The protection of biodiversity is necessary to preserve Earth’s life support system. Adoption of land use policies to achieve such protection arguably constitutes the greatest environmental challenge to this problem, nearly invisible to the public and refractory to traditional regulatory approaches, that the world will face this century. Although multiple reasons, both practical and moral, exist for caring about the accelerating rate of species and habitat loss, intrinsic characteristics of ecosystem degradation render environmental protection. The U.S. Endangered Species Act, along with public land protection, is necessary but not sufficient to preserve biodiversity. Private lands are a public value, requiring landscape-scale planning to preserve the public interest.
Unwise use of land and the resulting loss of biodiversity and degradation of ecological integrity arguably pose the most intractable of the currently foreseeable environmental challenges of the next century. Because the health of the human economy depends upon the health of ecosystems, the protection of ecological integrity is a challenge we dare not avoid. The solution must, of course, involve management, but it is not land that needs to be managed—it is the behavior of people. Appropriately managing how people utilize their land challenges our collective ability to understand the scientific dimensions of the problem, to convey that understanding to the public, and to overcome deeply held views about sacrosanct rights accompanying land ownership. Neither economic development nor any conceivable set of technological breakthroughs will independently solve the problem of land misuse. Indeed, the problem will likely be increasingly confounded in the future by new developments in science and technology that reinforce the illusion that humanity does not need wild habitat and the biodiversity that such habitat sustains.

Humans currently exploit land, as an ecological resource, in the same way that they exploit coal or phosphorous—by effectively mining it. The result is irreversible and non-substitutable loss. When we run out of fossil fuels, which were created long ago by sunlight, the integrity of the sun will remain and we can tap that renewable energy resource, thereby substituting for the exhausted fossil fuel resources. In contrast, when soils erode or species are driven to extinction, there are no
renewable alternatives. Polluted water can be treated and recycled, ozone holes eventually self-repair after CFC emissions are stopped, the atmospheric lifetime of greenhouse gases is on the order of decades to centuries, and most toxic substances released to the environment eventually disperse or decay to the point where hazard is greatly reduced. Again in contrast, humans cannot renew the gene pools within populations of plants and animals or the integrity of ecological functions after exploiting the land and destroying them.

The United States first acknowledged these problems a century ago when a few foresighted scientists and public leaders mounted a major effort to reverse our increasingly wasteful exploitation of forests, soil, and water. At that time, the focus was largely on the extraction of resources, such as timber, and the major concern was running out of such resources. A few voices, literally crying in the wilderness, noted ecosystem-level interconnections such as those between deforestation and soil erosion, soil erosion and siltation of water supplies, and siltation and the health of fisheries, thus speaking directly to the issue of destroying ecological integrity. These voices were the first to identify and plea for the protection of what we now call "ecosystem services."

In a different context, Alvin Weinberg coined the term "trans-scientific" to refer to particularly knotty technical problems with enormously complex ramifications for policy; one example he gave was the long-term disposal of nuclear wastes from nuclear power production. Science alone, he argued, could at best point to ideal, but not to workable, solutions. In his words:

[T]he price we demand of society for this magical energy source is both a vigilance and a longevity of our social institutions that we are quite unaccustomed to. . . . Is mankind prepared to extend the eternal vigilance needed . . . ?

1. An important exception would be certain toxic metals and radioactive substances that bioconcentrate and have such long environmental lifetimes that their environmental presence should be considered to be irreversible, undilutable, and effectively of infinite duration.


3. For example, George Perkins Marsh, Emerson Hough, and John Muir. See generally id.


5. Alvin M. Weinberg, Social Institutions and Nuclear Energy, 177 Sci. 27, 33-34
Although Weinberg focused on technology, the challenge of land use and biodiversity is, as this paper demonstrates, also worthy of the term "trans-scientific." Aspects of the science are profoundly difficult, value systems are in conflict, temporal scales of analysis and intergenerational effects are often muddled, ignored, or hidden, and the boundaries between science, law, economics, and politics have been unavoidably blurred. In numerous respects, the challenges posed by all other modern environmental issues, including global warming, pale in comparison.

In this paper, I describe the complexity and significance of land use dilemmas and suggest directions in which society might practically seek solutions.

1

BACKGROUND: WHAT IS THE PROBLEM?

A. What Is Biodiversity?

Diversity exists across a wide range of organizational scales within the biosphere—from the variety of genes within localized populations of individual species, to the variety of species in a habitat, to the variety of habitats that form the mosaic of a regional or continental landscape.

The most commonly used measure of biodiversity is the variety of species. In those terms, global biodiversity consists of about 1.5 million named and catalogued species. We know from intensive studies in the tropics, however, that numerous additional unnamed species exist, with the highly uncertain total being somewhere between 3 and 30 million species. As is true of the currently catalogued species, it is likely that a large fraction of the yet-to-be-discovered species are insects and, in fact, are beetles.

The species concept is only one way to measure the distinctiveness and, therefore, the variety of life. By that measure, marine ecosystems are relatively depauperate, containing as they do only about 15% of the named species

(1972).

6. The evidence for currently unidentified species comes from intensive efforts to examine all the insects in a few canopies of single trees in the tropics; by fumigating a canopy, collecting the dead insects, and comparing them to catalogued species it becomes apparent that many new species must exist. T. Erwin, Tropical Forests: Their Richness in Coleoptera and Other Anthropod Species, 36 COLEPTERIST BULL. 74-75 (1982).
inhabiting the Earth. But species are just one measure of taxonomic distinctiveness. At higher levels, we have genera, families, orders, classes, phyla, and kingdoms. Organisms in different phyla differ from one another vastly more than do different species in, for instance, the same family. At these higher levels, marine life is far more diverse, containing two-thirds of all the world's phyla and classes.

There is also diversity at a finer taxonomic level than that of species—the level of populations within species. This level of diversity is sometimes referred to as genetic diversity because reproductively isolated populations differ genetically from one another as a result of that isolation. This is the diversity that drives the evolutionary process of speciation. It is also the most difficult to document.

Finally, there is habitat diversity. At regional to continental scales, the landscape consists of a mosaic of habitat types. These habitats are ultimately the product of a diversity of climatic conditions, topography, geography, bedrock, and soil types, although they are frequently characterized by the plant species that find suitable niches within combinations of those abiotic parameters.

Biodiversity is clearly a multi-faceted concept. Moreover, these different levels of diversity (genes, species, higher taxa, and habitats) are linked—protecting diversity at any one of these levels entails protecting it at the others.

Consider first the need to protect diversity at the genetic level, which is one of the two issues—the other being the need to protect habitat diversity—about which most of the controversy now exists in the field of biodiversity protection. A stated goal of the U.S. Endangered Species Act (ESA/Act)\(^7\) is to protect genetically distinct populations (GDPs) or subspecies within species.\(^8\) Protecting GDPs, however, presents a number of problems. Measuring genetic distinctiveness is not a simple scientific task. In particular, a species may be found across a large area, perhaps even across the entire continent, whereas each of the many GDPs comprising a species is generally more localized. Thus a given tract of land is much more likely to contain an endangered GDP than an endangered species. For this reason, those in Congress wishing to scuttle the provisions in the ESA that address subspecies argue that the power to

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8. Id. § 1532(15).
protect populations is the power to drastically block economic development.

So we must ask ourselves: what is the value of protecting GDPs as opposed to "merely" protecting species? The answer is that different genetic combinations, which are critical to species preservation, confer different survival strategies within a species. Consider the salmon in the Pacific Northwest. Genetically, the fish differ. Some populations or individuals within populations may have, by chance, genes that will someday confer protection against global warming. If salmon are to survive the impending era of greenhouse conditions on Earth, we must protect the diverse gene pool today so that adaptation is possible tomorrow. To insure the protection of the species, we must protect a variety of distinct populations.

What about the dependence of taxonomic diversity on habitat diversity? Here, too, the ESA is explicit—the Act states that its goal is to protect not only organisms but also the ecosystems upon which they depend. To opponents of the ESA, however, habitat protection triggers claims that the Act is too powerful and too far-reaching. To an ecologist, it is nearly tautological that you cannot protect species and gene pools without protecting their habitats. The very factors that characterize habitat differences, such as climate and geologic substrate, are among the factors that define the suitable niches of individual populations and species. Moreover, the life-supporting capacity of the landscape is more than the sum of the capacities of the individual habitats that comprise the landscape mosaic; many life forms and hydrological, biogeochemical, and meteorological processes depend on, or are emergent characteristics of, the integrity of the mosaic.

A less obvious linkage is the dependence of habitats on species. In fact, the integrity of all habitats on Earth in part results from ecological processes such as maintenance of soil fertility, water quality, the composition of the atmosphere, and numerous other global household repairs. Diverse assemblages of species carry out these functions. Thus a variety of species maintains habitat, from the local and regional to the planetary level. The detailed dependence of ecosystem processes on the number of species in an ecosystem is not easy to determine; the result, as determined from experimental studies, depends on the details of how the studies are carried out. By artificially planting field plots with different numbers of plant species, researchers

9. Id. § 1531(b).
have shown that the integrity of ecosystem processes is enhanced by plant diversity.\textsuperscript{10} On the other hand, examining natural patterns of association in ecosystems between species richness and ecosystem resilience does not reveal any general patterns. A problem with all such observational studies, subject as they are to a limited time frame of investigation, is that they fail to capture the effects of species depauperization on ecosystem responses to rare events (for example, the hundred year drought).

B. Historic Losses of Habitat

Habitat is lost when it is eliminated completely—for example, when a natural wetland is drained or an old growth forest is clearcut. Habitat is also lost when it is severely degraded—for example, when water flow into a wetland is partially diverted or a forest is selectively logged. Degradation of large areas of habitat also occurs when patches within it are eliminated or altered so that the remaining area is fragmented and thus rendered unsuitable for organisms requiring large intact areas of habitat.\textsuperscript{11} The term "habitat destruction" is used here to refer to either loss or degradation.

Habitat destruction can be described in two ways: (a) current rate of destruction, for example, in units of hectares/year or percent loss per year, and (b) cumulative loss or degradation, expressed as hectares lost or as a percentage of some historic baseline value. Generally, surveys of habitat loss disaggregate habitat into categories such as dry tropical forests, coastal sand dunes, freshwater lakes, or tall grass prairie.\textsuperscript{12} No one has yet compiled a comprehensive summary of the current rates of destruction of major habitat types, but a number of studies have reviewed cumulative losses in particular regions, such as California,\textsuperscript{13} or for particular habitat types, such as U.S. wetlands.\textsuperscript{14} One recent review of cumulative loss and degradation


\textsuperscript{11} See DEBORAH B. JENSEN ET AL., IN OUR OWN HANDS: A STRATEGY FOR CONSERVING CALIFORNIA'S BIODIVERSITY 90 (1993).


\textsuperscript{13} See, e.g., id.

for all major habitat categories in the United States, assessing loss and degradation of U.S. ecosystems, is noteworthy for its broad scope and the fine level of disaggregation with which it treats habitat types and locations.\textsuperscript{15} At the same time, the study acknowledges that the information needed to provide uniform geographic coverage is missing, with habitat destruction better catalogued in the eastern United States than elsewhere. At a global level, cumulative losses have been estimated for tropical forests and other selected habitat types.

The following numbers, describing cumulative destruction, should be interpreted with three cautions. First, habitat that is designated as lost is not necessarily biologically depauperate. For example, grazed western grasslands and shrub steppe still support plants and animals, just not the same species found there prior to grazing. Second, habitat that is not considered to be lost may nevertheless be unable to support anywhere near the abundance and variety of species that it formerly did. In particular, habitat surveys tend to underestimate the effects on wildlife of fragmentation resulting from roads, recreation, rural housing, stream diversions, and other piecemeal intrusions that, individually, degrade habitat only slightly but which, cumulatively, significantly reduce the ability of the landscape to support wildlife. Third, air or water pollution and anthropogenic climate change could be affecting the viability of habitat without the consequences showing up on land surveys.

Cumulative losses of wetlands have, perhaps, attracted the most attention and scrutiny.\textsuperscript{16} This is, in part, because a sizeable fraction of animal (~1/2) and plant (~1/3) species listed under the ESA depend on wetland habitat.\textsuperscript{17} Although wetlands comprise only a small percentage of the U.S. land area, wetlands have been prime sites for conversion to agriculture or urban sprawl. According to a U.S. National Academy of Sciences (NAS) study, approximately 30% (117 million acres) of U.S. wetlands have been converted since the beginning of European settlement; if Alaska is excluded the loss rises to 53%.\textsuperscript{18}

In some regions, and for some types of aquatic habitat, the losses have been far more severe. For example, California has lost at least 80% of its historic interior and coastal wetlands.\textsuperscript{19}

\textsuperscript{15} See Noss et al., supra note 12.
\textsuperscript{16} Nat'l Research Council, supra note 14.
\textsuperscript{18} Nat'l Research Council, Wetlands: Characteristics and Boundaries (1995).
\textsuperscript{19} Jensen et al., supra note 11, at 84.
Over 85% of the flow of California's inland waters is now artificially controlled and 98% of the reach of its streams has been so degraded as to be unworthy of federal designation as wild or scenic rivers.\textsuperscript{20}

A recent study catalogues the extensive habitat loss within U.S. forests. Noss \textit{et al.} compiled results of numerous studies of habitat loss and concluded that, in the 48 coterminous states, loss or serious degradation has occurred in over 95% of "old growth" forest, 99% of the original eastern hardwood forest, and over 70% of riparian forest (with a 23% loss just since 1950).\textsuperscript{21}

Focusing in on more tightly-defined habitat categories, Noss \textit{et al.} list 27 specific habitats in the United States for which there has been greater than 98% cumulative destruction; they refer to these areas as "critically endangered."\textsuperscript{22} These habitats include longleaf pine forests in the Southwestern Coastal Plain, tallgrass prairie east of the Missouri River, dry prairie in Florida, native grasslands in California, and old growth pine forests in Michigan.\textsuperscript{23}

In addition, Noss \textit{et al.} define "endangered" habitats to be those with 85-99% cumulative destruction.\textsuperscript{24} They list 41 such habitats, including all old growth forests in Oregon and Washington, red spruce forests in the central Appalachians, coastal heathland in southern New England and Long Island, tall grass prairie, vernal pools in the Central Valley and Southern California, coastal redwood forests in California, and native shrub and grassland steppe in Oregon and Washington.\textsuperscript{25}

The picture is equally as bleak beyond the United States' borders. Among the many habitat types that are rapidly being destroyed around the globe, perhaps none attracts so much attention as tropical forests. Home to an extraordinary variety of species, tropical forest habitat is disappearing at current rates ranging in many nations from roughly 1/2% to 2% of remaining forest per year.\textsuperscript{26} An area of tropical forest approximately the size of the state of Pennsylvania disappears each year.\textsuperscript{27} Globally, the cumulative loss of tropical forest is almost 50% and cumulative


\textsuperscript{21} NOSS \textit{ET AL.}, supra note 12.

\textsuperscript{22} \textit{Id.}

\textsuperscript{23} \textit{Id.}

\textsuperscript{24} \textit{Id.}

\textsuperscript{25} \textit{Id.}

\textsuperscript{26} Michael Williams, \textit{Forests}, in \textit{THE EARTH AS TRANSFORMED BY HUMAN ACTION} 179-202 (B.L. Turner II et al. eds., 1990).

\textsuperscript{27} \textit{Id.}
losses in some nations, such as Madagascar, are as high as 90%. Tropical deforestation is largely due to two causes: timber harvesting and land clearing for grazing and crop production.

C. Historic Species Loss

Historically, there have been four major anthropogenic causes of species endangerment and extinction—over hunting or harvesting, introduction of alien species, spread of disease, and habitat degradation or loss.\textsuperscript{28} In some locations and for certain taxa, the first three have been the most critical. For example, the decline of many species of marine and terrestrial vertebrates can be largely attributed to commercial over-exploitation. Many Hawaiian bird species were driven to extinction or are now threatened by predation and diseases caused by introduced species.\textsuperscript{29} But for most species in decline and for those on the edge of extinction today, the most serious threat is habitat destruction. This is certainly true for the majority of the endangered and threatened plants\textsuperscript{30} and lesser-known invertebrates in the United States and is increasingly true for songbirds\textsuperscript{31} and freshwater fish.\textsuperscript{32}

For a variety of reasons, we have only a rough idea of the current rate at which we are losing species and the cumulative losses to date. One reason is the ten-fold uncertainty in the total number of species. Another reason, however, is that we do not even have an accurate idea of the percent loss per year. There are a few well-studied taxa for which we know accurately how many species there are today—such as North American birds—and for which we also know how many extinctions have occurred since European settlement.\textsuperscript{33} But for most taxa, historic records are inadequate. Estimating historic and predicting future losses of genetically distinct populations is even more difficult.

Where habitat loss is the cause of extinction, ecologists have

\begin{itemize}
  \item \textsuperscript{28} See Jensen et al., supra note 11, at 27-33.
  \item \textsuperscript{29} See Paul R. Ehrlich et al., Birds in Jeopardy 62-64 (1992).
  \item \textsuperscript{31} See Noss et al., supra note 12; Ehrlich et al., supra note 29.
  \item \textsuperscript{32} See J. David Allan & Alexander S. Flecker, Biodiversity Conservation in Running Waters, 43 Bioscience 32, 36 (1993); Robert R. Miller et al., Extinctions of North American Fishes During the Past Century, 14 Fisheries 22, 22 (1999).
  \item \textsuperscript{33} Four bird species of the continental United States are known to have gone extinct during the past several centuries: the great auk, the Labrador duck, the Carolina parakeet, and the passenger pigeon. Moreover, at least five bird subspecies have gone extinct and three other bird species very likely are extinct. See Ehrlich et al., supra note 29, at 62-64.
\end{itemize}
come up with a crude approach to approximating historic and predicting future losses of species. The method is based on a pattern or regularity that is often observed in ecosystems. It is called the species-area relationship (SAR) and it relates the number of species of a particular taxa (examples being birds or plants or mammals) to the area of the habitat in which the species are censused. There is a widely observed quantitative pattern to the SAR in nature: the number of species in a censused area tends to increase as the quarter power of that area. There are plenty of exceptions to the quantitative rule but the relative success of this relationship has motivated ecologists to use it to estimate the number of species lost when a given fraction of habitat is lost.

The calculation that provides the traditional estimate of extinction is simple: if, say, 25% of a habitat is destroyed, then the number of species that will survive is taken to be the number of species that 75% of the habitat can sustain. If the number of species is proportional to the quarter power of area, then the fraction that can be sustained in the remaining 3/4 of the area is $(3/4)^{1/4} = 0.93$. Hence, $1 - 0.93 = 0.07$ or 7\% of the species will become extinct. Based on this approach, global annual extinction from habitat loss is estimated to be between 1,000 and 10,000 species lost each year, with the uncertainty arising from the fact that the total number of species could range from 3 to 30 million species.

Even at the lower end of the estimate, this extinction rate is orders of magnitude higher than the "natural background" (that is, the pre-human) rate. In fact, if habitat loss continues at current rates, the resulting episode of species extinction projected over the next 50 to 100 years will be so severe as to resemble the extinction episodes that have occurred at intervals

34. That the number of species should increase with area but not linearly proportionally to area can be seen from a simple example: consider the number of plant species growing in California and the number in Nevada; the total number in both states must be greater than the number in either of the two states alone but it will not be the sum of the two numbers because some of the species in California also grow in Nevada. The actual form of the SAR can depend on the habitat type and the taxa being censused. The exceptions to the quarter-power rule take two forms: in some cases the number of species still grows like a power of area, but the power is not 1/4, while in other circumstances, the number of species does not grow like any simple power of area. The test of this is a plot of the logarithm of the number of species versus the logarithm of area—if that plot is a straight line, its slope is the power. For an excellent review of the SAR, see M. ROSENZWEIG, SPECIES DIVERSITY IN SPACE AND TIME (1995).

of roughly every few tens of millions of years when catastrophic
events, such as large asteroid impacts, caused massive
extinction episodes.  

This simple and frequently used approach to estimating
extinction under habitat loss is undoubtedly flawed—and we
cannot even say if it yields an overestimate or an underestimate.
First of all, the approach is oblivious to whether the lost habitat
happened to be particularly rich or depauperate in species (a so-
called "hot spot" or a "cold spot"). But that aside, and assuming
random areas were selected for deforestation, the habitat that
remains may consist of isolated patches, or it may consist of a
single large area and that distinction greatly affects the number
of species the remaining habitat can support. Moreover, if
remaining patches of habitat are shaped in such a way that they
are mostly edge with little interior, disturbances at the edges of
the remaining habitat may reduce its suitability for species.

D. Why Should We Care about Loss of Habitat and Biodiversity?

Table 1 provides a summary of all the major identified
reasons why we should be concerned about loss of biodiversity.
The table groups these reasons into five categories, arranged in
decreasing order of tangible significance and consequences
within the market-economic system. The first and second
categories, ecosystem goods and recreational opportunities, are,
to a limited extent, "accounted for" in policy. For example, our
Gross National Product takes into account market transactions
involving many types of ecosystem-derived goods; if a new drug
is derived from a plant growing in the wild, the sales of that drug
contribute to the GNP. On the other hand, when habitat is lost,
the lost opportunity for potential future sales of goods derived
from that habitat are not subtracted from our estimates of the
nation's wealth; moreover, no compensation is provided for the
disappointed potential future beneficiaries of those goods. By
way of contrast, society has recognized the obligation to

37. The concept of endemism may provide a better means of estimating
extinction, or at least of placing a lower bound on extinction. The species endemic to
an area are those that are unique to the area—they are found nowhere else.
Conservatively, those are the ones that will go extinct when an area of habitat is
destroyed. It has recently been shown that an "endemics-area relationship" follows
from the species-area relationship and can be used to give more reliable estimates of
extinction rates under habitat loss. A. P. Kinzig & J. Harte, Implications of Endemic-
Area Relationships for Estimates of Species Extinctions, 81 ECOLOGY 3305, 3305-311
(2000).
included. For example, inland and coastal wetlands play a role in sewage treatment because the organisms in these habitats detoxify a variety of discharged domestic, agricultural, and industrial waste products and effectively carry out secondary waste water treatment by assimilating inorganic nutrients. Moreover, wetlands help maintain potable groundwater supplies by recharging aquifers and reducing seawater intrusion into aquifers in coastal regions. In the first situation, the economic benefits from water treatment have been estimated from the cost of building and operating a water treatment plant capable of providing an equivalent service. The second benefit, preventing salt intrusion, actually played a role in a land use decision in South Florida, where the hazard to drinking water supplies that would result from drainage of the Big Cypress Swamp figured into the decision to protect this unique habitat. In that situation, the monetary benefit of this service was not estimated, but rather it was described in terms of the diminished quality of groundwater.

While it is tempting to seek improved monetary estimates of the benefits of ecosystem services, the South Florida example suggests that vivid and believable qualitative portrayals of the nature of these services and the ways in which our livelihood is linked to them may suffice. The general lack of public awareness

<table>
<thead>
<tr>
<th>Pollination of crops and natural vegetation; dispersal of seeds</th>
<th>Natural pest control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil formation and maintenance of soil fertility: maintenance of biogeochemical nutrient cycles</td>
<td>Reduction of erosion, including protection of riverbanks and coastlines, by vegetation</td>
</tr>
<tr>
<td>Moderation of extremes of weather and climate</td>
<td>Maintenance of hydrologic flow regimes, including mitigation of effects of floods and droughts</td>
</tr>
<tr>
<td>Maintenance of atmospheric composition: purification of air</td>
<td>Maintenance of water quality; detoxification and decomposition of wastes</td>
</tr>
<tr>
<td>Maintenance of a diverse gene pool</td>
<td>Maintenance of the “stage” upon which evolutionary processes unfold</td>
</tr>
</tbody>
</table>

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41. See id.
compensate, for future lost earnings, the family of a person killed in a factory accident.

The third category in Table 1, ecosystem services, is perhaps the least publicly recognized and discussed reason for caring about habitat loss. It is the consensus of ecologists who have studied the relationship between ecosystem integrity and the health of human society that the latter depends upon a variety of processes or functions carried out by healthy ecosystems. Table 2 lists the major types of ecosystem services.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>WHY SHOULD WE CARE ABOUT HABITAT AND BIODIVERSITY?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ecosystem Goods</td>
<td>About 50% of all our medicines, all of our food sources and fiber-producing plants, and even, of course, our pets and ornamental plants were derived originally from wild species.</td>
</tr>
<tr>
<td>2. Recreational Opportunities</td>
<td>From ecotourism to sales of recreational equipment, from provision of travelers' services to licences and park entry fees, eco-recreation is a major player in the economies of many nations today.</td>
</tr>
<tr>
<td>3. Ecosystem Services (see Table 2)</td>
<td>Sustain the world's economics.</td>
</tr>
<tr>
<td>4. Spiritual Significance of Nature</td>
<td>There are places on Earth that are sacred to some people, and the intense importance of those places to those people overrides countervailing economic interests.</td>
</tr>
<tr>
<td>5. Ethical and Moral Issues</td>
<td>Irreversible change is wrong; denying opportunities to future generations is wrong; human-caused extinction is wrong; disruption of the stage upon which evolutionary processes play out is wrong.</td>
</tr>
</tbody>
</table>

Although there have been efforts to place dollar values on some specific societal benefits accruing from some of these ecosystem services, such estimates should be understood as little more than rough guesses. They tend to underestimate the total dollar value of ecosystem services because only those benefits that happen to have been identified and quantified are


of ecosystem services suggests that such portrayals are, at the very least, a necessary first step in achieving the inclusion of these benefits as a factor in land use policymaking.

Other less anthropocentric reasons to care about habitat protection and biodiversity also exist. To many, these intrinsic reasons for caring are even more compelling than the practical ones because they have an ethical or moral foundation. They are summarized in items 4 and 5 in Table 1. To some extent, contrasting service value with intrinsic value creates a false dichotomy. For example, some people derive intrinsic satisfaction from the knowledge that their material livelihood is dependent on natural ecosystems. Moreover, there is a service value in living lives that are consonant with our deepest spiritual needs and our ethical and moral values—not doing so may debilitate us as much as would the absence of medicines or flood control.


The U.S. Endangered Species Act (ESA) is arguably the boldest piece of environmental legislation ever enacted by any nation. Its provisions have brought some species back from the brink of extinction, resulted in the protection of some parcels of land that would have otherwise been developed, and changed the terms of debate on habitat protection. Nevertheless, it is far from adequate in relation to the immensity of the challenge.

The original 1973 Act stated that:

- Endangered species must be identified and listed;\(^\text{44}\)
- Their critical habitat must be designated;\(^\text{45}\)
- Federal Agencies cannot jeopardize these species or adversely modify their critical habitat;\(^\text{46}\)
- Federal actions likely to jeopardize listed species can be

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43. These successes are the species that have been "de-listed" or at least pulled way back from the edge of extinction because of dramatic recovery in their numbers. These include, for example, the bald eagle, the peregrine falcon, the southern sea otter, and the black-footed ferret. Some species, like the Florida panther and California condor, are still in serious trouble, but have been greatly helped by the ESA. With a few exceptions, most of the success stories involve publicly admired species, as opposed to the uncharismatic creatures such as soil organisms that play a huge role in sustaining ecosystem functions.
44. 16 U.S.C. § 1533(a).
45. Id. § 1533(b).
46. Id. § 1536(a).
exempted only in extraordinary circumstances;\(^4^7\)

- Plans must be prepared and implemented for species recovery;\(^4^8\)

- Private parties cannot further endanger ("take") a listed species unless the harm is incidental and is accompanied by remedial planning.\(^4^9\)

Subsequent amendments and directives in 1978 and later encumbered the listing process with a variety of provisions, such as requiring application of economic criteria to the listing decision and requiring designation of critical habitat (a difficult decision to make) to be concurrent with listing.\(^5^0\) By delaying the listing process, these changes effectively threw a monkey wrench into all of the other features of the Act that are triggered once listing is carried out.

Of the approximately 1,000 species that have been listed during the history of the Act, about 1% have gone extinct, ~1/3 are declining, ~1/3 are stable, 1/10 are improving or are recovered, and for ~1/4 information is lacking. Although the Act requires that recovery plans be formulated and enacted for each listed species, the enormity of the task has prevented it being carried out for many species.

Has the ESA protected habitat? The ESA states that one of its goals is "to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved;"\(^5^1\) in addition, there are several provisions in the Act that are pertinent to ecosystem or habitat protection.\(^5^2\) Nevertheless, conservationists correctly argue that the Act is, in practice, essentially a species protection, rather than a habitat protection.\(^5^3\) Indeed, in some cases, irate landowners, fearful of finding an endangered species, have clear-cut or plowed under habitat on their property before any official survey of the land could take place. Section 7 of the ESA restrains federal actions that might harm an endangered species.\(^5^4\) Of the roughly 100,000 Section 7 cases that have arisen during the Act's history, fewer than 100 have resulted in blocked projects.\(^5^5\) More

\(^{47}\) Id. § 1536(g).
\(^{48}\) Id. § 1533(b).
\(^{49}\) Id. § 1538(a).
\(^{52}\) Id. § 1533(b).
\(^{53}\) Id. § 1536(g).
\(^{54}\) See CLEGG ET AL., supra note 50.
frequently, the outcome of these cases was a modification of project design and an avoidance of conflict.

It is, of course, difficult to know how many development projects the ESA has thwarted by simply existing as a threat or a bottleneck. Discussion of the Act's successes and failures lends itself to the sort of illogical rhetoric that surrounds the social welfare debate: "Welfare isn't working because the welfare lists are growing" (or substitute equivalent language for support for public education). The ESA is working better than the alternative of no ESA, but a recent National Academy study concluded that improvement is needed.\textsuperscript{55} For example, the ESA provisions regarding habitat protection on private land require clarification and strengthening. This is exemplified by the fact that, although there is no ecological basis for such a distinction, the ESA affords plants weaker protection than animals. At a more fundamental level, scientists express serious concerns about the nature of the burden-of-proof provisions in the Act. Currently, that burden rests on the Act's administrators; thus species and habitat are, in effect, considered to be healthy unless proven otherwise.

\textbf{F. Other Approaches to Protecting Biodiversity and the Integrity of Ecological Habitat}

The ESA holds a special place within the pantheon of environmental policy instruments. The Act's virtually inflexible goal of protecting endangered species is backed by law that, in principle, often trumps the legally-backed or traditionally-held rights that justify actions negating that goal. But the ESA may be weakened in the future and, as previously discussed, even in existing form, it contains loopholes and other weaknesses. Fortunately, the ESA is not the only policy instrument available for shaping land use policy and protecting biodiversity at the federal, state, and local level. Among available options are a wide variety of environmental protection laws, zoning restrictions, property tax policies, land acquisition programs, regional planning efforts, hunting and fishing regulations, and water allocation policies. Indeed, most of the creative thinking now occurring in the area of land use policy and species protection is directed at enlarging and strengthening these non-ESA approaches.

A comparative analysis and evaluation of the scope and effectiveness of this array of policy instruments cannot be undertaken here, nor to my knowledge has such a review been attempted. It is clear, however, that the effectiveness of these non-ESA approaches varies considerably with geographic location as a result of the variance in the matrix of state and local laws within which these instruments operate and sometimes collide.

That such a broad array of policy instruments has evolved to deal with land use decisions (in contrast, for example, to the relative simplicity of policies designed to deal with air quality) reflects the unique attributes of the challenge of land use and habitat loss. These unique attributes are described next.

II
WHAT IS SPECIAL ABOUT THE PROBLEM?

What is special about the challenge of habitat loss and its effects on biodiversity and on human well-being? How is this challenge different, scientifically, from the challenges posed by climate change, stratospheric ozone depletion, acid rain, and other environmental problems? What unique and particularly difficult problems does it pose for public policy? Why might this be the most intractable of all the currently identified environmental challenges?

A. The Centrality of Land Use: A "Thought Experiment"

A destructive kind of synergy is acting among our many environmental threats, with each reinforcing the severity and impacts of the others. But in many ways, land use has a special status within this web of interacting threats. Imagine for the moment that the human inhabitants of Earth are living in a sustainable fashion on the land, most native habitat is undisturbed, ecosystem functions are largely intact, and life's diverse forms are flourishing. Nevertheless, a sudden natural release of methane from the sea floor to the atmosphere is about to occur and the amount of this released greenhouse gas will result in a 6 °F globally-averaged warming. How concerned


57. This is within the range of estimated warming expected from a doubling of the atmospheric level of carbon dioxide, which will likely occur around the middle of the twenty-first century.
should the people be?  

The coastal wetlands and dune habitats are healthy, and thus the danger of coastal erosion, loss of coastal zone wildlife, and salt intrusion into water supplies will be minimal. The warming will raise sea level but because the people have not built their dwellings too close to the sea there will be no direct threat to their homes. Because habitat immediately inland of coastal wildlife zones is intact and undisturbed, these zones will generally shift inland slightly as sea level rises and wildlife populations will generally adapt to the change.

The warming will increase summer temperatures, but with plenty of unfilled and undrained lake, bay, and wetland habitat surrounding areas of human habitation, natural cooling mechanisms are expected to reduce the impact of "killer heat waves."

The warming will tend to increase the intensity of extreme droughts and floods, but intact forests and healthy soils will reduce the threat of soil erosion from more intense rainfall, the likelihood of drought, and the effect of drought on crops.

The warming will promote crop pests and provide disease insect vectors an opportunity to spread to higher latitudes, but with natural insect predators such as birds in abundance, and a diversity of crops planted on farms, minimal effects are anticipated.

The warming will cause many wild species that cannot tolerate the altered climate to seek out habitat either upslope or poleward where the climate will be favorable again; because of the plentiful protected land, ample corridors exist wherein many species can disperse to locations with more suitable climate.

Clearly, these imaginary people have far less reason to be concerned about their impending climate change than we do about ours. Their remaining ecosystems are better protected than ours are and their ecosystem services are sufficiently robust to protect their health and economic well-being against the assaults of climate warming. The ecological integrity of the land protects these people.

This is just one of numerous examples that can be offered to illustrate a general point: the effects of most environmental threats to humanity are greatly exacerbated by land use practices that destroy habitat and degrade ecosystem processes that provide ecological services to humankind. Although ecological degradation will greatly influence the effects of global warming, in contrast, it is more difficult to make the case that climate change will greatly exacerbate the effects of
deforestation. When a forest is clear-cut, the native biota in that forest are gone anyway, regardless of what the new climate is.

Not only does habitat destruction exacerbate the impacts of global warming, it also contributes to climate change. Land use practices have demonstrably altered climate in the past and are likely to do so at an even greater pace in the future. Indeed, at local to regional scales, land use impacts on climate can be comparable to, or greater in magnitude than climate changes anticipated from, say, a doubled carbon dioxide level in the atmosphere. Land use directly affects climate principally by altering the amount of sunlight reflected from the surface of the land and by altering evapotranspiration rates.\(^5\)

Moreover, deforestation indirectly affects climate because it results in the eventual net release of carbon dioxide to the atmosphere when the remains of the felled trees decompose. It is estimated that during the past few thousand years, anthropogenic alteration of landscapes, including deforestation and tillage, have released into the atmosphere an amount of carbon dioxide equal to about 75% of that released by fossil fuel burning since the beginning of the industrial revolution.\(^9\)

Land use practices can influence not only the intensity and consequences of global warming but also the impacts on human society of unusual weather events. In 1999, Hurricanes Dennis and Floyd caused tremendous damage in North Carolina, including flooding, erosion, and siltation. To the surprise of many, the storm resulted in putrescent masses of rotting organic matter washing down into the state's estuaries, which led to anoxic conditions and fish kills along the coastal zone. In one sense, the origin of this problem was hog and chicken farm wastes, fertilizers flushed from farms and lawns, and sewage. But the root causes involve land use practices that interacted in a negatively synergistic manner.\(^6\) The cumulative amount of

58. See generally INT'L GEOSPHERE-BIOSPHERE PROGRAMME (IGBP), 39 GLOBAL CHANGE NEWSLETTER 1-31 (1999) (providing an excellent set of brief but authoritative review articles on the effects of land use on climate). Closely related to this topic, it has been pointed out that changes in surface land cover induced by “greenhouse effect” warming will undoubtedly cause feedbacks to climate change. See Daniel A. Lashof et al., Terrestrial Ecosystem Feedbacks to Global Climate Change, 22 ANN. REV. ENERGY & ENV'T 75, 75 (1997). These effects have been studied both empirically and with mathematical models; unfortunately, there has been a lack of overlap between the locations and time scales that have been modeled and those for which solid data exist.


land in the state that has been deforested or tilled exacerbated the magnitude of the flow at flood crest and the amount of eroded soil carried by the surging waters. Prior degradation of coastal wetlands reduced the assimilative capacity of the estuaries to remove excess nutrient in fertilizers and sewage from the floodwaters. Finally, the sheer scale of hog and chicken farming operations in the state and the excessive amounts of fertilizer and pesticides used in farming resulted in an accumulation of inorganic nutrient, organic wastes, and toxic substances that were bound to be flushed out by a large surge in surface runoff.

B. Multiple Causes of Habitat Loss

The causes of habitat loss are varied and intertwined. Virtually every human activity affects how land and water are used, thus affecting the quality and quantity of habitat on Earth. In contrast, a single activity, fossil fuel burning, is primarily responsible for the emission of the greenhouse gas, carbon dioxide, to the atmosphere and a second activity, deforestation, accounts for virtually all the remaining carbon dioxide emissions. Activities that destroy habitat can range from subsistence living to harvesting wild species for commercial gain, from modern large-scale agriculture to backyard gardening, from large dam construction to off-road recreation. The way in which activities such as housing, recreation, transportation, agriculture, and mining are carried out, and the scale at which they are carried out, greatly influences the degree to which habitat destruction occurs; for each activity there is a continuum of options. Simplistic arguments abound for the virtues of, say, subsistence living, but even that lifestyle could be enormously destructive to habitat if practiced by 260 million people in the United States. These themes are revisited in "Towards a Solution" below.

Habitat loss is further complicated by the fact that the primary cause is generally not the emission of offending substances; thus land use challenges do not resemble classic pollution problems. Consider the contrasting case of global warming, where the emission to the atmosphere of a small number of substances (carbon dioxide, methane, and the other anthropogenic greenhouse gases) causes the environmental problem. Consequently, solutions to the problem of global warming can be conceptualized within the framework used to deal with classic pollution problems, for which there is ample
precedent in environmental measurement, regulation, and enforcement. Moreover, because the emitted substances causing global warming mix in the atmosphere, the combined effects of greenhouse gas emissions occurring at different places around the planet are independent of where those emissions occur. In contrast, the environmental effects of land use practices are highly dependent on the locations and the specific nature of those practices and, as in the example of hurricane damage in North Carolina, on the synergistic interrelationships among them.

C. Ambiguous Damage Symptoms

There is no agreed-upon set of useful measures for evaluating the severity of habitat degradation or biodiversity loss. In contrast, there are a small number of useful and agreed-upon measures with which scientists can communicate with each other and the public about the magnitude of climate change: globally or regionally-averaged temperature and sea level being two important ones. Similarly, scientists can describe the depletion of stratospheric ozone and its effects on ultraviolet radiation by using concentration and radiation flux contour maps; coupled with dose-response curves showing how cancer or other health effects of ultraviolet radiation depend on dose, the scientists can vividly portray the impacts on humanity. Acid rain can be characterized by its pH, and its effects on lake chemistry can be described by a chemical quantity called “alkalinity.” Counting the loss of gene pools, as a way of quantifying the loss of biodiversity, is impossible in most situations because the scientific technology for doing this is not adequate to the task. Counting extinct species is of limited value, not merely because the species concept is an ambiguous one in biology, but more importantly because species are only one of many measures of diversity in biology. Species loss is almost certainly not the best measure of the loss of ecosystem services but no alternative measure appears adequate to the task. More generally, we simply do not know of a widely applicable measure of the severity of habitat degradation except in special cases such as wholesale deforestation. By way of comparison with global warming, imagine the state of climate science if physicists could not agree about the meaning and utility of the concept of temperature.

Habitat loss is piecemeal in space and incremental in time. Thus, it is difficult to see a point where we are forced to say,
"enough is enough." Because habitat is "nickeled and dimed" away rather than lost in large and highly visible quantities, it is difficult to assert with confidence that any particular loss of a population or species is attributable to an increment of land destruction. Unlike the dramatic effects of a major toxic chemical spill or a nuclear power plant accident, the effects of habitat loss are usually subtle. As in climate science where benchmark values of atmospheric carbon dioxide (for example, a doubling from the pre-industrial concentration) or temperature change (for example, the temperature difference between the depths of the last ice age and today) can be defined and used as comparison points for seeing where we are today, we can compare species losses from anthropogenic habitat loss with species loss during a major asteroid impact. But whereas the paleoclimate record offers considerable insight into the likelihood of abrupt climate change in the near future, evidence from past catastrophic extinction events has yet to provide much insight for conservation biology today.

Unfortunately, our inability to predict future population and species losses, to estimate accurately historic losses of genetically distinct populations or species, and to define thresholds beyond which we dare not pass provides proponents of unrestrained land use with ammunition that they use unabashedly.

D. Difficulty Quantifying Links Between Ecosystem Processes and Human Well-Being

The benefits to humanity of habitat integrity and biological diversity are often the consequence of ecological services that are:

- invisible and, therefore, readily taken for granted. In the San Francisco Bay area, Lyme disease is relatively rare, even though the tick vector is abundant. One recently discovered reason for this is that a rather little-appreciated species, the fence lizard, which inhabits the rapidly disappearing open spaces around the already-settled areas in the suburbs, detoxifies the ticks when they attach to the lizard, as they frequently do. Another example of an "invisible" ecosystem service is the regulation of ultraviolet radiation levels at the Earth's surface. This ecosystem service is carried out by certain microorganisms, called denitrifying bacteria, which produce nitrous oxide as a byproduct of their metabolic activity. Nitrous oxide passes to the stratosphere where it
influences the concentration of ozone and that in turn influences the ultraviolet radiation flux that we receive.

- complex and, therefore, difficult to characterize, let alone quantify. Consider, for example, the factors that preserve genetic diversity within species of direct commercial benefit to humankind such as wild salmon or trees used for timber. Maintaining large total numbers of individuals within a species is critical to preserving genetic diversity, as is preventing artificially enhanced intermingling of different populations. Beyond that, scientists still only have a poor understanding of the ecological conditions maintaining genetic diversity.

- probabilistic in nature and spread over space and time and, therefore, the resulting degradation of human well-being that their loss entails is difficult to connect to specific acts of ecosystem degradation. For example, in hilly terrain, the benefits of forested landscape on flood and erosion control may only be apparent, on average, every hundred years when a major storm occurs; thus the people who suffer from a particularly intense event may not connect their vulnerability to the deforestation that occurred several generations earlier. Similarly, people living hundreds of miles downwind from a massively deforested area may not associate increased likelihood of drought with the loss of transpiring trees far upwind.

- rarely substitutable and, if they are, the substitution often brings either huge or unknown financial cost and unpleasant non-market consequences. Consider, for example, the use of chemical pesticides to replace the natural pest control that is lost when bird populations are reduced by habitat degradation. This replacement brings about a host of human and ecological health problems for which we do not even know the full cost today. More frequently, such substitutes do not exist, as is the case with natural genetic templates that can be exploited for new crop lines in agriculture and new drugs for medical care.

In contrast, local potential effects of global warming, such as sea level rise or intense heat waves or drought, would tangibly affect people in ways that are relatively easy to characterize (if not predict in detail) and are relatively easy for the public to grasp. We all experience the weather much more directly and vividly than we do the life support processes and the diverse life
forms that constitute a forest or a meadow. For all these reasons, people will undoubtedly continue to be even less responsive to the threats of loss of biodiversity than they are to the threat of climate change.

E. No Single Technological Fix

As a consequence of the fact that multiple activities lead to habitat destruction and there is an absence of a “controllable substance” causing the damage, no technology (such as low-cost hydrogen fuel cells or solar-thermal industrial heat generation for climate change prevention) has much chance of making a significant dent in the problem. In a misguided belief that genetic engineering can relieve us of our obligation to save genetic diversity, many technologically uninformed people claim that we can afford to destroy habitat because we can recreate genetic combinations whenever we choose. This ignores the fact that genetic engineering can alter genes by replacing selected ones with other selected ones, but it cannot do so without the natural templates. The reason for this is simply that natural selection has led to a literally unimaginable variety of options in nature—and we are currently losing genetic information far faster than we can study and blueprint it.

In certain situations, of course, technological solutions can be of the utmost importance in alleviating land use problems. For example, the development of techniques for producing large sheets of plywood from sawdust and scrapwood has reduced somewhat the rate at which large trees in old growth forest are being cut. There are undoubtedly opportunities to make further advances in the amount of food that can be produced on a unit of land, thereby reducing the need to convert natural habitat to cropland. Such advances, however, could well be negated by increasing human population, eroding soils, and possible water shortages resulting from climate change. Moreover, some proposed technological solutions to other challenges that we face might exacerbate land use problems; for example, enhanced use of biomass fuels to substitute for fossil fuel use might readily enhance demand for more cropland and thus increase human impacts on habitat.

F. Parks Cannot Solve the Entire Problem

If, in the past, there has been a single most important
category of solution, it surely has been the public purchase and protection of land. Historically, creating parks and refuges has been essential to the protection of biodiversity both in the United States and abroad. It is undeniable that continuing such land acquisition would help protect biodiversity in the United States. Creating environmental preserves, however, cannot adequately solve the land use dilemma. First, many biologically important types of habitat are not adequately included in our currently protected lands, with over half of the endangered species in the United States having 80% or more of their habitat in private ownership. These critical areas of privately owned land are sufficiently vast that no plausible scale of future public purchase of private land is likely to protect sufficient land to qualify as a "political fix." We return to this issue in the last section where we discuss regional planning on privately owned land. Second, in most categories of protected public land, including even officially designated Wilderness Areas, combinations of activities such as grazing or mining or hunting are perfectly legal; even if such activities are prohibited within the public land, activities on immediately adjacent lands can result in damage that spills across the borders of the park. Third, preserves do not provide adequate protection to migratory species, which may winter in a preserve but breed in unprotected and degraded habitat. Fourth, with the exception of a few parks such as Yellowstone or The Everglades, most protected areas are too small to sustain regional-scale ecosystem services such as moderation of the climate or the hydrocycle; they are also often too small to sustain wild populations of large carnivorous mammals. Fifth, many protected areas, including The Everglades, are not hydrologically isolated; thus water flowing into the park may be degraded either in quality from pesticides, fertilizers, and industrial wastes, or in quantity when water is diverted upstream for other uses. Sixth, there are severe political and economic limits to the amount of additional land that can be purchased. Seventh, for many of the species found primarily on private land, we do not have the data to evaluate their conservation status. In summary, parks are of great value for protecting ecosystems and biodiversity but the challenge is far greater. We must find new approaches for

61. This statement is not meant to detract from the tremendous contribution to conservation made by groups such as The Nature Conservancy that purchase and protect private lands for their value as habitat for rare or threatened species. For a more optimistic viewpoint than the one expressed here concerning the feasibility of safeguarding biodiversity by land purchasing, see Alexander N. James et al., Balancing the Earth's Accounts, 401 NATURE 323 (1999).
integrating privately held land into a network of quasi-protected habitat.

G. Private Land Use Rights in the United States Are Passionately Held

By and large, most people in the United States have accepted, albeit sometimes grudgingly, a certain set of constraints on what we can do on our own land. Thus, in certain locations with severe air quality problems, we accept constraints on the design and/or use of wood stoves in our homes. During times of severe wildfire hazard, we accept bans on backyard leaf burning. Some communities require that a landowner prune or remove trees to avoid blocking the others' views or maintain manicured front lawns. In addition, when a sufficiently great public interest is established, the public can use eminent domain laws to take land from an owner, with compensation. But the situations listed above all involve land uses that impose tangible aesthetic or safety impacts on our neighbors or involve some other clearly identified public interest at stake. Otherwise, the widely held view that land ownership is inviolate and that we can do what we wish on our own land is the prevailing force governing land use.

H. Acres, Genes, and Bytes: Speculations on Land Use as an Imbedded Challenge

Over the next 100 years, the problems we have been describing will be increasingly entwined with, and exacerbated by, two other global challenges: the increasing power and use of genetic engineering and the information revolution.

Genetic modification of plants and animals has the potential to provide direct benefits to humanity. For example, genetically-enhanced vitamin levels in foods could help alleviate worldwide malnutrition. But the potential for subtle forms of harm is also present. For example, genetic engineering provides the illusion that humanity can be weaned off its historic dependence on wild plants and animals as the raw material for selective breeding of its food crops and for a large share of its medicines. Were this illusion to become embodied in policy, efforts to save habitat and biodiversity would be even more impeded than they are today.

The belief that our well-being is independent of that of wild species is illusory for several reasons. First, if our habitats cannot sustain wild species, they are unlikely to sustain engineered substitutes. Secondly, substitutes maintained in
"gene zoos" are certainly not going to be regulating the hydrocycle, building soil, eating insect pests, and carrying out all the other functions listed in Table 2. Thirdly, while genetic engineering can modify the genetic composition of an organism, it cannot find substitutes for the templates that evolutionary processes have provided us in the form of adaptations in nature. For example, the genetic blueprint for nitrogen fixation can be modified and transferred, but if our ancestors had eradicated all such organisms we would lack the templates from which we could make further developments. In other words, while we increasingly have the technical capacity to build what we want when we know what it should look like, without templates we would lack the knowledge to determine what the desired genes should look like. Moreover, it would be a serious mistake to think that we have already discovered all the genetic opportunities that reside in our wild ecosystems.

Genetic engineering of germ cells (that is, engineering of traits that can be passed on to descendents) also brings with it the risk of accidentally releasing genetically modified organisms (GMOs) into the wild. Ever since people began breeding domestic plants and animals thousands of years ago, the risk of escapees altering natural ecosystems has existed. The difference is quantitative, not qualitative; selective breeding cannot produce the radical changes that genetic engineering can. The likelihood that an escaped GMO would alter natural ecosystems is widely debated. Evidence that a released GMO might alter the natural ecosystem comes from years of experience with the successful establishment of many wild species released from their natural habitat; exotic wild species that have been released accidentally or on purpose have had enormous effects on natural biodiversity. On the other hand, if scientists only modify somatic (non-reproductive) cells or successfully design GMOs to be sterile, these issues would not be of concern. Some conceivable worst-case scenarios certainly warrant further

62. One need only look around the San Francisco Bay area to see the effects of introduced organisms. Eucalyptus trees, introduced originally, and misguidedly, as a source of timber early in the twentieth century, now dominate many forested areas. The native, drought resistant, perennial grasses of our oak-grassland habitat have been out-competed by introduced annual grasses brought in originally for their value to cattle. The Bay, itself, now has abundant populations of many introduced invertebrate species. Andrew Cohen & James Carlton, Accelerating Invasion Rate in a Highly Invaded Estuary, 279 Sci. 555-58 (1998).

63. To take a single hypothetical example, consider the "manufacture" of microorganisms that can rapidly digest recalcitrant organic materials that are only slowly decomposable by ordinary organisms. Such designer microbes could clean up
study before we proceed any further with our technological capability for germ cell modification.

My concern over genetic engineering goes further, however. Throughout human existence we have affected human evolution by cultural modifications that influence the mating and breeding opportunities that our genetic blueprints allow us to take advantage of. Now we are on the threshold of affecting the blueprints themselves. While the capability does not currently exist, there can be little doubt that we will soon have the capability to genetically modify human lifespan, create designer human babies, and alter future human lineages by using new technological capabilities in germ cell modification. The option to have a designer baby would, if it became a reality, probably tend to reduce human diversity, channeling humanity toward homogeneity as a consequence of converging perceptions of what is desirable in people (just as international airwaves and printed matter channel once-remote societies toward a globally homogenized culture).

Homogeneity, genetic or cultural, is worrisome for a number of reasons. First, its effects on social equity are troublesome—it will surely be mainly the rich and powerful who can take advantage of the putative opportunity to extend life span and create designer babies. Second, unique cultures and unique habitats have historically been intertwined. The indigenous Tibetan culture and environment illustrate this two-way coupling. The Tibetan nomadic life style, their rituals associated with death, and many other aspects of their culture represented workable adaptations to their soil, their climate, and their wildlife. Integrating the Tibetan people into the economy of China obliterated an important reason for respecting and protecting the land. Now, Tibetans can earn cash bounties by shooting snow leopards and letting Chinese traders sell the pelts to overseas collectors. In addition, Tibetans are now able to provide meat for the Han Chinese colonizers of the region by greatly increasing sheep and yak herd sizes; this change comes at the expense of the habitat of native wildlife. Because a more homogenized society is likely to be satisfied with more homogenized habitats, enabling the homogenization of society could lead to declining diversity at the landscape scale—just one more nail in the coffin of oil spills and other types of organic chemical wastes. Confined to the organic substrate for which they were designed, such organisms might be of great value, but escapees that enter the mammalian gastrointestinal system might wreak havoc, and in a worst case scenario, humanity would be at grave risk.

64. See Harte, supra note 38.
of biodiversity. It may, of course, be farfetched to make this leap from designer babies to cultural homogenization to loss of landscape-scale biodiversity, and it may be very difficult to witness these interconnections, which of necessity operate in slow motion when viewed in real time. Looking back in historical perspective from the future, however, this linkage may well be apparent. About the only bright spot on this particular horizon is the near-certain backfiring of efforts to breed genetically modified "super children."

Information technologies pose threats that are related to those stemming from genetic engineering as well as presenting other unique hazards. An illusion offered by the information revolution is that "virtual realities" can substitute for experiences of nature. Another illusion these technologies encourage is the belief that high-speed processing of data will allow greater control of complex managed systems to the point where they can substitute for ecosystem services.

It is no illusion, however, that electronic communication makes it increasingly possible for people to live and work in remote areas, thereby increasing the dispersal of the population and thus the intrusion of people into wilderness—much the way that the automobile began doing many decades ago.

Finally, social isolation and loss of community are the price we may be paying for electronic togetherness. The effects of this on society's willingness to protect ecological integrity are unpredictable. Electronic communication is gearing up to be a highly effective means of political organization and mobilization, but we cannot foresee whether it will be used more effectively by those seeking to protect, or those seeking to exploit the land.

Humanity now possesses three mutually reinforcing capabilities: the capability to transfer information at unprecedented rates, to modify the land to an unprecedented degree, and to engineer genes for the first time. A common thread linking these three capabilities is that each appears likely to undermine society's level of concern about protecting biodiversity and the ecological integrity of the land. As mentioned, the revolutions in genetics and in information each inadvertently create the illusion that nature is unnecessary; thus they promote further biological depauperization of the planet. Loss of biodiversity may also feed further loss because for many people it is the memories of childhood experiences of nature that motivate later efforts to preserve wilderness and biodiversity. If children in the future do not even know what they are missing, they will be less motivated to save the little that is left.
Unique and complex problems, like that of habitat loss, do not necessarily call for unique complex solutions. The following section makes no case for radical legislative innovation, but rather argues that the solutions to our land use problems likely lie within the realm of rediscovered prosaic precedents.

III
TOWARDS A SOLUTION

Using land wisely and protecting biodiversity is essential to human well-being; to many it is a moral imperative. Our current science provides compelling insight into the dimensions of the problem and the need for action, but many gaps in our knowledge still exist. The complexity and uniqueness of land use issues suggests that the types of legal instruments developed to solve more conventional environmental problems may be inadequate for protecting biodiversity. Demographic and other societal trends suggest that the problem will become more, not less, intense in the future if we fail to enact new and effective policies. Thus the problem of land use and biodiversity poses a major challenge to science, to the law profession, and to planning and politics. While the challenge is great, it is not insurmountable.

Another quote from Weinberg will help us frame this discussion:

What are the responsibilities of the scientist in transcientific debate? Though the scientist cannot provide definite answers to trans-scientific questions any more than can the lawyer, the politician or a member of the lay public, he (sic) does have one crucially important role: to make clear where science ends and trans-science begins.65

I examine here two issues: the scientific advances needed to improve our knowledge of biodiversity, and some of the policies that will likely be needed if we are to prevent further loss of populations, species, and habitats.

A. Needed Science

Additional science is not needed to motivate conservation measures—compelling evidence based on sound science already exists. Rather, better science will give society increased confidence in the quantitative measures that express the magnitude of the crisis and the benefits from alternative

65. See Weinberg, supra note 4.
remedial policies.

Arguably, the greatest gap in our strictly scientific understanding of biodiversity exists not at the interface with policy; rather, it is the quantification and role of diversity at the genetic or population level where scientific knowledge is lacking. When an acre of old growth forest or wetlands is destroyed, we do not know how much distinct and unique genetic information is lost. Moreover, we do not know what the ecosystem-level consequences are of that loss. The reason we do not know these things is that adequate tissue sampling and genetic analysis, characterization, and cataloguing demand tremendous skill and time. Technical expertise in this area is drawn to the more financially rewarding biotechnology arena; field ecologists and taxonomists cannot even keep up with the need to characterize diversity at the scales of habitats and species. Increasing knowledge concerning population-level diversity in ecosystems is likely to bring many surprises, both with respect to our awareness of the magnitude of loss when land is destroyed and with respect to our understanding of evolutionary processes. This knowledge will not be acquired, however, until society makes a serious financial commitment to funding this neglected area of scientific research.

The second major need for more science is at the interface with policy. Here, the scope and direction of research should consciously and unabashedly reflect human values. Science has only explored and characterized the periphery of ecosystem services and the ecosystem processes that generate these services. The fundamental need here is to decipher and convey to the public an understanding of the value of these services—not so much to develop more accurate monetary estimates of the value of these services, but rather to understand in biophysical terms the nature and extent of these services and their dependence on how pristine an ecosystem is (including the degree to which population- and species-level diversity are intact). Because our values influence the relative importance we place on various ecosystem services and our desire to preserve them, the choices scientists make in conducting these studies can reflect those values. We have learned the hard way that the confidence placed by the public in information from the engineering community regarding, say, reactor safety, can be undermined by undisclosed biases that eventually surface. Thus, it is important for ecologists to be publicly clear about the values that shape their studies. Obscuring the unscientific facets of our ecological investigations is a symptom of unscientific thinking.
B. Needed Policy and Planning Approaches

I will not elaborate on the many valuable solutions that have been widely discussed elsewhere, such as:

- restore degraded habitat, decommission old dams;
- purchase more land, particularly large contiguous areas, and place it in protected status;
- provide further protection for existing parks and preserves, including enforcement of existing regulations on land use in protected areas;
- promote ecosystem-level planning in biodiversity "hot spots", such as has occurred in the Everglades, in California's South Coast shrub habitat, and in the Yellowstone Basin;
- personally reduce consumption and waste of resources;
- elect politicians who understand and are responsive to the problem;
- support local, national, and international environmental groups;
- continue the enormous progress that has been made in primary and secondary education in the area of conservation and environment; and
- provide property tax breaks and other financial incentives for landowners who preserve habitat;

Instead, I want to sketch two related tactical approaches for managing what people do on privately-owned land and one broader strategic direction that I believe society must pursue if we are to meet the challenge portrayed here. The tactical approaches are related to the fourth item in the list above, ecosystem-level planning, but would enhance the geographic reach of this strategy and expand it from regions that are biodiversity "hot spots" to a much broader range of habitats and locations.

As a result of our increasing numbers and affluence, huge areas of once ecologically healthy private land in the United States, far more land than is now or ever could be in public protected status, are gradually being converted to land with little ecological value. These lands either already, or soon will, fail to provide most of the benefits listed in Tables 1 and 2. One reason is that the vegetation planted on much of our private land is: (a)
non-native or for other reasons provides unsuitable habitat for native wildlife; (b) unmatched to the local climatic conditions so that, for example, it is dependent on scarce water during dry times; (c) incapable of adequately moderating the local climate; and (d) dependent on anthropogenic chemical pesticides and fertilizers. An additional reason is that much of this land is fragmented by fences, roads, water diversions, the presence of people, and other anthropogenic interruptions of the movement and other activities of wildlife, the flow of water, and the dispersal of plants. A third reason is that altered local climate, mixes of plant species that have disrupted carbon and nutrient cycling, the addition of non-native soils to replace lost native soils, compaction and other causes of reduced soil aeration and water-holding capacity, and disrupted surface runoff patterns disrupt biogeochemical processes on these lands.

The most obvious examples of this stem from the trends across the nation toward increasing suburbanization and exurbanization (extremely low density residential development in rural areas).\textsuperscript{6} First, consider suburbanization. No one aerially viewing places such as Contra Costa or San Diego Counties in California or practically any suburban area in the Eastern United States can avoid seeing the vast areas of suburban sprawl. During the mid-1980s in the United States, the average rate of land conversion from farmlands and forested lands to dwelling space was approximately 1.4 million acres per year; within a decade this rate had roughly doubled. The current land conversion rate of approximately 3 million acres per year represents a loss of 0.2\% per year of the total privately held land area of the United States. This trend is creating patchworks of ecologically incoherent micro-landscapes that, as a whole, cannot support the diversity of species and the ecological functions of the habitats that previously existed on the land.\textsuperscript{7} Along with efforts to improve land use practices accompanying agriculture and forestry, success or failure in reversing this

\textsuperscript{6} This phenomenon has been driven recently by a booming economy and by the revolution in electronic communications, providing people with the opportunity and flexibility to build their only, or perhaps second, home in remote mountainous or coastal locations. In California, the fragmenting effect on native habitat of exurbanization is readily witnessed along the Sonoma Coast, in the Napa Valley, and in the Lake Tahoe Basin.

\textsuperscript{7} Not all species decline, however, as a result of suburbanization. In many areas, deer, raccoons, skunks, and other animals readily exploit planted gardens, the contents of garbage cans, and other anthropogenic resources more effectively than they could the land that the suburbs replaced.
trend is critical to the future of ecosystem integrity in the United States.

The force guiding the "ecological" character of these new suburban and rural landscapes is by and large the desire of people to have pretty and sometimes edible or shade-producing plants in their enclosed yards. At the regional scale, some planning occasionally occurs to prevent housing development in ecologically sensitive areas and to preserve open space. Once the yards are carved out and homes are built, however, the detailed choices of what species are planted in those yards are mostly determined by a combination of homeowner nostalgia for certain plants and the species that local nurseries happen to be offering. With hundreds of thousands of homes springing up within what was once an ecosystem, the task of planning and coordinating to create landscapes with ecological integrity seems hopeless.

Yet, perhaps it is not. The barriers are two-fold: ecologically-informed planning may not be possible, or if it is possible, plans may not be easily implemented. Consider the specific issue of what people plant on their suburban half-acre plots. Ecologists possess the knowledge to do today, on a scale of hundreds or even thousands of square kilometers, what planners like Frederick Law Olmstead knew how to do over 100 years ago on a scale of city parks and university campuses. On paper at least, ecologists could devise a plan for suburban areas that would result in a mix of native backyard plants that provide suitable food, cover, and nesting sites in synchrony with the needs of native birds and other wildlife. Ecologically informed regional planning would take into account the biometeorological characteristics of plants, the functional role of soil, and the natural hydrology and biogeochemistry of the landscape. The ultimate goal would be to maintain the integrity of the mosaic of habitats that comprise the regional landscape.

The real issue is whether people would accept this. In one suburban area, the immediate environs of Santa Fe, New Mexico, ordinances designed to achieve this have been imposed on backyard planting. In other suburban areas, however, stories are legion of neighbors protesting the unmanicured appearance of yards with native plants. Education and successful demonstration projects are crucial to the success of such an effort. Modest property tax breaks for compliant landowners would expedite acceptance.

In the long term, the phenomenon of exurbanization may well pose an even greater threat than suburbanization. Across many of the more remote and relatively pristine areas of the
nation, even on private enclaves within public lands, private homes are being built at an enormously accelerating rate. Large amounts of newly acquired wealth, the product of a boom economy, are being invested in second homes, retirement homes, and rental property. Accompanying this, and often spurring it on, is the expansion of golf courses, ski resorts, and other recreational facilities. As the enclaves and interstitial spaces within large areas of public land are developed, the effect is to fragment the public lands, reduce their value as truly isolated wilderness and as wildlife habitat, and eventually interfere with ecosystem services. Ironically, the people building these wilderness homes choose the locations for precisely the qualities that their collective actions are degrading.

What can be done about this? The type of coordinated regional planning for suburban sprawl discussed above is not really a solution here because the newly developed lands are so spread out in space. On a smaller spatial scale, individual rural communities can attempt to zone development to keep the impacts of ruralization to a minimum. The economic pressures to permit unchecked growth, however, are quite potent. One solution might be to provide potential homeowners with the financial incentive to improve existing rural housing, where roads are already in place, rather than opening up new parcels for housing construction. Although urban housing renovation schemes can have serious equity consequences when they squeeze the urban poor from the rental market, this is less likely to be a problem in rural areas because property ownership is prevalent there.

Another approach is, of course, public acquisition of the most critical parcels of land. The goal would be the creation of large areas of contiguous protected land with private inholdings within those large wilderness areas limited by design to insure the ecological integrity of the region. A valuable tactic here could be carefully designed land swaps, where enclaves within, and connecting corridors between, protected lands would be acquired in exchange for already degraded public lands within or at the periphery of already despoiled areas. This would concentrate settled areas and preserve the integrity of the surrounding landscape.

Realistically, however, implementation of regional-scale planning with voluntary compliance and public purchase of rural enclaves and interstitial lands will not adequately solve the larger challenge. Probably only a "sea change" in attitudes about private property will suffice. Today, we accept constraints on
what we can do on our own land if and only if we are convinced that our own and the public's well-being is seriously at stake. The destruction of the ecological life support system on private lands across the United States does, in fact, threaten the public's well-being. But the science behind that statement (from the fascinating details, such as the discovery of the fence lizard's role in reducing the threat of Lyme disease, to the grand truths such as that forests protect fisheries, hedgerows support natural predators of crop pests, and water bodies moderate climate) has not been adequately communicated to the public.

Again, Weinberg:

But when what we [scientists] do transcends science and when it impinges on the public, we have no choice but to welcome the public— even encourage the public— to participate in the debate. . . . The most scientists can do is to inject some intellectual discipline into the republic of trans-science; politics in an open society will surely keep it democratic.68

Further down this road, the public will accept and promote ecologically-motivated constraints on what we do on our own land only when it is collectively convinced that the well-being of society hinges on that acceptance. In the long run, the solution will lie, as it must in a democracy, with an informed electorate acting, as it always does, out of its own perceived self-interest.

68. See Weinberg, supra note 4.