Unfortunately, we know the geographical ranges of only a small proportion of the already small proportion of species for which we have names. We do have a comprehensive understanding of the geographical patterns of species richness (*20*). Its lessons are not encouraging. First, we cannot extrapolate from one species group to the next. For instance, across a continent species richness in frogs may not correlate with the species richness in birds (*24*). Worse, the direction of the correlation—positive or negative—may differ between continents (*24*). Second, areas rich in species are not always rich in endemics (*24*). Simply, our understanding of endemism is insufficient for us to know the future of biodiversity with precision (*25*).

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Restoring Value to the World's Degraded Lands

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Roughly 43 percent of Earth's terrestrial vegetated surface has diminished capacity to supply benefits to humanity because of recent, direct impacts of land use. This represents an ~10 percent reduction in potential direct instrumental value (PDIV), defined as the potential to yield direct benefits such as agricultural, forestry, industrial, and medicinal products. If present trends continue, the global loss of PDIV could reach ~20 percent by 2020. From a biophysical perspective, recovery of ~5 percent of PDIV is feasible over the next 25 years. Capitalizing on natural recovery mechanisms is urgently needed to prevent further irreversible degradation and to retain the multiple values of productive land.

Rehabilitation of the world's degraded lands is important for several reasons. First, increasing crop yields is crucial to meeting the needs of the growing human population (*1*) for food, feed, biomass energy, fiber, and timber (in the absence of a massive increase in the equity of global resource distribution (*2*). Second, anthropogenic changes in land productivity have deleterious impacts on major biogeochemical cycles that regulate greenhouse gas fluxes and determine Earth's total energy balance (*3*). Third, biodiversity preservation depends, in part, on increasing yields on human-dominated land to alleviate pressure to convert remaining natural habitat (*4*). And fourth, land is frequently a limiting factor of economic output, and its degradation threatens to undermine economic development in poor nations (*5, 6*) and social stability globally (*7*).

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Here I estimate the rate at which potential direct instrumental value (PDIV) could be restored to degraded lands from a biophysical (as opposed to socioeconomic) perspective. PDIV is the capacity of land to supply humanity with direct benefits only, such as agricultural, forestry, industrial, and medicinal products. It does not incorporate indirect values [for example, ecosystem services (*8*)], option values, or nonuse values (*9*) and is thus a conservative measure of value. PDIV is not the same as potential net primary production (NPP), and may even vary inversely with it; for example, average NPP in agricultural systems is typically lower (and DIV higher) than in the natural systems they replace (*10*). Because PDIV depends on complex and variable factors such as human knowledge and preferences, it is impossible to quantify precisely.

Below I make rough approximations of changes in PDIV on the basis of global surveys of human-induced land degradation. Case histories of recovery from natural or human-induced disturbance are reviewed in order to derive estimates of the time required to restore PDIV to presently degraded lands. Finally, potentially illuminating projections are offered of future changes in PDIV.

Global Extent and Severity of Land Degradation

Land degradation refers to a reduction in the capacity of land to supply benefits to humanity. It results from an intricate nexus of social, economic, cultural, political, and biophysical forces operating across a broad spectrum of time and spatial scales (*11*). Here I consider only the biophysical agents of degradation that trace directly to human land use since 1945, although other proximate biophysical agents, such as air pollution (*12*), stratospheric ozone depletion (*13*), and climate change (*14*), are also important.

The geographic distribution of degraded land is poorly documented; even less well documented is the severity of degradation, which is typically judged qualitatively (*15*). The onset of degradation is often masked by intensification of land use that compensates, in the short run, for declines in the natural underpinnings of productivity; however, intensification usually exacerbates degradation, as do natural positive feedbacks (such as the concentration of soil resources by shrubs) (*16*). Global assessments have been undertaken of degradation of soils (in all biomes), drylands, and tropical forest lands.

Soil degradation. The extent of soil degradation induced by human activity since 1945 was evaluated as ~2 billion ha, or 17% of Earth's vegetated land, in a recent study sponsored by the United Nations Environment Program (UNEP) (*17*). Of this, ~750 million ha (38%) are classified as lightly degraded (defined as exhibiting a small decline in agricultural productivity and retaining full potential for recovery); ~910 million ha (46%) are moderately degraded (exhibiting a great reduction in agricultural productivity; amenable to restoration only through considerable financial and technical investment); ~300 million ha (15%) are severely degraded (offering no agricultural utility under local management systems; reclaimable only with major international assistance); and ~9 million ha (0.5%) are extremely degraded (incapable of supporting agriculture and unreclaimable).

The percent of area affected seems regionally to be independent of ecological zone or economic status; for example, it is 20%, 22%, and 23% in Asia, Africa, and Europe, respectively. The direct causes of these forms of degradation (and estimates of the relative importance of each) are overgrazing (35%), deforestation (30%), other agricultural activities (28%), overexploitation for fuel wood (7%), and bioindustrial activities (1%). Global rates of change in soil degradation are unknown. The UNEP study constitutes the first standardized global assessment and is the baseline for planned future monitoring on a decadal basis.

Drylands degradation. UNEP has also carried out a series of generally accepted global assessments of desertification (*15*). In the most recent assessment, desertification refers to land degradation in arid, semiarid, and dry subhumid areas (hereafter called drylands) resulting mainly from adverse human impact (*18*). Desertification is distinct from natural oscillations of vegetation productivity that occur at desert fringes (*19*); hyperarid deserts are not considered to be at risk of desertification and are excluded from assessments thereof (*18*).

The total desertified drylands area amounts to ~3.6 billion ha, or 70% of global drylands area (excluding hyperarid regions). Roughly 2.6 billion ha thereof exhibit no soil degradation, but have reduced crop yields, livestock forage, and woody biomass for fuel and building material (*20*). Of rangelands, which make up 88% of the drylands area, ~1.223 billion ha (27%) are degraded slightly or not at all; ~1.267 billion ha (28%) are moderately degraded; ~1.984 billion ha (44%) are severely degraded; and ~72 million ha (1.6%) are very severely degraded. Degradation classes are roughly comparable with those defined in the soil survey, and the principal direct causes of degradation are the same (*18, 21*). The rate of abandonment of drylands due to degradation is probably ~9 to 11 million ha year^{-1} (*22*). Rates of degradation seem to be accelerating, particularly in developing nations (*23*).

Tropical moist forest degradation. Land degradation in tropical moist forest afflicts ~427 million ha (*24*). The present global annual rate of tropical forest clearing (defined as depletion of forest cover to less than 10% in all types of tropical forest) is ~15.4 million ha year^{-1} (*25*) and is projected to accelerate (*26, 27*). In addition, an area of roughly equal size is disrupted, but not cleared outright, through selective logging and shifting cultivation (*26*). The extent to which clearing and disruption precipitate land degradation is unknown. Rates of abandonment of recently cleared areas, especially in hilly or mountainous regions, of as high as 75 to 100% are indicative of one extreme (*26, 28*). In general, probably only ~50% of the tropical forest land cleared each year expands the area yielding agricultural benefits, whereas the other half replaces abandoned lands (*29*).

Total degraded area. As a crude but conservative estimate of the total degraded area, I use the sum of (i) areas affected by soil degradation, (ii) drylands with vegetation degradation but no soil degradation, and (iii) degraded tropical moist forest lands, that is, ~5.0 billion ha (*30*). This amounts to ~43% of Earth's vegetated surface.

Time Required to Restore PDIV

There have been few attempts to rehabilitate degraded land on a large scale. Possible rates of recovery can be inferred from studies of succession on land that has experienced volcanic eruption, shifting cultivation, continuous agricultural production followed by abandonment, or reclamation. The time required to restore PDIV varies tremendously with ecosystem type, history and spatial pattern of land use, the degree of alteration of climatic factors, and the types of benefits ultimately desired—those derived from crop cultivation as compared to those derived from extractive exploitation of natural vegetation, for example.

Volcanic eruption. Following volcanic eruption, the regeneration of lost top- and subsoil may be the limiting process with respect to time and difficulty of rehabilitation. At one extreme, the rate of topsoil formation is especially rapid on volcanic ash; a mere 100 years after the 1883 eruption of Krakatau, for example, soil 25 cm deep had formed on a daughter island, Rakata (*31*). More typical soil formation rates are ~1 cm per 100 to 400 years, however. At such rates it takes ~3000 to 12,000 years to develop sufficient soil to form productive land (*32*).

Rates of colonization and succession are comparatively swift in the absence of natural impediments (*33*). Rakata serves as a model for the recovery of a presumably sterilized site 40 km from species source pools (*34*). Many generalist groups with high dispersal capabilities became reestablished during the first 50 years after eruption. However, important taxa with lower dispersal capabilities, more specialized resource requirements, or higher trophic positions remain poorly represented even today (*35*). Similarly, 23 vascular plant species were present on Surtsey two decades after its birth (of 450 on the Iceland mainland 35 km away), but only a few had become widely established (*36*).

Shifting cultivation. Shifting (swidden) cultivation generally involves slashing and burning of forest patches to create temporary fields that are harvested in a rotation

Table 1. Estimated severity of global land degradation under three different scenarios (A, B, and C) 25 years into the future (2020). Scenario A, degradation arrested immediately; scenario B, conservative rates of growth of degradation; scenario C, accelerated rates of growth of degradation. The percent total degraded land is given in parentheses.

Severity of degradation (% PDIV)	Time required to restore PDIV (years)	Degraded land (10^6 ha)			
		1995	A	B	C
Light (90)	3–10	1900 (38)	1150 (59)	3130 (40)	4360 (41)
Moderate (75)	10–20	2300 (46)	0 (0)	3530 (45)	4760 (45)
Severe (50)	50–100	750 (15)	750 (38)	1042 (13)	1335 (13)
Extreme (0)	>200	50 (1)	50 (3)	69 (1)	88 (1)

between brief periods of cultivation and longer periods of fallowing. Cultivation typically lasts 1 to 3 years, during which a combination of declining soil fertility, competition from weeds, and pest or pathogen outbreak conspires to diminish yields sharply (*37*). The plot is then left fallow. Long-term studies of recovery of productive potential in swidden systems are few (*38*), but fallow periods required to make a system sustainable are ~20 years (ranging between 5 and 40 years) in the humid tropics and may be considerably longer elsewhere (*39*).

Abandoned cropland and pasture. Rates and paths of natural succession vary widely on abandoned land formerly under continuous agricultural production. The chief commonality is the nonlinear relation between the intensity and duration of land use and the time required for recovery after abandonment. Factors influencing succession on old-fields (land abandoned after some combination of cropping and pasturing) are extremely complex, but the severity of erosion, initial floristic composition, and character of the ex situ seed source are paramount (*40*). In some areas, initial reestablishment of climax species was observed after 40 years of abandonment; in contrast, highly eroded fields experienced little succession during that period (*41*).

The conversion to pasture of up to ~43 million ha of Amazon rain forest over the past three decades (*42*) caused rapid declines in productivity and land abandonment after only 4 to 8 years of use (*43*). Extrapolation of rates of biomass accumulation and succession over 8 years since abandonment suggests that sites with a history of light use (20% of now-abandoned pasture) could reach forest stature in 100 years, those of moderate use (~70%) in 200 years, and those of heavy use (less than 10%) in 500 years or more (*44*). These estimates assume no further human impact. In many situations worldwide, recovery of productivity on abandoned land is prevented by burning (*45*) or episodic human exploitation of regrowth as it occurs.

Even without continued human disruption, however, regrowth of forest may not occur at all (as in the case of fire-climax grasslands (*46, 47*). For example, an agricultural area of ~3.5 million hectares in eastern Amazonia that was abandoned in the early part of this century had little vegetation aside from scrub and brush 50 years later (*48*). In India, trees have failed to establish in abandoned, desertified areas adjacent to sacred forest groves despite ample seed sources (*49*).

Table 2. Estimated rates of change in degradation classes (10^6 year^{-1}) used in scenario B (Tables 1 and 3).

Severity of degradation	Drylands	Tropical moist forest	Total
Light	35.0*	14.2†	49.2
Moderate	35.0*	14.2†	49.2
Severe	9.4‡	2.3§	11.7
Extreme	0.6‡	0.15‖	0.75

*These rates are derived from the mean rate of land degradation from 1945 to 1990, assuming that all currently degraded land was so rendered during that period (5.0×10^9 ha per 45 years = 111×10^6 ha year^{-1}). From this conservative estimate (given that rates of degradation have accelerated) is subtracted the rate of degradation to the severe and extreme classes, yielding 98.5×10^6 ha year^{-1}. Equal rates of growth of the light and moderate classes are assumed and degradation in tropical moist forest (TMF) subtracted, yielding $0.5(98.5 \times 10^6) - (14.2 \times 10^6) = 35.0 \times 10^6$ ha year^{-1}. †These rates assume that 100% of disturbed (but not clear-cut) TMF become lightly or moderately degraded, along with 84% of the clear-cut TMF [as 15% and 1% of the latter become severely and extremely degraded, assuming the same proportions as found in the soil degradation survey (*17*)]. Assuming equal partitioning between the light and moderate classes, the rate is $0.5[(15.4 \times 10^6) + 0.84(15.4 \times 10^6)]$ ha year^{-1} for each class. ‡Assuming 10×10^6 ha year^{-1} become severely or extremely degraded (see above) in the same relative proportions as reported for the soil degradation survey (*17*), namely, 15/16 and 1/16, respectively. §Fifteen percent of clear-cut forest [$0.15 (15.4 \times 10^6)$ ha year^{-1}]. ‖One percent of clear-cut TMF [$0.01(15.4 \times 10^6)$ ha year^{-1}].

Reclamation. Experience in reclamation of degraded areas, although limited, indicates unequivocally that human intervention may be effective (even essential) in ensuring a path and rate of succession that would achieve substantive improvements at time scales relevant to society (*50*). The potential for accelerating recovery is difficult to assess, as most degraded areas with known histories have not yet recovered. Moreover, recovery is nonlinear (with respect to time), and intervention can only accelerate some phases of the process.

Where land is suited to direct human use and has not been stripped of topsoil, substantial recovery may be achieved in as few as 3 to 5 years with intensive management (*51*) but more typically may take 20 years (*52*). However, recovery of self-sustaining, mature ecosystems in areas unsuited for intensive agriculture may take 100 years or more.

Projections of Future Land Productivity

Despite great uncertainties, I venture crude estimates of the present global loss of PDIV and possible future changes therein. The light, moderate, severe, and extreme degradation classes are assumed to correspond to a residual PDIV of 90%, 75%, 50%, and 0%, respectively (Table 1, column 1). These values are conservative in that severely (as well as extremely) degraded land is generally abandoned (*17*).

It is further assumed that the distribution among classes of the ~5 billion hectares of degraded land is proportional to that of degraded land in the global soil survey (summarized above), for which the data appear most reliable (Table 1, column 3) (*53*). On the basis of the foregoing evaluation of natural and human-accelerated recovery rates, rough rehabilitation times are proposed for each class of land (Table 1, column 2) (*54*). These estimates are optimistic in that all assume the higher rate of recovery from ranges of possibilities and that rehabilitation will not be hindered by soil loss, lack of colonists, climate change, further human impact, or other important factors.

Three scenarios of future changes in global PDIV are considered (Table 1) (*55*). In scenario A, degradation is arrested immediately. In 25 years, complete recovery

Table 3. Global extent of land degradation and corresponding loss of PDIV. Scenarios as in Table 1.

	Total degraded land (10^6 ha)	Vegetated land degraded (%)	Loss of PDIV on degraded lands (%)	Loss of PDIV on all vegetated land (%)
1995	5,000	43	24	10
Scenario A	1,950	17	28	5
Scenario B	7,771	68	23	16
Scenario C	10,543	92	23	21

occurs on 100% of land in the light class and on 50% of land in the moderate class; the other 50% in the moderate class moves into the light category; 0% of the land in the severe and extreme classes recover sufficiently to move up into another class. Scenario B assumes conservative rates of growth of each degradation class (derived in Table 2). Scenario C assumes rates of degradation double those used in B; these accelerated rates approximate what could occur if vigorous measures to prevent and reverse land degradation are not taken.

The analysis suggests that ~10% of global PDIV of land has already been lost (Table 3). From a biophysical perspective, recovery of half of this loss may be feasible in 25 years, provided that degradation is halted and strong rehabilitation measures are initiated immediately. In the absence of such measures, a very conservative extrapolation of present rates of degradation suggests that ~16% of global PDIV could be lost in 25 years. At more realistic, accelerated rates of degradation, this loss could reach ~20%. In the latter scenario (C), the land area irreversibly degraded from a socioeconomic perspective (in the severe and extreme classes) would increase by a factor of 1.8 over 1995 levels. These results are most useful for relative, rather than absolute, comparisons.

Costs and Benefits of Rehabilitation

Although a general lack of information on rehabilitation costs constitutes a serious shortcoming (56), the utter dependence of human well-being on productive land makes its continued degradation for short-term gain an unwise course. Moreover, the costs of off-site degradation may be substantial (57).

UNEP estimates the direct, on-site cost of failure to prevent desertification during the period 1978 to 1991 at between $300 billion and $600 billion (in U.S. dollars) (58). Currently, the total direct, on-site income foregone as a result of desertification is ~$42.3 billion year^{-1}. By contrast, UNEP's estimates of the direct annual cost of all preventive and rehabilitational measures range between $10.0 billion and $22.4 billion.

An enormous potential for recovery is inherent in most land types, but failure to realize this potential can result in rapid, essentially irreversible deterioration. Historically, land degradation has been implicated in the fall of great civilizations (59) and merits serious attention by this one (60).

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33. Impediments include (in Amazonia, for example) the aerial extent of pastures, which frequently cover hundreds or even thousands of hectares and make reestablishment of forest problematic because ~90% of the tree species have animal seed dispersers, of which very few venture into open pasture (*43*). Seed and seedling predators, particularly some ant species, are abundant in pasture and will remove experimentally placed seeds within minutes of placement [C. Uhl, in *Biodiversity*, E. O. Wilson, Ed. (National Academy Press, Washington, DC, 1988), pp. 326–332]. Microclimatic conditions (air and soil temperatures and humidity) are harsh and further limit seedling survival [C. Uhl, *J. Eco.* **75**, 377 (1987)].
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International Public Opinion on the Environment

David E. Bloom

This article analyzes public opinion data on environmental issues collected in two major surveys. The data reveal substantial concern about the environment in both developing and industrial countries along with perceptions that the quality of the environment has declined and will continue to decline. Developing country respondents rate their local and national environmental quality lower than do industrial country respondents, whereas both groups rate global environmental quality about the same. The data also reveal considerable willingness among the developing and industrial countries to accept responsibility for the world's environmental problems and recognition of the importance of governments in addressing local and national environmental issues and of strong international agencies in addressing transnational issues.

Free markets tend to work poorly in allocating resources for preserving and enhancing the environment. Indeed, negative externalities, public goods, or common property—all classic (and related) causes of market failure—are at the heart of most environmental problems (*1*).

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Whether by voting or government fiat, societies must make decisions about allocating resources to "environmental quality" (*2*). Voting mechanisms are at their best when political leaders know their constituents' preferences for environmental quality relative to their preferences for alternative uses of society's resources. Presumably, fiat rulers also benefit from having information about mass opinion. In this connection, public opinion polls are emerging as a potentially valuable source of information on people's perceptions about the seriousness and causes of environmental problems, their preferences for environmental quality, and their preferences among alternative solutions to different environmental problems. Unfortunately, as the various polls have been conducted mainly in industrial countries, little information has been available about developing countries.

Notable attempts to collect comparable public opinion data on environmental issues in a range of developing and industrial countries are a 1992 Gallup survey ("The Health of the Planet") of 29,618 individuals in 24 countries (12 developing and 12 industrial), whose total population represented 29% of the world's population at that time, and a survey conducted by Louis Harris and Associates in 1988–89 ("Public and Leadership Attitudes to the Environment in Four Continents") which gathered information from 8325 individuals in 16 countries (12 developing and 4 industrial), whose total population represented 29% of the world's population in 1989. Although individual responses to the Gallup and Harris survey questions are not readily available, country-level tabulations of responses to most questions have been published, allowing within-country comparisons of responses to different questions and between-country comparisons of responses to the same questions (*3*).

This article addresses three sets of issues: (i) What is the nature and extent of public concern about environmental quality? (ii) What are the perceived causes of environmental problems, and what countries are being blamed for those problems? (iii) To what extent is the public willing to bear the cost of environmental protection and cleanup, and do people recognize the essential role of governments and international agencies in that effort? The article distinguishes between local, national, and global environmental issues and compares industrial and developing countries (*4*).

Methodological Issues

The collection of opinion data by polling representative samples of large populations has expanded rapidly in the United States and abroad during the last six decades. At the same time, an extensive literature has developed on the information content of public opinion data. In a classic study, Schuman and Presser (*5*) reported on a series of rigorous analyses of the sensitivity of survey results to question form, wording,