

# Scientists *and their* Responsibility

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## Natural and Unnatural History: Biological Diversity and Genetic Engineering

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For more than 3,000 million years before the advent of human culture, the evolution of life on earth was shaped by a complex interplay between opposing forces: between molecular fidelity and genetic mutation; between genetic adaptation to local and immediate circumstances and the adaptive inertia of large populations constrained by development and phylogenetic history; between the origination of new species—of novel patterns of survival—and the extinction of established ones; and between the payoff of individual reproduction and the uncertainty of individual survival in the face of competition, predation, disease, and inimical physical environments. Human culture profoundly altered the scales of time and space within this causal network, through the intentional propagation of desirable genotypes of plants and animals (artificial selection), the indiscriminate shuffling of species of diverse geographical origin, the alteration of landscapes on a geological scale, and, now, the modification of the atmosphere on a global scale.

In Western culture, the traditional mythic view of nature as antagonist cast us always as either victims or heroes. This view still provides the stuff of romance for novels and filmscripts and draws readers to front page stories of the casualties and survivors of natural disasters and the first ascent of Nepalese peaks. But in reality, the current prevailing myth of industrial society is that we have achieved dominion over nature. We have stopped the flow of great rivers, changed the course of molten lava flows, and irrigated deserts. We have learned how to fly and to travel deep beneath the sea. We have found out how to control or even eliminate diseases. Meanwhile, however, we have begun to acknowledge the unintended consequences of human actions—the accumulation of toxic wastes, alteration of the atmosphere, permanent destruction of rain forest soils, extinction of entire faunas and floras. Perhaps in the long term, we may find ourselves the victims, not of nature as we found it, but of nature as we have remade it. In reality the scope of human intervention has placed us in a new role.

In this paper I will argue that the power of science and human technology has now completed the transformation of our relationship with nature not from antagonism to dominion, but rather from antagonism into the realm of ethical responsibility. I will explore some of the ethical issues raised by two contemporary confrontations between biological evolution and human technology. The first of these confrontations, between the homogenizing force of technology and the diversifying process of evolution, has produced an alarming acceleration in the loss of biological diversity.

The second, between the relatively slow, organismal processes of Darwinian selection and the powerful potential of genetic engineering to effect rapid genetic alteration by molecular techniques, presents not only immense opportunities but, perhaps, profound pitfalls as well. Finally, I will attempt to explore the scientific, technological, and ethical interactions between the issues of biological diversity and genetic engineering.

### Biological Diversity

Biological diversity is hierarchical. Within a species or a local population, genetic diversity may be measured by the number and frequency of genetically different individuals (genotypes), or by the number and frequency of alternative variants (alleles) for a given gene or set of genes. Between populations of the same species, diversity is usually measured as "genetic distance," based on the degree of correspondence between allelic frequencies (Nei 1972; Lewontin 1972). At the level of species, diversity depends on the number and frequency of species within some specified universe, such as a local assemblage, a habitat type, a political unit, a trophic level (carnivores, herbivores, green plants, or decomposers), or a taxonomic unit (a genus, family, or higher taxon).

An extensive literature exists on appropriate means for combining in a single index the number of categories (genotypes, alleles, or species), often called "richness," with a measure of the evenness of their representation (May 1981). Explicitly hierarchical measures of diversity have also been developed (Pielou 1975; Patil and Taillie 1977). Because "diversity" has no precise objective meaning, however, the choice of how to "measure" it has become partly a matter of tradition, partly a function of mathematical or statistical elegance, and partly a matter of taste.

We still do not know how many living species there are (or were,

say, 50 or 100 years ago) in most groups of microbes, plants, and animals—well-reasoned estimates for the total range from five to 30 million, of which only about 1.4 million are even described and named (Wilson 1988b). We know even less about genetic variation within species. These challenges, daunting though they are, are at least straightforward conceptually. In addition, however, evolutionary ecologists continue to struggle with questions that appear to have no conceptually easy answers (although many have been suggested) (Colwell 1979; Futuyma 1986; Wilson 1988a): Why did so many different species evolve? Why aren't there more? Why are tropical biotas more diverse than temperate ones? Why does so much genetic diversity exist within species? What controls the level of this genetic variability?

### The Structure of Biological Diversity

From the biologist's point of view, the living world is a complex patchwork, a kind of fractal landscape of entities within entities within yet other entities, some distinct and discrete, others vague but no less real. Consider a flagellate protozoan that digests cellulose, living in the gut of a termite in a Central American rain forest. Looking inward from its external structure, we see organelles and membranes, then enzymes, proteins, nucleic acids, and molecular pathways, all organized, all repeated in the next and previous generations.

Looking outward from the body wall of that single protozoan, we find a whole fauna and flora of other coevolved microbial symbionts in the termite's gut. The digestive system of that single termite defines a subpopulation of each symbiont species living within it. The termite, in turn, is a tiny part of a colony, a cog in the machinery of a complicated social machine that turns cellulose into more termites, carbon dioxide, and excrement. Individual colonies of this species of termite in the forest interact in mating flights to define the breeding population. The termites are the principal food of tamanduas (New World anteaters) and are food for a host of other mammals, birds, and other insects. Each of these species has its own population structure, and each differs from the rest. At the level of the forest ecosystem, the carbon cycle would slow to a halt without termites.

In rain forests a few dozen or a few hundred miles away, many of the species composing the termite fauna and the species list for other insects, mammals, birds, and forest trees will differ, yet the story will be much the same. In rain forests of Africa and Asia the pattern is repeated, with intriguing distinctions in each place, arising from diffe-

rent histories, somewhat different selection pressures, and simply from historical accidents.

### *Speciation, Extinction, and Biological Diversity*

Genetic variation is the raw material of evolution within species. Some of the new genetic variants (alleles) that arise continually through mutation are eliminated, and some are "fixed" by selection; some are maintained at an intermediate frequency by geographically and temporally varying selection, and some persist simply because there is strong selection neither for nor against them (Futuyma 1986).

The event of speciation, which we now usually envision as the splitting off of a new population from a parent population through reproductive isolation, permits the preservation of gene combinations adaptive to new circumstances and prevents them from being diluted or swamped by genes that were more appropriate in the ancestral context. Genetically, the incipient species is now free to go its own way under the guidance of natural selection. Although some new species apparently diverge rapidly from the ancestral stock, while others change little over long periods of time, speciation must be viewed as the principal mechanism fostering biological diversity. Because each successive episode of speciation in a lineage produces a new branch that itself may speciate, the process has the potential for producing an exponential increase in genetic diversity over time (Templeton 1981). Here, I speak of the origin of new species by the process biologists call *cladogenesis*—the branching of a lineage. This process is entirely distinct from *anagenesis*—a continuous succession of forms replacing one another without branching, *within* a single line—which many people envision when they hear the word "evolution." Figure 1, see pages 6-7, makes the distinction (along with other points to be discussed later).

The brake on this process, of course, is extinction—a perfectly natural phenomenon that has already removed more species from the face of the earth than the number that now exists, quite apart from any human influence. Superimposed on a long, slow increase, the total number of species has fluctuated over geological time scales—sometimes dramatically, when rare episodes of mass extinction interrupted long-term patterns (Raup and Sepkoski 1982; Raup 1988).

These patterns of *net change* in number of species, however, must be clearly distinguished from species *turnover*—the rate at which existing species are replaced by new ones through the combined effects of speciation (cladogenesis) and extinction. In geological history, turn-

over has nearly always been far greater than the rate of *net* change in species diversity—with the possible exception of periods of mass extinction. In other words, speciation and extinction rates have been roughly balanced over vast stretches of time (Stanley 1985).

The current alarm over real and potential extinctions caused by human activities must be seen in this context. From an historical point of view, the problem is not that extinctions are occurring, but that the expected *rates* of extinction, for most groups of organisms, are so high that the net change in species diversity, over an exceedingly short period of time, has vastly overwhelmed normal turnover rates (Myers 1979; Ehrlich and Ehrlich 1981; Wilson 1988a).

### *Economic Value of Species*

Why does extinction matter? Human beings, after all, are just as much the product of organic evolution as any other species. If our success means the demise of an extra few million species over the next hundred years, and if extinction—even mass extinction—is a natural phenomenon, then why be concerned? One way of collecting the answers to these questions is to pose another: In what sense do species have value? The many answers that have been given to this question by biologists, philosophers, and economists (e.g., Ehrenfeld 1976; Myers 1979; Caufield 1984; Callicott 1986; Norton 1986, 1987; D. H. Regan 1986; Sober 1986; Randall 1986; Wilson 1988a) may be divided into arguments based on the *instrumental value* of species and their diversity—which I have chosen to subdivide into arguments of *economic value* and of *scientific value*—or on the *intrinsic value* of species. This section treats arguments for the preservation of species based on economic arguments.

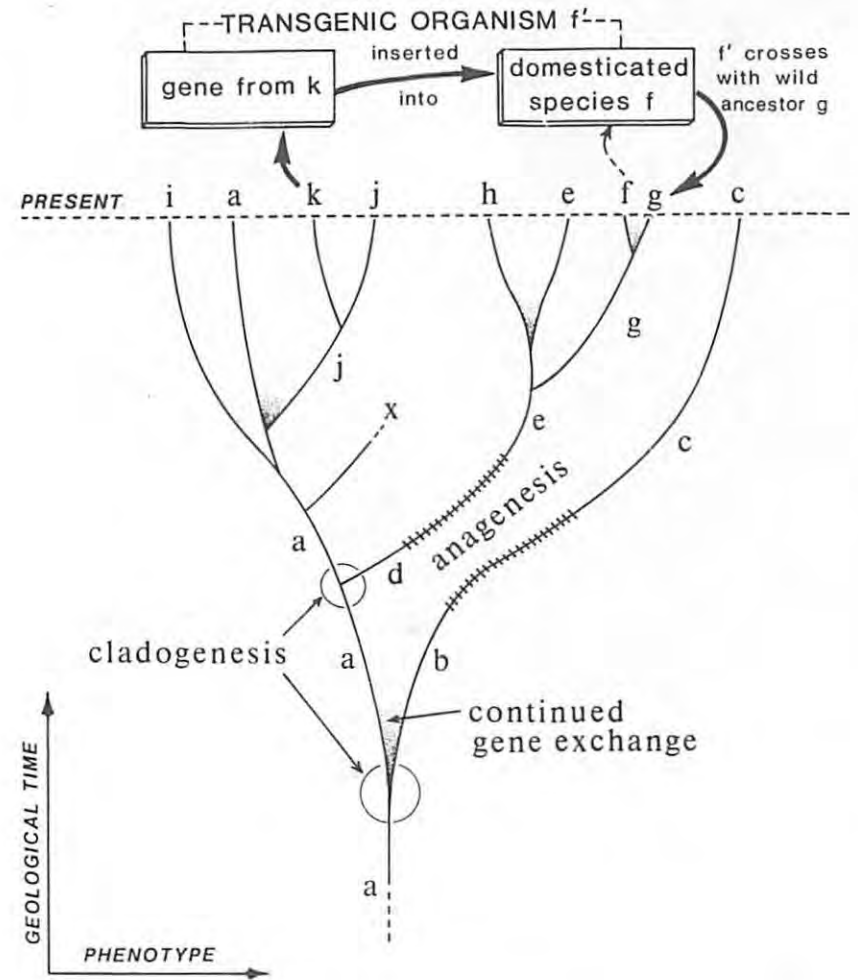
Civilization was founded on the adaptive "inventions" of other species. The domestication of food plants simply improved on the existing storage tissues of plants—seed endosperm, roots, tubers. With fiber plants, we simply improved and extracted the support tissues (linen, sisal, hemp, jute) or fibers involved in seed dispersal (cotton, kapok). The effective principles of drug plants, spices, herbs, and natural dyes rely heavily on compounds evolved by plants in protective response to the depredations of insects, mites, and diseases (Simpson and Connor-Ogorzaly 1986). The use of domesticated animals for work or transport simply exploits their existing capacity for locomotion; use of their pelts, hair, or feathers for clothing mimics the role these tissues serve for their original owners; human use of animal milk

exploits one of the fundamental evolutionary inventions of the mammals, and our use of honey an analogous invention of bees. "Domesticated" microorganisms make possible alcoholic beverages, leavened bread, cheese, yoghurt, and soy sauce, as well as industrial fermentation processes and many drugs.

In the past century, scientific breeders of plants and animals have reached back into the evolutionary history of domesticated species to recapture useful genetic traits from their wild relatives—sometimes from the true ancestral species, sometimes from evolutionary cousins. Resistance to disease, pests, or stress, nutrient balance, growth form, and fruit shape or quality have been developed in crops through hybridization with wild relatives, followed by complex breeding programs to combine desired traits in a single strain (Goodman, et al.)

Figure 1

A hypothetical phylogenetic tree illustrating modes of evolutionary change and the "conduit effect." *Modes of change:* Species are labeled with lower-case letters. Species *a* is the ancestor of all the others. Because *a* persists to the present unchanged, it would be an example of a "living fossil." Its most ancient descendant, species *b*, on the other hand, changes sufficiently over time through anagenetic evolution that it is eventually recognized as a "new" species *c* (although biologically *b* and *c* are one and the same species). With the further exception of the anagenetic origin of *e* from *d*, all other species in the figure arise by cladogenesis, or branching. In some cases (e.g., the origin of *d* from *a* or *f* from *e*), speciation is abrupt, with little or no gene flow between the new species and its ancestor. In many other cases (shown by stippling), gene flow continues for a long time before finally slowing to zero. Extinct species *x* stands for the multitude of species no longer extant. In a real tree covering a long span of geological time, there would be about as many extinct species as extant ones. *The conduit effect:* species *f* is a domesticated relative of wild ancestor *g*. Like many real domesticates, *f* can still cross with its wild ancestor. Transgenic organism *f'* is created by inserting into *f* a useful gene from species *k*, a member of the group of species (*i*, *a*, *k*, and *j*) long isolated genetically from the group to which *f* and *g* belong (*h*, *e*, *f*, and *g*). If the transgenic species *f'* is now inadvertently permitted to cross with wild ancestor *g*, the gene from *k* will have followed the biotechnological "conduit," shown by the heavy arrows, between lineages long isolated in nature.





1987; Iltes 1988). Improved breeds of domesticated animals have sometimes been developed in the same way. But crosses between species more distantly related than members of closely related genera were impossible for higher organisms until this decade, when the molecular and cellular techniques of biotechnology became feasible.

The economic argument for the preservation of wild relatives of key domesticated species has always been clear enough: they represent a potential source of commercially useful genetic material—"germ-plasm" (Witt 1985; Williams 1988). But what about the multitude of wild species—the vast majority of both the plant and animal kingdoms—that have no domesticated or commercially valuable relatives?

At least two general classes of economic arguments have been advanced for the preservation of these "unexploited" species. First, some of these species, in themselves, may prove to be of direct *commodity value* in the human enterprise (Norton 1988), or alternatively may be valued for their potential commercial usefulness at some future time (an aspect of *option value*) (Randall 1988). The second class of economic valuations rests on attempts to estimate the *noncommodity* (or *nonmarket* or *amenity*) value of species, or of biodiversity, as measured by the degree to which people consider the economic value of places, services, or experiences to be increased by the presence or existence of species or by biodiversity (Kellert 1986; Norton 1987, 1988; Randall 1988).

Few would base the argument for the commodity value of currently unexploited species on the prospect that important, totally new food plants are likely to be discovered among wild species—although many known food plant species with excellent nutritional value and promising ecological characteristics are underutilized (NAS 1975; Vietmeyer 1986). Prospects for the discovery of novel biochemical compounds, however, have motivated several well-funded, intensive commercial surveys of pharmacologically or biologically active natural plant products for possible use as drugs, biocides, and industrial biochemicals. Some of these efforts focus on plants used in folk medicine in traditional cultures, whereas others are simply "shotgun" surveys of plant material collected more or less at random, especially in tropical forests (Lewis and Elvin-Lewis 1977; Myers 1983; Farnsworth 1988). There are indications, however, that the advent of computer-designed molecules and the techniques of genetic engineering have already begun to displace these efforts in the pharmaceutical industry (Ehrenfeld 1988).

The latest economic argument for the preservation of as-yet-

unexploited species on the basis of their potential commodity value arises from the growing capability to transfer genetic traits among completely unrelated species—both microorganisms and higher organisms—by molecular and cellular techniques in the laboratory. The first genetically engineered plant to be approved for field-testing in the United States (approved in 1985) was a herbicide-tolerant tobacco strain constructed using genetic material from a bacterium (a *Salmonella* species that had become resistant to the herbicide), controlled by additional genetic sequences from a mammal (sheep) and another plant (soybean) unrelated to tobacco, all inserted using a second species of bacterium (*Agrobacterium*) (Comai, et al. 1983).

Gene technologies clearly stand among the ultimate beneficiaries of the vast library of tried-and-true evolutionary inventions of the millions of species in natural ecosystems, and thus have an interest in keeping these libraries in viable condition (Goodman, et al. 1987; Janzen 1987; Witt 1985). The difficulties in transferring any but the simplest traits to an unrelated species are currently formidable, but there is every reason to expect that many difficulties will be overcome in time. Already, traits requiring the coordinated action of more than one gene have been successfully transferred between species (Wong, et al. 1988). Twenty years ago, most biologists would have declared impossible—or at least extraordinarily unlikely—what has already been accomplished today.

Economic arguments for the preservation of species (or of biodiversity or habitat) based on *noncommodity* values rely on measures of the degree to which the value of a place is enhanced by the presence, or decreased by the loss, of particular species (or of a habitat). The value differential may be estimated from actual prices, for example, by comparing the sale price of architecturally equivalent homes at increasing distances from a nature preserve. Alternatively, survey methods may be used to assess how much citizens would, in principle, be willing to pay to keep a species or habitat, or how much they would be willing to accept as compensation for its loss. In theory, such surveys could be used to estimate the value people in one part of the world place on the very *existence* of a particular species or group of species elsewhere, which they may never have seen and will never see, outside photographs or films (for example, the blue whale) (Randall 1988).

Any biologist who has watched people visiting a botanical garden or zoo or who has looked through popular nature magazines will attest to the highly biased and uneven level of public interest in different

groups of species. For example, of the most recent 26 photographic covers of the American popular magazine *Natural History* that feature nonhuman animals, 65 percent are of mammals (4,000 species, only 0.04 percent of described animal species), including a disproportionate number of primates and bears. Another 20 percent feature birds (9,040 species, only 0.09 percent of described animal species). In contrast, only two covers (8 percent) are of insects (73 percent of described animal species and a much larger percentage of undescribed species), and one cover (4 percent) shows a noninsect invertebrate (23 percent of described animal species). (Figures for numbers of described species of living organisms are from Wilson 1988a.)

Some of the special appeal of mammals and birds rests on our morphological and sensory affinity with them (Kellert 1986), and some rests on familiarity alone (puffins—*Fratercula*—were unknown to most nonornithologists a decade ago, but are now familiar to the layperson and are doubtless, thus, more highly valued). Some of the appeal even rests on the vagaries of fads and fashion. In the past ten years, penguins, bears, and most recently, cows have become “fad animals” in the United States (and perhaps in Europe as well). While some of these historical shifts in public appreciation of nonhuman species may be evidence of an increasing appreciation of nature and a greater public commitment to conservation (an example of Norton’s [1987] “transformational value” of species), they form at best an unsteady platform for public policy.

However important noncommodity valuation may be in particular cases (e.g., Stoll and Johnson 1984), an exclusively species-by-species approach to the noncommodity economic valuation of biodiversity is not only impractical and liable to underestimate consistently the “contributory value” of species to ecosystem function (Norton 1987), but cannot be expected to lead to the even-handed protection of food webs and ecosystems—the key to long-term preservation. The strategy of protecting entire habitats and ecosystems by focusing popular appeals on familiar and evocative species, as exemplified by the campaign to save the giant panda, strikes many biologists as manipulative and somewhat disingenuous—but, nonetheless, most accept it as a means to an end. If the “amenity value” and “existence value” of natural entities can be increased by educational efforts (Randall 1986), then the best program for the promotion of even-handed species preservation from this strictly economic viewpoint calls not only for an attempt to get people to love tapeworms, termites, and toads, but also for a

full-scale effort to give biodiversity *itself* the same cachet as pandas and penguins.

### *Scientific Value of Species*

To evolutionary and ecological biologists, the prospect of an accelerating rate of extinction means the increasing loss of the best clues we have to the process and history of organic evolution and its ecological context. In principle, the value of scientific knowledge in ecology and evolutionary biology can be accommodated within the rubric of economic value, as discussed in the previous section. Indeed, significant commodity value may arise in biotechnology from evolutionary studies of various kinds, and the noncommodity (instrumental) value of scientific understanding to scientists and lay naturalists might be evaluated in some way. Because of my sense that economics fails to capture the essence of the scientific value of species and of biodiversity, however, I have chosen to take a separate approach to these topics.

To argue for the preservation of all species on the basis of their scientific value may seem excessive, given the practical impossibility of ever studying all living species, even superficially. Since not all species will become extinct, could not future biologists learn the same principles from the careful study of those that survive? This retort has some merit, but there are strong counterarguments.

First, the species that survive the next 100 years, assuming no increased efforts at preservation, will by no means be a representative sample of what now exists (Vermeij 1986; Norton 1986). We are just beginning the intensive study of species that are naturally and stably rare and of how they are able to persist while remaining rare (Rabinowitz 1981). Yet these rare species are almost always among the first to become extinct when habitat is destroyed or alien species are allowed to invade and take hold. Moreover, certain habitat types, such as temperate prairie and tropical seasonal forest, are especially suited to agriculture; thus, their biotas are even more likely to fall victim to extinction than those of other habitats. Finally, certain categories of species, such as large carnivores, or land birds on oceanic islands, are especially vulnerable to extinction (Diamond and Case 1986; Vitousek 1988).

Second, the study of ongoing evolutionary processes in natural ecosystems, which has become increasingly possible with the develop-

ment of new molecular and statistical techniques, loses much of its meaning under conditions of rapid habitat alteration or changes in the biota (e.g., Janzen and Martin 1982). A large but unknown proportion of the adaptations of all species are adaptive responses to other species (Futuyma and Slatkin 1983). When the composition of biological communities changes radically, these adaptations are difficult or impossible to interpret in the context of inevitably altered ecological relationships among surviving species.

Realistically, of course, it is already too late to preserve some species already on their way to extinction and even too late to set aside certain rarer kinds of habitat. Biologists of the next century will indeed have to make do with what is left, whatever we do in the meantime. The question then becomes how best to direct our efforts to maximize the long-term scientific return. At present, the consensus favors concentrating funds and efforts on the preservation of tracts or transects of relatively intact representative ecosystems, with minimal loss of species, and in some cases, to attempt restoration of rare habitat types and their associated biotas (Soulé 1986; Allen 1988; Wilson 1988a).

### *Intrinsic Value of Species*

The contention that all species have some entirely noninstrumental *intrinsic value* is at once the most fundamental and most difficult of the three justifications for species preservation that I have chosen to distinguish (Ehrenfeld 1976, 1988; Godfrey-Smith 1980; Callicott 1986; Sober 1986; D. H. Regan 1986; Taylor 1986). Here philosophical, biological, and logical pitfalls lie ready to capture the naive and the sophisticated alike, and I shall doubtless fall into one or another of them—at least by someone's criteria. As a nonphilosopher, I fear to tread where I know neither the subtle connotations of terms, nor the catalogue of accepted wisdom or the lists of acknowledged heresies. Nonetheless, having agreed to provide my "autonomous reflections" as a biologist, I will attempt to make clear a view of intrinsic value that I believe reflects the thinking of many or perhaps most biologists (at least organismal and population biologists) who have considered the matter.

For the purposes of this essay, we shall have to assume that we know what a "species" is and what an "individual organism" is; we will conceive of a species as composed of individual organisms that are genetically very similar due to recent common descent. In fact, scientific disputes abound concerning the proper definition of "species,"

and additional difficulties arise in defining "individual" for clonal species (Futuyma 1986)—quite apart from philosophical meanings of the term.

In my experience, biologists involved in evolutionary or ecological work consider it self-evident that all species have "scientific value," in the sense that I have used that term. Coming from a biologist, however, the argument that species ought to be preserved for their scientific value may appear narrowly self-serving. In any case, this argument only weakly and unevenly supports the principle that *all* species should be preserved because some are bound to be of more scientific interest than others, even in the long term. Consequently, biologists involved in political and economic struggles over the preservation of species (and their habitats) characteristically overlay their scientific justifications with a heavy veneer of economic arguments—in the broad sense discussed above.

In fact, however, both the scientific and (especially) the economic arguments are often tactical window dressing—a conscious attempt to appeal to the presumed values of the world of politics and business. Biologists certainly believe that scientific and economic arguments are valid and important, but a more fundamental motivation underlies them. When cornered, most organismal and population biologists, and some others as well, will admit to a strongly felt intuition that *every* nonhuman species has value *in itself* (Godfrey-Smith 1980; Callicott 1986; Collar 1986).

This intrinsic value (or "inherent worth" [Sitter 1989]) of a species is independent of whether the species is vital to human welfare, at one extreme, or an imminent threat to human welfare, at the other—although in the latter case (e.g., smallpox or the AIDS virus), we may choose to pursue the extinction of the species *despite* its intrinsic value. In its purest sense, this intuition ascribes intrinsic value even to species that are completely irrelevant to human welfare, of only redundant interest scientifically, and of negligible ecological significance.

Leaving aside theological justifications for the designation or instillation of intrinsic value in earthly entities, the term must inescapably imply human attribution of noninstrumental value. My basic claim here is empirical—that biologists behave, speak (usually off the record), and sometimes write in ways that reveal that they attribute intrinsic value to species. There are good reasons to believe that many nonbiologists, including the peoples of developing countries (Collar 1986), share this appreciation of nonhuman species for their own sake. I will also try to explore the meaning and ramifications of intrinsic



value for species and other natural entities, but whether these efforts succeed or fail in philosophical and logical terms, the empirical claim remains.

For a scientist, the real problem arises in attempting to explain—within the supposedly objective, value-free bounds of traditional scientific discourse—the conviction that species have intrinsic value. (Furber [1989] discusses the presuppositions implied by such a conviction.) Philosophers have additional difficulties with the issue (Callicott 1986; Sober 1986; D. H. Regan 1986; Norton 1987), and mainstream economists attempt to avoid it by putting a price on the intrinsic value of species in the form of “existence value” (Randall 1986). Scientists involved in public policy issues tremble at the thought that anyone might accuse them of sentimental—or worse, mystical—motivations, which are easily imputed to anyone claiming that, in principle, an unnamed species of tropical soil mite merits the same protection as the Bald Eagle. Nonetheless, in recent years the argument for species preservation on grounds of intrinsic value has become marginally respectable among biologists (e.g., Ehrlich and Ehrlich 1981), if still considered somewhat defiant of the traditional terms of scientific discourse.

*Individual value, individual rights, and appropriate care.* In practice, what does it mean to say that something has “intrinsic value”? Although, as we shall see, the argument leads inevitably into conflicts of value, there is no escape from the consideration of human life as a starting point in any such discussion (e.g., Jonas 1984; Callicott 1986). The example leads us into an important detour concerning the value of individuals, en route to a full consideration of the intrinsic value of species. In pursuing this course, I disagree with Norton (1987), who prefers to discard this line of argument because of the conflicts that arise. These difficulties, however, represent issues of genuine substance not only in the philosophy of conservation, but in public policy.

Our prevailing ethical system regards *individual* human beings as having intrinsic value, in the sense that ugly and handsome ones, old and young ones (though the starting point is in dispute), rich and poor ones, good and evil ones *share some irreducible, nonquantitative claim to our respect*, however abstract and grudging granting that respect may sometimes be. The moral claim each human being holds on our respect is usually stated in terms of a short list of “human rights” or “moral rights.” (Callicott [1986] discusses the intriguing history of the concept of “rights,” in this sense.) The conceptualization of human intrinsic value as conferring rights on individual human beings immediately

confronts us with a key question: Does the attribution of intrinsic value to an entity *necessarily* confer some appropriate set of “inalienable rights” upon that entity? I shall argue that the answer is “no.”

Certainly modern society has come to acknowledge the intrinsic value of human individuals by recognizing their moral rights. The fact that intrinsic value has been expressed in the language of human “rights” may be a consequence of the recognition, first, of human “wrongs”—through appreciation of the particular forms of injustice suffered by slaves, by children or women in the workplace, by homosexuals, by the disabled, and so on. By analogy, many of those who seek an end to the human exploitation of animals protest it as a violation of the “rights” of higher animals (e.g., T. Regan 1983; Sapontzis 1988); others seek to promote conservation by decrying the uncontested extinction of species or the willful destruction of ecosystems as a violation of the “rights” of species and ecosystems (e.g., Ehrlich and Ehrlich 1981). The power and appeal of rights language as a means to achieve such a variety of ends arises in part because of the connotation that rights are absolute, nonnegotiable, inalienable. The argument then inevitably centers on who or what has such rights, and why. Utilitarian philosophers (e.g., Sapontzis 1988) insist that, in addition to humans, only individual animals capable of pleasure and pain have rights—usually interpreted to mean the higher vertebrate animals, despite the actual impossibility of knowing where to draw the line. (Although few biologists would deny that nonhuman vertebrate animals *do* share sensations homologous with what we call pleasure and pain, equally few would be certain that other animals, including insects and other invertebrates, *do not* feel pleasure and pain.)

What does it mean to say that a nonhuman animal has rights? Consider a domesticated rabbit, raised in a laboratory cage for the production of antibodies. The assertion that the rabbit has the right to wholesome food, shelter, and protection from inhumane treatment is not entirely parallel with the same assertion for a human prisoner in a penitentiary, even if we assume that both are incarcerated for legitimate cause. Where humans are concerned, ethical philosophers consider it a settled issue that reciprocity is not an appropriate criterion for the assignment of rights (e.g., Norton 1987). A severely mentally disabled person or a comatose invalid nonetheless has the same rights as anyone else. Likewise, it is argued, the rabbit in the cage has the same basic rights as a human (food, shelter, freedom from pain and exploitation), even though the rabbit, unlike (in principle) the prisoner, cannot then or ever reciprocate in granting its caretakers the



same set rights that they are morally bound to provide. Philosophical heresy or not, the fact that a nonhuman animal cannot, *even in principle*, assume the duties and reciprocate the rights accorded it by its human caretaker casts the rights of animals in a different light from the rights of human beings. To the mentally disabled person and the invalid we may say, "There but for the grace of God, go I"—but it is no accident that none of us was born a rabbit.

Of course, I fully agree that we are morally bound to treat the rabbit humanely. But I suggest that our commitment to its humane treatment should arise not from a recognition of the rabbit's "rights," but from an informed judgment of its capacity for suffering, knowledge of its particular physiological and behavioral needs, and a recognition that our involvement in its current condition (including the domestication of the breed and the birth, confinement, and experimental use of this individual) creates a *responsibility* for proper husbandry and protection from suffering.

Whether or not we choose to express this obligation in terms of rights, at the core of our responsibility to the experimental rabbit lies a recognition (or intuition) of its *intrinsic value as a living being*. If the individual human life represents some kind of paradigm for the concept of intrinsic value, I suggest that individual *nonhuman lives* (of all species) have an analogous claim to intrinsic value, although I shall argue in the next section that the character of moral actions arising from that claim will vary greatly. (I shall also attempt to give a definition of *intrinsic value* without reference to this analogy.) Further, I shall suggest that when we attribute intrinsic value to an entity, we simultaneously create a responsibility, an obligation, to preserve and protect that entity through *appropriate care*—a key idea in this essay.

*How do we recognize intrinsic value?* I think many biologists attribute some intrinsic value to every individual living organism, not through some vitalist esteem for any mystical "life force," but simply because all living things amaze us by their *complexity* and by a quality that might best be called *improbability*—the quality of detail and organization that produces astonishment when one looks into a drop of pond water with a microscope to discover it teeming with exquisitely formed microscopic protists, crustaceans, and algae; that overwhelms the diver on a coral reef; that transfixes the ornithologist watching a weaver bird building a nest, or a bower bird its bower. In Sitter's (1989) words, the intrinsic value of living beings arises in part from their quality as "centers of relations independent of human will." My best stab at a definition of intrinsic value (to meet the challenge of Norton 1987) is

thus: "The worth inherent in any complex and improbable natural entity that represents a center of relations independent of human will."

Further, I suggest that the same qualities of complexity and improbability lead us to regard nonbiological individual entities, even, in some cases, "naturalized" human artifacts, as having value in themselves. Two personal anecdotes may help to make this point. I used to be a "caver"—an avid explorer of limestone caves. Serious speleologists, both amateurs and professionals, have a rigid code in regard to the treatment of cave formations. Nothing—not even the smallest and ugliest stalactite in the most inaccessible part of the most obscure cave—may be broken, defaced, or removed from a cave. Any visitor to a cave who violates this code is referred to as a "*vandal*," which my dictionary (*Random House Unabridged*, second edition) defines as "a person who willfully or ignorantly destroys or mars something beautiful or valuable." Although many cave formations also have positive or negative aesthetic value—arguably a form of instrumental value (Callicott 1986, footnote 15; Norton 1987)—to the caver, all have intrinsic value.

In my second example, a story of actual vandalism makes the point that objects made by human hands may also have intrinsic value. Some years ago, my parents acquired an isolated parcel of land in a remote part of the Rocky Mountains of Colorado. The place was once a thriving gold camp, but by the time they bought it, only a few ramshackle cabins remained, though some were still relatively intact, with decomposing furniture inside. In one of these cabins, was a broken-down player piano—one of those masterpieces of nineteenth-century mechanical invention that played music by itself, guided by perforated paper rolls. The cabinet of the piano had long ago been irretrievably damaged by the elements and the "player" mechanism no longer operated—hauling the piano out of the place would have cost far more than the little it was still worth. But some of the keys still worked, and we used to improvise a few barroom riffs to resurrect the spirits of the gold rush whenever we visited the place.

I shall never forget the day we arrived to find that the cabin—which had not even had a door since we had known it—had been mercilessly vandalized by someone with an ax. The piano had been hacked to pieces, the keyboard smashed, strings severed, legs crippled. Our outrage had little or nothing to do with the loss of whatever small monetary, aesthetic, or even historic value the piano may have had; it was truly an instrument of little instrumental value. Rather, the sight

of its intricate workings spilled on the floor—the product of hundreds of hours of care by unknown craftsmen's hands—seemed more like murder and mutilation than simple vandalism. We had valued the piano for itself—for its incongruous complexity in a place of disorder and decay, the improbability of its survival, and its role as a center of relations between physical materials and the intangibility of music, between past and present.

*Scales of intrinsic value and appropriate care.* Like cave formations and the player piano, living things—however lowly—are complex products of a complicated process acting improbably through long spaces of time, surviving against great odds, and bearing the marks of their history. Every individual organism is the product of the astonishing capacity of living things to arise, from a handful of molecules, as reflections of their ancestors. Yet there is no escaping the fact that we do not attribute the same level of intrinsic value to all individual organisms, as measured by accepted (or expected) levels of responsibility for individual, nonhuman organisms of different kinds.

Consider again the laboratory rabbit in its cage. I would feel an analogous moral responsibility, though in different measure, for the appropriate care of an experimental colony of ants in a plastic shoebox in my laboratory (food, water, and nesting material) and for a potted palm in the living room of my home (light, water, and nutrients). That we have a moral responsibility to care for each of them reflects their equality as entities of intrinsic value (cf. Sitter 1989). That appropriate care differs for rabbits, ants, and potted palms reflects their biological differences. Moreover, it would certainly be more reprehensible to allow a rabbit to starve to death than to kill a potted palm by negligence—because of the neural capacity of the rabbit for pain.

The intrinsic value of individual organisms must surely scale with biological complexity, sensory capacity, size, age, and generation time, or we are led into absurdities—even the most ardent proponent of animal rights probably swats mosquitoes in the bedroom and surely has no concern for the bacteria he or she kills with the toothbrush or digests with the yoghurt. As a biologist, I feel no ethical responsibility, though I certainly might have some scientific responsibility, for the appropriate care of bacteria growing in a petri dish. At the other extreme, keeping anthropoid apes in captivity—however humanely accomplished—requires in my opinion extremely strong justification and entails a moral responsibility not too distinct from the adoption of children (see Goodall 1987). Even within species, age and size matter. To my mind, the felling of a thousand-year-old, giant redwood

tree requires far more justification than the destruction of a seedling of the same species—which is equally an individual.

*Replaceability.* To argue for an ill-defined “sliding scale” of intrinsic value for individual organisms is not logically or philosophically tidy, but I see no alternative. I believe there may be, however, a unifying rationale, which at last will lead us directly to consideration of the intrinsic value of species. The unifying concept is *replaceability*.

The degree to which we find intrinsic value in individual organisms seems to be a direct function of how quickly and easily they may be replaced—or replace themselves, on a human scale of time and energy. A field mouse, because of its shorter generation time and smaller size, may be considered of less intrinsic value than a black bear, though both are replaceable. To an entomologist, collecting 100 individual (sterile) worker ants requires far less justification than collecting the single queen of a large colony. To a botanist, collecting leaves and flowers of a perennial plant for study is almost always preferred to collecting the entire plant. Although the single redwood seedling and the thousand-year-old mother tree are both genetic individuals of the same species, the seedling is easily replaced, but the tree is not. Likewise, most people would probably mourn the death of a human child more than that of a newborn infant and of a newborn more than a miscarried ten-week embryo.

*Intrinsic value and the replaceability of species.* By extension of the “human life” paradigm for individual intrinsic value, the human species as a whole presumably has some intrinsic value—at least as the sum of its parts. Intermediate between individuals and the human species at large, I would argue that human cultures have intrinsic value. The degree to which human beings tend to cling to their traditions, even if immersed in a different culture and sometimes at great sacrifice, seems to me to testify to a belief in the intrinsic value of cultural systems, although it would be difficult to separate the instrumental value of cultural conformity. Unfortunately, the idea of reciprocal rights of different cultures is far from established. Despite the often positive instrumental value of Western technological culture (such as sanitation practices and health care), the transformation and destruction of traditional non-Western cultures strikes many of us as akin to vandalism—the “willful or ignorant destruction of something valuable”—and irreplaceable.

A species or biological population, as a group of individuals, is conceptually closer to a cultural group than to an individual (in the usual sense of the word). Is a species—our own included—only as

intrinsically valuable as the sum of its intrinsically valuable parts? I think the answer is quite obviously "no," both for *Homo sapiens* and for every other species. I doubt that anyone would argue that our species will be twice as valuable when there are twice as many of us as there are now, assuming we get that far. Likewise, if only 1,000 humans survived a nuclear holocaust, the species as a whole would be no less valuable to its members than at present.

*A species has intrinsic value because it is essentially irreplaceable.* Biologists value species, in themselves, more than any individual organism within a species, for the simple reason that the loss of a species means the loss not only of every living individual member of that species, but of every future member as well—along with any daughter species that might otherwise have arisen. Nonetheless, a sliding scale clearly governs the level of concern and effort that both conservation biologists and the public are willing to expend to discover and save species in danger of extinction (e.g., Kellert 1986; Mittermeier 1988).

Once again, the notion of "replaceability" unites many of the criteria for interpreting the relative intrinsic value of species (apart from any additional scientific or economic value). In the same way that one individual may seem an adequate replacement for another of the same species, despite the actual differences between them, one of two or more extremely similar species will be valued less than a highly distinct species that stands out from the pack—or one of great geological age (D. H. Regan 1986). Thus the single endemic sundew species in a threatened temperate bog may be perceived as having greater intrinsic value than one of three very similar species of moss endemic to the same bog. In terms of replaceability of distinctive genetic information, this approach has some justification.

*Population welfare versus individual welfare.* In assessing the impact on biological diversity of habitat loss, pollution, scientific collection of organisms, or the introduction of geographically exotic or engineered organisms, biologists are generally concerned not with the survival of individual organisms, but with the welfare of populations (Vermeij 1986). For example, the Juan Fernandez Firecrown, an extremely distinctive and scientifically intriguing species of hummingbird, is found only on a small island (Isla Robinson Crusoe) 660 kilometers off the coast of Chile. Having survived 300 years of deforestation and the introduction to the island of rats, dogs, cats, pigs, sheep, goats, and a host of continental plants, the hummingbird is now severely threatened by the coati—a common, omnivorous, highly intelligent, and

charming tropical relative of the raccoon, which was intentionally introduced to the island in the 1930s. To save the Juan Fernandez Firecrown, it will be necessary to control or—preferably—eliminate coatis from the island (Colwell in press).

This example brings clearly into focus the clear potential for conflict between the valuation of individual organisms and the valuation of species (Norton [1987] discusses other examples at length.) No program has yet been mounted to eliminate or control the coatis on Isla Robinson Crusoe, but one may well imagine that the trapping, shooting, or poisoning of the coatis will be difficult to justify to those who place the welfare of individual animals (especially intelligent and beguiling mammals) above that of populations of endangered species.

This inherent conflict in values yields to no easy solution. The principle of replaceability argues for the preservation of species in preference to the preservation of individuals, when those ends are in conflict—but the argument carries weight only if one believes that individuals are more easily replaced than species. People whose chief contact with animals has been with personal pets—who are often unique individuals to us—tend to have great difficulty with the idea of replaceability. The owner of a beloved parakeet may find it impossible to agree with the biologist who argues for the humane sacrifice, required for a carefully planned scientific study, of a hundred chickadees from a wild population of 100,000 (Greene and Losos 1988). It is here that the course of action based on the human rights model for the treatment of individual animals differs most from the alternative view that we are responsible for the appropriate care, not only of individuals, but of species.

*Aesthetic value as a form of intrinsic value.* Among the lay public, one may guess at the prevailing societal criteria for organismal aesthetics (Kellert 1986) by noting the large amateur following for particular subgroups within higher taxa—chimpanzees, orangutans, and gorillas (but not tree shrews); parrots and hummingbirds (but not flycatchers or swifts); felids, canids, and bears (but not hyenas); mollusk shells (but not their inhabitants and not squid); butterflies and bright-colored moths (but not dull-colored groups of moths); palms, bromeliads, orchids, and "wildflowers" (but not grasses, not spurge). Clearly, bright colors, accessible behavior, and human-like qualities hold great appeal.

The aesthetic value of species is treated by some writers (e.g., Sober 1986) as essentially identical with intrinsic value and by others (e.g., Callicott 1986, footnote 15; Randall 1986; Norton 1987) as a



form of purely instrumental value that can in principle be accommodated in a strictly economic framework. In the case of natural entities, I prefer to view the appreciation of aesthetic value as an imperfect form of intrinsic valuation.

The trained naturalist's sense of "beauty" grows steadily broader with intimate understanding of the lives of organisms (Ehrlich and Ehrlich 1981)—the sense is not different in character, but only in compass, from the appreciation an orchid fancier has for orchid blossoms. To me, there is no more beauty in the colors and behavior of a hummingbird than in the structure and natural history of the microscopic mites that feed and breed in hummingbird-pollinated flowers and ride from plant to plant on the bills of the hummingbirds (Colwell 1985, 1986a, 1986b)—but then, I have studied both mites and hummingbirds for 20 years. I know biologists who find as much beauty in toads and salamanders, beetles, slugs, snapping-shrimp, spiders, algae, and roadside weeds as the amateur lepidopterist finds in a blue morpho butterfly.

In theory, I am comfortable with the idea that, for a given species, a certain level of aesthetic value overlies a certain level of intrinsic value. The level of aesthetic value depends on the objective morphological and behavioral attributes of the species in relation to the subjective cultural and intellectual attributes of the observer. The existence of intrinsic value, as discussed previously, arises from the complexity and improbability of species; the level of intrinsic value depends on features of the species that can be summarized by the concept of its replaceability. In practice, I see no way to distinguish clearly between the broad aesthetic value of a species and its intrinsic value. The intuition that species have intrinsic value may arise from aesthetic appreciation—aesthetic value is a means of perceiving intrinsic value, but is not identical with it.

#### *Intrinsic Value of Ecological Systems*

In a manner precisely analogous to perception of the intrinsic value of species, ecologists and evolutionary biologists (and others) perceive intrinsic value in coevolved ecological systems at many levels. The levels range from interactions between species, to biological communities and their interdependencies, to local ecosystems and their involvement with the physical world of material cycling and energy flow, and, finally, to the global ecosystem itself. Each of the entities in this vague hierarchy represents a center of relations independent of

human will and partakes of the qualities of complexity and improbability that I have argued are key criteria for intrinsic valuation. Thus, each invites us—I would say, requires us—to assume responsibility for its appropriate care.

And again, the level of effort we are willing to expend in such care will depend on the degree of distinctness—the replaceability of each system. The new Braulio Carrillo National Park in Costa Rica, for example, represents the last elevational transect of undisturbed tropical forest in Mesoamerica connecting lowland rainforest (50 meters elevation) with subalpine cloud forest (2,600 meters) (Pringle 1988). This magnificent mountain landscape faithfully represents the fast-disappearing Central American wet forest, where the descendants of ancient South American and North American biotas were brought together by the most recent appearance of the Isthmus, enriched with additional endemic elements from repeated episodes of isolation when the seas were high (Janzen 1983; Rich and Rich 1983).

Because it is, unfortunately, now unique and thus irreplaceable, Braulio Carrillo requires us to accept responsibility for its appropriate care—in fundamentally the same way that we are called to care for a unique and endangered species, or a captive chimpanzee in a critical program of health research. The appropriate care of Braulio Carrillo requires careful planning for the wise use of its resources in public education and enjoyment, biological tourism, and scientific research; protection from illegal woodcutting, hunting, fishing, mining, and squatters; and a long-term financial endowment to ensure the future of the park.

Just as the intrinsic value of a species is not simply the summation of the intrinsic value of the individuals that constitute it, the intrinsic value of a coevolved system of species interactions (for example) is no simple function of the value of its components. For example, the astonishingly intricate and wondrously varied form and function of flowers and their coevolved pollinators seem to me worthy in themselves of our valuation, quite aside from their economic value in agriculture or their usefulness to biologists in elucidating the process of natural selection. Moreover, some of the most fascinating cases involve such remarkable features as floral odors that mimic rotting flesh to attract pollinating flies, or prosthetic female insect genitalia that induce pseudocopulation (and pollination) by over-eager male insects—hardly the stuff of garden club aesthetics.

It must be admitted that, at the level of ecosystems—especially of the global ecosystem—separating intrinsic value from instrumental



value becomes increasingly difficult. One cannot lightly dismiss the economic value of the regenerative capacity of forests, savannas, and the plankton of the ocean, nor the power of living systems to cleanse and balance the components of the atmosphere, running waters, or the soil (Ehrlich and Ehrlich 1981; Norton 1987).

### Genetic Engineering

In March 1987, Clara H. Bauer of Pepin County, Wisconsin, wrote to the the U.S. Environmental Protection Agency, which invites public comment on proposed field tests of genetically engineered organisms:

I am concerned about . . . the Massachusetts Company that is planning to test genetically engineered alfalfa bacteria in . . . Pepin County. . . . I am very much against making little Pepin County a guinea pig so to speak. As you know nuclear power plants were to be safe but now we have had several mishaps. . . . What I want to ask you people is what do you think of this project? Is it all safe? Or are there dangers of contamination? If you think it is safe, I would ask that you draw up a guarantee to that extent . . . and I want all you people of the EPA to sign your names. This may sound stupid but you see I feel that as long as a guarantee is readily issued with our clocks, radios, microwave ovens, cars and most implements manufactured . . . it would be no more than fair for the EPA to render the same guarantee to us the few in Pepin County. . . . I think you people had better do much soul searching before you commit us here in Pepin County to a possible devastation which can not be repaired. I may be an old woman of 74 but I certainly would hate to leave an incorruptible detriment to my children, grand children, and great grandchildren and all future generations. . . .

Mrs. Bauer's letter candidly and poignantly presents some of the key ethical questions raised by any novel technology that affects the environment—in this case, genetic engineering. The questions are not new. They have confronted us before, with chemicals, pollution, and nuclear hazards: What are the moral and social responsibilities of individual scientists, corporate enterprise, and government agencies? What are the rights of individuals, especially those who live near testing or industrial sites? When risks are conjectural, how do we set rational limits on what experiments scientists should be permitted to do? Who should assess the risks? How should potential risks (especially long-term ones) be weighed against potential benefits (especially short-term ones)? What are our responsibilities to unborn generations?

Without minimizing the significance of other aspects of these far-reaching questions, I want to focus on the relationship between biotechnology and biological diversity. (By *biotechnology* or *genetic engineering*, I shall mean molecular and cellular gene technology.) I hope to be able to clarify some of the complex ethical questions that arise from this relationship through the application of ideas developed in the first part of this essay.

### Ecological and Evolutionary Risks of Biotechnology

Although virtually no controversy has arisen over the use of genetically engineered microbes in the confinement of industrial settings, biologists continue to disagree about the possible hazards of testing and using genetically engineered microorganisms, plants, and animals in the open environment. Although no one contests the fact that risks are highly case specific and that different kinds of organisms require different levels of oversight, overall assessments still range from confident reassurance to serious concern (Brill 1985a; 1985b; Colwell, et al. 1985, 1987; Davis 1987a; Fiksel and Covello 1988; Sharples 1983, 1987; NAS 1987; Colwell 1988b; Hodgson and Sugden 1988).

In the absence of actual data on engineered organisms in the environment, the diversity of expert opinion reflects a lack of consensus about which historical parallels are most relevant. Ecologists have insisted that there are lessons to be learned from the record of long-term environmental effects of nonnative organisms introduced by humans on every continent and island; the rapid evolution of pests, weeds, and pathogens; and the complex interactions and unexpected consequences of poorly considered environmental decisions in the past (Colwell, et al. 1985; Regal 1986, 1988; Sharples 1987; Colwell 1988a; F. Gould 1988a, 1988b; Simonsen and Levin 1988; Williamson 1988).

Meanwhile, molecular biologists tend to cite the impressive 15-year safety record for recombinant DNA research in the laboratory, the long list of critical contributions to human welfare made by traditional plant and animal breeding, and the safe use of nonengineered microbes in agriculture for many decades (Brill 1985a, 1985b, 1988; Davis 1987a, 1987b). In fact, each of these histories bears on the issue of risk, but to different degrees for different kinds of engineered organisms.

The great majority of genetically engineered organisms will surely

prove environmentally innocuous. Some will likely help to solve pressing ecological problems, such as the cleanup of toxic chemicals (Roberts 1987) or the replacement of chemical insecticides with environmentally safer microbial ones. The potential for significant risk, however, not only mandates scientific vigilance, but raises ethical problems. As Mrs. Bauer of Pepin County clearly comprehends, the release of an engineered organism (especially a microorganism) that causes some unanticipated harm will likely have effects beyond the point of application in both time and space. However difficult toxic waste dumps may be to clean up, the successful integration of a noxious organism, or simply a nuisance organism, into either a managed or natural ecosystem is probably permanent and not likely to respect property lines. As we have learned with toxic wastes, moreover, assigning legal liability after the fact is little help—either economically (given bankruptcy protection) or ecologically.

*Managed ecosystems.* In managed ecosystems (agriculture, silviculture), many of the potential hazards presented by genetically engineered organisms have counterparts in traditional technologies. Among other examples, the risk of crop failure in genetic monocultures as a result of the rapid evolution of newly virulent strains of plant pathogens (Doyle 1985) would be neither more nor less for a genetically engineered crop variety than for a variety produced by traditional crop breeding techniques. Likewise, the risk of inadvertently exacerbating a problem with an insect pest by the application of a pesticide that also eliminates natural enemies of the pest, a common problem with chemical pesticides, is no less likely with broad-spectrum engineered microbial pesticides. (In fact, many biotechnology companies are now attempting to broaden the host range of existing microbial pesticides to increase market share [Betz, et al. 1986].)

Other potential risks of engineered organisms in managed ecosystems are less familiar. For example, many commercial research groups are beginning to test crop plants that have been engineered to express pesticidal biochemicals in their tissues. The most common and feasible transformation at present involves inserting into the plant genome a toxin gene from the ecologically safe EPA-approved microbial pesticide, the bacterium *Bacillus thuringiensis* ("B.t."). To date, insect resistance to B.t. has been rare because the bacterium itself does not survive long after application. If expressed continuously by plants, however, especially if widely cultivated, rapid evolution of resistance in pest insects is a virtual certainty. The evolution of resistance would mean the loss of a rare and precious resource: an effective, safe, narrow-

spectrum microbial insecticide (Colwell 1988a; F. Gould 1988a, 1988b).

One of the principal concerns, from both ecological and evolutionary viewpoints, is the potential role of engineered organisms as "conduits" for the movement of genes between distantly related or completely unrelated organisms. Although a variety of natural mechanisms are known for the passage of genetic information *between* species, ranging from hybridization (by ordinary sexual reproduction) to much rarer and more arcane mechanisms (Miller 1988), the techniques of genetic engineering permit the routine movement of genes among genera, phyla, and even kingdoms. Once released in the environment, these novel genetic constructions may in some cases move with ease into the gene pools of close relatives of the engineered organism—which thus acts as a "conduit" between lineages previously isolated genetically for eons.

Figure 1 outlines this phenomenon. For example, genes now being inserted in crop genomes confer herbicide-tolerance, resistance to insect pests or plant pathogens, or tolerance for extreme physical factors such as saline soil, drought, or frost. Most crops have closely related, wild, weedy relatives, some of which are serious economic pests in field crops (e.g., wild relatives of rice in rice paddies, Johnson grass in sorghum). If the engineered crop hybridizes with a weedy relative, the weed will likely acquire whatever competitive advantage the crop obtained from the novel genes and become an even more serious pest (Colwell, et al. 1985; Ellstrand 1988). The same scenario applies to engineered animals, such as fish. The ecological effect is likely to be a release of the unintended recipient from one or another regulating factor that previously helped to hold its population in check. The evolutionary effect is the passage of genetic information from one evolutionary lineage to another by human intervention.

*Natural ecosystems.* In natural ecosystems, the issues of risk and responsibility are more profound. The hazards of greatest long-term concern arise from the "conduit" effect just outlined. Like managed ecosystems, natural ecosystems also support wild relatives of engineered organisms that may be altered (and may profit, to the detriment of other species) through genetic crossing with engineered relatives. Without appropriate oversight now, given the rapidly accelerating pace of research in biotechnology, our descendants may see the present period as the beginning of a massive reshuffling, under human direction, of the "evolutionary inventions" that 3,000 million years of natural selection have produced in the earth's biota.



Perhaps less likely than genetic "conduit" effects, but still possible, is the actual invasion of an unmanaged, relatively intact natural ecosystem by an engineered species itself. Suppose a game fish is genetically engineered to grow 50 percent larger than its ancestors, through the insertion of an extra gene for the production of growth hormone—a project already feasible and underway (*Sports Illustrated*, March 7, 1988; *New York Times*, June 1, 1988, 1). Releasing the fish in waters even where there are no nonengineered wild counterparts still poses serious ecological hazards.

Because larger fish eat larger prey, changes may be expected in the structure and composition of the prey community (through altered patterns of predation), as well as the composition and possibly the stability of the predator fauna (though altered patterns of competition) (Moyle 1986; Moyle, et al. 1986). In addition, ecosystem effects such as changes in aquatic primary productivity can result from such faunal shifts.

Suppose the engineered fish were (foolishly) introduced into a lake that historically had only smaller fish, with the intention of providing a better source of food for local people or simply under pressure from sport anglers. If the result were anything like the story of the (nonengineered) Nile Perch (*Lates niloticus*) in Lake Victoria, the result could be disastrous and far-reaching (Hughes 1986). Since its first introduction into the lake in 1960, as a food source for the local populace, this large, predatory fish has led to the extinction of literally hundreds of endemic fish species in the lake—which once had one of the richest fish faunas in the world. The Nile perch now feeds on small shrimp and its own young.

But the effects of this introduction do not stop at the lakeshore. Fish have always been a staple food of people living near the lake. The Nile perch is edible, but requires a higher cooking temperature than the native fish did to render its fat. The consequent effects of intensified firewood cutting on local forests may eventually prove a greater economic and ecological disaster than the loss of the native fish fauna.

The lesson is that any intentional introductions, whether of engineered or other organisms, must be assessed beforehand with the utmost care. In the case of the perch, for instance, none of the facts that would have been required to have predicted this scenario would have been hard to discover—apparently there simply was no effort to do so. Never previously exposed to any predator as large as the Nile perch, the local fish species were defenseless—a fact easily determined

by experiments with captive fish. Likewise, prior determination of the cooking temperature of Nile perch vs. native fish would have been a simple matter.

#### *Alteration of Natural Entities as Devaluation*

Logically and historically, to argue in principle against any alteration of the genetics of a species through human intervention is absurd. As discussed earlier, civilization was built on such interventions—intentional and unintentional. Even opposing in principle the crossing of species that never hybridize in nature falls flat as an argument against change from accepted practice—most of the tomatoes and strawberries we buy in the market carry genes for several genetic traits (e.g., disease resistance or texture) from wild relatives continents away from the farmer's field, introduced into crop germ lines by classical plant breeding techniques (Goodman, et al. 1987). Orchid fanciers' prize blossoms are frequently hybrid products of hand pollination—not just between orchid species, but between orchid genera that never cross in nature, because of the rigid fidelity of co-evolved pollinators (van der Pijl and Dodson 1966). And, of course, there are many other examples, from mules to tangelos.

Nonetheless, the spirit of the plea to move slowly—or not at all—with the genetic engineering of organisms is easily heard as an appeal based on the intrinsic value of species (leaving aside, for now, issues of human health, animal welfare, and environmental safety). But here we have a new element to add to the concept of intrinsic value developed earlier—the notion that *the intrinsic value of a species is diminished by its genetic alteration through human intervention*. I strongly suspect that most biologists would agree with this proposition—but *only for human intervention in the genetics of "natural" (wild) species living in reasonably "natural" ecosystems* (S. J. Gould 1985). All the examples cited (tomatoes, strawberries, orchids, mules) apply to domesticated—or at least captive—species under direct human management.

I struggle to define this devaluation in a way that carries it beyond what must appear a sentimental commitment to shielding "natural" species and other natural biological entities from human intervention. It is akin to the idea of "vandalism"—that to mar a thing of (intrinsic) value, especially when it is not even of our own making, is wrong. Certainly, neither I nor other biologists of my acquaintance would intervene in any natural process of change in a natural ecosystem—

except perhaps in a reversible experimental manner. Most of us would even choose not to stop a natural extinction, if we could somehow be certain that human intervention were not at fault—any more than we would try to stop a wolf in a wilderness area from inflicting a painful and terrifying death on a rabbit whose relatives we make great efforts to treat humanely in the laboratory.

In the case of the engineered fish discussed in the previous section, for example, I suspect that few biologists would object at all to the laboratory study of the novel genotype—even if its parents were taken from the wild (assuming their removal did not significantly harm the natural population). It is the release of the fish into a natural ecosystem that would bring on the objections and create the moral dilemma. Together with any resultant genetic, physical, and behavioral changes in the wild fish species itself, there would very likely be indirect effects on the biological community and possibly at the level of the entire aquatic ecosystem, as outlined above. (Any additional indirect effects on human welfare, as with the Nile perch, are separate issues.) These adverse effects amount to a human intervention in the structure, function, and relations between species—an intervention that devalues them.

#### Natural and Unnatural History

Some have argued that the distinction between domesticated organisms and wild species and between natural and actively managed ecosystems is philosophically vacuous. Sober (1986, italics his), for example, writes:

... to the degree that "natural" means anything biologically, it means very little ethically. And, conversely, to the degree that "natural" is understood as a normative concept, it has very little to do with biology. ... *If we are part of nature, then everything we do is part of nature, and is natural in that primary sense.* When we domesticate organisms and bring them into a state of dependence on us, this is simply an example of one species exerting a selection pressure on another. If one calls this "unnatural," one might just as well say the same of parasitism or symbiosis. ...

Sober is right to point out the contradictory and muddled use of the idea of *natural*. Nonetheless, the distinction he finds philosophically untenable is of fundamental importance to conservation biologists and environmentalists and lies at the heart of my ethical concerns about genetic engineering. I believe that a coherent restatement of the dis-

tinctions between "natural" and domesticated species and between "natural" and managed ecosystems can be developed that is both biologically and ethically coherent.

*Domestication and component communities.* Neolithic human groups were still "part of nature" in the same sense that wild primate species, toucans, or leaf-cutter ants are today. A few human tribal societies are still "part of nature" in this sense. In New World rain forests, leaf-cutting ants (*Atta* species) feed on the hyphae of a fungus that they cultivate in underground "gardens" on leaf and flower material harvested and chewed by the ants. The fungus is a highly domesticated species. Just as cultivated maize can no longer reproduce without human assistance, the fungus in the ant nest cannot reproduce without the attention of the leaf-cutting ants (Stevens 1983). Moreover, just as Mayan society depended critically on the cultivation of maize, the ants depend critically on their fungus. On a larger scale, just as Mayan agriculture partially transformed the landscape and ecology of Mesoamerica, the immense nests and kilometers of trails of leaf-cutting ants mold the microtopography of the forest floor. Moreover, their activities are surprisingly significant in the regulation of production and the cycling of nutrients in New World rain forests (Lugo, et al. 1973).

The most important parallel for the present discussion, however, concerns the place of the Maya and the place of the leaf-cutting ants in their relations with other species. One of the most consistent characteristics of coevolved assemblages of wild species ("biological communities") is their organization into smaller sets of strongly interacting species, with much weaker or infrequent interactions between these sets. This property has been recognized in empirical studies in the form of "component communities" (Root 1973), ecological "guilds" (Root 1967; Inger and Colwell 1977), "coevolved food-webs" (Gilbert 1977), and "food subwebs" (Pimm 1982). Theoretical work (Gardner and Ashby 1970, May 1981) suggests that such ecologically based "substructuring" of communities permits more species to coexist in dynamic equilibrium, for a given level of stability in the resource supply. The popular "wisdom" that "in nature, everything affects everything" must be qualified by adding a large variance term.

Neolithic human societies, like leaf-cutting ants and other "natural" species, each lived within a "component community" of strong interactions with a relatively few species, weak interactions with many others, but no significant interaction at all with most of the species in the landscapes they inhabited. In the case of the Maya, the strongest



interactions were with their domesticates (maize, beans, squash, and some lesser crops), whose welfare they favored, and no doubt with agricultural weeds and crop pests, whose welfare they did not. Weaker interactions included the plant and animal species whose habitat Mayan agriculture usurped or which they hunted or gathered in the wild state.

Likewise, in addition to the strong interaction leaf-cutting ants have with their fungal domesticate, the ants strongly affect certain tree species they favor as substrate for the fungal gardens. The ants also interact strongly with a whole zoo of inquilines and parasites that live with them. Their interactions with the myriad other inhabitants of the rain forest are much weaker or nonexistent. Many, probably most, species in natural communities are far more "insulated" within the causal web of species interactions than are leaf-cutting ants, which I chose intentionally for their key role in New World tropical forests.

*Resolution of the ethical dilemma.* On the scale of geological time, modern technological/industrial society emerged abruptly from within the component biological communities of Neolithic human cultures—the intervening millennia (in the Old World) or mere centuries (in the New) were but the blink of an eye in evolutionary terms. Yet that emergence has had the effect of transforming thousands upon thousands of weak interactions between human and wild species into strong ones and creating new interactions where none had existed.

*It is precisely this proliferation of strong interactions with other species, this explosive expansion of our sphere of ecological influence that is "unnatural" about contemporary human society.* Yes, we are part of nature, in that our actions profoundly affect other natural entities; yes, also in the sense that we are governed by the same physico-chemical laws as any other species. But we have come to be unique among the species of the earth in having largely escaped (though perhaps only temporarily) from the governance of forces within our component biological community.

Surely, the conviction that "natural species" and intact habitats and ecosystems ought to be protected from any human intervention that changes their character, relations, or stability arises chiefly from the consequences of that historic escape and the interventions it has made possible. The record of our past interventions can be seen in deforested, degraded, desertified, destabilized, eroded, filled, flooded, paved, and polluted landscapes and waters the world over. On a more abstract scale, I believe it is fair to say that, without exception, the net effect of the human enterprise on the hierarchical patterning of biological diversity has been toward elimination of boundaries, consolidation

of levels, and genetic homogenization—in addition to the actual extinction of species and the loss of ecosystems.

In reply to Sober's (1986) critique of the distinction between the "natural" world and the human world, I would begin by acknowledging that the word *natural* is a poor one for the job that I (and many others) have given it—to represent what is left of the pretechnological/preindustrial biological and geological world and its products and workings. *Natural* is a poor word because of the normative baggage it carries, which confounds the clear laying on of reasoned values—*unnatural* is even worse in this regard. Nonetheless, I hope I have made clear in what sense I consider the human position ecologically and evolutionarily "unnatural," and why the characteristics of that position further threaten the "natural" world.

Our moral responsibility for the appropriate care of *individual* organisms in agriculture, zoos, or gardens does not depend on whether they are wild or domesticated in origin, although the nature of that care will, of course, vary greatly from species to species because of biological differences. (We also have the responsibility to find out what those differences are and to design care and use protocols that respect them.)

I contend, however, that the role of domesticated *species* as co-evolved members of our ancestral component community (most domestications began millennia ago) places them in a biologically and ethically distinct class from "wild" species. As with wild species, we have the responsibility to preserve the genetic variation that exists in domesticated species. But unlike wild species, I see no ethical justification for any bar on genetic alteration of domesticates, by whatever technical means. Molecular and cellular techniques permit "wider crosses" and more rapid and precise alterations, but there is no logical distinction between the use of these techniques of "applied evolution" and the techniques of classical plant and animal breeding—by which our domesticates arose in the first place.

The intentional or accidental genetic alteration of wild species, however, represents a devaluation—a degradation of their intrinsic value, as discussed in the first part of this essay. Thus, perhaps, the first, most efficient, and most economical rule for the appropriate care of "natural" (wild) species, of the individuals that compose them, and of "natural" ecosystems is to intervene as little as possible, unless the intervention will help the species or the ecosystem recover from some previous human intervention (Wilson 1988b, Part 8).

At the same time, there is no contradiction in acknowledging that

feeding, housing, and clothing the human species depends on simplified and managed ecosystems—in agriculture, forestry, and fisheries. In those environments, we intervene regularly and will need to continue to do so, not only in the genetics of domesticated species, but in ecosystem functions such as nutrient cycling. The challenge is to limit our interventions to the places they are required.

### Conclusion

Some have suggested that the tools of biotechnology will actually add to the pool of biological diversity, by creating new genetic combinations not possible or not likely in nature, or even by the addition of completely synthetic genes to the products of evolution. In whatever measure this ambitious prediction comes true, the implication that laboratory art can truly imitate life betrays a narrowly reductionist view of adaptation and evolution. The diversity of organisms in nature arises from the interplay of genetic variation with the exigencies of life in environments teeming with other organisms and buffeted by shifting physical factors. The adaptive “inventions” of natural selection seem far more likely to be of use in creating new products and (I hope) solving serious ecological problems than any biological feature produced *de novo*. After all, nature has a head start on us of many hundreds of millions of years and maintains 100 million natural laboratories operating 24 hours a day.

Although important, an appreciation of the remarkable past record and future economic potential of natural species as a source of adaptive inventions is not enough. The inherent *complexity and improbability* of individual organisms, species, habitats, and ecosystems as *centers of relations independent of human will* merit our recognition of their *intrinsic value* and thus make us responsible for their *appropriate care*. The concept of *replaceability* provides a guide for choosing among alternative actions and for negotiating conflicts between the valuation of entities at different levels of the biological hierarchy.

Of course, we are a product of nature and occasionally still its victims. But the dismal history of our past effects on biological diversity, together with our need to use much of the earth's surface to feed ourselves, argues that the most effective—and probably the most efficient—way to preserve what we can of the diverse products of evolution is truly to set them aside, in as grand and integral a way as we can afford. I believe we must come to see ourselves no longer as equal participants in natural history, but as responsible for its nurture through appropriate care.

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