in malaria mortality in the late twentieth century. After World War II, a worldwide effort to eradicate malaria relied on insecticides (such as DDT, which killed the mosquitoes that carried the malaria plasmodium) and anti-malarial drugs (such as atabrine and quinine, which stopped the plasmodium from reproducing inside human bodies). The project saved an estimated 15-25 million lives but foundered when, among other things, mosquitoes and plasmodia evolved resistance to their respective poisons. Unable to reach its goal, the World Health Organization halted the program by 1972. By 2000, malaria killed roughly two million people each year.[17]

A fifth way is to look at the geographical scale of anthropogenic change. The increase of temperatures around the globe, apparently due partly to human production of greenhouse gases, has changed the evolutionary environment for species large and small. Pitcher plant mosquitoes in North America, to pick one example, hibernate (more precisely, enter diapause) on a schedule controlled by genes. Between 1972 and 1996, pitcher plant mosquitoes across a broad swath of the continent shifted their hibernation later in the year in response to warmer weather. On a regional level, humans seem to be changing sea levels, increasing ultraviolet radiation, transferring species across continents, contributing pollutants to air and water, and changing the pH of rain through additions of sulfur dioxide and nitrogen oxides.[18]

Most of these examples illustrate that anthropogenic evolution is a two way street. Not only do humans shape other species (which is important for those species); their evolution in turn has a significant impact on humans. The exception in these examples is the pitcher plant mosquito, whose evolution is important for scientists but has little direct influence on most humans. Indirectly, though, its evolution may be significant. If the earth continues to warm, we may look back on it as a harbinger of massive evolution yet to come.

EVOLUTION IN HISTORIOGRAPHY

OF ALL HISTORICAL fields, environmental history seems the most likely to have used evolution analytically. It studies ways in which humans have shaped nature, and it has drawn on scientific ideas to understand those processes. A search of over 33,000 entries in the Environmental History Bibliography at the Forest History Society, however, produced just eight entries in which authors used evolution as an analytical tool. Authors from fields other than environmental history wrote many of those eight. (We will look at exceptions to this pattern in the section below on evolutionary history.) The Research Register of the Documenting Environmental Change database at Cambridge University lists only one individual working on what may be termed biological evolution.[19]

Many factors may have contributed to this pattern, but three seem likely. First, historians may have lacked familiarity with evolution in general and anthropogenic evolution in particular. Few graduate or undergraduate programs in history require courses in science, much less in evolutionary biology. Even scholars who have taken courses in evolutionary biology may have learned little about anthropogenic evolution. Some of the most popular textbooks have omitted discussion of the topic. Eric Pianka, author of the textbook *Evolutionary Ecology*, wrote that he had "always tried to present evolutionary ecology as a 'pure' science."[20] Small wonder, then, if historians have seen evolution as something that has happened outside historical time and separate from human activity.

Recent publications in evolutionary biology may help correct this problem. Pianka, who devoted previous editions of his textbook to "pure" science, wrote in the introduction of the sixth (2000) edition of *Evolutionary Ecology*, "Humans now dominate ecosystems to such an extent that pure ecology has all but vanished from the face of the earth! Hence, in this edition, multitudinous anthropogenic effects are interwoven into every chapter." Pianka used loss of genetic variability, extinction, and evolution of microbes as examples of these effects. Evolutionary biologist Stephen R. Palumbi brought anthropogenic evolution to the center of his 2001 book, *The Evolution Explosion: How Humans Cause Rapid Evolutionary Change*. He describes humans as "the planet's most potent evolutionary force" and points to antibiotic resistance, HIV, and shrinking fish as examples of that force's effect.[21]

Second, historians may have seen evolution as less useful or important than other sciences in their work. The workhorse sciences of modern environmentalism, ecology and public health, have held pride of place in environmental history as well.[22] A search for "ecology" and its variants in the Environmental History Bibliography turned up 1,747 entries. "Health" appeared 503 times. Their preeminence is not surprising. Environmental concerns have drawn many scholars into environmental history, influenced their choice of research projects, and probably shaped their selection of intellectual tools.[23]

More precisely, historians may have seen some fields of ecology as more valuable than others. Two—evolutionary ecology and ecological genetics—have offered environmental historians bridges from ecology to evolution all along.[24] But environmental historians have tended to focus on community, ecosystem, and population ecology. Perhaps these fields (and public health) have appeared more useful in understanding problems of concern to environmentalists and environmental historians alike, such as wilderness, national parks and forests, wildlife, human disturbance, plant and animal invasions, and pollution.[25] This essay suggests that adding evolutionary ecology and genetics to the list enhances, rather than replaces, the fields already of greatest interest.

Third, historians may have opposed the use of evolutionary ideas for intellectual reasons. Sociobiologists and evolutionary psychologists have sought to attribute much of human behavior to genes and natural selection, a direct challenge to territory humanists and social scientists have thought their own. Any use of evolutionary ideas might seem to open the door to disciplinary

takeover. More broadly, the field of science and technology studies has encouraged a skepticism about truth claims by science. A related concern is political. We know that social Darwinists and eugenicists in the past have drawn on, and perhaps been inspired by, evolutionary biology. It is all to easy to read human ideas into nature, read them back out again, and justify the original ideas on the grounds that they are natural. If historians use evolutionary ideas, might they find themselves justifying biological determinism?[26]

These concerns have merit but pose no insurmountable barriers. Evolutionary biology has not subsumed any discipline with which it overlaps, even among the sciences. There is no reason to believe history is any more vulnerable than, say, ecology. Although sociobiologists and evolutionary psychologists have grabbed their share of headlines, we should not mistake them for evolutionary biologists as a whole. On the contrary, evolutionary biologists have marched among the shock troops against biological and genetic determinism. Their persuasiveness grows not out of rejecting evolution, but the opposite—mastering evolutionary theory and evidence. Paul Ehrlich, Stephen Jay Gould, Luca Cavalli-Sforza, Lynn Margulis, and Richard Lewontin have pointed out that humans carry nowhere near enough genes to encode every human trait, that applications of evolutionary biology in the past have been based on bad science, that race is a cultural rather than a biological construct, and that the environment deeply influences the expression of genetic as well as cultural traits. Imagine how much more powerful their arguments might be when joined with those from historians able to speak knowledgeably about the dimensions of human experience in which genes have or have not played important roles.[27]

Similarly, we should not let skepticism necessarily lead to rejection. Scholars in science and technology studies have made enormous contributions by historicizing ideas and demonstrating the social dimensions of what had been seen as "objective" endeavors. The outcome of this process should be to make us skeptical about all the analytical tools we use—whether from humanities, social sciences, or natural sciences—and at the same time welcoming of useful ideas, whatever their source. Finally, we must combat political misuses of any ideas, including those from evolution. My own conviction is that deeper knowledge makes citizens more, rather than less, politically effective.

Although various disciplines outside biology have created evolutionary fields, none is identical to evolutionary history. Nearly all the existing fields focus on human evolution, whether genetic or cultural, to the exclusion of non-human species. One exception is evolutionary (or Darwinian) medicine. Proponents of evolutionary medicine have argued that most physicians see the human body as a machine designed by a careless engineer. The task of the doctor is to fix broken machinery. Evolutionary physicians, on the other hand, see the body as an organism that has evolved methods to meet challenges. Faced with an infection, ordinary physicians might seek to control fever because it appears to be a problem caused by a pathogen. Evolutionary physicians agree that fever might be a problem caused by a pathogen—but, on the other hand, fever might be the body's means of killing off the pathogen by heating it to death. (Evolutionary physicians would

keep the idea of coevolution front and center. They expect that humans have evolved defenses against a certain pathogen, the pathogen may have evolved a way to circumvent the defenses, which might have led to further evolution in humans.) Keeping the fever down, then, might slow recovery. For our purposes, the important point is that human experience, in this case of disease, is the outcome of a long history of reciprocal evolution. The body has evolved defenses, and organisms have evolved ways to circumvent those defenses. (The rapid evolution of the AIDS virus is an excellent example.) An ahistorical understanding of the biology of humans and other species leads to misperceptions about causes and effects of ailments, which in turn leads to suboptimal treatments. Effective medicine demands historicizing the biology of humans and the organisms with which they coexist.[28]

Evolutionary history as described here also differs from efforts across the social sciences to develop evolutionary models of culture, behavior, and institutions. Unlike sociobiology and evolutionary psychology, these efforts do not ground their analyses in genes. Rather, they treat genetic evolution as the source of useful analogies. Evolutionary economists have studied firms as analogues of organisms, markets as analogues of natural selection, and routines (repeated ways of doing things, e.g., marketing) as analogues of genes. Anthropologists (and biologists) have treated genes and culture as parallel and interacting systems of information subject to selection. The two systems resemble each other in being heritable, shaping human behavior, and transmitting information imperfectly. They differ from each other in that genes pass information only from parents to children, while culture passes among non-relatives, skips generations, and enables individuals to inherit acquired characteristics from others.[29]

Although different from each other in several ways, and although evolutionary historians need not adopt their ideas, these fields illustrate the value of defining a research program as a field. Attaching "evolutionary" to the names of disciplines has helped scholars define their approaches, find others with similar interests (including people in other fields), and develop coherent literatures. Several of these fields have grown large enough to merit their own subject headings in the Library of Congress catalog.[30]

EVOLUTIONARY HISTORY

UNTIL NOW, "evolutionary history" has meant the object of study for evolutionary biologists. (Charles Darwin studied the evolutionary history of tortoises in the Galapagos.) Here we add a new meaning: evolutionary history is the field concerned with the role of evolution in human history. Attaching "evolutionary" to the name of our discipline should bring many of the same advantages we have just seen for other fields: self-definition, ideas for research, identification of common ground with other scholars, and development of a coherent literature. Ultimately, the field's value will lie in new or revised interpretations of history and biology.

Evolutionary history embraces a dynamic view of humans, nature, and their interaction. It sees:

- Humans, and a variety of social variables, as evolutionary forces,
- Organisms as plastic and adaptive rather than static or passive,
- Anthropogenic evolution as beneficial, harmful, or neutral for humans and other species, and
- Genes as parts of the environment and as historical actors.

This approach complements existing emphases in environmental history. Environmental historians have long argued that other historical fields overlook the importance of nature in history. Evolutionary history extends this insight by emphasizing the importance of organismal plasticity. Ecological history has focused on ways humans have changed environments; evolutionary history adds interest in the ways environmental changes have changed species. Ecological history has described ways in which humans have increased and decreased the populations of certain species; evolutionary history adds an interest in the ways humans have increased and decreased populations of genes. Public-health history has emphasized the importance of efforts to control pathogens; evolutionary history adds an interest in the ways pathogens evolve to circumvent control measures.

Evolutionary history builds on foundations laid by historians, biologists, and members of other disciplines. Several examples follow. A phrase at the beginning of each example emphasizes the link between a topic of interest to evolutionary biologists, on the one hand, and a topic of interest to historians, on the other. The examples illustrate the kinds of research questions evolutionary history can prompt, show the range of fields from which evolutionary historians may come and draw, begin to create a literature in evolutionary history, and suggest potential evolutionary revisions of common interpretations of the past.

WESTERN CIVILIZATION AS A BYPRODUCT OF ARTIFICIAL SELECTION

THE BEST KNOWN prototype of evolutionary history, physiologist Jared Diamond's *Guns, Germs, and Steel*, makes the case that adopting agriculture was the most revolutionary act in human history. As we have seen above, artificial selection—unintentional as well as intentional—was essential to that process. Other scholars, too, have found evolution a friendly framework for explaining the development of agriculture. In *Like Engend'ring Like*, Nicholas Russell challenges the idea that pre-nineteenth century breeders practiced methodical breeding. He found that "accidental, domestic-environmental selection," more than breeding for specific traits, drove increases in productivity of meat, wool, and other animal products. Domestication and controlled breeding selected for rapid growth and sexual maturation, Russell argues, simply because growers bred domestic animals as soon as they were ready.[31] If Diamond and Russell are right, accidental selection has played a surprisingly large role in Western history.

In recent centuries, science and industry have played increasingly important roles in evolution. Deborah Fitzgerald (a historian of science, technology, and the environment) has traced the rise of methodical selection in corn breeding in

the United States. In the nineteenth century, farmers improved their corn by saving the best seed to plant the next year. The arrival of government and industrial scientists shifted the locus of control from farmers to scientists. Responding to their own agendas as well as those of farmers, these scientists shifted from traditional, open-pollinated breeding methods to new, hybrid methods. Because hybrids did not "breed true," farmers now had to buy new commercial seed each year. The result was a massive change in the nature of corn. In 1933, hybrids grew on 0.4 percent of the corn acreage in the United States. By 1945, the share of land devoted to hybrids had soared to 90 percent.[32]

GENES AS AGENTS OF GEOPOLITICS

"GEOPOLITICS" usually brings to mind national leaders, armies, alliances, and strategic resources. Few would include "plant breeding" in the list. John Perkins, an environmental historian with a background in genetics, has challenged this view. Wealthy and poor nations alike, Perkins argues, saw increased food production as critical to their self-interest in the Cold War. Leaders of poor countries feared that insufficient food for growing populations could lead to loss of hard currency (to pay for imports) and create fertile ground for revolutions against the government in power. Leaders of wealthy nations feared political and economic instability, the spread of hostile ideologies, and weakening of alliances against the Soviet Union. Using wheat as his case study, Perkins shows how these fears motivated rich and poor countries to fund programs designed to boost wheat productivity rapidly through locating and transferring germplasm. Green Revolution would counter Red Revolution.[33]

If the Green Revolution enlisted genetic change as ally in geopolitical struggles, evolution also has posed a threat to national security. Through most of history, disease posed bigger threats to armies than did enemy soldiers. In the Pacific theater of World War II, malaria felled eight times more Americans than did Japan. Louse-borne typhus threatened to waylay the allied conquest of Italy. The arrival of the insecticide DDT, which was effective against malaria-carrying mosquitoes and typhus-bearing lice, seemed to be a miracle. So momentous was DDT's promise that its developer received the Nobel Prize in 1948. In the late 1940s, however, insects began showing resistance to DDT. Although this development threatened agriculture as much as public health, the United States Army led efforts to understand and counter resistance. In the 1950s, the Army organized conferences, commissioned reviews, and funded research. The result was a rapid growth in the number of publications on resistance, but researchers failed to find a way to stop this form of evolution. They could only suggest developing a stream of new chemicals, a chemical arms race that one could run but never win.[34]

GENES AS ECONOMIC AGENTS

FOR RURAL sociologist Jack Kloppenburg, the most important force driving evolution in agriculture has been capitalism. In *First the Seed*, he highlights three processes that facilitated capitalistic penetration of plant biotechnology between

1492 and 2000: political economy-commodification, institutions-division of labor, and world economy-germ plasm transfer. Kloppenburg notes that humans shaped the evolution of plants through dispersing, breeding, and eventually patenting life forms. Traditional plant breeding was "applied evolutionary science." With new biotechnology, such as genetic engineering, humans started "outdoing evolution" by moving genes across species. The result was that genes became a form a property, further facilitating commodification and accumulation of wealth.[35]

In *The Animal Estate*, cultural and environmental historian Harriet Ritvo argues that Victorians used animal breeding to resolve class anxieties. As industrialization twisted and strained the English class structure, breeders created elaborate class systems, replete with blue books and pedigrees patterned after those of the nobility, for horses and dogs. Published breed standards and show rings created islands of control and predictability in a turbulent world. At the same time, though, shows offered breeders from lower rungs on the social ladder a rare and treasured chance to compete against and defeat social "betters."[36]

INDUSTRIALIZATION AS EVOLUTION

AT FIRST BLUSH, the story of industrialization might seem to be one of the poorer candidates for revision. Industrialization is, after all, the replacement of organisms (where evolution occurs) with machinery. Farm mechanization offers a classic example of the standard argument. Productivity on American wheat farms increased in the late nineteenth and early twentieth centuries. Because yields per acre remained roughly constant while yield per worker increased, economic historians have credited this increase to new machinery. This view is consistent with the large literature showing that extending or replacing human labor with machinery increased productivity in a variety of occupations.[37]

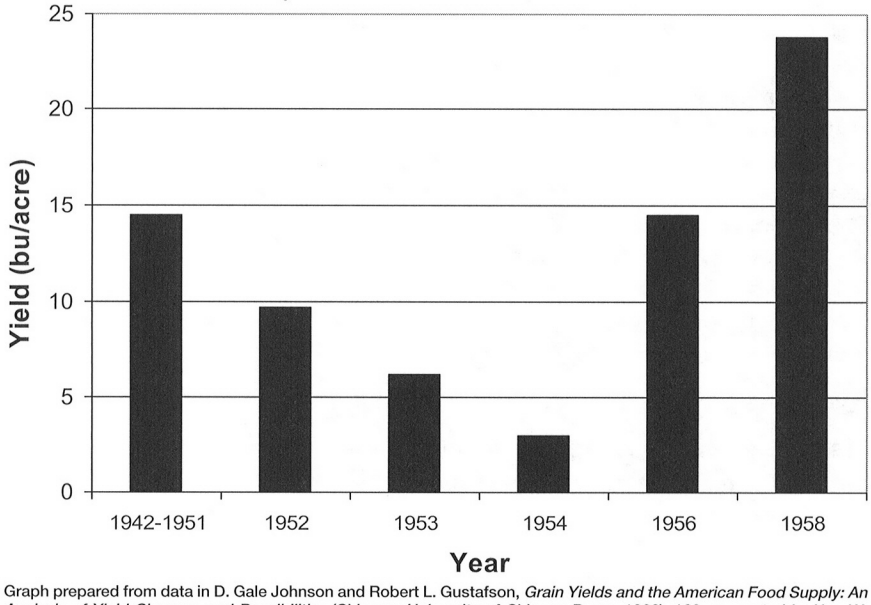
Economists Alan Olmstead and Paul Rhode have shown, however, that the received view is only about half right. The flaw lies in the assumption that organisms in wheat fields stayed constant. They did not. Farmers knew that wheat varieties "wore out" after several years, forcing them to plant new varieties to maintain yields. Wearing out resulted not from change in the wheat, but from change in the wheat's enemies. Insects, diseases, and weeds evolved to overcome a wheat variety's defenses, so breeders had to produce a stream of new varieties to keep pace.[38]

Without breeding, yields would have plummeted and productivity gains attributed to machinery would have been far smaller (see Figure 1). Evolutionary biologists call this phenomenon, in which an organism evolves just to stay in place, the Red Queen hypothesis. Olmstead and Rhode estimate that wheat breeding accounted for about 40 percent of the increase in wheat productivity in 1880 to 1940.[39]

The importance of plant breeding may seem obvious in retrospect, but a number of distinguished economic historians missed it. Contrast this oversight with the way we think about technology. Imagine we learned that a wheat farmer

Figure 1: The Red Queen Hypothesis in Action: Yields of Durum Wheat.

Between 1952 and 1954, black rust (a wheat disease) reduced yields from a nine-year average of 14.5 bushels/acre to three bushels/acre. The introduction of rust resistant varieties in 1956 returned yields to their normal level. Yields rose to a record 23.8 bushels/acre in 1958, despite weather that previously would have caused heavy losses from rust. Other diseases, insects, and weeds have had similar impacts on yields, forcing breeders and farmers to rely on constant evolutionary change in the form of new wheat varieties to maintain yields.



Graph prepared from data in D. Gale Johnson and Robert L. Gustafson, *Grain Yields and the American Food Supply: An Analysis of Yield Changes and Possibilities* (Chicago: University of Chicago Press, 1962), 120, as quoted in Alan W. Olmstead and Paul W. Rhode, "Biological Innovation in American Wheat Production: Science, Policy, and Environmental Adaptation," in Philip Scranton and Susan Schrepfer, eds., *Industrializing Organisms: Introducing Evolutionary History* (New York: Routledge, in preparation).

bought one tractor, never changed the oil or repaired broken parts, and never bought new machinery over the next fifty years. Without a second thought, we would predict a drop in productivity. We are not trained to predict the same pattern with organisms. "Continual innovation" is a phrase we usually associate with technology, but organisms are past masters at this process.

Wheat is not unique. A 2002 conference at Rutgers on "Industrializing Organisms" focused on the role of organisms in industrialization. The papers revealed that industrialization has often relied on organic evolution. Along with Olmstead and Rhode's work, examples include the breeding of hogs and chickens suited to "factories in the field," hemophiliac dogs suited to scientific laboratories, and trees adapted to industrial silviculture. Might future historians see mechanization as the first wave of industrialization, with biotechnology as the second wave that supplemented and replaced machines?[40]

RESOURCE COLLAPSE AS SIZE SELECTION

COMMON EXPLANATIONS for the collapse of live natural resources (fish, birds, and trees) are anthropogenic mortality and habitat destruction. A 1996 report from the United Nations Food and Agriculture Organization on worldwide

fisheries propounded this view. It concluded that 35 percent of the world's fisheries were declining. Another 25 percent were "mature," meaning that catches had leveled and probably would drop. The report blamed overfishing and damage to breeding grounds. Its policy recommendations, mainly limits on the numbers of boats and tonnage, grew out of this interpretation.[41]

Evolutionary history can revise this interpretation by demonstrating the effect of humans on fish genes as well as numbers. In his study of salmon in the American Pacific Northwest, environmental historian Joseph Taylor argues that fish hatcheries pushed salmon into "new evolutionary paths." Hatchery fish clumped together, carried less genetic variation, and were smaller than wild fish. These factors combined to increase mortality. Fishways in dams reinforced these trends. By causing more damage to large than small salmon, fishways selected for smaller and faster-maturing fish.[42]

Taylor's study emphasizes the impact of humans on fish in streams and rivers. We can push his analysis further by drawing on fisheries biologists to show that anthropogenic selection at sea also reduced catches. Between 1950 and 1990, the size of spawning salmon declined 30 percent. Absent humans, conditions favored big fish. Salmon hatched, went to sea, returned to their natal stream, and either laid or fertilized eggs. Big fish were better than small fish at fighting their way upstream and at competing for spawning sites. Ocean nets changed the odds. By snaring up to 80 percent of returning fish, the nets selected against large fish and for those small enough to slip through. Small fish produced fewer and smaller offspring than large fish, driving the number and size of salmon in the next generation even smaller. Smaller fish meant smaller tonnage (the usual measure of commercial fishery harvests) even if the number of fish caught remained the same.[43]

Size selection drove catches down in another way: by selecting for and against certain behaviors. Traditionally, going to sea for eighteen months was a good strategy because it made salmon bigger than if they stayed home. A few salmon (called jack) came back a year earlier than normal, and some (called parr) never went to sea at all. Traditionally, jack and parr competed poorly against big fish for spawning sites and mates. By catching ocean-going salmon, however, fishers altered the odds. Ocean nets selected for small fish that returned early or stayed home altogether and against fish that went to sea to get big (and be caught). Now jack and parr had as much chance at reproducing as the traditionalists who ventured out to sea, although they produced fewer and smaller offspring than did large fish. The number and size of ocean-going salmon declined.[44]

Our revision of the received view becomes more persuasive when we find similar patterns elsewhere. Whitefish in North American freshwater lakes once supported commercial fishing. The average size of whitefish declined between 1941 and 1965, when the fishery collapsed. In the 1940s, the average nine-year-old whitefish weighed 2 kilograms. By the 1970s, the average had declined to 1 kilogram. Observers blamed the size reduction on removal of older, bigger fish, but it also resulted from changing whitefish genetics. Young fish grew as rapidly in 1970 as they did in 1940, but adults grew more slowly. In the 1950s, nets caught

fish aged two years and up. In the 1970s, nets caught fish aged seven years and up. The 5.5-inch holes in nets had created a size threshold, beyond which fish grew at their peril.[45]

DOMESTICATION OF HUMANS

MOST OF THE literature on domestication implies that humans have sat in the driver's seat while other species rode in the back of the truck. The first word in the title of anthropologist Yi Fu-Tuan's analysis of pets, *Dominance and Affection*, reflects this view. For Perkins, who described the Green Revolution as one stage in a long evolutionary process, this unidirectional view is inadequate. "Wheat and people *coevolved* in ways that left neither much ability to prosper without the other," he argues.[46]

This bi-directional view opens the possibility that organisms domesticated humans as well as vice versa. Biologist Raymond P. Coppinger and English professor Charles Kay Smith have argued that since the last ice age, some 10,000 years ago, much of the most important evolution has taken place within the arena of human activity. Teaming up with humans was a good strategy for organisms faced with a rapidly changing environment.[47]

Popular writer Stephen Budiansky has made this argument in two books. In *Covenant of the Wild*, he suggests that domestic animals have "chosen" to become domesticates because this path offered more chances of survival than did living in the wild. The wolves that became dogs have thrived and now number in the millions in the United States. The wolves that remained wild find themselves all but exterminated in the lower forty-eight states. Budiansky expands on this theme in *The Truth about Dogs*.[48]

Another popular writer, Michael Pollan, argues a similar thesis about plants. In *The Botany of Desire*, he points out that bees probably "see" plants as doing work for them by supplying pollen and nectar, just as Pollan had seen his plants as doing work for him by producing vegetables. But the plants could just as well "see" the bee *and* Pollan doing work for them. Wild varieties of plants had to compete for resources with other species, protect themselves against herbivores, and hope for rain. Their domesticated relatives "got" Pollan to do that work for them, which enabled their genes to become much more common than the genes of wild versions.[49]

These examples illustrate the potential of evolutionary history to suggest unconventional hypotheses about the past. The arguments are not necessarily correct. If history is our guide, we would expect future research to support some ideas and falsify others. No matter what the outcome, though, finding out whether such hypotheses are correct would be useful and exciting.

CONCLUSION

HUMANS HAVE been shaping the evolution of so many other species, for so long, in so many ways, and for so many reasons that this process often has hidden in plain sight. In one morning, even before making it out the door, we might wake in

bed sheets made of cotton, dress in clothes made of wool, put on shoes made of leather, eat a breakfast made of wheat, butter, oranges, and eggs, read a newspaper made of wood pulp and soy ink, pat a dog, and admire flowers on the table. Every one of these materials and creatures bears the mark of anthropogenic selection, from cotton bred for large bolls to flowers selected for their showy display. Every one of them has a history. Every one of these histories has resulted from social and biological forces. And every one of these histories tells us about ourselves as well as other species.

The time has come for us to understand such histories in a coherent way. Scholars in a variety of disciplines and fields have built the foundation for such an inquiry, with biology and history leading the way along parallel, but too rarely intersecting, paths. Evolutionary history offers a way to link these endeavors. To biology, history offers understanding of the social forces that create selective pressures. To history, biology offers understanding of the ways organisms respond to such pressures. Together, as evolutionary history, they offer understanding of the ever-changing dance between humans and nature. The resulting synthesis just might lead us to new understanding of historical episodes as disparate as state building, capital accumulation, geopolitics, industrialization, and domestication.

The significance of such an understanding will grow as climate change and biotechnology expand the scale of anthropogenic evolution. Humans have long changed regional environments and thus the evolution of species in those environments. Climate change means these experiments have become global. Biotechnology, in its root sense of living technology, is nothing new. But genetic engineering has introduced a novel ability to move genes across very different taxonomic groups and accelerated the rate of evolutionary change. By 1999, genetically engineered plants accounted for about 55 percent of the soybeans, 60 percent of the cotton, and 36 percent of the corn grown in the United States.[50] If we are to understand how genetic engineering shapes human experience today and in the future, it behooves us to examine ways in which anthropogenic evolution has shaped us in the past.

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NOTES

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1. Theodosius Dobzhansky, *Genetics and the Origin of Species* (New York: Columbia University Press, 1937), 161.
2. San Jose scale was resistant to lime-sulphur. Black scale, red scale, and citricola scale were resistant to hydrogen cyanide. A. W. A. Brown, "The Challenge of Insecticide Resistance," *Bulletin of the Entomological Society of America* 7 (1961): 6-19. See also A. L. Melander, "Can Insects Become Resistant to Sprays?" *Journal of Economic Entomology* 7 (1914): 167-72; H. J. Quayle, "Resistance of Certain Scale Insects in Certain Localities to Hydrocyanic Acid Fumigation," *Journal of Economic Entomology* 15 (1922): 400-404; Walter S. Hough, "Colorado and Virginia Strains of Codling Moth in Relation to their Ability to Enter Sprayed and Unsprayed Apples," *Journal of Agricultural Research* 48 (1934): 533-53. Opposition to the idea of resistance continued well into the 1930s. See G. H. Cunningham, *Plant Protection by the Aid of Therapeutants* (Dunedin, New Zealand: John McIndoe Pub., 1935); and William Moore, "Studies of the 'Resistant' California Red Scale, *Aonidiella aurantii* Mask, in California," *Journal of Economic Entomology* 26 (1933): 1140-61; both cited in in H. J. Quayle, "The Development of Resistance to Hydrocyanic Acid in Certain Scale Insects," *Hilgardia* 11 (1938): 183-210.
3. Dobzhansky, *Genetics and the Origin of Species*, 161. See also Quayle, "The Development of Resistance to Hydrocyanic Acid in Certain Scale Insects," 183-84. For more on the rise of, and response to, resistance, see Edmund Russell, *War and Nature: Fighting Humans and Insects with Chemicals from World War I to Silent Spring* (New York: Cambridge University Press, 2001). A classic example of anthropogenic evolution in insects comes from the evolution of dark moths in response to industrial soot, which made light moths more visible to predators. See H. B. D. Kettlewell, "Selection Experiments on Industrial Melanism in the *Lepidoptera*," *Heredity* 9 (December 1955): 323; H. B. D. Kettlewell, "Further Selection Experiments on Industrial Melanism in the *Lepidoptera*," *Heredity* 10 (Dec. 1956): 287-300; R. R. Askew, L. M. Cook, and J. A. Bishop, "Atmospheric Pollution and Melanic Moths in Manchester and Its Environs," *Journal of Applied Ecology* 8 (1971): 247-56; Stephen Mosley, *Chimney of the World: A History of Smoke Pollution in Victorian and Edwardian Manchester* (Cambridge, England: White Horse Press, 2001), 45. The species Kettlewell focused on was the peppered moth, *Biston betularia* Linn. Recently, Kettlewell's methods have come in for criticism. See Judith Hooper, *Of Moths and Men: An Evolutionary Tale* (New York: Norton, 2002).
4. All of these views have emerged in discussions with scholars from a variety of disciplines.
5. Charles Darwin, *The Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life*, 6th ed. (London: Odhams Press, 1872), 64; Charles Darwin, *Variation of Animals and Plants under Domestication*, vols. I and II (1868, rev. 1883; reprint, Baltimore, Md.: Johns Hopkins University Press, 1998), I: 2, fn. 1. Darwin wrote in his autobiography that his idea of natural selection derived from his studies of domestication (just as his idea of the struggle for existence came from Malthus). See Nora Barlow, ed., *The Autobiography of Charles Darwin, 1809-1882* (1958; reprint, New York: Norton, 1969), 119-120. Historians have debated the accuracy of Darwin's memory. Some say that Darwin worked out natural selection and then applied it to domestication; others believe Darwin's memory was roughly correct. Michael Ruse, "Charles Darwin and Artificial Selection," *Journal of the History of Ideas* 36 (April-June 1975): 339-50; John F. Cornell, "Analogy and Technology in Darwin's

Vision of Nature," *Journal of the History of Biology* 17 (Fall 1984): 303-44; L. T. Evans, "Darwin's Use of the Analogy between Artificial and Natural Selection," *Journal of the History of Biology* 17 (Spring 1984): 113-40. Our concern here is with Darwin's linking of natural and artificial selection, which he indubitably did, rather than with the chronological priority of ideas.

On the history of Darwin's ideas more broadly and their impact, see Peter J. Bowler, *Darwinism* (New York: Twayne Publishers, 1993), and *Charles Darwin: The Man and His Influence* (Cambridge, Mass.: Blackwell, 1990); Michael Ruse, *The Darwinian Revolution: Science Red in Tooth and Claw*, 2nd ed. (Chicago: University of Chicago Press, 1999); E. Janet Browne, *Charles Darwin: A Biography* (Princeton, N.J.: Princeton University Press, 1996); Adrian Desmond and James Moore, *Darwin* (New York: Warner Books, 1992); David L. Hull, *Darwin and His Critics: The Reception of Darwin's Theory of Evolution by the Scientific Community* (1973; reprint, Chicago: University of Chicago Press, 1983); Gertrude Himmelfarb, *Darwin and the Darwinian Revolution* (Garden City, N.Y:, Doubleday, 1962); Robert M. (Bob) Young, *Darwin's Metaphor: Nature's Place in Victorian Culture* (New York: Cambridge University Press, 1985); Ernst Mayr, *One Long Argument: Charles Darwin and the Genesis of Modern Evolutionary Thought* (Cambridge, Mass.: Harvard University Press, 1991), and *The Growth of Biological Thought: Diversity, Evolution, and Inheritance* (Cambridge, Mass.: Belknap Press, 1982); Daniel C. Dennett, *Darwin's Dangerous Idea: Evolution and the Meaning of Life* (London: Penguin, 1995); Michael Ruse, *The Evolution Wars: A Guide to the Debates* (Santa Barbara, Calif: ABC-CLIO, 2000).

6. The literature on Darwinian evolution is too enormous to review here. For an introduction, see Douglas Futuyma, *Evolutionary Biology*, 3rd ed. (Sunderland, Mass.: Sinauer, 1998); G. C. Williams, *Natural Selection: Domains, Levels and Challenges* (New York: Oxford University Press, 1992); Ernst Mayr and William B. Provine, eds., *The Evolutionary Synthesis: Perspectives on the Unification of Biology* (Cambridge, Mass: Harvard University Press, 1980); and Steve Jones, *Darwin's Ghost: The Origin of Species Updated* (New York: Random House, 2000).
7. Darwin, *Domestication*, 1:6. On breeding in Darwin's era, see John Sebright, *The Art of Improving the Breeds of Domestic Animals* (London: John Harding, 1809); William Youatt, *Cattle, their Breeds, Management and Diseases* (London: Robert Baldwin, 1834); Roger J. Wood and Vitezslav Orel, *Genetic Prehistory in Selective Breeding: A Prelude to Mendel* (Oxford: Oxford University Press, 2001).
8. Futuyma, *Evolutionary Biology*. Darwin (*Origin*, 55) divided artificial selection into "methodical" and "unconscious" selection, but "intentional" and "unintentional" work better. Darwin's unconscious selectors in fact were methodical and conscious: they selected the best animals to breed with each other, making Darwin's terms misleading. (Darwin used "unconscious," I believe, because he wanted to argue that an unconscious nature could select the best individuals to mate.) His terms also do not accurately describe selection outside agriculture. When humans created insects resistant to insecticides, they did not act methodically in Darwin's sense of breeding toward some desired goal; they were selecting for traits opposite of what they wanted. Nor were they unconscious in Darwin's sense of selecting the best individuals to mate (or even in the more common sense of being unaware). They were not selecting individuals to mate, and they were conscious of results.
9. Darwin, *Origin*, 53-56.
10. James Bennet, "Cluck! Cluck! Chickens in Their Birthday Suits!" *New York Times*, 24 May 2002.
11. Darwin, *Origin*, 134, emphasis added.
12. Jared Diamond, *Guns, Germs, and Steel: The Fates of Human Societies* (New York: W. W. Norton, 1998).

13. Edward Hyams, *Animals in the Service of Man: 10,000 Years of Domestication* (London: J.M. Dent and Sons, 1972); H. Epstein, *The Origin of the Domestic Animals of Africa*, vols. 1-2 (New York: Africana Publishing, 1971); Frederick E. Zeuner, *A History of Domesticated Animals* (London: Hutchinson, 1963); S. Bokonyi, *History of Domestic Mammals in Central and Eastern Europe* (Budapest: Akademiai Kiado, 1974); Juliet Clutton-Brock, *A Natural History of Domesticated Animals* (Austin: University of Texas Press, 1989).
14. Jack R. Harlan, *Crops and Man* (Madison, Wis.: American Society of Agronomy, 1975), 69-70; B. Brouk, *Plants Consumed by Man* (London: Academic Press, 1975); Maarten J. Chrispeels and Davad Sadava, *Plants, Food, and People* (San Francisco: W.H. Freeman, 1977).
15. Stephen R. Palumbi, *The Evolution Explosion: How Humans Cause Rapid Evolutionary Change* (New York: W.W. Norton, 2001), 139-40; National Research Council, *Pesticide Resistance: Strategies and Tactics for Management* (Washington, D.C.: National Academy Press, 1986), 16-17. See also J. Mallet, "The Evolution of Insecticide Resistance: Have the Insects Won?" *Trends in Ecology and Evolution* 4 (no. 11, 1989): 336-40.
16. David Brown, "TB Resistance Stands at 11% of Cases," *Washington Post*, 24 March 2000, A14; S. B. Levy, *The Antibiotic Paradox: How Miracle Drugs Are Destroying the Miracle* (New York: Plenum, 1992); Palumbi, *Evolution Explosion*, 85.
17. "'Wonder Drugs' Losing Healing Aura," *Washington Post*, 26 June 1995. As the century closed, the World Health Organization launched a new effort called Roll Back Malaria, whose title suggested the more modest goals that seemed realistic in light of previous disappointments. R. S. Phillips, "Current Status of Malaria and Potential for Control," *Clinical Microbiology Reviews* 14 (January 2001): 208-26; J. F. Trape, "The Public Health Impact of Chloroquine Resistance in Africa," *American Journal of Tropical Medicine and Hygiene* 64 (Jan.-Feb. Suppl. 2001): 12-17; J. A. Najera, "Malaria Control: Achievements, Problems and Strategies," *Parassitologia* 43 (June 2001): 1-89; Palumbi, *Evolution Explosion*, 137-38.
18. William E. Bradshaw and Christina M. Holzapfel, "Genetic Shift in Photoperiodic Response Correlated with Global Warming," *Proceedings of the National Academy of Sciences of the United States of America* 98 (4 December 2001): 14509-11; Sean C. Thomas and Joel G. Kingsolver, "Natural Selection: Responses to Current (Anthropogenic) Environmental Changes," in *Encyclopedia of Life Sciences* (London: Macmillan, 2002), 659-64.
19. Cheryl Oakes, librarian and archivist at the Forest History Society in Durham, North Carolina, searched the database (titles and abstracts) on 9 September 2002. Although electronic searches are imperfect, the overall pattern is so strong that adding missed citations probably would have made little difference. Even omissions are telling, for they reveal that neither author nor abstracter thought evolution important enough to mention in a title, subtitle, or abstract. The database contains other works on the history of evolutionary ideas, and works that use "evolution" to mean change in general, but this search focused instead on material (genetic) evolution in action. Authors of the eight works include a popular writer, two evolutionary biologists, a paleoanthropologist, and the iconoclast Paul Shepard (twice): Stephen Budiansky, *The Covenant of the Wild: Why Animals Chose Domestication* (New Haven, Conn.: Yale University Press, 1999); Niles Eldredge, *Life in the Balance: Humanity and the Biodiversity Crisis* (Princeton, N.J.: Princeton University Press, 1998); Dan Flores, "Nature's Children: Environmental History as Human Natural History," in John P. Herron and Andrew G. Kirk, eds., *Human/Nature: Biology, Culture, and Environmental History* (Albuquerque: University of New Mexico Press, 1999), 11-30; Stephen R. Kellert, *Kinship to Mastery: Biophilia in Human Evolution and Development* (Washington,

D.C.: Island Press, 1997); Lynn Margulis, Clifford Matthews, and Aaron Haselton, eds., *Environmental Evolution: Effects of the Origin and Evolution of Life on Planet Earth*, 2nd ed. (Cambridge, Mass.: MIT Press, 2000); Rick Potts, *Humanity's Descent: The Consequences of Ecological Instability* (New York: Avon Books, 1997); Paul Shepard, *Coming Home to the Pleistocene* (Washington, D.C.: Island Press, 1998) and *The Others: How Animals Made Us Human* (Washington, D.C.: Island Press, 1996).

The one citation in the research register was to Laura Rival's work on the coevolution of human groups and rainforests, but she may be using "coevolution" in a general rather than specifically genetic way. Documenting Environmental Change, Centre for History and Economics, King's College, Cambridge University (*http://www.kings.cam.ac.uk/histecon/envdoc/index.html)*, viewed 10 September 2002.

20. Eric R. Pianka, *Evolutionary Ecology*, 6th ed. (San Francisco: Addison Wesley Longman, 2000), xiv. Douglas Futuyma's popular, 800+ page introductory textbook on evolutionary biology says little about domestication and omits Darwin's *Variation of Animals and Plants under Domestication* from its 41-page bibliography. The single indexed reference to breeding focuses on inbreeding and outbreeding in the wild. Domestication merits two brief mentions in the index to Ernst Mayr's 974-page opus on the growth of biological thought; "breeding" does not appear in the index. See, *The Growth of Biological Thought: Diversity, Evolution, and Inheritance* (Cambridge, Mass: Belknap Press of Harvard University Press, 1982). This pattern is not new. In *Origin* (31), Darwin chided his colleagues for not paying enough attention to domestic species.

    Books by agricultural scientists often make a nod to evolution and then drop the topic. Evolution does not appear in the index of F. G. H. Lupton, ed., *Wheat Breeding: Its Scientific Basis* (London: Chapman and Hall, 1987). Evolution appears once, in the context of an "evolutionary breeding method" that relies on the idea that natural selection weeds out weaker individuals, in Oliver Mayo, *The Theory of Plant Breeding*, 2nd ed. (Oxford: Clarendon Press, 1987), 175. Evolution appears on the first page and not thereafter in R. F. E. Axford, S. C. Bishop, F. W. Nicholas, and J. B. Owen, *Breeding for Disease Resistance in Farm Animals*, 2nd ed. (New York: CABI Publishing, 2000), ix. Evolution appears in the introduction and not thereafter in Everett James Warwick and James Edwards Legates, *Breeding and Improvement of Farm Animals*, 7th ed. (New Delhi: TATA McGraw-Hill, 1979), 5-7. Evolution appears three times, in each case implying that evolution ended with domestication, in Temple Grandin, ed., *Genetics and the Behavior of Domestic Animals* (London: Academic Press, 1998), 21, 146, 204. In contrast, Lewis Stevens divided the evolution of domestic fowl into three stages: evolution of the genus *Gallus*, emergence of domestic fowl from ancestors in *Gallus*, and development of current varieties and breeds. See, *Genetics and Evolution of the Domestic Fowl* (New York: Cambridge University Press, 1991).

21. Pianka, *Evolutionary Ecology*, xiv, 10; Palumbi, *Evolution Explosion*, 10.

22. The titles of early works in environmental history illustrate the pervasive influence of ecology: William Cronon, *Changes in the Land: Indians, Colonists, and the* ***Ecology*** *of New England* (New York: Hill and Wang, 1983); Donald Worster, *Nature's Economy: A History of* ***Ecological*** *Ideas* (New York: Cambridge University Press, 1977); Carolyn Merchant, *The Death of Nature: Women,* ***Ecology****, and the Scientific Revolution* (San Francisco: Harper & Row, 1980), and ***Ecological*** *Revolutions: Nature, Gender, and Science in New England* (Chapel Hill: University of North Carolina Press, 1989); Alfred Crosby, ***Ecological*** *Imperialism: The Biological Expansion of Europe, 900-1900* (New York: Cambridge University Press, 1986); J. Donald Hughes, ***Ecology*** *in Ancient Civilizations* (Albuquerque: University of New Mexico Press, 1975); Lester J. Bilsky, ed., *Historical* ***Ecology****: Essays on Environment and Social Change* (Port Washington, N.Y.: Kennikat Press, 1980); Arthur F. McEvoy, *The Fisherman's Problem:* ***Ecology*** *and Law in the California Fisheries, 1850-1980* (New York: Cambridge University Press,

1986). In her popular textbook, Carolyn Merchant notes that "ecological history" and "environmental history" often have been used interchangeably; she subsumes the latter under the former. See, *Major Problems in Environmental History* (Lexington, Mass.: D.C. Heath, 1993), 1.

Public health histories that contributed to the founding of environmental history do not cluster around a single term, but "pollution" often appears. See, for example, Martin Melosi, ed., *Pollution and Reform in American Cities, 1870-1930* (Austin: University of Texas Press, 1980). Joel Tarr's pioneering work first appeared largely in journals and is collected in *The Search for the Ultimate Sink: Urban Pollution in Historical Perspective* (Akron, Ohio: University of Akron Press, 1996).

23. Keyword search for "ecolog" (ecology and its variants) and "health" in titles and non-indexed fields (including abstract) conducted 29 November 2002. Donald Worster urged environmental history to stay close to environmentalism in his comments at the plenary session, American Society for Environmental History meeting, Durham, N.C., 28 March 2001.
24. E. B. Ford, *Ecological Genetics* (London: Methuen, 1964), and Eric R. Pianka, *Evolutionary Ecology* (New York: Harper & Row, 1974). Both appeared in multiple editions.
25. Ecological ideas useful in analyzing these issues include connectivity among species (often via the ecosystem concept), stability through species diversity, limits to growth (carrying capacity), habitat change, population dynamics, and extinction. Environmental historians often have drawn on the ecologists who emphasized these issues, such as Howard Odum, *Environment, Power, and Society* (New York: Wiley-Interscience, 1971) and *Systems Ecology: An Introduction* (New York: Wiley, 1983); Eugene P. Odum and Howard Odum, *Fundamentals of Ecology*, 2nd ed. (Philadelphia: Saunders, 1959); Robert H. MacArthur, *Geographical Ecology: Patterns in the Distribution of Species* (New York: Harper & Row, 1972); Robert H. MacArthur and Joseph H. Connell, *The Biology of Populations* (New York: Wiley, 1966); Charles S. Elton, *The Ecology of Invasions by Animals and Plants* (London: Methuen, 1958); Robert E. Ricklefs, *Ecology* (London: Nelson, 1973), and *The Economy of Nature: A Textbook in Basic Ecology*, 4th ed. (New York: W.H. Freeman, 1996); Paul R. Ehrlich, Anne H. Ehrlich, and John P. Holdren, *Ecoscience: Population, Resources, Environment* (San Francisco: W. H. Freeman, 1977) and *Human Ecology: Problems and Solutions* (San Francisco: W.H. Freeman, 1973).
26. On sociobiology, see Edward O. Wilson, *Sociobiology: The New Synthesis* (Cambridge, Mass.: Belknap Press of Harvard University, 1975), and *Consilience: The Unity of Knowledge* (London: Little, Brown, and Company, 1998); David P. Barash, *Sociobiology and Behavior*, 2nd ed. (New York: Elsevier, 1982); Richard Dawkins, *The Selfish Gene* (New York: Oxford University Press, 1976); Peter Koslowski, ed., *Sociobiology and Bioeconomics: The Theory of Evolution in Biological and Economic Theory* (New York: Springer Verlag, 1999); Michael S. Gregory, Anita Silvers, and Diane Sutch, eds., *Sociobiology and Human Nature: An Interdisciplinary Critique and Defense* (San Francisco: Jossey-Bass, 1978); Georg Breur, *Sociobiology and the Human Dimension* (New York: Cambridge University Press, 1982); Alexander Rosenberg, *Sociobiology and the Preemption of Social Science* (Baltimore, Md.: Johns Hopkins University Press, 1980); Robert W. Bell and Nancy J. Bell, *Sociobiology and the Social Sciences* (Lubbock: Texas Tech University Press, 1989); Arthur L. Caplan, ed., *The Sociobiology Debate: Readings on Ethical and Scientific Issues* (New York: Harper & Row, 1978); Ashley Montagu, ed., *Sociobology Examined* (New York: Oxford University Press, 1980); Michael Ruse, *Sociobiology: Sense or Nonsense?* (Boston: D. Reidel Publishing Company, 1984); Matt Ridley, *The Red Queen: Sex and the Evolution of Human Nature* (New York: Viking, 1993).

Some philosophers have treated evolution as a source of new questions or approaches within their fields. Evolutionary ethicists, for example, have treated Charles Darwin's *Origin of Species* (1859) and Edward O. Wilson's *Sociobiology* (1975) as challenging them to see whether one can develop an ethics based on genetic evolution. See Paul Thompson, ed., *Issues in Evolutionary Ethics* (Albany: State University of New York Press, 1995), back cover; Emmanuel K. Twesigye, *Religion and Ethics for a New Age: Evolutionist Approach* (Lanham, Md.: University Press of America, 2001). For supporters of evolution in philosophy, see Michael Ruse, *The Darwinian Paradigm: Essays on Its History, Philosophy, and Religious Implications* (New York: Routledge, 1993); Daniel C. Dennett, *Freedom Evolves* (New York: Viking, 2003) and *Darwin's Dangerous Idea: Evolution and the Meanings of Life* (New York: Simon and Schuster, 1995).

On evolutionary psychology, see Henry Plotkin, *Evolution in Mind: An Introduction to Evolutionary Psychology* (London: Penguin, 1997); Susan Blackmore, *The Meme Machine* (New York: Oxford University Press, 1999); Charles Crawford and Dennis L. Krebs, eds., *Handbook of Evolutionary Psychology: Ideas, Issues, and Applications* (Mahwah, N.J.: Lawrence Erlbaum Associates, 1998); Louise Barrett, Robin Dunbar, and John Lycett, *Human Evolutionary Psychology* (Princeton, N.J.: Princeton University Press, 2002); Steven Pinker, *The Blank Slate: The Modern Denial of Human Nature* (New York: Viking, 2002), and *How the Mind Works* (New York: Norton, 1997); David F. Bjorklund and Anthony D. Pellegrini, *The Origins of Human Nature: Evolutionary Developmental Psychology* (Washington, D.C.: American Psychological Association, 2002); Alan Clamp, *Evolutionary Psychology* (London: Hodder & Stoughton, 2001); David M. Buss, *Evolutionary Psychology: The New Science of the Mind* (Boston: Allyn and Bacon, 1999); Robert Wright, *The Moral Animal: Evolutionary Psychology and Everyday Life* (New York: Pantheon Books, 1994); Jerome H. Barkow, Leda Cosmides, and John Tooby, eds., *The Adapted Mind: Evolutionary Psychology and the Generation of Culture* (New York: Oxford University Press, 1992). For the case against evolutionary psychology, see Hilary Rose and Steven Rose, eds., *Alas, Poor Darwin: Arguments against Evolutionary Psychology* (London: Jonathan Cape, 2000).

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